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Special

**HISTORY OF THE AEC SODIUM COMPONENTS
DEVELOPMENT PROGRAM**

Volume II

Edited by H. W. Savage

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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DECEMBER 1966

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APPENDIX C

REPORTS OF SUBCOMMITTEE MEETINGS

Reports of Subcommittee on Shell-Side
Heat Transfer

Report of Meeting on April 7-8, 1960

The Subcommittee has engaged in the following activities since the BMI meeting in March, 1960:

1. Engaged in correspondence outlining points of view.
2. Met at Atomic International - April 7 and 8, 1960.
3. Developed a revised and improved engineering program.
4. Reviewed the Shell Side Heat Transfer Research Program at Brookhaven National Laboratory.

It is not expected that the Subcommittee's program, list of experiments, or equipment required will be defined fully so that it can be acted on by the Working Group at the Los Alamos Meeting.

On the other hand, the scope of the program can be outlined well enough that if changes to it are desired by the Working Group they can be incorporated. Choices remain amongst alternative statistical approaches which the Subcommittee will not have been able to evaluate before the Los Alamos Meeting. Also, some analytic work will still be in progress. The scope of the program as it is now evolving comprises four phases:

Phase I. Cross-Angular-In-Line Flow Heat Transfer

This program would involve four principal geometric variables: α (direction of flow relative to the tubes), tube array (square and equilateral triangular), tube diameter, and tube spacing (P/d). Statistically, it appears necessary for the experiments to be five-level, i.e., two limiting and three intermediate values for each variable for each of the two arrays. The sequence of experiments is expected to be so chosen that only one of the two arrays will need to be pursued for the full pattern of experiments. A second order rotatable (statistical) design will be used to define correlations of the variables. From these correlations equations will be developed to define the heat transfer parameters in terms of the variables. (Analytic studies by AI have been made in an attempt to predict the forms of these equations.)

For the test bundles of the above program, the significances of a) number of tubes, b) number of rows of tubes, c) number of tubes per row, and d) length of tubes, will be evaluated by a small number of experiments to determine, primarily, end and wall effects. Values for these variables will be so chosen that the effects on heat transfer in the bulk of the tube bundle will be small and, in any event, known.

With each test bundle a second statistical program will be used for the operating variables; a) mass flow in the tubes, W_t ; b) mass flow in the shell, W_g ; c) inlet temperature to the tubes, T_{t_i} ; and d) inlet temperature to the shell side, T_{g_i} . ΔT 's across the bundle will be dependent on the magnitude of variables a) to d).

From the foregoing, it should be possible to correlate the performance of square and triangular tube arrays, and to determine the contributions to heat transfer due to in-line, angular, and cross-flow regimes.

It has been estimated that the number of experiments will be on the order of 30. However, several alternative statistical patterns are possible within these regimes, and the advantages of each must be reviewed before selection.

It is to be noted that while the foregoing program is basic and directs its attention to what occurs in various flow regimes, it is not a re-search program to learn minutia around a single tube or in a single space between tubes and, therefore, cannot answer that type of question. On the other hand, it is not limited to any specific shell and tube heat exchanger design (e.g., Alco's), but, we think, will be applicable to any tube and shell design that has mixtures of the flows to be studied.

We have avoided carefully, any suggestion for bundles heated in any fashion dissimilar to what would be encountered in an actual exchanger. For this reason, electrically heated rods are avoided. Instead there is insistence that there be not only ΔT in the sodium in the direction of shell side flow, but that there also be ΔT in the tubes along their length and from one tube to another in a realistic manner. This led us to sodium within the tubes as well as in the shell side.

Phase II. Flow Characteristics - Fluid Dynamics

In order to pursue the approaches of Tinker, and in reality to apply the results of Phase I, one must understand with any specific heat exchanger configuration exactly what flow patterns exist. This phase is thus limited by configuration and the one recommended for general study is a multiple baffled exchanger using baffles which are segments of circles.

The program will propose two parts (a) an intensive literature search to uncover whatever is already available on the subject. (It is suspected that much of the data necessary may have been obtained by various investigations, e.g. Bergelin at the University of Delaware, which, if true, will either reduce or obviate our experimental work.) (b) an experimental program again using a statistical approach but with water to define hydrodynamic data where the literature is insufficient.

The Subcommittee will recommend that these two phases proceed concurrently since there is no obvious interference between them.

Phase III. Flow and Thermal Characteristics

This phase will be analytic and has the objective of determining what may be expected heat transfer-wise between regimes of the flowing shell side sodium. It is an attempt to set up a group of energy equations for the flowing sodium. Obviously these equations will not come from either Phase I or Phase II, but will be prominent when these two phases are combined.

A second objective is to shorten Phase IV below, for without analytically determined energy relationships it will be necessary (and still may be) to derive them from Phase IV.

Kurt Goldman (NDA) and J. S. McDonald (AI) are at work on this analytic study.

Another way of defining this study by way of comparison is to say that whereas Phase II will define velocity profiles and leakage paths for the sodium, the energy effects defined by Phase III will be combined with the output of Phases I and II to predict analytically the heat transfer performance of a complete exchanger.

We believe that a basic reason for discrepancies between existing data for sodium exchangers, and between performance with sodium and predictions based on correlations using other liquids is the high thermal conductivity of the sodium. That is, if the liquid has low thermal conductivity, the heat transfer is controlled by flow characteristics, i.e., turbulence. With sodium, heat transfer due to conduction may be as or more important than turbulence; thus temperature distributions become as or more significant than flow characteristics.

In any event, it is apparent that temperature gradients will exist in the flowing sodium due either to (a) its velocity characteristics, (b) the temperature of nearby tubes, (c) leakage streams, or (d) some combinations of these, and will require definition.

Phase III will be accomplished concurrently with Phases I and II and experimental verification will derive from Phase IV.

Phase IV. Verification Program

This phase will again be specific to an exchanger configuration. The list of experiments remains to be defined, since it will be contingent on the outcomes of Phases I, II, and III.

A statistical program could be devised around Phase IV alone. The results would be specific to the configuration chosen, and would require repetition for each new configuration. The length of such a program would be comparable to the expected length of the above four phases, provided Phase IV comprises a verification only and does not become extensive of itself to establish the relationships for Phase III. On the other hand, if Phase IV alone is done, the advantages of Phases I, II, and III will be lost for an exchanger of different configuration.

It is patently impossible to elaborate here on the many fine points discussed at some length in the April 7-8 meeting of the Subcommittee. However, we will try to answer any questions and incorporate any suggestions from the remainder of the Working Group. J. S. McDonald will be present at the Los Alamos Meeting to aid in this regard.

With regard to the Brookhaven program already under way, this was reviewed in detail at the request of COO.

The Subcommittee believes the BNL program to be good and useful work in an area not proposed to be covered by the foregoing program. The BNL program is a research program designed to correlate h_{HL} and h_{Hs} shall side heat transfer with earlier work in h_g and some present work on h_i .

it will study fine structure around electrically heated rods (which, in our opinion, do not simulate a realistic heat exchanger situation) transferring heat to shell side sodium or sodium-potassium alloy. It is not apparent that ENL would consider or has the temperament or facilities to shift to or do our Phase I. Since it is a research program and therefore strongly reflects the interests and professional proclivities of the individuals engaged in it, the Subcommittee suggests that it is outside the province of the Working Group (and certainly the Subcommittee) to guide or direct it. On the other hand, we will welcome the results when available.

We suggest also that after the Working Group has agreed on its shell side program, that the comments of qualified heat transfer experts and exchanger manufacturers should be solicited and welcomed, from the points of view of informing them of a probable advancement of the art, and to learn of suggestions any of them might have that might possibly improve our approach.

Submitted by: R. W. Dickinson
K. Goldman
H. W. Savage

Date: April 18, 1960

Report of Meeting on May 26-27, 1960

The Subcommittee meeting was attended by K. Goldmann (NDA), J. S. McDonald (AI) and H. W. Savage (ORNL), R. W. Dickinson (AI) was unable to be present.

The group had the following papers in hand:

1. Recommended Shell Side Sodium Heat Transfer Program, including Appendix I - prepared by McDonald and distributed at the Los Alamos meeting, April 28, 1960.
2. Appendix II - Tabulation of Bundle and Operational Specifications - prepared by McDonald early in May.
3. A Preliminary Cost Estimate and Schedule.
4. Comments on item 2 prepared by Savage, May 18, 1960.
5. Answers to the comments of item 4 by McDonald.

It was agreed that the primary objectives of the meeting would be to (a) resolve the details of the experiments called for in Appendix II, and (b) to formulate the first draft of the Work Scope required by the AEC for soliciting program proposals.

The Committee then debated the merits of Phase X, A.1 - Edge Effects Tests.

Since these were described as necessary to establish the number of rows of tubes, number of tubes per row, and length of tubes at various flow angles, it was pointed out that the 14 experiments proposed would not resolve the $\alpha = 0^\circ$ (in-line counterflow) case, nor would they establish for certain what the appropriate limits were for triangular arrays. This debate led to four groups of required experiments - totalling 26:

1. Bundles 1a through 3b, $\square$ array with 90° flow as described in Appendix II.
2. Bundles 4a through 6b, Δ array with 90° flow similar to those described as 1a through 3b in Appendix II.
3. Bundles 7a through 9b, either $\square$ or Δ array depending on a choice from (1) and (2) above, 45° flow like bundles 4a through 6b in Appendix II.
4. Bundles 10 through 14, either $\square$ or Δ array, 0° flow following an analytic study.

It was felt that for the 0° case an analysis could be performed for both triangular and square array to select that one which gives most h/unit pumping power, and that the parameter L/NP could be used for determining length of bundle (where N = No. of tubes per row, and P is pitch).

A table for relative merits of bundles of various sizes was drawn up in which it was assumed that all the tubes next to the wall were 50% effective in heat transfer from which it became apparent that the differences between bundles of large numbers of tubes will probably be small. On the other hand, it is desired to establish what the in-line heat transfer is when wall effects are excluded.

It seemed then important to have three experiments in which L/NP is constant but the bundle size changes, and three in which bundle size is constant and L/NP is changed.

Values of L/NP of 4, 6, and 8 were suggested, and tube bundles: 5×5 , 7×7 , 9×9 .

The basis for these choices of bundles was that for the $9 \times 9 = 81$ tube case the number of tubes inside those adjacent to the walls is $7 \times 7 = 49$, and when the total is $7 \times 7 = 49$ tubes, those inside total $5 \times 5 = 25$. Also this accentuates wall effect differences, while keeping the power requirements reasonable.

Thus, the two series of experiments should permit the determination of in-line counterflow heat transfer as a function of the number of tubes, effectiveness of tubes adjacent to the wall, and the length necessary to estimate entrance and exit effects.

At this point it became apparent that the Edge Effects Tests were approaching duplication of the Phase I, A.2 and 3 sequential tests, but on a less sound statistical basis. Said differently, the expansion of the Edge Effects Tests to evaluate $\square$ to Δ arrays and to include the 0° cases was leading to full factorial experiments using the variables, precisely the type which the sequential type experiments were designed to avoid.

Because of this it was decided to abandon the Edge Effects Tests and, on the basis of analytic approaches, to choose bundles of sufficient size to minimize edge effects. This seemed logical on two bases: (a) McDonald had essentially done this in choosing the previously described edge effects tests, and (b) cursory analysis indicated that except for very extreme variations, the differences in edge effects between bundles of acceptable size would be small anyway.

However, because of the lingering suspicions that there is likely to be a discontinuity in heat transfer results as one goes from pure cross-flow and approaches pure in-line flow, it is recommended that the group of experiments to evaluate in-line flow be retained as a check for the 0° cases in the sequential experiments (I-A, 2 and 3).

We would also not object to a small number of edge effects experiments if the proposer wished to verify the assumptions made in his analysis for choosing N , L , and number of rows of tubes.

The decision to eliminate Phase I, A.1 also eliminated Phase I, B.1.

In Phase I, B.2 and 3, it was agreed that for the turbulent regime, experiments 1, 4, 5, 7, 10, 11, 13 and 16 of the second group constituted a better set of experiments than the first nine listed from the point of view of deciding whether η or Δ array is to be used for McDonald's bundles 19 through 27.

On the other hand, all 25 experimental conditions have to be done with all bundles anyway, so there is no particular point to any sequence of operating conditions other than that which is most convenient to the operator. It was also agreed that the first set of conditions listed by McDonald should be repeated at least six times (whenever convenient) to provide a good estimate of experimental errors being experienced.

It was decided to list laminar experiments separately and to augment the ones shown by listing a number of bundles to be positioned in different positions to evaluate the effects of gravity on thermal convection effects.

Goldmann requested that the second column of operating conditions be given in terms of W_s/W_t , instead of Re_t . The first column should be in terms of W_s , rather than Re_s .

The group then turned to consideration of Phase II -- the fluid dynamics of heat exchangers. It seemed that the outcome of extensive experiments in this area when combined with Phase I results should enable the optimization of heat exchanger configuration. It was decided that this was not the objective of the present study but should be recommended to the full sodium committee as a possible additional program.

The objective of the present program was reiterated as being (a) one to establish sodium-to-sodium heat transfer as a function of flow direction, (b) to determine how the heat transfer for any given flow direction is affected by changes in operational variables, (c) to determine heat transfer interactions between flow regimes in an exchanger, and (d) to verify the application of the heat transfer and fluid flow data in a typical heat exchanger configuration. Consequently, flow characteristics for this program should be determined for only those exchangers planned to be used in connection with (d).

A review of the geometric parameters of a typical type JHX (as presented by McDonald) was made. It was decided to limit the variations to three of the parameters: D_1 , c_2 , and $\frac{D_1}{I_3}$. Those kept constant would then

be: P , d_2 , N , l , d , D_2 , $\frac{D_1 - D_2}{D_1}$, D_3 .

By using probable limiting values for each of the three variables, eight exchangers will be needed for both the hydraulic and sodium-to-sodium heat transfer experiments. This will permit a full factorial pattern of experiments and will allow the evaluation of all important interactions. A program of operating variables would also be prepared involving

$$W_s, W_s/W_t, \Delta T \text{ and } T_{s1}.$$

The selected three geometric variables were chosen because they affect respectively:

(D_1) -- bundle-to-shell clearance, and therefore the amount of sodium flowing in the principal bypass stream;

(c_2) -- velocity at the window; and

$\frac{D_1}{L_3}$ -- which controls baffle spacing, and therefore affects the amount of flow at any given angle of flow, α .

The initial statements of the first draft of the "Work Scope" for the AEC were written and are attached. Savage agreed to complete this first draft on the basis of information at hand, including specification of experiments required, and to recommend the extent and nature of appendices to be included.

McDonald was to consider the program of experiments needed for convection effects. He was also to define the eight verification units, to prepare a table of geometric factors and operating conditions for the main body of the Work Scope, and to recommend supporting information for the appendices.

It was decided that the program had reduced to the following requirements shown schematically.

Report to SCDP Chairman, June 13, 1961

Mr. T. A. Nemzek
U. S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Dear Tom:

Subject: Shell Side Heat Transfer Program

The Ad Hoc Review Group, formed at the Canoga Park March meeting to review the Shell Side Heat Transfer Program, has received several documents from Atomics International: (a) Discussion of Basic Unit Designs (794-41-276); (b) Plan of Action (796-41-289); (c) Test Loop Description (794-41-275); (d) Drawings for Basic Bundles 1 - 12; and (e) Drawings for the Test Loop (61AT4162).

While we have not had time to review each of these quite detailed documents with equal attention because some are of quite recent receipt, the Ad Hoc Group believes it has gained sufficient familiarity with them that the conclusions which were discussed with Atomics International representatives on Friday, May 26, are sound.

1. The Plan of Action appears to be a development problem in itself. The basic bundles are turning out to be sufficiently complicated in design that the use of carefully executed experimental and theoretical approaches will be needed to assure that they will provide the required data.
2. The specification from which Atomics International is working is apparently not sufficiently explicit in the theoretical and experimental approaches needed.
3. The theoretical approach taken by Atomics International for shell side heat transfer phenomena is not sufficiently rigorous as to mechanisms involved since it is based on parametric relationships derived by earlier studies and which are already known to be either incorrect or inadequate.
4. The designs of the ten cross-flow bundles are not believed adequate either fluid-dynamically or thermodynamically on the tube side.

Steps should be taken to assure well-developed flow conditions in the tubes in the heat transfer zone and to reduce the variation in flow between tubes to as near zero as possible. The adequacy of the design to achieve the

desired tube side fluid dynamics should be verified experimentally. We believe it is vital to the success of the basic experiments that experimental errors on the tube side be minimized since any errors occurring in the tube side determinations must, of necessity, be present in the shell side determinations.

5. The fluid-dynamic characteristics of the shell sides of the ten cross-flow bundles would be improved by increasing the number of tube rows in width and decreasing the number of tube rows in depth for the active part of each tube bundle, and by providing several inactive rows of tubes in the inlet and outlet shell side sodium.

6. The quality of the heat transfer results obtained will be strongly dependent on the accuracy of flow and temperature measurements made. It will, therefore, be important to use carefully calibrated devices judiciously located to provide data and to verify adequacy of the procedure by tests.

7. It is not expected that any of the improvements proposed will have major effects on the test facility, except as the space required for the bundles will change when they are redesigned. An improved bundle design using the present largest tube sizes may give rise to power requirements beyond the capability of the present test facility. Should this be the case, a reduction in scale for all the basic bundles should be feasible to avoid a major change in the test facility. It is not apparent that a small reduction in scale will have any significant effect on the quality of the ultimate results.

8. The method of handling experimental data with machine programming to determine both shell- and tube-side heat transfer coefficients simultaneously is basically sound. It is possible, however, for a machine program to converge on incorrect values for coefficients and exponents or to not converge at all. The Plan of Action should take these possibilities into account. Since the best a machine program can do is to provide numbers for equations previously defined, it is considered essential that the tube- and shell-side equations provide the most logical explanations possible of mechanisms involved in sodium heat transfer.

In the discussion of the foregoing subjects at the Lincoln, Nebraska meeting, it was apparent that the specifications had failed to convey an adequate appreciation of the theoretical approaches needed. Atomica International expressed the opinion that the program should result in improved expressions for the kinds of equations currently available. It was pointed out that even if such improvements were the goal, the tube side conditions needed considerable improvement, the results

would not be extrapolable beyond the limits of the experiments performed, and the equations would not include factors based on the unique thermal gradients and properties of the sodium.

The Ad Hoc Group stated that the intent of the basic program, whether or not explicitly stated in the specification, should be to derive equations to express what is going on in the sodium in terms of the physical mechanisms involved while the heat is being transferred. It was not felt that the results of the basic studies would be worth the money about to be spent unless a more rigorous and explainable theoretical approach could be developed for the equations to be investigated by the experiments. The nature of the theory to be investigated will also make it possible to define the instrumentation needed to obtain the measurements essential to verifying the theory.

Concern was also expressed about the staffing of the program. It appears almost certain that several heat transfer experts, dedicated to finding the solution of the problem, will have to work full time for a number of years. The development of the theory involved will also require the most sophisticated and ingenious approaches, of which these experts are capable. The Ad Hoc Group is of the opinion that a few experiments, carefully defined, both hydraulically and thermodynamically, should be designed and carried out to test the validity of the Plan of Action before the over-all plan for the basic bundles is engaged in fully.

It is possible to first obtain data and from these develop theories which explain the mechanisms occurring; and this may be the course which will be selected. However, with this course, it remains essential to minimize experimental errors on the tube side; minimize wall edge, and entrance tube effects on the shell side; calibrate and properly locate instruments; and go through enough of the beginnings of the theoretical logic that the foregoing steps are likely to be performed successfully, and meaningful data obtained to assist in the theory development.

Because of both the costs and the probable scientific impact of success or failure of the series of basic experiments, we think it essential to take whatever time is necessary to devise as sound and rigorous a Plan of Action as possible.

Very truly yours,

SIGNED: H. W. SAVAGE

Ad Hoc Review Group
H. W. Savage, Chairman
K. Goldmann
J. J. Morabito

Report of Meeting on July 27-28, 1961

Mr. T. A. Nemzek
Assistant Manager for Technical Operations
United States Atomic Energy Commission
9800 South Cass Avenue
Lemont, Illinois

Dear Tom:

Subject: Shell Side Sodium Heat Transfer Program

In accordance with your letter of July 11, 1961, a meeting of the Ad Hoc Sub-group of the Sodium Components Working Group was held at Atomics International July 27 and 28, 1961, to review progress on the Shell Side Heat Transfer Program and to make recommendations for its further development.

Due to vacations and other conflicts, Kurt Goldmann, UNC, and John Morabito, APDA, could not attend personally, nor could Kurt Goldmann's alternate, Sanford Israel. Consequently, the review group consisted of H. W. Savage and R. E. MacPherson of ORNL, Wayne Chase of APDA, R. E. Aronstein, AEC-CH, and Reuben Harris of AEC-DRD.

The AI contingent consisted of R. W. Dickinson, John McDonald, William Hallett, R. J. Begley, J. A. Leppard, and Prof. Byron Short of the University of Texas.

The Chairman of the Review Group summarized the entire situation and how it had developed, emphasizing particularly the events of the past nine months and the desire of the Sub-group to reach well-understood agreements with AI on the Plan of Action and its development. Your letter of July 11, 1961 to Joel V. Levy, AEC-Canoga Park, was read and served as the charge for the meeting. Since this letter summarized the Ad Hoc Review Group report to you dated June 14, 1961, the items mentioned in this report were covered one by one.

Exceptionally substantial progress was achieved in all problem areas, with agreements reached on approaches. The basic objectives in each discussion were (1) to assure recognition and common understanding of each problem area, and (2) to define an approach to each problem which would not be irreversible or catastrophic if adverse unanticipated events or analyses were encountered during execution of the work. In other words, it has been universally recognized and accepted by all that all phases of this program, including the Specification and Plan of Action, are development items, the scopes of which may vary from present versions as the results become known.

The Chairman pointed out that two areas did not warrant further extensive elaboration at this time because agreement already had been achieved. These were:

1. The statistical program
2. The test facility

In the case of the latter item, previously described objections or suggestions were either withdrawn or had been accepted, so that, as far as the Chairman knew, unless the ensuing discussions should require changes in criteria (which they did not), it was agreed that, so far as the Sub-group was concerned, AI could proceed forthrightly to completion of the test facility.

Several documents were made available by J. S. McDonald, AI, as follows:

1. Progress Letter No. 5, July 26, 1961
2. 796-41-332; July 25, 1961 - Discussion of Principal Questions on Shell Side Heat Transfer Program.
3. 796-41-333; July 25, 1961 - Discussion of Number of Tubes per Row.
4. Sketches pertaining to hydraulic experiments for the 45° bundle case (2 pages).
5. NAA-SR-6593, July 19, 1961 - Analysis of Some of the Edge Effects in Shell Side Heat Transfer.

Copies of these documents are attached.

Minutes for the meeting were taken by Bob Aronstein, and he will preserve these in his records. The ensuing report is a summary with no attempt to include a full recital of all details of the discussions.

The items will be discussed in the same order as they appear in the Ad Hoc Review Group Report of June 14, 1961.

1. The Plan of Action. Agreement was reached that this is in fact an item to be developed, refined and revised as necessary as the work progresses and that carefully executed experimental and analytic approaches will be used to evaluate its adequacy. As is pointed out below, the initial experimental and analytic approaches, all now agreed to, are neither superextensive nor all-inclusive, but do constitute sound bases on which to start.

2. The Specification. Agreement was achieved that this is a document subject to revision, refinement and improvement, but basically sufficiently inclusive to cover most of the scope.

As examples of scope changes it will be noted below that the program now recognized:

- a. The need for theory development.
- b. Testing of the theory at a future date.
- c. The need for determining tube side in addition to shell side coefficients.
- d. The possibility that the $\alpha = 18^\circ, 45^\circ, \text{ and } 72^\circ$ cases may be unnecessary experimental excursions.

3. Theoretical Approach. Document 796-41-332 states that "AI is not as yet prepared to report results of a theoretical approach to the problem. It is agreed that a theoretical analysis is needed - Prof. Short has been requested to undertake such a theoretical analysis."

The problem of defining mechanisms for accounting for thermal gradients and conduction in sodium was discussed at length to assure that, insofar as possible, semantics between individuals were not limiting understanding. AI agreed to make a preliminary report at the next meeting of the Working Group. The Chairman requested that AI arrange a conference with Kurt Goldmann to assure the maximum possible communication of ideas and coordination on this problem.

The Sub-group Chairman requests to be informed of the date and location of this conference so that all members of the Sub-group may attend, if feasible.

4. a. Tube Side Flow Problems. The results of AI's hydraulic tests were reviewed. Essentially these confirm that differences will exist between performance and analytic prediction, and that the differences vary with flow and probably with location of the tube row considered.

To avoid an extensive series of hydraulic experiments - perhaps as extensive as experiments for each and every bundle - AI agreed to design around the problem and provide tube side inlet and discharge plenums sufficiently large that velocity effects would be negligible and thereby assure uniform flow among the tubes. Presumably the plenums would become part of the test facility rather than parts of the bundles. Plastic or other suitable "hydraulic" models were recommended to verify the design.

b. Tube Length. It was decided after length discussions that irrespective of whether the tubes were long enough for establishment of uniform flow conditions in the tube, experiments would have to be run to define the tube side heat transfer coefficients as functions of heat flux and in relation to axial position along the tube (i.e., because flow conditions will be varying along the length of the tube, but consistently from one tube to another).

If the results are consistent for tubes of different size, (i.e., 3/8", 3/4" and 1 1/2") and predictable, then it will not be necessary to complicate the bundle design by making the tubes long enough to assure an $L/D > 40$ in advance of the heat transfer region.

It was also agreed that these experiments would be done for L/D ratios up to at least 60, and that at least one experiment would be performed in which part of the tube ($L < 10$ diameters) occurred ahead of the heat transfer region to evaluate the significance of avoiding occurrence of the initial flow end effect within the heat transfer zone.

If a serious inconsistency should be discovered to the extent that tube side coefficients would be unpredictable for designs proposed, then it is recommended that the designs be altered to achieve predictable situations consistent with the data from the single tube side coefficient experiments to be run.

The Sub-group recommends that these experiments proceed without further delay since fabrication of any of the basic bundles is dependent on the results.

5. a. Shell-Side Tube Configuration. After a lengthy discussion of available information, the sub-group agreed that the increased accuracy to be gained by increasing the number of tube rows can be expected to be both too small and too unpredictable to warrant complicating the test facility (an increase in shell side flow would have been required, and the improvement in results would be nominal, if any).

AI proposes to experiment with two basic bundles with and without screens ahead of the tubes to ascertain the extent to which the initial rows of tubes are adversely affected and how much. Since it is not clear that two rows of dead tubes at the shell side inlet will necessarily improve the quality of the shell side results, the Sub-group concurred with these experiments and recommends that they be done.

In any event, it appears that improvements in shell side performance (i.e., avg h/h_{ratio}) will be very small for the bundle as a whole and can be either disregarded or reconsidered

following interpretation of data from these and shell side flow experiments.

b. Flow Direction Problem for $\alpha = 18^\circ$, 45° , and 72° cases.
Two phases of the flow directional problem were discussed at length. (1) How may, for example, $\alpha = 45^\circ$ be achieved; (2) Is $\alpha = 45^\circ$ likely to be significantly different than $\alpha = 90^\circ$.

It is recommended that the question of definition of actual flow through an $\alpha = 45^\circ$ bundle be referred to AI for experimental determination using easy-to-handle fluids, visual techniques, etc. It cannot be decided whether an $\alpha = 45^\circ$ presently designed bundle is fully effective or not without this flow evaluation. This is because the tube inclination can be expected to crowd the flow through some part of the exchanger and to deplete it in the remainder.

In addition to flow evaluation studies, AI and the Sub-group agreed that the first three basic bundles should be used to obtain data for evaluating whether the $\alpha = 18^\circ$, 45° , and 72° cases were worth continuing in the program.

By choosing two bundles (e.g., #2 and #13) in which the only variation is $\alpha = 45^\circ$ or 90° , this evaluation may be achieved. If there is no significant difference then the $\alpha = 18^\circ$, 45° , and 72° cases should probably be discarded and the basic bundle program redesigned.

If significant difference does occur - as it may - it is recommended that AI propose an additional $\alpha = 45^\circ$ bundle to be tested, to resolve the question of whether the particular geometry of the first $\alpha = 45^\circ$ bundle happened to be the cause of the difference.

It was agreed that these bundles should constitute the initial experiments and would serve as vehicles to evaluate adequacy of the experimental approach in general, and the need for bundles with $0^\circ < \alpha < 90^\circ$ in particular. The fabrication and testing of these bundles should proceed as soon as acceptable redesign of the inlet and outlet plenums has been achieved. The Sub-group recommends deferment of the fabrication of subsequent bundles until experimental results of these first three bundles have been evaluated.

In connection with the foregoing, Prof. Short described an experiment he had done which indicated that in the $\alpha = 45^\circ$ case, one could expect head-on approach to a tube, slip in the downstream direction along the tube, passage over the tube nearly perpendicular to its axis, further downstream slip on the under side of the tube, and repetition of these phenomena at each succeeding tube.

Without fluid flow experiments and the foregoing heat transfer evaluation experiments, it seems unlikely that bundles for $\alpha = 18^\circ$, 45° , or 72° can be designed so that the flow regime of each can be predicted with accuracy sufficient for the present program specification. It is also important to assure ourselves that the results for a specific $\alpha = 45^\circ$ bundle are not a fortuitous happenstance due to the particular geometry used in the first experiment.

6. Flow and Temperature Measurement. Having reached agreements on principles to be followed in plenum redesign and understanding flow in both the tube and shell sides, agreement was reached next on flow and temperature measurements.

Assuming the above heat transfer and flow experiments and design sequences can all achieve their desired and expected results, it will now be necessary to measure mass flows only at both inlets and mixed mean temperatures at both inlets and both outlets. The techniques proposed by AI for flow measurement have been well tested, calibrated, and appear to be entirely adequate. It was agreed that mixing chamber temperature measurements will be made at all critical temperature points. Additional intermediate temperature measurements may be required to provide data for verification of heat transfer hypotheses.

7. Test Facility. With the conclusion to not recommend any increase in number of tubes or number of tube rows, the present test facility has sufficient capacity to handle the Basic Bundle program. The Sub-group recommends completion of the test facility as presently designed.

8. Machine Handling of Data. Data reduction by computer should be tested prior to its use for extensive correlation of experimental data. Such use is dependent on development of the analytic approach, and on testing the output of the computer for convergence to correct values using input data results for which are already known (perhaps by hand methods), and on further tests using initial experimental data. The Sub-group wishes only to remind AI of the possibility of a nonconvergence or incorrect convergence problem, and recommends that AI statisticians participate as needed to avoid such a dilemma.

In summary, the sub-group recommends and is in full agreement with AI, that AI should now:

1. Start the development of a more "rigorous" theory and give a report at the next Working Group Meeting.
2. Complete the present test facility.
3. Redesign the basic bundle inlet and outlet plenums to reduce velocity effects to negligible values.

4. Conduct single tube, tube side sodium heat transfer coefficient experiments for a range of tube sizes, flows, and heat fluxes.
5. Develop simple experiments to explain shell side flow in the basic bundles.
6. Fabricate and test one $\alpha = 90^\circ$ bundle and two $\alpha = 45^\circ$ bundles (probably of different tube lengths) as soon as an acceptable plenum redesign is achieved, to establish the significance and value to the program, if any, of bundles having $\alpha = 18^\circ, 45^\circ, \text{ or } 72^\circ$.
7. These three test bundles should be used to evaluate adequacy of the experimental and programatic approach before fabrication of other bundles is undertaken. It is expected that this evaluation can be made prior to completion of all of the experiments with these bundles and thereby minimizes subsequent delays to the future program.

The entire meeting was conducted with the full cooperation, harmony and participation of all parties present. It was clearly evident that AI has recognized the technical problems involved, has a good appreciation of their complexities and developmental consequences, has and is improving the program staffing, and can proceed within the foregoing recommendations to move on with the program.

The Sub-group feels that the meeting resulted in adequate clarification of the basis for proceeding with the Shell Side Heat Transfer Program, and that the program as recommended above should be implemented as promptly as possible.

The Sub-group is also of the opinion that periodic reviews, coupled with evaluations of important and/or potentially controversial items as they occur, should suffice (as it has with the GE Mass Transfer Program) to provide the future guidance of this program so that it will produce considerable meaningful data and a successful conclusion within a reasonable (but not, however, short) length of time.

H. W. Savage
Chairman, Ad Hoc Review Group

The contents of this document were summarized for Kurt Goldmann by telephone on July 28, 1961 and his concurrence as to the general approach was received. John Morabito has reviewed the contents and given his concurrence on August 1, 1961.

H. W. Savage
Chairman, Ad Hoc Review Group

Distribution:

T. A. Nemzek (8)	K. Goldmann	Wayne Chase	Byron Short
R. W. Dickinson (7)	J. J. Morabito	R. E. MacPherson	R. E. Harris

Report to SCDP Chairman, September 29, 1961

Mr. T. A. Nemzek
Assistant Manager for Technical Operations
United States Atomic Energy Commission
9800 South Cass Avenue
Lemont, Illinois

Attention: Mr. R. E. Aronstein

Subject: Shell Side Sodium Heat Transfer Program
References (a) 61AT6475, Dickinson to Nemzek,
August 21, 1961; (b) 61AT6780, Dickinson to
Nemzek, September 11, 1961; (c) Letter, Savage
to Nemzek, August 1, 1961

Dear Tom:

The shell side program inlet and outlet tube side plenum designs proposed by Atomics International are described in 796-41-341 attached to reference (a) and are embodied in Basic Bundle #12 in shop drawings attached to reference (b). The Ad Hoc Review Group for the Shell Side Program has considered the proposed design on its merits and in light of the discussion of this subject as summarized in reference (c) page 4. Our opinion, discussion, and recommendations follow:

1. The new plenum design is an improvement over those proposed earlier. However, it does not design around the problems as reference (c) recommends. Headers are still unique to and parts of the bundles, and because of the variety of different geometric shapes, each bundle will require individual "hydraulic" evaluation and probably modification after test for tube side flow uniformity. We would welcome an explanation justifying a variety of header geometries instead of a single configuration to which all tube bundles can be adapted.
2. Velocities in the plenums are still quite high in ratio to tube velocity, the difference being on the order of a factor of two. Velocity pressures, being dynamic, are always more difficult to make uniform than static pressures. Reference (c) recommends that plenum velocities be only a small fraction of the velocity in the tubes. We raise the question of whether there are space limitations or other technical considerations in the test facility which preclude achievement of low plenum to tube velocity ratios.
3. The velocity patterns in the inlet plenum are uncertain and variable from one rectangular duct geometry to another. The obstruction presented to the stream by the inlet header must

surely have a counter-effect on the velocity profile when it is normal to the flow stream and a more complicated counter-effect when it is placed at an angle with respect to the stream as in Bundle #12. Skewing of the velocity profile can be overcome by extending the tubes into the plenums so that all end in a plane normal to flow, and this may in fact be essential for adequate calibration of tube side coefficients. Bundle #12 does not provide for this contingency.

These uncertainties are not clarified by the cited reference, NACA-TN-1610, since it does not cover rectangular ducts or ducts with downstream header obstructions. Hydraulic experiments will be necessary to establish characteristics of each different duct and bundle geometry. We continue to recommend that the situation of extensive individual hydraulic experiments and its inevitable series of perhaps tedious modifications should be avoided if at all possible.

4. The AI plenum design is based on the premise that the principles successfully developed for ducts and transition pieces of circular cross-section with screens in the transition piece can be applied to transition and downstream ducts of rectangular cross-section. We would anticipate difficulty in achieving a flat velocity profile over the entire rectangular cross-section, and expect that a longer length of downstream duct will be required in the rectangular case than in the referenced circular case. More or less severe flow reductions should be anticipated in the corners. Based on the NACA reference, it appears that the dimension C plus E on the tube inlet side for Bundles 3, 6, 8, 9, and 12 may be too short for establishment of a sufficiently flat velocity profile in advance of the tube header. This dimension may also need to be increased by some amount sufficient to compensate for any counter-effect on the velocity profile imposed by the obstruction of the tube header downstream.

We know of no way to evaluate the significance of these parametric problems other than by experimental studies of readily modifiable models. We feel certain that Bundle #12 will be something less than ideal for these purposes.

5. In the hydraulic experiments AI proposes to scan only selected tube rows in evaluating uniformity of flow in all the tubes. For Bundle #12 this comprises 33 of 55 tubes. We expect that it will be desirable, if not essential, to measure the velocity in every tube.
6. It is obvious from the foregoing that we are not yet satisfied with the plenum design, the conceptual and analytic approaches, or the experimental program that will be involved. We believe it will pay in the long run to simplify and solve these problems on the drawing board rather than by modification following experiments.

7. However, there is another reason to complete the fabrication of Bundle #12 provided it will not compromise the test facility into becoming a difficult to change geometric arrangement of tube side inlet and outlet pipes.

A heat exchanger bundle will be required for proving operability of the test facility. Basic Bundle #12 can serve this purpose, and, in addition, may supply considerable data of use in evaluating bundles to be built subsequently.

Very truly yours,

Kurt Goldmann, UNC

J. J. Morabito, APDA

H. W. Savage, ORNL

Report of Subcommittee on Once-Through
Steam Generator

Report of GR Meeting, May 9, 1960

Subject: Sodium Component Committee
Sub-committee Meeting at Griscom-Russell Company,
Massillon, Ohio, May 9, 1960, Meeting Notes

Reference: Griscom-Russell Letter of March 17, 1960
to M. B. Powers, USAEC-COO

A sub-committee consisting of Messrs. Lockhart, Morabito, Smith, and Simmons visited the Griscom-Russell Company for the purpose of, 1) resolving a statement made on Page 5 of MSA Research Corporation's Report MSAR 60-38, "Revised Program on U.S. Atomic Energy Commission Contract AT(11-1)-765" regarding the use of Cr-Mo steels above 1000°F and, 2) a review of the items of work outlined in their referenced letter in order to clear the way for an early start on this contract.

The sub-committee spent the morning touring Griscom-Russell's plant. Special attention was given to the Fermi and Hallam steam generators which are now in production.

The meeting convened after lunch and those present from G-R were Messrs. Boni, Otten, Schroeder, and Tidball (plus a fifth whose name I failed to obtain).

From the very beginning Mr. Otten made it quite clear that the statement attributed to them by MSAR which was, "...G-R questioned the advisability of using Cr-Mo steels above 1000°F because of its rapidly decreasing strength above this temperature," was too all inclusive. He stated that the report should have referred to the high chrome croloys, specifically the 5 Cr-1/2 Mo-1/2 Ti, and that the statement did not apply to the 2 1/4 Cr-1 Mo material which they believe is useable to 1100°F. This statement clarified the material question.

The G-R personnel were queried regarding the type material testing program they deemed necessary for their use. They outlined briefly a proposed contract with Battelle Memorial Institute for obtaining fatigue data on three materials; namely, 2 1/4 Cr-1 Mo, 5 Cr-1/2 Mo, and 316 SS. The fatigue data would be determined at various temperatures in air by conventional methods. Curves would be plotted for temperatures of 950 - 1050 - 1150°F for 2 1/4 Cr-1 Mo and 750 - 850 - 950 - 1050 - 1150°F for the latter two materials. Ten points on each curve would be obtained.

A question was raised regarding the information required with respect to decarburization. G-R felt that hydrostatic stress-rupture tests should be made on fully decarburized tubing. They had no plans for additional tests. When asked regarding the advisability of fatigue testing decarburized material they had no definite opinion.

G-R was requested to review the area of material testing and to submit to the Commission a detailed materials testing program which they deemed adequate for their purpose.

The various phases of the G-R program as noted in the penultimate paragraph of their referenced letter was discussed in light of the committee's decisions made at the April 28, 1960 meeting. In particular the following was noted by Mr. Smith.

1. Control Studies were to be deferred until a definitive design was established.

2. Blaw-Knox type of tube stress analysis to be deferred until definitive design was firm.

3. The necessity for testing a model of the high temperature head was questioned. This subject was discussed at some length. Mr. Otten noted that their letter of September 9, 1959 to Mr. M. B. Powers discussed this subject. It was agreed by the committee members that they have now a clearer understanding of the purpose of the test. The purpose being to optimize the head thickness from a thickness (economic) standpoint. (In my opinion the necessity for this test is open to question.)

4. Welding tests to be delayed until the material selection is firm. Based on G-R's clarification of the use of 2 1/4 Cr-1 Mo at 1100°F, it was generally agreed that work should proceed in this area. G-R was to give the Commission a more definitive welding program.

5. The Commission is anxious that a proper materials testing program which meets the needs of G-R be started at an early date. The committee requested G-R to state in detail their needs in this respect and to define an adequate program for determining same.

6. The proposed 19 tube steam generator test at MSAR was rejected.

The meeting terminated with the understanding that the Commission would make every effort to initiate a contract with G-R as soon as possible in order that work can commence on the design, development and fabrication of a G-R sodium-heated steam generator.

W. R. Simmons

Reports of Subcommittee on Mechanical Properties
of Materials

Report of Meeting on May 24-25, 1960

FOREWORD

This subcommittee was set up as a result of the recommendations of the Sodium Components Development Program Working Group. Quoting from the minutes of this group dated April 27, 28, 1960:

"The Chairman then brought to the attention of the Working Group the revised programs of MSA Research Corporation for the determination of the property of materials exposed to 1200°F sodium. After considerable discussion the Group agreed that specialists in metallurgy from within their own parent organizations would be consulted by members of this Working Group to compare the original proposal with the modified proposal also to consider the equipment being assembled at MSA, and to establish an integrated program that would solve the problem originally proposed by the Group. The representatives from ORNL, AI, and NDA agreed to exchange among themselves their original proposals submitted to COO for undertaking this work. These members requested of the Chairman a copy of the original MSA proposal for doing this work. The Chairman agreed that if this were ethically and legally correct he would supply to the subcommittee copies of the technical portion of the MSA original proposal to COO."

Subsequently a letter dated May 11, 1960 and signed by T.A. Nemzek, COO, was sent out which further stated:

"This subcommittee will appraise the revised program of MSA, dated March 25, 1960, in relation to the original proposal and in relation to the current technical needs of a nuclear reactor system that will utilize 1200°F sodium as the heat transfer medium."

The subcommittee consisting of W. Anderson - A.I., J. DeVan - O.R.N.L., G. Stern - N.D.A. with K. Goldmann coordinating, met in Pittsburgh on May 24 and 25. In a briefing by K. Goldmann, the subcommittee discussed its intended goals, after which it exchanged individual opinions as to the adequacy of the MSA Research Corporations' revised program. It was unanimously agreed that changes in the program would be needed, particularly with respect to the selection of materials and types of properties to be measured. It was also agreed that under its intended charter the subcommittee should operate, if at all possible, to mold its recommended program to the technology available at MSAR.

At this point the subcommittee proceeded to MSA in Callery, Pa., where the details of the revised program dated March 25, 1960, were discussed with Messrs. Mausteller, Lee, King, and Reber of M.S.A. An inspection of the MSA research facilities and available equipment for this program was also made on May 24.

On May 25, the subcommittee met in the Penn-Sheraton Hotel in Pittsburgh, with T.P. Heckman, AEC-COO, as an observer and roughed out a program which is recommended herewith.

There are advantages and disadvantages to the use of a single pumped loop feeding various test ports, wherein physical properties are measured, simultaneously.

An obvious disadvantage of this arrangement is that all tests would be affected by any loop component failure. In addition, temperature control to the rigid specifications demanded for these tests may be difficult in a flowing system, especially, if as proposed by MSA in their Revised Program, samples were to be exposed at two temperature levels in the same loop. Another disadvantage of a single loop operating at two temperature levels, is the possibility of mass transfer masking the effects to be investigated in this program.

The advantages of a pumped loop are the environmental uniformity and the flowing sodium, which parallels power plant sodium component conditions.

In the light of these points and because one such loop had already been built, the subcommittee elected to adopt the loop approach, provided each loop is operated isothermally.

3.3.1 Creep and Creep-Rupture

The creep and creep-rupture tests will be run in isothermal, sodium, pumped loops with the main sodium stream sub-dividing to pass through each of the pots containing the creep specimens.

The sodium purity will be determined for each case as specified in the work scope (Section 4) and this impurity content shall be held as close to the specified range as possible throughout the tests.

Creep and creep-rupture tests shall conform to ASTM specifications as closely as possible, especially in regard to temperature control.

The choice of 316 stainless over a Croloy composition for the loop to be used in testing Croloy was based on the 316's suitability to test other materials if the $2\frac{1}{4}$ Cr - 1 Mo should be ruled out, or if the program is later expanded. In reaching this decision, it was realized that the ratio of Croloy to SS surface areas is different from that encountered in actual systems. Nevertheless, it was felt that these exaggerated conditions would give results in keeping with the objectives of this study.

3.3.2 Short Time Tensile Tests

The tensile tests are to be run on standard ASTM flat tensile specimens after exposure to sodium of various purities as outlined in the Work Scope.

1. PROGRAM OBJECTIVES

The objective of the program prepared by this subcommittee shall be to determine whether an environment of sodium and its normally anticipated

contaminants affects the physical properties of structural steels of interest for the construction of sodium system components.

This program shall attempt to determine whether designers need a new code to provide information for structural steels used in a sodium environment. It will not represent an attempt to provide a handbook for design engineers, although the data obtained will have statistical significance and validity for the properties measured under several defined conditions.

Impurity contents and test conditions shall be selected to represent fairly extreme, and in some cases, exaggerated conditions, and thereby, provide an answer as to whether or not sodium environments affect the behavior of structural steels at temperatures encountered in sodium-steam systems.

2. CONCLUSIONS AND RECOMMENDATIONS

1. Data shall be obtained from tests which are most likely to be sensitive to surface effects. It is expected that sodium, as well as the impurities found in sodium systems, will affect the surface of structural materials and thereby affect their performance. Therefore, special attention is being given to creep and fatigue tests.

2. Tests shall be devised to simulate systems using sodium, i.e., pumped sodium loops, in consideration of existing equipment and know-how at M.S.A.

3. Type 316 stainless steel shall represent the austenitic family of structural steels of interest. The same heat, fully annealed and having an ASTM grain size No. 5-7 shall be used throughout this program.

4. $2\frac{1}{4}$ Cr - 1 Mo Croloy shall represent the ferritic type of steel of interest. The same heat having a specified annealing treatment shall be used throughout this program.

5. Creep and fatigue tests on thin specimens will be used to determine whether or not the steels selected are affected by Na environments containing various amounts of impurities. Short time tensile tests will be run after exposure to various Na environments to establish reference points.

6. Isothermal pumped loops constructed of 316 stainless steel will be used to test the 316 and $2\frac{1}{4}$ Cr - 1 Mo steel, the former at 1200°F and the latter at 1100°F.

7. While other steels are of interest and specifically 304, 5 Cr - $\frac{1}{2}$ Mo - $\frac{1}{2}$ Ti, $2\frac{1}{4}$ Cr - 1 Mo - 1-Ti, and the 400 series, these will not be studied at this time for the sake of program simplification. If the $2\frac{1}{4}$ Cr - 1 Mo is ruled out at 1100°F because of recent corrosion test findings, then another analysis of ferritic steel can be substituted for it, or the temperature of test may be lowered to 1050°F or 1000°F, if power plant economics at these reduced temperatures are favorable.

8. Stress corrosion tests on separate specimens need not be run since the creep specimens can be used to compare corrosion in the unstressed and stressed portions. Weight change measurements can also be made by weighing

complete creep or tensile test specimens before and after exposure to the sodium.

9. To aid in interpretation of environmental effects, specimens after test will be subjected to metallographic, hardness and chemical examinations. Where significant effects on mechanical properties are found, other means of analysis such as x-ray diffraction, microprobe analyses, etc., will be used. Wherever necessary, these examinations and analyses should be handled through sub-contract arrangements.

10. Creep tests run in air and helium may be performed at an outside laboratory having the necessary equipment on hand. This will serve to avoid duplication of existing facilities and permit MSA to concentrate on pumped, isothermal, impurity-regulated, sodium loops.

3. DISCUSSION OF TEST PROGRAM

3.1 Test Materials

While a wide range of materials present themselves as logical candidates for mechanical property determinations, the committee elected to include only two types of materials for extensive study – namely 316 SS and $2\frac{1}{4}$ Cr - 1 Mo steels. This selection is intended to yield general information on the behavior of an austenitic and ferritic material respectively while still yielding data on alloys of present day importance.

The choice of 316 was made in part to bring sigma phase effects under this investigation, which would not have been possible had 304 SS been selected.

Testing additional materials would expand the program significantly.

Tests involving 316 SS will be carried out at 1200°F, whereas tests of the $2\frac{1}{4}$ Cr - 1 Mo material will be limited to 1100°F.

3.2 Test Environment

The following mechanisms associated with the circulation of sodium in metal systems at high temperatures may have important effects on the mechanical properties of prospective container materials for sodium.

1. Removal of surface oxide films.
2. Decarburization.
3. Solution attack (particularly if accelerated at grain boundaries).
4. Carburization.
5. Nitriding (of limited significance except for N₂ cover gas).

The second effect, that of decarburization, is likely to be of importance only in the case of the $2\frac{1}{4}$ Cr - 1 Mo material and has not been considered in conjunction with the 316 material.

In view of these effects, sodium purity is considered an extremely important test variable. Accordingly, four distinct impurity conditions have been proposed for each type of test and test material. Included for study of austenitic

stainless material (316) are tests run in the presence of pure sodium, of sodium contaminated by nitrogen, of sodium contaminated by carbon, and sodium contaminated by both nitrogen and carbon. It is not felt that a single test involving both carbon and nitrogen could replace tests of the individual contaminants, since interpretation of test results would be difficult. Further, it is possible that effects of either of these impurities might neutralize the effects of the other.

In the case of $2\frac{1}{4}$ Cr - 1 Mo material, an investigation of sodium contaminated by oxygen is included to point up any problem of decarburization which is expected to be accelerated in the presence of oxygen.

In order to delineate the effects of sodium on mechanical properties, it is essential to include within this program "control" tests that are operated in air and/or an inert environment (helium). As discussed in the conclusions, these tests could be obtained most economically through a subcontract with one of the testing facilities which afford this service.

3.3 Test Techniques

The program objectives dictate that data be furnished covering at least the following types of properties. These are properties which are relevant both because of the service temperatures and because of the physical characteristics of sodium.

1. Creep-rupture properties.
2. Short time tensile tests.
3. Mechanical fatigue.

There are advantages and disadvantages to the use of a single pumped loop feeding various test ports, wherein physical properties are measured, simultaneously.

An obvious disadvantage of this arrangement is that all tests would be affected by any loop component failure. In addition, temperature control to the rigid specifications demanded for these tests may be difficult in a flowing system, especially, if as proposed by MSA in their Revised Program, samples were to be exposed at two temperature levels in the same loop. Another disadvantage of a single loop operating at two temperature levels, is the possibility of mass transfer masking the effects to be investigated in this program.

The advantages of a pumped loop are the environmental uniformity and the flowing sodium, which parallels power plant sodium component conditions.

In the light of these points and because one such loop had already been built, the subcommittee elected to adopt the loop approach, provided each loop is operated isothermally.

3.3.1 Creep and Creep-Rupture

The creep and creep-rupture tests will be run in isothermal, sodium, pumped loops with the main sodium stream sub-dividing to pass through each of the pots containing the creep specimens.

The sodium purity will be determined for each case as specified in the work scope (Section 4) and this impurity content shall be held as close to the specified range as possible throughout the tests.

Creep and creep-rupture tests shall conform to ASTM specifications as closely as possible, especially in regard to temperature control.

The choice of 316 stainless over a Croloy composition for the loop to be used in testing Croloy was based on the 316's suitability to test other materials if the $2\frac{1}{4}$ Cr - 1 Mo should be ruled out, or if the program is later expanded. In reaching this decision, it was realized that the ratio of Croloy to SS surface areas is different from that encountered in actual systems. Nevertheless, it was felt that these exaggerated conditions would give results in keeping with the objectives of this study.

3.3.2 Short Time Tensile Tests

The tensile tests are to be run on standard ASTM flat tensile specimens after exposure to sodium of various purities as outlined in the Work Scope.

It is felt that an outside laboratory can be found which is set up to run these tensile tests inexpensively.

3.3.3 Fatigue Tests

Fatigue data for designers of sodium systems should provide measured values of cyclic strain and cyclic stress for use in analytical determination of service life. Axial fatigue tests are required to provide this type of data. However, for the purposes of comparison of effects within the objective of this program (comparison of strength properties in sodium and gas environments), bending fatigue tests are preferred. The advantages of bending fatigue are as follows:

1. The tests are more simple to perform in a flowing sodium loop.
2. The environments will be the same as those of the creep tests.
3. The test material in sheet form will be from the same heat as the creep tests.

A controlled-deflection bending test with standard ASTM sheet fatigue specimen having a tapered test section lends itself to approximation of the cycling strain and is preferred over a constant width section. If possible, the cyclic load to induce the bending shall be observed or recorded during the tests.

4. WORK SCOPE

4.1 Stainless Steel Specimens

The stainless steel specimens shall be tested in a type 316 SS, circulating sodium loop.

Specimens shall be completely submerged in flowing sodium.

The loop shall be operated isothermally at 1200°F. If practical, temperature controls shall maintain specimen temperatures within $\pm 3^\circ\text{F}$ to conform to ASTM Specs (E139-58T).

The loop shall have seven test stands connected in parallel; six for creep and creep-to-rupture and one for fatigue tests.

All specimens shall be type 316 SS, fully annealed and having an ASTM grain size No. 5-7. The surface shall be clean and free of oxide.

All surfaces of the specimen shall be brought to a uniform R.M.S finish by a method imparting a minimum of cold work to the surface.

The specimens shall be 0.065 in. thick.

4.1.1 Creep and Creep-to-Rupture Tests

The specimens shall have a gage length of 2 in.

Tensile loads and specimen width shall be selected to achieve the following conditions:

1. Creep-to-rupture in 500-1000 hr (new sample).
2. Creep-to-rupture in 3000-5000 hr (new sample).
3. Creep-to-rupture in 500-1000 hr (pre-exposed sample).
4. Load equivalent to creep rate of 1% in 10,000 hr (4000 hr min test).

Three identical samples shall be used for each test. Tests 1, 2, and 3 could be run sequentially with samples for Test 3 being pre-exposed during Test 2. Test 4, to be conducted concurrently with Tests 1, 2, and 3 where possible.

Identical tests shall be conducted for the following sodium conditions in the indicated order:

	Sodium	Contamination	Cover Gas	Cold Trap Temp
a.	Reactor grade	Average*	He	300 °F
b.	Reactor grade	Saturated C at 1200 °F	He.	300 °F
c.	Reactor grade	Avg Ca*	N ₂	300 °F
d.	Reactor grade	Avg Ca, * Sat. C	N ₂	300 °F

Control tests with three specimens each for tests 1, 2, 3, and 4 shall also be conducted in helium and air at 1200°F.

4.1.2 Short Time Tensile Tests

Six unstressed specimens shall be exposed to sodium during each test 4, and upon its completion shall be removed (without washing) and given a short time tensile test in either air or helium at 1200°F.

*** Exact values to be determined later.**

Three of these specimens shall be weighed prior to exposure and washed and reweighed just prior to the short time tensile tests.

4.1.3 Fatigue

The specimen widths shall be selected from the standard bend test configurations of ASTM Special Technical Publication No. 91 (see p. 31).

Deflections vs time should follow as nearly as practical a square wave pattern at a frequency of ~3 cycles per min.

Deflections shall be selected to achieve failure in less than approximately 1000 and 100,000 cycles as follows:

1. 1000 cycles (new sample).
2. 100,000 cycles (new sample).
3. 1000 cycles (pre-exposed sample).

Sample 3 could be exposed to sodium during Test 2. Tests 1 through 3 shall be repeated with identical specimens. Test sequence would be 1,2,3, 1,2,3, 1,2,3.

Fatigue tests could be run concurrently with creep and creep-to-rupture tests with the same sodium conditions listed in Section 4.1.1.

Control tests with non pre-exposed specimens identical to those used in tests 1, 2, and 3 shall be conducted with three in air and three in He at 1200°F.

4.2 Croloy Specimens

The Croloy specimens shall also be tested in a type 316 SS, circulating sodium loop which could be identical in design and construction to the loop used for the testing of the stainless steel specimens.

Operating conditions shall be the same as those described under 4.1 except that the operating temperature shall be reduced to 1100°F.

All specimens shall have a uniform and specified annealing heat treatment. All surfaces of the specimens shall be brought to a uniform R.M.S. finish by a method imparting a minimum of cold work to the surface.

4.2.1 Creep and Creep-to-Rupture Tests

Tests shall follow the same schedule as outlined for stainless steel . (Section 4.1.1) except that the sodium conditions at 1100°F shall follow the order and contamination conditions indicated below:

	Sodium	Contamination	Cover Gas	O ₂ Condition
a.	Reactor grade	Average*	He	300°F cold trap
b.	Reactor grade	Average*	He	200-300 p.p.m.
c.	Reactor grade	Avg Ca*	N ₂	300°F cold trap
d.	Reactor grade	Saturated C at 1100°F	He	300°F cold trap

4.2.2 Short Time Tensile Tests

The conditions shall be the same as indicated under 4.1.2 except that the temperature shall be 1100°F.

4.2.3 Fatigue

The conditions shall be the same as indicated under 4.1.3 except that the temperature shall be 1100°F.

* Exact values to be determined later.

Table 1 — Schedule for Specimen Testing and Exposure to Sodium in Loops*

	Loop 1			Loop 2		
	Sample Material 316 SS			Sample Material 2 $\frac{1}{4}$ Cr-1 Mo		
	Temp, 1200°F			Temp, 1100°F		
	Pots 1-3	Pots 4-6	Pot 7	Pots 1-3	Pots 4-6	Pot 7
Creep to Rupture						
500-1000 hr	xxx			xxx		
3000-5000 hr	{ xxx			{ xxx		
500-1000 hr	{ yyy			{ yyy		
	y'y'y'			y'y'y'		
Creep Rate (1% in 10,000 hr)						
4000 hr (min)	{ xxx			xxx		
Exposure for short time	{ yyy			yyy		
tensile†	{ yyy			yyy		
Fatigue‡						
1. 1000 cycles			x			x
			x			x
			x			x
2. 100,000 cycles			x y			x y
			x y			x y
			x y			x y
3. 1000 cycles			y'			y'
			y'			y'
			y'			y'

Nomenclature:

x — new sample under stress

y — new sample without stress to pre-expose

y' — pre-exposed y samples under stress

* Tests shall be repeated for each sodium condition as specified in the text.

† Actual tensile testing will be performed in either air or helium with three washed and three unwashed samples.

‡ Fatigue test sequence as stated on page 11 shall be 1,2,3, 1,2,3, 1,2,3.

Report of Meeting on February 15, 1961

Mr. T. A. Nemzek
Assistant Technical Director
Chicago Operations Office
U. S. Atomic Energy Commission
9800 South Cass Avenue
Argonne, Illinois

Dear Mr. Nemzek:

As requested by your office, the Materials Subcommittee of the Sodium Component Working Group met with Mine Safety Appliance Research Corporation (MSAR) on February 15, 1961 to review the materials program being carried out at their laboratory. This letter is to report to you and the Working Group the results of our discussions.

The Materials Subcommittee was represented by W. F. Anderson, III, J. H. DeVan, ORNL, G. Stern, NDA, and K. Goldmann, NDA coordinating. T. Lockwood and R. Radd represented AEC-COO. Participating MSAR personnel were K. R. Barker, Supervisor, Project Engineer, J. W. Masteller, Associate Director of Research and Manager of Research Division, K. L. Rober, Supervisor, Metallurgical and Inspection Engineering, C. H. Staub, Director, Marketing Division, and R. C. Werner, Associate Director of Research and Manager Engineering Division.

MSAR provided us with a memo on the "Physical Properties of Material Study" which together with the Subcommittee's June 10th report on the "Sodium Component Materials Program" served as a basis for our review. The following decisions were reached:

1. Temperatures in each test pot should be controlled to $\pm 5^\circ\text{F}$ at 1200°F .
2. The initial plugging temperature for the sodium circulating loops should be 500°F or lower.
3. The creep rate tests should be performed in such a manner that the constant creep rate is approximately 1% in 10,000 hours as previously recommended and not 1% in 100,000 hours as stated in the contract.
4. Enough samples should be exposed to sodium environment during the creep rate tests to perform short-time tensile tests with both washed and unwashed samples after their exposure to sodium.

5. The short-time tensile tests with these samples should be performed in helium only.
6. Additional outside laboratories which are believed to have facilities and machines available to perform tests in air and helium were suggested. These are Westinghouse Gas Turbine Division, New England Materials Testing Laboratory, U. S. Steel and University of Michigan.
7. MSAR had been given only a preliminary version of the June 10 report. We left copies of the final version with them.
8. The final version of the report cleared up a misunderstanding as to the order in which the fatigue tests were to be conducted and the number of samples which were required to perform these tests.
9. The "as is" reactor grade purity of the sodium should be specified further by the Sodium Component Group. The sodium should be analyzed for impurities before actual tests begin.
10. All test specimens should have a surface finish of 32 RMS or better.
11. Care should be taken to remove decarburized surfaces from 2-1/4 Cr, 1 Mo test samples and to maintain a neutral atmosphere during the normalizing heat treatment of these samples.
12. Care should be taken to provide as accurate a means as possible for measuring the strain during the creep rate tests.
13. A fatigue test procedure was discussed which appeared equally acceptable to that described in the June 10 report and appeared to have several advantages. This procedure consists of bending test specimens in form of strips (6" x 1/2" x 0.05" approximately) over a fixed mandrel. This procedure which reduces the cost of specimens provides a constant strain for each cycle, makes it easier to analyze the data, and according to experience by AI results in more consistent data. Disadvantages of this procedure are that the specimen surface does contact the mandrel and could initiate detrimental surface effects for the fatigue tests, sodium might not always contact the specimen in the critical region where the mandrel and specimen meet, and the procedure is not a standard one, recognized by ASTM or other organizations.

The meeting at MSAR has confirmed that the program originally outlined by the subcommittee on June 10, 1960 is well understood and has now been underway for approximately one month, delays being caused by contractual negotiations. The program has as its contractual objective the determination of whether an environment of sodium and its normally anticipated contaminants affects the physical properties of two types of structural steel used in sodium system components. However, an opportunity exists to use the physical property tests as a starting point for adding to the fundamental understanding of materials and their behavior under stress in the environments under consideration. It is hoped that advantage will be taken of these tests and specimens to intelligently probe into this area.

Very truly yours,

Kurt Goldmann
Subcommittee Coordinator

KG:npg

cc: R. W. Dickinson
R. E. Harris
R. W. Lockhart
J. J. Morabito
H. W. Savage
W. R. Simmons
W. R. Wykoff
W. F. Anderson
J. H. DeVan
G. Stern
T. P. Heckmann
F. A. Smith

Report of Meeting on January 9, 1962

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1.0 INTRODUCTION

In letters dated December 26, 1961, the Chairman of the Sodium Components Development Program Working Group, T. A. Nemzek, asked members of the Materials subcommittee to undertake another technical review of the Physical Properties of Material Work. In accordance with this request a review meeting was held at Mine Safety Appliance Research Corporation (MSAR) on January 9, 1962.

The subcommittee consisted of:

W. F. Anderson, AI

J. H. DeVan, ORNL

G. Stern, United Nuclear

K. Goldmann, United Nuclear - Technical Coordinator

T. P. Heckman, AEC-COO, Chairman

R. Radd, AEC-COO, Observer

MSAR representatives participating in the meeting were

Messrs:

Werner

King

Andrews

Lee

Reber

Rogers, and

Prof. Freeman (University of Michigan)

A pre-established agenda was closely followed and covered the following topics:

Jan. 8 Subcommittee Briefing Session

Jan. 9 Status Report by MSAR

Report from Professor Freeman

Inspection of Experimental Setups

Subcommittee Caucus (without MSAR)

Discussion of Status and Planned Work

Subcommittee Summary (without MSAR)

This report summarizes discussions and the conclusions and recommendations reached by the subcommittee as a result of this review.

2.0 PROGRAM STATUS

2.1 Background

The subcommittee originally convened on May 25, 1960 and as a result of its deliberations issued a report dated June 10, 1960 which attempted to outline in detail a program to determine whether an environment of sodium and its

normally anticipated contaminants affects the physical properties of two types of structural steel used in sodium system components. The subcommittee next met on February 15, 1961 to review the progress made by MSAR on that program. At that time MSAR was just starting to build the required loops and the subcommittee felt the program was well understood. An appeal for using this program as an opportunity to add to the fundamental understanding of materials and their behavior under stress in the environments under consideration was inserted in the subcommittee's letter of February 28, 1961, which reported on the February 15 meeting. The subcommittee also urged the Sodium Components Committee to strengthen the program by having MSAR engage a competent consultant.

The subcommittee reconvened on January 9, 1962, almost a year since its last previous meeting, to again review the program and progress at MSAR and to discuss the program with Prof. Freeman of the University of Michigan who is now acting as a Consultant to MSAR. Although not thoroughly briefed for this meeting Professor Freeman nevertheless made many valuable recommendations to the subcommittee and to MSAR concerning the programming and operation of the tests.

2.2 Tests in Sodium

The first of two forced convection loops to be utilized for fatigue, creep, and stress-rupture testing in sodium has been in "trial" operation since December 6, 1961. This trial run, which is nearly complete, has yielded the following facts concerning the ability of the loops to meet design specifications.

- a. Temperature control can be maintained within the specified $\pm 3^{\circ}\text{F}$ at all stations except for periods when

the cold trap has been in operation.* The cooling effect asserted on the main stream by cold trap operation could not be overcome by unit furnaces, and requires that a throttling valve be placed in the cold trap circuit. Valves have been ordered to permit this modification.

b. Specimen removal and installation can be accomplished without adversely affecting temperatures at other stations. However, effects of these operations on system purity remain to be evaluated.

c. Although this first loop was originally slated for operation with 316 stainless steel only, inclusion of 2 1/4 Cr-1 Mo specimens during the shakedown run will dictate assignment to 2 1/4 Cr-1 Mo tests.

The second loop, which is a duplicate of the first, will be ready for shakedown operation in 2 to 5 weeks. No estimate of the date when actual testing in either loop will be started can as yet be made.

2.3 Fatigue Tests in Air and Helium

Fatigue tests in air and helium on 316 stainless steel specimens have been completed by MSAR under the following conditions:

1. 3 tests in air and helium respectively at a maximum fiber strain of 2.18% and at a temperature of 1200°F.
2. 3 tests in air and 2 in helium at a maximum fiber strain of 0.56% at a temperature of 1200°F.

Tests in series 1, aimed at effecting failure in 1000 cycles, failed at between 570 and 600 cycles. Tests in series

* At the time the loop was inspected by subcommittee members, the temperature spread was found to be considerably greater than $\pm 3^{\circ}\text{F}$; however, MSAR advised that this definitely constituted an abnormal condition.

2, aimed at failure in 100,000 cycles, produced failures between 10,000 and 16,000 cycles. Accordingly, a third mandrel was made to establish an outer fiber strain of 0.25%, which is believed closer to the flexure limit for 100,000 cycles. Tests in air and helium using this mandrel design are presently in progress.

2 1/4 Cr-1 Mo steel specimens slated for air and helium fatigue tests were furnished with a smaller thickness than specified (0.040" compared to 0.065"). As a consequence it was decided to hold back tests of this material until new specimen stock could be obtained. Tests are still awaiting material delivery.

2.4 Creep, Stress Rupture, and Tensile Tests in Air and Helium

Under a subcontract with MSAR, the University of Michigan will perform stress-rupture, creep, and tensile testing in air and helium utilizing existing laboratory facilities at the University. In addition a second subcontract has been signed with Professor Freeman of the University of Michigan to provide consultant services for guidance of the program and for analyzing test data generated under sodium environments.

2.5 Thermal Shock Tests

This portion of the program had not previously been specified or reviewed by the subcommittee.

Construction of the loop for thermal shock tests is nearly complete. At the request of the AEC, work had been stopped on the preparation of a test specimen.

3.0 SUMMARY OF DISCUSSIONS WITH MSAR

Following a resume of the program status, the basic objectives of the tests, as originally prepared by the subcommittee, were

reviewed with Professor Freeman. The subcommittee reiterated that the intention of the immediate program was not to provide a materials property handbook for sodium systems but rather to determine whether the need existed for a new design code for high temperature sodium systems. To meet this objective, the subcommittee's program had called for the operation of tests at a limited number of stress levels (generally two) and, to afford statistical significance, with a minimum of three tests at each stress condition. It was the decision of the subcommittee that stress levels would be selected so as to yield a test period of relatively short duration (500-1000 hr) and another test period of relatively long duration (3000-5000 hr) and relatively low stress.

Professor Freeman pointed out certain difficulties in this program. Because of limited published data on the test materials and the marked variation in mechanical properties of these materials with heat treatment, he was dubious about his ability to pre-select stress levels to meet the suggested time criteria. Although the subcommittee countered that the time periods had been selected only to provide a reference for setting stress levels and were not in themselves important parameters (other than in permitting "short-time" and "long-time" tests), he made the valid point that economically he could not afford to end up on the long side of 5000 hrs in his low stress runs. Thus he was strongly in favor of operating at a series of stress levels, in which initial tests would serve as a guide in pinpointing stresses for longer time tests. He further emphasized that, by correlating the results of single tests at these stress levels with accepted behavior patterns for materials in the proposed temperature range, he would be able to gauge the significance of sodium effects equally as well as for three tests at each stress level.

In addition to this major revision, Professor Freeman suggested two other more minor program modifications:

- a. Stress-rupture tests of 2 1/4 Cr-1 Mo steel (in sheet form) would be unduly affected by oxidation at 1100°F and their significance would be questionable.
- b. Room temperature tensile tests of exposed specimens would provide a valuable supplement to currently programmed high temperature tensile tests.

At the conclusion of discussions with Professor Freeman, several points regarding loop operation were taken up with MSAR personnel. These pertained to temperature control of the test specimens, temperature effects on the bellows, and ambient temperature effects on creep measurements. The discussions culminated in several recommendations which are included in the next section.

The condition of test specimens was reviewed from the standpoint of completeness, historical data, sampling technique, and anticipated variability in properties. Three possible problems exist with the specimens:

- a. A major shortcoming is lack of notation as to where the stainless steel specimens were taken from sheet.
- b. Certain errors were made in gage length in machining the specimens which may or may not influence the tests by possibly deviating from calibration for strain in the creep specimens, and
- c. Although 316 SS specimen stock had been purchased in the form of annealed sheets, Professor Freeman questioned whether a cold stretching operation may have been performed by the manufacturer to meet "flatness" specifications. MSAR was asked to check this detail and, if verified, to determine its effect on property variability. A stress-relieving anneal was suggested by the subcommittee as a method for alleviating difficulties arising from this source.

In discussing the results of 316 stainless steel fatigue tests, MSAR questioned the subcommittee whether the 600 cycle failure point which has been achieved using the 3 1/8 inch anvil radius (2.18% strain) would satisfy the 1000 cycle requirement suggested in the subcommittee's program. It was agreed that the 600 cycle failure criterion completely satisfied the "1000 cycle" intent.

The thermal shock test was reviewed intensively at this meeting for the first time. After discussion and examination of equipment and discussion of proposed operating procedures, it was concluded that the test conditions as originally proposed would probably not have been met for the following reasons:

- a. No indication was given that heat capacity of the primary side of the heat exchanger was considered in evaluation of transient temperature conditions in the specimen.
 - b. Indication was given that heat transfer from continuous primary hot sodium flow in the heat exchanger had not been evaluated.
 - c. No indication was given that the temperature change in the sodium through the length of the specimen had been evaluated or considered.
 - d. No indication was given that the temperature drive through the sodium film between the bulk sodium and the specimen surface had been evaluated in the thermal shock.
- Additional problems with the originally proposed test would

be:

- a. Analytical separation of the effect of thermal shock on a thick wall and the effect of cyclic straining of the transition between dissimilar materials does not appear possible.
- b. Planned examination of the specimen to determine the existence of cracks would tell little about when the cracks had actually occurred.

Testing of the thermal fatigue specimen as proposed by W. F. Anderson of Atomics International, was reviewed by the subcommittee and MSAR personnel. The conclusions reached after some discussion of the proposed tests and system capability and requirements to perform the tests are presented in Section 4.7.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 General

Certain modifications in the test program, which had originally been outlined by the subcommittee, are recommended. It is to be emphasized, however, that these changes involve only the details of specifying stress conditions and in no way alter the basic objectives or scope of the program. No changes in the over-all number of tests, equipment design, or allotted contractual periods should be required by the suggested modification.

In the recommendations that follow it is not the purpose of this subcommittee to present in detail a new test program but rather to acknowledge the general changes required. The revised scheduling of tests remains the responsibility of MSAR and the University of Michigan and should be accomplished within the general time framework established for the original program. That is, scheduling of test should provide for the early generation of base line data from which conditions for longer time tests can be gauged. Further, scheduling should take into account the requirement for pre-exposing test specimens, which necessitates that unstressed specimens be included in the longer-time test runs.

Copies of all past and future progress reports from MSAR should be forwarded to Professor Freeman.

Copies of pertinent information from temperature strip charts and deformation records obtained during checkout and initial tests should be included promptly in progress reports.

All specimens broken during the checkout period are to be given at least metallographic examinations. Photomicrographs of same are to be included promptly in progress reports.

In general, it appears that satisfactory performance of the tests under this contract is now a possibility. However, it appears that MSAR has failed to fully appreciate the requirements and goals of this program. The personnel assigned to this project are generally weak in the area of physical testing programs and the interpretation of results of physical testing. It is, therefore, recommended that this program be technically monitored more frequently and that Professor Freeman be permitted to assume a stronger role in the guidance and actual direction of the program. This will require his presence in Callery more often than presently provided for.

4.2 Evaluation of Test Specimens

It is recommended that the "variability" of the specimens be investigated immediately. Such a check would entail a series of repetitive tests, most probably in the form of short-term stress-rupture runs. If a large scatter in results is found, corrective action, i.e., improvement in the source of specimen stock, should follow before the start of other tests.

4.3 Creep Rate and Creep to Rupture Tests

Rupture and creep rate tests should be taken over a range of nine different loads encompassing the load for rupture in 1000 hours and that load for a creep rate of 1% in 10,000 hours rather than the previously suggested three tests at each of two rupture loads and three tests at one creep rate load. This will provide a basis for a curve with nine points for creep rate and possibly six points or more for rupture time. Magnitude of the individual loads to be imposed on the specimen will be determined by Prof. Freeman for both the tests at the University of Michigan and at MSAR.

4.4 Fatigue Tests

In the case of fatigue tests, the test schedule should be modified to permit the testing of 2 specimens at each of 3 stress levels, in lieu of the present schedule which calls for 3 specimens at each of 2 stress levels. Present mandrels yielding approximately 600 cycles and approximately 15,000 cycles to failure should be retained plus the one additional mandrel intended to yield approximately 100,000 cycles. Only if the present mandrel being tested for this range (100,000 cycles) is not satisfactory, shall a new one be made.

4.5 Air Tests of 2 1/4 Cr-1 Mo Steel at 1100°F

Creep and creep-rupture tests of 2 1/4 Cr-1 Mo steel at 1100°F in air should be dropped from the test program.

4.6 Room Temperature Tests

A group of tensile specimens of both original material and material exposed for a long time in sodium should be tested at room temperature as well as high temperature.

4.7 Thermal Shock Tests

Performance of tests with the newly proposed single material specimen would be worthwhile in studying the applicability of basic uniaxial fatigue data to more complex geometries in thermal shock situations.

The present thermal shock system would have to be modified to perform the tests as proposed.

MSAR would probably require both consulting and engineering assistance in adequate re-designing of the system to perform this test.

Whether or not this test should be included with this present program of study of physical properties of material in sodium environment is a subject to be reviewed by the Working Group.

4.3 Sodium Loops

Steps should be taken to assure that temperature in the test pots are controlled to $\pm 3^{\circ}\text{F}$.

Bellows as presently installed in the creep equipment may accumulate frozen sodium and sodium oxide buildup which would introduce errors into the stress or load measurement on the specimen. Air leakage past the sliding O-ring may become a source for oxides. If found necessary, these difficulties should be eliminated.

The effects of variable room temperature on creep measurements should be evaluated.

Report of Meeting on November 29-30, 1962

REVIEW REPORT NO. 4

of the

Materials Subcommittee for the

Investigation of the Physical Properties
of Materials in High Temperature Sodium

performed by

MSA Research Corporation

under AEC Contract AT(11-1)-765

January 25, 1963

Submitted by:

W. F. Anderson, AI

J. H. DeVan, ORNL

J. M. McKee, UNC

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1. INTRODUCTION

On November 29 and 30, 1962, the 4th meeting of the Materials Subcommittee of the Sodium Components Development Program was held to review the investigation of the physical properties of materials in sodium performed by MSA Research Corporation (MSAR), Callery Junction, Pennsylvania. The group members that participated were:

W. F. Anderson, AI
 J. H. DeVan, ORNL, Technical Co-ordinator
 J. M. McKee, UNC
 T. P. Heckman, AEC-CH, Chairman

The meeting of November 29 convened in the MSAR offices in Callery, Pennsylvania with the following contractor personnel participating:

R. C. Andrews
 Prof. J. W. Freeman, University of Michigan, consultant to MSAR
 L. Kuschler
 J. W. Mausteller
 K. W. Reber
 S. L. Rodgers
 C. H. Staub
 F. Tepper
 R. C. Verner

A tour of the loop facilities was conducted by MSAR as the first item on the agenda; this was followed by a presentation of the project status based on the references: MSAR-62-126, MSAR-62-142, and a thirty-three page packet of data which was distributed at the meeting. Integrated with the presentation by MSAR were questions and discussions by the members of the Subcommittee and by Prof. Freeman regarding the metallurgical significance of the existing data and MSAR's plans for the balance of the investigation.

The Subcommittee held an evaluation meeting in the Penn Sheraton Hotel, Pittsburgh, Pennsylvania, on November 30, 1962, to examine in more detail the information obtained during the previous day. An outline for the report together with assignments for the drafting of separate sections were made at that time.

1.1 List of Materials Subcommittee Meetings

Meeting No. 1 held May 25, 1960 - reported June 10, 1960.
 Meeting No. 2 held February 15, 1961 - reported February 28, 1962.
 Meeting No. 3 held January 9, 1962 - reported February 15, 1962.
 Meeting No. 4 held November 29, 1962.

1.2 Purpose and Scope of MSA Program

The physical properties research program at MSAR was initiated for the purpose of determining the effects of reactor grade sodium, and normally

anticipated contaminants, upon representative types of structural steels of interest for the construction of sodium systems. Type 316 stainless steel was selected as representative of the austenitic steels, and 2-1/4 Cr-1 Mo was selected as representative of the ferritic steels. The maximum temperatures selected were 1200°F for the austenitic and 1100°F for the ferritic. The contaminants to be intentionally introduced into the sodium after the reactor grade sodium tests were completed would be oxygen, carbon, and nitrogen. The types of tests selected for revealing any possible effects of the environments upon the materials were tensile, creep, stress-to-rupture, and fatigue. In addition to these physical tests, appropriate chemical analyses and metallurgical examinations were designated for assisting in the interpretation of the physical properties.

2. SUMMARY AND CONCLUSIONS

The two loops being employed for sodium studies are fabricated of type 316 stainless steel with type 316 specimens in loop No. 1 and 2-1/4 Cr-1 Mo specimens in loop No. 2. The first series of tests, designated Test 1 in loop No. 1 and Test 2 in loop No. 2, are nearly complete with the preliminary results as follows:

2.1 Fatigue Tests

The plots of the data for both materials show little difference between helium and sodium environments; however, there is a decided difference for the plot of the air tests, with failures occurring considerably sooner in air.

2.2 Creep Tests

The shape of the curves for both materials in helium, air, and sodium are similar with a displacement of the creep rate ordinate that indicates a higher rate in sodium. This difference in the rate curve may be attributed to a difference in the testing equipment used for sodium from that used for the gas atmospheres. An improvement in deformation measuring equipment for an opaque environment is needed.

2.3 Tensile Tests

Specimens which were pre-exposed to sodium under zero-load conditions are awaiting tensile testing at the University of Michigan.

2.4 Stress-to-Rupture Tests

The results of the tests of type 316 specimens in air and sodium are in such close agreement that a single stress-rupture curve is justified.

In sodium tests of 2-1/4 Cr-1 Mo specimens, a shortening of rupture life resulted from pre-exposure of specimens to sodium; however, stress-rupture plots for all three environments appear to be converging at longer time tests irrespective of specimen treatment.

2.5 Future Program

Upon completion of tests 1 and 2, minor modifications will be made to the loops to improve the performance of the test equipment and hopefully the accuracy of test data.

The next test in loop No. 1 (test 3) will be a repeat of test 1 except that the sodium will be saturated with carbon as a contaminant. In the case of loop No. 2, it is recommended that the next test (test 4) be a repeat of test 2 except with oxygen level in the sodium increased to 300 ppm.

3. PROGRAM STATUS

The first series of fatigue, creep, and stress-rupture tests in sodium is nearing completion. This phase of testing has utilized two identical stainless steel forced convection systems containing standard* sodium. One of the loops (loop 1) has operated at 1200°F with type 316 stainless steel specimens, while the other (loop 2) has operated at 1100°F with 2-1/4 Cr-1 Mo specimens. The status of these tests is completely reviewed in MSAR's monthly reports Nos. 25[†] and 26[‡]. In brief, all test runs under phase I (standard sodium) are essentially complete except for specimens having been pre-exposed to sodium. To provide base-line data for evaluating sodium effects, the University of Michigan, under Dr. James Freeman, is conducting companion stress-rupture and creep studies in air and helium. Base-line fatigue studies in air and helium are being obtained by MSAR. The status of these tests is brought up to date in Progress Reports No. 25[§] and No. 26^{||}. Fatigue studies in air and helium have been completed under essentially all conditions. Creep and stress-rupture tests of "as-received" specimens have been either initiated or completed in air; however, tests of these specimens in helium and of specimens pre-exposed in sodium in both air and helium are incomplete.

4. EVALUATION OF DATA

4.1 Stress-Rupture Tests

316 Stainless Steel - A summary of the status of stress-rupture tests of type 316 stainless steel is shown below:

*"Reactor Grade" (low Ca) sodium with oxygen level controlled at an equivalent saturation temperature of 300°F.

[†]MSAR 62-126 issued October 19, 1962.

[‡]MSAR 62-142 issued November 14, 1962.

[§]MSAR 62-126 issued October 19, 1962.

^{||}MSAR 62-142 issued November 14, 1962.

Environment	Tests Completed	Tests In Progress	Tests Remaining
Sodium	6	3 ^a	0
Air	13	1	3 ^a
Helium	3	2	3 + 3 ^a

^aNine specimens which were pre-exposed in 1200°F sodium for 400 hr remain to be tested, three in each of the respective environments.

Plots of stress versus rupture time for completed tests show essentially no differences among the various environments. Similarly, the elongations attained at rupture show a normal variation with stress and are comparable in three environments. However, the effects of pre-exposing specimens in sodium remain to be evaluated. Also, the limited tests completed in helium make any conclusions regarding this environment extremely tentative.

2-1/4 Cr-1 Mo Steel - The test status for this material is summarized below:

Environment	Tests Completed	Tests In Progress	Tests Remaining
Sodium	7 + 3 ^a	1 + 1 ^a	3 + 3 ^a
Air	4	0	0
Helium	5	0	3 ^a

^aSpecimens pre-exposed in sodium for 4000 hr at 1100°F.

Like 316 SS, plots of stress versus rupture life for "as-received" specimens fall close to the same line in all three environments. It appears, however, that a slightly better life expectancy is realized in the air environment, although this superiority dwindles at longer test times. A limited number of pre-exposed specimens of 2-1/4 Cr-1 Mo steel have completed test runs in sodium. Results of these tests, while limited, show that pre-exposure causes a considerable reduction in life expectancy. The reduction appears greater at higher stress levels, indicating that the data points may converge at longer test times. How much of the reduction is due to prior sodium exposure (eg, decarburization effects) and how much to temperature effects (aging) is not yet known.

4.2 Creep Tests

316 Stainless Steel - Creep data obtained on this material are summarized below:

Environments	Stress (psi)	Steady State Creep Rate (%/100 hr)	Duration of Test
Air	13,000	0.215	3692
Air	12,500	0.15	1581 ^a
Air	11,500	0.035	3384 ^a
Sodium	13,500	0.67	4000
Sodium	12,500	0.31	4000
Sodium	11,500	0.17	4000

^aTest still in progress.

Comparison of test results in air and sodium (the only environments examined to date) indicates a consistently higher creep rate in sodium than in air. It is important to note, however, that specimen deformation in sodium is being measured by means of a dial gauge attached to a pull rod above the sodium, while in air tests, deformation is measured directly across the specimen gauge length. The deviations between air and sodium data are well within the range that could be attributed to errors in measurement. Furthermore, the direction of the deviation is in agreement with the expected error, i.e., higher deformations being registered by the dial gauge.

If one ignores the strong possibility of measurement error and blames instead the difference in environment, he is forced to conclude that the effect being realized is attributable to a strengthening effect of air. The deviation in creep rates between sodium and air shows up after only a few hours of testing has elapsed. Considering what is known concerning corrosion of 316 SS by sodium, it is unreasonable to assume that sodium could inflict a sufficient change in this short time to account for any measurable reduction in mechanical properties. On the other hand, the formation of an oxide film on 316 SS is realized rather quickly on exposure to air at 1200°F, and in certain cases, the presence of an oxide film has been found to benefit creep resistance. The possibility of a strengthening effect of air can be more positively evaluated when creep data in helium are forthcoming.

2-1/4 Cr-1 Mo - Creep tests of this material in sodium have produced rather anomalous results. At higher stress levels (designed to yield a creep rate of 0.4%/1000 hr in air), creep curves have exhibited an increasing creep rate with time. However, as shown below, at a slightly lower stress level (6000 psi), the creep rate in sodium showed about the same deviation from air as was exhibited by 316 SS.

Environment	Stress (psi)	Steady State Creep Rate (%/1000 hr)	Test Duration
Air	6000	0.12	3555
Sodium	6000	0.28	4000

At present no explanation for the unusual behavior of this material in sodium has been advanced. Although decarburization of the material in sodium can be expected to occur at the 1100°F test temperature, it is doubtful that this phenomenon would affect the creep behavior at higher stress levels (8000 - 10,000 psi) and not at lower stress levels (6000 psi).

4.3 Fatigue Tests

4.3.1 General - The most pronounced environmental effects on mechanical properties were expected to be achieved in the fatigue test, and results to date confirm this expectation. Substantial differences have been observed between the results of tests in air and tests in sodium. In general, the fatigue results, which show surprisingly little scatter, indicate a definite trend toward greater fatigue life in sodium than in air.

4.3.2 Fatigue Tests on Type 316 Stainless Steel - Sodium tests of 316 SS have demonstrated a definite improvement in fatigue life through the normal engineering design range as compared with air. Results of tests in helium and in sodium environments are in substantial agreement at the lowest strain range. At the highest strain, which is above the normal design range, tests in sodium yielded lower cyclic life than in air or helium.

The pre-exposure of stainless steel specimens in sodium did not substantially alter their fatigue properties in subsequent tests in air, helium, or sodium. However, the pre-exposure time was relatively short, being limited to 286 hr.

The test results in air at 1200°F at MSAR correspond generally to results of tests in air at 1200°F on type 304 stainless steel at Atomics International. Furthermore, specimens which were pre-exposed in sodium and tested in air at MSAR showed a reduction in fatigue life similar to that found in air tests of 304 specimens pre-exposed and carburized in sodium at Atomics International. However, the pre-exposed specimens when tested in helium or sodium at MSAR failed to exhibit this behavior. This poses a question as to whether the improved fatigue life in sodium is due to carburization of the type 316 stainless steel by the sodium or whether this improvement is a direct result of the sodium environment. The carbon analysis of the sodium indicates sufficient carbon content to have caused a carburized effect in type 304 SS, but it would have to be confirmed by analysis for carbon in the type 316 SS specimens.

4.3.3 Fatigue Tests on 2-1/4 Cr-1 Mo Low Alloy Steel - The results of fatigue tests of this steel in helium and sodium are in close agreement. The results of tests in helium and sodium indicate improvement of fatigue life by a factor of ten or more over the results of tests in air. There is no apparent effect of pre-exposure in the sodium environment, although the time of pre-exposure was limited to 323 hours.

The results of the tests at MSAR in an air environment at 1100°F agree substantially with results of tests at Atomics International at 1050°F in an air environment.

5. RECOMMENDATIONS

5.1 Equipment Modifications and Test Procedures

5.1.1 Modifications Proposed by Contractor - MSAR has suggested certain equipment modifications to obviate difficulties arising in the first series of loop experiments. These pertain specifically to problems encountered in maintaining precise control of the sodium level in the test pots and in controlling the rate of sodium flow through the cold trap.

These modifications, which have been put forward as a proposal to the AEC, appear both desirable and reasonable; hence, it is recommended that they be put into effect before the second test series is started. It is especially important that fluctuations in sodium level be minimized to avoid temperature fluctuations in the test pots.

5.1.2 Temperature Recording - Regardless of whether or not the modifications referred to above are accomplished, it is recommended that the temperature of the sodium next to the test specimens in each pot be recorded continuously on a multipoint recorder. At present, the thermocouple in each pot which was originally used for this purpose has been raised to indicate liquid level, and the next nearest couple is used on a non-recording controller. The data gives no reason to believe that the test temperatures have not been correct, but a continuous record is desirable in tests of this sort. If a new thermocouple well is not added, two 20-gauge thermocouples can be used in the present well, which has an I.D. of 0.210 inches.

5.1.3 Extensometer Development - Notwithstanding the minor problems noted above, the generation of test data in sodium has proved generally satisfactory in all areas excepting the measurement of creep rate. The difficulty associated with determining deformation rates of specimens completely immersed in sodium was, of course, well recognized at the start of the program. However, because the only unanticipated lack of correlation between air and sodium results has shown up in creep tests, the uncertainties of deformation measurements in sodium take on new importance.

Discussions of this problem with MSA indicated at least two possible approaches. The first, which would ease though probably not correct the problem, would be to lengthen the gauge length of specimens tested in sodium. The second and more complete solution lies in the design of an extensometer that could be attached directly to the gauge length and translate elongation through a read-out system above the sodium. It is recommended that MSAR explore some of the possibilities for such a system discussed during the review meeting and that, if a promising technique is found, a design proposal for a sodium extensometer be submitted for review by the Committee and the AEC.

5.1.4 Strain Measurements in Creep and Creep-Rupture Tests - It was previously recommended in a Subcommittee report of February 1962 (item 4.3 of that report) that creep and creep-rupture tests would together yield nine points on a curve for creep rate and six points or more on a curve for rupture life. The creep-rupture tests performed at MSAR to date have been considered as rupture tests only, and no attempt has been made to record creep rate in six of the nine potential creep tests. Thus additional data which could have been obtained on creep rate were not obtained.

It is recommended that calibration be made of creep in the gauge length of the specimens compared with over-all machine elongation, or dial gauge reading, in creep-rupture tests. Then, previous creep-rupture elongation data from dial gauges should be evaluated to obtain some measure of the creep rate which occurred in these tests. In future tests, if it is considered necessary to reinforce grip holes in the rupture specimens, then the machines must be recalibrated to obtain a new relation between creep rate in the gauge length and dial gauge readings. Creep rate results will then be obtained for all tests, whether rupture occurs or not.

5.2 Specimen Analysis

5.2.1 Relevance of GE Mass Transfer Studies - The results of General Electric's investigation* of sodium mass transfer in stainless and Croloy systems can be used to good advantage in MSAR's evaluation of the mechanical properties of these materials in sodium. GE's studies have yielded considerable insight into types of corrosion processes which play an important role at MSAR's test temperatures. Although the magnitudes of corrosion effects in the two studies will undoubtedly be different, the corrosion trends should be correlative.

There are two observations forthcoming from the GE studies which appear to have a particularly important bearing on the MSAR program. These concern the decarburization of 2-1/4 Cr-1 Mo steel in 1100°F sodium and the selective removal of chromium and nickel from stainless steel at 1100-1300°F. It is

*USAEC Contract AT (04-3)-189, P.A. No. 15.

urged that MSAR apply these findings to their evaluations of test specimens and data. The findings should be particularly helpful in deciding what types of analytic techniques should be followed in specimen examination.

5.2.2 Carbon Analyses - In view of the carbon transfer observed under similar test conditions at GE-San Jose, it is urged that analyses of test specimens be performed in the near future to determine the carbon contents associated with the mechanical properties measured to date. It appears likely that enough transfer has occurred so that analysis of the entire specimen cross-section for carbon, coupled with metallographic examination, will permit meaningful conclusions. An etchant of acid ferric chloride solution is recommended for preparation of metallographic specimens to study the extent of carburization. Specimens of both 316 SS and 2-1/4 Croloy should be analyzed. Carbon determinations on a few of the specimens with longest exposure times plus control specimens should be sufficient to give a fairly good idea of how carbon transfer may have affected data to date. This information will be helpful in choosing test conditions for the next run.

5.2.3 Specimen Examination - Post-test metallographic examination of representative specimens from each environment should begin without further delay. Any changes in microstructure from the pre-test condition should be noted and correlated with test conditions and mechanical property results. The objective in this work should be to understand the mechanism whereby any observed changes in mechanical properties occur. Such an understanding is essential to the prediction of properties in future sodium systems, which can be expected to differ from the present test specimens in various ways. For example, an observed change in creep strength could be due to composition changes either in a shallow surface layer or through the entire specimen thickness. The effect on a much thicker or thinner section would obviously depend on which mechanism was operative.

It is important to identify even those microstructural changes which seem unrelated to the mechanical properties measured, since long-term effects of liquid metal exposure often can be identified more readily in terms of metallographic examination than measurement of mechanical properties.

Metallography should be performed as a minimum on representative specimens of long term exposure in all media used and on all those showing unexpected results. Significant microstructural changes should be reported in the form of photomicrographs of appropriate magnification using care to avoid distortion due to polishing or etching techniques.

5.3 Future Test Program

5.3.1 General - The essential purpose of the Physical Properties Investigation at MSAR has been to disclose any basic gaps in mechanical property data

which must be bridged to design reliable sodium systems for service at 1100-1200°F. The first test series, almost complete, represents a significant step toward this objective, for it now allows tentative conclusions to be drawn concerning changes in mechanical properties manifested by uncontaminated sodium.

It has become increasingly apparent from the GE mass transfer studies that the structural materials selected for this program undergo finite compositional changes in sodium which are influenced both by the behavior of carbon and oxygen in the sodium and by the inter-alloying of dissimilar materials exposed in the same system. Continued correlation of the results of both programs and the determination of the influence of oxygen and carbon on physical properties is necessary to make the newly acquired design data completely useful.

The value and success of the MSAR program to date warrants its continuation under the objectives originally outlined by the Sodium Components Committee. Future tests should examine the effects of contaminants, principally oxygen, nitrogen, and carbon, on mechanical property changes induced by sodium.

5.3.2 Loop 1 (316 Stainless Steel) - The second test series scheduled for loop 1 (test No. 3) will examine the effects of carbon contamination in sodium on mechanical properties. This schedule is in agreement with the order of program priorities assigned in the first review meeting of the Materials Subcommittee.* It was recommended at that time that sodium in the loop contain an amount of carbon equivalent to saturation at the test temperature (1200°F). This is in keeping with the aim of the program of surveying for pronounced impurity effects.

It has been suggested by MSAR personnel that, prior to operating loop 1 with carbon in the sodium, a static pot test be utilized to study carbon analysis techniques. The Subcommittee also recommends that in these static test pots there should be inserted foil or coupons of type 316 SS, type 304 SS, 2-1/4 Cr-1 Mo, and Armco Iron. The extent of carburization in these should be correlated with the results of chemical analysis of sodium for carbon.

In operating loop 1 with sodium saturated with carbon, it is suggested that the carbon source be graphite. It is also recommended that the carburizing potential of the sodium in loop 1 be monitored by coupons or foils of type 316 SS, type 304 SS, 2-1/4 Cr-1 Mo steel, and Armco Iron, which will be inserted in the loop and removed and replaced by similar coupons at regular intervals. The amount of carburization occurring in these specimens should be correlated with the carbon analysis techniques and test results. It is also recommended that all available data on carbon in sodium from the test

* Report on Sodium Component Materials Program, June 1, 1960, p. 10.

program of General Electric-APED be forwarded to MSAR so that personnel at MSAR may familiarize themselves with these test results. They might then be more cognizant of what results to expect in tests at MSAR and methods of evaluating these results.

5.3.3 Loop 2 (2-1/4 Cr-1 Mo Steel) - The program next conceived for loop 2 parallels that scheduled for loop 1, namely, a test series to be operated with carbon-saturated sodium at 1100°F.

This proposed schedule conflicts with that recommended by the Materials Subcommittee following their first review meeting.* The complete test schedule drawn up at that time specified that the second test run for loop 2 be used to evaluate effects of oxide contamination and recommended that the run be operated with sodium containing 200-300 ppm oxygen. It was the Subcommittee's feeling, considering over-all program requirements, that the effects of oxide contamination on 2-1/4 Cr-1 Mo steel were of more pressing importance and priority than the effects of carburization. In fact it appeared that decarburization, rather than carburization, was the more likely program with this lower alloy material, a feeling which seems to have been confirmed in GE's mass transfer studies. Furthermore, there was strong incentive to postpone the carbon addition run for as long as possible, since the presence of carbon will necessarily impart certain changes in the loop wall which can seriously interfere with subsequent loop studies.

For these reasons, the review group strongly recommends that its initial proposal be followed and that oxygen rather than carbon effects be studied in the second test run of loop 2 (test No. 4). MSAR's objective in scheduling the second run with carbon stems from the convenience of having both loops on a similar test schedule. This small advantage, however, is more than offset by the several disadvantages discussed above.

* Report on Sodium Component Materials Program, June 10, 1960, pp. 11-12.

Report of Meeting on February 4-5, 1964

REVIEW REPORT NO. 5

of the

Ad Hoc Committee for the

Investigation of the Physical Properties
of Materials in High Temperature Sodium

performed by

MSA Research Corporation

Under AEC Contract AT(11-1)-765

March 4, 1964

Submitted by:

J. J. Purcell, AEC-CH

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1. INTRODUCTION

On February 4 and 5, 1964, the fifth meeting of the Ad Hoc Committee on Mechanical Properties of Materials in Sodium was held at MSA Research Corporation, Callery, Pennsylvania, to review the program being carried out by MSA. The following were in attendance.

Ad Hoc Committee Members

C. J. Klamut, BNL
J. H. DeVan, ORNL
J. M. McKee, UNC
J. J. Purcell, AEC-CH, Chairman

MSA Personnel

R. C. Andrews
L. Kuschler
F. Tepper
R. C. Werner

The purpose of the meeting was to review and evaluate testing which had been completed since the previous Committee meeting of November 29, 1962, and to recommend testing which should be carried out in this program. The Committee also looked into general needs of the sodium program with regard to physical properties of materials in sodium and will present its findings in a separate report.

1.1 List of Committee Meetings

Meeting No. 1 held May 25, 1960 - reported June 10, 1960.
Meeting No. 2 held February 15, 1961 - reported February 28, 1961.
Meeting No. 3 held January 9, 1962 - reported February 15, 1962.
Meeting No. 4 held November 29, 1962 - reported January 25, 1963.
Meeting No. 5 held February 4 and 5, 1964

1.2 Purpose and Scope of MSA Program

The physical properties research program at MSA was initiated for the purpose of determining the effects of reactor grade sodium, and normally anticipated contaminants, upon representative types of structural steels of interest for the construction of sodium systems. Type 316 stainless steel was selected as representative of the austenitic steels, and 2½ Cr-1 Mo was selected as representative of the ferritic steels. The maximum temperatures selected were 1200°F for the austenitic and 1100°F for the ferritic. The contaminants to be intentionally introduced into the sodium after the reactor grade sodium tests were completed would be oxygen, carbon, and nitrogen. The types of tests selected for revealing any possible effects of the environments upon the materials were tensile, creep, stress-to-rupture, and fatigue. In addition to these physical tests, appropriate chemical analyses and metallurgical examinations were designated for assisting in the interpretation of the physical properties.

2. PROGRAM STATUS

Tests #1 and #2 which measured physical properties of 316 SS and 2½ Cr-1 Mo in low oxide sodium have been completed. Preliminary results of these two tests were reviewed in the previous report (No. 4), and data

reported since that time have not changed the result reported in Report No. 4, that is, low oxide sodium does not affect significantly the physical properties of 316 SS or 2½ Cr-1 Mo. The loop operation portion of test #4, the test of 2½ Cr-1 Mo steel in high oxide sodium, is complete and the results are presented below in 2.1. Test #3, the test of 316 SS in high carbon sodium is in progress and is discussed in 2.2.

2.1 Results of Test #4

2.1.1 Fatigue - The fatigue tests of 2½ Cr-1 Mo steel in high oxygen sodium indicate no difference in fatigue properties of 2½ Cr-1 Mo in sodium with high or low oxygen.

2.1.2 Creep to Rupture - The results of the creep-to-rupture tests in high oxygen sodium show a consistently shorter life of both the exposed and original material than in low oxygen sodium.

2.1.3 Creep - The creep tests show that the creep rate was lower in 1100°F sodium with high oxygen than with low oxygen. However, the creep rate is still higher in sodium than in air or helium.

2.2 Status of Test #3

Test #3 is to be made on 316 SS specimens in 1200°F sodium with a high carbon activity, using loop #1, helium as the cover gas, and low oxygen in the sodium (30 ppm or less). Because reliable methods for obtaining and controlling high carbon sodium are not presently available, a number of preliminary tests were performed to prepare for test #3. A carbon source was inserted in loop #1 in a by-pass loop at the heater outlet. It consists of a stainless steel pot 6 inches in diameter by 24 inches long filled with 11 pounds of graphite rods (½ inch diameter by ½ inch long) with 35 micron stainless steel filter at the outlet. The standard test specimens were replaced by small tabs of four alloys (Armco iron, 2½ Cr-1 Mo, 304 SS, 316 SS) in two thicknesses (0.06 inch and 0.003 - 0.011 inch). With the entire loop flow routed through the carbon source at 1200°F, groups of these tabs were exposed for times of 1, 4, 6, 11, and 20 days and examined. In the 3½ months since the carbon source was put into operation considerable information has also been obtained on plugging, cold trapping, and plugging indicator operation in a high carbon sodium loop. Analysis of the tabs is not yet complete, and not all of the results of these preliminary tests are understood but a number of impressions are fairly definite as follows.

2.2.1 The carbon source is effective in increasing the carbon activity of the sodium.

2.2.2 The process appears to be rapid in light of effects noted on the plugging indicator and the tabs.

2.2.3 The carburization rate of 304 and 316 SS under these conditions is rapid. Three mil thick tabs broke in handling after 11 days. A preliminary estimate of the total carburization of standard 65 mil thick specimens in 4000 hours predicts a significant change in mechanical properties but not complete embrittlement. The predicted carburization rate is about the same as that observed at Atomics International under somewhat similar conditions (see NAA-SR-5282 by Anderson and Sneesby).

2.2.4 The 2½ Cr-1 Mo steel apparently also carburizes rapidly after a rather long incubation period (still tentative).

2.2.5 Carbon appears to reach an equilibrium surface concentration of 2 to 3 per cent on 304 and 316 SS.

2.2.6 During some two months of operation with high carbon sodium, gross carburization of the 316 SS loop piping occurred to a depth of 5 mils and noticeably to a depth of 10-15 mils. The carburization prior to this time was barely detectable.

2.2.7 No unusual change in the heavy metal impurity content of the sodium occurred as the result of carbon addition.

2.2.8 Atomics International, GE-San Jose, ORNL, and MSA have all occasionally observed an initial break in the plugging indicator curve (flow rate versus temperature) at temperatures higher than the oxygen saturation temperature. In the recent preliminary high carbon tests at MSA this "first break" temperature has shown an apparent correlation with the carbon activity or carburizing potential of the sodium. Next to tab tests, which are slow and expensive, it is at present the best available indication of carbon activity in sodium. The effect interfered with the detection of oxygen by the plugging indicator. It appears that oxygen will have to be monitored by chemical analysis of sodium dip samples. This technique is well established at MSA.

2.2.9 Standard chemical analysis of sodium dip samples for carbon has been essentially useless as an indication of carbon activity. Introduction of the carbon source in the loop produced no readily-detected change in the carbon content as determined by chemical analysis. The problem is believed to be due to particulate carbon in the sodium causing scatter and high results.

2.2.10 Cold trapping appears to remove carbon, as indicated by the first break in the plugging indicator curve, but at much slower rates than it removes oxygen.

2.2.11 As the temperature of the first break on the plugging indicator curve rises toward 900°F, deposition on the OCI (oxide control and indicating) system heat exchanger is observed. It is revealed first by loss of heat transfer and eventually by plugging. Residue from one such plug is presently being analyzed. Preliminary results indicate a carbon content of about 10 per cent. Such deposits are now routinely removed before the plugging stage by by-passing the cold trap, shutting off the cooler, and opening the plugging indicator valve for short periods. It appears that plugging of loop test circuits can be avoided by continuous use of the OCI system heat exchanger as a monitor of plugging susceptibility.

The above preliminary tests have been quite informative and helpful in preparing for the high carbon run. The analysis of these tests should be completed before proceeding with test #3. Examination of the tabs should be completed to obtain carbon concentration gradients. These should be used to calculate carbon diffusion rates and to predict the extent of carburization of unstressed 316 SS specimens in 4000 hours. This will provide a check of the present assumption that specimen carburization will not be so excessive as to preclude useful data production. It would also be desirable to get some indication of how much carbon has been removed to date from the carbon source.

Perhaps a radiograph of the carbon container in place may suffice. MSA has estimated that three pounds have been dissolved.

3. RECOMMENDATIONS

3.1 Procedure for Test #3

In view of the difficulty encountered in operating loop #1 with the carbon bed, and the failure of chemical analysis to indicate the carbon content in the sodium, the following operation procedure is recommended for test #3. The object of this procedure is to maintain as high a carbon concentration as possible within limits required to avoid plugging. The temperature differential which existed for run #1 should be maintained for future runs. The carbon bed should be kept on stream as much as possible. If the first break in the plugging indicator run occurs above 800°F, the loop should be cold trapped until this value is below 800°F. The loop should also be cold trapped when chemical analysis of dip samples shows the oxygen concentration to be above 30 ppm. A three-week run should be made without the test samples to establish the feasibility of this recommended procedure. If plugging or other difficulties are not encountered, test #3 may proceed as originally outlined and with addition of the samples listed below.

Discussions of the test results to date make it apparent that much additional information can be gained on mechanical property effects by the inclusion of additional test specimens in run #3. It is the Subcommittee's understanding that extra specimens can be included without significantly affecting either the test run or requiring equipment modifications. It is, therefore, recommended that these additional specimens be incorporated in run #3.

3.1.1 Carburization Tabs (316 SS, 2½ Cr, and Armco Iron) - Sufficient samples (similar to those used preparatory to test #3) should be included to allow withdrawal at approximately 1000, 2000, 3000, and 4000 hours of operation. These specimens are to be metallographically and chemically analyzed for carburization to afford a measure of carburization potential during various stages of the loop run.

3.1.2 Control Specimens - Specimens of 316 SS and 2½ Cr-1 Mo steel having the identical heat treatments as the stressed specimen and encapsulated in a helium environment are to be placed in the loop for 4000 hours exposure. These specimens are to have the same thermal history as the "pre-exposed" specimen and will be used as the control specimens for sodium pre-exposed specimens.

3.1.3 Impact Specimens - Impact specimens of the smallest standard cross section are to be inserted in test #3 for long-term sodium exposure. Specimens will be made of 316 SS and 2½ Cr-1 Mo steel and will be subjected to a room temperature impact test after sodium exposure.

3.2 General

3.2.1 Recommendations by Contractor - MSA reported some very interesting findings on the behavior of sodium-carbon systems as a result of their preliminary operations of loop #1 preparatory to the carbon-contamination run. Accordingly, they have pointed up the need for chemical studies of

carbon-contaminated sodium systems and have proposed a number of corollary experiments toward this end. Since nearly all the proposals are outside the scope of the mechanical property program, the Committee does not feel disposed to discuss them at length. However, we would urge that a special effort be made during the normal course of loop operation to glean, wherever possible, information bearing on the carbon-sodium system. In particular, one of the MSA recommendations suggests that an analysis of the plug which has been observed during carbon-saturated runs be collected by inserting a series of filters in series or parallel with the loop. The Committee recommends that this be tried either before or after run #3. When examining any plugs, the sodium should be removed in such a way as to minimize changes in the macro- and micro-structure of the plug. It is also recommended that filtered as well as unfiltered sodium samples be concurrently extracted from the loop at appropriate intervals during run #3 for carbon determination. The filter used in sampling should be free of carbon and have a pore size on the order of 5 μ or smaller.

3.2.2 Equipment Modifications or Additions - It has been the constant hope of the Committee that an extensometer suited to strain measurements in sodium would some day be forthcoming as part of the MSA program. This recommendation is discussed at length in Section 5.1.3 of the Committee's report No. 4. The Committee again emphasizes the need for this development. We urge that the various approaches for such a device, discussed at the last two MSA reviews, be evaluated to the extent that a proposal for their development be submitted to the AEC.

3.2.3 Specimen Evaluation - Further microprobe analyses should be made to examine long-term stress rupture and creep specimens tested in sodium. These analyses should be concerned with all the significant elements present in the materials under test. In particular, 316 SS surfaces should be carefully monitored for losses of nickel, chromium, and manganese. It is also recommended that microprobe evaluations be extended to 2½ Cr-1 Mo specimens particularly those tested in run #4 (high oxygen).

One of the notable effects observed in test #1 was the significant carburization which occurred in the gauge length of stress rupture specimens. This finding will be of considerable interest to designers; hence, the correlation between carburization and stress or strain should be expressed as quantitatively as possible. Figure 42 on page 45 of the Special Summary Report, MSAR 63-168, probably overstates the case due to confounding with time effects. For the points on this figure exposure time went up as the stress went down. Since the average carburization rate obviously decreases with time at any stress level, it would be instructive to replot the points on Figure 42 corrected to a constant exposure time. The Committee also feels that the carburization rate might prove to correlate better with total strain than with stress. It is suggested that representative 316 SS samples be examined for such a correlation. For example, the shoulders and tapered sections leading into the gauge length provide areas in a single specimen which have undergone variable strain and can be compared for differences in depth of carburization. It is also suggested that an effort be made to correlate carburization rate with the increase in surface area during the third stage of creep.

3.2.4 Reports - Topical reports including test results and significance with respect to sodium reactor design should be completed for tests 1 and 2 on an expeditious basis.

4. FUTURE TESTS WITH MSAR LOOPS

4.1 Loop No. 1

Following test #3 (316 SS in high carbon sodium) the loop will be a strong source of carbon. The next test in this loop must, therefore, be tied to carbon. Some possibilities which will be considered at the Committee's next meeting are: (a) test of 316 SS in sodium with less carbon than saturated, (b) 2½ Cr-1 Mo under carburizing conditions (The result of the 2½ Cr-1 Mo tabs which will be inserted during test #3 will provide further information on the value of such a test.), and (c) test of 304 SS under carburizing conditions.

4.2 Loop No. 2

Test #4 (2½ Cr-1 Mo in high oxide sodium) has just been completed in this loop. We recommend that 316 SS be tested in this loop in high oxide sodium. Following this test the Committee will meet to consider future tests for this loop. Some tests which will be considered are: (a) test of 304 SS in high oxide sodium, (b) test of nickel base alloys, and (c) test of titanium base alloys.

Testing of materials with a nitrogen cover gas should be deferred because it no longer appears of interest to designers.

Report of Meeting on August 19-20, 1964

REVIEW REPORT NO. 6
of the
Subcommittee for the
Investigation of the Physical Properties
of Materials in High Temperature Sodium
performed by
MSA Research Corporation
Under AEC Contract AT(11-1)-765

November 4, 1964

Submitted by:
J. J. Purcell, AEC-CH

1. INTRODUCTION

On August 19 and 20, 1964, the sixth meeting of the Subcommittee on Mechanical Properties of Materials in Sodium was held at the MSA Research Corporation, Callery, Pennsylvania. The following were in attendance:

<u>Subcommittee Members</u>	<u>MSA Personnel</u>
J. DeVan, ORNL	R. Andrews
L. Kelman, ANL	R. Hiltz
C. Klamut, BNL	L. Kuschler
J. McKee, UNC	F. Tepper
J. Purcell, AEC-CH, Chairman	R. Werner

The purpose of the meeting was to review and evaluate testing which had been completed by MSA since the previous meeting of February 4 and 5, 1964; to recommend future testing which should be carried out in this program; and to formulate a general program in the area of Mechanical Properties of Materials for Sodium Cooled Reactors. The following report reviews the Committee's discussions relative to the MSAR program; the discussions regarding general needs of the sodium reactors programs in the area of Mechanical Properties will be presented in a letter to the Chairman of the Working Group.

1.1 List of Committee Meetings

Meeting No. 1 held May 25, 1960 - reported June 10, 1960.
 Meeting No. 2 held February 15, 1961 - reported February 28, 1961
 Meeting No. 3 held January 9, 1962 - reported February 15, 1962.
 Meeting No. 4 held November 29, 1962 - reported January 25, 1963.
 Meeting No. 5 held February 4 and 5, 1964 - reported March 4, 1964.
 Meeting No. 6 held August 19 and 20, 1964 - reported November 4, 1964.

1.2 Purpose and Scope of MSA Research Program

The Physical Properties Research Program at MSA was initiated for the purpose of determining the effects of reactor grade sodium, and normally anticipated contaminants, upon representative types of structural steels of interest for the construction of sodium systems. Type 316 Stainless Steel was selected as representative of the ferritic steels. The maximum temperatures selected were 1200°F for the austenitic and 1100°F for the ferritic. The contaminants to be intentionally introduced into the sodium after the reactor grade sodium tests were completed would be oxygen, carbon, and nitrogen. The types of tests selected for revealing any possible effects of the environments upon the materials were tensile, creep, stress-to-rupture, and fatigue. In addition to these physical tests, appropriate chemical analyses, and metallurgical examinations were designated for assisting in the interpretation of the physical properties.

2. PROGRAM STATUS AND RESULTS

2.1 Three of the scheduled Physical Properties Program test runs have now been completed. These tests and the topical reports covering the results are listed below:

Test 1

316 specimens in 1200°F "as received" sodium low (30 ppm) oxygen.
 Topical Report No. 2, MSAR No. 64-18.

Test 2

2½ Cr-1 Mo specimens in 1100°F "as received" sodium low (30 ppm) oxygen. Topical Report No. 3, MSAR No. 64-81.

Test 4

2½ Cr-1 Mo specimens in 1100°F "as received" high (300 ppm) oxygen. Topical Report No. 3. Included with results of Test 2.

- 2.2 At the present time two other test runs (Nos. 3 and 5) are in progress. The parameters for these tests are:

Test 3

316 SS specimens in 1200°F sodium low (30 ppm) oxygen with carbon as the contaminant. Conducted in Loop 1.

Test 5

316 SS specimens in 1200°F "as received" sodium high (300 ppm) oxygen. Conducted in Loop 2.

Test 3 is presently scheduled for completion in February 1965. Test 5 will be completed in March 1965.

3. RESULTS OF TESTS 2 AND 4

3.1 Creep Rupture Tests

- a. The fatigue life of the Cr-Mo alloy was significantly (5 to 16 times) longer in helium and sodium as compared to air.
- b. The high temperature fatigue properties of 2½ Cr-1 Mo steel in sodium containing either low or high concentrations of oxygen were the same as in helium.
- c. Relatively short time (323 hours) exposure in 1100°F sodium did not indicate a change in fatigue life when tested at 1100°F in air or sodium, but the results were scattered for helium and the average reflected a shortened fatigue life.

3.2 Creep-Rupture Tests

- a. The creep-rupture properties of the 2½ Cr-1 Mo steel at 1100°F were identical in air and helium.
- b. No difference could be seen in the creep-rupture properties of the unexposed Cr-Mo alloy between testing in 1100°F sodium with a high (300 ppm) oxygen content and sodium with a low (30 ppm) oxygen content.
- c. Rupture tests in sodium on unexposed specimens resulted in slightly less rupture strengths than tests in air or helium. The results from tests on exposed specimens in sodium with 30 ppm or 300 ppm of oxygen were similar with the longer tests showing high oxygen sodium did introduce surface cracking and a faster rate of decarburization which would also suggest effects at prolonged time periods.

- d. Two specimens failed at light scribe marks: one in helium and the other an exposed specimen tested in air. This, in combination with the scatter experienced in the helium tests, suggests the possibility that 2½ Cr-1 Mo steel is notch sensitive when tested in helium or high oxygen sodium.

3.3 Creep Tests

- a. A comparison of the stresses to produce a minimum creep rate of 1% in 10,000 hours in the various environments shows the following:

<u>Environment</u> <u>1100°F</u>	<u>Stress for 1%</u> <u>in 10,000 hrs</u>
Helium	5300
Air	5800
Sodium (30 ppm O ₂)	5000
Sodium (300 ppm O ₂)	5000

- b. The creep tests in helium and high oxygen sodium indicate earlier third-stage creep than in air.
- c. The 2½ Cr-1 Mo steel may be subject to oxygen-stress concentration sensitivity in dilute oxygen environments during creep.

3.4 Tensile Tests

- a. The tensile results inexplicably showed higher strengths for air than helium. Tensile strengths of specimens that had been exposed for 4000 hours to either of the sodium environments were reduced from the original strengths in air or helium.
- b. There were no differences in tensile strength when comparing the two sodium environments or between washed and unwashed specimens that had been exposed to either of the sodium environments.
- c. The difference in air and helium tensile results may reflect temperature-and-time effects more than environment, since there was a longer heat-up time for the helium tests due to the out-gassing problems.
- d. No detectable alteration of the composition of the 2½ Cr-1 Mo specimens (other than carbon) was observed as the result of sodium exposure.
- e. The specimens showed an increase in ductility and a reduction in hardness after exposure to sodium.
- f. Although measurable changes in mechanical properties were experienced, these changes were significantly less than the property differences between heats of Cr-Mo steels. It could not be established that the magnitude of the change would be the same regardless of the initial strength level of the heat.

4. STATUS OF TEST 3

At the time of the last Subcommittee meeting, a preliminary run of Test 4 had just been completed with tabs of 316 SS, 304 SS, 2½-1 Mo, and Armco Iron in the loop to determine the carburization potential of the carbon bed. Also a plug had developed in the OCI portion of the loop just prior

to the meeting. This Subcommittee recommended an additional two to three week tab test to further evaluate the plugging problems which might jeopardize the completion of Test 3. The Subcommittee also recommended the following criteria for the operation of the loop.

- 4.1 Partial system flow was to be maintained through the carbon bed as long as the plugging temperature could be maintained between 750°F and 850°F by cold trapping or varying the carbon bed flow rate.
- 4.2 Since neither the plugging indicator nor the mercury amalgamation method could be relied upon for determining the system oxygen content, cold trapping would be done at maximum intervals of four days. (This was derived from oxide buildup data from previous tests.)

Since the tab data indicated that significant carburization would be forthcoming in Test 3, the decision was made to include impact test specimens among samples being exposed to sodium. Certain of the impact specimens were encapsulated in helium to provide control specimens with same thermal history as the sodium exposed specimens.

The second 20 day run was completed without additional plugging difficulties. The carburization rates of the tabs coincided with the first tab test.

Minor repairs and the fabrication of impact specimens to be exposed delayed the beginning of Test 3 again.

Finally, after a short period of operation to establish the proper test conditions, Test 3 was initiated on May 26, 1964. To date two creep-rupture runs have been completed with two additional runs in progress. The creep runs were delayed to evaluate the initial rupture data with respect to modifying the stress values used in Test 1 for the creep tests. Two creep runs have now been initiated at revised (higher than Test 1) stress levels. Difficulties in getting the fatigue unit into operation have delayed the fatigue runs until recently. At the present time, a low cyclic strain run is in progress.

Upon completion of the first creep-rupture run, a test unit was modified to expose specimens to both helium and to sodium such that they will have the same thermal history. This run is now in progress.

The plugging problems that were encountered at the end of the first tab run have not reoccurred. The operation has been changed since that time, in that flow through the PI circuit is maintained at high temperature rather than allowing it to freeze when not in use. At the time of the plugging it was thought that the plug may have developed in the OCI economizer when this unit was isolated and allowed to freeze.

5. RESULTS OF TEST 3

A series of tabular specimens were exposed to carbon saturated sodium prior to mechanical testing. Type 316, 304, and 2½ Cr-1 Mo specimens (305 mil) were significantly carburized within twenty days. Qualitative evaluation of photomicrographs showed the diffusion of carbon to be somewhat more rapid in 304 than in 316, and slightly higher carburization rates (as verified by carbon analysis) occurred in 304 than in 316. A twenty day test was repeated, and a reproducible carburization level was noted, suggesting that the carbon level of the sodium had not been significantly altered.

On the basis of the tabular data, carbon diffusion coefficients (at 1200°F) were computed for 316 (1.81×10^{-11} cm²/sec) and 304 (3.99×10^{-11} cm²/sec), with the 304 value in excellent agreement with a value obtained by AI (4.12×10^{-11} cm²/sec). Time extrapolations of these preliminary runs predict that in 4000 hours a heavy carbide case would be produced in these 300 series steels at least 20 mils in thickness.

At the time of this review, three stress rupture tests had been completed and a fourth was in progress, having reached 1700 hours. The available data suggest that creep and rupture strengths are being increased by carbon contamination, while the elongation at rupture is lowered. In the longest time test conducted to date (1700 hours), specimen elongation at rupture was still quite respectable (20%).

6. STATUS OF TEST 5

Test 5 provides for the exposure of 316 SS specimens to 1200°F sodium with high (approximately 300 ppm) oxygen. In early March the loop was charged and test conditions attained. Preliminary operation indicated that the chemical analysis for oxygen did not agree with the plugging runs. It was found that when the cold trap was first heated to 700°F all of the free sodium could not be extracted from the sample during the amalgamation step. It was felt that this might be caused by occlusion of sodium within Na₂O crystals. Heating of the sample aided in extracting the free metal. After the cold trap had operated for a period of time, this problem became less evident. Chemical O₂ analyses generally gave values located between the two breaks on the PI₂ curves. When the cold trap was cooled to 400°F, the chemical analyses agreed with the value which originally represented the lower break.

Tabs of 316 SS, 304 SS, 2½ Cr-1 Mo, and Armco Iron were then exposed for various lengths of time. At the completion of the tab runs the mechanical properties test specimens were installed and Test 5 was initiated in early July. To date two creep-rupture runs have been completed and two additional runs are in progress. Three creep runs are also in progress. Fatigue tests are to be initiated in the near future. A test unit has been modified to expose specimens identical to that in Test 3. This run is now in progress.

7. RESULTS OF TEST 5

Tabular specimens of 2½ Cr, 304, 316, and Armco Iron have been exposed to 1200°F sodium containing high oxygen. Tabular specimens are also inserted with each mechanical test specimen. Weight change data shows considerable scatter as compared to Test 3 weight change data, where significant weight increases were observed due to carburization. It is thought that this scatter in Test 5 is due to spalling of oxidation products either in sodium, during cooling, or in the alcohol wash step.

While the scatter of such tabular data exists, certain trends are apparent. The 2½ Cr and Armco Iron specimens generally showed weight losses, while series 300 tabs generally showed weight gain. This may be attributed to the cohesiveness of oxide coatings on stainless steel. Carbon analyses of specimens exposed for prolonged durations are in progress.

Metallographic examination shows exceedingly thin coatings on stainless specimens exposed to 1200°F high oxygen sodium, while 2½ Cr-1 Mo steel exhibits greater attack. Chemical analyses of 2½ Cr-1 Mo specimens, which include tab samples exposed prior to the start of Test 5 and tab samples removed at the completion of each stress rupture run, have in all

cases shown decarburization of this alloy. Similarly exposed stainless steel specimens and tabs have consistently shown carburization. The carbon levels in the later case have been quite variable but have ranged as high as 0.11%. The carbon being picked up by these stainless specimens is considerably more than is available from the few 2½ Cr-1 Mo specimens present. As in Test 1, the exact source of the carburizing potential in this loop is unknown.

8. RECOMMENDATIONS

8.1 304 Stainless Steel Tests

The designers of sodium- or potassium-cooled reactors such as FARET, SEFOR, and the MPRE (Medium Power Reactor Experiment), have selected 304 SS as the structural and fuel clad materials. This selection is based on the upgrading of 304 SS in the boiler code, lower cost of 304 SS, and a greater potential for sigma formation in 316 SS.

This Subcommittee does not consider the chemical makeup of 304 SS to be significantly different enough from that of 316 SS to produce any difference in the effect of sodium containing various impurities on the mechanical properties of the two 300 series steels. However, reactor designers have voiced a strong desire for proof tests on 304 SS to confirm these expected results.

We, therefore, recommend that tests be run on 304 SS in sodium. A detailed plan for these tests should not be formulated until the results of Test 3 and Test 5 are received. We recommend that MSAR be authorized to order 304 SS ahead of time so that the program will not be delayed by lack of material. If Test 5 shows that the mechanical properties are not significantly effected by a high oxygen sodium environment, we recommend that a test of 304 SS in low oxygen sodium be bypassed and a test in high oxygen sodium be run.

We also recommend that a test of 304 SS in sodium containing high carbon be considered; however, the detailed plan of the test should not be formulated until the results of Test 3 are received.

8.2 Incoloy 800 Tests

A material that is reportedly very resistant to corrosion by both sodium and water is Incoloy 800. There is very little data on this material, and reactor designers will not incorporate it in their designs until more experiments are run.

We recommend that the effect of sodium on the mechanical properties of Incoloy 800 be investigated. Such an investigation would require, however, a precursory evaluation of the corrosion behavior of Incoloy in a 316 SS system.

8.3 Carburization of 304 SS Versus 316 SS Test

The very preliminary results of Test 3 indicate a slightly higher carburization rate for 304 SS than 316 SS. We recommend a static test be run with both 304 SS and 316 SS in a high carbon sodium environment to resolve whether a significant difference in carburization resistance between these alloys does in fact exist.

8.4 Long Term Tests

The results of Test 4 left room for considerable speculation as to the effects of longer (over 4000 hours) time tests on 2½ Cr-1 Mo steel in sodium with high oxygen. There was some evidence of a slight strength decrease appearing at 4000 hours as well as an indication of notch sensitivity.

Also the longer term aging effects on 300 series stainless steels associated with sigma phase formulation and carbide migration have not been touched on in the tests to date. We recommend that long term static tests be run on 2½ Cr-1 Mo steel in a high oxygen sodium environment and a long term test of 316 SS and 304 SS be run in a sodium environment.

8.5 Carburization - Decarburization Test

There is need to know what to do in the event that a sodium system is inadvertently grossly carburized. Can it be decarburized in situ, for example, by introducing foil or other high surface area shapes of strong getter? If decarburization is possible, how will the resulting microstructure change affect its mechanical properties? We recommend that static pot tests be carried out to investigate these problems.

9. GENERAL

- 9.1 We recommend that a proposal be solicited from MSAR to carry out the static pot type tests mentioned above.
- 9.2 MSAR reported that they were searching the literature to determine existing knowledge regarding the influence of strain on carbon movement. Practically all they have found is in the foreign literature. Their findings will be pertinent to all engaged in sodium component design. They should be encouraged to keep us informed in this area and to make available those articles that they have translated.

Report of Meeting on February 23-24, 1965

REVIEW REPORT NO. 7
of the
Subcommittee for the
Investigation of the Mechanical Properties
of Materials in High Temperature Sodium
performed by
MSA Research Corporation

Under AEC Contract AT(11-1)-765

Submitted by:
J. J. Purcell
U. S. Atomic Energy Commission
Chicago Operations Office

June 25, 1965

1. Introduction

On February 23 and 24, 1965, the seventh meeting of the subcommittee on Mechanical Properties of Materials in Sodium was held at MSA Research Corporation, Callery, Pennsylvania, to review the program being carried out by MSAR. The following were in attendance:

Subcommittee Members

J. DeVan, ORNL
L. Kelman, ANL
C. Klamut, BNL
J. McKee, UNC
J. Purcell, AEC-CH (Chairman)

MSAR Personnel

R. Andrews
R. Hilty
L. Kuschler
F. Tepper
R. Werner

The purpose of the meeting was to review and evaluate testing which had been completed since the previous meeting in August 1964, and to recommend any future tests that might be appropriate.

1.1 List of Committee Meetings

Meeting No. 1 held May 25, 1960 - reported June 10, 1960
Meeting No. 2 held February 15, 1961 - reported February 28, 1961
Meeting No. 3 held January 9, 1962 - reported February 15, 1962
Meeting No. 4 held November 29, 1962 - reported January 25, 1963
Meeting No. 5 held February 4 and 5, 1963 - reported March 4, 1964
Meeting No. 6 held August 19 and 20, 1964 - reported November 4, 1964
Meeting No. 7 held March 23 and 24, 1965 - reported June 25, 1965

1.2 History

The subject program at MSAR should shortly fulfill the central objective outlined in the first of this subcommittee's review reports. Before discussing program results, a review of this objective appears to be in order.

"The objective of the program prepared by this subcommittee shall be to determine whether an environment of sodium and its normally anticipated contaminants affects the physical properties of structural steels of interest for the construction of sodium system components.

"This program shall attempt to determine whether designers need a new code to provide information for structural steels used in a sodium environment. It will not represent an attempt to provide a handbook for design engineers, although the data obtained will have statistical significance and validity for the properties measured under several defined conditions.

"Impurity contents and test conditions shall be selected to represent fairly extreme, and in some cases exaggerated, conditions, and thereby provide an answer as to whether or not sodium environments affect the behavior of structural steels at temperatures encountered in sodium-steam systems."

Because of time and monetary limitations, only two structural alloys, 316 SS and 2½ Cr-1 Mo steel, were considered for testing. The selection of these alloys was made to evaluate the behavior of both austenitic and ferritic materials, as well as to evaluate two materials which were promising candidates for use as structural materials for sodium cooled reactors. The choice of 316 SS over 304 SS was made in part to bring out the effects of sigma phase formation at high temperatures which is reportedly more predominant in 316 SS than in 304 SS.

The main intent of the program has been to uncover general effects of a sodium environment plus contaminants on the mechanical properties of materials of interest. The tools and techniques applied to this determination have yielded strength data of a classical and a directly useful form. However, the tests covered only a small representative fraction of those which the designer must consider. Nevertheless, the program can serve as an implicit guide to the designer in selecting data to employ in these uncharted areas.

Following the completion of Test 3 (316 SS in high C sodium) and Test 5 (316 SS in high oxide sodium), the information from all of the tests will be analyzed and put in a form usable by the designer. At this point, the original objective will be met.

Only in a few areas has the program shown significant differences between air data and that from sodium environment tests. Existing design codes for austenitic and ferritic steels appear relevant to sodium system design.

There are additions and natural outgrowths from the original program that this committee has considered. The committee has recommended the addition of tests of 304 SS in sodium environments: Test 6 (304 SS in high oxide sodium) and Test 7 (304 SS in high carbon sodium). These two tests were recommended as proof tests for reactor designers to verify the effect of a contaminated sodium environment on mechanical properties is no different for 304 SS than it is for 316 SS. Tasks that are natural outgrowths of the program are: (1) analysis of the cold traps used in the tests, (2) further fatigue tests, (3) creep to rupture tests in a helium atmosphere (there was oxygen contamination in University of Michigan tests), (4) testing of Incoloy 800 and Inconel 600, (5) carburization of 304 SS and 316 SS and decarburization of 2½ Cr-1 Mo.

2. Program Status

At the present time, there are two tests in progress: Test 3 (316 SS in high carbon sodium) and Test 5 (316 SS in high oxide sodium). Tests 1, 2, and 4 have been completed and are reported in MSA Report 64-18 and MSA Report 64-81.

2.1 Test 3 - Status

At the time of the last subcommittee meeting, this test was in progress with a few of the short-time creep-rupture tests and a couple of fatigue tests completed. Today, only the long-time creep-rupture runs on the exposed specimens in sodium, air, and helium and the fatigue tests in sodium remain in progress.

In general, the operation of Loop 1, in which Test 3 is being conducted, has successfully met the specified test conditions. However, the operation has not been without occasional difficulties. The major problems encountered were:

- (a) The continuing failure of bellows in valves due to a combination of poor valve design and carburization
- (b) The difficulty in maintaining a low oxygen concentration by cold trapping at 250° F and a high carbon concentration by circulating through the carbon bed at 1200° F "as needed" without plugging the OCI system. Plugging occurred most frequently in the OCI valves and pump.
- (c) Getting the test units, especially the fatigue test unit, on stream following the changing of test specimens. Plugging frequently occurred either in the charging inlet or the test unit outlet line.

The loop had to be drained on one occasion when leaks developed in the expansion tank wall. The poor positioning of external radiant heaters was the direct cause of this incident. The upper portion of these heaters was located above the internal sodium liquid level, thereby permitting the metal wall to reach sufficiently high temperatures to promote excessive oxidation of the tank wall in these areas. The tank was repaired in place, and the position of the heaters changed to eliminate this situation. No difficulties were encountered in draining or charging the system during this incident.

2.2 Test 3 - Results

The creep-to-rupture tests show significantly higher creep rupture times over several hundred hours. The elongations of the specimens are reduced by at least 50% as compared to the low oxygen sodium tests, but it is doubtful if the elongation values are real since numerous surface cracks are adding to the elongation measurements. There is little doubt that the ductility of this material has been significantly reduced by carburization as further attested by the reduction of impact strengths of exposed specimens.

The creep rate curves are not of the usual pattern established in the air, helium, and "clean" sodium because the carburization process is continuing throughout the testing. After an initial period, the effect of carburization begins to influence the creep strength of the specimen and causes changes in the creep rates. The changes are indicated by inflections in the creep rate curves.

In comparing the minimum creep rates, it becomes apparent that there is either a very abrupt change in the slope of the minimum creep rate versus stress curve, or that the minimum creep rates obtained at the low stresses in this carburizing environment are not real as compared to the usual minimum creep rates obtained in more inert environments.

The fatigue tests are still in progress, but the fatigue data to date does show the influence of this environment.

In general, the carburization rates of both 316 SS and 304 SS tabs have followed the predicted curves calculated from the data obtained from the twenty-day tests. The 304 material appears to have a significantly higher carburization rate.

At the present time, the creep-rupture runs on specimens that had been exposed for 4000 hours are being completed. Exposed specimens have been furnished to the University of Michigan for similar runs. The fatigue test program is also being completed.

2.3 Test 3 - Metallurgy

Exposure of specimens to high carbon sodium has provided materials representing 110 to 4074 hours of immersion. Analysis, in the form of metallographic, micro-hardness, chemical and x-ray measurements, reveals extensive surface carburization for the two stainless materials 304 and 316, but rather uniform carbon increase throughout the ferritic 2½ Cr-1 Mo material.

The two stainless materials show a rapid carbon buildup in the first hundred hours, changing to a much slower rate at longer times. For the most part, carbon increase is uniform with time, providing smooth plots of data. In a few cases, however, carbon absorptions deviate from the mean, usually to the low side.

In all specimens to date, 304 has a greater pickup and a deeper penetration than does 316 for the same time. Specimen surfaces are comprised of a very hard high carbon case, plus a transition zone between the case and the

unaffected base metal. Although carbon absorption is faster and the case thicker for 304, the transition zone is the same width for both 304 and 316.

X-ray analysis of bulk samples and extracted carbides show the predominant carbide to be $M_{26}C_6$ with the Fe/Cr ratio shifting to higher iron contents with time. There is not much difference in the Fe/Cr ratio for either 304 or 316. When the molybdenum is added in, however, the ratio of iron to total carbide-forming elements is measurably smaller for 316.

X-ray analyses show that in 304 there is considerable transformation to ferrite due to the removal of chromium from solution by carbide precipitation. Specimens exposed longer than 500 hours show strong ferromagnetism. Analysis of 316 samples shows that, even after 4000 hours, the degree of transformation is so small that the most intense peaks of the ferrite phase barely appear on the diffraction pattern.

Microprobe analysis of specimen surfaces indicates that chromium is the most readily removed alloying element. Evidence for nickel removal exists in 316 traces but is not strongly supported by 304 traces. Molybdenum and manganese do not appear to be extracted. All extractions proceed only to shallow depths and such losses should not affect material performance. The carbon case does affect properties, however, with 4000 hours of exposure reducing impact strength to 20% of its initial value. Not all of this reduction is due to carbon absorption. Exposure temperatures are in the sensitization range and 4000 hours exposure in helium results in a 50% loss in impact strength. Thus, internal carbide precipitation contributes strongly to loss of room temperature impact strength.

The ferritic 2½ Cr-1 Mo steel is different from the austenitic materials. It shows no carbide case, but rather a uniform carbon absorption throughout, attaining essentially a stable condition in a few hundred hours. With one exception, carbon contents are in the range of 2500 and 3500 ppm for all 2½-Cr-1 Mo specimens exposed beyond 100 hours. The carbon increase has little effect on impact strength and is evidenced in the microstructure only as carbide growth and coalescence. Extraction of chromium is observed, and although small, it is greater in comparison to its starting percentage compared to that of the 316 or 304 materials.

X-ray analysis of extraction residue shows the carbides to be mixed $C_1 + C_2$ type, $(FeCr)_3C_3$ and $(FeCr)_3C$. A measurable amount of molybdenum is substituted in the carbide phase but no molybdenum carbides are present. The carbides are iron rich and show an increasing Fe/Cr ratio with time.

2.4 Test 5 - Status

Test 5 had been in progress in Loop 2 approximately two months at the time of the last subcommittee meeting. Today, only the creep rupture tests on exposed specimens and several fatigue runs remain to be completed. The operation of Loop 2 at this high oxygen level has not been without incident. The problems arise in the operation of the OCI system and in getting the test units on and off stream without plugging these systems with oxide or mass transfer plugs. Incidents of plugging have been experienced in the test unit's inlet and outlet lines, valves, the cold trap, in the form of plugs and general plating. Hydrogen gas has been observed in the system cover gas and has been shown to vary in concentration with changes in the cold trap temperature. The plugging indicator and cold trap operating temperatures have been relied on for monitoring and controlling the oxygen concentration. The analyses of sodium samples for oxygen have not always been successful or in agreement.

2.5 Test 5 - Results

In general, the rupture strengths are running slightly above that obtained for the air, helium and clean sodium environments. The elongations indicate

a correspondent loss of ductility. The impact tests have not been completed at this time.

The creep rate curves are of the normal pattern as compared to Test 3, and show the minimum creep rates to be slightly less than in clean sodium. The creep rates obtained from the creep specimens are in good agreement with those obtained from the rupture specimens.

The fatigue runs had been interrupted for a period until the special runs for AI were completed. The evaluation of the fatigue tests is incomplete at this time because of this interruption and also due to the discovery that two of the three specimens tested at the high strain levels showed carburized cases. These two specimens showed failures of 14,500 and 13,400 cycles as compared to 9,474 cycles for the uncarburized specimens.

2.6 Test 5 - Metallurgy

Specimen exposure to high oxygen sodium covers the range of 100 to 4047 hours. Unlike the high carbon system, these specimens show erratic behavior.

In general, the stainless specimens absorb carbon even in the high oxygen environment. It is small in contrast, being 500 to 600 ppm in 4000 hours. There are exceptions, however, where either no carbon absorption occurs or a possible minor decarburization effect is observed. Even though carburization is small, 304 specimens exhibit ferromagnetic behavior when carbon pickup exceeds some 300 ppm.

The austenitic materials usually show weight gains which can be attributed to oxygen pickup and the formation of a scale composed of sodium ferrite or cromite. Scale is present on all stainless specimens exposed to high oxygen sodium and, since some specimens show weight losses or weight gains less than the total carbon pickup, it appears that a portion of the scale is spalled or dissolved by the sodium. The scale on the specimens is extremely tenacious and resistant to all known chemical descaling procedures. Comparison of x-ray line intensities indicates that the thickness varies from specimen to specimen but bears no relation to time.

The 2½ Cr-1 Mo steel shows its own behavior in high oxygen sodium. It shows strong decarburization in all cases, some values being down to the 50 ppm carbon level. The degree of decarburization is essentially time-dependent, although variations exist where the stainless materials show strong carburization. Unfortunately, the variation is not consistent and heavy carbon pickup by the austenitic materials may occur simultaneously with either a high or low value of decarburization of the accompanying ferritic tab.

The material generally shows a weight loss and an oxygen absorption, and both are consistent with time. In most cases, the sum of oxygen gain and carbon loss is sufficient to balance the total weight loss. This, coupled with the etched appearance of the surface and the complete absence of a scale, would appear to indicate dissolution in the sodium. In a very few instances, however, a sum of all factors shows a weight gain to have occurred. Thus, although the ferritic materials tend to behave predictably in the high oxygen environment, they do deviate on some occasions.

2.7 Analytical Investigations

Since August, 1963, analytical efforts have been directed toward determining concentration levels and effects of C, O₂, and H₂ in solution in sodium. Samples for emission spectrography and carbon analyses have been extracted each week from Tests 3 and 5. All carbon samples are extracted through a 5 μ micrometallic filter. Results continue to indicate segregation of the carbon species in the sampling tube during cooling. Tests have shown that hydrogen, if originally present in the sodium, can be pumped off under vacuum after the amalgamation of a sample. This improves the oxygen analysis and offers an alternate method for

hydrogen. Approximately 1% H_2 was found in the cover gas during Test 5. Neither H_2 nor carbon-containing gases were found during Test 3.

2.8 Cover Gas Analysis

Prior to the initiation of Test 5, the cover gas over the sodium in the expansion tank was analyzed by gas chromatography and mass spectrometry. Gas samples were taken with the cold trap at 400°F and at 700°F, the latter temperature being that specified for the high oxygen test. At 400°F, the H_2 concentration of the sodium metal was 12 ppm. When the cold trap was heated to 700°F, the H_2 concentration of the gas increased to 1.07% H_2 and the H_2 concentration of the metal increased to 33 ppm. These results are discussed more extensively in Progress Reports 45 and 46

In Test 5, H_2 concentration in the expansion tank was 1.23% which is in good agreement with the 1.07% H_2 found at the beginning of the run. Carbon-containing gases (CO , CH_4 , C_2H_4 , C_2H_2) were not detected; minimum limit of detection for each of these gases was 10 ppm. Nitrogen (4%) and argon (150 ppm) were found in the gas indicating an influx of air. Water vapor in the in-leaking air is a potential source of H_2 .

The cover gas of Loop 1, Test 3, was analyzed also. Since this system is purposely contaminated with carbon, the presence of carbon-containing gases in the cover gas was of particular interest. No carbon-containing gases were detected. Both N_2 and Ar were detected, indicating the influx of air into the system, but no H_2 was found. The absence of H_2 in the cover gas is attributed to the fact that the cold trap is operated at <400°F, thus maintaining the hydride content of the sodium at a low value. With the cold trap at 400°F, the hydrogen concentration of the sodium should be <2 ppm H_2 (< 50 ppm NaH).

3. Future Tests

3.1 Further Tests to Round Out Present Program

In reviewing the results of the current program, we find that in general there are no catastrophic effects of the sodium environment plus contaminants on the mechanical properties of the materials tested. There are indications of problem areas that come out of these tests where future tests are in order.

3.1.1 304 Stainless Steel Tests

As we have stated in our last report, this subcommittee does not consider the chemical makeup of 304 SS to be significantly different from that of 316 SS to produce any difference in the effect of sodium containing various impurities on the mechanical properties of the two 300-series steels. However, reactor designers have voiced a strong desire for proof tests on 304 to confirm these expected results.

We, therefore, recommend a series of mechanical tests to be run on 304 SS in both high oxide sodium and high carbon sodium.

3.1.2 Cold Trap Examinations

Because of the unique impurity conditions of Tests 3 and 5, the cold traps from these two tests should be examined. The results of such examination could give better understanding of the data from the tests and could give new understanding to the difficult problem of impurity control in sodium systems.

3.1.3 Thermal Fatigue Tests

Fatigue tests in high oxide sodium have given anomalous results. Further testing at high temperature may be in order. This point should be reviewed following the completion of Test 5.

3.1.4 Decarburization of 2½ Cr-1 Mo

The effect of decarburization on 2½ Cr-1 Mo at 1200°F did not produce any change in mechanical properties. The effect of decarburization on mechanical properties may be considered more important at lower temperatures, however, where deformation process may be more effected by dispersed carbides. Accordingly, there appears to be need of an evaluation of the effect of decarburization occurring at temperatures below 1000°F on the mechanical properties of 2½ Cr-1 Mo steel. Decarburization could be conducted in a static pot test and the decarburized specimens tested in air or helium.

3.1.5 Helium Tests

The helium tests run by the University of Michigan are suspect because of oxidation of samples during these tests. Re-run of the creep to rupture tests in a better-controlled helium atmosphere should clear up any doubts about this data. Every effort should be made to use existing facilities.

The decarburisation tests could be done in conjunction with the helium tests.

3.2 Additional Tests

In the course of carrying out the program, certain areas requiring investigation have come to the fore. These areas requiring investigation are not part of the present program, but we consider them well worth doing.

3.2.1 Pot Tests

Certain tests can be done in sodium-filled static test units containing test specimens of a variety of materials under specific test conditions to supply a particular piece of data. These include such factors as the effect of alternate carburization and decarburization on the microstructure of stainless steels; the dissimilar metal interaction between incoloy and 300-series stainless steel; and the effect of heat treatment on mechanical properties of carburized stainless steel.

3.2.1.1 Incoloy 800 and Inconel 600

Before considering a full range of tests for these materials, we recommend that they be exposed to 1200°F "clean" sodium and sodium saturated with carbon for 4000 hours. Following exposure the specimen would be metallographically examined and mechanically tested for creep to rupture.

3.2.1.2 Carburization of 304 SS and 316 SS

We recommend an exposure of 304 SS and 316 SS to a high carbon sodium environment for 2000 hours followed by creep and creep to rupture tests in "clean" sodium. To date, all the mechanical tests with the high carbon sodium environment were conducted so that "as received" specimens were being carburized during the mechanical tests. The recommended test would aid in the evaluation of a piping system that had been exposed to a high carbon environment followed by the cleanup of the system leaving a carburized component for operation in clean sodium.

3.2.2 Bellows Tests Program

Continuous failure of bellows in this program and in other programs points up the need for a comprehensive bellows development program.

Report of Subcommittee on Carbon Analysis

Report of Meeting on March 20, 1962

**Report #1 from the
CARBON ANALYSIS AD HOC REVIEW GROUP**

Prepared by the Review Group

**T.P. Heckman, AEC-CH, Chairman
R.W. Lockhart, GE, Technical Coordinator
R.W. Bane, ANL
K.Y. Eng and A.I. Hansen, A.I.
C.R. Moore, APDA
W.W. Sabol, GE
H. Steinmetz, UNC**

and edited for the Group by

R. W. Lockhart

**Submitted to the
USAEC Sodium Components Development Program Working Group**

June 1962

Report #1 from the
CARBON ANALYSIS AD HOC REVIEW GROUP
of the
Sodium Components Development Program Working Group

Meeting Time: March 20, 1962 - 0830 to 1700

Place: 1717 H. Street, Washington, D.C. - Room 1146 and 1157

Present: (1) R.P. Heckman, AEC-CH - Chairman
(2) R. W. Lockhart, GE - Technical Coordinator
(3) A. I. - K.Y. Eng
A.I. Hansen
(4) ANL - R. W. Bane
(5) APDA - C. R. Moore
(6) GE - W. W. Sabol
(7) UNC - H. Steinmetz

Object: To develop procedures for preparing several sodium samples containing the same carbon impurity level and with high homogeneity of the carbon in the sodium.

Reference: Letter report, "Results of the First Round Robin Analysis for Carbon in Sodium," by R. W. Lockhart and W. W. Sabol, GE-APED, dated February 23, 1962.

Recommendations

- A. The scatter of the first round data did not permit comparison of analytical methods.
- B. First round discrepancies were attributed mainly to sampling and preparation techniques.
- C. A second round is necessary for comparing the various sampling and analytical methods for determining total and/or elemental carbon in sodium.
- D. The second round samples should be taken from a forced circulation steel system operated for a minimum of 500 hours @ T_{max} 800°F with a plugging temperature of about 300°F (~10 ppm oxygen).

Procedures and specifications for preparing Second Round Samples:

1. Samples to be at 3 levels of total carbon:

Set 1 - low, ~18 ppm carbon

Set 2 - high, ~40 ppm carbon

Set 3 - special EFFR, ~70 ppm carbon (including carbonate)

Note: Set 3 samples should be procured as soon as possible before the Fermi sodium is cleaned up. Recommended preparation and sampling procedures are waived.

2. Sodium preparation as indicated in recommendation D. under the following conditions:

Set	#1 (low carbon)	#2 (high carbon)	#3 (special)
Loop accessory	Large area hot trap filled with stainless steel foil and operated at 1250 F.	Carbon shall be added as powdered graphite contained in a micrometallic "teabag" and held in a 1200 F sodium stream. The "black tea bag" should be weighed before and after exposure to the sodium.	EFFR as is: 220 F plugging temperature; Ni sampling cups.
Sampling temperature	750 F	850 F	5-600 F

3. Sample Container Specifications:

Material - Nickel

Size - $\frac{1}{4}$ " to $\frac{1}{2}$ " OD thin wall tubing at least 6" long(straight section)

Closure - Compression fittings outboard of stop valves.

Cooling - Horizontal position; air cooled

4. Sampling period:

Several samples should be taken simultaneously. At least 16 samples should be taken in an 8 hour shift.

5. Number of samples:

Some analysts recommended complete consumption of the sample for our carbon analysis; other favored dividing a sample into several parts prior to analysis either by extruding a small piece or by chunk selection in a dry box. It is recommended that each Laboratory provide at least 4 individual analyses for each set of samples. Thus the number (and volume) of samples required depends on which analytical laboratories are selected to analyse the second round samples and how many laboratories will be involved in the program. For example, the 16 samples described in item 4 could provide either samples for 16 laboratories that would divide the sample, including analysis by the supplier, or if the Ad Hoc Group (2/5) provided a representative sampling of the fraction of "total consumption" to "divided sample" laboratories, samples for 3 "consumption" laboratories (12) plus one each for 4 "divider" laboratories.

Discussion of the Methods of Analysis:

As reported in the reference several analytical methods were utilized during round robin 1. This Group concurred that each analytical laboratory should use their preferred method of analysis. Second round participating laboratories should be selected to include at least one of each of the methods previously used. During the March 20 meeting each representative discussed variations of his method compared to those described in the literature. A.I. representatives described two analytical methods for carbon that they are developing. One involved the isotopic dilution technique using C^{13} spike and the other monitored the C^{12}/C^{14} ratio during reactor operation. Details should be obtained from them. These methods appear promising and should be developed to the state where they can be compared with the present procedures. Method or

technique comments by all the organizations certainly provided improved communication between the analysts, confirmed the numerous variations in the analytical procedures and provided an atmosphere for constructive thinking about the various techniques employed.

There continues to be competition between dry and wet (Van Slyke) method of combustion of the carbon. Both methods are handicapped by tedious procedures and potential steps where impurities can be introduced into the analytical system.

Similar to the first round robin, each laboratory analyzing second round samples should report the

- 1) results of each individual analysis(at least 4 for each set of samples)
- 2) details of removal of the sodium from the capsule and preparation for analysis.
- 3) size of sample analyzed
- 4) details of the analytical method or variations from published methods
- 5) magnitude and frequency of blank determination
- 6) results of analyzing standards such as sucrose or benzoic acid.
- 7) comments on means of improving the method.

Reports of Subcommittee on Sodium Mass Transfer Program

Report of Meeting on January 19-20, 1961

Report On

GE SODIUM MASS TRANSFER PROGRAM

Prepared by

GE Project Group, R. W. Lockhart, Project Manager

G. Billuris

E. G. Dunn

F. Hetzler

and

Ad Hoc Review Group, H. W. Savage, ORNL, Chairman

J. H. DeVan, ORNL

John M. McKee, NDA

David I. Sinizer, AI

Submitted to

Sodium Components Development Program Working Group

January 21, 1961

I. INTRODUCTION

On January 19 and 20, 1961, an Ad Hoc Review Group met at the General Electric Company, San Jose, California, to discuss recent results of the sodium mass transfer research program at GE. The Review Group, which was assembled at the request of T. A. Nemzek, COO, Chairman of the AEC Sodium Component Development Program Working Group, consisted of David I. Sinizer, AI, John M. McKee, NDA, J. H. DeVan, ORNL, and H. W. Savage, ORNL (group chairman). The following report furnishes a summary of proceedings during this two-day meeting.

The objectives of the meeting were to comment on the available data and methods of analysis of the results from the sodium mass transfer investigation being conducted by GE, to assist GE in the recognition of problem areas, and to recommend to the Working Group priorities in test conditions and analyses for forthcoming phases of the test loop program. The meetings were attended by the members of the review group, C. V. Backlund, SFOO, G. Billuris, R. W. Lockhart, F. Hetzler and E. Dunn from GE. Part-time attendees from GE were D. Parker, K. D. Cohen and J. Birle.

The order of business at the meeting follows:

January 19, 1961

Welcome to GE - R. W. Lockhart
 Charge and Introduction - H. W. Savage
 Introduction to Mass Transfer Project - R. W. Lockhart
 Loop Operation - G. Billuris
 Metallurgical Analysis - F. Hetzler
 Statistical Analysis and Test Results - E. G. Dunn and F. Hetzler
 Inspection of Test Facility and Metallurgical Laboratory
 Discussion of Data - All Present

January 20, 1961

Discussion of Conclusions - All Present
 Draft Minutes of Meeting - Project and Ad Hoc Review Groups

II. SUMMARY AND CONCLUSIONS

1. Corrosion data are available from complete first runs on loops No. 3 (316 - 2 1/4 Cr), No. 4 (316 - 5 Cr) and No. 6 (5 Cr); from 1400-hr runs on loops No. 2 (316 - 2 1/4 Cr) and No. 5 (2 1/4 Cr); from a 700-hr run on loop No. 1 (316 S.S.).

2. Specimens from these loops have been or are being analyzed to obtain the following types of information: corrosion rates (in $\text{mg}/\text{dm}^2\cdot\text{mo}$), metallographic appearance, carbon content, and changes in mechanical properties (hardness and tensile strength).
3. During the development and initial operation of loop equipment, operating difficulties were experienced principally in the Conoseal flanges used with the specimen holders and in the EM pump cell. As expected, the output signals of flowmeters constructed of 2 1/4 Cr and 5 Cr steels were so low as to necessitate the use of auxiliary non-ferritic flowmeters in these loops. A final operating difficulty was contributed by the poor oxidation resistance of the Cr-Mo steels above 1000°F which caused serious attrition of flange faces in these loops and made sealing of the flanges difficult.
4. During the initial runs of loops in which the O_2 level of the sodium was established at 50 ppm, the oxide concentration in the system decreased substantially and necessitated the addition of Na_2O to the system. This decrease in oxide level appeared to be due to a cause other than the presence of a cold finger.
5. Except for the low oxide loop (No. 2), all loops have indicated an increased resistance to flow with time. The loss of flow rate appears to be associated with "fouling" of the relatively small passages of the specimen holder (C-2) in the cold leg.
6. The maximum corrosion rates of 316 stainless steel in combination with 2 1/4 Cr and 5 Cr steels, which occurred at the H-3 specimen holder (1200°F), were in the range of 10 to 260 $\text{mg}/\text{dm}^2\cdot\text{mo}$. In the all-316 loop, which operated at a maximum temperature of 1300°F, the corrosion rate (measured after 700 hr) was an order of magnitude higher (900 $\text{mg}/\text{dm}^2\cdot\text{mo}$).
7. A duplex grain structure, generally resembling banding, was observed in several 316 S.S. specimens; since the occurrence of this phenomenon showed no correspondence with loop position, the effect appears to be the result of pre-exposure heat treatment rather than corrosive attack in sodium.
8. Corrosion rates to date have shown no definable pattern with time. However, a notable dependence of corrosion rate on velocity has been demonstrated, based on rates measured at 21 fps and 7 fps.
9. Loops constructed entirely of either 2 1/4 Cr or 5 Cr steel (No. 5 and No. 6) revealed similar corrosion rates after 1400 hr. However, hot leg surfaces of the 2 1/4 Cr loop exhibited significant decarburization, while the 5 Cr loop surfaces showed no discernible carbon migration. Mechanical property determinations of the 2 1/4 Cr specimens indicated significant embrittlement of specimens exposed at 700°F and slight embrittlement of specimens at 1000°F.

10. Metallographic examinations of 316 stainless steel hot leg specimens exposed at 1200°F and 1300°F revealed the presence of a thin, fine-grained surface layer, tentatively identified as ferrite.
11. Sodium used in initial runs contained a relatively high calcium concentration; however, this does not seem to be significant in explaining the decrease in sodium oxide concentration which occurred during loop operation, since all of the calcium should have been precipitated as calcium oxide by the first addition of Na_2O . Analyses of sodium removed from the loop systems during operation have been somewhat inconsistent, particularly with respect to calcium determinations. Improved sampling techniques (i.e., use of standard samples) are being employed to determine the causes of analytical variations.

III. STATUS OF PROGRAM

1. The current status of the Sodium Mass Transfer Project operations is summarized below:
 - a. The first runs of loops 3, 4, and 6 have been completed and all samples analyzed except for metallurgical examination of loop 6.
 - b. The first runs of loops 2 and 5 are nearing completion (over 2000-hr of operation) with sample data available for the 700 and 1400-hr exposure periods.
 - c. For run 1 of loop 1 only the 700-hr exposure data are available. No radioactive tracer data are available.
2. The following data* were presented for discussion:
 - a. Curves showing variation of oxide concentration with time for loops 3 and 4.
 - b. Corrosion rate data sheets.
 - c. Results of metallographic examination.
 - d. Tabulation showing sodium impurity analyses.
 - e. Mechanical property data.

* Note: Except for photographs, these data have been presented in recent progress letters.

3. Difficulties which were encountered during loop operation are tabulated below:

a. Mechanical

- (1) Mechanical Joints - Failure of Marman Conoseal joints has been responsible for the majority of sodium leaks which have been encountered. This problem appears to have been minimized by using heavy-duty clamps and improved installation techniques. However, external scaling of the Cr-Mo medium alloy steels above 1000°F in the gasket region poses a continuing problem.
- (2) ΔP - The insertion of additional metallic samples during the final design stages of the loops increased the system pressure drop from about 60 psi to over 110 psi. Since the installed EM pumps are currently limited to about 100 psi outlet pressure, less than design velocities have been achieved. Due to the observed fouling (paragraph 3.a.(3) below), the velocities were further decreased as the run 1 tests continued. Higher velocities can only be achieved by the installation of new, higher head pumps or eliminating some of the sample flow resistance. If necessary to achieve higher velocities subsequently, consideration can be given to eliminating some of the high velocity and intermediate temperature samples and sample holders.
- (3) Fouling - Operation of loops 1 and 3 through 6 has been impaired by occasional flow reduction apparently caused by deposition products in the cold leg. Flow usually has been reestablished by dumping the loop and refilling or by varying the applied pump voltage over wide ranges. More recently it has been necessary to withdraw and clean samples from the cold leg sample holders (loops 1 and 5) to help eliminate the plugged condition. Samples have been replaced in the loops.
- (4) Pump Cells - Pump outage has been responsible for lost time on loops 1 and 2. A pump cell tubing failure during initial operation resulted in a sizeable sodium leak; the loop was down for several weeks until a new cell was built. Loop 1 is currently down as the result of losing a cell electrode. Spare pump cells are being fabricated to minimize down time.
- (5) Flowmeters - Flow measurements in chrome moly flowmeters have been erratic and, at the low flows used in plugging runs, very difficult to determine. The extremely small signal and pronounced variations due to thermocouple effects contribute to the difficulties. In the bypass lines of loops 2, 3, and 4, stainless steel flowmeters have been installed to minimize the uncertainty in flow measurements for plugging determinations.

b. Mechanical Properties

The mechanical properties of 2 1/4 Cr alloy have changed with time and temperature. The most discernible change occurred at 700°F, where the initial hardness of Rockwell B85 increased to Rockwell C32 at the end of 2800 hours. A proportionate change in room temperature tensile and yield strengths was noted. The elongation was not so markedly changed with 8% at Rockwell C32 versus 15% originally. The elongation may be questioned from the standpoint of the non-standard specimen, however.

At 1000°F the properties were less disturbed with a Rockwell B95 being the ultimate value after 2800 hours exposure. At 1100°F the strength was noted to decline to a Rockwell B60 value. This is postulated to be a manifestation of a second order effect of time and temperature. That is, the strength and hardness increases to a maximum then declines with increasing time at temperature. The time period required to reach the maximum decreases with increasing temperature.

c. Metallographic Appearance

Decarburization of 2 1/4 Cr steel was noted at all temperatures. The amount of decarburization was difficult to estimate in some samples because the structure changes with time. Chemical analyses show a steady decrease in carbon level from .11 originally to approximately .04 at 1200°F. The 5 Cr material on the other hand gave no physical indications of either structural change, property change or decarburization. Chemical analyses of the sample for carbon have not yet been run, however.

A layer was noted on the 316 material. This layer was identified by hardness and magnetic properties to be ferritic in nature. No change in properties or structure was noted except for an increasing concentration of carbides in the grain boundaries noted at 1200°F. A duplex grain structure was noted on these specimens.

d. Temperatures

A measurable temperature difference existed between the two maximum temperature region sample holders. In general, sample holder H3 was observed to be 5 to 15°F greater than H3R, which is downstream of H3.

The combination of manual and automatic control of the heaters and cooler dampers has provided control to ±20°F of the desired temperature values. This variation appears tolerable for purposes of the test program.

e. Oxide Concentrations

Based upon plugging determination, the system oxide concentration generally decreased with time. Cold trapping was effective in initially bringing the oxide level back up to 50 ppm (450°F saturation temperature). With continued operation it was found necessary to dump sodium and refill at 500°F or higher in order to obtain 50 ppm oxygen. Excess Na_2O was added to the dump tank as a last resort to provide the required oxygen.

It should be emphasized that the four loop appendages to the circulating loop (namely, the dump tank line, bypass inlet line, cold trap and plugging indicator outlet lines) were controlled at temperatures above 450°F during normal loop operation.

f. Sampling and Analyses

Most of the sodium samples used for impurity analysis were taken from the dump tank at 500°F with the loop drained. High calcium results suggest that precipitated CaO may be picked up during the sampling operation.

Because it appears that more representative sodium samples can be obtained from the circulating loop, the surge tank - at about 670°F - was recently sampled on loop 6 prior to completion of run 1. Analytical results are not yet available for comparison with the dump tank sample.

Regarding the sodium analysis, it should be pointed out that the emission spec. standards were revised after samples S1a - S6a had been reported. In addition, the Ca analysis procedure (by emission spec.) is currently being revised.

Wet chemistry procedures have also been improved since the original samples were analyzed and the lower detection limits currently reported by chemistry are well below the values thus far obtained.

IV. SUMMARY OF TEST RESULTS

1. Weight Change Data

a. Magnitude of observed corrosion rates

In initial tests of 316 - 2 1/4 Cr and 316 - 5 Cr bimetallic loops, which operated at a maximum temperature of 1200°F and with an oxide concentration of approximately 50 ppm, corrosion rates at the point of maximum temperature ranged from 10 to 260 $\text{mg}/\text{dm}^2\cdot\text{mo.}$ (The equivalent rates of uniform surface removal are 0.06 to 1.6 mils/year.) These observed weight change values are rather high, suggesting that the

mass transfer rate is quite sensitive to oxygen content. Average corrosion rates over 3000 hours at 1200°F in a forced convection loop run with low oxygen at AI ranged from 2.2 to 14.2 mg/dm².mo for similar alloys.*

In the case of the 316 - 2 1/4 Cr loop, 316 specimens (which were in heated sections of the loop only) gained weight at temperatures of 1000°F or below and lost weight at 1100°F or above. The 2 1/4 Cr specimens (which were in cooled sections only) gained weight at all recorded temperature positions. In contrast, 316 specimens in the 316 - 5 Cr loop lost weight at all positions in the heated section and 5 Cr specimens gained weight at all positions in the cooled section.

Corrosion rates in the all - 2 1/4 Cr and all - 5 Cr loops (which to date have been measured only up to 1400-hr) are of the same order of magnitude as the bimetallic loops. However, corrosion rates in the all - 316 stainless steel loop, which operated at 1300°F, after 700-hr were an order of magnitude higher than for the 1200°F systems. Considerable operating difficulties have been encountered in the latter system and may have contributed to the seemingly high rate of mass transfer.

b. Velocity Effect

Corrosion of hot end specimens appears to increase significantly with flow velocity. DeVan has observed this at higher temperatures in the Inconel-NaK system. Velocity presumably varies considerably around the periphery of specimen cross section, but the manifestations of attack (probable ferrite film) in the 316 S.S. specimens occurred to approximately the same degree around the periphery.

c. Corrosion vs. Specimen Thickness

The 6 mil thick foil specimens consistently show lower corrosion rates than the 1/16" thick specimen at the same temperature and velocity. This could be due to the fact that the foil affords a more limited "reservoir" of transferring elements than the thicker specimens.

d. Corrosion vs. Time and Temperature

- (1) Corrosion vs. Time - Corrosion vs. time can be followed for high and/or low velocity specimens in three loops for two or more time periods. The average corrosion

*AI internal memo from A. J. Birkle to W. J. Anderson, dated 9-9-60, "Summary of Test Status of 488 Alloy" (Project 7519 - 4442)

rate is seen to jump up or down by large factors with no correlation from loop to loop or period to period. There is good reason to believe (but not evident from the data) that the actual average corrosion rate either remains constant or decreases gradually with time in a consistent manner. The corrosion rate in specimens exposed for the first and last half of a 2800-hr test also varies in an improbable and inconsistent manner.

- (2) Corrosion vs. Temperature - Where the corrosion rates at 1000°F and 1100°F for a given loop, velocity and time period have been measured for specimens in both the increasing and decreasing temperature portions of a loop, the corrosion rate in the heated leg is observed to be higher than that in the cooling leg. There is some theoretical and experimental evidence from other work that for short circuit times the corrosion rates at identical temperatures and velocities should be independent of whether heat is flowing into or out of the sodium.

e. Significance of Weight Change Data

E. Dunn (GE) has shown that the standard error for weight change measurements on the specimens in any given holder after any given test period is only 3 mg/dm².mo, a fairly small fraction of the measured values. The improbability of the results discussed in IV.1.d above suggests that the "standard error" of weight change measurements from period to period and from position to position may be much larger. Efforts to clarify these anomalies as more data are obtained seem essential before good significance can be assigned to the weight change data. Both questions (corrosion vs. time and corrosion vs. temperature) are fundamental to a basic understanding of the mass transfer process in sodium at these temperatures.

2. Results of Metallurgical Examination

a. Decarburization of 2 1/4 Cr

Carbon analyses on 2 1/4 Cr specimens showed decarburization by sodium increasing from slight at 700°F to 60% at 1200°F and 2800 hours. Decarburization had been expected at the high temperatures, but not at 700°F. The decarburization was apparent on micrographs of 1000°F specimens, but not at higher temperatures. In the latter the higher diffusion rate of carbon may have leveled out the carbon gradient through the specimen.

b. Mechanical Property Changes in 2 1/4 Cr at 700°F

No obvious explanation for the observed mechanical property changes at 700°F is at hand, since carburization should proceed quite superficially if at all at this low temperature.

Thus it seems in order to review this particular 2 1/4 Cr - 1 Mo heat with regard to its susceptibility to "blue brittleness" or "temper embrittlement" phenomena. In this regard, it may be desirable to heat treat control specimens at 700°F in an inert atmosphere to establish whether or not the changes in mechanical properties are in any way related to sodium exposure.

c. Stability of 5 Cr Alloy

No significant change in mechanical properties or carbon content was detected in the 5 Cr specimens. This also had been expected.

d. Surface Layer on 316 S.S.

Thin surface layers formed on 316 S.S. specimens exposed at 1300 and 1200°F for times as short as 400 hours. These layers were identified as ferritic and were similar in appearance to those observed by the review group on the stainless steel from sodium loops run at higher temperatures. The Widmanstätten structure observed in the initial stages of layer formation is probably ferrite rather than carbide precipitation.

Certain photomicrographs of 316 stainless steel specimens displayed a highly duplex grain structure not unlike the banded structures in poorly homogenized hot rolled steels. Since it appeared randomly in both hot- and cold-leg specimens, this phenomenon appeared to be the result of pre-exposure heat treatments rather than related to recrystallization or corrosion effects during testing.

3. Other Problem Areas

a. Oxygen Depletion Mechanism

The need to continually add oxygen to the sodium, first by diverting flow through a heated cold trap and eventually by addition of 6 g. of Na₂O at a time via the sump tank, is one of the more surprising results of the first run. It suggests that there is an oxygen sink somewhere in the system, but the exact nature of the sink has not been identified. All side arms off the loop were held at 450°F (the cold trap temperature) or higher up to and including each shutoff valve. Sinizer suggested that some oxygen may combine with carbon in the sodium and/or container material to form CO or CO₂, which escapes to the gas over the surge tank. Some evidence of this has been found at AI. Other possible sinks suggested were (1) reaction with the calcium in the sodium (2) precipitation with mass transfer deposits as a complex oxide, and (3) scale formation on steel in colder areas and possible diffusion into the steel. The

calcium theory is doubtful since one gram of Na_2O would theoretically precipitate all of the calcium originally present in the sodium (and calcium is still being found in samples of sodium). DeVan pointed out that removal of oxygen by combination with iron would have tied up larger amounts of oxygen than the weight loss data would imply at first glance. Presumably several mechanisms are operating simultaneously. Analyses of surge tank gas for CO and CO_2 and efforts to catch and analyze significant amounts of any sludge formed would be desirable.

b. Loop Fouling

The gradual loss of flow velocity observed with time on several loops is believed significant from the standpoint of operating such systems for long times, even with large diameter openings. If this phenomenon is encountered again in the low oxygen tests of run 2, the review group feels that identification of fouling deposits will become as important as the original objectives of this run. Operation of the loops should then be interrupted for several weeks, if necessary, for careful investigation of fouling causes.

c. Inconsistencies in Sodium Analyses

Sodium analyses have been based on samples removed from the sump into which sodium was discharged while withdrawing loop corrosion specimens. Considerable scatter has been found in analyses of the sodium from loop to loop as well as within a single loop. Calcium analyses have been especially spurious. It is felt that some of the scatter may be introduced by the presence of various amounts of solid matter within the sodium. For this reason, the review committee suggested that sodium samples be withdrawn at the surge tank and that both filtered and unfiltered samples be removed. GE has already taken steps to improve the correlation between wet chemical and spectroscopic results through the use of standard samples and by using the same aliquot for both analytic methods of analysis.

The impurity content of the sodium, other than oxygen and possibly calcium, is not believed to exert a significant effect on mass transfer results.

4. Significance of Results

On the basis of the data now at hand, only limited conclusions can be drawn regarding the ramifications of test results on the design of higher temperature sodium systems.

- a. Corrosion rates determined in the case of 316 stainless steel at both 1200°F and 1300°F show a considerable increase over the results measured for this material at 1000°F or below. However, in every case the results apply to systems which

have contained a relatively high oxygen concentration (~ 50 ppm). Thus the establishment of corrosion rates representing realistic "design data" must await the results of lower oxide tests proposed for run 2. In the brief examinations made of hot leg specimens from the 316 stainless steel loops, the mode of corrosive attack appeared to be quite uniform, i.e., was not intergranular in nature. For this reason, it is suspected that effects of cold leg deposition on system operation (e.g., fouling) will be felt more acutely in systems operated at 1200°F than the attrition of hot leg surfaces per se. Again, this factor can be properly evaluated only after the results of low oxide runs become available.

- b. Tests completed to date show an unexpected but apparently real effect of velocity on corrosion rate in the temperature range 1200 – 1300°F . This result is interesting not only because of its implications in reactor design, but also because it indicates a change in the mechanism which has been generally accepted for the corrosion of iron-base alloys in sodium below 1000°F . For this reason, it is the recommendation of the review group that a parametric study of velocity be conducted immediately after Run 2.
- c. A final effect having disturbing implications concerns the trend toward embrittlement of $2\frac{1}{4}$ Cr steel specimens observed at 700°F . The committee was at a loss to explain the cause of embrittlement and thus to evaluate its ultimate consequences. However, taken at face value, the drop in ductility in specimens at 700°F (down to 8%) does represent a serious design limitation for this material.

V. SUGGESTIONS FOR PROGRAM MODIFICATION

1. General

It was the consensus of the Ad Hoc Review Group that the Sodium Mass Transfer Project at GE, San Jose, has been ably initiated. It promises to provide meaningful information toward an understanding of mass transfer problems in sodium systems at elevated temperatures. The review group's comments on suggested program modification, in general, fall into three categories: 1) definition or clarification of the program scope, 2) modification of operational aspects, or 3) problem areas where amplification of information gathering is advisable.

2. Program Scope

a. Oxygen Level in Run 2

The group felt that the scope of the program as now defined was satisfactory for the over-all program. It was agreed that the second series of runs should proceed as planned with the oxygen level reduced from the 50 ppm of Run 1 to a level

of about 10 ppm, as represented by a cold trap temperature of 300°F. There was agreement that the oxygen level be maintained by continuous replenishment from a constant-temperature cold trap, if possible. There was disagreement as to whether oxygen should be added through the dump tank in the event the oxygen level drops with time in the second series of runs. While this point remains to be resolved, it is probable that oxygen replenishment will not be the problem in Run 2 that it was in Run 1.

b. Order of Test Runs

In the project as now operated, the definition of ΔT is the temperature differential between the hottest specimen holder in the "hot leg" and the coldest specimen holder in the "cold leg". As a result of the observed changes in corrosion rates with velocity, and the lack of unanimity of the group as to what effect should be expected, it was the consensus of the group that velocity variation may be a more significant variable in mass transfer than ΔT . It is, therefore, suggested that Run 3 be used to evaluate velocity effects.

c. Analytical Model of Mass Transfer

The significance of the temperature profile around the loop was the subject of considerable discussion. In Run 1, for example, the temperature profile in the loop consisted of increasing temperature from 1000°F to 1200°F in the four specimen holders of the "hot leg" and decreasing temperatures from 1100°F to 700°F in the three specimen holders of the "cold leg". Since the dwell time of an elemental volume of sodium at a particular temperature in the vicinity of the specimens in each holder may affect the rate of solution in the "hot leg" or deposition in the "cold leg", it is suggested that some further study be given to establishment of an analytical model of the solution and deposition processes in the loops as they are affected by temperature, heat flux, and velocity profiles. It was felt that the existence of such an analytical model might guide future experiments and methods of data presentation and analysis.

d. Loop Fouling

In Run 1 fouling caused by an as yet undetermined mechanism was observed with an attendant increase in pressure drop and decrease in flow velocity in specimen holders. The cause of specimen fouling was discussed at length. Preliminary evidence points to the location of fouling as being in the small passages between the specimen and the specimen holding slot of the specimen holder. A rapid calculation indicated that a deposit .001" thick on the specimen and the slot restricts the flow passage by about 6% in the GE loops. The fouling is,

therefore, accentuated in these loops compared to conventionally designed sodium systems where severe flow restrictions are intentionally avoided.

Since there is some evidence of a tie between fouling and oxygen concentration, fouling may be less likely to occur in Run 2 (10 ppm oxygen) because of the low oxygen content of the sodium. If it does occur in any loop in Run 2, it was agreed that the specimens should be removed from that loop and continuation of that run be delayed while the nature of the fouling is investigated. The run would be continued only after a study of the chemical nature of the deposits had been completed. X-ray or electron diffraction analysis should be a useful tool in identifying the nature of deposits.

3. Operational Procedures

a. Temperature Monitoring

Temperatures at each continuously monitored "hot leg" specimen holder (H3) during Run 1 ranged $\pm 15^{\circ}\text{F}$ in one loop, $\pm 20^{\circ}\text{F}$ in three loops, $\pm 25^{\circ}\text{F}$ in one loop, and $\pm 30^{\circ}\text{F}$ in one loop. Temperature variations in the continuously monitored "cold leg" specimen holder (C3) ranged $\pm 15^{\circ}\text{F}$ in two loops, $\pm 20^{\circ}\text{F}$ in three loops and $\pm 25^{\circ}\text{F}$ in one loop. It was felt by the group that this variation was of relatively minor significance at this stage of the investigation. However, it was suggested that every effort be exerted to minimize these temperature swings within the operational limits of the existing equipment.

b. Pressure Drop

During Run 1 it was found that maximum velocity obtainable was about 21 ft/sec instead of the design velocity of 30 ft/sec. It was the group consensus that operation of Run 2 at the same velocities as Run 1 is indicated. No equipment changes will be necessary. However, the proposed Run 3 (evaluation of the effect of velocity) may require some equipment modification if it is felt at that time that higher flow velocities are required than can now be obtained with present equipment.

c. Sodium Impurities

The validity of defining oxygen content in terms of plugging meter temperature was discussed at length. (At least four different curves of oxygen solubility vs. temperature appear to exist. It may be that the Working Group should suggest additional work to resolve these inconsistencies.) It is suggested that perhaps interaction between impurities such as carbon and oxygen may affect plugging temperature. More

frequent monitoring of oxygen content by plugging runs is suggested for the GE project. Analysis of the sodium for carbon is also suggested. Analysis of the gas over the sodium in the dump tank is proposed as a possible clue to the decrease in oxygen content of the sodium observed during Run 1. It was suggested by the group that some thought be given to determining the oxygen content at which the decreasing oxygen content observed in Run 1 will level off.

4. Additional Data Requirements

a. Temperature Profile

The paucity of data at other than certain selected temperatures was noted by the group. This ties in with the suggested consideration (V.2.c.) of the effect of temperature profile on mass transfer. It was felt that additional correlation of temperature with solution or deposition rates at various points in the loop should be attempted.

It might be possible to obtain a more complete profile of mass transfer rates vs. temperature by the inclusion of additional low velocity specimens at appropriate points in the piping (as distinct from specimen holders). These would be inserted at the start of each run and examined only at the end of the run. An attempt should be made to cover the complete range of temperatures.

Programming and monitoring of the temperature profile may be of greater significance than only the ΔT as now reported for the project.

b. Pre-Exposure Metallurgy

Certain anomolous metallurgical observations may have been avoided by more complete pre-exposure metallurgical examinations. For example, the extreme decarburization of the 2 1/4 Cr specimens held for 700-hr at 700°F was not expected. It was felt by the group that this may have been the result of pre-exposure treatment. It is suggested that in future runs pre-exposure characterization of samples might go far toward resolving anomolies in post-exposure examination. It is further suggested that the effect of material prior history be included in the program. Consideration may have to be given later to including additional samples having a variety of pre-exposure heat treatments. It would be of interest, for example, to observe whether differences exist in the behavior of samples taken from hot-rolled plate or extruded tubing which are typical of metallurgical structures found in practical sodium systems. Some effort should be expended to clarify the unusual grain structure observed in 316 S.S. specimens to make sure that it is in fact extraneous to the sodium exposure.

c. Impurity Content

More frequent oxygen and carbon content monitoring is suggested. Some effort to check the plugging meter oxygen determinations by chemical analyses of sodium samples seems desirable, particularly during the remainder of the first series of runs. Carbon has been suggested as a possible contributor to the mechanism of oxygen depletion. It is, therefore, suggested that the cover gases be analyzed for CO and CO₂ to determine whether carbon-oxygen reactions have occurred.

d. Effect of Exposure Sequence

It was noted in Run 1 that observed corrosion rates appeared to be affected by the time "era" during which specimens were exposed. For instance, there was little correlation between corrosion rates observed for a material exposed for the first 1400 hours of a 2800-hour run and the same material exposed for the second 1400 hours of the same 2800-hour run. This apparent effect bears further investigation.

e. Other Materials

It was proposed that extension of the present work scope include study of other materials developed for high temperature sodium systems. Typical examples are 4S4 and 4S8 developed by Atomics International. This could be accomplished by low velocity specimens in the piping.

5. Methods of Data Presentation and Analysis

It was felt by the group that two aspects of project reporting require additional clarification. Methods of data reporting and subsequent data analysis might project from an analytical study of mass transfer mechanisms. Such a study could give guide lines for setting up experiments and point the way to methods of data reporting and analyses. Insofar as is possible, consideration should be given to statistical methods of multiple correlation in deciding what experiments and measurements are to be made. The method of data presentation devised by GE-San Jose is satisfactory and will permit cross-correlation of data.

It is suggested by the review group that GE Project personnel present to the Working Group in the near future an integrated plan for data analysis. This presentation should include statements of the parametric bases under which they propose to analyze data. It is then the function of the Working Group to determine whether the parametric variations proposed by the Project for data analysis solve the needs of the program and present information in the most useful manner.

VI. RELATIONSHIP TO OTHER PROGRAMS

The corrosion data generated by GE's mass transfer investigation bears an important relation to the program on mechanical property determinations being conducted by Mine Safety Appliances. One piece of information discussed above which appears significant in conjunction with MSA's program concerns the decarburization of 2 1/4 Cr specimens at 700°F. While the effects of decarburization should be manifested in MSA's tests, effects occurring at cold leg positions will not. Thus, the "pre-conditioning" and subsequent evaluation of 2 1/4 Cr specimens at cold leg positions is indicated.

NOTE: The contributors to this report have concurred with the foregoing edited version through telephone conversations with the Chairman of the Ad Hoc Review Group. In view of the method used, each has agreed to supplement this report with additional personal communications concerning discrepancies, if any, contained above.

H. W. Savage, Chairman
Ad Hoc Review Group

Report of Meeting on October 2-4, 1961

Report #2

on

GE SODIUM MASS TRANSFER PROGRAM

Prepared by

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Submitted to

Sodium Components Development Program Working Group

November 22, 1961

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Report #1 January 21, 1961

Report #2 November 22, 1961

I. INTRODUCTION

On October 2, 3, and 4, 1961, the Ad Hoc Review Group for Sodium Mass Transfer Studies met at General Electric Company, Atomic Power Equipment Department, San Jose, California, to discuss recent results of the Sodium Mass Transfer Program at GE. The review group meeting was held at the request of the AEC Chicago Operations Office in order that the AEC might have the benefit of technical advice of the review group members. The review group consisted of R. E. Aronstein, AEC Chicago Operations Office (Chairman), H. W. Savage, ORNL (Technical Coordinator), J. H. DeVan, ORNL, J. M. McKee, UNC, and D. I. Sinizer, AI.

The objectives of the meeting were to review and comment on the sodium loop data and methods of analysis, to assist in the recognition of problem areas, and to make recommendations to the AEC and the Sodium Components Working Group regarding the program.

The meetings were attended by the members of the review group, J. P. Holliday, San Francisco Operations Office, E. G. Brush, G. Billuris, L. F. Epstein, D. W. Gaylor, F. J. Hetzler, and R. W. Lockhart from GE.

The following report summarizes the proceedings during this meeting and presents the evaluations and recommendations of the review group. The order of business at the meeting was as follows:

October 2

Welcome to GE - R. W. Lockhart
 Introduction for the AEC - R. E. Aronstein
 Technical Introduction and Charge - H. W. Savage
 Introduction to the Mass Transfer Project - R. W. Lockhart
 Metallurgical Results and Analysis - F. J. Hetzler
 Inspection of the Test Facility
 Presentation of Theoretical Model - L. F. Epstein
 Discussion of Theoretical Model - All Present

October 3

Discussion of Data - All Present
 Statistical Design of Test Program - D. W. Gaylor
 Inspection of Results at Metallurgical Laboratory
 Analysis of Mass Balance - R. W. Lockhart
 Further Discussion of Theoretical Model - L. F. Epstein
 Discussion of Information Presented - All Present
 Drafting of Group Report - All Present

October 4

Drafting of Group Report - All Present

II. SUMMARY

The following summarizes the evaluation of the program as of October 1, 1961:

1. Malfunctions in loop operations, per se, are no longer serious problems.
2. Loop fouling is nearly as severe at low (12 ± 2 ppm) oxide concentration as it was during high (46 ± 4 ppm) oxide runs.
3. Maintaining 12 ppm oxide concentration requires fewer oxide additions than during 46 ppm operation. During early low oxide runs, oxide removal was required because of oxide inleakage through valves.
4. Weight loss results vary with velocity apparently to the 0.9 ± 0.3 power.
5. Corrosion at 12 ppm oxide appears to be about one-half that at 46 ppm.
6. It is not clear from the mass transfer results to date whether there is interaction between observed velocity and oxide dependencies.
7. Corrosion is temperature dependent, but runs have not been performed at more than one maximum temperature or ΔT .
8. Statistically significant variations in weight change rates with time have not yet been found. However, some data indicate that specimens change weight more during the second half of a run than during the first half.
9. Weight gains occur throughout the cooled legs of the loops and apparently in the heated legs to temperatures of about 1000°F. Weight gains have also been observed at 1100°F in the heated legs of the 316 stainless steel-2 1/4 Cr loop. Usually weight losses occur in specimens in the heated leg. The pattern would be consistent with a system in which the sodium is approaching saturation with corrosion products in the heated leg and is essentially saturated in the cooled leg. However, sufficient data are not available for a definitive test of this theory.
10. Weight losses measured in isothermal sections decrease in the direction of flow.
11. Mass balances (which have been based on data from specimen holders) are inconclusive.

12. Normal loop circuit time at 0.5 gpm is of the order of 7 minutes; about 4 minutes is spent in traversing the heated leg and specimen holders at the highest temperature. About 75% of each loop is in very slow motion in heaters, coolers and surge tank; about 24% is at very low velocity in connecting passages; and only 0.1% is at substantial velocities at the test specimens.

Data have not been presented to substantiate that corrosion rates and mechanisms have the same parametric dependencies under these extremely different dynamic situations. The extent to which this arrangement complicates data interpretation remains to be evaluated.

13. The slow movement of sodium through the heaters apparently acts to promote saturation of the sodium at its highest temperature. The coolers and surge tank, on the other hand, act as only partially effective removers of corrosion products. Accordingly, the specimen holders and specimens can undergo either dissolution or deposition at a given temperature, depending on which leg of the loop contains them.
14. The role of carbon in the observed mass transfer is not yet understood.
15. Weight change rates have not varied appreciably with the material of loop construction.
16. Metallurgical effects with time have been small.
17. Fouling material for the all-316 loop has been identified as alpha-iron.
18. Considerable progress has been made in developing an analytic model to describe the mass transfer process. Statistical evaluations of data are being made to confirm its applicability. The expert contributions of Messrs. Epstein, Brush, and Gaylor have done much to strengthen these approaches.
19. The over-all program shows three distinct types of experiments:
 - a. Partial replication tests using selected variables, keeping all others constant.
 - b. Partial or full replication tests of certain variables identified as either:
 - (1) of primary parametric significance—e.g., the velocity dependence, or
 - (2) a significant "anomaly"—e.g., the "downstream" effect.

- c. Partial or full replication of variables defined as important to development of the analytic model or statistical analysis —e.g., the time dependence.
20. The program (as of November 1, 1961) has now completed:
- a. A series of runs at high oxide level.
 - b. Part of a series of runs at low oxide level—with the remainder in progress.
 - c. A special series of 7-sample, 700-hr runs at two velocity levels on both of the 316 stainless steel-2 1/4 Cr. loops.
21. The program has now in progress:
- a. Two runs at low oxide levels.
 - b. One low-oxide run in which all hot leg specimens are at the maximum loop temperature, and all cold leg specimens are near the minimum loop temperature.
 - c. One run in which fouling material is being collected.
 - d. Two 2800-hr, 7-sample runs in the velocity and time dependence group.
22. The Review Group recommends that GE attempt resolution of the oxide and velocity dependencies by statistical analysis before proceeding with further experiments. It may also be impossible to complete this resolution without additional experiments in which one or both of these variables is held constant, and/or a third oxide level is tested.

The Group also recommends that GE define any additional primary variables to be tested in the present screening program prior to the selection of "best" material combinations. The Review Group believes that the number of variables may be so large as to make it impractical to test all of them with all materials.

The Group also recommends strongly that GE provide a means of resolving the dependence of the weight change data on the loop geometry. The present specimen arrangement apparently may not permit a full mass balance, or definition of the parametric dependencies for each of the different dynamic situations in the loop. It may be desirable to provide additional loops of new design in which velocity, while variable over a range, will be essentially constant throughout the loop, and which will be conducive to providing specimens covering the entire temperature profile.

III. DISCUSSION OF TEST RESULTS

A. Progress

A total of 13 test runs have been completed and 6 runs are currently in progress. The completed test runs include run 1 for all six loops plus runs 2-2, 2-3, 3-2, 3-3, 3-4, 3-5, and 4-2. A summary of all these runs with pertinent conditions is covered in "List of Test Conditions - August, 1961" issued by GE in Mass Transfer Program Progress Letter 26.

Several additional short-duration tests have been conducted to supply information for questions regarding (1) change in plugging temperature vs time with no oxide adjustment, and (2) collection and identification of loop fouling material.

Prior to the current review, a packet entitled, "Ad Hoc Review Group Packet - Oct. 1961," by R. W. Lockhart was distributed to members of the Review Group. This packet* contained a summary of available data and preliminary analysis to assist in the program review. Of the items included in the packet, the following were discussed at the review meeting:

1. Loop geometry, temperature, and flow characteristics.
2. List of test conditions.
3. Influence of test conditions on mass transfer rate and preliminary mass balances.
4. Five-way tables containing mass transfer rate, hardness, carbon content and X-ray fluorescence data.
5. Metallurgical examination of run 1 samples.
6. Nature and characteristics of the corrosion and mass transfer in sodium.
7. Statistical design for the mass transfer experiments.
8. Flow and plugging temperature behavior during loop operations.

Since the January, 1961 meeting of the Review Group, operating difficulties associated with Conoseal joint failures and flow measurements have been largely eliminated. All ferritic steel flange joints operating above 1000°F have been replaced with ferritic steel lined, 316 stainless steel flanges in order to minimize the external scaling problem.

*Note: Most of the information in this packet is contained in recent progress letters.

B. Significant Findings

1. Operating Behavior

(See Tab 11, Ad Hoc Review Group Packet - October, 1961)

At a nominal concentration of 46 ± 4 ppm oxygen ($440 \pm 10^\circ\text{F}$ plugging temperature) the system plugging temperature generally decreased with time; however, in the 12 ± 2 ppm oxygen runs, the plugging temperature ($305 \pm 15^\circ\text{F}$) tends to increase with time. The oxygen increase for the low oxide runs had been found to be attributed to known sources (1) atmospheric contamination such as during removal of sodium or corrosion samples and (2) more prominently slow leakage of oxide-rich, dump-tank or cold-trap sodium into the circulating loop. Recent plugging temperature and surge level data indicate that the latter source apparently can be reduced by controlling the dump tank temperature at 290°F (corresponding to an oxygen saturation of 10 ppm based upon KAPL data).

Loop fouling, as evidenced by the decrease in flow rate with time during a test run, has been appreciable in the three monometallic loops (1, 5, 6). In the bimetallic loops this effect has been less significant but observed during each run. The rate of fouling in low oxide runs is generally somewhat less than that encountered in high oxide runs.

Commercial grade sodium was used in run 1, and except for run 3-2, all subsequent runs have used reactor grade sodium. Of the impurities analyzed (Fe, Cr, Ni, Mn, Mo, Ca, K, Li, and C), calcium was the only element which showed significant concentration difference in the two grades of sodium. Calcium analyzed 500 ppm at the beginning of run 1. By the end of run 1 and later, all calcium measurements have been below the lower limits of detection (~ 10 ppm). Although samples are taken from the circulating stream (at the surge tank), both Fe and Ni appear to be present at concentrations well below the liquidus values calculated from L. M. Handbook (TID-5277) KAPL data.

2. Weight Changes

With the exception of Loops 2 and 3 (both 316—2 1/4 Cr loops) specimens in the heated section of the loops characteristically have exhibited a weight loss, the rate of loss increasing with specimen temperature. Plots of log weight loss rates versus the reciprocal of absolute temperature do not depart significantly from a straight line. Average results are summarized in Tab 8, GE Ad Hoc Review Group Packet. On the average, weight loss rate at a given

temperature is proportional to velocity to the 0.9 power velocity in the range 4-21 fps. Ninety-five per cent confidence limits on the exponent are 0.6 to 1.3. The data do not indicate a significantly different velocity exponent for the different loops or for different temperatures. An effect of position (independent of temperature) on mass transfer rates has been noted:

H3/H3R (foil)	= 5.8
H3 (inlet)/H3 (outlet)	= 1.2
C3 (inlet)/C3 (outlet)	= 2.0

Weight gain rates (see Tab 8, GE Ad Hoc Review Group Packet) in the cooled section of the loop generally decreased as temperature decreased. The data did not show a significant departure from a linear relationship between log weight gain rate and the reciprocal of absolute temperature. The slopes of these weight gain plots were considerably less than for the weight loss plots in the hot leg.

There were no statistically significant differences in weight change rates as observed from specimens removed at 700, 1400, 2100, and 2800 hr. On the other hand, hot leg weight losses during run 1 for specimens inserted at the 1400-hr point averaged 1.5 times higher for the second 1400 hr of the run than those present only during the first 1400 hr, possibly indicating a seasoning effect.

3. Metallurgy

- a. Pre-Exposure Metallurgy. The examination of metallurgical data in January, 1961 indicated three important areas of concern: (1) a 2 1/4 Cr—1 Mo surface carbon gradient; (2) a decrease of mechanical properties in the 2 1/4 Cr—1 Mo steel; (3) a duplexed structure in the 316 stainless steel corrosion specimens. These three areas were traced to insufficient control of treatments accorded specimens prior to operation. Careful control has eliminated these effects in recent tests.
- b. 2 1/4 Cr—1 Mo Low Alloy Steel. Specimens of 2 1/4 Cr—1 Mo steel underwent significant decarburization in a monometallic system at a temperature of 1200°F and in a bimetallic system (2 1/4 Cr—1 Mo, 316 stainless steel) at temperatures of 1100° and 1200°F. A change from 0.11% to 0.04% nominal carbon in a four-month period has been noted. This would imply a serious loss in mechanical strength for 2 1/4 Cr—1 Mo steel at temperatures above 1100°F.

Flanges fabricated with 2 1/4 Cr-1 Mo were replaced with material clad with 316 stainless steel on the air-side to prevent scaling at the joints.

- c. 5 Cr-1/2 Mo-1/2 Ti Low Alloy Steel. Additions of 1/2 titanium to 5 Cr-1/2 Mo steel have effectively stabilized carbon at temperatures up to 1200°F in both the mono- and bimetallic systems. Loss of carbon has not exceeded 0.02% nominal content in specimens exposed for four-month periods at 1200°F and 500°F ΔT .

Corrosion of an intergranular nature similar to the air-side oxidation has been observed at temperatures above 1000°F. This corrosion did not appear until the loops incorporating the material had run for two months. Data concerning this phenomenon is insufficient at this time for further comments.

Air-side oxidation has proved to be a problem equally as serious as that encountered with the 2 1/4 Cr-1 Mo at temperatures of 1100°F and greater.

- d. 316 Stainless Steel. An increase in nominal carbon content from 0.05% to 0.11% was noted in specimens of this material exposed at 1000-1200°F in the bimetallic 316 stainless steel 2 1/4 Cr-1 Mo loops. Carbon transport in the 316 stainless steel monometallic and the 316 stainless steel 5 Cr-1/2 Mo-1/2 Ti bimetallic loops was of a minor nature. Carbon analysis indicated a gain of no greater than 0.02% nominal carbon in the latter mentioned loops.

An austenitic to ferritic transformation was observed at the sodium-316 stainless steel interface for temperatures in the 1100-1300°F region. Although probably due primarily to cold work, the transformation may have been aided by preferential leaching of metallic elements by the sodium. Work hardening has been observed to increase the transformation by a significant factor (i.e., a 6 mil cold rolled foil specimen completely transformed to a ferritic structure in four months when exposed to 1300°F sodium with 50 ppm O_2). The transformation is of engineering significance; therefore, further study of this phenomenon is considered necessary.

Annealed specimens with a localized deformation (introduced by a shearing operation) commonly had a Widmanstätten structure. This structure produced "spikes" extending into the austenite from the free surface, to a depth of 6 to 10 mils. These spikes may be ferritic; identification is being aided through use of the X-ray microprobe.

Examination of micrographs of 316 stainless steel exposed in run 2 (10 ppm O_2) for times of about 700, 1400, or 2800 hr in Na at 1000°F revealed an anomalous and unexplained surface phenomenon (Tab 10 Ad Hoc Review Packet, October, 1961). Close examination of the actual specimens by members of the Ad Hoc Review Group revealed the possibility of intergranular penetration about 1 grain deep at the specimen surface and a surface zone with somewhat different etching characteristics at the surface. This zone appears to increase with increasing exposure from about .005 in. after 700 hr to about .007 in. after 1400 hr and about .010 in. after 2800 hr. Twin bands evident in the interior of the material are not evident in the surface zone. This behavior was not observed in specimens exposed at higher temperatures which lends credence to the hypothesis that the effect is associated with diffusion phenomena since at higher temperatures it is possible that accelerated diffusion could eliminate any concentration gradients which might cause the observed anomaly.

- e. Identification of the Loop-Fouling Product. Fouling product traps consisting of 60-mesh stainless screen and micrometallic filters were placed in the cooling region of the monometallic 316 stainless steel loop. When a decrease was observed in the loop flow, the traps were removed for analysis. Sodium oxide was separated from the traps employing ammonia extraction techniques to prevent disturbance of surface particles.

When cleaned, the traps had a dark surface residue of a dendritic nature. X-ray diffraction analysis of the dendrites indicated a composition mainly consisting of alpha iron. Chemical analyses indicated other elements common to 316 stainless steel were also present in proportions consistent with the composition of 316 stainless steel.

Following the previous examination, the traps were subjected to an ethyl alcohol and distilled water rinse. This rinse removed the bulk of particles clinging to the trap. The alcohol-water rinse had been previously employed in specimen cleaning; thereby explaining the absence of dendrites in early observations.

Initial success incorporating the ammonia-extraction and X-ray diffraction techniques have provided a first understanding of the fouling problem. A continuing program following this pattern should be pursued as part of the metallurgical examination of hot and cold zone transport products.

4. A Model for Oxidation and Mass Transport in Sodium Systems.

Concepts of the nature and characteristics of the oxidation and mass transfer phenomena in liquid metals in the past have been based largely on observations made at low temperature ($T < 1000^{\circ}\text{F}$) and small ΔT values. The model developed from these considerations has been extensively described in the open literature; for example, in the paper by Epstein, L. F., "Chemical Engineering Progress - Symposium Series," 53, 67, (1956). The theoretical picture is that the processes observed are dependent on:

- a. A chemical reaction with the oxygen in the sodium forming oxides (either wholly or partially adherent and having varying degrees of protectiveness) of some of the metallic constituents of the system.
- b. A process of solution of the loop materials in the hot zone through spallation, dissolution, or chemical reaction of the oxide films; and through direct non-ionic solution in the presence of defect film structures, and metallic deposition in the colder regions of the system. The rate for this process is determined by:
 - (1) Rates of oxide spallation or solution.
 - (2) Rate of dissolved oxide reduction.
 - (3) Rates of metallic solution and deposition phenomena.
 - (4) Diffusion of dissolved metal through the liquid sodium solvent.
 - (5) Diffusion of constituents in solid solution in the metal to the liquid-solid surface.

From these concepts it is possible to predict the form of the dependence of the oxidation and mass transfer rates on such variables as time, temperature, ΔT , flow velocity, oxygen content, etc. In the present experiments, the results to be expected at higher temperatures, ΔT 's, and flow velocities have, to a first approximation, been estimated by extrapolation of the older information, and a major task in this study has been to compare the results of the new work with these predictions from theories derived from studies made under somewhat milder conditions of temperature, ΔT , and flow velocity.

The data obtained from the first few runs in the present study in several respects are in agreement with the previously developed models extrapolated into the new regions of operation. As predicted, the mass transfer rates follow an Arrhenius type of temperature dependence (e.g.: $R = ke^{Q/RT}$); and they increase with increasing oxygen content. The rates for the two kinds of phenomena (a) and (b) have different temperature coefficients, however; and the relative importance of the possible processes (which may take place simultaneously) changes as the temperature increases. The change from weight gain to weight loss behavior is not inconsistent with the model nor is it in disagreement with the thermodynamic and thermochemical data on the oxides derived for the elements in stainless steel, in particular those of chromium. Preliminary data have also indicated that the $v^{0.8}$ dependence of the mass transport rate on flow velocity, predicted in the case that diffusion in the liquid is rate controlling, is followed in these systems.

The model does not analytically account for at least one effect observed in tests (although it is not openly at odds with the conceptual model), and one or two observations are apparently opposed to expected behavior. It does not account, analytically, for instances where different species are simultaneously absorbing and dissolving (and/or oxidizing). In the present tests there are two instances of such interactions. The first involves carbon whose source is unstabilized low alloy loop components, which is absorbing in significant amounts into stainless steel specimens, some of which are losing weight. The second involves the preferential leaching of alloying constituents, particularly chromium. Austenitic stainless steel is a metastable phase normally; and its transition to the equilibrium ferritic form is prevented only by a careful balance of the Fe-Ni-Cr ratio. If preferential solution upsets a critical balance, γ to α

transition may take place, with the subsequent formation of a ferritic layer, whose mass transport rates and carbon diffusivity (considering the layer as a separate alloy) could well be substantially different from the parent alloy. In regard to the latter phenomenon, it is interesting to note that the diffusion of chromium in stainless steel and in the ferritic layer might constitute a rate limiting step and, if so, the mass transport weight loss rate should be time dependent. No time dependency of the corrosion rate has been determined from the data available to date; however since the experimental error is rather large, the possibility of a time dependent relation cannot be excluded.

Some anomalous effects which may be inconsistent with the model have also been observed in this work. For instance, high velocity samples at the same temperature but at different points in the loops have shown markedly different corrosion rates (both in magnitude with the same direction—weight loss—in an isothermal section where they were separated by distances measured in inches, and in magnitude and direction—loss and gain—in sections separated in distances measured in feet and containing a temperature peak between them). These observations might be explained by a velocity-dependent, hydrodynamic influence on basic solution kinetics, particularly in the concept of how saturation affects the driving force as classically measured by the degree of undersaturation or supersaturation. However, a definitive interpretation of these data, and an examination of their compatibility with the previous model postulate remains to be developed.

It is the opinion of GE that the available data attest to the broad validity of the concepts included in the model outlined above.. Some questions exist as the proper values of the parameters to be inserted into the equations; and these must be clarified, it is felt, by further experiments before it will be entirely possible to make quantitative predictions from this model of the rates of oxidation and mass transfer in high temperature sodium systems. Some peculiar effects have been observed, as were mentioned above, which may possibly require extension and modification of the theoretical picture; but this is by no means certain as yet.

C. Analysis of Findings

1. Significance to Sodium-Cooled Reactors

Four generalizations may now be made regarding the significance of presently accumulated test information to the design of sodium systems.

- a. The effect of velocity on corrosion rate, which had been indicated in early test results, continues to be borne out in later and more closely controlled experiments. At the present time, the velocity dependence (in the turbulent flow regime) has been established within the range $v^{0.6}$ to $v^{1.3}$.
- b. The fouling of cold leg specimen holders by corrosion products (predominantly iron) and an attendant decline of flow with time was not significantly reduced in low oxide runs (10 ppm) compared to high oxide runs (50 ppm). Thus, the build-up of cold leg deposits in systems operating at temperatures above 1100°F continues to be a disturbing finding in these studies. It is conceivable that this fouling will impair heat transfer across the surface.
- c. At an oxide level of 50 ppm, the operation of mass transfer loops as a closed system (i.e., no O_2 being added or subtracted) was accompanied by a steady decrease in oxide concentration with time. Although not completely resolved, it appears that the cause for this decrease may be associated with the "partition" of oxides between the sodium and the loop wall. In initial loops in which the oxide concentration was dropped to 10 ppm, oxide level no longer showed a decrease but rather displayed a slow rise with time. However, this was later explained by inleakage of high oxide sodium and a recent loop at 10 ppm has required oxide additions. It therefore appears that oxide content in the 1000-1200°F temperature range may prove to be a more dynamic variable than in lower temperature reactor systems.
- d. A plot of weight loss rate versus reciprocal temperature for all high velocity samples indicates essentially equal corrosion resistance for type 316 stainless steel and the two ferritic chromium steels at 1200°F. This similarity prevails whether loops are monometallic or bimetallic.

2. Relationship to Other Studies

Some aspects of the hot leg weight loss data represent a departure from the behavior observed in previous sodium loop studies.

- a. In the pioneering studies on stainless steel at KAPL, corrosion by sodium at 1000°F was not sensitive to flow velocity; weight gains were observed and the rate limiting step was concluded to be chemical reaction of steel and sodium oxide. The observation of weight loss and strong effect of velocity observed in the present tests suggests that diffusion into the sodium is the rate limiting step at 1200°F. A similar velocity effect was observed by DeVan on Inconel at higher temperatures (1300-1500°F).

b. Two consistent features of the weight loss data require careful analysis.

- (1) Tabs lose weight at all stations where the sodium temperature is above 1000°F and rising (H2, H3, and H3R) and gain weight at all stations where the temperature is falling.
- (2) The rate of weight loss is several times higher at station H3 than at station H3R, which is at the same temperature as H3 but about 29 inches downstream.

These results could be readily explained if the concentration of container elements in the sodium remained close to the saturation value at all temperatures around the loop. There is evidence, however, that this may not be the case. If the entire heated area of the loop were assumed to lose weight at the rate of 100 mg/dm²-mo (typical of Tabs H3, where the highest loss rates were observed), the solute concentration for the total volume of sodium involved would increase only 0.05 ppm in passing through the heated leg. The actual rise is probably considerably lower than this. On the basis of KAPL solubility data, the equilibrium solubility of container elements in sodium increases on the order of 10 ppm between 700°F and 1200°F.* Thus, it is evident that the actual change in solute concentration represents a small fraction of the solubility range per circuit (based on KAPL data). If so, it would seem that, in contrast to the observed trends, the rate of weight loss should be about the same at all points of equal temperature and flow velocity in the loop.

Holman, when at American Standard, investigated this question in several stainless steel thermal convection loops circulating sodium at higher temperatures. He found that the tabs consistently lost weight above a given temperature in both the heated and cooled legs and gained weight below that temperature. Furthermore, specimens at a given temperature, whether in a heated or cooled section, exhibited the same weight change. Corrosion studies of lithium at ORNL indicate similar behavior.

Epstein and Sinizer postulate that a phase shift between maximum solute concentration could account for both of the observations noted in (1) and (2) above. However, others

*Using NRL solubility data, $\Delta C_{\max}$ is ~ 0.01 ppm

feel that this postulate is inconsistent with the natural convection situation in much of the loop—in particular the very low velocities and long residence times (~ 7 minutes) in about 75% of the loop—as compared to the very high velocity and extremely short residence time at the specimens which occupy only about .001 of the loop volume. However, an analysis for this postulate should be considered.

($\sim 50\%$ of loop volume is in the heaters and 25% in the surge tank. In the total loop, about 74% of the sodium is moving so slowly that natural convection motion probably predominates; 25% is moving slowly in connecting passages, and about 0.1% is at high velocities in the specimen holders. The interaction of the considerable number of different, interconnected geometric configurations, many of them at quite low velocities, on mass transfer processes is imponderable at present.)

IV. EVALUATION OF THE PROGRAM

A. Current Status

Since the first meeting of the Ad Hoc Review Group in January, 1961, GE has made significant progress in achieving the objectives of the program. The operational deficiencies have been virtually overcome, and questions of materials pre-treatment raised in the earlier review have been answered. The experiments performed since January have been in line with the recommendations to study the materials (a) at low oxide sodium, (b) at several velocity levels, and (c) to determine causes of fouling. Substantial progress has been made in defining an analytical model to describe the mass transfer process.

The test program is sufficiently advanced to have firmly established mass transfer as a problem area in the design of 1200°F sodium systems if the material of construction is 316 stainless steel, $2\frac{1}{4}$ Cr-1 Mo, or 5 Cr- $\frac{1}{2}$ Mo. So far as the GE-APED loops are concerned, the corrosion behavior is not grossly different for these materials.

The test program has revealed such an impressive number of variables apparently affecting the mass transfer that there is now a serious problem as to how to proceed.

This problem is related to the objectives of the program, which were basically:

- a. To rate the materials and combinations of them and to select the most suitable of them for 1200°F sodium service.
- b. To determine the mass transfer problems and the nature of the phenomena involved.
- c. To study means of coping with or reducing the mass transfer and resulting problems.

A rating method has not been reported and at this stage a selection would be virtually qualitative. It is apparent that full definition of the mass transfer problems and the nature of the corrosion phenomena will be quite an extensive program for any material or material combination. Nothing has been done yet about coping with the problems because their definition is still incomplete.

B. Unanswered Problems

1. The GE-APED analytical model for mass transfer appears to be successful in explaining surface solution rate effects, diffusion in the liquid state, and changes in metallurgical properties of metals; but it requires expansion to account for variations in corrosion rates, mechanisms of deposition, and gross effects on mass flow through loop. "Downstream effect" has been observed in which mass removal rate is less in a second specimen holder in series than in the first holder with the same temperature, velocity, and configuration. An explanation for this behavior and its engineering significance is lacking.
2. The power law variation of material removal rate with velocity requires verification, especially at very low velocities. GE believes that corrosion rate should be corrected for local point conditions. Both of these statements suggest that there may be differences in corrosion behavior which depend on the physical flow conditions which exist. Dependence of corrosion and deposition rate on configuration requires full evaluation to provide an acceptable method of making an approximately accurate mass balance analysis throughout a loop.
3. Reference was made in the January, 1961 review to the need for establishing temperature profiles for the loops and for making approximately accurate identification of weight loss and weight gain regions and determination of mass balances for total mass transfer. It is becoming increasingly apparent that a thorough analysis of an entire loop is needed to resolve throughout all of the loop the parametric relationships, the "anomalies," and the imponderables that are being observed.

A thorough evaluation of the entire loop and the variables that its many geometric configurations introduce, may possibly lead to a need for design simplification to permit improved measurement and more complete understanding of critical operational and geometric variables.

4. No consistent change in metal removal rate with time can be detected for times to 2800 hours. Verification for longer exposures is required, since information applicable to long time loop operation is an objective of the GE-APED program.
5. The development of an analytical model requires comprehensive data on weight change as a function of temperature and position around the loop. Accordingly, additional specimens are needed to provide data at temperatures below 1000°F.
6. Loop fouling appears to be nearly as severe in low oxygen (12 ppm) loops as in high oxygen (46 ppm) loops. While, as recommended in the January Ad Hoc Review, loop operations to investigate fouling have been carried out, it is apparent that this phenomenon may be the most serious deleterious consequence of mass transfer in the systems being studied. An experimental program designed to reveal the causes and nature of fouling deposits is indicated.
7. Verification of a presumed "loop seasoning" effect is required. Limited quantitative data are available to confirm the existence of this effect. A few additional tests are suggested to verify the existence of this effect.
8. Further study is required to explain certain surface effects observed in 316 stainless steel after Na exposure at 1000°F. The possibility of intergranular penetration and compositional changes after 1000°F exposure to 2800 hours is not observed after higher temperature exposure.
9. It is suggested that Na sampling techniques be modified to minimize admission of air to the system during sampling. A modification in technique can avoid some of the changes in oxygen content now observed after sodium sampling.
10. GE-APED has proposed that certain test runs be made to evaluate "loop configuration effects" in the statistical analysis of data. No quantitative method for characterizing these "loop configuration effects" has been presented. Further clarification by GE-APED is indicated.

11. In run 1 oxygen content decreased with time from the nominal content of 50 ppm. It was proposed in the January 30 Ad Hoc Review Group report that the mechanism to account for this oxygen depletion be studied. Data are not available to support the GE contention that the depletion is associated with the loop fouling or corrosion process. Further analysis and study of this phenomenon is indicated.
12. The effect of very low oxygen content on metal removal rate is largely unknown. Additional runs to delineate this effect may be advisable.

C. Approaches to Problems

The foregoing list of unanswered problems is quite extensive. Many are of primary significance; others are secondary. Not all of the primary ones have been tested experimentally, nor is it probable that there are sufficient data to perform an adequate statistical analysis to evaluate either empirical or theoretical expressions of parametric relationships of the variables. The Review Group considers it important to pursue both empirical and theoretical approaches.

GE-APED has considered the ramifications of a statistical approach. The number of runs per loop required to explore effects of operating variables depends on the number of variables to be investigated and on the specimen arrangement used. GE has embarked on an exploratory program which entails one-half of all of the total number of combinations of variables with each factor at two levels. If all tests are completed, this pattern of experiments would guarantee that independent variables are not confounded with each other. These exploratory data will serve two purposes: (1) to check a theoretical model for the factors; and (2) if an adequate model cannot be developed, then to provide part of the data with $(2k + 1)$ additional runs per loop, where k is the number of factors to be studied empirically. From these runs a polynomial mathematical function consisting of additive linear, quadratic, and cross-product (interaction) terms of all the factors studied can be estimated as an approximation to the true model. Since target values for velocity, temperature, and oxygen concentration generally are not obtained, multiple regression techniques will be used for data analysis.

To appreciate the extensiveness of a one-half replicate factorial sequence of tests, four primary variables each at two levels require $1/2 (2^4) = 8$ tests for each material. Since there are five materials, this would comprise $8 \times 5 = 40$ tests. If one additional variable required study, the total tests would be doubled.

In order to interpret the data from these exploratory runs, GE states that it is necessary to have a measure of the experimental variation among supposedly identical runs on the same loop and among supposedly identical runs on different loops. For this purpose, GE is now conducting check runs as listed in the Packet, Table 3, Tab 3. These runs are presumed also to give velocity effects in the cold leg, which is part of the exploratory data not obtained from using the present 26-specimen arrangement. The appearance of position and "seasoning" effects have occurred. GE believes that these need to be resolved in order to properly interpret the results from the basic exploratory runs. Runs 1-3, 4-3, and 6-3 have been proposed next (Tab 4) to check position effects. It seems advisable to GE to perform a similar test on loop 2 or 3 which has a constant specimen geometry around the loop except for the foil. GE suggests that this run could be substituted possibly for one of the three runs proposed to test position effects with the 26 specimen arrangement. Run 2-5 is suggested to check "seasoning," being a duplicate of 2-1. Run 3-7 is proposed essentially to complete this type of condition for all loops. Run 5-3 was to continue on the exploratory experiment at a lower maximum temperature.

To undertake a statistical experimental program involving the whole gamut of prospective variables appears formidable. It appears to the Review Group that it is now essential to:

1. Determine the problem involved in statistical analysis by attempting one using all present data, and particularly in view of the fact that it appears that velocity and oxide effects may be interacting.
2. Separate the variables into groups of primary and secondary importance defining the mass transfer problems. This will require further study of the results to data and would be for the purpose of determining which additional primary variables, if any, must be investigated experimentally with all material combinations before the "most suitable" material can be selected.
3. Devise a planned program of experiments which will provide the data required for making the selection of "most suitable" material with the minimum number of additional runs.
4. Continue the development of the theoretical model for mass transfer; since if this approach is successful it will not only provide a sound (and not empirical) basis for understanding the mass transfer process, but will also provide a sound basis for deciding which experiments are important to confirm the theory.

5. Minimize the experimental investigation of variables of secondary importance until the material selection is made, and then reconsider on the basis of all the data available, whether any of these variables need experimental investigation to determine the extent of the problem and how to cope with it.
6. Develop a means of understanding the mass transfer process throughout the entire loop—even if this means providing a new design for more effective control and measurement of the operating variables. The Review Group considers it essential to achieve ability to predict mass transfer behavior at any point in a circulating system and to make adequately accurate mass balances.
7. Devise an experimental program to be undertaken using only the "most suitable" materials selected, which will be extensive enough to define the mass transfer phenomena in detail, the operating and materials problems which will be encountered, and an approach to coping with those of the problems which limit the usefulness of the material.

Because of the extensive analytic problems described above, discussion of experimental conditions for runs beyond those currently in progress has been deferred pending clarification of the data and their significance. Analytic work is in progress at GE, and the third meeting of the Review Group with the GE Project Group should be scheduled before completion of present runs in order to discuss conditions for the next runs.

V. CONCLUSIONS

The Second Ad Hoc Review of the GE Sodium Mass Transfer Program raised a number of questions pertaining to the extensiveness of the program if it sought to answer all the apparent problems. These were referred to the Sodium Components Working Group for advice. The advice received was to the effect that:

1. The directives for the program should be reviewed.
2. The present program was a materials screening program to isolate those materials most suitable for 1200°F sodium service.
3. The mass transfer problems inherent in using these "most suitable" materials should be defined.
4. Studies should be undertaken in sufficient magnitude to understand the problems and how to cope with them.

Considering this general directive, the Review Group summarizes the problem of future experiments as follows:

1. The first series of runs for all material combinations at 1200°F, 500 ΔT, same velocity pattern, and 50 ppm oxide has not been completed. Loop 1—all 316 stainless steel—has not been run at these conditions. It may be advisable to schedule this run.
2. The second series of runs for all material combinations at 1200°F, 500 ΔT, same velocity pattern, and 10 ppm oxide will be completed by December, 1961, and will thus comprise runs 1-2, 2-1, 4-2, 5-2, and 6-2.
3. In neither series of runs has a consistent velocity pattern been adhered to throughout. Using present data there will be two velocity patterns for the first series (Item 1 above), and for the second series of runs (Item 2 above) there will be three velocity patterns.

It should now be ascertained by statistical analysis if the velocity and oxide effects are separable by analysis. If they are separable, the data for the two series can be normalized and it may be possible to judge the relative merits of the materials and the severity of the attack for each.

If the effects are not separable by statistical analysis (i.e., the effects are in fact confounded), then they should be separated by experiment and parts of both series may have to be repeated holding flow constant throughout.

Statistical analysis of all data presently available by multiple regression techniques will be done by GE and should demonstrate whether the effects can be separated or true interaction exists.

4. Several variables in addition to oxide and velocity are of primary importance in determining the severity and nature of the attack. Prominent in this group are maximum temperature, time, and "downstream" effect.

It will be necessary to determine which of these additional variables must also be investigated experimentally before judgments can be reached on the nature and severity of the attack on material combinations under study. The statistical analysis referred to above can be expected to shed light on this subject as well.

5. It will probably be desirable after completion of the above work to select one or more of the material combinations for detailed examination of the mass transfer and corrosion phenomenon. These investigations should include studies of variables of second order importance to total mass transfer but necessary to full development of the analytic model describing the process. These variables are not expected to have large effects on mass transfer rates, but may alter it in some way or distribute the corrosion and deposition in differing fashions.

To accomplish this will require assurance that there is a meeting of the minds on the division of all the variables between those of prime and secondary importance for:

- (a) Selecting the "best" materials combinations.
 - (b) Developing a thorough understanding of the mass transfer phenomena for the "best" material combinations.
6. Since under the present directives it is necessary to describe the nature and severity of the attack and to select the "best" material combinations for further studies, a method should be developed for cataloging or rating the materials with regard to mass transfer processes. While GE has presented all of the results obtained to date, it has not yet reported a method for compiling these data for materials-rating purposes. GE should make recommendations in this area.

Report of Meeting on November 30-December 1, 1961

Report #3

on

GE SODIUM MASS TRANSFER PROGRAM

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Submitted to

Sodium Components Development Program Working Group

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- V. CONCLUSIONS

I. INTRODUCTION

On November 30 and December 1, 1961, the Ad Hoc Review Group for Sodium Mass Transfer Studies met at AEC, Chicago Operations Office, to discuss recent results of the Sodium Mass Transfer Program at General Electric. The review group meeting was held at the request of Chicago Operations Office in order that the AEC might have the benefit of technical advice of the review group members. The review group consisted of R. E. Aronstein, AEC-CH (Chairman), H. W. Savage, ORNL (Technical Co-ordinator), J. H. DeVan, ORNL, J. M. McKee, UNC, J. J. Morabito, APDA, and D. I. Sinizer, AI. Mr. Morabito has joined the Review Group at the request of the AEC to represent the needs of the plant designer.

The objectives of the meeting were to discuss the results of the analysis of the data and to recommend future effort for the program to the AEC and the Sodium Components Working Group.

In addition to the Review Group, the meetings were attended by D. Gardiner, ORNL, D. W. Gaylor, GE, and R. W. Lockhart, GE.

The following report summarizes the proceedings during this meeting and presents the evaluations and recommendations of the Review Group. The order of business at the meeting was as follows:

November 30

Welcome and Introduction for the AEC - R. E. Aronstein
 Technical Introduction - H. W. Savage
 Review of Program Progress - R. W. Lockhart

December 1

Presentation of Statistical Analysis - D. W. Gaylor
 Discussion of Information Presented - All Present

II. SUMMARY

The following summarizes the third Ad Hoc review meeting:

- a. None of the materials or material combination has been shown to be unusable nor is any one clearly the best. There is insufficient information to rate the materials at this time.
- b. The program should proceed according to the five run fractional replicate statistical plan developed during the meeting to determine the effect of the primary variables: T_{max} , oxygen contamination and ΔT . Other runs to complete the full replicate program may be required to determine the effects of interaction between the primary variables. Some deviation from the base program for special runs to explore or evaluate new or suspected variables may be desirable from time to time. Any proposed deviation from the statistical plan should be carefully evaluated and justified.
- c. The statistical analysis of available corrosion data and the development of the theoretical model should continue.
- d. GE should complete the analysis of the radioactive tab runs and recommend whether this technique should be continued.

- e. Additional work beyond, or simultaneously with, the present program will be required to determine the effect of variables of second order importance necessary to develop the analytical model, to permit application to system design and evaluate new materials.
- f. The loop flow fouling material which has been observed in the cold leg should continue to be investigated thoroughly for composition and for potential thermal and flow problems in a large loop. In addition, the AEC should undertake a separate investigation of the fouling phenomena and the effect on sodium systems.
- g. Control of plugging temperatures has been improved. Loop 5 is the only one showing an increase with time, but is presently believed to be under better control.
- h. Sodium sampling procedure has been modified to reduce chance of loop contamination.
- i. All runs on all loops have exhibited some flow fouling.
- j. Fouling appears to be more severe at 50 ppm oxygen than 10 ppm.
- k. The monometallic loops generally show higher fouling rates than the bimetallic.
- l. GE has proposed the addition of more pipe samples, more pipe sample locations, and modification of certain sample holders to permit more uniform specimen loading patterns.
- m. The presence of a downstream effect in an isothermal region has been confirmed and has been shown to be very significant. Additional data is being collected.
- n. Close co-ordination with the MSA Materials Program should be maintained by the AEC to evaluate the effect of metallurgical changes on physical properties.

III. DISCUSSION OF PROGRAM - GENERAL ELECTRIC

a. Loop Operations

October 1, 1961 - November 27, 1961

1. Plugging Temperatures

Since the last Ad Hoc Review, control of plugging temperatures has been considerably improved, largely as the result of:

- (a) maintaining the dump tank at 300°F so that any leakage of sodium into the main loop causes negligible oxide change.
- (b) adjusting ΔP between the surge tank and the expansion tank such that there is essentially no pressure difference across the dump valve, thereby minimizing leakage from the dump tank to the system.

Modification of the sodium sampling procedure (recommended at the previous Ad Hoc Review) has also contributed. By using a pre-evacuated glass tube inserted inside a portable metal tube:

- (a) the time period for sampling is decreased by > 50%.
- (b) the gas flow area exposed to atmosphere during sampling is appreciably reduced.

Available data show that the new sampling technique results in an incremental increase of less than 2 ppm oxygen in the loop sodium. For example, the loop 2 plugging temperature increased from 305°F to 315°F (2ppm O₂) and the loop 4 plugging temperature increased from 280°F to 285°F.

Only run 5-1 currently shows evidence of uncontrolled plugging temperature increase with time. Two loops (runs 2-4 and 4-4) indicate a gradual decrease with time. The other loops do not show a significant nor consistent oxygen change with time.

TABLE I - LOOP OPERATION SUMMARY
10/1/61 - 11/27/61

<u>Loop</u>	<u>Material</u>	<u>Run</u>	<u>Operating Time*, hr</u>	<u>% Rated Flow**</u>	<u>Plugging Mean, °F</u>	<u>Temperature Change with time</u>
1	316SS	2	1205/2165/6990	73/35	305	~ 0
2	316-2½	4	1376/2072/6972	24/24	305	Decrease
3	316-2½	6	993/1527/8176	71/65	309	~ 0
4	316-5	3	691/700/7636	40/38	296	~ 0
		4	595/595/8231	40/33	295	Decrease
5	2½ Cr	2	1318/2664/5628	56/56	315	Increase
6	5 Cr	2	440/2805/6605	45/36	316	~ 0
		2F	734/734/7339	48/41	305	~ 0

* First number before slant line is accumulated time over review period, second number is total accrued time for specified run and third number is total time that sodium has circulated in loop.

** Numbers before and after slant line represent initial and current (or final) flow values respectively.

2. Flow Fouling

TABLE II - FLOW CHANGE DURING TEST RUN
(From daily data sheets through 11-6-61)

<u>FLOW, gpm</u>			<u>AVERAGE CHANGE</u>	
<u>Loop</u>	<u>Run</u>	<u>Ave.</u>	<u>100(gpm/wk)</u>	<u>% wk*</u>
1	1	0.40	-13.5	-33.7
	2	0.60	- 3.71	- 6.18
2	1	0.70	- 0.42	- 0.60
	2	0.60	- 3.60	- 6.00
	3	0.26	- 0.43	- 1.65
	4	0.24	- 0.41	- 1.71
3	1	0.53	+ 0.03**	+ 0.06
	2	0.52	- 1.91	- 3.67
	3	0.29	- 1.14	- 3.93
	5	0.90	- 5.50	- 6.11
	6	0.72	- 1.84	- 2.55
4	1	0.41a.	0.00	0.00
		b.	- 2.52	- 6.15
		c.	- 0.55	- 1.34
	2	0.35	- 0.42	- 1.20
	3	0.39	- 0.48	- 1.23
5	1	0.35	-10.9	-31.2
	2	0.55	- 2.70	- 4.92
6	1	0.49a.	- 1.16	- 2.37
		b.	-11.7	-23.9
		c.	- 4.78	- 9.75
	2	0.40	- 8.61	-21.5

Notes: *Based upon average gpm for run.

**Change rate values are questionable due to incomplete flow data for first 900 hrs. of test run.

a. Change during 1st 1600 to 2200 hrs.

b. Change during last 600 to 1200 hrs.

c. Overall average during run.

A review of the data in Table II shows the following:

- (a) All the loops currently exhibit definite evidence of fouling.
- (b) Except for run 6-2 (and deleting the questionable run 3-1 flow change data) fouling is more severe at 50 ppm oxygen than at 10 ppm oxygen.
- (c) The monometallic loops (1,5,6) generally show higher fouling rates than the bimetallic loops.

3. Completed Test Runs - Summary

TABLE III - FLOW, PLUGGING TEMPERATURE & OPERATING TEMPERATURE
(Mean values for completed runs)

<u>Run</u>	<u>Flow, gpm</u>	<u>Temperatures, °F</u>		
		<u>Plugging</u>	<u>C3</u>	<u>H3</u>
1-1	0.40	428	793	1297
2-1	0.70	309	690	1181
2-2	0.60	327	698	1179
2-3	0.26	317	704	1200
3-1	0.53	432	693	1198
3-2	0.52	296	707	1198
3-3	0.29	323	706	1199
3-4	0.69	328	702	1202
3-5	0.90	311	699	1202
3-6*	0.70	309	706	1202
4-1	0.41	418	703	1192
4-2	0.35	319	699	1197
4-3*	0.39	296	701	1199
5-1	0.35	435	688	1185
6-1	0.49	424	696	1179
6-2*	0.40	316	705	1197

* Runs completed since October 1, 1961. Run 3-6 was terminated at 1527 test hours due to pump failure and excessive fouling.

b. Metallurgical Analysis

October 1, 1961 - November 27, 1961

A total of 52 new corrosion samples were examined during the subject period. These included: 13 - 316SS, 31 - $2\frac{1}{4}$ Cr-1Mo, and 8 - 5 Cr- $\frac{1}{2}$ Mo - $\frac{1}{2}$ Ti specimens.

This brings the total number examined up to 373. Several specimens were re-examined for specific items. These are discussed below:

1. $2\frac{1}{4}$ Cr - 1 Mo

Nothing new.

2. 5 Cr - $\frac{1}{2}$ Mo - $\frac{1}{2}$ Ti

Since October, 81 5 Cr- $\frac{1}{2}$ Mo- $\frac{1}{2}$ Ti corrosion specimens have been re-examined. In general, the results are inconclusive. Depths of penetration were recorded; however, significant trends have not been established. The identification of the penetrant is being pursued with X-ray diffraction techniques.

3. 316SS

Intergranular attack to a depth of one grain was suggested at the October meeting. All fifteen of the worst appearing specimens were examined by repolishing and etching with Modified Murakami's

Reagent. When examined under the new etching conditions, nothing was observed that could be termed intergranular attack, although precipitation similar to the centrally located grains was observed.

4. Surface Gradient Anomaly

Twelve samples of 316SS exposed at 1000°F were studied to obtain further information on the apparent surface layer formed at this temperature. Depth of the gradient was recorded and plotted on the attached curve (Figure 2). A steady increase in gradient thickness with operating time is indicated.

Identification of the unidentified phase or phases is being pursued through X-ray techniques; however, results are not available yet.

c. Analytical Models

It was noted that the NRL solubility of iron data (which is about a factor of 1000 less than that reported in the Liquid Metals Handbook) more closely fits the change in concentration in the hot leg based on the observed corrosion rate. X-ray fluorescence and radioactive tracer data indicate that chromium is the material that has the highest mobility. No data for saturation of Cr in sodium has been found.

Dr. Epstein has started to modify his analytical model so that it can be applied to various locations in a loop. He intends to present his results at the IAEA Symposium on the Thermodynamics of Nuclear Materials, Vienna, Austria, May, 1962, and to the AEC-NASA Liquid Metal Corrosion Meeting at Brookhaven in mid December.

d. Loop Characteristics and Test Conditions

A review of the loop geometry and the two sample loading patterns was presented. Table IV (attached) presents various geometrical data that are useful in obtaining surface to volume ratios, residence time, and factors that may be useful for correlating the downstream effect. The following curves were also presented: loop pressure drop as a function of flow (it was noted that the pump head was increased from 105 to 180 psi during run 3-6 before it was terminated) (Figure 1); depth of the surface gradient anomaly on 316SS specimens 1000°F (Figure 2) as a function of time; and corrosion data from the first "H-C" run (run 4-3, performed to examine the downstream effect) plotted as a function of the product of the surface area times velocity for each section of the loop in an isothermal zone (Figure 3) and as a function of the sodium residence time (Figure 4).

The October list of test conditions (Table V) was discussed indicating Type I and II runs and also special runs to examine inter-relationship of geometrical and test conditions. The test conditions in the "next" column were reviewed. An alternate to the proposed run 1-3 was listed as normal test conditions except 250 F Δ T (950 F minimum temperature). With the possibility of the aforementioned change, GE proposed that the test conditions listed in this column be accepted as the short range test program.

TABLE IV

LOOP GEOMETRY TABULATION
(Based upon standard run & sample loading)

COMPONENT	T	L	S	V	S/V	A	v*	t*	Sv*
1. Pump	675	94.3	82.4	5.70	14.5	.0604	2.64	2.98	218
2. Pump-H1 Htr Line	675	4.34	8.5	1.32	6.44	.304	.521	.69	4.42
3. H1 Heater	850	13.0	370.	121.	3.05	9.35	.018	60.2	6.68
4. Htr-H1 Inlet	1000	3.84	7.5	11.7	.64	.304	.550	.58	4.11
5. H1 Sample Holder									
a. 3/4" D. Hole	1000	2.80	6.00	1.24	4.84	.442	.380	.61	2.28
b. 9/16" D. Hole	1000	1.80	3.10	.45	6.88	.250	.670	.21	2.08
c. Inlet Sample slot	1000	2.94	9.20	.092	100.	.0311	5.38	.045	49.6
d. Crossover	1000	1.26	10.4	.583	17.8	.357	.470	.22	4.88
e. Outlet Sample slot	1000	2.94	3.06	.030	102.	.0103	16.3	.015	49.8
f. Outlet	1000	1.80	1.75	.374	4.67	.208	.806	.19	1.49
6. H1 Outlet-Htr In.	1000	10.4	21.2	3.18	6.68	.304	.550	1.58	11.6
7. H2 Heater	1050	7.00	207.	65.5	3.31	9.35	.018	32.4	3.73
8. Htr-H2 Inlet	1100	3.84	7.50	11.7	6.42	.304	.560	.57	4.20
9. H2 Sample Holder									
a. 3/4" D. Hole	1100	2.80	6.00	1.24	4.84	.442	.387	.61	2.32
b. 9/16" D. Hole	1100	1.80	3.10	.45	6.88	.250	.683	.21	2.12
c. Inlet Sample slot	1100	2.94	9.20	.092	100	.0311	5.48	.045	50.3
d. Crossover	1100	1.26	10.4	.583	17.8	.357	.478	.21	4.96
e. Outlet Sample slot	1100	2.94	3.06	.030	102	.0103	16.5	.015	50.5
f. Outlet	1100	1.80	1.75	.374	6.68	.208	.821	.18	1.44

NOTES:

T= Temperature, °F

A= cross sectional area, in²

L= Length, in

v= velocity, ft/sec

S= wetted surface area, in²

t= residence time, sec.

V= Sodium volume, in³* All values based upon flow rate= 0.50 gpm

TABLE IV (Cont.)

COMPONENT	T	L	S	V	S/V	A	v*	t*	Sv*
10. H2 out-Htr In.	1100	10.4	21.2	3.18	6.68	.304	.560	1.55	11.8
11. H3 Heater	1150	7.00	20.7	65.5	3.31	9.35	.018	32.4	3.73
12. Htr-H3 Inlet	1200	3.84	7.50	1.17	6.40	.304	.567	.56	4.25
13. H3 Sample Holder									
a. 3/4" D. Hole	1200	2.80	6.00	1.24	4.84	.442	.392	.60	2.35
b. 9/16" D. Hole	1200	1.80	3.10	.450	6.88	.250	.694	.21	2.14
c. In. sample slot	1200	2.94	3.06	.030	102.	.0103	16.8	.015	51.4
d. Crossover	1200	1.26	10.4	.583	17.8	.357	.487	.21	5.06
e. Out. sample slot	1200	2.94	3.06	.030	102.	.0103	16.8	.015	51.5
f. Outlet	1200	1.80	1.75	.374	6.68	.208	.821	.18	1.44
14. H3Out-H3R In.	1200	24.0	54.7	7.30	6.53	.304	.567	3.52	3.08
15. H3R Sample Holder									
a. 9/16" D. Hole	1200	3.16	5.63	.790	7.13	.250	.694	.38	3.91
b. In. sample slot	1200	2.94	9.20	.092	100.	.0311	5.57	.045	51.2
c. Crossover	1200	1.26	10.4	.583	17.8	.357	.487	.21	5.08
d. Out. sample slot	1200	2.94	2.72	.032	85.0	.0105	16.5	.015	44.8
e. Outlet	1200	1.80	1.75	.374	6.68	.208	.821	.18	1.44
16. H3R Out-Cooler In	1200	53.9	106.	16.4	7.09	.304	.567	7.91	60.1
17. C1 Cooler	1150	20.0	66.0	17.3	3.81	.864	.199	8.43	13.1
18. Cooler-C1 Inlet	1100	2.0	6.6	1.73	3.81	.864	.198	.85	1.30
19. C1 Sample Holder									
a. 3/4" D. Hole	1100	2.65	7.24	1.17	6.17	.442	.386	.57	2.79
b. 9/16" D. Hole	1100	1.75	3.10	.438	7.08	.250	.683	.21	2.12
c. 5/8" D. Hole	1100	2.94	5.80	.906	6.40	.308	.553	.44	3.21
d. Crossover	1100	1.26	10.4	.583	17.8	.357	.477	.22	4.96
e. Out. sample slot	1100	2.94	9.20	.072	100.	.0311	5.47	.045	50.3
f. Outlet	1100	1.75	3.10	.438	7.08	.250	.683	.21	2.12
20. C1 Out-Cooler In.	1100	4.60	13.7	3.97	3.45	.864	.198	1.94	2.72
21. C2 Cooler	1050	20.0	66.0	17.3	3.81	.864	.197	8.48	13.0
22. Cooler-C2 In.	1000	2.0	6.6	1.73	3.81	.864	.195	.84	1.29

TABLE IV (Cont.)

COMPONENT	T	L	S	V	S/V	A	v*	t*	Sv*
23. C2 Sample Holder									
a. 3/4" D. Hole	1000	2.65	7.24	1.17	6.17	.442	.380	.58	2.75
b. 9/16" D. Hole	1000	1.75	3.10	.438	7.08	.250	.670	.22	2.07
c. 5/8" D. Hole	1000	2.94	5.80	.906	6.40	.308	.545	.44	3.16
d. Crossover	1000	1.26	10.4	.583	17.8	.357	.470	.22	4.88
e. Out-sample slot	1000	2.94	9.20	.092	100.	.0311	5.40	.045	49.6
f. Outlet	1000	1.75	3.10	.438	7.03	.250	.670	.22	2.08
24. C2 Out-Cooler In	1000	4.60	13.7	3.99	3.45	.864	.195	1.97	2.68
25. C3 Cooler	850	78.6	267.	68.2	3.81	.864	.191	34.3	51.0
26. Cooler C3 In.	700	2.00	6.60	1.73	3.81	.864	.186	.90	1.23
27. C3 Sample Holder									
a. 3/4" D. Hole	700	2.65	7.24	1.17	6.17	.442	.362	.61	2.52
b. 9/16" D. Hole	700	1.75	3.10	.438	7.08	.250	.640	.23	1.98
c. Inlet Sample slot	700	2.94	9.20	.092	100.	.0311	5.15	.047	47.4
d. Crossover	700	1.26	10.4	.583	17.8	.357	.447	.24	4.55
e. Out Sample slot	700	2.94	9.20	.092	100.	.0311	5.15	.047	47.4
f. Outlet	700	1.75	3.10	.438	7.08	.250	.640	.23	1.98
28. C3 Outlet-FM	700	2.60	8.56	2.25	3.81	.864	.186	1.16	1.59
29. FM Pipe	700	17.0	19.4	1.77	11.0	.104	1.54	.92	30.0
30. Surge Tank **	700	4.0	151.	199.	0.76	49.8	.003	103.	.45
31. Surge Tk-FM Pump	675	52.0	101.	15.9	6.37	.304	.522	8.30	52.8
32. Bypass Line									
a. Inlet	675	14.	27.3	4.26	6.40	.304	.521	2.23	14.2
b. FM pipe	675	18.	20.5	1.87	11.0	.104	1.54	.98	31.6
c. Aux. Cooler	675	17.	55.8	14.7	3.80	.864	.184	7.70	10.2
d. 5/8" D. Line	675	41.	61.8	7.42	8.31	.181	.885	3.86	54.6
e. PI Cooler	675	17.	55.8	14.7	3.80	.864	.184	7.70	10.2
f. Return Line	675	16.	31.2	4.86	6.28	.304	.521	2.56	16.3

**Based upon 4" sodium level in ST.

TABLE V

List of Test Conditions - October 1961

Completed					Test Conditions	Present	Next
					<u>Loop #1 (316 SS)</u>		
<u>1-P</u>	<u>1-1</u>	<u>1-1F</u>			Run number	<u>1-2</u>	<u>1-3 ***</u>
1300	1300	1300			T _{max} , °F	1200	1200
500	500	500			ΔT, °F	500	500
50	50	>50			Oxygen, ppm	10	10
26	26	2 + 2F			Sample Arrangement	26	26
18&6	12&4	18			Velocity, ft/sec	18&6	18&6
No	Yes	No			Radioactive Tab	Yes	No
4	7,14,28	4,8			Samples removed,100's hr	7,14,28	7,14,28
June '60	Oct '60	May '61			Starting date	Aug '61	Jan '62
11/11/60	5/16/61	7/6/61			Completion date	-	-
-	-	"F"			Special Condition*	-	"B"
					<u>Loop #2 (316 SS-2½ Cr)</u>		
<u>2-1</u>	<u>2-2</u>	<u>2-3</u>			Run number	<u>2-4</u>	<u>2-5</u>
1200	1200	1200			T _{max} , °F	1200	1200
500	500	500			ΔT, °F	500	500
10	10	10			Oxygen, ppm	10	10
26	7	7			Sample arrangement**	7	26
21&7	20	7			Velocity,ft/sec	7	21&7
No	Yes	Yes			Radioactive Tab	Yes	No
7,14,28	7	7			Samples removed, 100's hr	28	7,14,28
Oct '60	May '61	July '61			Starting date	Sept '61	Feb '62
2/9/61	7/14/61	8/26/61			Completion date	-	-
-	-	-			Special Condition	-	"C"
					<u>Loop #3 (316 SS-2½ Cr)</u>		
<u>3-1</u>	<u>3-2</u>	<u>3-3</u>	<u>3-4</u>	<u>3-5</u>	Run number	<u>3-6</u>	<u>3-7</u>
1200	1200	1200	1200	1200	T _{max} , °F	1200	1200
500	500	500	500	500	ΔT, °F	500	500
50	10	10	10	10	Oxygen, ppm	10	10
26	26	7	7	7	Sample Arrangement	7	26
17&6	17&6	7	20	27	Velocity, ft/sec	20	21&7
No	No	No	No	No	Radioactive Tab	No	No
7,14,28	7	7	7	7	Samples removed,100 hr	28	7,14,28
Aug '60	Mar '61	Apr '61	June '61	Aug '61	Starting Date	Sept '61	Feb '62
12/9/60	4/10/61	5/28/61	7/20/61	9/3/61	Completion date	-	-
-	"A"	-	-	-	Special Condition	-	"D"

*Special conditions or remarks:

"A" - 4S8 and 4S4 steel alloy samples in the cold leg sample holders.

"B" - All hot leg sample holders at 1200°F; All cold leg sample holders at 700°F (if possible without modifying sodium system).

"C" - Re-run of 2-1 after ageing.

"D" - Same as 3-1 except 10 ppm O₂; Same as 2-1.

"F" - Run to obtain fouling material.

** 7 sample loading arrangement has a single, identical velocity sample in each holder.

TABLE V (Cont.)
List of Test Conditions - October 1961 (cont'd)

Completed			Test Conditions	Present	Next
			<u>Loop #4 (316 SS-5Cr)</u>		
<u>4-1</u>	<u>4-2</u>	<u>4-3</u>	Run number	<u>4-4</u>	<u>4-5***</u>
1200	1200	1200	T _{max} , °F	1200	
500	500	500	ΔT, °F	500	
50	10	10	Oxygen, ppm	10	
26	26	26	Sample Arrangement	26	
12&4	11&4	12&4	Velocity, ft/sec	12&4	
No	Yes	No	Radioactive Tab	No	
7,14,28	7,14,28	7	Samples removed, 100's hr	7,14,28	
Aug '60	May '61	Oct '61	Starting date	Nov '61	Apr '62
1/11/61	9/18/61	10/29/61	Completion date	-	
-	-	"B"	Special Condition	"B"	
			<u>Loop #5 (2½ Cr)</u>		
<u>5-1</u>			Run number	<u>5-2</u>	<u>5-3</u>
1200			T _{max} , °F	1200	1100
500			ΔT, °F	500	500
50			Oxygen, ppm	10	10
26			Sample Arrangement	26	26
12&4			Velocity, ft/sec	15&5	15&5
No			Radioactive Tab	No	No
7,14,28			Samples removed, 100's hr	7,14,28	7,14,28
Sept '60			Starting Date	July '61	Dec '61
3/6/61			Completion date	-	-
-			Special Condition	-	-
			<u>Loop #6 (5 Cr)</u>		
<u>6-1</u>	<u>6-2</u>		Run number	<u>6-2F</u>	<u>6-3***</u>
1200	1200		T _{max} , °F	1200	1200
500	500		ΔT, °F	500	500
50	10		Oxygen, ppm	10	10
26	26		Sample Arrangement	3 + 3F	26
15&5	13&4		Velocity, ft/sec	13&4	13&4
No	No		Radioactive Tab	No	No
7,14,28	7,14,28		Samples removed, 100's hr	-	7,14,28
Sept '60	May '61		Starting date	Oct '61	Nov '61
1/11/61	10/19/61		Completion date	-	-
-	-		Special Condition	"F"	"B"

*** Detailed test conditions will be presented after additional data is available and prior to the completion of the present run.

As a result of existing experience, it was proposed to make the following loop modifications as soon as test operation permitted.

1. Provide pipe sample location between the surge tank and pump. (Replace an elbow with a tee and an appropriate welded or flanged access port.)
2. Modify H3 insert so that loading pattern could be identical to H1 or H2. (Plugs could be used to maintain present pattern if desired.)
3. Modify H3R insert pattern so that either foil samples (present design) or regular samples could be used. (Normally one would be plugged.)
4. In bimetallic loops, pipe samples downstream from H3R and also downstream from C3 should contain both hot and cold leg sample materials in their respective order.
5. Provide access to first and third heaters so that "pipe" size corrosion samples can be inserted.

e. Statistical Analysis

Data from loops 4, 5, and 6 for runs 1 and 2 have been subjected to multiple regression statistical analysis. These data make up about half of the 200 hot leg specimen and about half of the 200 cold leg specimen data now available for analysis. The maximum loop temperature was approximately 1200°F and the minimum temperature approximately 700°F for all of these data. Run 1 was approximately 45 ppm oxygen and run 2 approximately 15 ppm.

It must be understood that any results given at this time are preliminary and will be changed slightly as refinements to the analytical techniques are added. These are discussed later.

The general approach has been to subject the data to a least squares multiple regression analysis. This makes it possible to analyze the data where the target values for oxygen, velocity, time and temperature were not and could not be strictly adhered to. This technique simply fits the best curve or surface through the data points, relating corrosion rate to time, velocity, oxygen, temperature and position effects. A factorial type experimental plan of combinations of two levels of these factors is needed to keep from confounding these factors. (See Table VIII).

In this program, as in many experimental programs, a small proportion of the data vary markedly from the remainder of the data. Individual data points may be far out-of-line due to numerous causes such as: non-homogeneous material, specimen preparation and handling, loop operation, laboratory measurements, data handling and computational errors. It is highly desirable to discard these bad data that bias the results. A statistical test based on the reduction in the scatter, standard deviation, due to discarding suspicious values was used. In doing this, a few good but extreme values are discarded. This penalty is undoubtedly worth absorbing in order to obtain unbiased results. About 5% of the data points were discarded on the basis of varying extremely from other comparable data points.

Employing the Philco Transact 2000 Computer has made it possible to try a large number of different models at low cost. The model which appears to be the best of the types tried in the hot leg is:

$$|R_i| = b_0 t_i^{b_1} v_i^{b_2} P_i^{b_3} e^{b_4 \left(\frac{1}{T_i - 460} \right)} a_i^{b_5} e^{b_6 D_i} \quad (1)$$

where the b's are parameters to be estimated from the data, $|R|$ is the absolute value of the rate of weight loss for the i th specimen in $\text{mg}/\text{dm}^2\text{-mo}$, t_i is the length of time in hours the i th specimen is exposed in the loop, v_i is the velocity in ft/sec , P_i is the plugging temperature in $^{\circ}\text{F}$, T_i is the temperature in $^{\circ}\text{F}$, a_i is the age of the run or sodium while the i th specimen is exposed and D_i is a downstream factor within each isothermal region of the loop.

Age, a , in equation (1) can be best illustrated by the following diagram of specimen removal, where the x's indicate the loading and sample removing time.

In slot #1, a specimen is removed at 700 hours and replaced by another specimen which is removed after 2100 hours at the end of the 2800 hr run. The exposure time, t , for these two specimens is 700 and 2100 hours, respectively. As a first approximation to age, the age of the run (sodium) at the mid-point of the time the specimen was exposed is used. The ages for the two specimens are $(0 + 700)/2 = 350$ and $(700 + 2800)/2 = 1750$ hours, respectively. Age applies to the run or sodium, not to the specimen. In slot #2, $t = 1400$ for both specimens and $a = (0 + 1400)/2 = 700$ for the first and $a = (1400 + 2800)/2 = 2100$ hours for the second specimen. In slot #3, $t = 2800$ and $a = 1400$ hours for that specimen.

D_i is a downstream correlating factor

$$D_i = \sum_j A_j v_j$$

where A_j is the surface area at a velocity of v_j upstream from a specimen at its temperature, in effect, D is a measure of concentration of corrosion products in the sodium.

In equation (1), t and v entering the model to some power was predictable by previous theory. Plugging temperature rather than oxygen concentration in ppm was chosen since no universal method for relating concentration to plugging temperature is in use. Plugging temperature is the basic measurement taken and can be

converted to ppm. Current conversions indicate that $R = Kp^b$ or $R = K \exp(bp)$. Since we essentially have only two plugging temperatures, approximately 320 and 420°F, the two points will fit either p^b or $\exp(bp)$ equally well and the choice is immaterial until a third oxygen level is introduced in the program. Temperature has the form of an Arrhenius term from theory. The mechanism of age is not well understood. Results are not conclusive, but aging here appears to result in low corrosion rates at the beginning of a run (sodium) increases rapidly and possibly level-off after several hundred hours. More and longer runs are needed to investigate this behavior. When, $b < 1$, introducing the term a^b in the model approximates the aforementioned behavior. Two results led to the introduction of a downstream factor in the model. First, the ratio of inlet to outlet corrosion rates in H3 under the same conditions was about two. Secondly, the ratio of H3 to H3R corrosion rates under approximately the same conditions was about four. Introduction of the D term in the model does a good job of determining the position effects for the specimens.

As written, equation (1) is a first approximation from which corrosion rates can be predicted within the range of experimental data used. Each factor enters equation (1) independently. That is, we obtain the average effect of velocity averaged over oxygen concentration. Interaction terms will be introduced later to determine if and how the effect of velocity is dependent on oxygen. Similarly, for other pairs of factors.

In order to apply least squares, the logarithm of equation (1) is taken giving

$$\ln |R_1| = b_0 + b_1 \ln t_1 + b_2 \ln v_1 + b_3 \ln p_1 + b_4 \left(\frac{1}{T_1 - 460} \right) + b_5 \ln a_1 + b_6 D_1 \quad (3)$$

This gives a model with simple linear additive terms. Each term is the product of an unknown coefficient, to be estimated from the data, and a measured value. The errors, $\ln |\text{observed results}| - \ln |\text{predicted results}|$ have a fairly constant standard deviation. The coefficient of variation (standard deviation expressed as a per cent) is about 25% in the hot leg and 50% in the cold leg.

In order to use logarithms, only the negative data in the hot leg and only the positive data in the cold leg were used. An analysis technique should be tried which fits the hot and cold leg simultaneously without discarding any data because of sign.

A summary of the computer results for the hot leg analysis of loops #4 (316SS-5Cr), #5(2½ Cr) and #6(5Cr) are presented in Table VI.

The results are heavily weighted by Run 1 (~ 45 ppm Oxygen) since Run 2 data (~ 12 ppm) are incomplete for loops 5 and 6. The value of b_0 is the extrapolated corrosion rate at $t = 1$ hour, $v = 1$ ft/sec, $p = 1^\circ\text{F}$, $a = 1$ hour, and $D = 0$. The model fitted to the data is good only in the range of the experimental points. The value of b_0 helps establish the absolute value of the corrosion rate in the range of data. The value of b_0 itself, which is an

TABLE VI

$$|R| = b_0 t^{b_1} v^{b_2} p^{b_3} e^{b_4} \left(\frac{1000}{T - 460} \right)^{b_5} a^{b_6} \frac{D}{100}$$

Least Squares Estimates of Parameters with 95% Confidence Limits

Loop	$\ln b_0$	time b_1	vel b_2	plug b_3	temp. b_4	age b_5	downstream b_6
#6	3.86±8.55	-.12±.34	1.06±.24	.79±1.64	-20.70±4.65	1.01±.33	-1.10±.20
#6 pipe	3.44±8.76	-.18±.34	1.22±.13	.61±1.68	-18.89±3.98	1.07±.33	-1.09±.20
#5	-4.53±10.10	-.04±.57	.68±.28	2.79±1.59	-16.97±5.39	.30±.47	-.74±.22
#5 pipe	-5.34±9.70	-.01±.59	.46±.19	2.37±1.60	-18.70±5.31	.28±.48	-.78±.23
#4	8.73±5.76	-.33±.36	.77±.23	1.80±.83	-31.67±4.73	.76±.31	-.70±.19
#4 pipe	8.65±6.21	-.30±.32	.82±.12	1.72±.75	-31.57±3.83	.78±.29	-.71±.17

extrapolation to the extreme points listed above, is meaningless. The values for b_1 are not significantly different from zero. The exponent for velocity ranges from 0.5 to 1.2 with the theoretical value of 0.8 near the center of this range. Since plugging temperature effects are quite variable a third oxygen level is needed. Temperature effect is greatest in loop 4. Loop 4 generally has lower corrosion rates at 1000° and 1100°F but since its slope is steeper, loop 4 corrosion rates are as high or higher than loops 5 and 6 at 1200°F. Selection of good and bad materials is premature at this time. Using the values for the b 's in the model, one can compute corrosion rates for the three loops. Curves can be plotted and the performance estimated. It is unlikely that a material will consistently show higher or lower corrosion rates, but will depend upon the conditions (values of v , p , t , etc). Age is not well understood. It probably should be an exponential type term which approaches an asymptote. As age now appears in the model, it does an adequate job of describing the existing data $350 < a < 2100$ hours. At the present time, run age and sodium age are identical. The downstream exponent, b_6 , is fairly consistent and may be a universal term. D does a good job of fitting the data, though D may be related to another physical parameter which is more meaningful.

The relative importance of the variables in the model for these loops and the range of variables are listed below:

Hot Leg Results

<u>Variable</u>	<u>Range</u>	<u>Factor Change in Corrosion Rate*</u>
Downstream	0-200 (Av)	4-7
Temperature	1000-1200°F	4-15
Velocity	1-18 ft/sec	4-32
Plugging Temp.	320-420°F	1-2
Age	350-2100 hours	1-6
Time	700-2800 hours	1-1.6

*Factor changes are for the indicated range of the variable. The limits show the factor change for the smallest and largest coefficient from Table VI for each variable.

For example: in loop #4, the downstream effect, from Table VI, is $\exp - 0.007 D$. For $D = 0$ the effect is 1.0 for $D = 200$ (say from H3 to H3R) the effect is $\exp - 0.007 (200) = 0.25$, i.e., a factor of four. In loop #6 the downstream effect is estimated to be $\exp - 0.011 D$ giving a factor of 9 between $D = 0$ and $D = 200$.

Cold Leg Results (weight gain rates) - tentative

<u>Variable</u>	<u>Effect on Corrosion Rate</u>
Velocity	approximately linear
Temperature	may be slightly positive, slightly negative, or zero
Downstream	slightly larger effect than in hot leg
Plugging Temperature	higher the oxygen level, the lower the weight gains. May indicate loop age or weight gains at places other than on specimens.
Age and Time	Unknown

The following experimental plan, which includes a one-half fractional replicate of a 2^3 experiment, is recommended to estimate the main effects of the factors ΔT , T_{max} , and oxygen which are varied on a run to run basis.

TABLE VII

Experimental plan for variables studied on a run to run basis				
Oxygen, ppm	45 ppm		12 ppm	
ΔT , °F	500	250	500	250
$T_{max} = 1200^\circ\text{F}$	Run I	*	Run II	Run IV
$T_{max} = 1100^\circ\text{F}$	*	Run V	Run III	*

*Conditions to check interactions.

Runs I and II are nearly completed. Run II vs. Run III will give an estimate of the effects of T_{max} . Run II vs. Run IV will give an estimate of ΔT . Runs III and IV could be interchanged. Runs I through V will give a measure of the main effects of ΔT , T_{max} , and oxygen. The three blanks in the table would have to be completed to check for interactions among these three variables. The values of time, velocity, age, and downstream are automatically varied and estimable within each run.

The temperatures within the hot leg must be fixed for these runs. Additional runs are necessary to study age, temperature profile and downstream effects to help interpret and extrapolate the results obtained from the runs presented in Table VII.

f. Future Test Program

1. Material Selection

Material selection from this project's data (corrosion standpoint) should be established on the basis of:

(a) Acceptable metallurgical properties

Caution for: (1) Carbon content

(2) Sensitization

(3) Intergranular Penetration

(4) Ferritic layer on SS

(b) Acceptable corrosion rate

Variables such as those described in the mathematical model should be considered. Materials with low sensitivity to the variables that are predominant in the system being designed should be chosen.

2. Test Schedule

(a) Six Loops

(1) Short Range (12/1/61 - early summer 1962)

Same as "next" run on October List of Test Conditions and as summarized in the following table.

(2) Long Range (early summer 1962 - summer 1964) Table VIII.

(Note: The author took the liberty of converting the proposed test conditions, originally presented variable by variable, to the fractional replicate plan that was presented by Don Gardiner and Dave Gaylor. See Table VII - Experimental Plan for Variables - in the preceding section on Statistical Analyses.)

GE recommends that the long range test program consist of a base program developed from the aforementioned fractional replicate plan, interspersed where necessary with special test conditions. The special conditions, in most cases, are expected to fit one of the five primary variable conditions but differ in:

- (a) Sample loading pattern (including fouling material "filters").
- (b) Temperature profile around the loop (such as the present H-C runs where all hot leg sample holders are operated at one temperature and all the cold leg sample holders at another).
- (c) Changing the loop flow rate to extend information on the velocity effect.
- (d) Length of time for the sample exposure.

The test conditions and schedule shown in Table VIII presents G. E. 's proposed sequence of test runs to obtain data from at least one loop for each of the five base program conditions as soon as possible and consistent with the preceding paragraph. Completed and present test conditions are indicated in the Table, as well as proposed future test conditions.

TABLE VIII - Test Conditions

Loop	FY 1961	FY 1962	Future Test Run Sequence
1	I	F ¹ II IV	V III HT
2	II	S ² II ³	III IV HT
3	I S ⁴	S ² II	IV III V
4	I II	HC ⁵ HC ⁶ IV	III V
5	I	II III	IV V
6	I	II F ⁷ HC ⁶	V III IV

Symbols

- I to V - primary variable test conditions - details on next table
- F - run to obtain flow fouling material. (Most samples are removed; filters are placed in cold leg).
- S - special test runs - details outlined in notes.
- HC - Hot-Cold run. T_{max} on all hot leg sample holders; T_{min} on all cold leg sample holders.
- HT - Hot trap. Lower oxygen level than present program.

Notes

- (1) T_{max} @ 1300 F; I conditions
- (2) 7 samples (one each holder); two flows; two times: II conditions;
- (3) 5600 hours (2xtime); samples of 1400 and 2800 hours.
- (4) 700 hrs; 4S8 alloy in cold leg; II conditions
- (5) 700 hrs; HC; II conditions

(6) 2800 hrs; HC; II conditions

(7) II conditions

where

Run	Oxygen	ΔT	T_{max}
I	high	high	high
II	low	high	high
III	low	high	low
IV	low	low	high
V	high	low	low

The values of time, velocity, age, downstream and perhaps unrecognized secondary variables will be automatically varied and estimable within each "primary variable" run.

3. Additional Loops

- (a) One additional loop similar to the 316SS loop (#1) to expedite obtaining data on mono-metallic stainless systems such as T_{max} at 1300°F, hot trapped (extra low oxygen) sodium and special runs to investigate material anomalies such as the ferritic layer formation and the effect (or lack) of heat treatment on samples.
- (b) Two loops (one mono-metallic; one bi-metallic) that have different geometrical characteristics to evaluate data from existing six loops and to provide "scale up" factors. This is important for the utilization of the program data for other systems.

4. Auxiliary Data

Provide or arrange for obtaining experimental data on:

- (a) "Air-side" corrosion after a sodium leak.
- (b) Saturation of steel composition materials, such as Cr, Fe, Ni in sodium in the presence of steel.
- (c) Extent to which steel can be carburized or decarburized in sodium systems.
- (d) Amount of "flow fouling" in a system with larger cold leg passages.
- (e) Amount of thermal (heat transfer coefficient) fouling caused by deposition products.

IV. EVALUATION OF THE PROGRAM

a. Current Status

Nothing has developed since the October Ad Hoc Review to change the evaluation of the program contained in Report #2 on the GE Sodium

Mass Transfer Program, November 22, 1961. GE is taking steps to clear up areas where questions were raised. Specifically:

Item IV-B-4 - GE will make recommendations regarding runs exceeding 2800 hours. Achieving long runs may be difficult because of fouling in the cooling leg. Some modification of the cooling leg such as removing of some samples may be required.

Item IV-B-5 - GE recommended adding samples in the heaters and other areas to provide mass transfer information. See "Loop Characteristics and Test Conditions" Items 1-5. The Group concurs with this recommendation.

Item IV-B-9 - GE has modified their sampling techniques to reduce chances of loop contamination. The modified procedure adds less than 2 ppm oxygen to the loop.

Item IV-C-1, 2, 3, and 5 - Since the October meeting, GE has made significant and encouraging progress in statistical analysis and correlation of the experimental data. The statistical analysis has shown downstream effect to be a significant factor along with temperature and velocity. It is possible that downstream effect is related to several things such as geometric factors and velocity.

Statistical programs to provide the data required to select the most suitable materials for service being considered were discussed. GE has prepared a revised program of experiments which will determine the independent effects and interactions of oxygen concentration, velocity, maximum temperature, and delta T. The program is designed to provide information on the independent effects of these variables before completion of the entire statistical program. Completion of the program will require about two years. (See Table VII).

Co-ordination of the statistical analysis and the theoretical approach should be maintained. Each should contribute to the other.

The Ad Hoc Review Group recommends that testing should not deviate from the statistical program without due cause. Any deviation should be thoroughly examined and justified. This will result in determination of primary mass transfer effects and evaluation of materials at the earliest possible date. Special investigations should be done independently or after completion of the present statistical program.

The runs with the heating and cooling legs of the loop at constant temperatures (H-C runs) should not be substituted in the statistical plan of experiments for standard runs. The standard loop temperature profile should be maintained unless the relationship of the modified profile to the regular can be established. The H-C run data should be included in the statistical analysis.

Loop configuration should not be changed significantly until the statistical program has been completed.

GE proposed that there should be additional loops operated to determine the effect of geometry and/or scaling up on mass transfer.

As geometry factors are among the most important of the additional variables to be studied, GE should make detailed recommendations of methods for conducting these studies.

GE should complete the analysis of the data from the runs containing radioactive tabs. The results should be reviewed by the Ad Hoc Group.

Much significant information has been developed by this program to date. An interim report should be prepared by GE in the near future to report the results of the program to date. The report should include an engineering evaluation and interpretation of the data to make it of use to the designer.

b. Unanswered Problems

1. It is necessary to begin development of a long range plan to provide information in areas which will not be covered in the current program. Questions of geometry effects and new materials will require new loops. More detailed studies of other variables will require additional runs and possibly loop modification. GE should continue their long range planning to develop detailed recommendations. Preliminary plans are given under f., "Future Test Program."
2. The program was instituted to provide answers on mass transfer with principal application to the secondary system. The principal concern was for mass transfer and resulting metallurgical effects. The fouling effects which have developed require investigation to determine the significance of these fouling products to the primary system and heat exchangers. It is recommended that the loop flow fouling material which has been observed in the cold leg should continue to be investigated thoroughly for composition and for potential thermal and flow problems in a large loop. In addition, the AEC should undertake a separate investigation of the fouling phenomena and the effect on sodium systems.
3. The role of carbon transport in mass transfer is not known and should be investigated.
4. Close co-ordination between the mass transfer program and the MSA Materials Program is necessary. The significance of the metallurgical effects observed in the mass transfer work to the physical properties of the materials should be determined by the MSA program. The effect of decarburization of $2\frac{1}{4}\text{Cr}-1\text{ Mo}$ on its physical properties should be established as soon as possible.

V. CONCLUSIONS

- a. None of the materials or material combination has been shown to be unusable nor is any one clearly the best. There is insufficient information to rate the materials at this time.
- b. The program should proceed according to the five run fractional replicate statistical plan developed during the meeting to determine the effect of the primary variables: T_{max} , oxygen contamination and ΔT . Other runs to complete the full replicate program may be required to determine the effects of interaction between the primary variables. Some deviation from the base program for special runs to explore or evaluate new or suspected variables may be desirable from time to time. Any proposed deviation from the statistical plan should be carefully evaluated and justified.

- c. The statistical analysis of available corrosion data and the development of the theoretical model should continue.
- d. GE should complete the analysis of the radioactive tab runs.
- e. Additional work beyond the present program will be required to determine the effect of variables of second order importance necessary to develop the analytical model, to permit application to system design and evaluate new materials.
- f. The loop flow fouling material which has been observed in the cold leg should continue to be investigated thoroughly for composition and for potential thermal and flow problems in a large loop. In addition the AEC should undertake a separate investigation of the fouling phenomena and the effect on sodium systems.
- g. Additional test loops with different geometry will be needed so that present apparent corrosion anomalies (possibly geometry dependent) can be resolved and so that project data can be more reliably used for application to reactor plant size systems.

LOOP D-FLOW VS WP (NORTH & DADS CELL EMFLOW) (7 SAMPLE LOADS)

FIGURE 1

Report of Meeting on September 26-28, 1962

SODIUM COMPONENT DEVELOPMENT PROGRAM WORKING GROUP
AD HOC COMMITTEE REPORT ON REVIEW OF
EXPERIMENTAL INVESTIGATION OF MASS TRANSFER IN 1200°F SODIUM SYSTEMS

December 12, 1962

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1. Introduction

On September 26-28, 1962, the Ad Hoc Review Group for Sodium Mass Transfer Studies met at General Electric Company, APED, San Jose, California, to discuss recent results of the Sodium Mass Transfer Program at GE (USAEC Contract AT(04-3)-189, P.A. No. 15). The review group meeting was held at the request of the Chicago Operations Office in order that the AEC might have the benefit of technical advice from the review group members. The review group consisted of T. P. Heckman, AEC-Chicago (Chairman); H. W. Savage, ORNL (Technical Coordinator); J. H. DeVan, ORNL; D. A. Gardiner, ORNL; J. M. McKee, UNC; D. I. Sinizer, AI; and J. P. Holliday, USAEC-San Francisco. John J. Morabito, APDA, could not attend because of schedule conflicts. In addition, the meetings were attended by the following GE representatives: R. W. Lockhart (Project Engineer), G. Billuris, E. G. Brush, L. F. Epstein, R. S. Young, E. L. Dunn, D. W. Gaylor, W. L. Pearl, J. D. Mottley, J. E. Boyden, and C. N. Spalaris.

This was the fourth meeting of the group. Reports of the previous meetings have been issued.^{1,2,3} Broadly stated, the objectives of the meeting were to review results obtained to date within this program, to evaluate these results with respect to original objectives and overall requirements of the Sodium Component Development Program, and to consider the merits of further work within the present scope as well as directions of effort suggested for future work. Within this general framework was the specific consideration of implications of this work on design and operation of sodium-to-sodium heat exchangers and sodium-to-water steam generators. In addition, a very brief review was made of recent developments in the U. S. Atomic Energy Commission's Nuclear Superheat Materials Program.⁴ However, the cursory nature of the review did not permit an evaluation of the applicability of this work to design, materials selection, and operation of sodium-to-water heat exchange systems. Thus, the present report deals in detail only with the mass transfer and corrosion phenomena occurring in sodium-metal systems, and implications of current water and steam corrosion research will be reviewed at a later date in a letter to T. A. Nemzek.

The present review was confined to data obtained during the period October, 1961 to September, 1962, as reported by GE in the Ad Hoc Review Data Folder, September, 1962. Earlier data obtained prior to October 1, 1961, can be found in the GE report entitled Ad Hoc Review Group Packet, dated October, 1961, and have been covered in earlier Ad Hoc Committee reports.

It is important to stress that all conclusions reached during this review session are based only on the data which are currently available from the experimental plan and which represent only parts of the data to be available ultimately. Since the data from the program are being derived in accordance with the statistical arrangement of the program, these data should not be given final significance until the statistical analysis of the entire program has been completed. Hence, the group's conclusions must be regarded as preliminary.

The order of business at the meeting was as follows:

September 26

Introductory and Welcoming Remarks - T. P. Heckman
 Background and Purpose - H. W. Savage
 Summary of Program Status - R. W. Lockhart
 Review of Previous Ad Hoc Group Recommendations - H. W. Savage
 Metallurgical Results - R. S. Young
 Tour of Mass Transfer Test Facilities - All Present
 Sodium Oxide Investigations in the USSR - J. H. DeVan
 Results of Microprobe Analysis of Surface Effects - E. G. Brush
 Status of Analytical Model Development - L. F. Epstein

September 27

Analysis of Data by Linear Regression Techniques - E. L. Dunn
 Tour of Nuclear Superheat Test Facilities - All Present
 Selection of Materials for Nuclear Superheat Service - C. N. Spalaris
 Further Discussions of Statistical Plan Results - E. L. Dunn and
 D. W. Gaylor
 Revisions to Present Program and Future Experiments - R. W. Lockhart
 Discussions of Information Presented - All Present

September 28

Drafting of Group Report - All Present

2. Conclusions and Recommendations

2.1 General Conclusions

a. Carbon migration rates have been relatively high in 2 1/4 Cr-1 Mo loops at temperatures above 900°F. In bimetallic 316 SS-2 1/4 Cr loops, the transfer of carbon from the 2 1/4 Cr-1 Mo material to the 316 stainless steel makes the use of this combination questionable. In the case of monometallic 2 1/4 Cr-1 Mo loops, decarburization has generally been observed at all loop positions above 900°F. However, it is felt that decarburization will not seriously affect the potential use of 2 1/4 Cr-1 Mo steel, particularly since loss of strength with temperature (decarburized or not) and air-side corrosion limits its use to about 1000°F.

b. In the bimetallic 316 SS-5 Cr loop, no significant carbon transfer has been observed in 2800 hours. This combination is promising if austenitic steel is required in the hot leg. However, a low allowable design stress and fabrication requirements complicate the use of air-hardening 5 Cr in heat exchanger applications.

c. In bimetallic loops of 316 SS-2 1/4 Cr and 316 SS-5 Cr, mass transfer of substitutional constituents appears to proceed at about the same rate in loops with either material combination under the conditions tested so far.

d. In monometallic ferritic systems no great differences in corrosion behavior have yet been shown, except that carbon is transferred from 2 1/4 Cr-1 Mo steel and not from 5 Cr steel. Both appear to be equally satisfactory for sodium containment to their maximum allowable service temperatures. Fabrication difficulties and low allowable design stress above 1000°F may limit the choice of 5 Cr steel for some applications.

e. Monometallic 316 stainless steel systems appear satisfactory from the standpoint of both metallic and carbon transfer under the conditions investigated.

2.2 Specific Conclusions

a. Carbon transfer is potentially the most serious corrosion effect observed to date because of the possible changes in mechanical properties of austenitic steels after excessive carburization.

b. Metal transfer effects on mechanical properties appear relatively minor for normal cross sections, although fuel cladding may be an exception. Side effects of metal transfer on flow characteristics (e.g. buildup of deposits in the cold leg of a system) may be of greater significance. Furthermore, the observed transfer rates appear sufficient to produce a sizeable activity buildup in cold leg regions of a primary sodium coolant circuit.

c. The "empirical" corrosion model has been developed with good success. Its use is probably restricted to interpolation within the specific system and conditions studied.

d. The "analytical" model for some processes involved in mass transfer has been studied. Application of these processes to formulation of a system model still remains to be done.

e. The "empirical" model appears to have great value in analyzing mass transfer effects within the range of test conditions and material combinations of the particular GE loops, but the analytical model is potentially more useful since it can permit extrapolations to other systems and system conditions.

f. As anticipated, the effect of oxygen appears to be a significant factor in the mass transfer of metal elements. Improved correlation will be possible after the fractional replicate test program is complete.

2.3 Recommendations

a. The indications of carbon transfer in certain loop combinations require that further data be obtained on the significance and control of this element. A basic understanding of the carbon transfer process in sodium is tantamount to predicting the degree and patterns of carbon movement under variable operating conditions. Studies are also needed to examine the relationship between carburization (or decarburization) of stainless steels and carbon-oxygen levels in sodium.

b. Surface compositional studies of corrosion specimens should be expanded to include analyses of carbon, molybdenum, manganese, and other elements which are present in sufficient quantities to make them important to the over-all mass transfer process.

c. Sensitivity of the statistical analysis being applied to corrosion data can be markedly improved by increasing the number of distinct time points at which corrosion measurements are made. The technique of reinserting specimens in the loop after weight measurements are taken would allow more time points to be accumulated without modifying the specimen holders. Accordingly, this technique should be evaluated in long-term loop tests now under way.

d. Observations of mass transfer phenomena have progressed to the point where they can be effectively applied to basic studies of corrosion mechanisms. It is particularly important to examine the relationship between local solution (or deposition) rates and solute concentration changes occurring throughout the sodium circuit.

e. Scheduling of subsequent loop tests should be aimed at completing the one-half replicate factorial program as soon as possible.

3. Program Status

3.1 Test Program, Project Variables - Loop Operation

The 5-run fractional replicate test program established at the December 1961 meeting is nearly one-half complete. Details of the number of hours and operating conditions for each loop are tabulated under Section 1 of the 1962 Data Folder.⁵ Each loop has doubled its operating time since the last meeting; one loop has completed 2800-hr test runs of Types I, II, III, and IV which are listed in Table I. Included in Section 1^(Ref 5)

Table I Test Conditions

Run Type	T _{max} - °F	ΔT - °F	Plugging Meter Temp. °F (Oxygen level - ppm)
I	1200	500	450 (~ 50 ppm)
II	1200	500	305 (~ 10 ppm)
III	1100	500	305
IV	1200	250	305
V	1100	250	450

is a list of special tests operated to obtain the following information: 1) investigation of the fouling problem; 2) replicate runs with loops 2 and 3; 3) the "downstream" or HC tests run on loops 4 and 6 where as much of the hot leg as possible is at 1200°F and as much of the cold leg as possible is at 700°F; and 4) long-time runs on loops 2 and 3.

When all five runs of the experimental plan are completed for any loop, the effects of the "primary" variables T , ΔT , and O_2 level can be assessed, although they may not be free of two factor interactions. Some information on the "secondary" variables such as time, velocity, downstream effect, age, and as yet unrecognized variables, may also become apparent.

If the proposed loop schedule is followed, the five runs for loops 1, 3, 4, and 5 will be completed by the end of calendar 1963. As indicated, one run period has been scheduled for reruns of questionable data for one of the interaction run types (in the event that the replicate test pattern indicates that interaction of variables may be occurring), and one for more complete sectioning of loop components for metallurgical data. After completing this phase of the task, additional test runs are recommended to study geometry, lower oxygen, and temperature effects and to repeat some existing test condition with carbon additions to the sodium. All carbon to date in the sodium and in the metal samples has occurred without intentional addition of carbon to the loops. Since carbon can be transferred in significant quantities in sodium systems, more data on the significance and control of the element should be obtained.

It was recommended that loop 2 be operated only under Type II conditions (Table I) and used for long-time and variable geometry runs. Because of many operating difficulties encountered with loop 6, there is concern that the loop may not complete all five runs. At present loop 6 is operating on the Type II "hot-cold" run to obtain a maximum number of samples at 1200°F and to obtain more downstream data.

3.2 Metallurgy Presentation Summary

The objectives of metallurgical examinations to date are outlined in Section 4 of the 1962 Data Folder.⁵ Briefly, the observations of major interest are: (1) an alpha transformation structure on the surface and carburization in a 2-4 mil surface band on 316 stainless steel;

(2) decarburization and surface composition changes (alloying-diffusion zone) on 2 1/4 Cr-1 Mo; and (3) minor surface carburization and intergranular penetration to a maximum of 1 grain diameter in 5 Cr-1/2 Mo. The individual observations of metallurgical behavior were supplemented with measurements of weight changes, total carbon analysis, x-ray fluorescent analyses taken on specimen surfaces, and electron probe microanalysis. These data show that significant mass transfer of carbon from loop cold legs of 2 1/4 Cr-1 Mo to hot legs of 316 stainless steel occurs with maximum gains and losses in total carbon resulting in the H3 and C1 positions, respectively. 2 1/4 Cr-1 Mo used in a monometallic system (loop 5) showed a carbon loss in the hot leg as well as in the cold leg (C-1 position). Indications are, however, that the carbon loss from 2 1/4 Cr-1 Mo is greater when 316 stainless steel is present in the hot leg.

In general, x-ray fluorescent results for surface chromium and nickel in loops 1, 2, 3, and 4 show losses of both components and a corresponding increase in iron concentrations. Microprobe analyses of a selected sample from loop 3 showed a concentration profile which was in good agreement with x-ray fluorescent results. The two monometallic ferritic loops (5 and 6) were more difficult to analyze using the x-ray fluorescent data.

The most exhaustive metallurgical examinations have been made on material from loop 3, run 7 (316 SS-2 1/2 Cr-1 Mo). Among the important observations were:

- a. Ferritic layer maximum development is greatest in H3 and H3-H3R positions where the layer reaches approximately 0.3 mils in thickness.
- b. Zones of heavy precipitation, presumably carbides, exist below the ferritic layers on the 316 stainless steel.
- c. Carbon is removed from 2 1/4 Cr-1 Mo and is transported to 316 stainless steel.

For subsequent use of these materials in reactor systems, the most severe effect appears to be carbon loss from 2 1/4 Cr-1 Mo and transport to a 316 stainless steel sink. The second most severe effect is the phase change at the 316 stainless steel surface and carbide buildup under this surface layer. Tensile strength would not necessarily be affected, but creep and stress-rupture could very likely be changed. One other metallurgical observation of some importance concerned the intergranular

penetration of 5 Cr-1 Mo steels to a depth of about one grain diameter at temperatures of 1000°F and greater. However, this attack was limited to exterior grains and disappeared at longer operating time, presumably because of the attrition of these outermost grains.

3.3 Statistical Analysis

At the Chicago meeting of the Ad Hoc Review Group in December, 1961, it was agreed to proceed with a fractional replicate experimental plan to study the effects of ΔT , $T_{\max}$, and oxygen between runs. This plan is presented in Section 6 of the 1962 Data Folder.⁵ In general, two or three of the five runs have been completed for each loop. The effects of velocity, position, time, and temperature changes within the loop are studied within single loop runs. The general approach for analyzing weight change data has been a multiple regression least squares technique. This technique requires a mathematical function relating weight changes to the variables mentioned above. The model used and results obtained during the past year are given in Section 6.^(Ref 5) Analysis of the data showed inconsistent effects of time and prior loop operation ("age"). Although fairly good prediction of corrosion rates during the first 2800 hours can be made using this model, extrapolation to longer time periods cannot be justified. It was noted that weight change of a sample is a result of both a steady state corrosion rate and the weight change during an initial period before the steady state condition was reached. Hence a new model of the following form was tried:

$$\Delta W_a = \Delta W_o + R t + C t^2,$$

where ΔW_a is an adjusted weight change corrected for the effects of different velocity, temperature, and position; and ΔW_o is a threshold weight change obtained by extrapolating the steady state corrosion rate to time zero; R is a corrosion rate constant for the steady state; and C establishes the second order dependence of corrosion rate on time. There has been some evidence in the data that a steady state corrosion rate has not been reached in 700 hours. Longer time runs are being conducted to study this ΔW model which appears to be closer to the physical situation and which should provide better extrapolation to long-time service. The data

have been analyzed with several types of position (downstream) factors as described in Section 6.^(Ref 5) The hot-cold (H-C) runs have been used to provide more loop length within an isothermal region to provide more "downstreamness." To date, the position (downstream) effect has been evaluated primarily at 1200°F and 700°F. It is proposed to study "downstream" at other temperatures in order to provide valid corrections for "downstreamness" throughout the loop at other temperatures.

4. Evaluation of Program

4.1 Metallurgical Results

Metallurgical studies are providing important insight into the migration patterns of the major alloying elements comprising the loops and the contributions of each element to the over-all mass transfer rate. In particular, a clearer pattern of carbon movement in various loop combinations has emerged, and initial measurements have been made of the relative losses of nickel, chromium, and iron occurring at stainless steel surfaces.

As originally had been feared, carbon migration rates have been disturbingly high in loops constructed partly or wholly of 2 1/4 Cr-1 Mo steel. However, carbon movement in higher alloy systems has been of little or no consequence in tests as long as 2800 hours. The 2 1/4 Cr-1 Mo specimens in both monometallic and 316 stainless steel bimetallic loops show significant carbon losses at all locations where temperature exceeds 900°F. The rate of carbon depletion in both systems is very rapid, and carbon levels appear to attain effectively steady state values within the initial 700-hr loop sampling period. This steady state value decreases with increasing specimen temperature and at 1200°F drops essentially to zero. Steady state values are approximately the same at corresponding cold leg points of monometallic and bimetallic 2 1/4 Cr-1 Mo systems.

Based on what is now known about the effect of decarburization on low chromium steels, it is not believed that decarburization will seriously impair the mechanical properties of the material. However, the prolific carbon supply afforded by decarburization of this steel at temperatures above 1000°F may jeopardize its use in circuits constructed in part of 316 stainless steel. This eventuality is discussed in Section 4.2.

Mass transport rates of metal components, which heretofore have been derived solely from weight loss determinations, are presently being correlated with concentration changes induced at hot and cold leg surface. Available data indicate that chromium, nickel, and manganese are dissolving preferentially with respect to iron. This finding supports the metallurgical observation that corrosion of 316 stainless steel surfaces results in the formation of a thin ferrite surface layer.

The transport rates, as determined both by weight loss and concentration gradient determinations, continue to be encouragingly low up to 1200°F. Furthermore, none of the materials combinations at this time shows a clear superiority or inferiority from the standpoint of metal transfer rates. It is interesting in this regard that ferritic materials have actually shown somewhat lower metal losses than 316 stainless steel, presumably because of the selective depletion of nickel from the latter material. Although bulk transport rates are low, the transfer of radioactive chromium and other elements in primary sodium circuits will require careful evaluation for personnel accessibility.

Hot leg attack in 316 stainless steel loops has been manifested by the formation of a thin ferrite layer on specimens above 1000°F in temperature. The growth rate of this layer over a 2800-hr period appears to show a square root dependence on time. It is not known, however, whether growth will be continuous with time or whether a steady state thickness will eventually be achieved. In either case, the growth rate is slow enough that the layer should have little effect on mechanical properties assuming normal reactor geometry cross-sections. An evaluation of its effect on relatively thin fuel cladding must await the results of longer-term loop exposures.

Although the metallurgical studies completed to date have been extremely helpful, several factors remain to be evaluated. Surface compositional studies must be extended to include analyses of molybdenum, manganese, and other important components of the steels under study. Because of the important implications of carbon transfer in experiments to date, there is need for a statistical basis by which to evaluate the precision and accuracy of past and future carbon determinations. In addition, it is necessary that selected specimens be analyzed for carbon as a

function of distance from the specimen surface to indicate carbon diffusion rates and the kinetics of the carbon transfer process. Finally, the growth rate of ferrite on 316 stainless steel surfaces must be better defined as a function of temperature.

4.2 Carbon in Sodium

In the GE Mass Transfer Program, tests now completed have shown a significant pickup of surface carbon in Type 316 stainless steel. The pickup is particularly evident in bimetallic 2 1/4 Cr-316 stainless steel loops 2 and 3, where the 2 1/4 Cr cold leg acts as a carbon source, as predicted from capsule tests at Atomics International,⁶ B&W, and others. In the statistical analysis of data from the GE Mass Transfer Program, a carbon correction has been applied to weight change data obtained from loop tests. The statistical analysis, therefore, refers only to the transfer effects associated with substitutional atoms such as Cr, Ni, Fe, Mo, and Mn. However, movement of carbon is of extreme importance since its effects may be strongly felt in mechanical property changes in austenitic (300 series) stainless steels.⁷

Study of the effects of carburization on mechanical properties of Type 316 stainless steel has been largely neglected in the past. The program now under way at MSA is, of course, designed to produce this information. However, some inferences can also be drawn by analogy from the better known behavior of carburized Type 304 stainless steel. Work at other sites^{7,8} has shown that room temperature tensile properties of Type 304 are not greatly affected by carburization from the as-received level (0.08 carbon max) up to about 0.7%. In general, carburization effects a slight increase in tensile strength, a proportionally greater increase in yield strength, and a decrease in the elongation and reduction of area. Unfortunately, the high temperature creep behavior of carburized 304 stainless steels is not as well documented. It is known that austenitic stainless steels can exhibit a transition from ductile to brittle failure as temperature increases at a constant strain rate or, conversely, as strain rate decreases at a constant temperature. The effect of carburization in 304 stainless steel is to decrease the temperature or increase the strain rate at which the failure mode changes from ductile to

brittle. This phenomenon can be significant in the behavior of fuel element cladding which may be subject to slow strain rate loading as internal pressure builds up from fuel dimensional changes and fission gas release during irradiation.

The effects of carburization on fatigue life or strain cycling of Type 316 stainless steel are largely unknown. In Type 304, the first effect of surface carburization is to improve fatigue life by providing a surface layer under residual compressive stress. However, if the carbon level becomes too high the surface can crack and reduce the fatigue strength.

It is probable that a surface carbon content up to 0.5% will not affect the service behavior of austenitic stainless steel. It is also probable that surface carbon above 1% will prove unacceptable in stressed sodium system components, although the allowable surface carbon can be defined only after further study. A conservative empirical criterion in current use at AI is based on an allowable surface carbon content of 0.5% in carburized stainless steel with a metallographically detectable case depth of about 1/10 of the section thickness. The lower limit of metallographically detectable carbon in the case is about 0.3% carbon. In order to meet the requirements of this criterion, a more complete understanding of the kinetics of carbon transfer in sodium systems is required. More significantly, the effect of system variables such as temperature, flow, surface area and exposure time on carburizing potential of the sodium can be of greater importance than the actual carbon content of the flowing sodium. It is entirely possible that in a dynamic system carburization of stainless steel components can be significantly less than in a static system, even though both systems contain the same amount of carbon as indicated by standard techniques of chemical analysis. A more complete definition of the analytical model of carbon transfer can contribute to an understanding and prediction of expected behavior.

The carburization of austenitic steels is a significant mass transfer effect in the sodium systems under study. For example, a specimen of Type 316 steel from Run 3-7 showed a carburized case depth of about 0.004 in. on each side, with a mean carbon content in a 0.060-in. thick sample of 0.081%. (The as-received carbon concentration was 0.045%.)

If a linear carbon concentration gradient in the surface layer is assumed as a first approximation, a simple calculation leads to a surface carbon content of about 0.67%. This carbon content may eventually prove to be tolerable, but it exceeds the conservative allowable limit of the tentative AI criterion.

Since carbon transfer is of such significance, greater emphasis must be placed on carbon studies in the GE Mass Transfer Program. It should be noted that past and current work indicate that an interaction of oxygen and carbon in the sodium may be involved in the carbon transfer process.⁹ This interrelationship is complex, however, as demonstrated by unpublished studies at Atomics International which show that oxygen in amounts up to 50 ppm has no measurable effect on the carbon transfer rate.

4.3 Empirical Model and Statistical Analysis

4.3.1 Experimental Design

The effects of the primary variables, $T_{\max}$, ΔT , and oxygen are being estimated through the use of a one-half replicate of a 2^3 factorial design augmented by one additional run. The five runs on each loop comprising this design are being performed as quickly as the loops are available. It is possible to schedule the runs on Loops 1 through 5 so that the five runs will all have begun operation before the end of calendar 1963. In fact, the entire fractional replicate plan can be completed by that time on Loops 4 and 5. The best that can be done toward completing the plan on Loop 6 will require the use of this loop until July, 1964.

The dependence of weight loss, ΔW , on time, t , is being examined with the data currently available. At present the hypothesis that ΔW is a linear function of t in the range $t = 700$ to $t = 2800$ is being subjected to test. Whatever empirical model is considered tenable, it is intended that the function chosen be used to extrapolate ΔW to much higher values of t . The sensitivity of the test of the adequacy of the function is related to the number of distinct values of t which are available to fit the model--the greater the number of distinct values of t , the greater the sensitivity of the test.

It seems doubtful that extrapolations of the present data to five- or twenty-year periods will be significant because of the small number of time points on the curve and the scatter in the weight change measurements. Longer runs represent the best although most expensive solution, and a few such runs have been initiated. Increasing the number of distinct values of t within the present test period is the next best solution and would allow for better extrapolation when a reasonable model is found. This could be accomplished by 1) increasing the number of specimens in each holder, 2) modifying the present removal pattern, or 3) reinserting specimens in the loop after weight measurements at selected time intervals are completed. The first approach would involve a redesign of the specimen holders and the second approach would sacrifice the amount of data gathered at any one time period. Thus the third approach appears the most plausible. It is therefore recommended that the possibility of specimen reinsertion be evaluated using specimens in H-2 and C-2 holders in Loops 2 and 3, starting at the next scheduled specimen removal period (5600 and 2800 hours, respectively). Comparison with specimens left in the holders for the entire runs will then show whether washing and weighing the tab affected its weight change during the following period. If no effect is found, this procedure of washing and replacing specimens should be expanded rapidly to include all specimens at each scheduled shutdown. This approach is especially important for long runs.

4.3.2 Empirical Representation of Corrosion Data

Preliminary analyses on each run in each loop are being performed using a model which expresses the logarithm of the modulus of corrosion rate as a linear function of the experimental variables. The model is admittedly empirical and suggested by the data. In the absence of an analytical model, a trial-and-error testing of empirical models is probably the best approach that can be made at this time.

It is not as important to judge the adequacy of the models by the significance of the coefficients in the models as it is to judge their adequacies by their abilities to predict corrosion rate for the several combinations of the experimental factors. The purpose of the study is to predict. Therefore, the adequacy of a model should be judged by its ability to predict.

The empirical method has brought to light unusual effects which have been given the names, "age" and "downstreamness." The fact that these effects had not been anticipated before the startup of the loops is evidence that the empirical approach has been worthwhile.

The models examined so far do not include the effects of $T_{\max}$, ΔT , or oxygen, since data dependent on variation in these factors are not yet available and will not be available until the one-half replicate design is completed. When complete data are available, the estimates of the coefficients in the models will change and probably new and different empirical models will be suggested.

While the metallurgical implications of carbon transfer are becoming clear, the role of this element and its probable interactions with oxygen and metals have not been factored into the statistical analysis. In fact, these effects have been excluded by the technique of "correcting for carbon." In the absence of any theoretical postulates, it is important to test available data for the statistical significance of any expression for the carbon data and to evaluate the interactions of carbon and oxygen.

The available data are now being studied to find empirical approaches for separating initial and steady state corrosion rates. It is important that these regimes be separated. Hopefully, the analysis should also provide insight as to the significance of the "age" term in the present empirical equation. In attempting to obtain an empirical fit to the ΔW versus time curves, it would seem preferable to try exponents of t between $1/2$ and 1 because of the physical significance of such an equation. Completion of this analysis may reveal that the time period for the initial corrosion regime prior to the steady state regime is longer than present run lengths provide. It will almost certainly be a different period for each loop type.

In similar studies conducted a few years ago on stainless steel specimens in sodium at 1575°F ,¹⁰ a considerable decrease in the mass transfer rate of substitutional elements was found during the first 1500 hours; and rates were still decreasing slightly at 5000 hours. This decrease was accompanied by the same sort of metallurgical changes at the specimen surface as observed in the present study. Since these changes are brought about by solid state diffusion, the rate of which decreases with decreasing

temperature, it is unlikely that the mass transfer rate will reach a steady value during the present 2800-hr test period at 1200°F.

4.4 Analytical Model

In the first Ad Hoc Review Group Report,¹ an analytical model of mass transfer was discussed. In that report the comment was made that "...the existence of such an analytical model might guide future experiments and methods of data presentation and analysis." Since that time, the study of the type of analytical model suggested in the first report has proceeded relatively slowly; but a clearer definition of the nature of that analytical model has evolved.

When discussing "models" of the mass transfer process the Ad Hoc Review Group has been describing two separate concepts. The first of these is the so-called "empirical model" now under intensive study in the GE Mass Transfer Program. The second approach is an attempt to formulate a true "analytical model" of the mass transfer process in terms of known solubility and diffusion behavior. In the "analytical" model, a mathematical expression for mass balance in the loop system must be formulated by taking account of the solubility rate and diffusion relationships, surface areas, flow velocities, temperature, and time. The objective of such a formulation is to set up mathematical expressions whose generalized solution can lead to extrapolation of mass transfer data from the GE test loops to other loops or reactor systems of different geometry and varying temperature and flow conditions. An "analytical" model is the more valuable, since data can then be extrapolated from test loops to other systems and operating conditions. On the other hand, the "empirical" model is strictly applicable only for the loop and conditions used for its formulation.

In the GE Mass Transfer Program, the "empirical" model has been studied with good success. Furthermore, the increased knowledge of metallurgical processes at work and the recent improvement in quantitative measurement of alloy constituents in specimens should feed important new information to the statistical evaluation, and should result in acceleration of theoretical postulations and improvements in the analytical model. The latter model has thus far been studied in terms of only one of the

contributing processes, namely, the mechanisms of metal solution in sodium.^{5,11} The deposition processes have been neglected, and an over-all system mass balance formulation has not yet been attempted. It is particularly important that mass balance equations be formulated to relate local solution and deposition rates to attendant concentration changes in the circulating sodium. It is probable that the "downstream" effect could be interpreted by such a relationship. A careful analysis of these phenomena would greatly benefit the statisticians who are attempting to formulate an empirical correlation of so-called downstream effects observed in the GE loops.

Metallurgical and chemical examinations of stainless steel specimens indicate that relatively steep concentration gradients of nickel and chromium are being induced at surfaces exposed to sodium. This finding strongly suggests that the solution rates of these two alloying additions are controlled by the rate of diffusion of each element in the stainless steel matrix. At first glance, this behavior would seem to conflict with the additional observation that mass transfer rates are dependent on velocity, since, if solid state diffusion rates are controlling, neither velocity nor flow rate should significantly affect the mass transfer rate. (This is the case, for example, in INOR-8--fused fluoride circuits where corrosion is controlled by chromium diffusion rates in INOR-8). However, when one considers the role of the third (and probably most important) component of the container wall, namely, iron, this apparent contradiction becomes less puzzling.

Because of the greater susceptibility of nickel and chromium to sodium attack, leading to their selective removal from the steel, the concentration of iron at exposed surfaces will correspondingly increase following the onset of corrosive attack. As concentration increases, however, so must the contribution of iron to the over-all mass transfer rate. Considering the relatively high surface concentration of iron, it is reasonable to suppose that the rate limiting step in the solution of this element will be diffusion in the liquid rather than diffusion in the solid metal. Hence, by this reasoning it seems plausible that two components, namely, nickel and chromium, can exhibit concentration profiles which necessarily imply a solid-state diffusion limitation on corrosion,

while the over-all corrosion rate, after iron has begun to play a significant role, shows a velocity dependence.

If this line of reasoning is valid, certain corollary arguments must hold true, two of which can be examined experimentally.

a. A rigorous solution of diffusion equations under the rather complicated boundary conditions postulated (i.e., diffusion across a receding interface) will be extremely difficult. Nevertheless, one expects that these equations, when solved or approximated, will show a time dependence of corrosion rate somewhat as follows: chromium and nickel mass transfer rates, initially high, will decrease with time following an approximately parabolic rate curve. The mass transfer rate of iron will increase from an initially low value to an approximately steady-state value. In both cases, the formation of a significant ferrite layer will eventually impose secondary rate effects; and in the case of nickel and chromium, this effect should appear as a "down-turn" in corrosion rate.

b. Mass transfer deposits (or products diffusing into the cold-leg wall) must, under the argument presented, change in composition with time. Initially rich in nickel and chromium, deposits will increase in iron until a steady state composition, low in chromium and nickel and high in iron, is reached. This also infers that deposits might initially form as austenite, later as ferrite.

5. Experimental Program

The program of current and proposed loop tests is summarized in Section 1 of the 1962 Data Folder.⁵ Run time is about 60%, downtime about 35%, and load factor is about 90%; this means that about 10% of sodium time is not at operating conditions.

With the exception of Loop 2 (all type II operation) and Loop 6 (Type II, H-C temperature distribution), each of the other loops is being tested according to the one-half replicate factorial plan plus one test from a complementary one-half replicate agreed to about a year ago. The one-half replicate program requires a minimum of about 2 1/2 years for completion per loop, i.e., about six months for each of five different runs. It is important to point out that any loop sequence cannot be terminated short of the full sequence without completely compromising the model and statistical analysis. It is strongly recommended

that the scheduling of the loops be such as to complete the test plan as soon as possible.

Table II indicates the earliest date at which the present loop program could complete its sequence of five tests.

Table II Projected Loop Test Schedule

Loop	Material	Runs to be Completed as of 10/1/62	In Operation as of 10/1/62	Estimated Earliest Completion Date
1	316 SS	3	1	Dec. 63
2	316-2 1/4 Cr	not being used in the fract. repli. series		
3	316-2 1/4 Cr	3	1	Dec. 63
4	316-5 Cr	2	1	June 63
5	2 1/4 Cr	2	1	June 63
6	5 Cr	3	-	June 64

This means that of 25 tests required (as of 10/1/62), 10 have been completed, 4 are in operation, and 11 are scheduled for the future. If Loop 6 is deleted from the program, the earliest completion of loop operations would be December, 1963, although analysis and interpretation of results would, of course, require longer.

Because Loops 2 and 3 are identical and only one is needed for the factorial replicate plan, one of them, namely, Loop 2, is being used for long term runs. As pointed out earlier, it is probable that corrosion rate for any material combination has at least two successive phases for which the time dependences are different. The onset of the second or so-called steady-state phase may not occur within the 2800 hour time limit of present loop operations. If so, longer runs of the other four material combinations will be required. As an initial approach, each final run of the present fractional replicate could be operated for an extended time period.

While Loop 6 may be rejected as possessing little merit over Loop 5 (all 2 1/4 Cr), its inclusion in the series is recommended since it will assist in evaluation of Loop 4 (316-5 Cr), which appears to be a more favorable combination than Loops 2 and 3 (316 SS-2 1/2 Cr) for use above 1000°F.

An ultimate object of this program is to convert the terms of the empirical model to terms expressing accurately the mechanisms, phenomena and processes involved. In the absence of postulations of theoretical expressions to be tested with the data, the program will end with the best empirical equations expressing the phenomena. Delineation of these equations--one for each loop type--cannot be explicit (or accurate) before completion of the one-half replicate series of experiments for each loop type. If an important interaction of variables exists at that time, additional tests in the other one half of the full replicate will be needed for resolution.

Each theoretical postulate which is tested and found valid will also assist in sorting out the interactions of variables at the end of the one-half replicate series. The development, testing, and proving of these postulates are essential before extrapolations of data can be made beyond the boundaries of the present data. Confinement to interpolations is presently one of the serious limitations of the empirical approach. Geometry is an especially sensitive variable in extending results from the present loops to other systems. Accordingly, some tests of the validity of this kind of extrapolation will be required within the program.

The current difficulties in developing an analytical model by which to describe observed corrosion kinetics spring in part from uncertainties as to what corrosion processes are taking place inside these loops. Rather small-scale efforts to gain new insight into these uncertainties via exploratory tests could yield important dividends. Only a nominal cost would be involved in the operation of small thermal convection loops of the type used by Holman^{12,13} in the investigation of sodium corrosion at higher temperatures. Tests of this sort could supplement and support the theoretical analysis of the pumped loop data. In particular, such loops might help resolve the reasons for the degree of fundamental differences in the corrosion patterns of stainless steels at 1200°F as compared to those found at 1500°F.

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Report of Meeting on February 11-15, 1964

**SODIUM COMPONENT DEVELOPMENT PROGRAM WORKING GROUP
AD HOC COMMITTEE REPORT
ON REVIEW OF
EXPERIMENTAL INVESTIGATION OF MASS TRANSFER
IN 1200°F SODIUM SYSTEMS**

April 1, 1964

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1. Introduction

On February 11-15, 1964, the Ad Hoc Review Group for Sodium Mass Transfer met at General Electric Company-APED, San Jose, California, to review the Sodium Mass Transfer Project at GE under USAEC Contract AT (04-3)-189, Project Agreement No. 15. This was the fifth review of the Sodium Mass Transfer Project; reports of the Committee's previous reviews have been issued.^{1,2,3,4} The last previous formal review session held by the Committee was in September, 1962. In addition, members of the Committee held informal discussions with GE in April, 1963. An interim report on the project's status at that time was issued.⁵

In summary, the objectives of the fifth review session were as follows:

a. Establish the adequacy of present mass transfer and corrosion data as bases for empirical and theoretical models for predicting behavior patterns of selected container materials in 1200°F sodium service.

b. Review previous conclusions regarding behavior of the materials under test.

c. Evaluate the effects of oxygen and carbon impurities in sodium on mass transfer and corrosion rates.

d. Determine what additional runs or reruns are needed, if any, to complete the present program.

e. Evaluate the designs of two new loop systems intended for studies of the effects of system geometry on mass transfer and corrosion rates.

The Ad Hoc Review Committee consisted of J. P. Holliday, USAEC-SAN (Chairman); H. W. Savage, ORNL (Technical Coordinator); J. H. DeVan, ORNL; D. A. Gardiner, ORNL; J. H. McKee, UNC; D. I. Sinizer, AI; and J. A. Bailey, USAEC-SAN. Principal GE participants were R. W. Lockhart (Project Engineer), E. G. Brush, E. L. Dunn, L. F. Epstein, J. L. Jaech, L. E. Pohl, and R. S. Young.

The order of business during the review was as follows:

February 11

Introductory remarks	J. P. Holliday
Background and purpose	H. W. Savage
Project resume	R. W. Lockhart
Analysis of weight change data	J. L. Jaech, E. L. Dunn

Material examination and metallurgy results	R. S. Young
Surface composition analysis and model	E. G. Brush
Future test plans for current program	R. W. Lockhart

February 12

New loop design review	R. W. Lockhart
New loop test program planning	J. L. Jaech
Tour of test loop facility	Ad Hoc Committee
Individual and subcommittee discussions	

February 13, 14

Ad Hoc Committee discussions
Drafting of committee report

February 15

Conference with General Electric Company

The program has progressed to > 95 per cent completion of originally planned experimental work for the 5-run fractional replicate program of experiments. Some months, possibly a year, of data reduction, analysis, and evaluation remain for this program. The next group of experimental runs for the existing six loops has been presented, and recommendations are being made that the program be augmented by studies in additional loops. The plan and objectives for the next group of experiments are being developed but at the time of this review were not fully definitive.

2. Conclusions and Recommendations

2.1 Conclusions

The conclusions listed in Section 2 of the previous report⁴ are still relevant with minor modifications and extensions noted below. The additional comments fall into two classes: (a) technical output from the program and (b) comments on program planning and execution.

2.1.1 Effects of System Variables on Sodium Corrosion

The analysis of corrosion data by the linear regression method⁵ has provided quantitative (although tentative) estimates of the effect of individual program variables. Although these estimates could change as further data are assimilated, they are valid indicators of which variables are major and which are minor.

a. Temperature.— Lowering loop temperature from 1200°F max to 1100°F max typically reduced the corrosion rate by a factor of about three. About the same factor of reduction was observed at these two temperatures within individual loops.

b. Loop ΔT .— This is the least significant of the primary variables studied. Lowering the loop ΔT from 500 to 250°F reduced the corrosion rate by an average factor of 1.4, but with low statistical significance.

c. Oxygen Content of Sodium.— This variable is significant. Decreasing the oxygen concentration from 45 to 15 ppm (based on plugging meter readings) lowers the corrosion rate by a factor of three.

There is preliminary evidence that 316 stainless steel loses Cr and Ni preferentially at the lower oxygen level, while Fe is preferentially transferred at the higher oxygen level. Complex oxides of Fe, Cr, and Ni with Na have been detected in mass transfer deposits.

d. Alloy Type.— Type 316 stainless steel, 2 1/4 Cr-1 Mo, 5 Cr-1/2 Mo steel and combinations of these all show about the same level of mass transfer. In low oxygen sodium, corrosion rates are generally less than 1 mpy and appear acceptable for reactor systems from the standpoint of structural integrity. One exception is Loop 1 (all 316 stainless steel) which has shown higher than expected weight losses at 1200°F.

e. Carbon Transfer.— Carbon transfer from 2 1/4 Cr-1 Mo steel to 316 stainless steel continues to be a major corrosion effect. Loss of carbon from 2 1/4-1 Mo steel has now been observed below 800°F. Design applications of this alloy above 900°F ⁱⁿ sodium should allow for at least a 50 to 80 per cent carbon loss. However, the observed carbon transfer is not expected to produce unacceptable mechanical properties in either end of such systems.

f. Time.— Metallurgical changes in hot leg corrosion samples have been observed up to 14000 hours, suggesting that the corrosion rate is still changing. Weight loss data from the two long runs indicates that little decrease in the rate occurs after the first 700 hours, but the data are too scanty for definite conclusions. It is encouraging to note that no unfavorable corrosion trends have been observed on tabs examined even after 17000 hours.

2.1.2 Program Planning and Execution

a. Three loop runs involving loops 1, 2, and 6, remain to be completed under the original program objectives. However, additional runs under this program may be necessary to evaluate variable interactions or to resolve the credibility of questionable loop findings.

b. The loop results examined to date suggest that geometry and velocity effects should receive primary consideration in any experimental program

growing out of the present program. However, finalization of any "phase II" program should await a better clarification of the parametric relationships of these variables which is being generated under the current program analyses.

c. It is possible to use the parametric relationships developed under the current loop program as a design basis for sodium reactor systems either proposed or now under development. Although of definite value, these extrapolations point out two limitations of the present loop program. These concern ¹⁾ the need for additional data to analyze the effects of fuel element hot spots and ²⁾ the gross velocity and temperature profile differences between the present loops and typical sodium coolant systems.

2.2 Recommendations

a. A serious limitation in the present program continues to be development of an adequate analytical model for the mass transfer process. Progress has been made in developing models of the solution process, but there is little progress in development of an over-all model embodying the inter-relationships of dissolution rates, deposition rates, and coolant chemistry changes (of which the process models are a part). The over-all mass transfer model can be developed even without the process models. It is recommended that development of an analytical model which will predict the corrosion rate and elemental material distribution throughout the loop system be pursued as rapidly as possible.

b. It is recommended that the parametric form of variables used to correlate present data be examined carefully to optimize the methods of data presentation. Specifically, it is felt that use of the L/Dm and mass flow per unit length of hydraulic perimeter variables are open to question.

c. Surface compositional studies of corrosion samples and loop metallurgical samples should be continued. Elements to be studied should include C, Fe, Cr, Ni, Ti, Mo, Mn, and other elements or compounds which are present in sufficient quantities to make them important to the over-all mass transfer process. The hypothesized effect of O_2 in preferential leaching of Cr, Ni, or Fe from an austenitic hot leg must be examined more closely for the effects of prior history and for consistency with known diagrams and diffusion behavior.

d. Recent data indicate that it is practical to reinsert samples which undergo a negative weight change. It is recommended that all such samples be weighed and reinserted at each shutdown to gain additional time points

in the tests to be run in the existing test loops. Further, the design of new loop systems should consider this (and any other) method to provide more extensive time point data.

e. The programming of tests to be operated in the near future in the existing six corrosion loops should be guided by the following three requirements:

1. Completion of original fractional replicate program
2. Evaluation of variable interactions
3. Special corrosion tests of value to a particular reactor system

Tests outside the scope of these requirements should be considered in the context of a "phase II" experimental program, which, in the Committee's opinion, can not be formulated with precision until the analysis of the present program data is more complete.

f. In any future test conceived for the present loops, a primary objective should be to preserve the structures for complete examination as a last step in completing analysis for the present program. For this reason, it is recommended that intentional carbon additions not be made until after destructive loop examinations have been completed.

g. The continuing evaluation of the data from the complete Five-Run Fractional Replicate Program (completion of data analysis varies from 50 to 80 per cent among the various loops) may indicate that additional exposure data will be required to resolve interactions of test variables. There will also be an incentive to rerun certain tests to resolve data that are apparently out of line. However, interaction-type runs (under Type VI, VII, or VIII test conditions)* will in most cases suffice to check questionable runs as well as provide further information on variable interactions.

*Run Types VI, VII, and VIII have not previously been identified. They are as follows:

Type VI: 1100°F $T_{\max}$, 500°F ΔT , high oxide

Type VII: 1200°F $T_{\max}$, 250°F ΔT , high oxide

Type VIII: 1100°F $T_{\max}$, 250°F ΔT , low oxide

The full replicate uses three variables, each at two levels, requiring eight condition types. Types I, II, III, IV, and V comprised the fractional replicate plan used in experiments done to date, Types VI, VII, and VIII complete the full replicate and may be used to test for variable interactions or for comparisons with types already run.

It is recommended that present data be used to check the assumption of no interdependence between the primary variables. If some interaction is indicated, consideration should be given to running the other half (run Types II, VI, VII, and VIII) of the Full Replicate Program on selected loops. In this event, a written plan of action should be prepared. It is suggested that a choice of significance level exists which can increase the power of the interaction test.

3. Program Status

3.1 Current Test Program and Loop Operations

Since the September, 1962, Ad Hoc Committee meeting, the major objective of the Sodium Mass Transfer Program loop operations has been to complete the Five-Run Replicate Program, whose test conditions are noted in Table 1. During this period, 13 runs in the five test loops (1, 3, 4, 5, and 6) have been completed; these runs, together with 11 earlier runs, account for 96 per cent of the objective. One Type III run on the 5 Cr loop (#6) remains for completion of the five-run fractional replicate program. Sample exposure is about to commence in this loop and should be finished by June, 1964. Details of the number of hours, run conditions, and numbers of exposed samples for all the loops are tabulated in Table 2.

Table 1. Test Conditions for Five-Run Fractional Replicate Program

Run Type	T _{max} (°F)	ΔT (°F)	Plugging Meter Temperature, °F (Oxygen Level - ppm)
I	1200	500	450 (~ 50 ppm)
II	1200	500	305 ~ 11 ppm)
III	1100	500	305
IV	1200	250	305
V	1100	250	450

Reported test results for eleven runs completed in calendar year 1962 and five runs completed in the first six months of 1963 have been published in GEAP-4182 and GEAP-4438, respectively. Preliminary data on more recent runs through January, 1964 have been reported in the monthly progress letters.

Loop 5 was the first to complete its 5-run plan. Because further experimental data were needed to understand the interrelationships between the "carbon-sodium-oxygen-steel" system, this loop was selected for chemistry studies of the sodium and cover gases. It was desired to determine the

Table 2. Loop Operating Summary (2/10/64)

Loop	Material	Run Type	Run Hours	Total Pump Hours	Number of Samples		
					Sample Holders	In Pipe	Total
1	316SS	I*(1300°F)	3858				
		II	2165				
		IV	2816				
		III	2811				
		V	2814				
		I (1200°F)	2368				
		Totals	16832	18741	370	170	540
2	316SS- 2 1/4 Cr	II	22792	24516	140	53	193
3	316SS- 2 1/4 Cr	I	2729				
		II	7164				
		IV	5629				
		III	2806				
		V	2827				
		Totals	21155	23123	272	216	488
4	316SS-5 Cr	I	2802				
		II	6312				
		IV	2809				
		V	2800				
		III	2832				
		I (seasoning)	671				
		Totals	18226	20463	288	165	453
5	2 1/4 Cr	I	2697				
		II	3002				
		III	2808				
		IV	2753				
		V	2818				
		Totals	14078	17432	192	93	285
6	5 Cr	I	2792				
		II	9265				
		V	2823				
		IV	2802				
		III	(Starting)				
			17782	19397	238	105	343
Totals - All Loops			110865	123680	1500	802	2302

changes, if any, in the form and amount of impurities in both hot- and cold-leg regions. Accordingly, a high temperature (1200°F) Na sampling port and plugging indicator were incorporated in the maximum temperature ($T_{\max}$) region to supplement a similar sampling station already at the minimum temperature ($T_{\min}$) position. The determination of oxygen in both hot- and cold-leg regions was planned (and has been made) using both of

the plugging indicators. A semiautomated cooling air control was developed to permit making controlled, and therefore reproducible, plugging runs, so that flow anomalies such as the "double-break" in the plug indicator observations could be studied more effectively.

Because of two major sodium leaks in this newly installed equipment, and the time consumed in developing safe procedures for taking high temperature (1200°F) Na samples, the chemistry runs for Loop 5 have not been completed. When repairs of damage from the most recent leak have been effected, the first of these runs will commence.

Loop 4, which was the second loop to complete its initial run plan, has undergone a metallurgical examination of selected components. Representative sections of piping including the bimetallic joints and the H3 and Cl sample holders were cut from the loop. New sample holder inserts were installed and new piping replaced those parts removed for the examination. The loop was restored to operating status and has run for 700 hours at Type I conditions to "season" it prior to the next test run.

Loops 1 and 3 were the most recent to complete their run plans and are being prepared for loop metallurgical examinations. The last run (Type I) in the 316 stainless steel loop (#1) produced so much flow fouling that two "unscheduled" sample removals were necessary to try to alleviate the situation. Ultimately, the run was terminated prior to its scheduled operating period when the low flow prevented specified test temperatures from being maintained.

The last run (Type V) in the 316-2 1/4 loop (#3) involved considerable trouble in trying to maintain cold trap flow, giving evidence that the cold trap is probably loaded after some 3 1/4 years of use. It will be removed for examination and replacement of the mesh while the loop is undergoing metallurgical examination. The 316-2 1/4 loop (#2) has continued at the Type II conditions for evaluation of long-time effects and has completed more than 24,000 total hours of running at these conditions.

Carbon diffusion studies in 316 stainless steel were begun in a stainless steel isothermal test loop borrowed from another program. Five short runs were completed between August and October, 1962. The studies were interrupted by the need to return the loop to its original project but were started again in October, 1963. About 12 runs, each requiring approximately two weeks of exposure time, are planned; four have been completed.

3.2 Proposed Future Loop Schedule

The future test program as proposed by General Electric Company^{*} for each of the six loops, and for additional equipment to provide data on within-run variables is outlined below. Except for Loop 2, all tests follow a partial dissection of the loop for metallurgical examination. An approximate schedule is shown under Section 4 of the 1964 Data Folder.⁶ Except as noted below, test plan and operating procedures for each run will be the same as used previously in the Five-Run Fractional Replicate Program.

3.2.1 Loop 1: 316 Stainless Steel

Three runs are proposed, essentially extrapolations of earlier fractional replicata data, to provide data at third level of maximum temperature, very low oxide, and to study effects of a controlled addition of carbon.

- a. Objective: third level of maximum temperature at low oxide level.

Conditions: 1300°F T_{max} , 500°F ΔT , 10 ppm oxide.

Comparisons: with earlier Run 1-1 at high oxide, and with earlier Run 1-2 at 1200°F T_{max} .

- b. Objective: third level of oxide at maximum temperature.

Conditions: 1300°F T_{max} , 500°F ΔT , 5 ppm oxide.

Comparisons: with earlier Run 1-1 at high oxide, and with run (a) immediately above at 10 ppm oxide.

- c. Objective: add carbon at 2800 hours, run to 5600 hours.

Conditions: 1300°F T_{max} , 500°F ΔT , 10 ppm oxide, carbon spike.

Comparisons: with (a) and (b) above.

Operating procedures: adjust 2800-hour operation sampling plan for 5600 hour period; improved cold trap may be required.

3.2.2 Loop 2: 316 stainless steel - 2 1/4 Cr Croloy

Three runs are proposed with a loop metallurgical examination inserted between the second and third runs. Essentially, the runs would further extend long term data beyond 20,000 hours, investigate initial corrosion effect in a thoroughly seasoned loop, and observe changes in corrosion rates resulting from changes in specimen configuration.

^{*}It will be observed that the Review Committee has not agreed with the future test program as proposed by General Electric Company. (See Sections 2.2 and 4.4.2.)

- a. Objective: continue long term operation.
 Conditions: 1200°F $T_{\max}$, 500°F ΔT , 10 ppm.
 (Type II of fractional replicate plan.)
 Comparisons: with prior results from Loop 2, and with runs 3-2 to 3-7 inclusive of Loop 3.
- b. Objective: determine initial corrosion rates of new specimens in a thoroughly seasoned loop.
 Conditions: 1200°F $T_{\max}$, 500°F ΔT , 10 ppm
 (Type II of fractional replicate plan.)
 Comparisons: with prior results from Loop 2, with (a) immediately above, and with results from runs 3-2 to 3-7 inclusive of Loop 3.
- Operating Procedures: change sampling procedure to provide data at 350, 700, 1050, and 1400 hours of operation.
- c. Objective: metallurgical examination of Loop 3, including partial dissection of selected regions.
- d. Objective: evaluate changes in loop component geometry.
 Conditions: 1200°F $T_{\max}$, 500°F ΔT , 10 ppm.
 (Type II of fractional replicate program)
 Comparisons: with prior results of Loop 2, with (a) and (b) immediately above, and with results from runs 3-2 to 3-7 inclusive.
- Geometry modifications: to be decided, but may include reversing direction of flow in hot-leg sample holders, adding high velocity specimens in the cold-leg, and adding specimens with heating or cooling thermal flux.

3.2.3 Loop 3: 316 stainless steel - 2 1/4 Cr Croloy

Three runs are planned to provide additional data within fractional replicate operating ranges. One of these is a run to gain insight on interactions and requires operating conditions in a not previously used segment of the full fractional replicate plan. The second and third runs are for further studies of carbon transfer and distribution. A metallurgical examination is to follow the runs.

- a. Objective: test for interactions between loop operating variables maximum T, and thermal gradient, loop ΔT .
 Conditions: 1100°F max T, 500°F ΔT , 50 ppm.
 (Type VI of full replicate program)
 Comparisons: with run 3-1 having same conditions except 1200°F $T_{\max}$, and with run 3-10 having same conditions except 250°F ΔT .

b. Objective: study carbon distribution.

Conditions: $1200^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 10 ppm.

(Type II of fractional replicate plan.)

Comparisons: with runs 3-2 to 3-7 inclusive, and with Loop 2 runs.

Operating conditions: repeat run (2800 hours) 3-7 except add

sampling period at 2100 hours. Add carbon spike at 2800 hours and sample at 3500, 4200, 4900, and 5600 hours of operation.

c. Objective: evaluate effectiveness of carbon gettering hot trap.

Conditions: $1200^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 10 ppm

(Type II of fractional replicate plan.)

Operating procedures: add carbon at start of run and continuously operate carbon gettering hot trap.

d. Objective: metallurgical examination of Loop 3.

3.2.4 Loop 4: 316 Stainless Steel - 5 Cr Croloy

Three runs are planned in which the first is to test interactions between fractional replicate plan variables, the second is to emphasize downstream factors, and the third to examine effects of either carbon or higher temperature operation.

a. Objective: test for interactions between loop operating variables, $\text{max } T$, and thermal gradient, loop ΔT .

Conditions: $1100^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 50 ppm.

Comparisons: with Loop 4-1 having same conditions except $1200^{\circ}\text{F } T_{\text{max}}$, and with Loop 4-6 having same conditions except $250^{\circ}\text{F } \Delta T$.

b. Objective: evaluate downstream effects at 1100°F in an HC type run.

Conditions: 1100°F hot-leg, 600°F cold-leg, 50 ppm.

Comparisons: with (a) immediately above, and with previous Runs 4-1 and 4-6.

c. Objective: evaluate either effect of carbon addition, or the effect of increasing T_{max} to 1300°F .

3.2.5 Loop 5: 2 1/4 Cr Croloy

Five runs are proposed for this loop, all at conditions previously tested in the fractional replicate program. One is a repetition of the earlier Type III runs to confirm or improve the data obtained. The other four runs are short runs to provide data for comparing sodium impurities in loop hot- and cold-legs, and for interpreting the plug indicator phenomenon known as the "double break."

- a. Objective: comparison of sodium impurities in hot- and cold-legs and interpretation of plug indicator data.

Condition 1 (300 hours): $1100^{\circ}\text{F } T_{\text{max}}$, $250^{\circ}\text{F } \Delta T$, 50 ppm
(Type V of fractional replicate plan).

Condition 2 (300 hours): $1200^{\circ}\text{F } T_{\text{max}}$, $250^{\circ}\text{F } \Delta T$, 10 ppm
(Type IV of fractional replicate plan)

Condition 3 (1400 hours): $1200^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 10 ppm
(Type II of fractional replicate plan)

Condition 4 (1400 hours): $1200^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 10 ppm
(Type II of fractional replicate plan)

Test Plan: Plugging indicators will be provided for both hot- and cold-legs. Special specimens will be provided in plug indicator lines and coolers. Hot- and cold-leg sodium, and cover gas will be analyzed.

Comparisons: between conditions 1, 2, 3, and 4 immediately above, between condition 1 and earlier Run 5-5, between condition 2 and earlier run 5-4, and between conditions 3 and 4 and earlier run 5-2.

- b. Objective: repeat of Run 5-3 to confirm or improve previous data.

Conditions: $1100^{\circ}\text{F } T_{\text{max}}$, $500^{\circ}\text{F } \Delta T$, 10 ppm.

Comparisons: with earlier Run 5-3.

- c. Objective: loop metallurgical examination.

3.2.6 Loop 6: 5 Cr Croloy

Operation is not planned beyond the present Type IV run to complete the fractional replicate plan. The loop will be examined metallurgically and retired or rebuilt.

3.2.7 Loop 7: Isothermal 316 Loop Available from Another Program.

This loop will continue to be used for 150- to 300-hour tests of carbon diffusion into 316 stainless steel, and to observe effects on carbon diffusion of metallurgical history and fabrication of specimens. Metallurgical samples will be placed both upstream and downstream of carbon sources to the loop. Carbon sources will include Na_2CO_2 . Sodium and cover gas analyses will be made. Operation will include hot trapping for control of both oxygen and carbon. Test conditions will be isothermal at either 950°F -10 ppm, 1050°F -10 ppm, or 1050°F -50 ppm.

3.2.8 Loops 8 and 9: 316 Stainless Steel

Two loops, larger than loops 1 through 6, are being designed for higher flows, higher heat flux, higher velocities, and a variety of special sample holders. The objectives are expected to include studies

of "within-run" variables to evaluate the effects of geometry and time, the evaluations of temperature and velocity transition effects, downstream or position effects, and effects of heat flux. Sample holders are designed to provide data at a large number of time points, and to permit adequate and frequent measurements over run times as long as three years.

3.3 Metallurgy Presentation Summary

The objectives of metallurgical examinations are outlined in Section 4 of the 1962 Data Folder.⁷ Results of examinations of samples exposed in runs within the Five-Run Fractional Replicate Plan completed to June of 1963 are reported in GEAP-4182 and GEAP-4438. The observations of major interest are (1) selective removal of alloying constituents from 316 stainless steel hot legs and deposition in cold leg areas, and (2) carburization of 316 stainless steel and decarburization of 2 1/4 Cr-1 Mo steel in bimetallic systems. Examination techniques were expanded to include a more extensive use of electron microprobe analysis and the measurement of carbon gradients and surface carbon on 316 stainless steel samples. In addition, information on the effect of sample washing and reinsertion was obtained and tentative conclusions reached.

All runs completed to date were compared from the standpoint of weight changes observed and mass transfer of metal constituents as shown by x-ray fluorescent surface analysis. It has been found that the loop profiles for weight change all bear a constant relationship in terms of weight loss in the hot legs--the losses are greatest in the first maximum temperature holder (H3), less in the upstream holder (H2) at a lower temperature, and lowest in the first hot leg holder (H1) and the downstream H3R holder (at the same temperature as H3). Cold leg weight gain profiles remain highest in the first two holders (C1 and C2) and lowest in the last holder (C3) at the lowest temperature. This relationship of weight changes was noted for all run types and loop material combinations.

Analysis of the compositions of exposed surfaces indicate that the weight changes of specimens are related in certain cases to preferential changes in iron and in other cases to preferential changes in chromium and nickel. In the case of 316 stainless steel loops containing low oxygen sodium (approximately 10 ppm), chromium and nickel were preferentially removed from hot leg surfaces and deposited on cold leg surfaces in accordance with weight change profiles. The particular cold leg material, whether

a ferritic steel or 316 stainless steel, had no significant effect on this process. In the case of a high oxygen run (1-5, approximately 50 ppm O_2) in the 316 stainless steel loop #1, the above relationship appeared to reverse itself. In this case, preferential movement of iron from hot- to cold-leg surfaces was indicated, reflecting a probably change in mechanism. The process of selective leaching in the hot-leg and consequent compositional changes generally result in the growth of a ferritic layer that appears metallographically to grow to limiting thicknesses of approximately 0.5 mil. This has been observed at least out to 14,000 hours of exposure (Loop #2). Much less preferential metal transfer has been observed in ferritic loops than in the bimetallic and all-316 stainless steel loops.

Carbon transfer has been found to be relatively insignificant in 316 stainless steel and 5 Cr steel loops or when 5 Cr is used as the cold-leg material with 316 stainless steel as the hot-leg material. Significant carbon transfer is still found for loops comprised all or in part of 2 1/4 Cr-1 Mo steel. When used in a monometallic loop, about 60 per cent of as-received carbon is lost in hot-leg areas operating over 900°F. Only minor carbon changes are indicated in cold-leg samples from low oxygen runs. High oxygen in Loop #5 (Run 5-5) produced equivalent losses in hot- and cold-leg positions; that is, both hot- and cold-leg samples showed about 60 per cent carbon loss. Carbon transfer from 2 1/4 Cr-1 Mo steel to 316 stainless steel has been followed to 14,000 hours in a Type II run (1200°F T_{max} , 500°F ΔT , 10 ppm O_2). Gain in gross carbon in excess of 0.18 w/o has been found in the 316 stainless steel hot-leg, while loss of carbon by the 2 1/4 Cr in the Cl position at 1100°F in the cold-leg has approached 0.02 w/o. These compare to as-received carbon concentrations of 0.045-0.055 w/o and 0.105 w/o for 316 and 2 1/4 Cr steel, respectively.

Surface carbon calculations based on bulk carbon concentration and measured carbon diffusivities are being made. Surface carbon contents of about 0.3 w/o have been calculated on 316 stainless steel at 1000°F to 1200°F for 7000 hours of exposure with a 2 1/4 Cr steel cold-leg. Experiments are in progress to provide needed data on carbon diffusion rates.

Data on the effect of washing and reinsertion of samples for additional exposure show that no effect occurs in the hot-leg for weight loss situations; however, cold-leg samples yield data which is somewhat erratic and difficult to interpret.

Examination of representative areas of Loop #4 (316 stainless steel hot-leg/5 Cr-1/2 Mo-1/2 Ti cold-leg) has shown in general the same results that would be predicted from corrosion sample analysis. Additional effects were observed that included intergranular penetration of 316 stainless steel in the high temperature hot- to cold-leg crossover (near C1 cooler inlet). This was also observed along with surface pitting on 5 Cr steel in cold-leg areas. The loop had experienced about 19,000 plus hours of running time prior to examination.

3.4 Statistical Analysis

The fractional replicate experimental plan to study the effects of ΔT , $T_{\max}$, and oxygen level between runs has been completed except for one run in Loop 6. Statistical analyses of the data are in progress. Preliminary results on the effects of between-run variables have been obtained. In addition, a revised expression to describe the time effect has been developed.

In the original empirical model used to relate corrosion rate, R , to operating variables, exposure time, t , entered the model in the form:

$$\ln R = a_0 + a_1 \ln t$$

Although this described the data within the experimental region, it does not extrapolate to longer exposure times in a realistic fashion, since it implies that steady state is never reached unless a_1 is zero. Further, extrapolation to zero exposure time is not possible.

To overcome these difficulties, a three-step estimating procedure was developed as detailed in GEAP-4183. This gives an estimate of the steady state corrosion rate if, indeed, steady state is attained by 700 hours; but the interdependence of the data points, and the lack of homogeneous variance, results in an estimate whose associated uncertainty is difficult to assess.

For these reasons, a revised model was developed. This is of the form:

$$\ln R = a + b (t + 1)^{-1}$$

where t is the exposure time in 700-hour units. The parameter a is the steady state corrosion rate, which is the quantity of interest in analyses used to evaluate the effects of other variables. The parameter b defines the time at which steady state is reached, and was estimated to be $2.26^{+0.44}$ (2σ) for all positions but C-1 and C-2, in which cases b is not different from

zero. This implies that approach to steady state is reached somewhere between 700 and 1400 hours in all positions but C-1 and C-2, where steady state begins at time zero. It should be kept in mind that although these conclusions are based on a large number of data points, there are only limited data beyond 2800 hours. Further, there are relatively few cases where more than three different time points are available, although some loops have been interrupted at 2100 hours to provide an additional time point, as suggested during the last Ad Hoc review. Whether or not the extrapolation to longer periods of time is applicable requires experimental confirmation.

In the course of the analysis, two other results were found:

(1) Comparison of the initial 1400-hour sample, which saw two loop startups, with the replacement 1400-hour sample, which saw only one, indicated that there is no effect of loop startup on corrosion rate; each sample experienced only one initial effect.

(2) Samples that were washed and reinserted, using the current cleaning procedure, appear to behave like original samples in the hot-leg, experiencing only one initial effect. In the cold-leg, it is more likely that an initial effect is experienced with each reinsertion. These findings are based on a limited number of data points.

With respect to the between run variables, ΔT , $T_{\max}$, and oxygen level, preliminary estimates of their effects have been found using two statistics as measures of responses--total weight change of the hot-leg samples and corrosion rates at a given set of conditions as estimated by the three-step procedure. Results are listed:

(1) No significant differences between loops are noted.

(2) Responses to changes in maximum temperature are similar to responses to local temperature changes made within runs. The Arrhenius coefficient b (from the expression $\exp. [b (T_{\max} + 460)^{-1}]$) was estimated from the two responses and found to be -25×10^3 and -30×10^3 , respectively.

(3) Estimates of the responses to changes in ΔT are expressed as $\Delta T^{.25}$ or $\Delta T^{.50}$. This result is not inconsistent with either an exponent of zero or one, both of which have been proposed.

(4) Oxide level was varied by a factor of four. Corresponding corrosion rates were found to vary by about the same factor.

For "within-run" variables, effects are similar to those previously reported. Velocity changes of a factor of three cause a corresponding factor

of nearly three in corrosion rate. Location of a sample 70 diameters downstream (approximately one sample length) results in reduction in the weight change by a factor of two. Temperature effects are linear on the Arrhenius reciprocal scale with coefficients equal to between -25×10^3 and -30×10^3 , consistent with the estimate of the effect of changing maximum temperature, as noted in point (2) above. The intimate tie-up of the downstream and velocity effects with loop geometry somewhat obscures these estimates. Loop geometry was held nearly constant for the present loops; hence, application of the temperature coefficient to other systems must follow their demonstrated applicability with other geometries.

Currently, analyses are being made to determine the extent to which the coefficients of the within-run variables differ from run to run. Corrosion estimates will be used to the extent warranted by the data. Once this is completed, a re-evaluation will be made of the effects of the "between-run" variables.

3.5 Analytical Model Advances

The compositional changes at alloy-sodium interfaces have long indicated that wall diffusion processes play a role in the transport of alloy components in sodium heat transfer systems. The extent to which such processes influence the morphology, and particularly the kinetics, of the transport mechanism is of paramount importance. Quite obviously, these will be significant links in the mathematical model chain that most accurately describes the total transport mechanism. Such a model will provide the experimenter with one of his greatest tools: the ability to design experiments to measure the effect of heat transfer system variables on corrosion.

The behavior of the wall diffusion process in the present loop systems is being examined by electron microprobe analysis. The initial effort has been centered around the 1200°F region of loops 2 and 3. Two models have been considered, the first having received the greatest analytical attention. Both involve the hypothesis that alloy oxides are the primary transporting species, (i.e., the first step in going from alloy to sodium is the creation of alloy oxides. As such, both models essentially consider that sodium is merely a carrier for oxygen, being otherwise, inert, except that it has a limiting capacity to hold dissolved

oxide at any temperature. Coupled with oxide defect structure, this concept can account for a downstream effect in the presence of a powerful oxidizing medium.

The first model adopts the premise that the oxidation process is partially selective: that is, all major alloying elements enter the oxide phase, although the noble element, iron in this instance, enters it at a much slower rate than do the active elements, nickel and chromium. Secondly, it postulates that the non-entry of iron is controlled by a displacement reaction; that is, most iron oxide that tends to form is reduced by the surface concentration of chromium. This leads to an equilibrium surface concentration of all elements which, when once attained, will arrest any further selective oxidation. Based on iron, the model contains the following expressions, all applicable to Figure 1:

$$C(x,t) - C_{\infty} = \frac{\bar{x}}{2\sqrt{\pi Dt}} e^{-x^2/4Dt}$$

$$C_{Lx} - C_{\infty} = \frac{\bar{x}}{2\sqrt{\pi Dt}}$$

$$C_{Lx} = C_{eq} + (C_{\infty} - C_{eq}) e^{-at}$$

$$\frac{d\bar{x}}{dt} = C_{\infty} \left[1 - \frac{C_{\infty}}{C_{Lx}} (1 - e^{-at}) \right] \frac{d(\Delta_w)}{dt}$$

where,

$C(x,t)$ = concentration of element in alloy at given depth x below surface and at given time t , g/cm^3

C_{∞} = concentration of element in alloy below "disturbed" layer (equal to original concentration of element in the alloy), g/cm^3

C_{Lx} = surface concentration of element at (receding) sodium-alloy interface, g/cm^3

C_{eq} = equilibrium (steady state) surface concentration of element, g/cm^3

FIGURE - I

$\bar{x}$ = excess mass of element (compared to original mass)
at given time t , grams

Δw = weight change of alloy at given time t , g/cm²

D = diffusivity of element in alloy, cm/sec

α = rate at which $C_{\Sigma x}$ approaches C_{eq} , sec⁻¹

The corrosion rate $d(\Delta w)/dt$ is taken from the approximation:

$$\Delta w = k_0 t \exp \left[\frac{k_1}{t + 1} \right]$$

and from this and the expression for $C_{\Sigma x}$, $\bar{x}$ is given by:

$$\bar{x} = \frac{C_{\infty}}{\alpha C_{eq}} k_0 \exp \left[\frac{k_1}{t + 1} \right] [(2 C_{eq} - C_{\infty}) (1 - e^{-\alpha t}) - (C_{eq} - C_{\infty}) (1 - e^{-2\alpha t})]$$

Microprobe traces have been completed for the following type 316 stainless steel specimens (all at 1200°F): in-pipe specimens from position (H3) at 2800 and 8000 hours (velocity 1 fps); slot specimens from inlet position (H3I) at 1400, 2800, and 5600 hours (velocity 7 fps) and position (H3I) at 2800 and 7000 hours (velocity < 3 fps); and slot specimens from outlet positions (HS-0) at 2800 and 5600 hours (velocity 23 fps). The results reveal that α , the specific rate constant for the climb of $C_{\Sigma x}$ to C_{eq} , is independent of velocity, but that C_{eq} increases with increasing velocity. There is no constant pattern of x_0 , the maximum composition disturbance depth, but it never exceeds 2 mils. The constants k_0 and k_1 , also estimable from the last expression, were such that the calculated weight changes within a few per cent for nearly all specimens examined by the microprobe.

However, microprobe traces on long term (14,000 hours) in-pipe samples show that x , the excess stored mass of iron, and consequently x_0 , increase after C_{eq} has been achieved. This suggests that the first model needs modification. The logical modification involves the mathematical concept of a moving boundary, and of chromium and nickel losses

at the alloy-sodium interface that are proportional to their diffusive rate of supply. These lead to the equations, in x' , as applied to Figure 2:

$$\frac{1}{\rho} \frac{d(\Delta w)}{dt} = k_{Fe} (1 - C_{Ex}) + k_{(Cr + Ni)} C_{Ex}$$

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x'^2} - \frac{\partial C}{\partial x'} \frac{1}{\rho} \frac{d(\Delta w)}{dt}$$

with boundaries

$$D \frac{\partial C}{\partial x'} \bigg|_{x' = 0} = k_{(Cr + Ni)} C_{Ex}$$

$$C = [C_{\infty}]_{(Ni + Cr)} \text{ at } x' \gg 1$$

The expression may need modification to include the concept of mixed selective-nonselective removal. However, its solution will indicate a steady state condition at which C_{Ex} will become constant and at which the excess stored masses in the alloy phase will be constant. Theoretically, this steady state should correspond to the end of the transient in the weight loss time curve. This latter model is now being treated for computer evaluation of the microprobe data previously discussed. In this approach, where numerical approximations appear indicated, weight change data (that is, $d\Delta w/dt$ in the differential equation) will be represented by the expression

$$\Delta w = k_0 t \exp \left[\frac{k_1}{t + 1} \right]$$

which has been showing some promise in the statistical calculation of operating parameters.

4. Experimental Program Evaluation

4.1 Metallurgical Results

The further assimilation of metallurgical data has strengthened many of the generalizations put forth during previous meetings but, inevitably, has introduced confusion in others. The detailed review given to metallurgical findings in the last Ad Hoc Committee report⁴ is applicable without

FIGURE - 2

qualification to the bulk of newly acquired data and will not be repeated here. Rather, this review will concentrate on trends which are at odds with the earlier generalizations and on the results of a significantly long-term run which implements the original findings.

4.1.1 Surface Leaching Effects

X-ray fluorescence analysis has been used to indicate changes in surface concentration of Fe, Ni, and Cr for several runs in loops with 316 stainless steel hot-legs. The heretofore consistent trend of preferential nickel and chromium losses in these samples was contradicted by results of Runs 1-5 and 4-6, both of which were high oxygen runs. Analyses of specimens from both runs showed that preferential transfer of iron accounted for most of the observed weight changes. It is suspected that preferential movement of iron may be symptomatic of 316 stainless steel systems having a relatively high oxygen content (approximately 50 ppm), whereas the chromium and nickel transfer observed in earlier analysis is symptomatic of lower oxygen systems. However, since loop runs 1-5 and 4-6 both reflect the effects of several prior runs, the effects of loop "aging" as a possible cause cannot yet be excluded. Further, the results observed in run 1-6 (high oxygen, $T_{\max} = 1200^{\circ}\text{F}$) do not appear to fit the stipulated high oxygen pattern, since x-ray fluorescent examinations of hot-leg specimens from this test reflect chromium and nickel losses. Thus, the effect of prior runs on the Fe, Cr, and Ni content of the loop must be considered before the validity of the postulated effect of O_2 on preferential leaching can be properly assessed.

The effect of composition changes on the microstructure of Fe-Cr-Ni alloys should also be considered in evaluating the metallographic appearance of preferentially leached surfaces. A cursory examination of the Fe-Cr-Ni ternary diagrams⁸ indicates that preferential leaching of Cr and Ni should lead to zones resembling pure Fe. Such a zone would be metallographically distinguishable from γ austenitic. However, if Fe is leached preferentially, it is difficult to visualize how the surface layer could attain a single-phase composition distinguishable from the virgin 316. If only Fe is leached and Cr and Ni are left behind in their original ratios, two-phase surface layers might be expected. A single-phase structure distinguishable from γ austenite would appear only if the surface layer approaches pure Fe in composition. The preferential leaching hypothesis, therefore, requires more careful evaluation before its validity can be accepted.

4.1.2 Loop Dissection and Examination

Examinations of 316 stainless steel specimens at the time of the last meeting have shown very little evidence of corrosion at operating temperatures up to 1200°F. The effects observed were confined to the development of a thin ferrite surface layer and, in the case of bimetallic loops, to surface carburization. However, examinations of 316 stainless steel pipe samples removed from loop 4 preparatory to refurbishing the loop indicate a mode of attack (or apparent attack) quite different from that experienced in corrosion samples. The samples were taken from the section of tubing connecting the H3R and C1 specimen holders. The operating conditions experienced by the samples are summarized in Table 3.

Visual examination of half-sections of the tube revealed the presence of relatively deep fissures running parallel to the tube axis. Subsequent metallographic examination showed the fissures to be intergranular in nature reaching depths as high as 7 mils. These fissures are most probably manifestations of fabrication defects. The removal of sections from other 316 stainless steel loops (1, 2, 3) expected shortly should clarify the significance of this so far isolated finding.

Table 3. Operating Conditions of Loop 4
Prior to Removal of Loop Sections

Temperature (°F)	<u>O₂ = 45 ppm</u>		<u>O₂ = 10 ppm</u>	
	$\Delta T = 500$	$\Delta T = 250$	500°	250°
1200	3500	-	6300	2800
1100	-	2800	2800	-

In the destructive examination of the loops after completion of their scheduled test program, it is recommended that the following steps be included whenever they seem likely to yield new information:

1. Examine heaters and coolers for corrosion effects associated with thermal flux.
2. Examine all regions with maximum thermal stresses, especially those areas where sodium streams of different temperature mix.
3. Examine all dissimilar metal joints.
4. Examine loops exhaustively for deposition sites. Since mass transfer deposits are sometimes fragile, it is desirable to cut the loop into logical

sections after draining and before washing. The alcohol and water washings from each section should then be filtered to recover any loose deposits. Each section should then be split to permit examination of all interior surfaces.

5. Examine exterior surfaces for extent of oxidative attack. This is especially important for the ferritic alloys.

4.1.3 Carbon Transfer in Sodium

In the 4th Ad Hoc Review group report⁴, the effect of carbon transfer and its relation in the GE Mass Transfer Program were discussed at length. In the present review, further data on carbon transport were given for longer term loop runs. After 7000 hours in loop 2, significant decarburization of 2 1/4 Cr-1 Mo steel from 0.105% to about 0.035% was observed at 1200°F. Decarburization to about 0.075% was observed at 1100°F, and to about 0.095% at 700°F. These levels were not appreciably below those realized in 2800-hour loop runs or in earlier studies.⁹ However, the slight decarburization at 700°F would not have been predicted from information available⁹ at the start of the GE Mass Transfer Program.

An apparent reversal of carburization rate was noted in two of the longer term loop runs. In runs 3-8 and 2-5, 2 1/4 Cr-1 Mo specimens at the C-1 positions (1100°F) exhibited a loss of carbon for approximately 400 hours of operation and an apparent "recarburization" thereafter. The minimum carbon content realized (at approximately 4000 hours) was somewhat higher than the minimums which were generally attained in previous test. These results suggest that the carburizing potential within these systems can shift suddenly as a result of outside influences encountered during long term runs.

As discussed in a previous report⁴, the elevated temperature mechanical properties of Cr-Mo steels are not affected significantly by carbon content. It can, therefore, be inferred that the observed decarburization of 2 1/4 Cr-1 Mo will not measurably affect the service life.

A potentially more serious effect results from the carbon introduced from decarburization of the 2 1/4 Cr-1 Mo steel, which acts to carburize any austenitic steels used elsewhere in the system. In the continuous run of loop 2, the expected carburization of the 316 stainless steel hot-leg was observed on both 7000 and 14,000-hour specimens. Hardness gradients showed a case depth about 0.012-in. deep after 14,000 hours at 1200°F.

This observed depth is consistent with the depth expected from published information.¹⁰ The indicated surface carbon of about 0.35% to 0.40% after this exposure is consistent with a criterion established elsewhere⁹ for infinite life of sodium-carburized austenitic stainless steel. From this information it is implied that the 316 stainless steel - 2 1/4 Cr-1 Mo combination is satisfactory at least from the standpoint of the effect of carbon transfer under GE loop conditions on mechanical properties.

In the 4th Ad Hoc Review Group Report⁴, it was recommended that greater emphasis be placed on studies of carbon transfer problems. This work is now being carried on by the GE group. They have encountered disagreement between their own correlations of microhardness and carbon content of austenitic stainless steel and correlations reported by others.¹¹ Some of the discrepancy may stem from the fact that the earlier work relates to 304 stainless steel while the present work refers to 316 stainless steel. It is suggested that this discrepancy be discussed and reconciled in a meeting between the earlier workers and the present workers at GE.

Despite the importance of carbon studies, it is recommended that the present loops not be assigned to runs involving direct carbon additions. It is believed that destructive examination of the present loops may serve a more useful purpose in the present program phase. Carburization runs in the present loops with intentional carbon additions could easily obscure evidence of extreme interest to the present phase of the program; hence carburization studies are better left to a follow-on phase, using loops specially designed for that purpose.

4.2 Empirical Model and Statistical Analysis

4.2.1 Experimental Design

The one-half replicate of the 2^3 factorial design will be completed shortly with the completion of a Type V run on loop 3. Along with additional Type II runs, this will provide data for five types of runs on each of five loops (loops 1, 3, 4, 5, and 6). The multitude of responses, both derived and directly measured, should then be subjected to a "complete blocks" analysis. In fact, some of the responses are currently being analyzed in this manner, in spite of the difficulties attendant with the analysis of incomplete data. This will allow for comparisons between loops, the measurement of the effects of ΔT , maximum temperature, and oxygen level, and loop-by-run type interaction. There is some evidence of this interaction in

the analysis of data already collected, although it is possible that the interaction is a result of some data which might be outliers.

A "within-loops" analysis of the data from the five-run types is possible for the four loops in which all five runs are complete. The "within loops" analyses are being held back by the work being done on the development of appropriate derived responses such as steady state corrosion rate statistics.

Additional data on weight loss, ΔW , have been obtained for an increased number of distinct exposure time, t . This was accomplished by weighing and reinserting test specimens as suggested in Section 4.3 of the previous Ad Hoc Committee report.⁴

4.2.2 Empirical Representation of Corrosion Data

Considerable progress has been made in deriving an empirical model for the description of weight change. Two things are of particular significance in this derivation. One is the abandonment of the concept of loop age in describing weight change. Besides being difficult to rationalize on a theoretical basis, its arithmetic description was rather arbitrary. Later loop runs appeared to exhibit little age effect, and it appeared that aging was associated only with runs which were interrupted frequently. Although the age factor may still be used to describe weight change in an empirical model, other models which do not include an age factor appear to describe the data at least as adequately. The abandonment of the age factor as it had been defined is gratifying.

Another item of significance was the redefinition of the dependent variable as weight change per unit area per unit time rather than the absolute value of corrosion rate expressed in $\text{mg}/\text{dm}^2\text{-mo}$. This allowed for the expression of a time dependent weight change as

$$\ln R = a + b (t + 1)^{-1}$$

as stated in Section 3.4 This model is particularly appealing because it appears to reflect the behavior of weight change realistically and is consistent with theory. It cannot be overemphasized, however, that accurate estimation of $\underline{a}$, the steady state corrosion rate, requires large values of $\underline{t}$.

The derived response, $\bar{a}$, is used to measure the effects of velocity, temperature, and "downstreamness" within a run. It is here that a difficulty arises. To measure these effects, one requires an estimate of $\bar{a}$ for each sample position in a run. It is impossible to estimate $\bar{a}$ or $\bar{b}$ with only one time point as is the case for the high velocity specimens. Therefore, the average $\bar{b}$ for the sample positions with multiple time points has been used to calculate the $\bar{a}$'s for the single time point positions and for the multiple time point positions. This creates a covariance among the several $\bar{a}$'s, the form of which is not now known. At present, the covariance is being ignored because it will take some careful theoretical effort to describe it. To ignore the covariance, which is the same as taking it to be zero, is admittedly wrong. How bad this is cannot be said until the statistical theory has been worked out. Work should continue on estimating the effects of velocity, temperature, and downstreamness, despite the theoretical difficulties. These estimates of effects should in turn be used as derived responses for the "complete blocks" analysis.

In the 1964 Data Folder (Tab 2, Item 1), the rate of metal removal is concluded to be constant with time, i.e., to reach a steady state, after about 700 hours. A review of weight loss data from the H-3 section of the two longest runs, 2-5 and 3-8, suggests that the corrosion rate may be in fact still decreasing at 14,000 hours. The analysis is hampered by the fact that the corrosion versus time curves for most slots are obtained by summing the weight losses from a succession of virgin tabs inserted in that slot during the run. The initially high corrosion rate of virgin tabs, well documented by now, is thus factored into the curve several times along its length, producing a higher and more constant slope. In both long runs, when a single tab was used for the entire test period, the average corrosion rate was lower than that deduced from successive new tabs. Unfortunately, there are not enough data points on original tabs at intermediate times to permit a significant determination of whether a constant corrosion rate was in fact achieved in 14,000 hours. This information would have been provided by successive weighings of original tabs, as specifically recommended for long runs in the previous report⁴, p.16.

The observed depletion of nickel and chromium from stainless steel is a solid state diffusion process which would be expected to proceed slowly. Metallographic and microprobe analyses have indicated that over 5000 hours might be required for the resulting ferrite layer to reach a

steady state thickness (tab 3, p.3). Therefore, the assumption of a constant corrosion rate after 700 hours, which is justified as an interim conservative design basis, should not be pragmatically adopted in the data analysis.

4.2.3 Extrapolation of Parametric Relationships to Reactor Systems

It is possible to use the parametric relationships developed under the current loop program as a design basis for sodium reactor systems either proposed or under development. Although of definite value, such extrapolations point out two limitations in the present loop program. In the first case, the core geometries and specific power levels of current fast (oxide) reactor concepts give rise to potential hot spots which could run as high as 1400°F in reactors with outlet temperatures of only 1100°F. Within the framework of the present loop program, it is not possible to evaluate potential hot spot effects above a temperature of 1200°F. A second limitation concerns the fundamental difference between the velocity and fluid temperature profiles of the present loops and typical reactor coolant systems. The difference is such that extrapolations of downstream effects outside the present loops could be in serious error.

4.3 Analytical Model

The last Ad Hoc Committee Report⁴ devoted considerable discussion to the objectives and approach embodied in the analytic mass transfer model which it is hoped will be developed from the GE loop results. Much detailed study has been given to the formulation of a solution model which satisfies observed program results. It is unfortunate, however, that the model is still being approached only in terms of this one contributing step (dissolution) and has not yet advanced to a consideration of the over-all loop system. Sufficient corrosion rate data now exist to relate local solution and deposition rates of transferring elements to attendant concentration changes in the circulating sodium. Such information can give insight to the probable rate controlling zones or steps within the system¹² and thus can yield general information of great value to both the analytical and theoretical models.

The downstream effect has proved to be one of the major factors affecting the observed corrosion rate. Since it was not originally anticipated as a variable, the present loops were not designed to separate it from velocity and surface-to-volume ratio effects. As a result,

there is no way to test the significance of the present choice of downstream parameter, L/DM . The in-pipe samples between H3 and H3R would have provided a test, but the weight changes of these tabs were too small to measure with significant accuracy.

The L/DM parameter assigns a downstream factor of 70 to the flow channel around a "hockey stick" tab versus 72 for the 30-inch length of pipe between H3 and H3R. This requires that corrosion decrease significantly from the inlet to the outlet end of the tab. Apparently no such decrease has been observed metallographically. The inlet and outlet ends of an H3 single slot specimen holder from loop 4 were examined metallographically after 20,000 hours of testing. No difference was observed in corrosive attack at the two ends. These observations suggest that most of the measured decrease in sodium corrosiveness may occur in (or on) the pipe between specimen holders. Predictions of downstream effects in reactor systems based on the present empirical model would appear to be highly questionable. Note that in a typical reactor sodium is heated in a high velocity region and then enters a low velocity isothermal region, whereas the reverse is true in the present loops.

The above situation points up the need to derive an analytical model for the downstream effect based on physical processes and to test it. Report GEAP-4313, which was distributed during the meeting, appears to be a laudable start in this direction. Time was not available for a critical review of this report, but further development and application of the proposed model to existing data at GE is recommended. In view of the critical role assigned to oxygen in this model, it would seem instructive to test it on the downstream effect results obtained in high oxygen runs.

4.4 Program Planning

4.4.1 Review of Current Status

The objective of the Mass Transfer Program has been to provide information on the effects of 700 to 1300°F sodium on commercially available structural alloys suitable for power reaction applications. Type 316 austenitic stainless steel and 2 1/4 Cr-1 Mo and 5 Cr-1/2 Mo-1/2 Ti ferritic steels were chosen for initial investigation as representative of those alloys showing the most promise. An experimental program was initiated in 1959 at GE-APED to study metallurgical, mass transfer, and other time

and temperature dependent phenomena associated with use of these structural alloys in reactor sodium circuits. Three monometallic and three bimetallic loops were constructed to carry out the experimental program.

Five system variables expected to have the largest effect on corrosion and mass transfer were factored into a fractional replicate experimental plan. These variables are maximum sodium temperature ($T_{\max}$), temperature difference between the loop hot- and cold-leg (ΔT), sodium oxide concentration, velocity, and time. The test schedule used in the execution of this program and the levels of each of the variables are described in Table 1. The raw data from this program have been obtained by weighing and examining test specimens exposed in the loops for various times under appropriate loop conditions. In addition, the samples are subjected to chemical analysis, metallographic examinations, x-ray fluorescent analysis, and microprobe studies.

An empirical approach to data correlation was based on computer solutions of multiple linear regression least-squares equations, expressing functional relationships between the variables. A second approach to data correlation involved a theoretical analysis of data in terms of mathematical expressions for postulated physical, chemical, or metallurgical mechanisms. Both approaches to data correlation as well as the experiments themselves have revealed some unexpected or undefined variables or parameters. Analysis can be completed only after completion of the entire fractional replicate plan. Therefore, proper and final assessment^{*} of the significance of unexpected effects or the possible definition of new parameters must be based on the complete analysis. The analysis is now in progress but is not yet completed.

The fractional replicate plan has required a minimum of 25 loop runs (five loops, five runs per loop); 24 loop runs have been completed. The last run will be completed in June, 1964. A sixth loop duplicating the bimetallic 316-2 1/4 Cr loop of the fractional replicate plan has been used to provide data over an operating period in excess of two years. A seventh loop, of different configuration, has been available for special

^{*}Preliminary assessments now available, may not be changed by final results, and in general are adequate for planning and organizing programs beyond the present scope, provided the significance of the preliminary assessment can be evaluated.

studies on carbon transfer. Extent of completion of analysis is shown in Table 4.

Table 4. Approximate Per Cent Completion of Analysis

Loop	Materials Analysis	Mathematical Analysis	Total Analysis
1	65	60	63
3	50	50	50
4	65	65	65
5	80	75	83
6	65	60	63

Three variables, in addition to the five considered in the fractional replicate plan, appear to have an important effect on loop results. They are loop geometry or configuration, loop and/or sodium age, and the presence of carbon. The very low velocities in regions of the loop between specimen holders has precluded an adequate measurement of corrosion rates in these regions; hence, the assessment of geometry effects has been limited. Interactions between variables are possible, but their existence cannot be postulated prior to completion of appropriate mathematical tests using all of the data for a single loop. Such mathematical tests are possible for Loops 1, 3, 4, and 5, but have not been made. If interactions are postulated, testing of each hypothesis requires additional loop operations in those parts of the full (not fractional) replicate experimental plan not used to date.

Good progress is being made on development of empirical and theoretical models to explain time dependencies. As pointed out in the previous Ad Hoc report,⁴ the need for observations at more time points has been recognized and partially overcome, but the suggestion of extending each final run of the replicate plan to a double length run has not been followed.

On the other hand, the recognized "downstream" effect continues to be difficult to resolve. The hydraulic features (therefore, geometries) of the isothermal passages in which it occurs may exert a strong influence on the magnitude and character of the phenomenon. It is especially important to determine the magnitude of the downstream effect in the

relatively sluggish non-isothermal sections immediately preceding the isothermal passages since, to the extent that it is operative in these sections, the maximum corrosion rates which are observed at the entrances of isothermal passages will be lower than a "true" maximum. Resolution of this difficulty by theoretical or empirical study and with a carefully designed experimental plan appears to be essential to the understanding of this problem.

4.4.2 Future Program

As discussed above, it is the Committee's opinion that the completion and analysis of tests within the current one-half replicate program will essentially fulfill the program objectives which comprised the original work scope of the GE Mass Transfer Program. Thus, the future tests being proposed by GE for operation in the six existing loops can be divided into two categories. In the first category are tests needed to complete the presently outlined program plus follow-on tests to evaluate questionable runs or to check variable interactions. Other tests, because they represent an outgrowth rather than extension of the present program are considered by the Committee to fall under a subsequent or "Phase II" corrosion investigation.

The Committee's position in general is that the original scope of the GE Mass Transfer Program will be met by a minimum of three additional loop operations: (1) a 1300°F, 500°F, 10 ppm operation of all 316 stainless steel loop 1; (2) long term (> 20,000 hours) operation of bimetallic loop 2 at present operating conditions; and (3) completion of the last fractional replicate run, 6-6, with all 5 Cr Croloy loop 6. The Committee recommends that these operations be followed by thorough metallurgical examination of all loops. As a maximum, analyses of the present data may show need for additional runs to (1) repeat previous fractional replicate conditions to confirm or improve data, and (2) to evaluate interactions between variables by tests involving test conditions in the unused part of the full replicate plan. The Committee does not consider it wise to spike the present loops with carbon before a thorough metallurgical examination is performed.

The Committee prefers to review tests beyond those outlined above in the context of a new experimental program following the present program. Such a program should logically be guided by postulations and

parametric relationships developed from the present investigation. Unfortunately, the present analytic phases must be carried much further to completion than is now the case to formulate such relationships accurately. To amplify this statement, the analysis of data forthcoming from the present program is only about 50 to 80 per cent complete among the various loop systems (see Table 4).

It is recognized that the six existing loops may provide useful tools for special corrosion tests of value to particular reactor systems. Such a requirement would, in the Committee's opinion, represent a useful (and immediate) future test program for these loops. In any future test conceived for the present loops, however, a primary objective should be to preserve the structures for complete examination as a last step in completing analysis for the present program. This means that current and immediate operation of a loop should be consistent with its prior history.

References

1. "Report on GE Sodium Mass Transfer Program," January 21, 1961, attached to transmittal letter from H. W. Savage to T. A. Nemzek, dated January 30, 1961.
2. "Report #2 on GE Sodium Mass Transfer Program," November 22, 1961, attached to transmittal letter from H. W. Savage to R. E. Aronstein, dated November 22, 1961.
3. "Report #3 on GE Sodium Mass Transfer Program," attached to transmittal letter from R. E. Aronstein to T. A. Nemzek, dated March 13, 1962.
4. "Ad Hoc Committee Report (#4) on Review of Experimental Investigation of Mass Transfer in 1200°F Sodium Systems," December 12, 1962, attached to transmittal letter from H. W. Savage to T. P. Heckman, dated December 12, 1962.
5. Letter from H. W. Savage to John Holliday dated May 10, 1963; also letter from D. I. Sinizer to John Holliday dated June 3, 1963.
6. Lockhart, R. W., Ad Hoc Review Data Folder, February, 1964.
7. Lockhart, Robert W., Ad Hoc Review Data Folder, September, 1962.
8. ASM Metals Handbook, 1948 Edition, p. 1261.
9. Hayes and Shepard, "Corrosion and Decarburization of Ferritic Cr-Mo Steels in Sodium Coolant Systems," Atomics International Report NAA-SR-2973, December 1, 1958.
10. Sinizer and Pearson, "Relationship of Carburizing Temperature to Operating Temperature Limitations in SRE," Atomics International Report, NAA-SR-Memo 7804, November, 1962.
11. Anderson and Sneesby, "Carburization of Austenitic Stainless Steel in Liquid Sodium," Atomics International Report, NAA-SR-5282.
12. Scott and Prados, "Relationship Between the Rate-Controlling Step of the Mass-Transfer Process and Distribution of Corrosion Attack," Oak Ridge National Laboratory Report CF-58-7-104, July 16, 1958.

Report of Subcommittee on Sodium Components
Test Installation Design Review

Report of Meeting on September 18, 1961

Mr. T. A. Nemzek
United States Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Dear Tom:

The SCTI Ad Hoc Review Committee met at AI on September 18, 1961. The members present were Dr. Richards, AEC Chairman, Mr. Lockhart, Mr. MacPherson (representing W. Savage) and Mr. Moribito. Mr. Wykoff could not make the meeting or furnish an alternate due to the short notice and his own tight schedule. The purpose of this meeting was to review the AI design of the SCTI to determine the adequacy of the facility as designed.

Mr. Cygan, the AI Project Engineer was the principal who furnished the committee with the information requested and various individuals were brought in during the meeting to discuss specific phases of the work. There was no formal presentation made - instead questions were asked and if answers were not readily available, the answers were requested for presentation at the October 5 meeting of the Sodium Components Working Group. The AI personnel were extremely cooperative in attempting to obtain the information requested. It became very obvious that a clear understanding of what was meant by the committee's request on capability of the facility was not understood by AI. As a result of this, some very specific requests were made in order to arrive at a feeling for the adequacy of the facility. The sequence followed was to determine the limiting characteristic of each system for steady state operation, transient operation, adequacy of instrumentation, reliability from the standpoint of the effect of failures on the system. The safety aspects were not covered at the meeting. A brief resume of the discussion is listed below by systems:

I. Primary Sodium System:

The limit on maximum temperature of this system appears to be the sodium heater. Though it is possible that other limits may exist in the SS 304 system and valves. The present maximum metal temperature on this heater is 1370°F with 1300°F sodium outlet temperature. This maximum temperature does not include gas side maldistribution and is readily average maximum temperature. The maximum temperature was not established. The pressure stresses were checked at 1371°F and found adequate bending stresses, and thermal stresses were not included. Both the maximum temperature and maximum stress were requested of AI for the October 5 meeting. The committee asked for the basis of selecting the maximum allowable temperature and evidenced

concern about the possibility of stress corrosion occurring on the gas side of the unit since the 304 will be fully sensitized at these temperatures. The AI position of Mo problem since there is no corrosive medium was not fully resolved.

The limiting component on flow appears to be the pump. A great deal of discussion occurred on the capability of the system; however, it appears that the system capability is adequate to test the Alco Equipment to 120% of nominal flow. Since the data was extrapolated rather crudely, AI was requested to report on the system pressure drops at 120% flow to demonstrate the flow adequacy of the system. It should be noted that the Primary Sodium Pumps have been fully modified by decreasing both the speed and impeller diameter to the maximum. Any additional capabilities will require a new pump.

The power limit is on the sodium heater and this data has been presented in the heater calculations. The power limit is of a function of ΔT and top temperature.

A review of the transient capability of the facility indicated that most of the transients could be satisfactorily performed. One exception is the failure of a primary pump without failure of the secondary pumps. This transient has not been fully developed, but it appears to be difficult, mainly because of the difficulty in avoiding damage to the sodium heater. The method of performing the transients involves operation of many valves which influence each other. AI is simulating the control system and is doing an excellent job of evaluating their control plan.

At the present, there is no provision for testing an intermediate heat exchanger independently. The present cooler in the system is used for transients and does not have sufficient capability for testing an IHX. The present Alco Test Program calls for separate testing of the IHX and many of these tests cannot be run even with the steam generator. A more careful review of the Alco Test Program is required to establish the need for separate testing and whether this testing can be satisfactorily performed in a figure of 8 loop.

A rather rapid review of instrumentation was conducted and this appeared to be reasonably well in hand.

II. Secondary Sodium System

The maximum design temperature of the secondary loop was 1300°F — the limit on temperature was not clearly established — it will probably be determined by flexibility.

The Secondary Sodium Pump does not have sufficient capability to test the Alco units at 120% flow. Some rather rapid extrapolation of data presented by AI indicated that the required head for 120% flow was 51 psi with a 40 psi head available from the pump. AI was requested

to review this data and if they established that the deficiency existed to be prepared to present a recommendation for removing this deficiency. The freeze seal pump originally planned for this loop has been replaced with the Argonne Allis Chalmers Free surface pump. The control aspects of the secondary loop and the method of approach to evaluating the control problem looks excellent.

Steam and Feedwater System

The steam and Feedwater system is designed for 2800 psi - 2500 psi steam - the flow limiting condition appears to be the Boiler Feed Pump. However, the pressure reducing desuperheating status also appears limiting - the flow limit was not clearly established - velocities at normal flow in the lines is 15,000 feet per minute - these are 4" lines. It would appear that the velocity is high for such a small line and may already be limiting.

Thermal transients are not fully established at the steam end of the cycle - the method of handling the failure of secondary flow was explored and the method of accomplishing this was not available at this time.

Reports of Subcommittee on Steam Generator Testing

Functions of Ad Hoc Committee on Steam Generator Testing

To: Glen W. Wensch, Division of Reactor Development, Headquarters Date: September 26, 1963

From: Andrew E. Mravca
Chicago Operations Office

Subject: Steam Generator Testing Program

OM:AEM

In compliance with your request at the recent Sodium Components Working Group Meeting (August 20, 1963), I am submitting the following information which describes the manner in which we propose to carry out the functions of the above subject Ad Hoc Committee.

Membership

Chairman - Andrew E. Mravca, CH
Member - George Gower, CH
Member - Kenneth Kuczen, ANL
Member - Kenneth Hoffman, BNL
Member - Robert MacPherson, ORNL

Current Plans

The committee will review the Sodium Component Test Installation capabilities and the test requirements of the sodium components now installed in the SCTI and the components now being designed and built for testing.

Schedule

October 15 - Assemble and forward to all the Ad Hoc Committee members a data package containing the following and requesting their review and comments.

- a.) Brief history and background of the SCTI.
- b.) SCTI system description and drawings.
- c.) All available information on the steam generators to be tested and their associated test programs.

October 30 - Receive comments from above requests.

November 4-5 - Visit Baldwin-Lima-Hamilton and possibly Babcock & Wilcox.

November 11-12 - Hold meeting at CPAO and visit SCTI.

November 13-14 - Prepare report and submit to DRD.

Future Plans

- a.) This committee will continue to keep currently informed on all component testing. Meetings will be called as needed to formulate and recommend operational direction; review and recommend plant modifications, if needed, and maintain program operation surveillance.
- b.) All future components (those not covered in the initial review) prior to installation for testing in the SCTI will receive a review in regard to system capability and adequacy of the test facility to do the job.
- c.) This committee will continually review the needs of the overall Sodium Component Development Program in regards to component testing in order to recommend a course of action which will provide the maximum and most fruitful use of the SCTI.

The information presented above is our thinking on the direction that should be taken by the Sodium Components Testing Program Ad Hoc Committee. We would appreciate any comments you may have on the above matter.

cc: C. Richards, CPAO
K. Kuczen, ANL
K. Hoffman, BNL
R. MacPherson, ORNL

Report of Meeting on November 13-15, 1963

STEAM GENERATOR TEST PROGRAM

AD HOC COMMITTEE

REPORT NO. 1

November 19, 1963

On November 13, 14, and 15, 1963, the Ad Hoc Committee members visited Atomics International to review the SCTI Program and to discuss the modular steam generator concept which they proposed to the AEC. Those present for the Committee were:

A. Mravca, Chairman
G. Gower, Member
K. Hoffman, Member
K. Kuczen, Member
R. MacPherson, Member

Those contacted at Atomics International and Canoga Park Area Office were:

CPAO

J. V. Levy
C. W. Richards
W. G. Armstrong

AI

D. T. Eggen
D. F. Casey
R. Cygan
W. Hallett
L. T. Bogaert
G. Kazlauskas
W. T. McSweeney

SCTI

Construction of the SCTI was about 92% complete as of November 15, 1963. Atomics International (AI) currently estimates that construction will be completed by January 1, 1964. A copy of the revised schedule for completion of construction work and the checkout program is enclosed. The new shipping date of May 18, 1964, for the steam generator being fabricated by Baldwin-Lima-Hamilton (BLH), is shown. Because of the delay in shipment of the BLH steam generator AI stated that all the bids for installation of the steam generator have been rejected and new bids will be solicited at a time which will permit about two months of work preceding arrival of a steam generator.

AI expects to initiate the pre-operation testing program on the SCTI beginning in January 1964 and continuing for a period of seven (7) months thereafter. Briefly the checkout sequence would be as follows:

1. Instrumentation checkout without sodium in the system.
2. Primary system checkout with sodium at isothermal conditions.
- *3. Secondary sodium system checkout with steam generator.

*If the steam generator is not available at the time required for Item 3 above, AI plans to test the secondary sodium system with a spool piece in place of the steam generator. Under these circumstances the secondary system would be tested isothermally and the feedwater and steam system checkout would be deferred until a generator were available.

4. Feedwater and steam system checkout.
5. Begin testing program.

Considering the work remaining to be accomplished it is believed that the current schedule represents the least possible time to complete the construction and checkout of the SCTI. In view of the many time-consuming problems which are generally encountered in checking out a complex facility such as the SCTI it is recommended that AI be encouraged to proceed with completion and checkout of the system as rapidly as possible and not program the checkout schedule with delivery of the steam generator should its schedule be further delayed.

The SCTI testing capabilities and the test program developed for the Alco-BLH steam generator have been subject to a continuing review by the Sodium Components Working Group and the facility, as it now exists, appears to be capable of performing the detail program set forth in the Alco report (APAE-122 "Test Program for 30 Megawatt Prototype Sodium Intermediate Heat Exchanger and Steam Generator," September 14, 1962, Alco Products, Inc.) with one recognized exception - the inability to test the IHX without a heat sink. Dr. D. T. Eggen assured the Committee that all previous official comments concerning SCTI design modifications have been acted upon.

Additional recommendations are:

1. The need for check valves after the condensate and booster pump should be evaluated. With the present design, a pressure buildup would occur in the condenser if a pump failed.
2. The methods for draining condensate from potential holdup locations in the steam system should be evaluated to assure proper drainage.
3. The safety valve locations and settings should be reviewed with respect to the ASME code.
4. The cold pre-operation tests should include mechanical checkout on shimming of equipment, hangers, etc.
5. The Committee members would like to receive copies of the pre-operation test procedures and results. It should be noted that the above information could be submitted as internal memo, or working type documents. Preparation of this information in formal or topical reports is not hereby requested.
6. Certain departures (notably weld reinforcement and surface contour) from the radiographic standard, paragraph UW-51, Section VIII were observed in sodium piping welds. This was brought to the attention of Atomics International personnel.

AI Modular Steam Generator

Based on a technical review the Committee recommends that two (2) modular steam generators (consisting of two boilers and two superheaters in parallel) as per the Atomics International concept, be fabricated and tested in the SCTI. Two modular units of the 37-tube design have a collective rating of 21 MWt. The SCTI is designed to operate up to 35 MWt. The Committee believes that a test of two units in parallel will suffice to study flow stability and flow distribution between the modules. Additionally, it appears prudent to reserve some excess testing capacity within the installation to allow for over-design testing, with the objective of determining the maximum performance capability of the modules.

The proposed AI fabrication schedule (see Figure 2) calls for having the first unit available for installation about seven months after authorization to proceed. The second unit would be available two months after the first module is available. Atomics International recommends that the first module be installed in the SCTI in July 1964. The Committee feels that the proposed schedule is tight; and therefore, it is probable that the Alco-BLH steam generator will be available for installation prior to receipt of the first module. It appears prudent at this time to defer a decision on the order of testing. It is planned to make a recommendation on this subject when the generator delivery schedules can be established with confidence.

The modular steam generator possesses a number of features which make it desirable for use in large sodium cooled reactor power plants. It can be easily adopted to both sub and supercritical steam conditions. Steam plant capacity can be increased by simply adding more modules of a standard design. It also provides improved plant availability due to the relative ease of replacing modular units. The proposed AI concept also includes several promising design features such as: (1) a simple butt weld for the tube-to-tube sheet joints, (2) relatively thin sections for the tube sheets and shell to reduce thermal transient stresses, (3) no requirement for special provisions for differential thermal expansion between the tubes and shell, (4) crevice-free construction, and (5) capability for complete radiography of tube-to-tube sheet welds. Operating experience with this design should yield significant data which will be applicable to larger modular steam generators as well as other concepts.

Dr. Eggen stated that AI does not claim any proprietary rights in respect to the modular concept. He further stated that the BLH Company holds a patent right covering the internal tube-to-tube sheet welding process which AI plans to use for the fabrication of the modular units. AI currently has an agreement with BLH providing unrestricted use of the welding process for the experimental units to be installed in the SCTI.

A royalty charge is anticipated on modules for commercial application.

The Committee is interested in actively following the development of the test program for the modular steam generator units. AI should be urged to provide information on this subject to the Committee as it becomes available. Although a firm design of the modular units has not yet been prepared, it appears to the Committee that the present intention of AI is to minimize internal instrumentation (primarily thermocouples) in the modular units. The Committee believes that it is desirable to include thermocouples to monitor the shell side sodium temperatures and flow distribution as well as tube wall temperatures. This instrumentation would provide a possible means of detecting liquid level in the evaporator unit.

AI plans to examine the problem of instrumentation for the modular units and recommend an approach which would be adequate to validate design calculations and permit determination of operating characteristics.

○ MILESTONES -
SYSTEM
INSTALLATIONS

▽ MILESTONES -
UNIT
INSTALLATIONS

1 COMPLETE STEAM PIPING AND
ACCESSORIES

2 COMPLETE INERT GAS SYSTEM

3 START TCC CONTRACT

4 START EQUIPMENT SETTING

5 START ELECTRICAL SYSTEM

6 START PIPING SYSTEM

7 START GAS PREHEATING
SYSTEM

8 START INSTRUMENTATION

9 COMPLETE EQUIPMENT SETTING

10 COMPLETE SODIUM SYSTEM
PIPING

11 START SYSTEM INSULATION

12 COMPLETE PIPING SYSTEM

13 START SYSTEM CHECKOUT -
TOTAL

14 START INSTALLATION PACKAGE

15 COMPLETE GAS PREHEATING
SYSTEM

16 COMPLETE SYSTEM INSULATION

17 COMPLETE ELECTRICAL SYSTEM

18 COMPLETE INSTRUMENTATION

19 INSTALL ALCO STEAM
GENERATOR

20 COMPLETE INSTALLATION
PACKAGE

21 COMPLETE SYSTEMS CHECKOUT -
TOTAL

22 ISOTHERMAL SODIUM SYSTEM
TEST

23 COMPLETE ISOTHERMAL SODIUM
SYSTEM TEST

(A) INSTALL DESUPERHEATER

(B) INSTALL SODIUM PREHEATER

(C) INSTALL SODIUM COOLER

(D) SHIPMENT OF AEC FURNISHED
STEAM GENERATOR FROM BLH

(E) DELIVERY OF AEC FURNISHED
STEAM GENERATOR

(F) DELIVERY OF A.I. FURNISHED
MODULAR STEAM GENERATOR

SCTI MASTER SCHEDULE 10/30/63

Figure 1

Report of Meeting on December 18, 1963

On December 18, 1963, the SGTP Ad Hoc Committee members visited Baldwin-Lima-Hamilton Corporation (BLH) to review the work being done on the Alco/BLH sodium heated steam generator. Those committee members present were:

A. E. Mravca, AEC-CH - Chairman
G. C. Gower, AEC-CH - Member
K. D. Kuczen, ANL - Member
R. MacPherson, ORNL - Member

(Mr. K. Hoffman, BNL, was unable to attend due to illness; however, he did review this report and concurs with the contents.)

Those contacted at BLH and others present were:

BLH

P. S. Otten, Project Manager
R. B. Abderhalden, Project Engineer
S. Chopko, Shop Foreman

Others

Donald M. Carden, NYO
C. E. Peterson, AI

The purpose of the committee's visit was to examine visually the internal hardware and instrumentation of the steam generator before final closure welds are made and to review the assembly procedure and schedule.

Steam Generator Status

At the time of our visit, the steam generator tube nest was being assembled, internal thermocouples had been installed, and the two inner rows of tubes were in place.

During the process of expanding five tubes into the positioning guide ring, the expander rollers broke in two tubes. Airetool Manufacturing Company, consultants, had been called in to assist in determining the cause of this breakage. Two possible causes for the roller breakage appear to be (1) the tubes were rolled without a lubricant, and (2) there may be some interference between the end of the roller and the tube's sine wave curvature. The representatives of the Airetool Company recommended the use of a special lubricant called "Lube-a-tube." This lubricant was developed for applications requiring zero chloride contamination. The lubricant is water soluble and should not present a cleanup problem. G. Whitefield Richards of 1731 Wood Street, Philadelphia, Pennsylvania, manufactures the lubricant.

At the committee's request, BLH performed several tube expansions on typical samples, both dry and with a lubricant. Visual examination of a sectioned specimen after rolling without a lubricant indicated scoring of the internal surface. The depth of the score marks appear to be less than 5

mils. (The Inconel thickness is a nominal 32 mils.) It was felt that the possibility of more severe damage in the actual tube bundle was unlikely; therefore, replacement of the tubes does not appear warranted. Verification of this conclusion by boroscopic examination is planned. If boroscopic examination does indicate that the integrity of the Inconel liner has been jeopardized, it is recommended that these tubes be plugged. Replacing the tubes at this stage of fabrication involved considerable danger to damaging the trepan area of the tube sheets. Plugging these tubes would not significantly reduce the capacity of the unit.

Also discussed were the assembly bars BLH installed to assist in placing the tube nest into the shell. These bars, as now positioned, may present a differential expansion problem since the upper and lower tubesheets are tied together through the baffle structure. To permit unrestrained expansion of the baffle structure, it is recommended that these bars be cut loose at the upper end, after having served their purpose, and attached to a floating ring to prevent the possibility of flow-induced vibration in the bars. BLH concurs and will initiate this operation after the tube bundle has been placed inside the shell.

The steam generator shell internal structures (shroud ring, upper thermal shielding and flow impingement shroud) are welded in place. The lower thermal shielding sections have been assembled around a dummy tube nest and inserted into the shell for a dimensional check. As approved by CH, seven inches at the upper end of the lower shell thermal shield was removed to allow an improved fit up of the tongue and groove seal. Also designers had been contacted previously and an analysis made of the increased leakage this shortening may produce. The rationale behind the shield shortening was reviewed for the benefit of the committee. It does not appear that shortening of the thermal shield will cause any significant reduction in the steam generator performance.

Of the 600 tube holes (both upper and lower) drilled through the tubesheets, two holes will require special attention. Both of these holes are located in the upper tubesheet. They are hole 27, row 2; and hole 1, row 4. BLH was in the process of making preliminary tube-to-tubesheet expansions to determine if they could safely expand a tube to the extent necessary to repair hole 27, row 2, in the upper tubesheet by the approach they have proposed. (BLH was requested by letter from Mattmueller to Otten, dated November 27, 1963, to perform this preliminary expanding.)

Tube-to-Tubesheet Welding

Our visit included a tour of the weld shop where one welder was in the process of making practice welds on a steam generator mock-up tubesheet. No welders had been qualified to date (December 18, 1963). Several weld passes on mock-up tubesheet blocks were witnessed and examined by the committee. For the tube-to-tubesheet welding operation, the steam generator, which is about 45 ft long, will be uprighted and placed in a pit. Scaffolding will be used to support the welding equipment and welders. Fourteen working days (two 12-hr shifts) have been scheduled to complete the 600 tube-to-tubesheet welds.

Fabrication Schedule

The schedule for completion of the steam generator is given briefly below:

12/23/63	Fit and tackweld lower tubesheet to shell.
1/6/64	Install sodium outlet nozzle thermal liner.
1/27/64	Complete lower tubesheet weld to shell.
2/24/64	Complete upper tubesheet joints.
3/16/64	Complete lower tubesheet joints.
3/30/64	Fit and tackweld upper and lower high pressure heads.
4/13/64	Complete head girth welds and overlay with Inconel
4/27/64	Apply strain gages and hydrotest tube side.
5/11/64	Hydrotest shell.
5/18/64	Final cleaning, reinstall covers and crate for shipping.

Due to accumulated slippages to date and the delay resulting from the tube expanding problem, it appears that BLH is about 14 working days behind the above schedule.

High Temperature Steam Loop

The purpose for constructing and operating the high temperature steam loop was primarily to obtain information on the bimetallic sine wave tubes and tubesheet joints under simulated operating conditions so that this information could be incorporated into the steam generator design. Due to the schedule slippage resulting from recent loop modifications and considering the status for fabricating the steam generator, it is not possible to obtain information from the loop to be factored into the steam generator design. In addition, it is questionable whether any information from the test loop will be made available in time to verify the integrity of the steam generator.

Conclusions

As a result of this visit, several conclusions were reached.

- a. BLH did not make the normal preliminary practice runs on simulated geometries of the tube-to-guide ring rolling procedure prior to initiating such work on the steam generator.
- b. BLH has not replaced the welding engineer associated with the steam generator tube-to-tubesheet welding. Mr. C. J. Ascenzi left BLH about three weeks ago.
- c. No welders as yet have been qualified to perform the tube-to-tubesheet welding procedure.
- d. It is unlikely that BLH can complete the steam generator and have it ready for shipment before June 30, 1964.

Recommendations

- a. It appears that the tube-to-header welding procedures are technically sound and should result in a weld suitable for the purpose intended. However, the committee recommends the following:
 - 1. The welding procedure be under the surveillance of a welding engineer assigned to the fabrication of the steam generator.
 - 2. No less than three welders be qualified to perform the tube-to-tubesheet welding and that the qualification procedure commence as soon as possible.
 - 3. The Commission request that BLH submit sectioned welds, radiographs, etc., that were used as a basis for the qualification of the welders. These submittals should then be reviewed by a welding expert from the National Laboratories or other sources as deemed necessary to review the welder qualification prior to the actual welding of tube-to-tubesheet joints.
- b. The results of the boroscope examination on the first five tubes rolled into the guide ring should be reviewed by the Commission at which time it can be decided whether these tubes should be plugged.
- c. The assembly bars should be cut loose at the upper end and welded to a ring-like structure to allow unimpeded expansion of the baffle structure and prevent possible bar vibration due to sodium impingement.
- d. Due to test loop modifications and the schedule slippage, further work on the high pressure-high temperature steam loop should be discontinued.

Report of Meeting on December 19-20, 1963

On December 19 and 20, 1963, the SGTP Ad Hoc Committee visited the Babcock and Wilcox Company (B&W), Barberton, Ohio, to review and discuss the work they are doing under the second sodium-heated steam generator contract.

The committee members present were:

A. E. Mravca, AEC-CH - Chairman
G. C. Gower, AEC-CH - Member
K. D. Kuczen, ANL - Member
R. MacPherson, ORNL - Member

(Mr. K. Hoffman, BNL, was unable to attend due to illness; however, he did review this report and concurs with the contents.)

The principal people contacted at B&W were:

T. S. Sprague, Manager, Nuclear and Special Product Engineering
J. F. Harvey, Assistant Manager, Nuclear and Special Product Engineering
J. H. Ammon, Technical Advisor, Nuclear and Special Product Engineering
P. B. Probert, Manager, Sodium Boiler Development Project
J. G. Clark, Functional Engineering Group
F. Armstrong, Welding Section of Quality Control
G. R. Forrer, Chief, X-ray Tech., Quality Control
R. K. Allen, Alliance Research Center
T. M. Campbell, Jr., Alliance Research Center
J. R. Carver, Alliance Research Center
E. Fortner, Alliance Research Center
C. R. Kakarala, Alliance Research Center
W. A. Keilbaugh, Alliance Research Center
P. J. Kovach, Alliance Research Center
W. Markert, Jr., Alliance Research Center
H. H. Poor, Alliance Research Center
J. P. Rowe, Alliance Research Center
T. O. Speidel, Alliance Research Center

Highlights of this trip are summarized below:

a. B&W Organization

Paul Probert opened the meeting by discussing the B&W organization which will handle this work. A copy of the organizational chart is attached.

b. Role of Steam Generator Ad Hoc Committee

At Mr. Probert's request, Mr. Mravca discussed the role that the Steam Generator Ad Hoc Committee plays in the Commission program. Mr. Mravca advised him that: (1) the committee is an advisory body which makes technical recommendations to the Sodium Components Working Group headed by Dr. G. Wensch, AEC Headquarters, and (b) if the recommendations are considered by the Working Group to be of merit, AEC Washington then takes the appropriate action through the cognizant Commission contracting officer who issues instructions to the contractor. Mr. Mravca emphasized that the only source of instructions for their contract would be the contracting officer or persons designated by him.

c. Steam Generator Design

The design of the large steam generator was discussed in considerable detail. B&W pointed out some of the problems associated with their design and acknowledged other potential problems cited by the committee members. The salient problems discussed were:

1. Coiled water-tube arrangement having inlet and outlet headers at the same elevation are difficult, at best, to drain and may present a problem during initial system cleanup.
2. The sodium flow bypass arrangement creates a mixing problem at the steam generator outlet nozzle.
3. Gas space annulus will require constant draining due to sodium refluxing.
4. Methods for detecting sodium level have not been worked out as yet.
5. Long-travel bellow-seals are proposed to seal the bypass sodium flow valve stem. Oxide buildup may be a problem and operation, while cold, may cause rupture.
6. Designing the shell for 300 psig, as specified, forces the shell-separation-flanges to be very thick and, hence, costly.

All of the above problems are recognized by B&W and will be studied further. On several of the problems discussed, the committee recommended various people known to have worked on similar problems who would be of assistance if contacted.

The large boiler preliminary design is scheduled for completion April 1, 1964. At that time the major design effort will be shifted to the 30 Mwt prototype. Seven months' design effort is planned on the prototype with fabrication of the unit scheduled to start November 1, 1964, and continue to August 1965. B&W stated that they plan to get firm fabrication dates

for the prototype from their shop shortly and will forward their information to the AEC when available.

d. R&D Program

B&W reviewed the status of the R&D program which has been approved under the contract.

1. Effect of heat transfer on two-phase flow in coiled tubes.
2. Materials - carbon transfer experiments.
3. Corrosion rates of Cr 2 1/4 and 316 SS in Na-H₂O reaction products.
4. Chemical simulation of sodium environment for leak testing.
5. Development of an automatic butt welder for tube-to-tubesheet welds.
6. Development of a point source X-ray for tube-to-tubesheet joint inspection.

The R&D program status is essentially that reported in their Sixth Quarterly Progress Report, which was then just completed for issuance; and copies were distributed to the members. The status will not be reported here except for a few salient items.

e. Heat Transfer Loop

The heat transfer loop is in the process of being modified to accommodate the coiled tube test section. Loop shakedown and modification is scheduled to start in January 1964. The coiled section is about 27 feet long, 0.75" OD and 0.170" wall thickness. Six thermocouples are located circumferentially around the tube every six inches of tube length. There is a 30 degree shift in thermocouple orientation every six inches. Voltage taps are also located on six-inch centers. Heat fluxes in the range of 150,000 Btu/hr·ft² are expected in this loop which will operate at 2600 psig.

f. Materials - Carbon Transfer Experiments

B&W presented in considerable detail their view on the information necessary to design a sodium-heated steam generator to the specifications in the contract. They agree that mass transfer has been, and is being, studied and the results reported; but it is their opinion that there is not enough information to predict, with any degree of confidence, the extent of mass transfer, and the effects on mechanical properties, which will occur in a sodium-heated steam generator designed for thirty years of operation.

Further, they (B&W) explained that the published results of mass transfer studies are often difficult to interpret, or even conflicting, and a lack of agreement on transfer rates and the effects of different variables exist. These differences and uncertainties in reported literature indicate that predictions of the effects of mass transfer would be of questionable value.

An example was cited as being representative of the current general technique used to study mass transfer. This technique involves insertion of a specimen in a complex sodium loop where the specimens are periodically removed and replaced with new materials. This technique changes the loop conditions such that each sample has been exposed to a different and largely unknown environment. The effect of these changes are difficult to factor into predicting material lifetime performance for power plants.

The purpose of the current program is to study the carbon and mass transfer effects in a sodium-heated steam loop containing both austenitic and ferritic materials (TP 316SS and Croloy 2 1/4). The ratio of ferritic to austenitic materials, the ratio of steel surface to sodium volume, and the fluid temperatures, pressure, and mass velocities will duplicate insofar as possible those expected in the steam generator.

The functional design of the test loop has been completed and detail design of the test components is proceeding. Long delivery items, such as the sodium and water pumps, have been ordered.

The test program agenda is scheduled to be completed shortly. Briefly, B&W has geared the program toward determining the mass transfer mechanism (they are concentrating on diffusion) and the effects of mass transfer on the mechanical properties of the materials of construction.

B&W stated that at present neither the mechanism nor the rate-controlling step of carbon transfer in the sodium system are very well defined. Therefore, no reasonable extrapolation of short-term data can be made to predict long-term effects. B&W indicated that they, therefore, plan to submit a proposal for an extension to the original program to study in detail the diffusion mechanism in mass transfer, because they believe that such a study will yield information for predicting the long-term behavior of materials including mechanical properties in a sodium system.

Conclusions

- a. The design of the large sodium-heated boiler appears to be technically sound at the present stage of design.

- b. The prototype design will start in about three months and will mock up pertinent design parameters of the large boiler without regard to performance or cost optimization of the prototype.
- c. B&W's manufacturing capabilities, with respect to steam generating equipment appear to be very adequate.
- d. B&W has been requested by CH to resubmit a Na-H₂O reaction experimental program more in line with their original proposal in regard to scope and level of support.
- e. B&W personnel said that they plan to submit a proposal in the near future to extend the mass transfer experimental work.
- f. The B&W organization to conduct the work under the contract appears very capable.

Recommendations

- a. The committee recommends that the appropriate researchers from the B&W-ARC present their plans for extending the mass transfer program to the Ad Hoc Committee for Mass Transfer.
- b. If a. above is not possible in the near future, invite B&W to give a presentation in Washington to the Sodium Component Development Program Working Group at their next meeting.
- c. B&W should present an analysis and justification for lowering the shell design pressure if their detail analysis warrants this change.

Status Report on Steam Generators as of January 16, 1964

1. Introduction

The purpose of this presentation is to review the status of the Sodium-Heated Steam Generator Development Program. The objective of this program is to provide an engineering design and operational experience basis for sodium heated steam generators capable of sodium design temperatures of 1200°F to produce 1050°F steam. The four major elements of this development effort consist of:

- a. Sodium Component Test Installation
- b. First Steam Generator - Alco/BLH
- c. Second Steam Generator - B&W
- d. Modular Steam Generator - AI

Salient aspects of the status of the four efforts are described below:

a. SCTI

The sodium component test installation is a large liquid metal system designed for developmental and proof testing of prototype sodium-heated steam generators and sodium-to-sodium heat exchangers. The system has capability for units between 30 and 35 Mw with operating sodium temperatures up to 1300°F for short periods and 1200°F continuously. The sodium is heated in a 35 Mw gas-fired sodium heater. Heat rejection from the system is through a forced draft cooling tower which supplies cooling water to the steam condenser. No useful work is done by the steam generated in the testing. Instead, the high pressure steam passes through several pressure reducing stations and a single desuperheating section before introduction into the steam condenser.

Operational testing is to determine the steady state performance of units to ascertain that heat transfer specifications have been met. These data will serve to verify or disprove the theoretical approaches utilized in design of a specific unit. Proof testing will be concerned primarily with subjecting a particular unit to the thermal and flow transients that are required in the application. The transient capabilities of the facility are those that were designated for evaluation of the first prototype units designed by Alco.

Status -- Construction of the SCTI is now about 97 per cent complete. All major equipment items are installed with the exception of the steam generator and its associated equipment. With the exception of the steam generator construction completion is estimated to be February 15, 1964. The remaining installation work is being performed by the Technical Construction Corporation (contractor) and includes (1) steam and sodium piping insulation, (2) control wiring for the heater system and (3) instrumentation wiring. The instrumentation

system checkout work will be started on January 20. Four instrumentation technicians have been assigned from AI's instrument group to perform the instrumentation checkout.

System Checkout --

- (1) Instrumentation checkout without sodium in the system.
- (2) Primary system checkout with sodium at isothermal conditions.
- * (3) Secondary sodium system checkout with steam generator.
- (4) Feedwater and steam system checkout.
- (5) Begin testing program.

*If the steam generator is not available at the time required for Item (3) above, it is planned to test the secondary sodium system with a spool piece in place of the steam generator. Under these circumstances the secondary system would be tested isothermally and the feedwater and steam system checkout would be deferred until a generator is available.

Considering the work remaining to be accomplished it is believed that the current schedule represents the least possible time to complete the construction and checkout of the SCTI. In view of the many time-consuming problems which are generally encountered in checking out a complex facility such as the SCTI, it was recommended that AI be encouraged to proceed with completion and checkout of the system as rapidly as possible and not program the checkout schedule with delivery of the steam generator should its schedule be further delayed.

Test Program -- The SCTI testing capabilities and the test program developed for the BLH steam generator have been subject to a continuing review by the Sodium Component Working Group; and the facility design, as it now exists, appears to be capable of performing the detail program set forth in the Alco report (APAE - 122) with one recognized exception - the inability to test the IHX without a heat sink.

Operating Crew -- At present AI has 7 men assigned to the operating staff for SCTI. Two of the four operating crews will be on board by April 1, 1964. The other two crews will be available by July 1, 1964. The operational staff may reach a total of 23 if it is desirable to operate on a 24-hour per day, 7-day per week schedule. Pre-operating checkout, operating, and startup procedures, are being developed by the existing staff.

General -- In November 1963, AI cancelled all the bids for installation of the Alco/BLH steam generator when it became apparent that the generator delivery date was delayed to May 18, 1964. AI now plans to solicit bids for this work during the latter part of January 1964. Based on a recent study, AI indicated that they plan to recommend installation of the Alco/BLH steam generator and modular steam generators in parallel at the SCTI. Only one unit would be hooked up and operated at a time. AI's recommendation letter is expected next week.

b. BLH

The work at BLH consists of completing the fabrication of the Alco steam generator. The steam generator is a once-through type, shell-and-tube construction incorporating a fixed tube bundle, sine wave tubes, and disc and doughnut baffles. The unbaffled portion of the steam generator is used to provide for a sodium gas blanket and rupture disc. The water side high pressure heads are hemispherical and each include a manway to provide access to the tubesheet for inspection and maintenance.

The sodium side of the steam generator is constructed of 316 SS. The upper and lower tubesheets and heads feature 5/8 inch minimum thickness Inconel overlay on 316 SS. The tubes feature a bimetallic construction with a metallurgically bonded .032 inch thick Inconel inner tube on the water side, bonded to a nominal 1/2 inch OD stainless steel, with a .072 inch wall thickness.

Status -- The steam generator shell internal structures (shroud ring, upper thermal shielding, flow impingement shroud) are welded in place. The steam generator tube nest has been assembled and the internal thermalcouples have been installed. Currently BLH is fitting and tackwelding the lower tubesheet to the shell.

The Alco IHX has been fabricated and installed in the SCTI.

Fabrication Schedule -- BLH's schedule for completion of the steam generator is as follows:

1/27/64	Complete lower tubesheet weld to shell. Complete upper tubesheet weld to shell.
2/24/64	Complete upper tube-to-tubesheet joints.
3/16/64	Complete lower tube-to-tubesheet joints.
3/30/64	Fit and tackweld upper and lower high pressure heads.
4/13/64	Complete head girth welds and overlay with Inconel.
4/27/64	Apply strain gages and hydrotest water side.
5/11/64	Hydrotest shell.
5/18/64	Final cleaning, reassembly covers, and crate for shipping.

Due to accumulated slippages to date and the delay resulting from the tube expanding problem, (to be mentioned later) BLH is about fifteen working days behind the above schedule. Based upon the Committee's review during a visit to BLH on December 18, 1963, it appeared that the steam generator will more likely be ready for shipment by June 30, 1963.

Recent Fabrication Problems -- The specifications call for expanding the tubes without lubricant into a positioning guide ring,

however, during the initial expanding operation, considerable difficulty has been encountered with the expanding roller breaking. This procedure was subsequently abandoned and, an alternative method consisting of tackwelding the tubes to the positioning guide ring was utilized. The tackweld penetrates the outer stainless steel tube about half the thickness, (36 mils).

R&D - High Temperature Steam Loop -- The purpose for constructing and operating the high temperature steam loop was primarily to obtain information on the bimetallic sine wave tubes and tube sheet joints under simulated operating conditions so that this information could be incorporated into the steam generator design. Due to the schedule slippage resulting from recent loop modifications and considering the status for fabricating the steam generator, it is not possible to obtain information from the loop to be factored into the steam generator design. In addition, it is questionable that any information from the test loop will be made available in time to verify the integrity of the steam generator. Due to the schedule slippage in the loop operation further work on the loop has been discontinued.

c. B&W

The objective of the B&W work is to develop a sodium-heated steam generator design of a size such that three such units operated in parallel will accommodate a 1000 Mwe sodium-cooled reactor. A 30 Mwe prototype of the large steam generator design will be built and tested in the SCTI. The scope of work under the contract consists of two (2) phases.

Phase I

- (1) Preliminary design of Full-Size Sodium-Heated Steam Generator.
- (2) Supporting Research and Development Work.
- (3) Preliminary design of 30 Mwt Prototype Steam Generator.

Phase II

- (1) Detail design of Prototype Steam Generator.
- (2) Fabrication of Prototype Steam Generator for Installation and testing at SCTI, Santa Susana, California.
- (3) Final Design Report relating the performance of the Prototype to the design of the Full-Size Steam Generator.

The status of work under Phase I is as follows:

- (1) Preliminary Design Full-Size Boiler -- The reference steam generator design consists of an integral evaporator-superheater of the once-through type and of single-tube-wall construction. Concentric helical coils are being used for the boiler and superheater sections. The steam generator is designed to permit the superheater and boiler tube banks to

be individually removable for inspection or repair. Currently the boiler bank consists of Cr 2½ and the superheater material is type 316 SS.

The current design has a reheater located in a separate vessel. The first concept of a reheater is a helical coil.

Separate studies are being made to determine the economical and technical feasibility of combining the reheater, superheater and boiler into one vessel.

The reference full-size steam generator design is about 75 per cent complete and is scheduled to be completed by April 1, 1964.

- (2) 30 Mwt Prototype Steam Generator -- Design work on the 30 Mwt prototype steam generator has been started (five months ahead of the original schedule) in order to have a pace to work from in trying to model the problems of the full-size steam generator. Final design of the prototype is scheduled to be completed by November 1, 1964.

- (3) R&D Program -- A schedule for the R&D program is attached.

- (a) Heat transfer on two-phase flow in coiled tubes.

Objective - The purpose of this program is to determine the effect of making a tube in a coil configuration on:

- A. the location of the Departure from Nucleate Boiling,
- B. the nucleate and film boiling heat transfer conductances.

The results of this program are essential to be able to determine accurately the amount of heat transfer surface required for the steam generator being designed under this contract and assure the tubes will not suffer fatigue or corrosion failures due to temperature fluctuations at the DNB point.

Status - B&W's heat transfer loop is presently in the process of being modified to accommodate the coiled tube section. Loop shakedown and modification is scheduled to start in late January 1964.

- (b) Materials - Carbon transfer experiments.

Objective - The purpose of this program is to study the carbon and mass transfer effects in a sodium-heated steam generator containing both austenitic and ferritic materials, and to determine that these materials will be satisfactory on both the sodium and the water side for use under the planned operating conditions.

Status - The current program is geared to studying the carbon and mass transfer effects in a sodium-heated

steam loop containing both austenitic and ferritic materials (TP316 SS and Cr 2½). The ratio of ferritic to austenitic materials, the ratio of steel surface to sodium volume, and the fluid temperatures, pressure, and mass velocities will duplicate insofar as possible those expected in the larger generator design.

The functional design of the test loop has been completed and detail design of the test components is proceeding. Long delivery items, such as the sodium and water pumps, have been ordered.

The test program agenda is scheduled to be completed shortly. B&W has geared the program toward determining the mass transfer mechanism (they are concentrating on determining diffusion coefficients) and the effects of mass transfer on the mechanical properties of the materials of construction for their specific system.

(c) Corrosion rates of Cr 2½ in Na-H₂O reaction products.

Objective - The objective of this program is to provide information pertaining to the rate of corrosion of Cr 2½ steel with the reaction products of a water-to-sodium leak. A second objective is to be able to postulate the mechanism of reaction between Cr 2½ steel and the sodium-water reaction products.

Status - At the beginning of October an investigation was initiated on the determination of the corrosion rates of Cr 2½ steel in aqueous sodium hydroxide solutions. Corrosion data has been obtained in a 24.2 weight per cent aqueous solution of sodium hydroxide at 140, 170 and 200°F at time intervals of ½, 1 and 3½ and 7 hours. An examination of the data indicates a reasonable progression of corrosion of the metal as the temperature is increased and as the time of exposure of the metal to the sodium hydroxide solution is lengthened.

Future corrosion data of Cr 2½ will be determined at the boiling point of the 24.2 weight per cent sodium hydroxide solution using the same time intervals used at the lower temperatures. Concentrations of aqueous sodium hydroxide solutions of approximately 50, 75 and 98 per cent will then be investigated for their corrosive effects on Cr 2½ steel.

(d) Chemical simulation of sodium environment for leak testing.

Objective - This program is to find a suitable reagent to leach out oxide inclusions in Cr 2½ and Type 316 SS.

Status - Specimens of weld slag from Cr 2½ and Type 316 SS have been made. Tests to determine the solubility of this slag in sulfamic acid, ethylenediamine tetracetic acid, (EDTA) and the tetrasodium salt of EDTA have been started.

Preliminary experimental results to date indicate that a 5 per cent solution of sulfamic acid removes approximately 85 per cent of the weld slag from 316 SS weld specimens.

- (e) Development of point source X-ray for tube-to-tubesheet joint inspection.

Objective - This program is to demonstrate the feasibility of constructing a point source for radio-graphing the tube-to-tubesheet welds.

Status - The actual design of this source will depend on diameters and thicknesses of the tubes for the steam generator which is being designed. Work on the x-ray source will be begun as soon as the design work on the steam generator has advanced far enough to set the configuration of the tube ends to be x-rayed.

- (f) Development of an automatic butt welder for tube-to-tube-sheet welds.

Objective - The work under this program is to complete the development of the welding machine and quality control procedures and demonstrate the ability to produce sound welds in tubes of the sizes and materials used in the boiler being designed under this contract.

Status - Work on this welding procedure has awaited having design work on the Full-Size Steam Generator far enough to define the location and types of welds, thicknesses, etc. Sufficient layout drawings have been made to define most of the welding considerations. Calculations are being made on the design of a welding machine to handle all tube sizes, thicknesses, and materials for this boiler.

- (g) Sodium Water Reactions.

This portion of the R&D program has not been started. B&W has recently been requested to develop a program which is more in line with their original proposal in regard to scope of work and level of support. A letter outlining such a program was received from B&W on January 14, 1963. B&W stated that the "minimum scope" program in support of the prototype will cost approximately \$93,900 and would include:

- A. Engineering analysis by APDA of the sodium-water reaction problem on the boiler being designed under their contract (\$69,015).
- B. Corrosion investigations of Cr 2½ steel in products of sodium-water reaction (\$24,075).

B&W further stated that the actual model testing and more general sodium-water reaction work (estimated at \$606,940) can probably be deferred, but should be accomplished as quickly as possible. B&W would like to see the latter program supported as a backup to the 1000 Mwe steam generator design.

d. Modular Steam Generator - AI

The AI modular steam generator concept has in the past been mainly one of conceptual design study and fabrication development. Recently the Commission has provided authorization to fabricate and test two 37-tube steam generators (consisting of two boilers and two superheaters in parallel) as per the AI concept. The modules are designed for generating 2400 psi steam at 1050°F. The evaporator will be constructed of 5 Chrome - $\frac{1}{2}$ moly ferritic steel. The superheater module will be constructed of 321 SS. The two modules have a collective rating of about 21 Mwt thermal whereas the SCTI is designed to operate up to 35 Mwt.

In November 1963, AI has planned advanced procurement orders for the modules (prior to receipt of AEC authorization) and expect to start fabrication and assembly of units in April 1964. Completion of the first module (one boiler and one superheater) is scheduled for July 1964, and the second unit is scheduled for completion in September 1964. AI plans to fabricate the modules in their own shops. Final fabrication drawings of the modules have recently been completed and will be submitted to the Commission shortly.

5. Future Program Plans

- a. Review welder qualification at BLH.
- b. Review B&W sodium-water reactor program.
- c. Review SCTI operating procedure.
- d. Recommend who will analyze BLH unit test results and prepare final report.
- e. Evaluate AI study for installation of both BLH and Modules simultaneously.
- f. Coordinate B&W test program requirements and schedule for testing 30 Mwt prototype in the SCTI with Atomics International.

6. Summary

During calendar year 1964 we should see:

- a. Completion of construction and pre-operational checkout of the SCTI.
- b. Installation and testing of the BLH steam generator.
- c. Fabrication of the modules - possibly some testing.
- d. A final design by B&W on the 30 Mw prototype.

In summary a significant amount of experimental data from the SCTI program should be generated.

STEAM GENERATOR PROGRAM SCHEDULE

(R&D Program)

Report of Meeting on March 11, 1964

On March 11, 1964, the SGTP Ad Hoc Committee members met at Santa Monica, California, to discuss with Ralph H. Jones, DRD, Headquarters, various aspects of sodium-water reaction as they may apply to steam generator design.

Those Present

R. H. Jones, DRD, HQ (Speaker)
A. E. Mravca, CH (Chairman)
G. C. Gower, CH (Member)
K. D. Kuczen, ANL (Member)
R. E. MacPherson, ORNL (Member)
L. A. Whinery, LASL (Member)
C. W. Richards, CP, AEC (Visitor)

Mr. Jones began his presentation with a review of the background work which has been carried out on the sodium-water reaction. He briefly reviewed experimental work at Mine Safety Appliances (MSA) Atomic Power Development Associates (APDA), General Electric (GE), Nuclear Development Associates (NDA), and IIT Research Institute (formerly Armour Research Foundation). He then covered in detail a theoretical study he had performed while employed at Atomics International (AI).

The MSA sodium-water work was for the submarine program, and the tests led to the conclusion that the problem was not serious for that application. The APDA experiments gave an indication of the nature and extent of pressure pulses resulting from the sodium-water reaction as well as the effect of system inertance and capacitance thereon. Work at GE and NDA was not directly applicable due to the nature of the tests performed. The studies by IIT Research Institute of the Alco steam generator unit used a simplified model and were compromised somewhat by this fact.

The AI study performed by Mr. Jones was concerned with the Alco unit and made the following assumptions:

- a. No shock wave was generated by the reaction.
- b. The rupture diaphragm did not relieve until 50 milliseconds after the start of the reaction period.
- c. The sodium-water reaction was considered instantaneous, producing Na_2O and H_2 .
- d. There was no steam-sodium reaction.
- e. No sodium hydride was formed.
- f. Heat transfer in the failed tube was unaffected so that the water and steam feed temperatures were constant.
- g. Sodium was considered incompressible (fluid capacitance omitted).
- h. The shell side pressure increase did not influence the feed flow of steam and water.

By taking into account the various flow rates to the reaction site, the type and heat of reaction, the inertance of the secondary system, the pump characteristics, and the system flow characteristics a system model was developed with which energy release and pressure rise calculations could be made.

Certain of the pressure rise data are tabulated below.

<u>Failure at</u>	<u>Mean Reaction Site Sustained at Pressure During First 50 Milliseconds (psi)</u>		
	<u>Number of Tubes Ruptured</u>		
	<u>1</u>	<u>2</u>	<u>10</u>
Lower Tube Sheet	465	725	2050*
Mid-plane	315	455	1000*
(Pressure at Lower Rupture Diameter)	(245)	(355)	(805)*

* Extrapolated values

Energy deposition in the heat exchanger structure was investigated based on the sodium-water reaction model and on the true-stress, true-strain curves for the materials involved. This technique for predicting failure was defeated by the inability to define the volume and thus the capacity of the energy deposition sink. It was, however, roughly apparent that a failure at the lower end of the steam generator could cause yielding of the shell. It also appeared that catastrophic rupture of the steam generator was possible under certain "worse case" conditions.

As a result of this investigation the following steam generator design criteria have been specified:

- a. The flow area in the tubes should be as small as practical.
- b. The shell side free-flow area should be as large as practical.
- c. The steam pressure should be as low as practical.
- d. The shell side configuration should be as simple as practical with no solid cross baffles and with grill type tube supports.
- e. The shell side pressure drop should be as low as practical.
- f. The rupture diaphragms should be located close to the possible reaction sites.
- g. Reliance should not be placed in gas spaces as cushions against pressure surges.
- h. The steam generator shell strength should not be increased to accommodate pressure surges without investigating the effect on the complete secondary system. The rupture problem may move to the secondary piping or to the IHX.
- i. Pressure limiting devices should be considered which can be installed integral to the unit. Sacrificial gas volumes of various types would limit pressure surges.

Adoption of these design criteria will lead to a steam generator design which has the best possibility of surviving the side effects of a massive steam-water reaction.

Based on the results of this study of the Alco unit, AI is urged to adopt any of the following procedures not already incorporated in the test program.

- a. Except in extreme emergencies, access to the steam generator pit should be forbidden during periods when both the sodium and steam system are in operation. Extreme safety precautions should be taken when such access is necessary.

- b. Access to the test facility building should be forbidden during transient operations. (Currently this procedure is specified in the SCTI operating rules and regulations.)
- c. Access to the test facility during normal operation should be limited, and personnel should normally wear full protective clothing while inside.

Atomics International is also urged to consider the problem of escape routes for personnel working at various locations on the SCTI structure in the event of a serious sodium fire.

The Committee feels that the theoretical study carried out by Mr. Jones provides considerable insight into the problems associated with analysis of sodium-water reactions and their effects. We would, therefore, urge publication (reproduction) of the work and its distribution to interested parties.

Report of Meeting on March 12-13, 1964

On March 12 and 13, 1964, the Ad Hoc Committee members visited Atomics International (AI) to review the following aspects of the SCTI and modular steam generators.

a. SCTI

1. Construction status.
2. Action taken on previous Committee recommendations.
3. Installation of steam generators.
4. Preoperational testing and procedures.

b. Modular Steam Generators

1. Fabrication status.
2. Test program for modules.
3. Instrumentation for modules.
4. ESADA Na-H₂O interaction studies for 61 tube modules.

<u>Committee Members Present</u>	<u>Those Contacted at</u>	
	<u>AEC-Canoga Park</u>	<u>AI</u>
A. Mravca, Chairman	C. Richards	D. Casey
G. Gower		J. Cochran
K. Hoffman		C. Conners
K. Kuczen		D. Eggen
R. MacPherson		W. Hallett
L. Whinery		L. Johnson
		J. Leppard
		W. McSweeney
		S. Siegel
		T. Withers

SCTIConstruction Status

The present schedule indicates that the Technical Construction Corporation contractor will finish the construction work by April 1, 1964. The major portion of the work remaining to be done is electrical. The contractor is presently working on a "punch list" prepared by AI. A 60-hr work week has been put into effect by the contractor to assure completion by April 1, 1964.

Action on Committee's Previous Recommendations

Atomics International's comments to the Committee's previous recommendations on the SCTI are attached to this report. The Committee is in agreement with AI's recommendations with two exceptions - (a) installation of internal instrumentation for the modular steam generators, and (b) need for

check valves in condensate and booster pump discharge lines. The Committee suggests that the check valves be installed for the added protection they afford. Instrumentation for the modules will be discussed later in this report under that subject heading.

Installation of Steam Generators

In October 1963, the AEC asked AI to investigate the possibility of concurrent installation of the Alco/BLH and the modular steam generators in the SCTI. This study resulted in AI's recommendation to install support structures in the test pit to accommodate both steam generators. Atomics International, however, does not believe that both units should be placed in the pit at the same time. Although no serious accidents should occur during the tests, there is always the possibility that a tube may fail during the testing program and that the shell could be breached. In this event, though it does not constitute a hazard outside the immediate area of the steam generator, possible damage could result to the generator located adjacent to it. Atomics International states further that blast protection could be installed around the adjacent steam generator, but they do not recommend doing so since the time saved is not commensurate with the cost of the blast protection.

The Committee reviewed in detail AI's recommendation for dual support structure installation and concurs with their approach. In studying the piping arrangement drawings for the dual installation the Committee expressed concern to AI about certain aspects of the design relative to expansion of rupture disk blow-off lines. Atomics International will look into this matter and make known their findings.

Preoperational Testing and Procedures

Atomics International has divided the testing program into three phases. They are:

- a. Preoperational testing.
- b. Plant performance testing.
- c. Individual component test.

Preoperational testing was due to start January 20, 1964; however, union workers forbade AI technicians to energize equipment for checkout purposes as long as Technical Construction Corporation electricians were on the job. Checkout of part of the pneumatic instrumentation was accomplished by a joint occupancy agreement. Checkout of the electrical equipment will start April 1, 1964. (See attached schedule.)

The purpose of the preoperational testing is to assure preparedness of each system of the plant for operation. Seventeen preoperational tests are planned, and these will include visual inspection and mechanical checkout of equipment, pipe hanger adjustments, setting of relief valves, instrumentation response and adjustment, etc. These tests will also cover

sodium system preheating and filling and hydraulic tests at isothermal conditions.

The purpose of the plant performance phase of the test program is to place the system into operation as an integrated plant. During this phase the operating parameters will be established and should verify the degree to which the SCTI design criteria have been fulfilled.

The first test will be concerned with the electrical power and will be followed by the instrument air system. These tests are planned to proceed up to the time a steam generator is installed, at which time they will be temporarily suspended. After the installation of the steam generator, the preoperational tests will continue to November 1964. Filling of the primary system with sodium is planned for the last week in June; the secondary system is scheduled for filling the middle of September. The plant performance test is due to start the first of November and run for two months. Steam generator testing is to start the first of December 1964.

To acquaint the Committee members with the SCTI organization and their approach to the testing program the following documents were passed out.

- Outline of the operations manual.
- Section I of the operations manual.
- Standard operating procedures for the cooling water system.
- Preoperational test objectives.
- PERT schedule for the preoperational test program.
- Preoperation Test, AIP-009, Electrical Power.

Atomics International has geared its operating organization for SCTI in a fashion quite similar to that utilized on the Hallam Nuclear Power Facility. Several of the key SCTI operating personnel have worked on the Hallam startup program. The SCTI operating organization and startup plans appear to be technically sound.

MODULAR STEAM GENERATORS

Status

All the materials for the modules have been ordered. Tooling design for fabricating the modules has been completed. Due to unexpected difficulty (porosity in the weld) in making acceptable tube-to-tubesheet welds with 5 Cr-1/2 Mo material AI has changed the order of production so that two high temperature modules will be fabricated first then the two low temperature modules will follow. Previous plans were to fabricate one evaporator and one superheater for shipment together. The above-mentioned change will afford AI additional time to solve the welding problem. Atomics International is confident that procurement of vacuum melt forged heads will eliminate the porosity in the welds. Dr. D. Eggen said that they hope to have solved the welding problem by April 15, 1964. If this schedule is met, AI believes that they will have 90-95% confidence in meeting the module fabrication schedule. The present schedule shows completion of two

high temperature modules by July 26, 1964, and two low temperature modules by September 20, 1964.

Test Program for Modules

The criteria for the modular steam generator test program have been established. (Letter, Casey to Waters, et al., AI, dated October 7, 1963.) Dr. Eggen promised drafts of the detail program for the Committee's review by June 1964. Atomics International currently envisions that the test program in the SCTI will require a duration of one year.

Instrumentation for the Modules

The instrumentation for the modular steam generator proposed by AI consists of externally mounted thermocouples and strain gages. The thermocouples are to be arranged so that circumferential and axial temperature measurements can be made on the shells. This, in effect, will give the temperature distribution of the sodium in the modules. The strain gages will measure the strain of the shell, and therefore, the strain of the tube bundle. The tube stresses of the bundle can then be calculated. Inlet and outlet fluid temperatures and flows will also be measured in the headers of the units.

Atomics International has analytically determined that flow instability will not occur in parallel operation of their modular units. Based upon the same analysis they also are confident that flow instability within a single unit will not occur. However, since the design has fixed tube-sheets, if flow instability did occur, some tubes could become overstressed. Although yielding would probably prevent failure within the time of testing, it is unlikely that an overstressed tube could endure 30-year life design.

Atomics International has investigated very thoroughly the stress conditions which will exist under pressure loading of the heads. Strain measurements are not presently planned to determine the combined effect of thermal, thermal cyclic, and pressure loadings.

In addition to the above-mentioned instrumentation the Committee recommends the following:

- a. Install internal thermocouples, in both low temperature modules (evaporators), to measure the tube side fluid temperature at the exit of individual tubes. The tube side fluid exit temperatures can be measured either on the steam side or on the shell side in the gas space. Ideally, fluid temperature measurements at the exit of each tube are most desirable. However, nine thermocouples located in the gas space and arranged in such a fashion to effect a temperature traverse seem to be a minimum. All these thermocouples should be located at the same elevation. If the thermocouples are placed on the steam side, the effect of flow disturbance created by the thermocouples should be considered. Thermocouples if located on the shell side do not present this problem.

- b. Install thermocouples to measure the mixed, mean inlet and outlet temperatures of each low temperature (evaporator) and high temperature (superheater) module. Both the sodium side and the steam-water side should be provided with such thermocouples.
- c. Install strain gages on the heads of the units in the region of the tubesheets.

ESADA Na-H₂O Interaction Studies for 6l Tube Modules

The Committee met with representatives of AI to discuss the sodium-water reaction work being carried out for ESADA by AI. This work is related to the modular steam generator design currently being investigated at AI.

The purposes of the ESADA program are:

- a. To evaluate the effect of a module failure on a reactor system.
- b. To evaluate the effect of a single-tube failure on a module.
- c. To evaluate the use of rupture diaphragms for relieving pressures in case of a tube failure.
- d. To evaluate the effectiveness of separator tanks downstream of rupture diaphragms in handling discharged solids.

This program was presented by J. Leppard.

Summary of Steam Generator Program as of June 11, 19641. Introduction

The following is a highlight summary of the Steam Generator Test Program activities since the last meeting of April 14, 15 and 16, 1964.

2. Summary of Program Activitiesa. SCTI

On a time and materials (T&M) type contract various minor additions and modifications are being made to the SCTI. It was determined that the cold trap lines needed rerouting and additional lighting for night operation was required. These are being taken care of presently. Painting of the iron structural members is in progress and safety guards are being added to several pieces of rotating equipment.

In July work will start on installing a quick sodium dump system for the sodium heater. This entails the installation of a two-inch line from the heater outlet that will be maintained hot whenever the heater is in service. Also in July two metallurgical specimen holders will be installed: one in the primary loop, the other on the secondary side. These are needed to assist in carbon monitoring.

Contracts were let to install the structural members and support for both the Alco/BLH and the modular steam generators and also to supply prefabricated spool pieces and piping for the modular units. The structural work should be completed in mid-July and the piping spool should be completed the second week in August.

Preoperational checkout has been completed on the instrument air system and work is now in progress on the electrical power, inert gas, natural gas and primary preheat systems. By the end of June, if the cold trap work doesn't interfere, the primary loop should be filled with sodium. Work is continuing on the plant standard operating procedures. Preoperational checkout is now about two weeks behind schedule.

b. Alco/BLH - First Steam Generator

All of the tube-to-tubesheet welding was completed May 19, 1964. Vacuum pump oil, estimated to be about a quart, that had leaked into the shell-side of the unit has been flushed out with a naphtha compound. Samples were taken on the third and fourth flushing and tests of the solution showed the naphtha to be free of oil. Chemical analyses will be obtained on the oil and flushing compound. After the flushing, an MS test was performed on the unit and accepted. Total indicated leak rate was 4.5×10^{-7} cc/sec.

The unit was moved from the welding area to the "can" shop and the upper and lower channel heads were tack welded in place. BLH is now in the process of completing the head-to-tubesheet welding. It is scheduled to be completed June 10.

Nondestructive testing is next in line. BLH has plans to install 83 strain gage sites of the low temperature type. These are required to fulfill the requirements of Section III of the Test Program, as described in APAE Report 122. Past plans were to have AI install high temperature gages in 73 of these sites, however, AI reports that procurement of these gages from General Electric Company did not materialize. This is probably for the best when one considers the likelihood of gage damage in shipping and erection at the SCTI.

Seven of the nine thermocouples (T/C) that pierce the lower tube-sheet periphery have been damaged. This was done during the maneuver in which the unit was being prepared for the lower tube end-welding. BLH has plans to repair these T/C's or have others do so.

BLH has been informed of the desirability to pneumatically test the shell side of the steam generator. Preliminary indications from BLH on this matter are that they are reluctant to do pneumatic testing because they do not have adequate facilities. Makeshift blast protection may be required. It is hoped to resolve this problem soon.

The following is the best schedule available for the completion of the unit:

Complete high pressure head installation	6/10
Complete strain gage installation and hookup	6/17
Complete nondestructive testing	6/24
Prepare and ship to AI	7/6

c. B&W - Second Steam Generator

Design Work - The design of the large-size steam generator is essentially complete. Attention is now being directed to completing the preliminary design report which is to be ready for distribution June 17, 1964. Preliminary drawings of the large steam generators have been processed by the B&W pricing and estimating department, and cost data for this unit will be included in the design report. Layout drawings of the prototype steam generator are complete. This design, which is considerably more detailed than the large unit design, has been given to the pricing and estimating department also. Cost data for the prototype will be available about June 15 and, according to B&W, should be within plus or minus 10% of the actual fabrication costs. Previous estimates for building the prototype were based on a rough estimate of the time the unit may be in the shop.

Atomic Power Development Associates, under a subcontract to B&W, has started work on the development of a mathematical model for use in evaluating the consequences of a sodium-water reaction in the prototype steam generator. The basis for this model will be a compilation of all the available sodium-water reaction work done to date. George Gower, Ralph Jones and I visited B&W on April 2 and 3, 1964, to review the status of their design work. Ralph made several recommendations to B&W with respect to possible design changes that would enhance the capability of the steam generator to withstand a sodium-water reaction.

B&W R&D Program - The model boiler test loop B&W has built has been debugged and filled with sodium. An unexpected situation arose with respect to the heating capability of the sodium heater. The loop configuration caused inductive reactance and a high lagging current. The current capacity of the power transformer was exceeded before full heat output was reached. This problem, together with a piping vibration problem, has been resolved and the loop is in operation. Although heat transfer is not the prime objective of this loop, data has been collected and analyzed with respect to subcooled nucleate boiling. It has been determined that higher heat fluxes in this region of the model boiler exist than B&W predicted. This effect tends to allow the exit region of the boiler section, which is Croloy material, to run hotter than the design limit. These data are being studied to determine if changes in the prototype design are necessary.

The two-phase flow on a coiled tube experiment has been completed and the results are due to be published this month.

The R&D program to develop a butt-welded tube-to-tubesheet joint has been completed. B&W will recommend that this technique not be used because of difficulty in interpreting radiograph of the completed weld. This welding process causes a hump on both sides of the weld and a circumferential seam at the juncture. These inherent weld characteristics tend to mask weld imperfections that would normally show up in the X-rays. Other suitable welding techniques are available and can be used on the prototype steam generator, and no problem is anticipated here.

d. AI - Modular Steam Generator

Sixty-eight of the stainless steel tubes have been accepted; fifteen others are questionable and may have to be replaced. Seventy-four tubes for the two units are required; nine are spares. The 5 Cr- $\frac{1}{2}$ Mo tubes are presently being inspected at the vendors. The 321 SS and 5 Cr- $\frac{1}{2}$ Mo billets for the steam generator heads have passed inspection and are now being machined. The completed SS heads are due at AI June 27; the 5 Cr- $\frac{1}{2}$ Mo heads are to follow soon after. The 321-H SS shell material is due June 9 and the 5 Cr- $\frac{1}{2}$ Mo shell pieces are due June 10.

A 5 Cr- $\frac{1}{2}$ Mo tube-to-tubesheet weld specimen failed to pass a bend test. It is apparent that some additional post-weld heat treating is needed on the boiler unit tube-end welds. AI is currently studying this problem. AI reports that the previous problem of porosity in the 5 Cr- $\frac{1}{2}$ Mo tube-end welds has been resolved.

Several of the handling tools such as slings and strongbacks have been designed and built. The welding jigs and fixtures have also been designed and fabricated. The remaining assembly tools, etc. are currently in design or fabrication.

AI was requested to include a minimum of nine T/C's to sense the tube walls temperatures at the exit of the low temperature modular units. This design has been completed and drawings have been sent to members of the Steam Generator Test Program Ad Hoc Committee for their review and comment.

The current schedule for the module fabrication indicates that the two stainless steel H.T. modules will be completed next August and the two L.T. Croloy units are to follow in mid-October.

3. Steam Generator Program Schedule

(See attachment)

STEAM GENERATOR PROGRAM SCHEDULE

Report of Meeting on August 12, 1964 Regarding
B&W Full-Size Generator

On August 12, 1964 a meeting was held in the offices of U.S. Atomic Energy Commission in Germantown, Maryland to discuss the design of the Full-Size Steam Generator. A rough draft of the Design Report on the Preliminary Design of the Full-Size Steam Generator had been transmitted to the Commission just prior to the meeting. Those in attendance were:

AEC & NATIONAL LABORATORIES

G.C. Gower - AEC, COO
K. Hoffman - BNL
R.H. Jones - AEC, Washington
R.W. MacPherson - ORNL
A.E. Mravca - AEC - COO
C.A. Pursel - " "
F.A. Smith - " "
Dr. G.W. Wensch - AEC, Washington
L.A. Whinery - LASL
J. Wimberg - AEC, COO

BABCOCK & WILCOX COMPANY

R.C. Barnett - Nuclear Products
J.G. Clark - N&SP Engineering
A.L. Evans - " "
J.E. Hocking - " "
F.A. Perrera - " "
P.B. Probert - " "
R.C. Dannatt, Jr. - Washington Eng.

Some of the items discussed were covered in letters transmitted to the Commission either before or during the meeting. Where there was a written discussion of some particular problem these written discussions are attached hereto. In the cases where no written discussion had been prepared the oral discussions are summarized briefly below. The major subjects discussed are as follows.

I. Commission Questions, per F.C. Mattmueller's letter July 29, 1964:

In Mr. Mattmueller's letter he transmitted six questions that had been raised about the design of the Full-Size Steam Generator. The writer's letter of August 4 summarizes these questions and attaches answers to four of the six questions.

Commission question No. 4 relating to the stress loadings in the short tube bends is discussed in Mr. J.E. Hocking's Memo to File dated August 11, 1964. A copy of this Memo was given to the Commission during the discussion.

II. Location of Secondary Sodium Pump:

One of the questions that had been raised at the time of a Commission visit to Barberton related to whether the sodium pump should be located in the hot or cold leg. A complete discussion of this problem is included in Mr. Clark's Memo to File dated September 8, 1964.

III. Sodium-Water Reaction:

There have been three questions raised relating to sodium-water reaction problems. They are as follows:

1. The effect of a tube rupture in the feedwater downcomer channel and the possibility of utilizing the inert gas annulus as a buffer to eliminate sodium-water reaction pressures.
2. The horizontal forces on the tube support bars as a result of a sodium-water reaction.
3. The adequacy of a rupture disc in the gas space to relieve the pressure generated from a tube rupture at some distance below the sodium level.

Only a small amount of work has been done on sodium-water reaction problems under this Contract because B&W has a Sub-Contract with APDA to study these problems in the B&W Steam Generator. Delays in signing this Sub-Contract delayed the starting of the analysis work on the Full-Size Steam Generator so that this information was not available for the Preliminary Design Report or for the Review Meeting. APDA plans to have the analysis work on the Prototype Steam Generator completed in time for the Preliminary Prototype Design Report.

In the rough draft of the Preliminary Design Report on the Full-Size Steam Generator some steady-state calculations were included. As a result of the discussion at the Review Meeting it appears that the steady-state calculations have almost no meaning as design calculations because they are not the worst case and probably tend to only confuse the problem. (The final draft of the Design Report has been revised to eliminate the steady-state sodium-water reaction calculations.

The writer obtained verbally some data on sodium-water reaction pressures from the analysis that was made by APDA and Detroit Edison Company for the Fermi Steam Generator Hazards Report. The peak hydrogen bubble pressure was extrapolated from this data to the leak rate and depth of sodium above the leak for the B&W Full Size Steam Generator. These data would predict a hydrogen bubble pressure of approximately 1200 psi, 1 millisecond after origination of the leak. The mean pressure integrated over the first 50 milliseconds, based on the same data, would be 328 psi.

None of these data are conclusive in predicting whether there will be structural damage in either the downcomer area or to the tube support bars as a result of a sodium-water reaction. APDA is modifying a computer program they have written for predicting the pressure resulting from the sodium-water reaction. After they have run our boiler configuration on their computer program a more thorough dynamic shock type of stress analysis will have to be made to determine if the various portions of the Steam Generator can survive a large sodium-water reaction.

IV. Problem Areas in Full Size Steam Generator and How Modeled in the Prototype Steam Generator:

A written discussion on this subject was prepared and submitted to the Commission. This discussion is contained in the writer's letter of August 7.

V. Cost - Full Size and Prototype Steam Generator:

The cost data on both the Full-Size and Prototype Steam Generators have been transmitted to the Commission by separate letter. One of the severe problems in this Contract has been that the cost of the Prototype has increased approximately 40% from the cost estimate included in the original proposal. The cost of material and labor have increased some since the time of the Proposal, November, 1962, but the major reason for the cost increase is that to adequately model the problem areas of the Full Size Steam Generator the weight of the Prototype is significantly higher than for the original Prototype Design. The cost of the Prototype is higher than the original design mainly because the Prototype now designed is larger and weighs more.

VI. Schedule:

An approximate schedule was distributed at the meeting showing the necessity for ordering long lead materials, such as superheater tubes, forgings, and some tooling, early. This schedule showed 15 months of actual fabrication time. If long lead items are ordered soon and fabrication starts in February of 1965 the Prototype Steam Generator would be shipped to SCTI in early May, 1966. Any delay in starting fabrication will delay the delivery of the Prototype by about the same amount of time.

VII. Additional Discussion:

There was some discussion of deviations from the specifications as listed in Appendix C of the Contract. A summary is being prepared listing these specifications and how the Full-Size Steam Generator meets these specifications. This summary will be submitted to the Commission when completed.

There was some discussion of the various phases of the R&D program. The work scopes for the various projects under the R&D program are being up-dated and these proposed revisions to the work scope will be submitted to the Commission.

Attachments

P.B. Probert
Project Manager, N&SP Engineering

The Babcock & Wilcox Company

TELEPHONE
753-4511
AREA CODE-216

BOILER DIVISION
BARBERTON, OHIO

CABLE ADDRESS
BANDW

August 4, 1964

Mr. F. C. Mattmueller
Contracts Division
U.S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

AEC Contract: AT(11-1)-1280
B&W Contract: 610-0067
Subject: Sodium-Heated Steam
Generator Development

Dear Mr. Mattmueller:

In your letter of July 29, 1964, you refer to the six questions relating to the Sodium-Heated Steam Generator being designed under this Contract. These questions are as follows:

- "1. The effect of a tube rupture in the feedwater downcomer channel and the possibility of utilizing the inert gas annulus as a buffer to eliminate sodium water reaction pressures.
- "2. Possibility of gas entrainment at the sodium-gas interface.
- "3. The conceptual 1000°F reheater is tubed with 2½ Cr except for a section at the hot end which is 5 Cr. This overcomes the exfoliation problem with 2½ Cr above the 900°F range. Age hardening of 5 Cr under operating conditions may be a problem.
- "4. Stress loadings during transients under differential expansion may result in failures at the relatively short tube bends.
- "5. There appears to be the possibility of sodium flow striations between concentric tube coils which might be sufficient to cause significant reduction in the units' performances.
- "6. Circumferential temperature gradients in the tube walls and from low to high velocity sodium (possibly as much as 200°F) may result in a significant change in the heat transfer coefficients from the averages used for the design calculations."

A discussion of each of these questions with the exception of Items 1 and 4 is attached. The analysis of tubing flexibility had been made for Item 4, but a difficulty was found in the computer program making it necessary to make a new analysis. The results of this analysis will be submitted as soon as it is completed. If the risers and downcomers prove to be too stiff, the first row of coils can be freed from the tube supports to give flexibility.

The discussion of Item 1 will be submitted as soon as possible.

If you have any further questions please call.

Very truly yours,

THE BABCOCK & WILCOX COMPANY

P. B. Probert (JGC)

P. B. Probert
Project Manager
Nuclear & Special Products Engineering

/fo
Attach

cc: K. Hoffman - Brookhaven National Laboratories
RH Jones - US AEC Washington
KD Kuczen - Argonne National Laboratory
R. MacPherson - Oak Ridge National Laboratory
CA Pursel/GC Gower - US AEC Chicago

August 4, 1964

AEC Contract: AT(11-1)-1280
B&W Contract: 610-0067

2. Gas Entrainment:

Calculations show that the separating velocity for a bubble (of equilibrium size) of argon gas moving up through molten sodium is approximately 1.2 ft/sec. The velocity of the sodium flowing down through the tube bundle of the superheater is approximately 7 ft/sec, so any bubble that gets into the tube bundle will be carried down with the sodium.

Above the elevation of the superheater tubes the velocity of the sodium downward is 1.8 ft/sec. This is marginal from an entrainment point of view.

The sodium distributor system discharges below the surface of the sodium in the steam generator. The design of this system must be arranged to disturb the surface of the sodium as little as possible to prevent local vortices from forming and entraining argon gas in the sodium.

It has been planned to build an inexpensive water model of the sodium distributor for the Prototype Steam Generator to prove out the distribution beneath the surface without entrainment of gas.

The center bypass valve as shown on the drawings for the Full-Size Steam Generator will produce entrainment at some loads because the sodium level will be some distance down in the center pipe. To prevent entrainment resistance must be added to the flow through the center pipe to raise the sodium level in it above the upper valve ports.

3. Hardening of Croloy 2 $\frac{1}{4}$ or Croloy 5:

Both Croloy 2 $\frac{1}{4}$ and Croloy 5 are "Air Hardening" alloys. This means that if these alloys are cooled quickly in air from above the upper critical temperature (approximately 1400 F) they will develop a hard, brittle, martensitic structure.

A good example of this type of hardening occurs in a weld joining tubes made of either of these materials. In the "as welded" condition, the weld and heat affected zone of the tube is very hard and brittle.

To have suitable properties for service in a steam generator, each weld must be heat treated before the steam generator goes into operation. The heat treating operation is a part of the manufacturing process if the welds are made in the shop, or are a part of the welding specification if the welds are to be made in the field. When the welds are carefully made and heat treated as specified, there has been no problem in service with hardening of either Croloy 2 $\frac{1}{4}$ or Croloy 5.

We have not been able to find any examples of age hardening of either Croloy 2 $\frac{1}{4}$ or Croloy 5 in service. These alloys are used at mean metal temperature up to approximately 1100 - 1125 F in superheaters and other heat exchange equipment.

There will be a small amount of precipitation of alloying elements in the grain boundaries of both Croloy 2 $\frac{1}{4}$ and Croloy 5. This precipitation tends to make the alloy a little softer and more ductile. The effect is very small, and is automatically taken into account because long-term creep and stress-rupture tests are made on representative samples of each alloy. These samples undergo the same precipitation as the alloy will undergo in service. The design allowable stresses at high temperature are based on the results of the long-term tests.

5. Flow Stratifications:

Trouble has been experienced from time to time in sodium intermediate heat exchangers and steam generators from flow stratification. The stratification on the sodium side has resulted in hot and cold streams that have persisted throughout the heat exchanger resulting in high thermal stresses in some local areas and heat transfer performance less than predicted.

Flow stratification has been observed on a number of horizontal sodium heat exchangers and steam generators. The IHX's and steam generators for the Sodium Reactor Experiment exhibited stratification. The SRE steam generators, fabricated by The Babcock & Wilcox Company, had water flow unbalance that added to the effect of sodium-side stratification. The cold sodium tended to sink to the bottom of the horizontal shell. The hot sodium rose to the top of the shell and stayed there throughout the length of the steam generator. The lattice type tube supports did not promote remixing of the hot and cold streams. In the case of the SRE steam generator, the water-side unbalance was cured by orificing the tubes at the feedwater inlet end. This decreased the overall temperature unbalance on the sodium side enough that the unit met its expected performance.

To limit the amount of sodium-side stratification, it is very important to have the sodium flow downward as it is cooled and have the water flow upward as it is heated. This allows the changes in density of the sodium and water to aid, rather than hinder, mixing and flow balancing.

The coil tube bundles being used for the steam generator designed under this Contract tend to prevent hot and cold streams from forming because the coiled tubes cross over both the hot and cold streams during each turn of the coil.

One possible source of sodium flow stratification or unbalance would be non-uniform spacing of whole rows of tubes to leave wide and narrow lanes down through the steam generator. To investigate this the following "worst case" assumptions were made:

1. All coils are the nominal diameter.
2. One coil is shifted off center, to the right for instance, as far as it will go.
3. The next coil outside the one above is shifted as far to the left as it will go.
4. These wide and narrow spaces between the tubes persist top to bottom throughout the whole superheater and boiler bundles.
5. No credit is taken for mixing of the sodium in the cavity between the superheater and boiler bundles.

The greatest difference in spacing of the tubes allowed by the manufacturing tolerances is ± 25 per cent from the nominal tube spacing. The nature of the cross-flow pressure drop characteristic is such that the mass velocity will be equal in the wide and narrow spacings so the flow (lb/hr) will vary directly with spacing.

An analysis was made of the performance of the steam generator with sodium flows 25 per cent more and less than the average full-load flow.

From the attached curve it will be noted that varying the sodium flow ± 25 per cent varies the sodium outlet temperature ± 72 F and -56 F. Since these unbalanced flows will exist on opposite sides of the same steam generator unit, the sodium will mix after leaving the coils. In the worst case, the mixed sodium temperature would not be more than 23 F higher than the sodium temperature for the steam generator with balanced flow. A similar condition exists for the steam temperature, as shown on the curve.

These wide and narrow lanes will not exist throughout the steam generator, and therefore the temperature unbalance will be considerably less than 23 F, and the overall performance will be close to the predicted value.

6. Circumferential Temperature Gradients in Tube Walls:

Circumferential temperature gradients are produced by variations in the sodium side heat transfer coefficient and/or variations in the steam side coefficient.

For this analysis, the sodium coefficient was varied by a factor of five from the forward to the rear stagnation point (12,840 to 2570 B/hr-ft²-F).¹ The average sodium heat transfer coefficient used in the design was 7135 B/hr-ft²-F.

The steam side heat transfer coefficient can be either film boiling or nucleate boiling, depending on the location of the tube. However, regardless of the coefficients, the steam temperature inside the tube and the sodium temperature outside the tube are constant values for any location. Changes in the heat transfer coefficients result in a variation of heat flux around the tube.

The maximum temperature gradient around a tube occurs at the film boiling outlet, and reaches a maximum value of 31 F. The attached sketch shows the temperatures and heat transfer coefficients used in the analysis. Therefore, the effect of circumferential gradients on heat transfer would be small.

The resistance of the sodium film is very small when compared with resistance of the steam or water film and the tube metal resistance. If the sodium side heat transfer coefficient was reduced from an average value of 7135 B/hr-ft²-F to 2570 B/hr-ft²-F, a reduction of 64 per cent, the amount of heat transfer surface required would only increase by 12 per cent. Therefore, the small error introduced by a varying sodium velocity should not materially affect the amount of surface required.

1 R.J. Hoe, D. Dropkin, O.E. Dwyer, Heat Transfer Rates to Crossflowing Mercury in a Staggered Tube Bank - I. ASME Paper No. 56-SA-28.

Report of Meeting on October 13-14, 1964
Regarding SCTI and Modular Generators

On October 13 and 14, 1964, the Standing Committee members visited Atomics International (AI) to review the following aspects of the SCTI and Modular Steam Generators (MSG).

1. SCTI

- a. General Status
- b. Schedule
- c. Preoperational Testing and Procedures
- d. Component Testing - Data Reduction and Presentation
- e. Quick Dump of Na Heater
- f. Safety Analysis of SCTI
- g. Strain Gage Installation on ALCO Unit, Etc.

2. Modular Steam Generators

- a. Fabrication Status
- b. Fabrication Difficulties
- c. Schedule
- d. Quality Control
- e. Final Design Report
- f. Test Program

Persons Contacted

<u>Committee Members Present</u>	<u>CPAO</u>	<u>AI</u>
A. Mravca, Chairman	C. Richards	W. Dillingham
G. Cower		D. Eggen
K. Kuczen		W. Hallett
R. MacPherson		A. Jarrett
L. Whinery		M. Lemcoe
		V. Renoe
		T. Withers

1. SCTI

a. General Status

At the time of this visit the Owl Construction workers were making the necessary sodium and water piping connections to the ALCO steam generator, attaching the various blow-off lines to the emergency Na catch tanks and installing the vent lines between the catch tanks and locations outside the test area enclosure. This work is approximately 40 per cent complete now and is expected to be completed by November 30, 1964.

The primary sodium loop, which had been preheated preparatory to sodium filling, was cold. It had been determined a few days before our visit that the primary system dump tank was short in capacity by about 1000 gallons. Atomics International had terminated the primary loop preheat as soon as the shortage in capacity was verified. Atomics International was in the process of studying possible ways of obtaining additional capacity.

It was determined that the primary storage tank was designed for 5000 gallons at a time when the SCTI main loop piping was to be six-inch lines. Subsequent to this time the pipe size was changed to ten inches and the resulting increase in sodium volume necessary was not factored into the tank size. It appears that the secondary storage tank is also short in capacity by about 1500 gallons.

Preparations were being made to connect the primary sodium storage tank to the secondary storage tank to temporarily circumvent the sodium storage problem. This is stated to take three weeks at which time preheat and fill of the primary loop will resume. Atomics International proposes to either connect to or relocate a 4000 gallon sodium storage tank (now located at the Hallam Pump Test Loop) to resolve this problem.

The operating crew members on shift at the time of this visit were engaged in cleaning and inspecting the shell side of the main steam condenser and cooling tower area as per check out procedure.

Just prior to the Committees' visit additional personnel had been added to the SCTI operating crews and evaluations staff. At present there are four, three-man operating crews, five men on a maintenance crew, and ten evaluation engineers. There are five men assigned to supervisory and assistance positions to make a total of thirty-two men. Of these thirty-two men, five engineers and three operators had recently been borrowed from other programs within AI on a temporary basis. Atomics International has requested authorization to place the SCTI workers on a six-day week.

Since July 1, 1964, progress on the over-all SCTI project has been approximately 50 per cent of that expected.

b. Schedule

Since the discovery of the shortage of sodium storage space for the primary and secondary loops and since the resolution of this problem will effect the over-all SCTI schedule, AI has not issued a revised schedule that takes this problem into account as of yet (October 14, 1964). It is

believed by AI, however, that they will not start actual testing before February 15, 1965, (optimistic date). It is believed that testing will start by March 30, 1965.

Contrary to the previous plans to conduct a plant performance test on the SCTI which would overlap by one month, the actual component testing, AI plans now to start plant performance and component testing at the same time.

Contrary to the Committees' prior report (Report No. 5) in which actual component testing is estimated to start in December 1964, it is now apparent the testing may not start before March 1965.

c. Preoperational Testing and Procedures

Check out of the many systems in the SCTI continues to reveal discrepancies. For example, it was found that two vent connections on the IHX had been joined, thus permitting purge gas to leak from the primary loop across to the secondary side. Also, pressure transducers on the feed-water piping had been connected to fixed locations, thus preventing any relative motion between the sensors and the readout instruments during temperature changes.

Of the 24 separate preoperational test procedures required, 15 have been written of which 13 have been approved. Of the 13 approved procedures seven tests are complete and the remaining 6 tests are being conducted. It appears that about 50 per cent of the preoperational procedures are complete.

d. Component Testing - Data Reductions and Presentation

It is AI's intention to divide the total test program for the ALCO steam generator and IHX into specific parts and conduct these tests on an individual basis. As these tests are performed some data reduction will be made and analyzed to determine the adequacy and sufficiency of the data. The various tests when completed will be evaluated and prepared as interim reports. At the completion of the total test program AI shall prepare topical reports on the steam generator and IHX.

e. Quick Dump of Na Heater

Last June AI was planning on installing a quick-dump line to drain the Na heater in the event of a tube rupture. Since then AI has made a study of the effect quick draining would have on the heater. This study concluded that draining the heater tubes before the brickwork has cooled down is not practical because the empty tubes lack adequate

heat capacity to absorb the residual heat. Overheating of the tubes appears to be a definite possibility if they are drained and other methods of heat removal are not utilized. In the event of a leak, AI now plans to secure the burners, close the inlet sodium valve and continue to operate the forced draft fan. Attached is NAA-SR-10250 which presents the results of their study on this matter. The Committee is reviewing this study.

f. Safety Analysis of SCTI

The Committee was briefed on a recent safety analysis AI has performed on the SCTI. This analysis appeared to be patterned after a typical industrial safety review. Atomics International has determined from the literature the Threshold-Limit-Values of the various sodium-water reaction products and compared this data with what the local atmospheric concentrations might be under the various credible accidents that could occur at the SCTI. The data presented to the Committee was preliminary. Atomics International expects to complete the analysis and prepare the report in the near future.

g. High Temperature Strain Gage Installation

Atomics International representatives briefed the Committee on the history behind the installation of strain gages on the ALCO steam generator from the inception of the idea at ALCO in 1962 to the present time. The purpose being to place this task in proper perspective with respect to the needs of the program. Also discussed was the procurement problems associated with the General Electric Company high temperature gages. From this discussion it was learned that AI has 118 GE gages that are satisfactory for installation on the ALCO unit. Approximately 25 more gages are needed to complete the job. Because of this shortage AI has bought and tested high temperature gages from Douglas Aircraft and Baldwin-Lima-Hamilton (BLH). The most promising have been the BLH gages showing good steady state stability, however, they exhibit poor thermal shock features. Atomics International appealed to the AEC members present for this discussion to ask GE to reconsider their previous refusal to supply gages beyond the last shipment of 140.

Because of the limited life of the strain gages at operating conditions, AI plans to proceed with the steady-state testing of the ALCO unit without gages installed. However, plans are being made to provide removable openings in the insulation at the required locations to facilitate future gage installations when needed just prior to transient testing of the unit.

2. Modular Steam Generator

a. Fabrication Status

At the time of the Committees' visit the two evaporator units were in the final stages of completion. Yet to be completed were the installation and welding of the split-half shell sections and the thermocouple penetration housing and end-caps on both units. Tube-to-tubesheet welding on the high temperature modules had been started. During the visit dye penetrant inspection of some of these welds was in progress.

b. Fabrication Difficulties

The majority of the tube-to-tubesheet welds on the evaporator (LT) modules required a second weld pass to completely fuse the joint. The integrity of the weld apparently is not jeopardized by this added pass; however, almost double the time is needed for the welding.

One of the LT module tube joint welds experienced a burn-through due to an operator error. This tube was in an outside row which permitted the technicians to cut out and successfully replace a two-inch section of that tube.

There has been some difficulty in making acceptable weld joint on certain parts of the 5 Cr $\frac{1}{2}$ Mo shell sections. Several of these welds have had to be repaired. With the 5 Cr $\frac{1}{2}$ Mo material, post weld heating is necessary. Special equipment has had to be procured to do this work.

Atomics International's original plans to hydrotest the MSG's before welding on the steam/water nozzles and the outer shell has had to be changed since difficulty was experienced in adequately blanking off at the tubesheet to nozzle junction. Current plans are to weld on the nozzles and to affect a seal at the smaller nozzle openings.

c. Schedule

The Committee's previous report on the MSG indicated that AI would complete the fabrication of the two superheater (HT) modules by July 26, 1964, and the two LT modules by September 20, 1964. The LT modules are now being fabricated first and may be completed in October 1964. The HT units are slated to be completed by December 1, 1964.

d. Quality Control

The quality control techniques used by AI to inspect the tube-to-tubesheet welds were discussed in considerable

detail. It was learned that the technique used to x-ray inspect these welds allows good definition of between 70 and 80 per cent of the weld seam. A modified porosity chart, taken from Section Eight of the ASME Boiler Code, is used by AI. This chart sets the limit of acceptable porosity in 0.095 inch thick material by reducing the porosity size limit for 0.25 inch thick material by the ratio 0.095/0.25. Atomics International representatives believe that their quality control techniques for the MSG's are more than adequate to meet the applicable ASME Code requirements.

e. Final Design Report

Atomics International has prepared a rough draft of the final design report on the MSG's. This report has been reviewed by the Committee members and their comments verbally given to AI. In general the Committee felt the report is adequate.

f. Test Program

The test program for the MSG is approximately 30 per cent complete. Rough drafts were due in June 1964, the current estimate now is January 1965.

Attachment:
NAA-SR-10250

Status Report of Steam Generators Program as of March 1965Introduction

Review the major topics pertaining to steam generator testing discussed during the last meeting in Chicago on November 16 and 17, 1964. The major discussion topics were:

- (1) Shortage of sodium storage in the primary and secondary systems of the SCTI
- (2) Installation of the ALCO steam generator (about 75% complete at that time)
- (3) Difficulty in obtaining suitable high temperature strain gauges in sufficient quantity to fulfill the testing objectives
- (4) Status of MSG's (about 70% complete at that time) and repair of damaged superheater tube
- (5) The start of fabrication of the B&W prototype was deferred for about six months to permit APDA and B&W to more thoroughly investigate the damage potential resulting from Na-H₂O reactions. APDA briefly explained the scope of work they will be doing to assist B&W.

Updating

Since the status of the SCTI and MSG's is slated to be presented in detail tomorrow afternoon, I shall not go into these programs unless there are questions or other related topics that would benefit from a discussion now.

B&W

The B&W effort, as you are aware, falls into three main areas:

- (1) Preliminary design of Full-Size Sodium-Heated Steam Generator; this work is complete, except for updating following the Na-H₂O reaction work;
- (2) Preliminary Design of 30 MWt Prototype Steam Generator;
- (3) Supporting Research and Development Work.

A. Full-Size Steam Generator

The design work on the full-size steam generator is essentially complete. APDA has reviewed the large S.G. design with respect to its capability to withstand a Na-H₂O reaction and, as you are aware, APDA is setting up to do tube-wastage and air/water tests to assist and verify the analysis. As the APDA study progresses, there will be design changes and updating of the preliminary drawings.

B. Prototype Steam Generator

Presently, ordering information is being prepared to send out for quotations on the long lead items such as a tube coiling machine, tubesheet forgings, and shell flanges. Detail drawings of the superheater stainless steel tubing sections are being made to set the ordering length. SS tubes are also long lead items and are due for delivery next June.

Layout drawings of the Prototype, as it will be installed in the SCTI test pit, have been prepared. Detailed stress analysis of the structures and supports for static and dynamic loadings, such as earthquake and piping reactions, is in progress.

B&W has started a Preliminary Control Study on the prototype primarily to help identify the prototype instrumentation and assist in preparing the test program.

This work is in the initial phase where a computer program is being set up. This work is being integrated with the control study work AI has previously done on the SCTI systems.

A meeting between B&W and AI is to take place in the near future to identify those areas where liaison will be beneficial.

C. Current R&D Projects at B&W

(1) Model Steam Generator - Carbon Transfer and Corrosion Loop

The sodium rig has continued in normal operation and has completed slightly over 5,500 hours of full temperature operation. It is estimated that the loop will complete the 8,000 hours of scheduled operation by next June.

Results of the examination of the Croloy 2 1/4 specimen exposed to 980°F sodium for 2,000 hours indicated a partial decarburization to a depth of approximately 5 mils. Examination of Type 316 specimens after 2,000 hours exposure to 1100°F sodium revealed some precipitation of carbides on the sodium side which is attributed to sensitization of the material rather than carburization from an external source. No further change was observed in the Type 316 materials after exposure for 4,000 hours. However, decarburization

of the Croloy 2 1/4 specimen had progressed to a depth of approximately 10 mils after exposure for 4,000 hours.

Paul Probert was asked to prepare a preliminary report on the samples removed from the loop to date. A copy of this report will be distributed for your review. B&W has also prepared and distributed a Second Progress Report (BAW-1280-18) on the operation of this loop. If you have not received a copy of this report and want one, let me know.

(2) Sodium-Water Reaction Study by APDA

Work at APDA under the Subcontract continues on the analysis of Sodium-Water Reaction problems in the Full-Size and Prototype Steam Generators. At the time of the last meeting, APDA had made some preliminary computer runs using the simplified mathematical model and indicated where the model needed refinements. This mathematical model has been revised to account for two parallel flow paths of the products of the sodium-water reaction. Run of this new computer program using the configuration of the Prototype Steam Generator has resulted in curves of hydrogen bubble pressure, bubble size, and sodium slug velocity for several different numbers of assumed tube failures and locations. These data include plots of hydrogen bubble pressure for the failure of 1, 13, and 25 tubes at two different locations. These pressure plots will be included in the next B&W Monthly Progress Report. Briefly, however, the worst case in which pressures were plotted is for all 25 tubes of the prototype boiler bundle to rupture at the bottom of the downcomer shroud box. This assumed accident results in a pressure prediction of 5,000 psi at 1 millisecond following the initiation of reaction which decays to 1050 psi at the end of 100 milliseconds.

Separate calculations made by B&W show that the shell liner can withstand approximately 900 psi pressure for 1 second, and the shell can stand approximately 1,000 psi for 1 second after the liner has failed (shell design pressure = 300 psig). There is a probability that the Prototype vessel can withstand pressures from five to six times as high as these for the very short times, (such as 1 millisecond) of greatest concern in the sodium-water reaction analysis.

These preliminary data seem to indicate that the prototype shell may possibly stand up under the very short term pressure pulses even if all 25 boiler tubes were to rupture.

APDA is in the process of refining the computer program to take in account the change in water leak rate. All calculations to date have been based on an instantaneous full flow leak rate which continued unimpeded for the duration of the reaction considered.

B&W will continue to study the strength of the vessel for shock loadings of very short time intervals to determine with more assurance what the vessel can actually stand during the interval times between 1 microsecond and 1 millisecond.

APDA is proceeding with the design of the air-water model test and the tube corrosion tests. Data from these tests will help determine the propagation rate of failure from one tube to the next and provide some insight into the damage potential that may exist in the Full-Size Steam Generator which has 676 tubes in the boiler section.

(3) Flow Model of Sodium Distributor

(Pass around photographs)

One of the areas of concern arising out of the Full-Size Steam Generator Design Review was sodium distribution and gas carryunder. B&W has built a water model test rig about 1/3 scale of the Prototype sodium distributor. This rig was built to screen sparger configurations for use in a large more sophisticated rig that has just been designed.

(Explain photographs)

(4) Welding Development

A tungsten-inert-gas (TIG) welding head with a cold wire feed has been built and tested. This apparatus is essentially the same that AI used on the modules except that a cold wire feed mechanism has been added. B&W welding engineers are hopeful that by the addition of the wire feed mechanism better tube-to-tubesheet welds can be made on the thicker tube-wall material specified in the Large Steam Generator and Prototype designs. AI was successful in fusion welding 5/8" OD x 0.095" wall tubes; however, two passes were required to obtain the desired penetration.

B&W has made successful welds with the newly made apparatus on 5/8" OD x 0.076" wall. Some effort is

being concentrated on trying various lip shapes to be machined on the back side of the tube sheet that will help locate the tube and hold it securely during welding.

To prevent the possibility of slag inclusions in the tube sheet forgings penetrating through these relatively thin projections, it is planned to clad the back side of the tubesheet forging using weld deposit of the same material as the tube sheet and machine these lips from the cladding. When properly done, this weld deposited material is much cleaner than the base forging. This technique for obtaining higher quality material in critical areas is commonly used on nuclear components and is not new.

(Prototype boiler inlet tubes dia. = $5/8$ OD $\times$ 0.076" wall
 Prototype boiler outlet tubes dia. = 1.0 OD $\times$ 0.165" wall)

(5) Corrosion of 2 1/4 Croloy on Products of Na-H₂O Reactions

Recently B&W chemists have modified an autoclave to study the corrosion rate of 2 1/4 Croloy in aqueous sodium hydroxide at temperatures in the range of 1250°F. Tests in this apparatus will give corrosion rates at temperatures corresponding to the maximum pressure expected in the B&W steam generators. Prior work at temperatures in the range of 700°F, as you are aware, gave corrosion rates in the range of 1" per year in 98% solutions, and by extrapolating this data to the 1500°F range one could envision very high corrosion rates similar to what was observed in the Fermi steam generator.

Tests in the modified autoclave will be starting as soon as the equipment has been debugged. It is hoped that the data resulting from this work will dovetail and correlate with the tube wastage tests APDA is now setting up to do under the subcontract.

(6) Chemical Simulation of Sodium Environment for Leak Testing

Work in this area is of low priority and is being performed on a fill-in basis. It is about a 3 man-week effort and will be completed prior to June 1965.

D. BLH

BLH has completed drafts of a Fabrication Report and a Hydrotesting Report. They have been reviewed by Commission personnel and should be issued shortly. As-built drawings are now in the preparation stage.

Minutes of Meeting on June 18, 1965 Regarding
B&W Steam Generator Design Review

Attendees:

<u>B&W</u>	<u>APDA</u>	<u>SCDP COMMITTEE AND AEC</u>	
P. Probert	W. L. Chase	O. E. Dwyer	C. A. Pursel
J. C. Clark	J. A. Ford	W. R. Simmons	R. H. Jones
T. P. Farrell		R. Wykoff	J. Holliday
J. E. Hocking		H. W. Savage	C. W. Richards
F. A. Perrera		K. Hoffman	J. Dissler
		K. Kuczen	G. C. Gower
		L. A. Whinery	J. J. Purcell
		R. E. MacPherson	J. Wimberg

This meeting was held to review the prototype steam generator design and the results of related Na/H₂O reaction work being performed by APDA. This memorandum will give a brief description of the meeting content, conclusions and recommendations.

Discussion

The meeting was opened by R. H. Jones, DRD&T, Headquarters, with the B&W and APDA representatives excused. Mr. Jones said the purpose of the meeting was to review B&W work to determine if it was appropriate to proceed with the Phase II effort. Ground rules were discussed which dealt mainly with a) the safety aspects of the B&W steam generators, b) having a high degree of confidence that the concept was worthy of pursuing through the fabrication and testing stages, and c) the concept should have a strong likelihood of being accepted by industry.

B&W and APDA representatives joined the meeting and presented information on a) the status of the prototype design, b) Na/H₂O reaction analysis work, c) dynamic bursting strength of the full-size steam generator vessel and liner, and d) quality control. B&W and APDA representatives were excused. The following members were asked to give their opinion of the material presented.

W. Simmons - Approach is very conservative - there are a few non-conservatives factors but these are due to a lack of specific knowledge - knowledge that is not available now and probably will not be available for sometime. It appears to be a reasonable calculated risk to proceed.

R. Wykoff - Seconded Simmons remarks and agreed that we should proceed.

O. Dwyer - Had very little to add to the above - design appears conservative - quite safe but there remains a concern on tube wastage.

H. Savage - Agrees with steam generator Standing Committee - is reasonably satisfied with the quality control - specifications appear good and may benefit by review by others for a cross check with those previously used in the industry. Should check the work-energy approach against the force-mass-acceleration principles. Should clarify the leak rate specification.

Pursel - Very conservative design - main concern should be a one tube rupture. Should sharpen up various portions of the report . . . does not see much more than could be done.

Dissler - In some areas may be over conservative. Some areas are not so conservative but those that are overshadow them. Should look into the bulging analysis - has no objection to proceeding.

Gower - Each member of the standing committee, except MacPherson was asked to express his opinion - all expressed their confidence in the design and were in favor of proceeding.

Holliday - There may be areas where in future units some of the conservatism could be eliminated.

Richards - Nothing to add.

Conclusions

A general conclusion may be made that the steam generator as designed is very conservative and in spite of the few areas mentioned below where additional work is necessary to "round-out" the design report it appears appropriate to proceed with fabrication and testing of the prototype. Following are several specific conclusions:

1. B&W has used room temperature strain hardening coefficient data instead of high temperature (900°F) values in preparing the dynamic bursting strength analysis of the prototype and full size steam generators.
2. B&W has not as yet completed the analysis of the center tube collapsing phenomenon that may occur under Na/H₂O reaction conditions in the prototype steam generator.
3. B&W has only given a cursory review to the possibility of having localized bulging of the prototype and full size steam generator vessels under dynamic loadings and localized heating effects.

4. B&W has not completely explained the localized movements of the tube supports and baffle structures under conditions that may result from a Na/H₂O reaction within the boiler tube bundle.
5. The overall helium leak rate 0.01 micron cu ft/hr specified by the contract should be sharpened up to reflect a more stringent specification.
6. The annulus between the prototype steam generator vessel and the liner should be fitted with a 2" diameter opening for draining purposes.
7. The dynamic bursting analysis performed on the prototype and full size units has used only one method of approach to determine the vessel strengths under dynamic pressure pulses. Another method used, such as the work-energy approach, should be correlated with this work.

Recommendations:

It is recommended that B&W proceed with the prototype fabrication and as a parallel effort, within the next sixty days, modify the design report to include:

1. A dynamic bursting strength analyses for the prototype steam generator which has taken into consideration strain hardening coefficients corresponding to the maximum operating temperatures the shell and liner materials may incur.
2. A dynamic structural analysis of the prototype steam generator's center tube assembly under the various modes of collapse that may result from a sodium water reaction within the unit.
3. An analysis of the possibility and consequences of having localized bulging of the prototype steam generator vessel and liner during the dynamic pressure loadings predicted and presented by APDA in their study of the prototype design. Also, in this regard, consider the likelihood of localized overheating of the vessel and liner from a nearby Na/H₂O reaction which may also result in bulging.
4. A clarification of the structural analysis work which deals with the localized movements of the tube supports and baffle structure under conditions that may result from the occurrence of a Na/H₂O reaction within the bundle assembly.
5. A correlation, if possible, of the two methods of approach:
a) force-mass-acceleration equations of motion, and b) work and energy, available to study the behavior of the liner and vessel walls when subjected to dynamic internal pressures.

With respect to fabrication of the prototype it is recommended that B&W:

1. Review the helium leak testing requirements and specifications for the steam and water side portions of the prototype to establish a more stringent, total permissible leak rate than 0.01 micron cu.ft/hr which is specified in the contract.
2. Redesign the vessel liner annulus sodium drain to incorporate at least a two-inch diameter opening for draining purposes.

CC: J. Wimberg, CON

Long-Range Planning
Report NYO-10725, January 1964

NYO 10725

Jan. 1964

RESEARCH AND DEVELOPMENT PROGRAM FOR
CIVILIAN POWER REACTORS
SODIUM COMPONENTS

Prepared for the Liquid Metal Cooled Reactors Branch
Division of Reactor Development
US Atomic Energy Commission

J. Wise - New York Operations Office
USAEC

O. E. Dwyer - Brookhaven National Lab.
AUI

DISTRIBUTION LISTSodium Components Development Program
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Section 1INTRODUCTIONPurpose of this Report

Currently, work is under way under various projects sponsored by the Liquid Metal Cooled Reactors Branch, Division of Reactor Development, US Atomic Energy Commission directed toward the design, fabrication and test of steam generators and heat exchangers; the investigation of the physical and chemical (corrosion) properties of structural materials in a sodium environment; and the development of two types of meters for the measurement of the oxide content in sodium. To some extent these projects were supported on the basis of their individual worth rather than in accordance with a current overall research and development plan. In this report, a research and development program for sodium components is set forth that takes into account the current objectives of the sodium cooled civilian reactors program, the present status of this program, and the current state of development of sodium components and sodium technology.

Domain of Sodium Components

The sodium components development program is considered, in a general sense, to be concerned with all portions of the reactor primary system other than the reactor vessel and its contents. In this sense, the sodium components include heat exchangers, pumps, steam generators, valves, instrumentation, controls and sodium purification equipment. In addition sodium purification, analysis and monitoring are included in the domain of sodium components development.

* * * * *

The program plan presented in this report is an initial attempt by the writers, and they recognize the extent to which contributions and corrections can be made by the other members of the Sodium Components Development Program Review Group. It is expected that comments and suggestions will be made by the other members and that the plan will be revised in accordance with these comments. The revised plan will then be submitted to the Liquid Metal Cooled Reactors Branch for assistance to it and utilization by it in support of future work.

Section 2FACTORS INFLUENCING THE RESEARCH AND DEVELOPMENT PROGRAMGeneral

Unfortunately for working up a sodium components research and development program, it is not a matter of simply listing program objectives and current status and then putting together what studies would be required to attain the technical goals. Many factors come into play, and development of a program becomes an optimization problem; and one for which no detailed solution will satisfy everyone. Also, these factors will change with time, so that the program plan can be expected to require corresponding updating. However it is thought that the plan presented, in its general sense, can be acceptable to most; and also acceptable in its details, even though there may be differing individual preferences on the detailed level.

This section of the report briefly discusses these factors.

Schedule Factors

In a recent talk* by Dr. Pittmann, he indicated the following schedule for fast breeder reactor development:

<u>Year</u>	<u>Item</u>
1969	Decisions regarding technical alternatives; initiation of design for prototype
1973	Prototype operation
Early 1980's	Demonstration plants (400-800 MWe) operation
1989	1000 MWe commercially competitive plant

Alternatively, schedules have been considered depicting operation of a 1000 MWe fast breeder reactor plant in 1978. It is fairly certain that the time schedule for development of specific components for competitive fast breeder operation 25 years hence is quite different from that required for competitive fast breeders in about half that number of years.

Putting together a detailed development plan for a period of the order of 25 years is considered wasteful in effort. It will be a fortunate occurrence if time does not drastically affect a general plan for such a long period - let alone a detailed one. For the purpose of the plan presented in this report an arbitrary division was made into a short-term period (approximately 5 years), a long-term period (to about 1975),

*Remarks by Dr. Frank K. Pittmann, Director, Division of Reactor Development, USAEC at the Fast Breeder Reactor Conference, 12/3/63 in Detroit, Michigan.

and a far-distant period (beyond 1975). Details for the far-distant period were not incorporated in the research and development plan, it being considered that work in that period would involve advanced development of what will have been completed by the end of the long-term period and development of new concepts and problem areas brought to light in the short-term and long-term periods. Parenthetically, it is expected that solutions will have been reached for all the current problem areas by the end of the long-term period.

The schedule upon which the program plan is based takes into account experience to be obtained from plants currently in operation (Hallam, Fermi, EBR-1, EBR-2), a possible sodium-graphite prototype starting operation in 1970, a fast breeder prototype operating in 1973, demonstration fast breeder plants in the early 1980's, and a large competitive plant by 1989. As explained above, experience to be obtained from operation of the competitive large fast breeder plant is considered to be too far in the future to have effect until after the long-term period.

Economic Factors

Perhaps the prime factor determining the goals that will have to be achieved is the competitive cost of electric power. Barring some type of subsidization to support the conservation of resources by promotion of a breeder economy, it can be expected that industry, for the most part, will select power plant concepts based on the then current economics or what can be expected in the then moderate future. The proponents and owners of fossil and hydro resources can be expected to be active continuously in attempting to reduce costs of their fuels and power from them. The recent decision of Consolidated Edison of New York to change from a large nuclear power plant at Ravenswood, New York City, to long-line transmission of power from hydro, though to some extent influenced by public concern over siting, is a case in point.

It is to be hoped that, with the advent of prototype and demonstration plants, private industry can foresee a growing market sufficient for it to take at least a moderate share in support of components and sodium technology development. At present, such support, to all practical purposes, does not exist.

The time when completed development, based on technical requirements and considerations, is required can always be expected to lead that imposed by budgetary limitations. It was considered impractical to scope the costs of the research and development program presented in this report until the writers had an opportunity to discuss budgetary expectations with the people of the Liquid Metal Cooled Reactors Branch, and it was considered preferable that these discussions take place subsequent to review of the plan by members of the Sodium Components Development Program Review Group. In addition, the writers have not lost sight of the difficulty of developing a good cost picture.

Technical Factors

Although the domain of the sodium components development program does not include the reactor proper, any development plan cannot divorce the reactor from consideration. The reactor operating conditions will set the temperature, pressure and flow requirements in the complete primary system, and the radioactivity and fission products characteristics of the sodium stream between the reactor and the heat exchanger. In the period of time covered by the plan presented herein, it can be expected that advanced reactor design will change inlet and outlet reactor conditions from present thinking, most probably in the direction of imposing increased requirements on the sodium components.

The development plan is geared primarily to the fast breeder concept and does not give much weight directly to the sodium-graphite reactor concept on the basis that fast breeder component development imposes more stringent requirements, and the greater emphasis on the fast breeder program.

It is postulated that development will generally go through a first-round (prototype) stage in which the effort will be directed to achieving a practical working device, and then to a second-round stage to develop a more advanced device. The design factors of concern include technical requirements, schedule requirements, capital and operating costs for the component, safety, reliability, maintenance, size (capacity), etc.

It is considered that fundamental research, e.g., heat transfer, model for sodium contaminant chemistry, etc., will be performed at national laboratory or university type facilities, and that the basic engineering data developed there will be used to develop design and manufacturing procedures at industrial facilities. Test and demonstration is expected to be accomplished in industrial facilities complemented by reactor facilities in operation and specific test facilities.

Sight should not be lost of the fact that the technical development should not be carried along on the basis of technical considerations alone. The important considerations are overall effect on power costs and safety.

Updating

Comments on the plan presented in this report will be solicited from members of the Sodium Components Development Program Review Group and incorporated in a revised edition. It is expected that the revision will also include additional emphasis on the treatment of costs for implementing the plan and performing the work.

It is intended and expected that the development plan will be updated periodically to factor in progress on the projects, changes in requirements, and considerations of new concepts.

Section 3SODIUM COMPONENTS DEVELOPMENT OBJECTIVES AND PROBLEM AREASAreas of Interest

For convenience in considering parts of the sodium component development program separately the realm of sodium components has been classified into four areas of interest:

Equipment
Materials
Sodium technology
Miscellaneous

The tabulations presented below for each of these areas of interest depict the scopes of these classifications and some of the items of consideration involved in the development work.

EquipmentTypes of studies:

Equipment design - Development of engineering design data
Utilization of basic heat transfer data
Utilization of basic fluid flow data including
fouling, erosion and cavitation considerations
Extrapolation of previous experience to large
size components

Equipment fabrication - Quality control
Development of new manufacturing procedures
Problems of component size

Equipment testing - Acceptance tests
Performance tests; including considerations of
maintenance, cleaning, ready isolation of equipment,
ready removal of equipment from system;
repair in system
Static tests - integrity and strength
Steady state tests - operating and standby conditions
Transient tests - start up, shut down
operational perturbations
large perturbations within system capability
large perturbations beyond system capability

Goals of equipment design and fabrication:

Simplification	Reproducibility
Reliability	Sensitivity
Accuracy	Cost
Safety	

Items of equipment:

Heat exchangers
 Steam generators
 Pumps
 Instrumentation - level, flow, temperature, pressure
 Valves
 Traps and other purification devices
 Controls - level, flow, temperature, pressure

Controlling parameters:

Temperature
 Pressure
 Size
 Cost (capital and operation)
 Vibration

MaterialsTypes of studies:

Physical properties of materials of interest (stainless,
 2 1/4 Cr-1 Mo, 5 Cr-1/2 Mo)
 Chemical properties (corrosion) of materials of interest

Study objectives:

Measurement of properties in regions and environments of interest

Controlling parameters:

<u>Physical</u>	<u>Chemical</u>
Temperature	Temperature
Temperature cycling	Flow velocity
Load cycling	Time
Thermal shock	Impurities (kinds and concentrations)
	Mass transfer including temperature gradient and thermal cycling effects

Sodium TechnologyTypes of studies:

Development of model to depict chemical interactions (corrosion and mass transfer)
Analytical procedures - simplified, reliable, reproducible methods
Purification - systems and procedures to maintain impurity concentrations within acceptable limits
Monitoring equipment - convenient measurement of sodium characteristics and impurity concentration
Reactions with environment resulting from failure of equipment
Integrity: sodium/air and sodium/water reactions - studies of the thermodynamics, kinetics and control of the reactions

Study objectives:

The objectives are to maintain sodium in the system within acceptable purity limits with associated purification and monitoring.

The impurities of principal concern are oxygen, carbon, hydrogen. Potentially other materials may be of concern also.

Controlling parameters:

Temperature
Time
Kinds and concentrations of impurities

Miscellaneous

This category is a catch-all classification. Items of interest are discussed below.

Standards:

A convenient and profitable means to consolidate and screen the knowledge, techniques, etc. being developed under the sodium components development program is the use of standards. Use of this technique will improve uniformity of results and provide a convenient means to make accepted procedures knowledgeable and available to all participants in the program. It is recommended that efforts be directed towards establishment of standards as rapidly as possible.

Surveys:

Information developed by participants in the development program is usually presented in the form of reports, mostly in periodic type reports. Experience has shown that these reports, in practice, are not available to many of the participants, and the reports themselves, being periodic, usually describe technical progress with limited attention to evaluation and overall conclusions. Also, complementary work at separate facilities

receives limited integration. For use by the Liquid Metal Cooled Reactors Branch and Review Group members it is considered that brief surveys of the various facets of the sodium components development program should be made. The surveys should define and clarify the objectives, problem areas, status of work being performed, etc. These surveys should be useful in providing a uniform understanding of the opinions and considerations of the Review Group members.

It is thought that these surveys could be prepared by members of the Review Group or operations office personnel closely concerned with the particular subject of the survey.

Reactor Design Criteria and Advanced Concepts:

As mentioned previously, the reactor cannot be divorced from the domain of sodium components when considering sodium components development. System economics, reactor parameters such as breeding ratio, doubling time, the interrelated breeder/thermal reactor economy, etc. affect the reactor directly and the other components in the sodium system indirectly. Whenever the sodium components development plan is updated or revised some attention should be given to the effect of any changes in reactor operating conditions or design concept.

This may readily be accomplished by discussion with reactor design groups in the thermal and the fast breeder field. Such discussions can also provide helpful information if comments by these people on the status and objectives of the sodium components program are elicited.

Continual attention should be given to new and advanced concepts - evaluating the technical and economic worth of the idea and considering the justification of support of development through feasibility evaluation and subsequent engineering.

Other Liquid Metal Development:

Other liquid metal work, such as that for power reactors by the Europeans, and that for compact reactor and space application by other groups in the AEC structure and in NASA should be surveyed for possible utilization and to limit unintentional duplication of effort.

Present Status

Information has been developed to the extent that prototype size heat exchanger and steam generator units have been designed and are being fabricated for test operation. Operating experience is being obtained from operation of a small sodium-graphite power reactor and two small fast breeder reactors, one in the Fermi power plant and the other (EBR-2) being operated primarily to provide core neutronic data.

Limited information has been obtained on the physical properties and corrosion characteristics in a sodium environment of some materials of interest.

Present Work

The tabulation below describes the work currently being sponsored under the sodium components development program.

EquipmentDesign and Fabrication

Babcock & Wilcox - Design of steam generator for large plant

Alco, Baldwin-Lima-Hamilton - Construction of intermediate heat exchanger and steam generator (prototype size)

Atomics International - Design of modular type steam generator

Test

Baldwin-Lima-Hamilton - Performance test on steam generator element

Atomics International - Performance tests on prototype steam generator and intermediate heat exchanger

Westinghouse - Analysis of Fermi cold trap to evaluate its performance and obtain cold trap design data

Westinghouse - Preliminary design of large sodium pump test facility

MaterialsChemical

Baldwin-Lima-Hamilton - Corrosion studies in conjunction with test of steam generator element

General Electric - Corrosion studies in six loops evaluating effects of various materials of construction, time, temperature, flow rate and impurity composition

Physical

Mine Safety Appliances - Physical properties; strength, creep and fatigue of materials of interest

Sodium Technology

Analytical procedures - Screening of carbon analysis procedures by a "round robin" of various laboratories

Monitors

Atomic Power Development Associates — Development of Blake resistivity meter for oxide analysis

United Nuclear Corporation — Development of a continuous reading oxide meter based on an electrochemical cell application

Problem Areas

In the design and construction of equipment problem areas exist in obtaining correlations in the regimes of interest for heat transfer and fluid flow; distortion and strength considerations due to thermal gradients and thermal shock; performance reliability; extrapolation to large size equipment, manufacturing quality control; and satisfactory operation of moving parts in sodium, e.g., seals and bearings.

Work is needed to obtain materials with improved properties over these now available. More information is desirable on the effects of radioactivity and fission products in the sodium phase.

Additional knowledge is needed on the integrated effects of combined impurities. Improved analytical methods hinder study of the effects of impurities in the system. Improved means of monitoring the sodium is also an important area.

Section 4RESEARCH AND DEVELOPMENT PROGRAM FOR SODIUM COMPONENTS

The sodium reactor facilities now operating and those contemplated in the future are tabulated below with their dates of operation. These times indicate when these facilities can become available for testing and engineering measurements and also the schedule requirements for component development of these items that will be developed for specific plants.

<u>Operation</u>	<u>Facility</u>	<u>Size</u>
Current	Hallam	75 MWe
Current	EBR-1	
Current	EBR-2	16 1/2 Mwe
Current	Enrico Fermi	200 MWt
	FARET	50 MWt
	SEFOR	
1970	Sodium graphite prototype	200 MWe
1973	Fast breeder prototype	200 MWe
1980's	Fast breeder demonstration	400-800 MWe
1989	Large fast breeder	1000 MWe

The tabulation below provides a listing of development projects and related information.

<u>Item</u>	<u>Development Project</u>	<u>Supported by</u>	<u>Facility</u>	<u>Estim. Cost</u>	<u>Period Performance</u>
Heat exchanger or steam gener.	Larger units dsgn, mfg, test " "				
Pump	Test large, high temp. pump				
Valves	Develop large units				
Instrumentation	Develop large capacity units				
Traps	Develop design criteria and dsgn. procedures, fiss. prod.				
Controls	Develop large capacity units				
Materials	Improved materials Tests in expanded environmental range Bimettalic matls.				

<u>Item</u>	<u>Development Project</u>	<u>Supported by</u>	<u>Facility</u>	<u>Estim. Cost</u>	<u>Period Performance</u>
	Studies of gas and f.p. diffusion				
Sed. impur.	Develop model for chemistry Control by inhibi- ters, etc.				
	Mass transfer studies				
Sed. analysis	Improved and stand- ardized methods				
Purifica- tion	Improve trap design Investigate other methods				
Monitoring equipment	Complete O ₂ meter development Develop C, H ₂ , f.p. meters				
Na/H ₂ O react.	Study kinetics Improve eqpt. dsgn. to limit effects Improve sed. samp- ling techniques				
Surveys	Implement-contin. effort				
Standards	" "				
Summary reports of operating and maintenance experience					

Reports of Subcommittee on Analytical Procedures
for Determining Impurities in Sodium

Report of Meeting on February 18-19, 1964

Location: New York Operations Office, USAEC
Conference Room A

Attendance: R. W. Bane, ANL
D. T. Eggen, AI
R. W. Lockhart, GE
G. Waterbury, LASL (acting)
L. Newman, BNL
J. C. White, ORNL
J. Wise, NYO (Chairman)

Purpose: In accordance with instructions from the Working Group, a meeting of the Subcommittee on Analytical Techniques for Sodium was called by the Subcommittee chairman to expand the charter of the Subcommittee, to develop a program for carrying out its purpose under the charter, and to consider the status of the AEC-sponsored carbon round-robin analysis program.

Meeting Items: The following items were covered at the meeting and are discussed in some detail below:

1. Subcommittee charter and name
 2. Subcommittee program for implementation of its responsibilities under the charter
 3. Sodium contaminant program
 4. Carbon round-robin program
 5. Subcommittee business
-
1. Subcommittee charter

The origin of the subcommittee was as an ad hoc committee for the AEC-sponsored carbon round-robin analysis program, and it was called the Ad Hoc Committee on Analytical Techniques for Sodium. In light of the expanded scope of its interests, as directed by the Working Group, it is proposed that its name be changed and the proposed charter be approved by the Working Group.

Name

Subcommittee on Sodium Impurities (of the AEC Sodium Components Development Program Working Group)

Charter

In the development program for sodium-cooled civilian power technology, and specifically for sodium-contaminant systems, studies are performed for the purpose of understanding the principles and control of corrosion, mass transfer, solids disposition, radioactivity buildup, temperature limitations, and similar operational characteristics of such

systems and related equipment. The purpose of the Subcommittee on Sodium Impurities is to survey, evaluate and comment on such work performed by AEC contractors and others in the areas of fundamental theory, analysis (including sampling), operation, purification and monitoring of sodium-contaminant systems. In addition to consideration of work in progress, the Subcommittee's further purposes are to comment on proposals for work to be performed, and to recommend work to be performed to achieve program requirements.

2. Subcommittee program for implementation of its charter

To carry out its purpose under its charter, the Subcommittee will

- a. hold meetings of its members to review work underway and evaluate the work
- b. maintain liaison with other organizations supporting and doing work in sodium technology
- c. review pertinent sections of reports of work being performed on sodium technology - reports distribution will be arranged by the AEC and/or by individual arrangements of the Subcommittee members
- d. follow the carbon round-robin analysis program and similar programs as may be initiated in the future
- e. arrange for meetings and symposia as may be worthwhile to define and clarify the problems in the areas of interest

The Subcommittee will furnish its comments, evaluation of work being performed and suggestions for work to be performed to the Working Group.

3. Sodium contaminant program

The problem areas and programs (current and recommended) that were considered at the meeting are discussed below:

a. Reasons for interest in sodium contaminants

corrosion
mass transfer
temperature limitations
disposition of solids
radioactivity buildup

b. Areas of interest

fundamental theory (analytical models) to explain chemical and physical effects

qualitative and quantitative analysis — procedures and
 sampling
 purification and control
 monitoring and system operation

c. Contaminants of interest

The contaminants of principal interest at present are carbon and oxygen. The sources, effects and other information for these and other contaminants are tabulated below:

<u>Contaminant</u>	<u>Source</u>	<u>Temperature Criteria</u>	<u>Effect</u>	<u>Concentration Range*</u>
Oxygen	Reactor sodium Handling Sampling Cover gas	All temp.	Corrosion of structural material	0-10 ppm
Carbon	Reactor sodium Mass transfer	Above 900F	Carburization and decarbur- ization	0-100 ppm (?)
Nitrogen	Handling		Nitriding and denitriding	
Hydrogen	Reactor sodium Cover gas moisture	Below 600F	Effects zir- conium and refractory materials	
Fission products	Reactor	All temp.	Radioactivity	Less than sodium 5-day reading
Calcium	Reactor sodium		Nickel trans- fer	Less than 10 ppm
Metallic oxides	Mass transfer	All temp.	Effects cor- rosion rate	

d. Work underway

Work known to be in progress at the sites indicated or
 work contemplated at these sites is indicated below:

United Nuclear Corporation — Development of a continuous reading
 meter for measurement of oxygen in sodium
 Proposal for support of development of a carbon meter

Westinghouse Electric Corporation — Analysis of contaminants in a cold trap from the Fermi plant in an effort to evaluate its performance

Atomics International — SRE and Hallam operational analysis and examination of components

Evaluation of control devices

Removal and monitoring of contaminants

Definition of fission products problem

APDA — Development of resistivity meter

General Electric — Sodium mass transfer loops

Fast ceramic reactor program

SEFOR program

Mine Safety Appliances — Measurements of physical properties of materials in a sodium environment

ORNL — Development of analytical procedures for oxygen, nitrogen, carbon and hydrogen

LASL — Development of analytical procedures for carbon and nitrogen

BNL — Heat transfer measurements

ANL — Development of analytical procedures for oxygen and carbon as a tool for future studies of the fundamental chemistry of these materials in sodium

e. Problem areas and recommended programs

Problem areas and recommended work are discussed under headings of the areas of interest.

Fundamental theory There is very little knowledge and very few measurements for chemistry, thermodynamics (equilibria of coexisting contaminants), kinetics and solubilities. There is not much work underway in these areas. Work is needed for understanding and defining the problems in the other areas of interest. It would be expected that this fundamental work would be undertaken by universities and national laboratories, but time is a factor and some work by industrial organizations may be of benefit.

Analysis — Procedures Accuracy and precision for the measurement of carbon and oxygen in the low ppm range is needed. It is not yet apparent what the analytical procedural problems for other contaminants are.

The capability of laboratories to exchange samples and duplicate analyses had not yet been demonstrated. Until this can be done, it cannot be certain what the worth of analyses from individual laboratories are.

The electrochemical meter for oxygen is considered an important tool and should be supported as long as it shows promise. Also, the development of chemical procedures for the measurement of oxygen should be supported for measurement in the low ppm range.

The results of the carbon round-robin analysis should be evaluated and work supported as indicated by the results.

Analysis - Samples Sample preparation, handling and heterogeneity of the samples have been pointed up as problem areas by the carbon round-robin program. Work should be done to define the problem, and to develop techniques to minimize the effects.

Recommended sample preparation and handling procedures should be set up and evaluated by different laboratories. Probably a smaller number of laboratories than the carbon round-robin program participants would be preferable.

Purification and control The effects of additives should be investigated as a means for controlling the effects of impurities. Methods and devices for addition of these materials would have to be developed.

Trap design and design procedures and alternative equipment should be studied in an effort to produce reliable and economic equipment. Equipment permitting ready discharge of the trapped material would be desirable.

Monitoring Continuous monitoring equipment, specific to individual contaminants, is the goal in this area.

4. Carbon round-robin analysis program

A separate report is being prepared for this work. The results indicate a problem area exists in sampling - including preparation and handling. Though the analyst members of the Subcommittee consider the method of analysis for carbon (which is fundamentally the procedure used for analysis of carbon in metal) to be sound and capable of measuring in the low ppm range with precision, it has not yet been demonstrated for carbon in sodium. Until the sampling problems are overcome it will be difficult to prove the method.

5. Subcommittee business

A meeting of the Subcommittee will be held in conjunction with the next meeting of the Sodium Components Development Program Working Group meeting.

The chairman explained to the members that it was desirous to limit membership to people from non-industrial organizations and that consideration was being given to dropping the two members from industrial organizations, probably with the completion of the report on the carbon round-robin program. At the meeting, and here again, it must be emphasized that these two members were considered a very vital and helpful part of the group and it is considered that it is important that their particular talents be made up by additions to the group. This opportunity is taken to thank them for their participation in the past and it is expected that they will prove helpful in the future as consultants on specific problems.

Report of Meeting on April 17, 1964

Location: Hollywood Roosevelt Hotel, Hollywood, California

Attendance: R. W. Bane, ANL
D. T. Eggen, AI
R. W. Lockhart, GE
G. Waterbury, LASL (acting)
L. Newman, BNL
F. A. Smith, ANL
J. C. White, ORNL
J. Wise, NYO (Chairman)

Purpose: The meeting was called as a general meeting, however substantially the only order of business was consideration of the draft of the report on the round robin carbon analytical program and the round robin program itself.

Meeting Items: The following items were covered at this meeting and are discussed in some detail:

1. Draft report for carbon round robin analytical program
 2. Carbon analysis program
 3. Future meeting arrangements
1. Draft report for carbon round robin analytical program

It was judged that the report prepared by GE is a satisfactory presentation of the round robin program. While the Subcommittee does not completely concur with the results of the statistical analysis, it recommends publishing and distributing the report. Editorial type comments were noted and will be furnished to the AEC along with the Subcommittee's recommendation.

In general, the Subcommittee considers that the round robin program has indicated problem areas in sample preparation and sample handling, and that no method of analysis for carbon in sodium has been shown to be capable of performing in the low ppm range of interest. The problems associated with sample handling and preparation have clouded the analytical efforts, so that while no analytical method has been demonstrated to be satisfactory, none have been ruled out; and in the opinion of many of the Committee the analytical methods employed should eventually prove to be satisfactory.

2. Carbon analysis program

There was not sufficient time for the Subcommittee to reach full agreement on a detailed plan for what should be done next. However the following areas of work were discussed and there was general concurrence in the merits of such work in addition to the recommendations in the draft report.

- a. Solicitation of proposals to perform work (supported by the Commission) with the objectives of resolving the sample preparation and sample handling problems, followed by the evaluation of analytical methods.
- b. Separation and individual resolution of the problems of sample preparation, sample handling and analysis.
- c. No continued large round robin effort -- in the future when satisfactory sample can be prepared consider the worth of a smaller round robin limited to active participants.
- d. Non financial support of work by interested laboratories -- e.g. supplying samples, making results from other laboratories available. AI has some 250 ppm C (by chemical analysis) non-carburizing sodium that may be available for testing. AI would like to perform additional studies before offering it.

Recently (5/26) Ralph Bane of ANL requested samples for work in comparing low temperature combustion with high temperature combustion analysis.

- e. AEC support of chemistry work (thermodynamics, kinetics and reaction mechanisms). While this is perhaps outside the scope of work to be supported by the LMCR Branch, the need for this knowledge and the limited effort underway warrant LMCR support in "selling" such support to other AEC branches.

3. Arrangements for future meeting

Presuming acceptance of the proposed charter, a Subcommittee meeting will be called (1) to review AEC (and other) supported projects underway and (2) to develop and define objections for work that should be performed.

Report of Meeting on June 30, 1964

Location: Argonne National Laboratory, Building 208, Conference Room B

Attendance: R. W. Bane, ANL
L. Newman, BNL
F. A. Smith, ANL
G. R. Waterbury, IASL (acting)
J. Wise, NYO (Chairman)

Purpose: The meeting was called as a general purpose meeting (1) to review and comment on work being performed relating to sodium impurities and (2) to discuss area for new work of use that might be performed.

Meeting Items: The following items were covered at the meeting and are discussed in some detail below.

1. Review of minutes of former meetings
2. Miscellaneous business items
3. Review of AEC and other sodium impurities work
4. Areas for new work
5. Next Subcommittee meeting

1. Minutes of former meetings

The minutes of the February 18-19, 1964 and April 17, 1964 meetings were read and accepted without change.

2. Business items

a. J. Wise informed the members of the Commission's current interest in having experienced people with sodium components background for duty at European sodium facilities sites.

b. E. Anderson's (AEC Headquarters) interest in sodium impurities analytical work was made known to the members by J. Wise. Copies of minutes of Subcommittee meetings will be sent him, and he will be advised of Subcommittee meetings whose agendas may be of interest to him.

c. J. Wise informed the group of Dr. Wensch's indication that, for the present, there be no official AEC representation to the ASTM subcommittee headed by D. Kirkbride which is considering setting up standard procedures for the analysis of oxygen in sodium. Inasmuch as some of the Subcommittee members are also members of the ASTM group it was considered that the Subcommittee would be kept fully aware of the progress of the ASTM group.

d. The members were asked again to forward experience resumes to the chairman for transmittal to Dr. Wensch.

e. Receipt of reports of AEC sodium impurities work by the Subcommittee membership was reviewed. J. Wise will arrange for distribution of such reports to the members.

3. Review of Sodium Impurities Work

a. United Nuclear Corporation, Oxygen/sodium meter

Work is progressing on design of units for field testing. Work on laboratory measurements of cell response, temperature coefficient, effects of impurities, etc. is drawing to a close. Utilization of the thermal convection loops will continue for life testing. The members gave general endorsement to the progress and direction of the work.

b. Westinghouse Electric Corp., Cold Trap Examination

Work has progressed along development of a trap coring technique. The procedure is to force a 1-inch diameter tube, with a sharpened tip into the trap, after drilling entrance holes through the trap shells, by blows from a jackhammer or manually by use of a sledge hammer. Corings have been obtained successfully.

Comment from the membership was generally affirmative. It was suggested that samples for analyses be obtained from above and from below the mesh region.

c. United Nuclear Corporation, Carbon meter

UNC's intent to perform some experimental measurements to demonstrate the technical feasibility in the near future was mentioned.

The members were interested in the outcome of this work since it is considered that a carbon meter is a very desirable instrument.

d. United Nuclear Corporation, Electrochemical sodium purification

The Air Force supported work at UNC investigating the purification of sodium electrochemically (essentially the electrochemical meter driven in reverse by an applied voltage) was described briefly. The work to date has not achieved high efficiencies of cell operation and difficulties were encountered in mechanical failure of the electrolyte material.

e. Other

Work by J. DeVan at ORNL in sodium/oxygen analysis was mentioned. His technique involves the use of Zr foil as a getter material and measurement of the pickup of oxygen by the Zr from contaminated sodium. No results of this work were known.

Carbon round robin - It was considered, on the results of the previous round robins, that no additional extensive round robin be used to study the carbon analysis problem. However, it was considered that small specific interlaboratory efforts, initiated by the individual laboratories, could be worthwhile.

4. Areas for New Work

The members attempted to define areas of work in sodium impurities that should be performed but which are not as yet supported. This is set out in the accompanying table.

The approach was to consider the four fields of concern: sodium chemistry, sodium contaminant analysis, sodium purification, and sodium systems monitoring; and for each of these (1) survey and define the problem areas, (2) evaluate these problem areas in terms of SCDP requirements, and (3) indicate the areas where research and development should be profitable.

No attempt was made to set out programs of approach in these R&D areas. It was considered these would be forthcoming as the results of solicitations to perform work to resolve the problem areas.

It was considered that the short term interest would emphasize the interest in oxygen and sodium, and longer term interest would involve other contaminants and fission products.

5. Next Subcommittee meeting

It was decided, beginning with the next meeting, to initiate holding meetings concurrently with visits to sites at which sodium impurities work is being performed in order to enable first hand review of the work. APDA, UNC, MSA and GE were mentioned as potential contractor sites for visits.

J. Wise will set the next meeting date and arrange to hold it in conjunction with such a visit.

Potential Areas for Sodium Impurities Work

<u>Field</u>	<u>Problem Definition</u>	<u>SCDP Requirements</u>	<u>Potential Areas of Work</u>
Sodium chemistry	Re chemistry of sodium reactions (models), compound forms; thermodynamics (the equilibrium distribution of impurities); and reaction kinetics (the speed with which changes will occur) data is almost nonexistent. This knowledge would be extremely useful in understanding the phenomena and for component design	Basis for component design of sodium systems and for analytical and monitoring procedures	Promote interest in other AEC branches by advising of LMCR Branch requirements LMCR Branch support of work
Sodium analysis	Inconsistency of results between laboratories Effects of interferences between contaminants Difficulties in preparing samples, handling samples, sampling, and analysis	Needed for monitoring sodium systems and establishing operational procedures	Solicit proposals: State problem areas and objectives (prep. of samples, sampling, handling samples, analysis with interlaboratory reproducibility) Request proposals outlining work scope to resolve problems and achieve objectives Oxygen, carbon, hydrogen, etc.
Sodium purification	Cold and hot trap design is an art, not a science	Improved techniques, equipment, efficiencies Fission product removal	Economic evaluation of alternative procedures Re cold traps Develop analytical model Engineering design data Autopsy vs. devices designed for obtaining information Kinetics of particle nucleation
Sodium monitoring	Data is being developed by plugging meter, Blake meter, etc. However data is insufficient and apparently better devices are needed. Fission products not yet monitored	Required for system operation (normal) and indication of failed fuel elements	Indicate Commission interest and solicit proposals

Report of Meeting on October 15-16, 1964

Location: Holiday Inn Motel, Detroit, Mich.

Attendance: L. Newman, BNL
A. J. Romano, BNL
F. A. Smith, ANL
G. R. Waterbury, LASL
J. Wise, NYO (Chairman)

Purpose: The meeting was called as a general meeting to review sodium impurities work underway, discuss areas for new work, and to visit APDA and review its work in the field of interest.

Meeting Items: The following items were covered at the meeting and are discussed in detail below.

1. Business items
2. Review of active sodium impurities work
3. Areas for new work
4. Review of APDA work
5. Next Subcommittee meeting

1. Business items

a. C. R. Metz of LASL informed J. Wise that because of the press of other work he would not be able to perform as a member of the Subcommittee. He suggested G. R. Waterbury, who had acted for Metz at the last two meetings, as his replacement. Subject to affirmation by Dr. Wensch, Waterbury will serve as a Subcommittee member.

b. The delinquent members were reminded to submit their experience resumes.

c. The minutes of the June 30, 1964 meeting were accepted.

d. A general agenda for the APDA meeting on October 16 was discussed and checked out with APDA personnel

2. Review of sodium impurities work

a. United Nuclear Corporation, Oxygen/sodium meter

The first field type units have been constructed and are being checked out in the forced circulation loop. Results thus far are encouraging.

One of the field test sites will be APDA, and a second ANL. The third site has not yet been determined. LASL, SCTI and MSA were mentioned.

The field meters should be ready in the early part of 1965.

b. United Nuclear Corporation, Carbon meter

Some experiments have been run but data is not yet available, although carbon diffusion from sodium through an iron wall was picked up by reaction with hydrogen to form methane.

c. Westinghouse Electric Corporation, Cold trap examination

Westinghouse has had difficulties in demonstrating analytical capability for analysis of sodium samples. Three series of analyses were run with APDA, ORNL and MSA providing varying check analyses.

Samples were removed from the trap and analyzed. Interferences at high oxygen levels were observed by formation of a black crud-like deposit during analysis which interfered with removal of the sodium phase during the amalgamation process.

The first two series of analyses showed no consistency between Westinghouse and APDA and ORNL. Also Westinghouse's more numerous analyses showed a wide range of results.

A meeting of APDA and ORNL personnel at Westinghouse was arranged. Both APDA and ORNL offered several comments re modification of Westinghouse procedures and equipment. In private communications to J. Wise, both Bradley of APDA and Goldberg of ORNL considered that Westinghouse did not as yet have experience and capability sufficient to perform the work.

A third series of analyses was run with Westinghouse modifying procedures, taking into account ORNL and APDA comments at the review meeting. A limited number of analyses was performed. The results indicated better agreement, on the surface, than the first two series. However because of variation in sample size (which Westinghouse has stated is a large factor), variation effects in sample location, and the limited number of results, the members of the Subcommittee considered results of the third series inconclusive. The members felt it would be preferable to have the analytical work performed at an experienced, recognized laboratory.

d. APDA

See 4 below

e. Carbon Round Robin Report

The report has been approved for publication and should be distributed shortly.

3. Areas for new work

The three items listed below were discussed by the Subcommittee and were endorsed by the members.

a. Industrial laboratory for sodium analysis

At present, analytical sodium support for engineering studies is limited because of the use of support analytical laboratories which have a separate and independent work load. Development of competent laboratories at each engineering site to supply capability beyond routine analyses is not considered warranted. It is conjectured that there is probably sufficient need for a single laboratory that could undertake non-routine and developmental sodium analytical work that such a laboratory could be supported by charging for the work performed.

The benefits would be the availability of a laboratory to perform work which, at present, often is not performed, support of the laboratory by its own work, and the common "meeting place" for non-routine analytical work.

F. A. Smith and G. R. Waterbury have the assignment of preparing a survey letter to inquire of industrial facilities their needs for such a laboratory and the potential utilization of the laboratory. Subject to Working Group approval and review of the survey letter, it would be sent and the results of the survey published. The expectation is that the results would indicate the economic feasibility of the laboratory and that, with this incentive, industry could be expected to support the laboratory.

b. The following is noted as an item for remedial action, relative to the integration of work. It has been noticed at large facilities with varied programs that there is often a lack of integration of these programs so that one may be useful to another. It is considered that such integration should be on a level above the individual projects, and should be pursued with more vigor than at present. This in no way should be construed to curtail any interrelations that exist on the project level.

c. Independent support of analytical work. For the most part, sodium analytical work is pursued in conjunction with, and as required by, engineering development projects. It is considered by the Subcommittee members that such support would be more efficient, more economical, and desirable for work beyond immediate needs.

This work should be directed toward development of analytical procedures for routine analysis of sodium contaminants. A level of effort of about 6 men is considered reasonable.

It is noted that APDA people consider the development of analytical methods important.

4. Review of APDA work

In general the members of the Subcommittee were strongly impressed with the character of the work being performed, the approaches taken, the experience of the people, and the interest of APDA personnel in their work.

The hospitality of APDA people and their efforts in assisting the Subcommittee is noted. A letter of appreciation and thanks will be sent to APDA by J. Wise, with copies to Dr. Wensch and the Chicago Operations Office.

The work reviewed at APDA is described briefly:

a. Sodium technology loop

The loop was inspected and its operation discussed. APDA noted it considered contaminant injection as an item for additional improvement.

The loop will be used to compare operation and study operation of sodium instrumentation. Future utilization may include study of sodium purification devices.

b. Analytical laboratory

The laboratory was visited and the methods for oxygen, carbon and hydrogen were discussed. APDA methods have been standardized within its laboratory, and it has been able to achieve high standards of reproducibility. The analyst members of the Subcommittee indicated they were favorably impressed with the laboratory, including equipment and procedures.

Work is underway on development of hydrogen analysis by amalgamation of the sodium. At ambient temperatures dissolved gaseous hydrogen is measured, heating to about 300F would decompose the hydride, and decomposition at 950F would release hydrogen from the hydroxide form. The method therefore could be used to assay the form of hydrogen in the sodium sample. The results of the work are not sufficiently along to draw firm conclusions, but apparently Fermi sodium measures about 7 ppm hydrogen with most being in the form of dissolved gas, about 10% in the form of the hydride, and very little in the form of hydroxide.

It is of interest to note that thermodynamic and solubility information on the various forms of hydrogen that exist in sodium has been published recently by McClure, as a PhD thesis at the University of Washington, and the results of the APDA work are in good agreement.

c. Na/H₂O reaction loop

A brief description of the sodium-water reaction loop was presented. It is scheduled for construction in early 1965, and will investigate wastage of steam generator tubes by sodium leaks.

5. Next Subcommittee meeting

The next meeting will be set and arranged by J. Wise taking into account visit to a sodium facility for first hand review of the work being performed, Working Group requirements, and convenience with attending related meetings, e.g., ASTM subcommittee.

Report of Meeting on February 24, 1965

Date: February 24, 1965

Location: New York Operations Office, New York, N. Y.

Attendance: R. Bane, ANL
J. Dissler, NY (Chairman)
L. Newman, BNL
A. Ramano, BNL
F. Smith, ANL
G. Waterbury, LASL
J. White, ORNL
J. Wise, NY

Purpose: The meeting was called as a general meeting to review sodium impurities work currently underway and to discuss a program for the resolution of the problems associated with sodium contaminant analysis.

Meeting Agenda: The following items were covered at the meeting and are discussed in detail below:

1. Business items.
2. Review of current sodium impurities work.
3. Sodium contaminant analysis program.
4. Next committee meeting.

1. Business Items

- (a) J. Dissler, the new chairman of the committee, was introduced to the members by J. Wise. The new chairman indicated that J. Wise would be retained as a committee member because of his background and experience in the field.
- (b) The minutes of the October 15-16, 1964 meeting at APDA were accepted.
- (c) The modified committee charter, as submitted by J. Wise to Dr. Wensch for approval, was presented for the committee's consideration. There was general agreement among members that the modified charter was more specific and more clearly defined the primary concern of the committee, and was therefore an improvement over the present charter. The members unanimously recommended approval of the modified charter.
- (d) The new chairman apprised members that future changes in committee size and membership might be required because of the increasing size of the committee. The chairman indicated that the committee size was greater than that of the other Working Group Standing Committees, and perhaps this was proper

because of the broader nature or scope of the committee as contrasted to the other Working Group Committees, i.e., surveillance of programs at several facilities rather than a single program at a single facility. Although the new chairman was not aware of any existing limitations or ceiling on committee size and membership, he indicated that a future reduction in membership may be necessary or desirable.

F. Smith suggested the possibility of eliminating duplicate members from ANL and BNL, although the members in each of these cases represent different disciplines, i.e., engineering and chemistry.

2. Review of current sodium impurities work

(a) ASTM Committee Program

F. Smith of ANL, a member of the ASTM B-3 Committee on Corrosion of Non-Ferrous Metals and Alloys, reported on the recent meeting (February 8 and 9, 1965) of the ASTM Committee in Cleveland, Ohio. A task group working on sodium systems is about to launch a round robin analysis for oxygen in sodium, which will be primarily concerned with analysis of oxygen contaminant in the low (10) ppm range, but will not be specifically oriented to the mercury amalgamation technique. Samples for the oxygen round robin analysis are being prepared by L. Rosenblum of NASA and will be supplied to the 17 participants by March 15, 1965. F. Smith indicated that the rationale for the round robin is the investigation of the human element in handling and analysis of samples, thereby placing great importance on preparation of uniform and homogeneous samples. The consensus of opinion among the Working Group Committee members was that the oxygen round robin program was premature in that more work should be devoted to developing of sampling, handling, and analysis techniques and standards prior to embarking on a round robin. Although the committee members expressed some hope for agreement among round robin participants, they expected no great improvement over the outcome of the second carbon round robin.

(b) United Nuclear Corporation - Electrochemical Oxygen Meter

Field tests of the oxygen meter will be conducted at three sites: APDA, ANL, and LASL. Fabrication and assembly of the nine housings for the field units is complete and acceptance testing of probes is underway prior to shipment of probes to the field sites. The distribution of field test meters will be as follows: 4 at APDA, 3 at ANL, and 2 at LASL. A training program was conducted at United Nuclear during the week of February 15-19, 1965 for the purpose of familiarizing personnel from the sites participating in the field tests, with the theory, construction, installation, and operation of the oxygen meter. An operating manual for the meter is also being prepared and will be published prior to initiation of field tests.

(c) United Nuclear Corporation - Carbon Meter

UNC has performed some feasibility experiments, the results of which were reported at the last Working Group meeting. Carbon diffusion through an iron wall of a sodium filled capsule was detected by means of carbon reaction with hydrogen gas to form methane. A UNC proposal is expected shortly, which will solicit AEC support for development of engineering data, and design, development, fabrication, and field test of a carbon meter.

(d) Westinghouse Electric Corporation - Fermi Cold Trap Examination

Chemical analyses of cold trap samples by APDA for oxygen, carbon, and hydrogen have been completed and will be incorporated in the Westinghouse final report expected in draft form in early March. Some Westinghouse chemical analyses were performed in conjunction with the APDA analyses but Westinghouse decided for the most part, to use APDA data. Analysis of cold trap samples for nitrogen is being performed by LeDoux and will be completed shortly.

3. Sodium Contaminant analysis program

Various approaches to defining a program of work on sodium contaminant analysis were presented for the committee's consideration and comments. The alternatives receiving predominant consideration were: (1) A comparison and evaluation of the mercury amalgamation and vacuum distillation methods for determination of oxygen in sodium, proposed by F. Smith, and (2) a program of work on development of sampling, handling, and analysis techniques for determination of oxygen, carbon, and hydrogen in sodium, proposed by J. Wise.

After review and discussion of the alternate programs, it was agreed that the program directed at development and standardization of sampling, handling, and chemistry was the more comprehensive program and really attacked the basic problems, i.e., elimination of potential sources of contamination in sampling, handling, and analysis, of particular concern in the determination of contaminants in the low ppm range.

The program would cover oxygen, carbon, and hydrogen, and would investigate the basic chemistry, i.e., possible interactions and interferences, in the analysis for these contaminants.

It was agreed that the proposed program would be presented for the Working Group's consideration according to the following outline:

I. Letter of transmittal to Chairman of Working Group

A. Solicitation Package

1. Letter of solicitation
2. Technical background
3. Scope of Work
4. Information required in proposal

- B. Invitee List
- C. Selection Criteria
- D. Justification or support for proposed program
- E. Estimate of cost and schedule.

The contents and detail of the proposed program are the subject of a separate submittal to the Working Group.

F. Smith proposed a further area of work which consisted of a concurrent operations analysis program, similar to the present arrangement between COO and AI for the Hallam plant, to survey on a monthly basis operating conditions and sodium chemistry of major sodium cooled reactors, and test facilities, i.e., Fermi, EBR-II, Dounraey, SRE, etc. Determination of sodium contaminant levels in operating reactor plants would provide a valuable bench mark or reference point which could then be used to set requirements for sodium contaminant analysis methods. Such data is now lacking with the result that, coolant chemistry requirements set by various organizations are not really substantiated, but based on conservative safety or ignorance factors. The committee recognized the need for operations analysis data and recommended that this work be performed. A preliminary outline of the contents of the proposed program is presented in a separate submittal to the Working Group.

4. Next committee meeting

The next committee meeting will be set by the chairman and will probably precede the next SCDP information meeting scheduled to be held in Chicago in late Spring or early Summer of 1965.

UNITED STATES GOVERNMENT

Memorandum

TO : Glen W. Wensch, Chairman
Sodium Components Development Program Working Group

DATE: MAR 1 1965

FROM : Joseph J. Dissler, Chairman
SCDP Working Group Standing Committee for Sodium Impurities

SUBJECT: PROGRAM FOR DEVELOPMENT OF ANALYTICAL PROCEDURE FOR SODIUM
CONTAMINANTS ANALYSES

R:JW:SCDP

At a meeting of the Standing Committee held at NYO on February 24, 1965 a program for the resolution of problem areas in sodium contaminants analysis and development of analytical procedures was discussed and developed. The purpose of this memorandum is to submit this program for your consideration and recommend that the work be performed. It is further recommended that NYO be authorized to solicit proposals and select a contractor to conduct the program.

The objectives of the proposed program are to resolve the problems associated with sampling, sample handling, the chemistry of the interacting contaminant forms, and the analytical procedures for the contaminants of principal interest: oxygen, carbon and hydrogen. The labor and materials costs are estimated to be about \$200,000 a year and the work will require approximately two years to complete. Equipment costs will vary dependent upon the particular facilities of the selected contractor. Estimated equipment costs are \$150,000 (to be costed in the first year) if the contractor does not have appropriate equipment available, however, it is considered that the actual costs will be much lower because of the probability that the selected contractor will possess extensive sodium equipment and facilities that may be adapted or modified to suit the program requirements.

The proposed program is presented herewith in the following appendixes.

Appendix A - Letter of solicitation (with enclosures describing technical background, scope of work, and information required with the proposal)

B - List of invitees

C - Proposal evaluation criteria

Appendix D - Justification for proposed program

E - Estimates of cost and schedule

It is recognized that the final form of several of the above listed appendixes are the responsibility of the contractor selection board that will be concerned with the selection. However, the appendixes provide a convenient format to describe the proposed program, and should be considered as illustrative of their final form.

The following items are noted in support of the program:

1. It is recognized that considerable effort has been spent at many laboratories to develop satisfactory procedures for sodium containment analyses. It is considered that the prime reason for lack of success to date is the failure to set up a fully integrated program based upon the recognized problem areas and providing for strong direction and administration. The proposed program will accomplish this.
2. While satisfactory analytical procedures are needed now, particularly in conjunction with much of the development work underway, the need for the capability of monitoring future high sodium temperature operational systems is a strong argument for initiation of the proposed work.

It is the unanimous opinion of the Standing Committee that the work be performed and therefore the proposed program is submitted for your review, consideration, and comment.

cc: Members of Sodium Components Working Group
Members of SCDP Working Group Standing Committee
for Sodium Impurities

UNITED STATES
ATOMIC ENERGY COMMISSION
NEW YORK OPERATIONS OFFICE
376 HUDSON STREET
NEW YORK, NEW YORK 10014

TELEPHONE NO
YUKON 9-1000

SUBJECT: INVITATION TO SUBMIT PROPOSALS FOR SODIUM CONTAMINANT
ANALYSIS PROGRAM

Gentlemen:

The Atomic Energy Commission is interested in initiating a program of work directed toward resolution of problems associated with sodium contaminant analysis. The overall objectives of the program are development of standards for sampling, handling, and chemical analysis for oxygen, carbon, and hydrogen in sodium.

Your company is invited to submit a proposal for the performance of this work which is further defined in Enclosure II hereto.

The performance of this work requires general capability in the field of liquid metal technology, with specific competence in the area of sodium contaminant analysis, i.e., sampling, handling, and chemical analysis of sodium for oxygen, carbon, and hydrogen. To give a general indication of the magnitude of this project as envisioned by the AEC, it is estimated that the work will require approximately a two year effort and cost in the range of \$400,000 to \$500,000.

A Contractor Selection Board has been established by the New York Operations Office to solicit and evaluate proposals and recommend selection of a contractor whose proposed program offers high probability of success.

It is desired that the proposer have the capability to conduct the entire project within its own organization unless, owing to lack of equipment or facilities, the proposer finds it necessary to subcontract for certain phases of work, e.g., oxygen analysis by neutron activation technique.

Selection of the contractor will be based primarily upon an evaluation of (1) the technical approach proposed in pursuit of the objectives and program stated in Enclosure II, (2) the interest and capability of the organization in carrying out the work, including its pertinent experience in liquid metal technology in general, and in sodium contaminant analysis in particular, and (3) qualification and availability of personnel to be assigned to the proposed work, and adequacy and availability of equipment and facilities.

Guidance as to information to be included in proposals is given in Enclosure II. In the event there is any information in a proposal which the proposing company considers to be of a proprietary nature, that particular information should be so identified. The company should also identify in its proposal any technical information, process, procedure or material proposed to be used in the performance of the work, in which the company has any background patent or proprietary position. In this connection, it is intended that full background patent and technical data clauses will be included in the contract.

It is anticipated that the resultant contract for this work will be negotiated on a cost type basis. The contract will contain provisions generally used by the Atomic Energy Commission in contracting for similar cost-type research and development work with commercial organizations such as contained in the Atomic Energy Commission Procurement Regulations and the Federal Procurement Regulations with the consideration of the allowability of costs based on Subpart 9-15.50 and Section 9-7.5006-10 of the AECPR. In addition, the appropriate clauses required by FPR 1-3.814 will be included in the contract.

If you are interested in proposing to undertake the work defined in Enclosure II, copies of your proposal should be submitted in time to reach the undersigned on or before 1965.

Inquiries regarding this invitation or the work involved should be addressed in writing to the undersigned. It will be appreciated if you will acknowledge receipt of this invitation and advise whether you intend to submit a proposal.

Sincerely yours,

Chairman, Contractor Selection
Board

Enclosures:

- I Technical Background
- II Scope of Work
- III Information Required in Proposal

Enclosure I to Appendix ATechnical BackgroundIntroduction

The principal sodium contaminants of concern in the development of the large fast breeder reactor and associated sodium components are oxygen (because of the relation of system materials corrosion to oxygen content), carbon (because of mass transfer of this element between materials in the system - carburization and decarburization - and consequent change in the physical properties of the materials) and hydrogen (because of the need for ascertaining early indication of leakage in the steam generator and potential materials embrittlement). Analysis of these contaminants is essential for monitoring operational systems, and evaluation of data from experimental systems.

Difficulties have been experienced both in laboratories and between laboratories in achieving satisfactory precision and reproducibility of analyses for low level contamination (ppm) and high level contamination (hundreds of ppm). While some laboratories have standardized procedures to indicate some measure of precision, there has not been any substantial agreement between laboratories. Also these standardized procedures have been for a limited range of the parameters involved.

Existence of the contaminants in more than one chemical species, and probable interactions between these species further complicate the analytical problem. For instance, the solubility of carbon in sodium is given in the literature as a function of oxygen in the system, plugging indicators show double break points, and chemical analysis shows carbon in sodium to exist in several compound forms.

"Round-robin" analytical programs to evaluate inter-laboratory procedures (e.g., the NASA oxygen in potassium "round-robin", and the two AEC carbon in sodium "round-robins", described in GEAP-4602) have not been successful programs.

Problem Areas

The problem areas that have been highlighted are:

1. Sampling - representation of the system by the sample, sample heterogeneity (phase and concentration changes upon cooling), changes upon removal from system and by ambient contamination.
2. Sample handling - contamination by ambient atmosphere and sample container.
3. Interactions between the several species of contaminants that exist concurrently, and interferences with analytical procedures.

4. Analytical procedure - specificity for particular chemical compound, removal of representative aliquot from the sample, definition of adequate aliquot size for heterogeneous sample, methods standardization, and demonstration of inter-laboratory reproducibility.

Program Objectives

Resolution of the above problem areas comprise the objectives of the program. Successful completion of the program should result in demonstration of standardized procedures for analysis of oxygen, carbon and hydrogen, in the forms represented by samples, for high purity (ppm) and low purity (hundreds of ppm).

Enclosure II to Appendix A

Scope of Work

The objective of the work is to obtain standardized methods of analysis of high precision, (10%) accuracy and reproducibility (including sampling and sample handling, demonstrated by inter-laboratory measurements) for oxygen, carbon and hydrogen (individually and coexistent) to high and low purity ranges.

Work shall be performed to achieve these objectives, and will include the following tasks.

Task 1 - Survey, Evaluation, and Definition of Problem Areas

- a. Literature survey of the contaminant chemistry of sodium systems for oxygen, carbon and hydrogen covering the forms of compounds that exist, their equilibria concentrations, chemical interactions and the rates of change with varying physical conditions. Evaluation of the contaminant chemistry in terms of analysis problem areas. Definition of extent of problem areas as affected by sodium chemistry.
- b. Survey of procedures (including sampling, sample handling, analysis, standards, and chemistry) at reputable SCDP and other sodium laboratories of recognized analytical methods for oxygen, carbon and hydrogen. Consideration of these procedures in terms of the recognized problem areas and evaluation of the potential favorable and unfavorable factors qualitatively and quantitatively.

Task 2 - Sample Handling Development

By reduction of the adverse factors involved (and/or controlling conditions), and using reproducibility of analysis results as a measure, standardize (preliminary) sample handling procedures. After standardization, quantitatively evaluate the parameters of sample handling experimentally. Based on these measurements and the work performed on Task 1, establish improved standard sample handling procedures which will enable sample handling to be performed within the requirements for 10% analysis precision.

Task 3 - Sampling Development

By reduction of the adverse factors involved (and/or controlling conditions) employing the improved sample handling procedures developed in Task 2, and using reproducibility of analysis results as a measure, standardize (preliminary) sampling procedures. After standardization, quantitatively evaluate the parameters of sample handling and other sampling procedures experimentally. Based on these measurements and the work performed in Task 1, establish one or more improved sampling procedures which will enable sampling to be performed within the requirements for 10% analysis precision.

Task 4 - Development of Analytical Procedures

For the following methods for oxygen analysis - distillation, amalgamation, neutron activation, and electrochemical meter (1 instrumentation package and 2 probes and housings to be supplied by the Government); for the following methods for carbon analysis - wet oxidation, high temperature dry oxidation, and low temperature dry oxidation; and for mutually agreed (by the proposer and the Commission) other methods for oxygen, carbon and hydrogen, modify analytical procedures (based on the work performed in Tasks 1, 2 and 3) for improved procedures to measure oxygen, carbon and hydrogen (individually and coexistent) in the high and low purity ranges. Evaluate the precision, accuracy and reproducibility of the improved methods experimentally, using recovery of known added amounts of contaminants to "standard" sodium and results from the different methods as measures. If warranted, a second round of procedures improvement (based on the experimental evaluation) and further evaluation should be performed.

Task 5 - Interlaboratory Demonstration

Based on the work previously performed prepare samples (which can be shown to be measurably identical by the methods developed in Task 4) for a round-robin analysis to be

performed under Commission auspices. The laboratories involved can be presumed to have been informed of the work performed in this program and to be sufficient in number to furnish a statistical evaluation of the principal methods. The contractor selected for this program shall evaluate the results of the round-robin and prepare a report thereof.

Enclosure III to Appendix A

Information Required in Proposal

Without in any way limiting the proposer's prerogative as to information contained in its proposal, it is requested that such information include the following:

1. A detailed outline and description of the proposed program to resolve the problems associated with sodium contaminant analysis and develop standards for sampling, sample handling, and chemical analysis techniques for oxygen, carbon, and hydrogen in sodium. The proposer should identify the important technical problem areas anticipated and the planned approach to overcoming them, and the project schedule should provide specific information to indicate time and effort required to resolution of these problems.
2. A breakdown of the estimated cost of each phase or task of the above program. NYO Cost and Price Analysis Form (NY-272), Enclosure IV, has been provided as a guide to the desired format of the required cost estimates, and may be used by the proposer if desired. In addition, the proposer must complete and execute two (2) copies of the Certificate of Current Cost or Pricing Data, Enclosure V.
3. A resume of the qualifications and experience of the technical personnel (including consultants) proposed to be assigned to the work and the extent of their participation in this work. Indicate whether assignments will be on a full or part-time basis. If part-time, show the approximate percentage of time that will be spent on this work. The proposer should include a Project Organization Chart, showing the organization of key project personnel, and their relationship to corporate management.
4. An organization chart of the company should be included. Information demonstrating the proposer's financial capability to undertake the proposed contract, i.e., an up-to-date financial statement, should also be included.
5. A resume of the qualifications and availability of any subcontractors that may participate, along with a statement of the scope of their participation. The proposal must contain a description of any major part of the work to be subcontracted.

6. An enumeration of the equipment and facilities considered necessary in carrying out the investigations, together with data showing (1) which of such equipment and facilities is presently available to the proposer, and (2) the manner in which the proposer would obtain the remaining equipment (specifically pointing out any sub-contracting arrangements for such purpose.)
7. A resume of past experience and current work by the proposer in the area of liquid metal technology and sodium contaminant analysis.
8. The basis for the proposer's interest in performing this work and the respects in which this work is interrelated with other activities of the proposing organization.
9. The proposer's ability to promptly initiate and vigorously pursue the proposed work.
10. An identification of any processes, procedures, or materials proposed to be used in the performance of the work in which the proposer has any patent, background or proprietary position.

Appendix BList of Invitees

A tentative listing of potential bidders who are considered technically qualified to perform the work is presented for consideration by a contractor selection board. The list includes industrial contractors, national laboratories, and sodium manufacturers. Although it is recognized that the national laboratories are well qualified to perform this work, an inherent problem in administration of such a contract with a national laboratory may be difficulty with Commission project control and direction. Furthermore, utilization of the national laboratories for this work does not encourage maximum industrial participation.

Argonne National Laboratory

Atomic Power Development Assoc.

Atomics International

Battelle Memorial Institute

Brookhaven National Laboratory

E. I. duPont deNemours & Co.

General Electric Company

Ledoux & Company

Los Alamos Scientific Laboratory

Mine Safety Appliance Research Corp.

Oak Ridge National Laboratory

United Nuclear Corporation

Westinghouse Electric Corporation

U. S. Industrial Chemical Co.

Appendix CEvaluation Criteria

The following tentative criteria and weighting factors are recommended for a Contractor Selection Boards consideration, as a basis for evaluation and rating of proposals.

<u>Criteria</u>	<u>Weighting Factor</u>
1. Comprehension of Problem Proposers understanding and grasp of the basic objectives and scope of program.	10
2. Technical Approach Caliber of technical approach proposed with respect to each phase of work; program planning, sampling, handling, chemistry, and analysis.	35
3. Contractors Experience and Capability Overall competence of the Contractor as indicated by the following factors: (a) Background and experience of the proposing organization in the area of sodium contaminant analysis, i.e., sampling, handling, and chemical analysis for oxygen, carbon, and hydrogen. (b) Qualification and availability of technical personnel to be assigned to the project. (c) Adequacy and availability of required apparatus, equipment, and facilities. (d) Proposers interest in the project and his ability and willingness to initiate and vigorously pursue the program to its successful conclusion.	50
4. Project Cost and Schedule Reasonableness of cost and time estimated by proposer for carrying out the work.	5

Recommended Scoring Procedure

The following scoring procedure is presented for a Contractor Selection Boards consideration, as a means of scoring the above criteria by the application of rating factors.

Outstanding	1.0
Excellent	0.8
Good	0.6
Fair	0.4
Marginal	0.2
Unacceptable	0

Appendix DJustifications for Proposed ProgramGeneral Comments on Sodium Contaminant Analysis

Good procedures for analysis of sodium contaminants are needed for purification of sodium, monitoring operating and experimental systems, and evaluation studies of effects in experimental systems. Current techniques, such as chemical analysis and gross effects monitoring (e.g., by plugging meter), suffice for purification and operating systems, although better techniques are desired. However, for experimental systems and the high-temperature systems of the future current procedures are inadequate for precision, accuracy and reproducibility.

Present analytical techniques are limited in number and in capability. "Specific" procedures include chemical analysis, neutron activation, and some meters like the electrochemical oxygen meter and the hydrogen meter. "Gross" techniques include the electrical resistivity meter, the plugging meter, and control of cold trap temperature. For all, except for certain of the meters (which have not had extensive field use as yet), there are major problems of precision, accuracy, reproducibility and specificity.

Sodium contaminants, in general, are of interest because of their corrosion effects, their radioactivity effects, and for some their nuclear cross section effects in the reactor core. However, as a practical matter, the contaminants of present major interest may be limited to oxygen, carbon and hydrogen.

Contamination arises from the manufacturing process (here current purification procedures are adequate to control the impurity levels to design requirements), from normal operation of sodium systems (during which sodium gains impurities by contact with the ambient atmosphere, mass transfer corrosion, etc.), and from gross perturbations to systems (e.g., a steam generator leak).

Problem Areas

Experience and studies to date have indicated the following to be the principal areas:

1. Chemistry

- a. Lack of knowledge as to the chemical forms in which the contaminants exist (e.g., NaOH-Na₂O)

- b. Interactions and interference reactions between the various contaminants and chemical forms of specific contaminants.
- c. Paucity of information on concentration equilibria for the various chemical forms. For example the following compound forms probably exist in varying concentrations at different physical conditions:
 - i Na_2O , NaOH , Na_2CO_3
 - ii H_2 dissolved, NaH , NaOH
 - iii Na_2CO_3 , C dissolved, C undissolved, CO_2 , CO , metallic carbide
- d. Paucity of information on the rates of change to equilibrium conditions.

2. Sampling

- a. Changes of sample upon removal from the system by alteration of thermodynamic conditions and by contamination
- b. Techniques for obtaining the sample
- c. Heterogeneity changes
- d. Procurement of representative sample
- e. Paucity of information on sample size requirements

3. Sample Handling

- a. Contamination by environment, contamination between the sampled system and the analyst and also in the analytical procedures.
- b. Contamination by sample vessel

4. Analytical Procedures

- a. Current procedures are not always sufficiently specific. For instance some methods do not differentiate between oxygen in oxide and hydroxide forms, although an equilibrium between the two can be presumed to exist because of the reaction; $\text{NaOH} + \text{Na} = \text{Na}_2\text{O} + 1/2\text{H}_2$
- b. Removal of representative aliquot from sample
- c. Definition of adequate aliquot size for heterogeneous sample

- d. Methods standardization and demonstration thereof between laboratories
- e. Standards of "pure" sodium

Sodium Component Development Program Analytical Requirements

Currently the contaminants of principal interest are oxygen, carbon and hydrogen in the high purity range (ppm) for operating systems, and in the low purity range (hundreds of ppm) for experimental systems. Although, it can be expected that other contaminants (e.g., nitrogen and radioactive elements) will become of interest in the future as system temperature increases and as more reactor systems become operative, the short range program needs can be limited to these three major impurities.

Information can be expected from current programs. For example, the electrochemical meter (which is specific for oxygen ion) has shown promise in studies at UNC and will shortly undergo field evaluation; the imminent ASTM oxygen round sodium program can be expected to highlight the problem areas still more; the analytical work at APDA and other SCDP laboratories can be expected to provide new information. However, most of this work is limited to specific conditions of interest, and the results can also be expected to be limited accordingly.

Criteria for Development Program for Sodium Analysis

The appreciable amount of work already performed for development of satisfactory analytical procedures is recognized. However much of this past work was done with limited and restricted goals, e.g., achievement of reproducibility for a specific system under specific sampling and analytical procedures. It is felt quite strongly that the many facets of, and relationships between, the various problem areas require a unified program taking into account all of the problems that exist, and pursuing the work vigorously along a planned and logical path.

In order to realize a high probability of success in the program, it is considered quite important that there be strong leadership with respect to technical direction, with the program goals and methods of approach kept constantly in mind.

The purpose of the proposed analytical development is to obtain methods for monitoring impurities in operating systems, evaluation of contaminant chemistry in experimental systems, calibration of other methods and instruments, and studies of impurity effects in operating and experimental sodium systems with precision, accuracy, and reproducibility. For the current program the contaminants are limited to oxygen,

carbon and hydrogen in systems up to 1200°F and for impurity levels in the ppm and hundreds-of-ppm ranges.

The objective of the proposed work is to obtain standardized methods of analysis (including sampling and sample handling, demonstrated by interlaboratory measurements) for oxygen, carbon and hydrogen (individually and coexistent) in the high and low purity ranges.

Appendix EEstimate of Cost and Schedule

Preliminary estimates have been made of equipment and operating costs for the proposed program of work. Although it is expected that the contractor selected to conduct the work may be able to adapt or modify existing equipment at costs lower than shown below, the equipment cost estimates include the costs for construction of a forced convection loop, and a glove box integral with the loop.

<u>Costs</u>	<u>First Year</u>	<u>Second Year</u>	<u>Total</u>
Equipment			
Forced Convection Loop	\$100,000		\$100,000
Integral Glove Box	50,000		50,000
Sub Total - Equipment	\$150,000		\$150,000
Labor and Materials			
Loop operation - 3 men	\$ 90,000	\$ 90,000	\$180,000
Chemical analysis - 3 men	90,000	90,000	180,000
Materials	10,000	10,000	20,000
Sub Total - Labor & Mtls.	\$190,000	\$190,000	\$380,000
Total - Program Costs	\$340,000	\$190,000	\$530,000

Schedule

The period of performance should be targeted for completion in two years.

Reports of Meetings on Mass Transfer Program Review

Report of Meeting on February 24, 1964

Attendance:

C. A. Pursel	AEC-CH	Chairman
C. Klamut	BNL	Member
H. W. Savage	ORNL	Member
W. R. Simmons	ANL	Member
W. R. Wykoff	LASL	Member
J. J. Morabito	APDA	Consultant
R. J. Gariboldi	AEC-CH	Visitor
G. C. Gower	AEC-CH	Visitor
J. J. Purcell	AEC-CH	Visitor

At the last Sodium Components Development Program meeting in Washington on January 16 and 17, 1964, Dr. G. W. Wensch specifically requested Mr. C. A. Pursel to be chairman of a committee or task force which would resolve two specific questions relative to the GE Mass Transfer Program:

1. What should be done with the existing six loops at GE upon completion of the present phase of the program?
2. Should the two new loops, proposed by GE, be built in accordance with their current proposal?

The meeting was held at Chicago at the suggestion of Mr. Savage. He, together with the other members of the Ad Hoc Committee on Mass Transfer, had visited GE since the January Sodium Components Development Program meeting.

Mr. Savage described the GE Mass Transfer Program and the proposed new work. He stated that the original objectives of the Mass Transfer Program had been about 80 per cent completed. Five of the loops had each completed five runs. The sixth loop had been run almost continuously. The maximum temperature range of the loops has been between 1100 and 1200°F with a goal oxygen content of either 10 or 50 ppm.

The Present Program

1. The present Mass Transfer Program at GE consists of the completion of a half-replicate factorial set of experimental runs. It will be completed in about one year. This includes reruns necessary to firm up the data. A list of these reruns now exists but is not considered final.
2. The Ad Hoc Committee has recommended that upon the completion of the one-half replicate factorial program, the loops be cut up and examined.

3. GE has suggested spiking one or more of the existing loops with carbon at the completion of the program. The Ad Hoc Committee has rejected this suggestion since it would probably disturb the chance for obtaining meaningful data that would result from dissecting the loops.
4. A real "downstream" effect has been observed in the operation of these six existing loops. GE states that an uncertainty factor of 10 now exists with respect to the phenomena as compared to the variables which have been identified as affecting mass transfer.

The term "downstream" is used to describe the observation that the corrosion rate is less for each sample in the direction of flow with all other variables equal. The only apparent explanation is based on solubility, saturation considerations. It is believed that, in order to correlate data of the noted "downstream" effect, a L/D or surface-to-volume ratio would be required as a parameter. The terms "saturation solubility," "downstream effect," "L/D ratio or surface-to-volume ratio" are used somewhat interchangeably to express the same phenomena.

5. It is possible that the sodium is still somewhat near saturation as it reaches the first sample. The maximum corrosion rate in a liquid metal cooled reactor, outside of the core, might therefore be higher than the corrosion rate observed in the GE loops. The corrosion rate of a heated sample could also be higher than those observed since the sample is not heated. Examination of the heaters in these loops would not supply comparative corrosion data because of the very low sodium velocity past the heaters.
6. The existing loops at GE leave something to be desired with respect to geometry and velocity conditions. These conditions do not permit a quantitative mass balance to be made directly. Reliance must be placed upon indirect measurements.
7. In response to a question concerning the use of the present loops for 304 SS corrosion studies (the loops are made of 316 SS), Mr. Savage stated that this probably would disturb the deposition of corrosion products in the loop and reduce the chance for obtaining meaningful data after dissection of the loops.

The Proposed Program

1. The primary purpose of the two new loops would be to explore the "downstream" effect. Two loops are proposed in order to increase the volume of data and speed up the solution to the problem.
2. The GE proposal which was available to the Committee did not contain a definitive experimental program. The Ad Hoc Committee does not have such a program in its possession.

Recommendations1. Six Existing Loops

- (a) The Committee saw no reason to disagree with the Ad Hoc Committee's recommendation that following the completion of the one-half replicate factorial program, the loops should be cut up and examined.
- (b) No further use for the portions of the six loops which would remain was suggested.

2. Two New Loops

- (a) The Committee was in full agreement that the "downstream" effect needed resolution and, in particular, the maximum corrosion rate of unheated samples should be determined.
- (b) There was general agreement that the corrosion of 304 SS should not be significantly different than that of 316 SS. However, it was strongly recommended that duplicate runs be made on a 304 SS loop in order to demonstrate that a difference does not exist (the FARET and SEFOR reactors are to be constructed with 304 SS).
- (c) The Committee found it difficult, if not impossible, to attempt to evaluate the design of the proposed loops in the absence of a definitive experimental program. They agreed that the design criteria for the loops should be based upon the experimental program and that final evaluation of the proposed loops would be based upon comparison of the design with the design criteria.
- (d) The Committee did note that the new loop design, as proposed, did not appear to adequately consider the surface-to-volume ratio, which may be an important parameter in the "downstream" effect.
- (e) The Committee recommended that GE prepare a definitive experimental program which would resolve the "downstream" effect.
- (f) They further recommended that GE prepare a precise set of design criteria for the new loops based on this program.
- (g) The utilization of single loops in which the loops themselves become the specimens, and which would permit a quantitative mass balance, should be compared with the existing loop design and experimental philosophy.
- (h) The Committee recommended that a loop be constructed of 304 SS in order to verify the assumption that there is no essential difference in the corrosion rates between 304 SS and 316 SS.

The chairman stated that in order for the next phase of the mass transfer studies to get under way at GE in FY 64, it would be necessary for any requirements for changes in design of the new loops or complete new design be finalized by the Committee by about April 1, 1964.

The chairman stated that he would contact the San Francisco Operations Office and the General Electric Company and request that they prepare the additional information required by the Committee to reach a decision.

C. A. Pursel, Director
Reactor Engineering Division

Report of Meeting on March 2, 1964

ATTENDANCE:

R. B. Richards	GE SAN JOSE
J. A. Bailey	AEC SAN
C. A. Pursel	AEC CH
E. L. Zebroski	GE SAN JOSE
R. W. Lockhart	GE SAN JOSE
G. D. Collins	GE SAN JOSE
S. L. Mitchell	GE SAN JOSE
B. Wolfe	GE SAN JOSE

The committee which was selected to review the future of the GE Mass Transfer Program, with specific reference to the proposed two new loops, met in Chicago on February 24, 1964.

The purpose of the subject meeting was to relay the requests and recommendations of this committee to the San Francisco Operations Office and the General Electric Company.

As a result of the meeting, the following actions will be taken:

1. GE will prepare a written statement on additional work in mass transfer which they could perform.
2. The statement will direct itself to:
 - a. The resolution of the effects of variables which are not in the current GE Mass Transfer Program.
 - b. A definition of the needs for additional data in terms of the utilization of the data by reactor designers.
 - c. A definition of the metallurgical properties of materials which need resolution to meet these needs.
 - d. A statement of design criteria for additional loops which would be required to perform the above work.
 - e. The design of one or more loops which would meet these design criteria.
3. GE will consider:
 - a. The means for determination of the maximum corrosion rate in a sodium cooled reactor outside of the core.

- b. The desirability of utilization of single loops in which the loops themselves become the specimens as compared to the existing loop design in which specimens are inserted into loops.
 - c. The needs and utilization of a quantitative mass balance.
4. A portion of the program will be a recommended means of verification of the assumption that there is no essential difference in the corrosion rates between 304 SS and 316 SS.

The written description will be completed on or about April 1, 1964, and will be mailed to the members of the Ad Hoc Committee via the San Francisco Operations Office and to the members of the Special Committee through the Chicago Operations Office.

Shortly after the descriptions are distributed, a meeting will be held to resolve the construction of new loops in GE. General Electric personnel will be invited to the meeting to explain and discuss their written material.

C. A. Pursel, Director
Reactor Engineering Division

Task Force ReportMEMBERS

The members of the Task Force were as follows:

C. A. Pursel, Chicago Operations Office, Chairman
O. E. Dwyer, Member, Brookhaven National Laboratory
C. Klamut, Alternate Member, Brookhaven National Laboratory
H. W. Savage, Member, Oak Ridge National Laboratory
W. R. Simmons, Member, Argonne National Laboratory
W. R. Wykoff, Member, Los Alamos Scientific Laboratory

GENERAL COMMENT

The Task Force made the general observation that its work and the work of the Ad Hoc Committee on GE Mass Transfer would have been much simpler had it been formally consulted during the formulation of the GE Phase II Mass Transfer Program, including the development of Process Specifications for the new mass transfer loops, as opposed to being presented with, in effect, an accomplished fact.

PURPOSE OF THE GENERAL ELECTRIC MASS TRANSFER PROGRAM

It was assumed that the purpose of the work at GE on Mass Transfer is to:

Develop a mathematical expression relating selected key measurable variables, which could be used by reactor designers to predict point by point corrosion rates in those portions of the system external to the reactor core.

All the discussions, conclusions and recommendations which follow are based on this fundamental premise.

PROBABILITY OF SUCCESS

The Task Force believes that with sufficient data it is possible to develop such a mathematical expression which will have some usefulness in future reactor design. It is expected that the expression and the confidence that can be placed in it will improve with time.

The Task Force believes that it may be necessary to use more than the six variables which were originally selected.

FORM OF THE MATHEMATICAL EXPRESSION

The Task Force observed that the mathematical expression which is being developed may well correlate the data, but appears to have no strong theoretical basis. They believe that the expression would be used with more confidence by engineers in extrapolating to reactor systems if it had a stronger theoretical basis.

DOWNSTREAM EFFECT

The Task Force recognizes that the addition of a variable such as L/D or S/V would improve the mathematical expression insofar as the observations from the present loops are concerned. They believe, however, that the basic phenomena has to do with solubility, saturation effects and that the magnitude of this observation may be a strong function of the specific design of the present six loops. They believe that if the loops had been more nearly an engineering mockup of a typical reactor system, downstreamness might not have been observed as a strong effect.

RECOMMENDATIONS

The Task Force recommends the following:

1. Insofar as feasible, the new loops should be designed as engineering models and possess the best estimates of the operating conditions in reactor systems.

For example:
 - a. The circuit time should be more nearly 25 seconds than the 47 seconds which is being proposed.
 - b. The minimum and maximum average velocities in the channels containing the corrosion samples should be approximately 10 and 30 ft./sec, respectively.
 - c. The ratio of wetted surface to sodium volume should be decreased over that in the current loops rather than increased.
 - d. The heated section should be in a high velocity region.
2. The Task Force recommends that weight loss data from a heater section be taken under conditions simulating those existing for the fuel cladding; i.e., heat flux, temperature, and flow rate should be studied at anticipated reactor conditions. Material dissolved from fuel cladding affects corrosion in heat transport circuit and also influences the deposition of dissolved steel in the cold portion of the heat transfer circuit.
3. The design of the new loops should not be so heavily directed toward the development of empirical constants for an additive L/D or S/V term. The design, however, should make simple provisions for determining whether or not the downstream effect is still a major variable in an engineering model, and what the quantitative effect is.
4. The Task Force noted that a weight change had been measured in successive corrosion samples. They recommend that a single corrosion sample be divided in such a manner that the weight change in the initial can be compared with the weight change in this downstream section.
5. The Task Force recommends that the work at General Electric de-emphasize any attempt to either verify or fully understand saturation-solution phenomena.

It does recommend that this type of work be carried on under a separate, but related program, which would direct its attention to, for example, the development of phase diagrams for the sodium alloys which are flowing by the corrosion samples.

6. Attention should be directed toward the continued improvement of the mathematical relationship between the variables which are now being used.

However, the Task Force strongly recommends that if the results of this work are to be used for their intended purpose, an additional relationship between the variables be developed which has a sounder theoretical basis. For example, it may be possible that a calculated term involving shear stress at the wall of the corrosion sample should be included in this correlation.

7. The Task Force recommends that the mass transfer corrosion effects of 304 SS be investigated and compared with existing 316 SS corrosion data by means of all 304 SS loops which are comparable to both the present designs and the new engineering models. The Task Force continues to believe that 316 SS is representative of the 300 series SS. However, since SEFOR and FARET are constructed of 304 SS, it is believed that it is essential that data be taken from all 304 SS loops which can be directly compared with the data which has been developed for 316 SS loops to verify that, in effect, there is little difference in the corrosion rates.
8. The Task Force recommends that the deposition of dissolved material in the cold portion of the loops be given thorough study. The location, extent, and manner of deposition should be determined. A mathematical correlation of deposition would be very desirable.
9. The Task Force is not now willing to accept the design of the proposed new loops and requests that the General Electric Company present written Process Specifications* to the AEC and through them to the Standing Committee for Mass Transfer.
10. The Task Force recommends that the Process Specifications be reviewed by the Standing Committee for Mass Transfer and the results reported to the Working Group.
11. The Task Force recommends that the manner of achieving the over-all objectives continue to be left to the ingenuity of the General Electric personnel.
12. The Task Force strongly recommends that, as soon as Phase I is finished, the results be reported for application to other systems without waiting for Phase II results. Shortcomings of these results from Phase I should also be included.

The members of the Task Force reviewed this report in draft form. They have not reviewed it in final form.

 CLAUDE A. PURSEL
 Chairman

* Process Specifications are sometimes referred to as functional specifications, design criteria, or design scope.

COMMENTS BY THE CHAIRMAN

During the preparation of the Task Force Report, many discussions were held among members of the Task Force and with other persons interested in the Mass Transfer Program. Some of the highlights of these discussions are included here for the information of those reviewing the report. These comments have not been reviewed by the members of the Task Force, but it is believed that they would be in general agreement with the comments.

1. A basic ground rule for the Sodium Component Development Program, and of the General Electric work on Mass Transfer, is that the work should be limited to the hardware outside of the reactor vessel. The design of the two new loops proposed by General Electric is based on this ground rule.

The only known explanation for the observed downstream effect is that the circulating sodium contains corrosion products in concentrations much nearer to the saturation point than was originally contemplated.

In an operating reactor the greatest weight loss will undoubtedly be from the fuel element jackets and the observed downstream effect indicates that in an all stainless steel system there may be little or no steady-state weight loss from any other portion of the system.

It seems essential that the basic ground rule for corrosion-deposition work be relaxed to include simulated fuel element jackets. That is, the heater section should have surface temperatures and average coolant velocities which are typical of future reactor designs. A cosine heat flux from the heater jackets would be desirable.

2. Each member of the Task Force expressed concern that the inability to accept the proposed design of the two new loops would reflect adversely upon the General Electric people who have been working on this program. They are well satisfied with the performance of the workers to date.

The recommendation to change the basic ground rule, so that the effects of an unanticipated phenomenon can be explored should not reflect adversely on anyone associated with the program.

3. Corrosion data, and economic evaluations both tend to raise questions as to the advisability of continuing to concentrate on a target mixed mean sodium outlet temperature of 1200 F.

The proposed design criteria would undoubtedly result in a maximum heater surface temperature of approximately 1400^oF. This appears to be too high for a practical application of stainless steel under the Civilian Power Program. However, it is believed that corrosion rates at this temperature would be valuable since it would permit interpolation of data.

4. Recommendation 5 needs further amplification. Design engineers need a mass transfer correlation which they can use with some confidence. If this is to be completed in a timely fashion, it will have to be through an engineering, empirical approach.

It is equally essential that a vigorous, scientific, basic technology program be implemented as soon as possible to complement the engineering studies. This type of work is outside of the charter of the Sodium Components Development Program and would undoubtedly have to be funded through other sources.

Each member of the Task Force felt so strongly about the need for this type of work that each of them expressed a desire to lend his support to the program.

5. There was considerable discussion about the terms, "mathematical expression," "model," "empirical relationship," "theoretical analysis," etc.
 - a. A mathematical expression of some type that correlates the data so that it can be used for extrapolation to other conditions is essential.
 - b. This mathematical expression, of whatever form, will be an empirical expression in that it will be based upon the data which would be obtained from loop operation.
 - c. The current mathematical expression, although it could be made to give a reasonable fit to the data, had little or no theoretical basis and, therefore, would not be used with confidence by engineers for extrapolation.
 - d. A truly theoretical model would probably be so complex that an empirical expression in terms of measurable variables could not be developed in the foreseeable future.
 - e. A mathematical expression which had a sounder theoretical basis than the one now being considered could and should be developed as a parallel effort.

APPENDIX D

AEC INVITATIONS TO BID AND SPECIFICATIONS

STEAM GENERATOR

UNITED STATES
ATOMIC ENERGY COMMISSION

WASHINGTON 25, D. C.

April 22, 1958

Gentlemen:

The Atomic Energy Commission is soliciting proposals for the design, development, manufacture and test operation of less expensive and more reliable steam generators of advanced design and improved performance for use in sodium cooled reactor systems.

Attached is a functional specification which establishes the goal of the program. As visualized by the AEC this program would consist of the parts described in the attachments and might extend over a five year period. However, all proposers are invited to submit their own organizations' suggestions for the program scope and not necessarily duplicate present Commission views.

If you are interested in participating in this program, a proposal should be submitted to the AEC and received not later than May 26, 1958. At the minimum, your proposal should contain information which addresses itself to the following points:

1. Your proposal for the program, sub-divided into phases and including a proposed test program to verify operational requirements.
2. Proposed time and manpower schedules for each phase of the program.
3. Estimated costs for each phase including labor, material, equipment and indirect cost.
4. Qualifications and experience of your company directly pertinent to carrying out the program.
5. A list of the key personnel you would propose to assign to each phase of the program and their qualifications.
6. A description of the manufacturing, inspection, test and research facilities available to you which you would intend to use in the program.
7. A description of the facilities you would propose to acquire or which you would expect the AEC to furnish.
8. Such other information as you believe will be useful to the AEC in selecting the contractor for this program.

In formulating your proposal, you should be aware that it is the intent of the Commission to support other work in the general area of sodium technology under other contracts. This work will have a bearing on your proposed program. Such supporting efforts will include work on decontamination methods, development of gas and sodium purification devices and the problem of sodium frosting. In addition, many AEC contractors are presently undertaking research and development work on new materials, leak testing and detection and other pertinent problems.

We will appreciate knowing by April 30, 1958 whether or not you intend to submit a proposal.

Any questions you may have regarding this invitation should be submitted in writing to the undersigned.

Proposals should be submitted in sextuplet and addressed to James J. King, Secretary, Sodium Components Selection Board, Division of Reactor Development, U. S. Atomic Energy Commission, Washington 25, D. C.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "James J. King". The signature is fluid and cursive, with a large loop at the beginning and a long, sweeping tail that extends to the right.

James J. King, Secretary
Sodium Components Selection Board

Attachments

As stated above

AREAS OF WORK TO BE INCLUDED IN THE
STEAM GENERATOR DEVELOPMENT PROGRAM

1. Familiarization with Sodium Technology - This would include contact and liaison with AEC contractors presently working in the field as well as a literature survey.
2. Design and Analysis - This would include (a) conceptual designs and preliminary analysis of a full scale unit, (b) detailed design of the full scale unit, (c) detailed design of any proof testing models proposed to test the full scale design.
3. Thermal Stress Analysis - This includes steady state as well as transient analysis of stresses induced in materials.
4. Materials Selection - This includes such research and development as may be necessary to verify properties of materials selected.
5. Investigation of special heat transfer problems introduced on the steam side of the generator by the use of sodium.
6. Consideration, Investigation and Evaluation of Possible Sodium-Water Reactions.
7. Leak Detection and Identification of the Location of the Leak.
8. Means of Handling Gross Sodium-Water Leaks and Gross Pressure Surges Induced Thereby.
9. Development of Welding and Fabrication Methods - This would include non-destructive testing and inspection procedures.
10. Maintenance - This will include methods of repair and maintenance and the design, fabrication and testing of any special tools necessary for maintenance operations.
11. Economic Analysis of Unit - This would include evaluation of various factors affecting estimated costs such as choice of materials, fabrication, testing and maintenance as they relate to the overall economics of the unit.
12. Operational Tests - This would include formulation and execution of a test program to verify all operational aspects of a full scale unit.

EQUIPMENT SPECIFICATION FOR STEAM GENERATOR

I. SCOPE

This specification covers the requirements for a steam generator required to generate superheated steam from a heat source of 70 thermal megawatts by circulation of non-radioactive liquid sodium.

II. DESIGN DATA

Operating conditions (based on 100% load)

Steam Side

Temperature at unit outlet	1050°F
Pressure at unit outlet	2200 psig
Feedwater temperature	~600°F
Design temperature (boiler, if super-heater is used)	~700°F
Design temperature (superheater if used)	1200°F
Design pressure	2500 psig
Steam quality leaving unit	99.75% @ 125% rated steam flow
Steam purity leaving unit	1 ppm total solids

Sodium Side

Rated heat load (approximately)	2.39×10^8 BTU/hr.
Rated flow	As calculated
Inlet temperature	1140°F
Outlet temperature	650° - 850°F
Operating pressure	100 psig
Design temperature	1250°F
Maximum pressure drop (across steam generator)	15 psi

Steam Generator Operation

The steam generator will be operated to give constant pressure at the turbine inlet.

The sodium inlet temperature to the unit will be allowed to float depending upon the reactor outlet temperature which may vary by 60°F maximum below peak temperature. The goal is to have the temperature of the sodium returning to the intermediate heat exchanger maintained as constant as practicable.

The steam temperature at the unit exit will not be controlled, but will float between its full load value and the temperature of the entering sodium. Its exact value will depend on the configuration of the unit.

The sodium flow rate will vary approximately linearly with load.

Normal startup and shutdown procedures will be specified by the proposer. Normal minimum startup rate will be 100°F/hr on sodium side.

After startup, or at any time within the range of 15% to 100% load, load change will be made by changing sodium flow rate and power to match demand. Normal rates of change are:

- a. Full range ramp: $\pm 5\%$ (of full load value) per minute from 20 - 100%.
- b. Short time ramp: $\pm 20\%$ (of full load value) in 1 minute.
- c. Step change: $\pm 10\%$ (of full load value).

III. STEAM GENERATOR TRANSIENTS

This section indicates the transients that shall be used in calculating steam generator stresses.

Normal Operation

Number of startup cycles for use in design: 1,000

Number of operating cycles for use in design: 10^6

Casualty Conditions

The steam generator units shall be capable of withstanding the following thermal transient conditions:

Condition	Sodium Temp. at Start of Transient	Predicted Max. Rate of Change of Sodium Temperature for 3 seconds	Predicted Duration of Transient	Sodium Temp. at End of Transient
Primary Reactor Sodium pump stops. Secondary sodium flow to generator continues.	1140°F (inlet)	- 35°F/sec	14 sec	650° to 850°F (inlet)
Sodium flow stops. Feedwater flow continues.	1140°F (inlet)	- 35°F/sec	16 sec	650° to 850°F (inlet)
Feedwater flow stops. Sodium flow continues.	650° to 850°F (outlet)	+ 50°F/sec	9 sec	1140°F (outlet)

The above transients are subject to revision depending upon generator design.

The predicted number of cycles of each above condition during the life of the equipment is about 25.

IV. WATER ANALYSIS

To be specified by proposer.

V. MATERIALS

To be specified by proposer. Only materials commercially available should be considered. Material selected must be compatible with conditions.

VI. MAINTENANCE

The unit should be so designed as to be accessible for inspection and repairing or plugging of tubes. A design using sodium on the outside and water or steam on the inside should permit the complete inspection of the interior surfaces of pipes or tubes which contain sodium.

APPENDIX APART BFUNCTIONAL SPECIFICATIONS FORSODIUM-SODIUM HEAT EXCHANGERSI. SCOPE

This general specification is intended to serve as a guide in establishing the requirements for design, development and fabrication and test operation of sodium heat exchange equipment for sodium cooled, nuclear power plant application.

II. GENERAL REQUIREMENTS

1. The sodium-sodium heat exchanger will be suitable for transferring heat from a radioactive primary sodium reactor coolant to a non-radioactive secondary sodium coolant.
2. The operating conditions are given under "Detail Requirements."
3. In general, the heat exchange equipment shall be designed to utilize conventional configurations which permit maximum use of existing fabrication procedures, skills and equipment.

III. DETAIL REQUIREMENTS1. Sodium-sodium heat exchanger - operating conditionsa. Primary sodium side

(1) Inlet Temperature	1200°F
(2) Outlet Temperature	700°F to 900°F
(3) Design Pressure	100 psig
(4) Maximum Pressure Drop	15 psi

b. Secondary sodium side

(1) Inlet Temperature	To be recommended
by proposer
(2) Outlet Temperature	1140°F
(3) Design Pressure	100 psig
(4) Maximum Pressure Drop	15 psi

c. Heat transfer capability	~ 70 MW (2.39×10^8 BTU/hr)
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2. Transientsa. Normal

- (1) Normal and planned startup and shutdown rates not to exceed temperature changes of 100°F/hr.
- (2) Power changes in the operating range will be accomplished by varying sodium flow.

- (3) Linear increase in load from 10% to 100% in three minutes. (Use 10,000 cycles for design.)
- (4) Step change in steam demand of 10% of rated steam flow in three seconds. (Use 1 million cycles for design.)

b. Reactor Scrams

- (1) The predicted changes based upon operating conditions are:
 - (a) Primary sodium inlet temperature drops 60°F in first $\frac{1}{2}$ second.
 - (b) It drops a total of 130°F in 6 seconds.
 - (c) The predicted sodium temperature at the end of the condition is the normal sodium outlet temperature.
- (2) Number of cycles for use in design: 1000

c. Casualty Conditions

- (1) Primary pump stops, but secondary pump continues to run. The predicted changes are to be specified by the proposer. Number of cycles for use in design: 5.
- (2) Secondary pump stops, but primary pump continues to run. The predicted changes are to be specified by the proposer. Number of cycles for use in design: 5.

d. General Conditions

- (1) The sodium nozzles shall be designed for a total moment of 40,000 ft.-lbs. and a 4000 lbs. thrust.
- (2) The exchanger shall permit complete gravity drainage of the shell and tubes through the inlet and/or outlet nozzles, or drain connections.
- (3) Shells and channels shall be vented where gas traps may occur. Helium and/or nitrogen gas may be entrained in the sodium due to leakage of the pump seal and other sources.
- (4) The tube sheets (if used) shall be accessible during shutdown for repair of a defective tube and shall require a minimum of cutting of headers and piping.
- (5) The heat exchanger will be located in a concrete vault and will be inaccessible during operation due to Gamma radiation.
- (6) Experience indicates that a shell and tube heat exchanger will rapidly go isothermal during low flow rates and at shutdown conditions. Prior to reaching the isothermal conditions, severe temperature gradients are experienced across the faces of the tube sheets. This is caused by the rapid temperature stratification of the fluids.
- (7) It may be necessary occasionally to simultaneously close the inlet and outlet valves of a circulating loop and isolate the heat exchanger. This isolation will cause an internal convection flow that will result in the exchanger eventually going isothermal.

- (8) It is necessary to minimize the temperature gradients, particularly at the tube sheets, by slowing the rate of approach to the isothermal condition. Extreme care must be exercised in orienting the baffles, locating the inlet and outlet nozzles, and in the general design of the heat exchanger in order that rapid stratification may be overcome.
- (9) In addition to the calculations normally required by applicable codes, stress analyses of combined mechanical hydrostatic and thermal stresses in all critical areas will be performed by the proposer prior to initiation of fabrication. The AEC will furnish an appropriate structural design basis which specified allowable values for combined stresses, conditions for using creep and stress-rupture properties and similar information required for adequate stress analysis.

IV. STRUCTURAL DESIGN BASIS

The achievement of a well-proportioned design which satisfies safety as well as operational requirements requires particular attention to design, fabrication and welding techniques, and inspection and testing procedures. The following shall be carefully considered:

1. The ASME Code and TEMA Class R standards shall be used as the minimum design requirement for all components. However, conformance to the codes does not necessarily constitute a suitable design.
2. Design drawings shall reflect full appreciation of the stresses associated with gross structural discontinuities.
3. A minimum of local structural discontinuities shall be used.
4. It is essential to evaluate completely the stress and strain values caused by the loadings and transients as indicated.
5. Calculated stresses and deformations shall be restricted to the elastic range with the possible exception of the extreme transient conditions as indicated in this specification.

V. MATERIALS OF CONSTRUCTIONS

Only materials which are known to require no extensive development and which are compatible with specified service conditions shall be used for construction.

VI. CLEANING

The general, commercial cleaning procedures, such as ASTM Standard A380-54T for cleaning stainless steel, shall be considered acceptable. Specific cleaning procedures shall be recommended by the proposer.

VII. TESTING AND INSPECTION

The testing and inspection necessary is to be recommended by proposer.

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
9800 SOUTH CASS AVENUE
ARGONNE, ILLINOIS

August 20, 1962

Gentlemen:

The United States Atomic Energy Commission, as a part of its Sodium Components Development Program, intends to select a firm to design, develop, and fabricate a prototype or model of a large sodium to water steam generator of improved design. You are invited to submit a proposal to provide the desired work and services.

The work is to include the development of a preliminary design of a 1000 MWT sodium cooled steam generator system, the performance of supporting research and development, the design and fabrication of a prototype (or model) steam generator (30 MWT maximum), preparation of a program for testing the prototype in the Commission-owned Sodium Components Test Installation (SCTI) facility at Santa Susanna, California (described in enclosure 3), and evaluation of the degree of success of the project by analysis of the test and operating data.

The objective of this work is to continue the development of the technology necessary to permit industry to supply sodium to water steam generator systems of improved design for use in large, sodium cooled, central station, nuclear power plants.

The work is to be performed under a cost-type contract implemented by program letters. A model contract is enclosed (enclosure 1). Appendix C of the model contract includes design objectives, specifications, and details of the work and services to be performed.

Your proposal must provide the information requested in the Questionnaire (enclosure 2) in the order specified therein. All proprietary information contained in or accompanying your proposal must be clearly identified as such.

A Contractor Selection Board will evaluate your proposal on the basis of your responses to the Questionnaire.

Prerequisite to selection are financial responsibility and your willingness to accept the essential AEC contract provisions.

August 20, 1962

The Commission reserves the right to reject any or all proposals received as the result of this invitation.

In order to be considered, your proposal must be received by the undersigned not later than 2:00 P.M. CST on November 13, 1962.

To facilitate the preparation of proposals, the Commission will hold a pre-proposal conference to give the background for the project and to discuss any questions concerning the proposal. This conference will be held September 20, 1962, in Building 200 Auditorium at the Argonne National Laboratory, Argonne, Illinois, and will begin promptly at 10:00 A.M. CDT.

You are invited to send not more than three representatives to this conference. The conference will be, in the main, technical in nature.

A description of the SCTI which will be used in performing the test of the prototype is enclosed (enclosure 3).

We would appreciate receiving a response from you by September 12, 1962, stating whether or not your firm will be represented at the pre-proposal conference, together with the names of those who will attend.

Sincerely yours,

C. A. Pursel, Chairman
Contractor Selection Board

Enclosures:

1. Model Contract
2. Questionnaire
3. Description of SCTI

APPENDIX C

STEAM GENERATORDESIGN OBJECTIVES, SPECIFICATIONS,
WORK AND SERVICES

1. PURCHASER: U. S. Atomic Energy Commission
2. NAME OF PROJECT: Steam Generator
3. PROJECT OBJECTIVE:

The over-all objective of the Steam Generator project is to develop the technology necessary to permit industry to supply a large sodium cooled steam generator of improved design. This technology would be available for use by the nuclear industry in large, sodium cooled, central station, nuclear power plants. The objective is to be achieved by: (a) developing the design of a 1000 MWT sodium cooled steam generator system which is based on reasonable extrapolations of current technology and the assumed successful conclusion of an approved program of research and development, (b) fabrication of a prototype steam generator (maximum 30 MWT), (c) testing of the prototype by others in a Commission-owned facility, and (d) evaluating the degree of success of the project by analyses of the test and operating data.

4. 1000 MWT STEAM GENERATOR SYSTEM

- 4.1 Definition and Design Bases:

The 1000 MWT Steam Generator System includes, but is not limited to, all necessary evaporators, superheaters, steam drums, moisture separators, interconnecting piping, headers, instrumentation, and controls; and associated auxiliary equipment.

The design shall be based on current unclassified technology; reasonable extrapolations of current unclassified experimental data, fabrication techniques, and engineering technology; and the assumption of the successful outcome of the research and development to be performed under this contract.

- 4.2 Design Objectives:

The 1000 MWT Steam Generator System shall be designed to meet the following objectives:

- 4.2.1 Produce steam at the lowest cost with due consideration for capitalization and maintenance costs within the limitations imposed by this Appendix.
 - 4.2.2 Achieve a minimum availability factor of 90%, computed on an annual basis, over a design service lifetime of at least 30 years.
 - 4.2.3 Provide the basis for the necessary research and development to support the design and fabrication of the prototype steam generator.

4.2.4 Minimize mechanical and thermal stresses.

4.2.5 Minimize the consequences of accidental mixing of sodium and water or steam due to equipment failure.

4.3 Specifications:

The 1000 MWT Steam Generator System shall be:

4.3.1 Costed in accordance with Section 110, Volume 1 of the "Guide to Nuclear Power Cost Evaluation," 1962 Edition.

4.3.2 Easily accessible for maintenance and inspection.

4.3.3 Designed and fabricated in accordance with all applicable codes.

4.3.4 Designed in accordance with the following steady state operating and design conditions:

4.3.4.1 Operating steam temperature at the outlet, 1050°F.

4.3.4.2 Operating steam pressure at the outlet, 2200 psig.

4.3.4.3 Operating feedwater temperature to the steam generator, 600°F.

4.3.4.4 Design temperature of the sodium side of the steam generator system, 1200°F.

4.3.4.5 Design pressure of the water side of the steam generator system, 2500 psig.

4.3.4.6 Water entering the evaporator, 1 ppm total solids maximum.

4.3.4.7 Design and operating heat load, approximately 3.4×10^6 Btu/hr.

4.3.4.8 Operating inlet sodium temperature, 1140°F maximum.

4.3.4.9 Operating sodium pressure, 100 psig maximum.

4.3.4.10 Design sodium pressure, 300 psig.

4.3.4.11 Pressure at the steam generator outlet, constant.

4.3.4.12 Sodium inlet temperature, linear variation with load between 1140°F and 650°F if a once-through type steam generator is used.

4.3.4.13 Sodium inlet temperature, linear variation with load between 1140°F and 1050°F if a recirculating type steam generator is used.

4.3.4.14 Sodium outlet temperature, constant as practicable.

4.3.4.15 Maximum startup temperature change, 100°F/hr. on the sodium side.

4.3.4.16 Power changes within the range of 20% to 100% of load, sodium flow rates to match load demand.

4.3.5 Designed to withstand the following transients:

OPERATIONAL TRANSIENTS

<u>No.</u>	<u>Type of Transient</u>	<u>Initial Temperature °F</u>	<u>Final Temperature °F</u>	<u>Rate of Change</u>
10 ³	Ramp	200	1200	+1000°F/48 hr.
10 ⁶	Cycles	1195	1200	+5°F/sec.
10 ⁴	Ramp	1200	1110	-90°F/15 min.

LOAD TRANSIENTS

<u>No.</u>	<u>Type of Transient</u>	<u>Value (% of load)</u>		<u>Rate of Change</u>
		<u>Initial</u>	<u>Final</u>	
25	Ramp	20 100	100 20	± 5% full load/min.
25	Ramp	Any Operating Point		± 20% for full load/min. in 1 min.
25	----	Any Operating Point		Step Change of 10% of full load

FLOW TRANSIENTS

<u>Condition</u>	<u>Sodium Temp. at Start of Transient</u>	<u>Predicted Max. Rate of Change of Sodium Temperature for 3 Seconds</u>	<u>Sodium Temp. at End of Transient</u>
Primary reactor sodium pump stops. Secondary sodium flow to generator.	1140°F (inlet)	-35°F/sec.	650°F (inlet)
Sodium flow stops. Feedwater flow continues	1140°F (inlet)	-35°F/sec.	650°F (inlet)
Feedwater flow stops. Sodium flow continues.	650°F (outlet)	+50°F/sec.	1140°F (outlet)

5. PROTOTYPE STEAM GENERATOR

5.1 Definition:

The Prototype Steam Generator is a module, model, section or segment of the 1000 MWT Steam Generator described in Section 4 of this Appendix.

5.2 Design Objectives:

The Prototype Steam Generator shall:

- 5.2.1 Be capable of demonstrating, by testing in the Sodium Components Test Installation facility (SCTI), as described in enclosure 3 to the letter of invitation, that the design of the 1000 MWT Steam Generator System meets the Design Objectives and Specifications of Section 4 of this Appendix.
- 5.2.2 Upon completion, provide the bases for improving the cost estimate of the design, fabrication, and operation of the 1000 MWT Steam Generator System.

5.3 Specifications:

The Prototype Steam Generator shall:

- 5.3.1 Have a heat rating between 25 and 30 MWT inclusive and have the capability of being tested in the AEC Sodium Components Test Installation facility. (Minor modifications to the SCTI will be considered.)
- 5.3.2 Have a total helium leak rate no greater than .01 micron cu.ft./hr.
- 5.3.3 Include sufficient instrumentation, such as thermocouples, strain gauges, and pressure transducers, to confirm the design, fabrication and operating characteristics of the Prototype Steam Generator and to provide the experimental data necessary to evaluate the design adequacy of the 1000 MWT Steam Generator System.
- 5.3.4 Be fabricated, tested, and cleaned using fluids compatible with materials of the unit.
- 5.3.5 Be hydrostatically tested on the water side, using demineralized water with corrosion inhibitors.
- 5.3.6 Be pneumatically tested on the sodium side using inert gas.
- 5.3.7 Be designed and fabricated in accordance with all latest applicable codes.
- 5.3.8 Be dry, free of foreign materials and filled with inert gas for shipment.
- 5.3.9 Comply with all Specifications in Section 4.3, except for items 4.3.1, 4.3.4.7, 4.3.4.15, 4.3.4.16, and 4.3.5. (cf. 6.2.2.4 and 6.2.2.10.)

6. DESIGN SERVICES

6.1 1000 MWT Steam Generator System

The Contractor shall:

- 6.1.1 Perform a preliminary design of the 1000 MWT Steam Generator System in accordance with Section 5 of this Appendix.
- 6.1.2 Submit for the written approval of the Contracting Officer a "Preliminary Design" report which will include, but not be limited to, the following:
 - 6.1.2.1 A narrative description of the steam generator, complete with such tables, graphs, charts, and reduced drawings as are necessary to: (a) describe the degree to which each Design Objective of Section 5.2 has been met, (b) show that each Specification of Section 5.3 has been met, and (c) fully describe any unique or advanced design features or operating characteristics.
 - 6.1.2.2 Specifications for materials and equipment.
 - 6.1.2.3 Preliminary analyses of thermal and mechanical stresses in critical areas.
 - 6.1.2.4 Description of the necessary R&D Program, broken down as to Tasks and Subtasks, together with cost estimates by Fiscal Years and a schedule in accordance with the PERT format.

6.2 Prototype Steam Generator

The Contractor shall:

- 6.2.1 Perform a preliminary design of a Prototype Steam Generator which is based on the Design Objectives of Section 5.2 and meets the Specifications of Section 5.3 of this Appendix.
- 6.2.2 Prepare a "Preliminary Prototype Steam Generator Design" report which will include, but not be limited to, the following:
 - 6.2.2.1 A narrative description, complete with such tables, graphs, charts and reduced drawings as are necessary to: (a) describe the degree to which the Prototype Steam Generator meets the Definition of Section 5.1 and the Design Objectives of Section 5.2, (b) show that each applicable Specification of Section 5.3 has been met, and (c) fully describe design modifications to the SCTI, if necessary, and any critical or unusual problems of fabrication, procurement, shipment, testing, or analyses.
 - 6.2.2.2 Procurement specifications of all materials and equipment.
 - 6.2.2.3 Specifications of all operating transients.

- 6.2.2.4 A tabulation of transients, to be applied to the Prototype, to simulate the transients of Section 4.3.5 for the 1000 MWT Steam Generator System.
- 6.2.2.5 An analyses of the thermal and mechanical stresses which are required to confirm that those imposed by the tabulated prototype transients are representative of the stresses imposed in the 1000 MWT Steam Generator System by the transients in Section 4.3.5 of this Appendix.
- 6.2.2.6 Analyses of the thermal and hydraulic characteristics of the prototype, together with sample calculations and the bases for the analyses.
- 6.2.2.7 A design analyses of the predicted performance characteristics of the prototype at 20%, 40%, 60%, 80%, 100%, and 125% of rated load.
- 6.2.2.8 An analysis and justification for the selection of materials of construction.
- 6.2.2.9 Description of the procedures for meeting Specifications 5.3.2, 5.3.4, 5.3.5, 5.3.6, and 5.3.8 of this Appendix.
- 6.2.2.10 A cost estimate by Fiscal Years and a detailed schedule, in PERT format, for the work remaining to be performed under this contract.

7. EQUIPMENT

On written approval of the "Preliminary Prototype Steam Generator Design" report by the Contracting Officer, the Contractor shall:

- 7.1 Fabricate the Prototype Steam Generator in accordance with the approved preliminary design.
- 7.2 Provide an Operations and Maintenance Manual, including instructions for normal operation and repair and maintenance procedures.
- 7.3 All special tools required for installation, repair, and maintenance of the Prototype Steam Generator.
- 7.4 Prepare for shipment and ship the Prototype Steam Generator to Atomics International, a Division of North American Aviation, Inc., Canoga Park, California, for testing in the SCTI.

8. INSTALLATION AND TESTING

The Contractor shall:

- 8.1 Witness and approve the installation of the Prototype Steam Generator at the Sodium Components Test Installation facility.
- 8.2 Witness all key tests in the approved test program.
- 8.3 Prepare a "Prototype Steam Generator Test" report which shall include, but not be limited to, the following:

- 8.3.1 Details of the tests performed.
- 8.3.2 All pertinent test data.
- 8.3.3 An evaluation of the results of the test program.
- 8.3.4 A description and evaluation of any maintenance, repairs, and unanticipated operating characteristics.
- 8.3.5 A comparison of the results of the test program with the objectives and purposes of the work under this contract.

9. RESEARCH AND DEVELOPMENT

The Contractor shall perform the research and development work as approved by the Contracting Officer (Re: Section 6.1.2.4).

DESIGN STUDY FOR SODIUM COMPONENTS TEST INSTALLATION

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

February 16, 1959

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for an engineering study of a sodium components test facility. This study will include the following general areas of work:

1. Develop design criteria for a test facility, including supporting services that will satisfy the attached scope of work.
2. Recommend site requirements and location limitations for such a facility.
3. Make preliminary drawings and cost estimates for a new facility.
4. Make a survey and evaluation of agreed upon available sites that with limited modifications would meet the requirements established in the attached scope of work.

The proposer shall include in the response to this invitation the following information:

1. Brief history of the company and a resume¹ of experience in work allied to the proposed effort.
2. The names and qualifications of key personnel who will be assigned to contract.

3. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
4. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
5. A list of the current major Government contracts and other work of this general nature.
6. The organization's current financial statement.
7. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by March 16, 1959, to Mr. Thomas P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

Thomas P. Heckman, Secretary
Sodium Component Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Sodium Components Test Facility

NATURE AND SCOPE OF WORK

The contractor will make a conceptual study of a sodium components test facility that will be capable of subjecting sodium components to both steady state and transient conditions expected in full size nuclear power electric generating stations. The following types of components are scheduled for testing in this facility: 30 MW sodium to sodium heat exchangers, 30 MW sodium to H₂O steam generators, valves and throttling devices, flow indicators, pressure indicators, and other instruments which may be developed.

Since the purpose of the test facility is to develop data that can be used in the design of full scale components, many of the capacities of the facility must be variable.

Wherever possible, available existing equipment should be utilized if economically desirable. For example, the AEC has available for possible use in this facility an oil-fired sodium heater built by the Babcock and Wilcox Company having a maximum design specification of 125,000,000 BTU/hr. at 1,200°F sodium outlet and 870°F sodium inlet.

The contractor will supply the AEC with a design criteria of the facility, an estimate of time to construct, a preliminary cost estimate, and a survey of existing facilities which would be suitable with minor modification to accommodate the desired tests.

This contract will be cost-plus-fixed fee and is expected to be for a period of approximately four months. Interim reports shall be furnished at appropriate times during the progress of the work.

PREVIOUS TEST WORK

Considerable experience has been accumulated in the general area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number 1955 O-351326.

GENERAL SPECIFICATIONS OF TEST FACILITY

The sodium component test facility must be capable of operating a fossil fuel-fired sodium heater together with auxiliaries and accessories to allow testing of liquid metal components on a continuous or intermittent basis. The test facility must be capable of indicating and recording data on a continuous basis for a contract term of several years. Besides the primary test loop, the following are examples of supporting equipment which may be required: railroad siding or truck docks equipped with an overhead crane, oil storage, building for the heater and a series of component test cells, instrument and control center, heat sink, water supply and purification system, sodium storage and purification system, etc.

The testing cells, primary piping, and servicing utilities will be so arranged to allow an easy change between test setups.

All components tested in this facility may be inspected by non-destructive means, before, during the test period, and after the tests. All of the test data shall be recorded in a systematic way so as to allow analysis of the inter-relationship of materials, fabrication techniques, design, and operating conditions of the test components.

A typical set of test conditions would be as follows for a sodium-H₂O steam generator:

Rated load, continuous	30 MW
Sodium flow maximum	3500 gpm
Maximum sodium temperature, continuous	1200°F
Maximum sodium temperature difference	500°F
Maximum sodium pressure	150 psi
Maximum sodium pressure drop across the steam generator	25 psi
Sodium purity	less than 30 ppm oxygen
Sodium flow rate	variable - proportional to load, up to 30 ft./sec.
Maximum steam temperature, continuous	1050°F
Feedwater purity	less than 0.5 ppm solids
Maximum startup rate	100°F/hr.
Full range (20%-100%) transient	≤ 5% of full power/min.
Temperature transient	35°F/sec. for 14 sec.

Similar specifications will be established for each of the components to be tested.

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

The following laboratories and industries received letters of invitation on:

Engineering study of sodium components test facility

Mr. William S. Morris, President
Alco Products, Inc.
30 Church Street
New York 7, New York

Mr. Robert S. Stevenson, President
Allis-Chalmers Manufacturing Company
1126 S. 70th Street
Milwaukee 1, Wisconsin

Mr. W. L. Martwick, President
Foster Wheeler Corporation
666 Fifth Avenue
New York 19, New York

Mr. Kenneth B. Ris, President
Griscom-Russell Company
Massillon, Ohio

Mr. Mark Cresap, Jr., President
Westinghouse Electric Corporation
Post Office Box 2278
3 Gateway Center
Pittsburgh 30, Pennsylvania

Mr. Dan A. Kimball, President
Aerojet-General Corporation
Post Office Box 296
Azusa, California

Mr. Morris Nielsen, President
The Babcock and Wilcox Company
161 E. 42nd Street
New York 17, New York

Mr. Hubert G. Ebdon, President
Combustion Engineering, Inc.
200 Madison Avenue
New York 16, New York

Mr. Richard S. Reade, President
American Radiator Standard Sanitary Corp.
Ross Heat Exchanger Division
1407 West Avenue
Buffalo 13, New York

Mr. Warren L. Smith, President
M. W. Kellogg Company
711 Third Avenue
New York 17, New York

Mr. Charles M. Rice, Manager
Reactor Engineering Department
American Standard Atomic Energy Div.
369 Whisman Road
Mountain View, California

Mr. John T. Ryan, Jr., President
M.S.A. Research Corporation
201 N. Braddock Avenue
Pittsburgh 8, Pennsylvania

Mr. John R. Menke, President
Nuclear Development Corporation of
America
5 New Street
White Plains, New York

Dr. Chauncey Starr, Vice President
Atomics International
A Division of North American
Aviation, Inc.
1911 First Street
Detroit 26, Michigan

Mr. J. K. Horton, President
Southern California Edison Company
601 W. Fifth Street
Los Angeles 53, California

Mr. Walker L. Cisler, President
Detroit Edison Company
2000 Second Avenue
Detroit 26, Michigan

Mr. Alton P. Donnell, General Mgr.
Atomic Power Development
Associates, Inc.
1911 First Street
Detroit 26, Michigan

Mr. Robert W. Hartwell, General Manager
Power Reactor Development Company
1911 First Street
Detroit 26, Michigan

Mr. B. A. Schmickrath, Asst. Engr. Mgr.
United Aircraft Corporation
Pratt and Whitney Aircraft Division
Connecticut Operations
CANEL

Mr. George L. Irvine, Regional Vice President
General Electric Company
840 South Canal Street
Chicago, Illinois

Post Office Box 611
Middletown, Connecticut

Mr. A. C. Kotchian, Vice President
Lockheed Aircraft Corporation
Georgia Division
Marietta, Georgia

Dr. Norman Hilberry, Director
Argonne National Laboratory
Post Office Box 299
Lemont, Illinois

Dr. Frank H. Spedding, Director
Ames Laboratory
Post Office Box 14A, Station A
Ames, Iowa

Dr. Leland J. Haworth, Director
Brookhaven National Laboratory
Upton, Long Island, New York
(enclosed in memo. to:
Merril Eisenbud, Manager
New York Operations Office
CC: Pittman, DRD, w/encl.
Dunham, B&M, w/encl.)

Dr. Norris E. Bradbury, Director
Los Alamos Scientific Laboratory
Los Alamos, New Mexico
(enclosed in memo. to:
K. F. Hertford, Manager
Albuquerque Operations Office
CC: Pittman, DRD, w/encl.
Starbird, MA, w/encl.)

Dr. A. M. Weinberg, Director
Oak Ridge National Laboratory
Oak Ridge, Tennessee
(enclosed in memo. to:
S. R. Sapirie, Manager
Oak Ridge Operations Office
CC: Pittman, DRD, w/encl.
Bloch, PROD, w/encl.)

OPERATION OF SODIUM COMPONENTS TEST FACILITY

An Invitation to Contractors to Operate a Sodium Components
Test Facility

The U.S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. This development program is expected to continue for at least five years subject to available funds.

The Commission wishes to contract for the operation of a facility that will test liquid metal components under conditions that will closely simulate nuclear reactor operation. It is the desire of the Commission that the organization selected will operate the facility and have prime responsibility for technical direction of design and construction efforts. The components to be tested will be furnished by the Commission and will include all types of sodium components used in the process of generating steam in a nuclear power plant with the immediate emphasis on heat exchangers and steam generators. The programing of component testing will be subject to the approval of the Commission.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities which will augment this effort, with location and general description.
2. Proposer's approach to performing the subject work.
3. Proposer's attitude toward doing the work on a Government-owned site. Use of a Government site has not been determined.
4. Brief history of the company and a resume of experience in work allied to the proposed effort.
5. The names and qualifications of key personnel who will be assigned to this contract.
6. Based on the tentative schedule outlined in the attachment, your anticipated man-power schedule for the Phase I work of this project.
7. State to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
8. List the current major Government contracts and other work of this general nature.
9. Submit the organization's current financial statement.
10. Furnish any additional information which you feel may be of assistance to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the program as outlined in the following pages and submit a proposal with 6 copies by January 9, 1959, to Mr. T. P. Heckman, Secretary, Sodium Components Contractor Selection Board, U.S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois, that will satisfy the objectives cited.

PROPOSED WORK AND SCHEDULES

The proposed work will be performed in three separate phases with each succeeding phase dependent upon the review of the previous phase by the AEC.

Phase I

The contractor will make a conceptual design of a sodium components test facility that will be capable of subjecting sodium components to both steady state and transient conditions expected in full size nuclear power electric generating stations. The following types of components are scheduled for testing in this facility: 30 MW Na to Na heat exchangers, 30 MW Na to H₂O steam generators, valves and throttling devices, flow indicators, pressure indicators, level indicators, oxide concentration indicators, temperature indicators, and other instruments which may be developed.

Since the purpose of the test facility is to develop data that can be used in the design of full scale components, many of the capacities of the facility must be variable.

Wherever possible, available existing equipment should be utilized if economically desirable. (For example, the AEC has available for possible use in this facility an oil-fired sodium heater built by the Babcock & Wilcox Company having a maximum design specification of 125,000,000 BTU/hr at 1200°F Na outlet and 870°F sodium inlet.)

The contractor will supply the AEC with a conceptual design of the facility specifications, schedules, cost estimates, and operating procedures for meeting test conditions in the test facility at the end of Phase I of the contract.

This contract will be Cost-Plus-Fixed Fee, and Phase I will be for a period of four months.

Phase II

Phase II will include technical direction of the detail design of the facility.

Phase III

Phase III will include direction of construction of the test facility and operation of the test facility. Phases II and III are subject to the availability of funds.

PREVIOUS TEST WORK

Considerable experience has been accumulated in the area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955, and are very similar to the proposed project.

This reference handbook is unclassified and available for purchase through the U.S. Government Printing Office by the number, 1955 O-351326.

SPECIFICATIONS OF TEST FACILITY

The sodium components test facility must be capable of operating a fossil fuel fired sodium heater together with auxiliaries and accessories to allow testing of liquid metal components on a continuous or intermittent basis. The test facility must be capable of indicating and recording data on a continuous basis for a contract term of several years. Besides the primary test loop, the following are examples of supporting equipment which may be required: railroad siding or truck docks equipped with an overhead crane, oil storage, building for the heater and a series of component test cells, instrument and control center, heat sink, water supply and purification system, sodium storage and purification system, etc.

The testing cells, primary piping, and servicing utilities will be so arranged to allow an easy change between test setups.

All components tested in this facility may be inspected by non-destructive means, before, during, and after the tests. All of the test data shall be recorded in a systematic way so as to allow analysis of the inter-relationship of materials, fabrication techniques, design, and operating conditions of the test components.

Other measurements, calculations, and tests as may be acceptable to both parties of the contract will be made during the contract period.

A typical set of test conditions would be as follows for a sodium to H₂O steam generator:

Rated load (continuous)	30 MW
Na flow maximum	3500 gpm
Maximum Na temperature, continuous	1200°F
Maximum Na temperature difference	500°F
Maximum Na pressure	150 psi
Maximum Na pressure drop across the steam generator	25 psi
Na purity	less than 30 ppm oxygen
Na flow rate	variable - proportional to load, up to 30 ft/sec
Maximum steam temperature, continuous	1050°F
Feedwater purity	less than 0.5 ppm solids
Maximum startup rate	100°F/hr

Full range (20-100%) transient	$\pm 5\%$ of full power/min
Temperature transient	35°F/sec for 14 sec

Similar specifications will be established for each of the components to be tested.

FLOW CONTROLLER

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

Gentlemen:

The Atomic Energy Commission is soliciting proposals for the design, development, manufacture and test operation of less expensive and more reliable flow control mechanisms of advanced design and improved performance for use in sodium cooled reactor systems.

Attached is a functional specification which establishes the goal of the program. As visualized by the AEC this program would consist of the parts described in the attachments and might extend over a five year period. However, all proposers are invited to submit their own organizations' suggestions for the program scope and not necessarily duplicate present Commission views.

If you are interested in participating in this program, a proposal should be submitted to the AEC and received not later than June 16, 1958. At the minimum, your proposal should contain information which addresses itself to the following points:

1. Your proposal for the program, sub-divided into phases and including a proposed water test program to verify operational requirements.
2. Proposed time and manpower schedules for each phase of the program.
3. Estimated costs for each phase including labor, material, equipment and indirect cost.
4. Qualifications and experience of your company directly pertinent to carrying out the program.
5. A list of the key personnel you would propose to assign to each phase of the program and their qualifications.
6. A description of the manufacturing, inspection, test and research facilities available to you which you would intend to use in the program.
7. A description of the facilities you would propose to acquire or which you would expect the AEC to furnish.
8. Such other information as you believe will be useful to the AEC in selecting the contractor for this program.

In formulating your proposal, you should be aware that it is the intent of the Commission to support other work in the general area of sodium technology under other contracts. This work will have a bearing on your proposed program. Such supporting efforts will include work on decontamination methods, development of gas and sodium purification devices and the problem of sodium frosting. In addition, many AEC contractors are presently undertaking research and development work on new materials, leak testing and detection and other pertinent problems.

We will appreciate knowing by May 16, 1958 whether or not you intend to submit a proposal.

Any questions you may have regarding this invitation should be submitted in writing to the undersigned.

Proposals should be submitted in sextuplet and addressed to James J. King, Secretary, Sodium Components Selection Board, Division of Reactor Development, U. S. Atomic Energy Commission, Washington 25, D. C.

Sincerely yours,

James J. King, Secretary
Sodium Components Selection Board

Attachments

As stated above

AREAS OF WORK TO BE INCLUDED IN THE
SODIUM FLOW CONTROL DEVELOPMENT PROGRAM

1. Familiarization with Sodium Technology - This would include contact and liaison with AEC contractors presently working in the field as well as a literature survey.
2. Design and Analysis - This would include (a) conceptual designs and preliminary analysis of a full scale unit, (b) detailed design of the full scale unit.
3. Materials Selection - This includes such research and development as may be necessary to verify properties of materials selected.
4. Development of Welding and Fabrication Methods - This would include non-destructive testing and inspection procedures.
5. Maintenance - This will include methods of repair and maintenance and the design, fabrication and testing of any special tools necessary for maintenance operations.
6. Operational Tests - This would include formulation and execution of a water test program to verify all operational aspects of a full scale unit.

TENTATIVE FUNCTIONAL SPECIFICATION, SODIUM FLOW CONTROL DEVICES

I. SCOPE

This specification is intended to cover throttling devices for high temperature molten metallic sodium service.

II. DESIGN DATA

Size Range

20" normal commercial pipe size.

Valve or Device Type

No mandatory types are specified. Throttling is to meet the requirements as described.

Installation

Normally, the line run is to be horizontal with the device stem (if used) vertical and up. The device shall also be completely operable in a vertical line run with the valve stem (if used) approximately horizontal. Wherever possible, installation shall be such as to take advantage of a clean drain of the device.

Flow Medium Data

Medium: Molten Metallic Sodium
 Temperature: 1200°F to 500°F
 System Pressure: 100 psig to 0.5 psig
 Carbon Contamination of Sodium: 1000 PPM to 50 PPM

Ambient Conditions

Temperature: 150°F
 Atmosphere: Dry nitrogen gas
 Radiation Level: 10^5 R/Hr

General Construction Materials

To be specified by proposer and acceptable to AEC

Fluid Containment Requirements

External Leakage - zero over anticipated life of 10 years at continuous exposure to 1000°F.
 Stem Backup Seal (where applicable) - A backup seal device is to be incorporated in the device in addition to the primary seal. This backup seal is to provide a stem seal of zero leakage over an anticipated life of 500 cycles after the failure of the primary seal.

Flow Requirements

Throttling Characteristic: Approximately linear
 Throttling Rangeability: Approximately 20:1 overall including operator and position indicator. Note: Device shall exhibit negligible vibration particularly in the low flow range.

Operator Requirements

Power Operator - Operator shall be of such construction as to resist anticipated radiation level for a period of two years. Manual operation over-ride is to be provided.

General Design Requirements

The ASME unfired pressure vessel code shall be used as the minimum design requirement of the component.
 Stress analysis of the device structure is most important. Temperature changes in the order of $\pm 35^\circ\text{F}/\text{sec}$ for periods of 3 or 4 seconds are anticipated. The device should be capable of withstanding at least 1000 such cycles during its lifetime.

Maintenance

If maintenance is required during life time of this device, the proposer is to provide methods and tools for such maintenance taking into consideration the operating environment (remote maintenance may be necessary).

Test Operation

The device is to be successfully tested in water service under specified conditions (excluding radiation). The test program is to be formulated by the proposer.

PURPOSE OF THE CONTRACT

This contract recognizes that it is an objective of the Commission to assist and encourage the development of nuclear power reactor systems capable of

producing economic electric power from nuclear energy. It is further recognized that the Commission desires to sponsor research and development leading to more economical and better performing external components for sodium-cooled reactor systems.

This agreement further recognizes that the Contractor has conducted and possesses the necessary facilities and capital equipment to conduct design and development work and to manufacture throttling devices and operators for sodium-cooled reactor systems.

It is the purpose of this contract to provide the terms and conditions under which the Contractor will undertake the design and fabrication of a less expensive, more reliable prototype throttling device and operator of advanced design and improved performance for use in a sodium test loop.

It is the intent of the Commission and the Contractor that the work under this agreement shall be carried on in a spirit of friendly cooperation with a maximum of effort and common sense in achieving their common objectives.

In order to carry out the purposes of this contract, and subject to the provisions of the Atomic Energy Act of 1954, as amended, the parties hereto agree as follows:

NATURE AND SCOPE OF THE WORK

1. The work under this agreement shall be unclassified and shall consist of the design, fabrication, and delivery to the Commission of a flow control device and operator of advanced design with a torque tube seal as set out in Contractor's proposal dated June 20, 1958 as amended by supplemental proposal dated August 15, 1958, meeting the performance specifications set out in Appendix A (which Appendix is attached hereto and made a part hereof) for test in a sodium test loop. Said performance specifications are a program objective and do not represent a warranty on the part of the Contractor.
2. The flow control device and operator to be delivered pursuant to Section 1. hereof shall be tested as follows:
 - a. In a static gas atmosphere at 1000°F;
 - b. Cold water flow tested to simulate, wherever possible, actual service conditions.
3. The Contractor shall also deliver to the Commission the following information:
 - a. Detailed drawings of the flow control device and operator including all features;
 - b. Specifications for all parts;
 - c. Methods of inspection and maintenance to be used during service;
 - d. Fabrication methods and procedures used;
 - e. Report operability at high temperature and cold flow characteristics based on the test performed pursuant to Section 2. hereof;

- f. Predicted performance of a twenty-inch flow control device and operator on extrapolation of the data on the ten-inch flow control device and operator developed under this contract;
- g. Cost estimates for the manufacture of a twenty-inch flow control device and operator.

ANALYSIS OF SODIUM FOR LOW-LEVEL OXIDE CONTENT

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

January 23, 1959

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for the development of a fast and reliable method for the determination of oxygen in sodium at concentrations below 10 ppm.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume' of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel that will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of the current major Government contracts and other work of this general nature.
7. The organization's current financial statement.
8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by February 23, 1959, to Mr. T. P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

A handwritten signature in cursive script that reads "T. P. Heckman".

T. P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Analytical Method for Oxygen (10 ppm or less) in SodiumBACKGROUND INFORMATION

The attainment of economic nuclear power will, to a large extent, be determined by the ability to achieve higher thermal efficiencies and utilization of low cost, low cross section structural materials. In the case of sodium-cooled reactors, it is anticipated that operating temperatures will run at 1200°F sodium outlet from the reactor and structural materials may include zirconium alloys for higher neutron economy and ferritic steels for cost reduction. This will impose more stringent requirements on sodium purity with respect to oxygen, and consequently, on the analytical methods for its determination.

Analytical techniques developed to date permit the determination of oxygen in liquid sodium to a level of 10 ppm $\pm$ 10 ppm. While this sensitivity is adequate for systems containing ferrous alloys and stainless steels, metals such as zirconium, niobium, and beryllium have oxygen tolerance levels considerably below 10 ppm. This development of improved analytical methods is, therefore, indicated.

Considerable experience has been accumulated in the area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955, and are similar to the proposed project. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 O-351326.

NATURE AND SCOPE OF WORK

The contractor shall develop a fast and reliable high sensitivity method to determine oxygen concentration in sodium at oxygen levels below 10 ppm. A study of sampling techniques is to be a part of this program. The contractor will review existing methods and try to improve and/or combine these methods to achieve the objective. The possibility of a new approach should be investigated.

At the conclusion of the contract, the contractor will submit a topical report describing the method of analysis developed and the investigation leading to this developed method. The method of analysis should be adaptable to the conditions stated in the Functional Specifications.

The contractor will review available literature to avoid a duplication of effort. Attached is a sheet listing supporting programs of AEC for supplying industry with technical information.

FUNCTIONAL SPECIFICATIONS

Operating Conditions - Sodium

Temperature, maximum	1200°F
Flow velocity	up to 30 fps
Flow rate	up to 12,000 gpm

Pressure	150 psig
Purity, oxygen	0 - 500 ppm
Analytical Technique	
Range of oxygen purity	1 to 10 ppm
Sensitivity and accuracy	1 ppm
Sampling technique	Compatible with operating conditions

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

MASS TRANSFER OF MATERIALS IN SODIUM

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

January 23, 1959

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for the investigation of mass transfer in the temperature range of 1000°F to 1300°F to enable the reactor and component designers of sodium cooled systems to appraise the problem in terms of materials of fabrication of these components.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume' of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel that will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of the current major Government contracts and other work of this general nature.

7. The organization's current financial statement.
8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by February 23, 1959, to Mr. T. P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

T. P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Experimental Investigation of Mass Transfer in 1200°F Sodium SystemsBACKGROUND INFORMATION

Considerable experience has been accumulated in the area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955, and are similar to the proposed project. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 O-351326.

SCOPE OF WORK

The contractor shall perform tests to determine mass transfer in high temperature sodium systems constructed of specified materials. Test conditions and tests to be performed are described in the "Detailed Requirements and Specifications."

Based on test data developed under this contract, the contractor shall describe the mass transfer phenomenon for given materials as a function of sodium temperature, purity and flow velocity, system temperature drop, and material surface condition.

The contractor will submit a topical report at the end of the contract period describing in detail the work accomplished, the data derived, and conclusions. Interim reports will be submitted describing work in progress and results obtained on a quarterly basis.

Reliability and economy in components for 1200°F sodium service is a goal. With this in mind the contractor shall conclude from data developed materials best suited for reactor power plant system components. Methods for preventing, or operating limits which will prevent, mass transfer in the system should be considered.

The contractor will review available literature to avoid a duplication of effort. Attached is a sheet listing supporting programs of AEC for supplying industry with technical information.

DETAIL REQUIREMENTS AND SPECIFICATIONS

1. Sodium test loops. The test loops will be constructed to provide reliable continuous operation under the following conditions:

Sodium temperature	hot leg	1300°F maximum, 1000°F minimum
	cold leg	600°F minimum
Pressure		100 psig maximum
Sodium velocity		30 ft./sec. maximum
System Delta-T		500°F maximum, 200°F minimum
Sodium purity		less than 50 ppm oxygen

2. Test loop materials. Initial investigations will be limited to the following materials:

Stainless steel - types 304, 316, 310, 347

2½ crolloy, 5 crolloy, 15 Cr - 1 Mo

3. Test. Tests will be conducted with each material as follows:

Hot leg at 1000, 1100, 1200, 1300°F

System Delta-T for each hot leg temperature of 500, 400, 300, 200°F

Sodium impurity - constant at less than 50 ppm

Flow velocity - constant

Minimum time - 3000 hours

4. From 3 above the promising materials will be subjected to further tests at hot leg and system Delta-T specified above but in addition varying sodium velocities of 30 ft./sec., 20 ft./sec., 10 ft./sec.
5. Sodium purity will be varied to determine the effect on mass transfer at 1200°F hot leg temperature with a system temperature drop of 400°F on the promising materials at a constant sodium flow rate.
6. The most promising materials will be subjected to a long-term (one to two year) test with a hot leg temperature of 1200°F, Delta-T of 400°F, flow velocity of 25 ft./sec., sodium oxide concentration of less than 50 ppm, and a loop pressure of 100 psig.

Analytical methods. The contractor shall submit analytical procedures to be used to determine mass transfer rates showing accuracy at all anticipated rates. Emphasis is to be placed on methods for determining very slow mass transfer rates. The method for measuring sodium purity shall be described in detail by the contractor. Analytical methods shall be approved by the contracting officer prior to proceeding with the experimental program.

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established

in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

PHYSICAL PROPERTIES OF MATERIALS IN SODIUM

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

January 23, 1959

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for a program of materials testing which will establish those physical properties of materials that are necessary to result in reliable and economical designs of high temperature sodium components.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume' of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel that will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of the current major Government contracts and other work of this general nature.

7. The organization's current financial statement.
8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by February 23, 1959, to Mr. T. P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

T. P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Properties of Materials Exposed to 1200°F SodiumBACKGROUND INFORMATION

Sodium cooled reactors have the attractive potential of very high thermal efficiency at low sodium pressure. The limits to which the temperature can be raised are governed by the physical properties of the materials used in the sodium system. The existing data at the proposed temperatures are very limited.

Considerable experience has been accumulated in the area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955, and are similar to the proposed project. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 O-351326.

NATURE AND SCOPE OF WORK

The contractor shall perform tests on materials listed in "Functional Specifications" to determine the physical properties of those materials under exposure to sodium at 1200°F and under stressed conditions. In addition to material samples, welded joints of various materials shall be tested. The welded joints will simulate welded system components and will be joints of both similar and dissimilar metals. Tests of materials under stress will also include thermally shocking specimens from 1200°F to 500°F in 20 seconds. The effect of exposure to nitrogen shall be investigated. The contractor shall submit a topical report relating the tests accomplished and the results at the conclusion of the contract period.

The contractor will review available literature to avoid a duplication of effort. Attached is a sheet listing supporting programs of AEC for supplying industry with technical information.

FUNCTIONAL SPECIFICATIONS

Materials to be tested:

Ferritic steels - $2\frac{1}{4}$ Cr - 1 Mo, 5 Cr - 1 Mo

Ferritic Stainless Steel - 15 Cr - 1 Ni

Austenitic Stainless Steel - 304, 316, 317

Welded joints to be tested - as above (similar materials) and several samples of ferritic steel welded to austenitic

Sodium Conditions:

Temperature
Purity

up to 1300°F
10, 50, 100 ppm oxygen - 100, 300,
500 ppm carbon (must be analyzed
for other impurities)

Temperature transients
Exposure to nitrogen at 1200°F
i.e., to study effects at sodium-
nitrogen interface

-35°F/sec. for 20 sec.
Nitrogen must be analyzed
for impurities

Effects to be investigated:

1. Effect on the physical properties of materials from exposure to 1200°F sodium, varying oxygen and carbon impurities and exposing sample to sodium blanketed by nitrogen at high temperature.
2. Effect on the physical properties of materials due to severe thermal shock in addition to exposure listed above.

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

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Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

The following laboratories and industries received letters of invitation on:

Investigation of mass transfer in the temperature range of 1000°F to 1300°F.
Materials testing.
Determination of oxygen in sodium at concentrations below 10 ppm.

Mr. Dan A. Kimball, President
Aerojet-General Corporation
Post Office Box 296
Azusa, California

Dr. B. D. Thomas, President
Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

Mr. Robert S. Stevenson, President
Allis-Chalmers Manufacturing Company
1126 S. 70th Street
Milwaukee 1, Wisconsin

Mr. Walter C. Hasselhorn, President
Cook Electric Company
2700 Southport Avenue
Chicago 14, Illinois

Dr. Frank H. Spedding, Director
Ames Laboratory
Post Office Box 114A, Station A
Ames, Iowa

Dr. Norman Hilberry, Director
Argonne National Laboratory
Post Office Box 299
Lemont, Illinois

Mr. Fred Kremer, Business Manager
Armour Research Foundation
of Illinois Institute of Technology
10 West 35th Street
Chicago 16, Illinois

Dr. Chauncey Starr, Vice President
Atomics International
A Division of North American Aviation, Inc.
Post Office Box 309
Canoga Park, California

Mr. Alton P. Donnell, General Manager
Atomic Power Development Associates, Inc.
1911 First Street
Detroit 26, Michigan

Mr. Morris Nielsen, President
The Babcock and Wilcox Company
161 E. 42nd Street
New York 17, New York

Mr. Richard Stetson Morse, President
National Research Corporation
70 Memorial Drive
Cambridge 42, Massachusetts

Mr. John R. Menke, President
Nuclear Development Corporation of America
5 New Street
White Plains, New York

B. A. Schmickrath, Asst Engr Mgr
United Aircraft Corporation
Pratt and Whitney Aircraft Division
Connecticut Operations
CANEEL
Post Office Box 611
Middletown, Connecticut

Mr. Ashton J. O'Donnell, Manager
Program Development
Stanford Research Institute
Menlo Park, California

Mr. Crawford H. Greenewalt, President
E. I. du Pont de Nemours & Company
Du Pont Building
Wilmington, Delaware

Mr. Benjamin Bynun Turner, President
Ethyl Corporation
100 Park Avenue
New York 17, New York

Mr. Robert Paxton, President
General Electric Company
Atomic Power Equipment Department
2151 South First Street
Post Office Box 254
San Jose, California

Mr. Frederick de Hoffman, Vice President
General Dynamics Corporation
General Atomic Division
Post Office Box 608
San Diego 12, California

Mr. John T. Ryan, Jr., President
M.S.A. Research Corporation
201 N. Braddock Avenue
Pittsburgh 8, Pennsylvania

Mr. Joseph Fistere, President
Mallinckrodt Chemical Works
3600 N. Second Street
St. Louis 7, Missouri

Dr. Leland J. Haworth, Director
Brookhaven National Laboratory
Upton, Long Island, New York
(enclosed in memo. to:
Merril Eisenbud, Manager
New York Operations Office
CC: Pittman, DRD, w/encls.
Dunham, B&M, w/encls.)

Dr. Norris E. Bradbury, Director
Los Alamos Scientific Laboratory
Los Alamos, New Mexico
(enclosed in memo. to:
K. F. Hertford, Manager
Albuquerque Operations Office
CC: Pittman, DRD, w/encls.
Starbird, MA, w/encls.)

Dr. A. M. Weinberg, Director
Oak Ridge National Laboratory
Oak Ridge, Tennessee
(enclosed in memo. to:
S. R. Sarin, Manager
Oak Ridge Operations Office
CC: Pittman, DRD, w/encls.
Bloch, P&OD, w/encls.)

Mr. Robert E. Hulse, Vice President
U. S. Industrial Chemicals Company
Division of National Distillers & Chemical Corp.
99 Park Avenue
New York 16, New York

Mr. Mark W. Cresap, Jr., President
Westinghouse Electric Corporation
Post Office Box 2278
3 Gateway Center
Pittsburgh 30, Pennsylvania

SHELL-SIDE HEAT TRANSFER

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for a program of research and development to establish reliable shell side heat transfer correlations for sodium for a wide variety of tube and shell heat exchanger geometries.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume' of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel that will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of current major Government contracts and other work of this general nature.
7. The organization's current financial statement.

8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by 1959, to Mr. Thomas P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

Thomas P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Na or NaK Shell Side Heat TransferBACKGROUND INFORMATION

Methods for predicting liquid metal heat transfer coefficients developed from fundamental heat transfer theory have been satisfactorily substantiated by experimental data for liquid metals flowing through round tubes and annuli. However, these methods have proved entirely inadequate for predicting liquid metal heat transfer performance in heat exchange units. Generalized equations found to be satisfactory for normal fluids in shells frequently predict Nusselt numbers for liquid metals which may differ from experimental results by as much as a factor of 10. This inadequacy is of little consequence in the design of heat exchangers where the heat transfer is between liquid metal and some other fluid which has a low heat transfer coefficient in comparison with the liquid metal. However, in the design of liquid metal-to-liquid metal heat exchangers and liquid metal heated steam generators, the liquid metal heat transfer coefficient may be a significant factor in determining heat exchanger dimensions required to meet specified operating conditions. In the case of liquid metal steam generators, it is usually preferable for structural design reasons to carry the high pressure steam in the tubes with the liquid metal in the shell. Where liquid metal shell side performance is an important factor, it has been necessary to develop an empirical relationship from experimental data obtained for the particular shell side geometry being considered. At this time, it is impossible to reliably evaluate by analytical method liquid metal heat transfer performance for a wide variety of shell side geometries. Such an evaluation would strongly aid in the selection of the shell side geometry best suited for any particular liquid metal heat exchanger application.

Considerable experience has been accumulated in the general area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 O-351326.

NATURE AND SCOPE OF WORK

A literature survey should be made of the existing data and the methods used in determining the data. The proposed work should be approached first from a fundamental analytical basis and followed by an experimental program. The experimental program should result in the development of equations that will prove reliable in the design of large capacity liquid metal heat exchangers and steam generators that can be fabricated at a cost that is comparable, over-all, to the present day stainless steel fabrication of commercial equipment.

FUNCTIONAL SPECIFICATIONS

1. Liquid metal - Na or NaK
2. Flow - Both laminar and turbulent flow
Use Reynolds Number 400,000 as an upper limit
3. Coolants - (1) Sodium or NaK
(2) H₂O

4. Temperature range - 500° to 1300°F
5. Heat flow rates - to 200,000 BTU/ft.² hr.
6. Geometric parameters - (a) tube size - 1/4" to 1" i.d. diameter (b) tube spacing c-c - 1 1/2 diameters to 4 diameters (c) other configuration which would meet requirement of reliability and economic fabrication

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

SODIUM AND NaK SHELL SIDE HEAT TRANSFER COEFFICIENT
RESEARCH PROGRAM

I. Purpose

A program of research and experimental work is sought, the purpose of which will be to establish reliable shell side heat transfer correlations for sodium and NaK for a wide variety of tube and shell heat exchanger geometries.

II. Justification

Methods for predicting liquid metal heat transfer coefficients developed from fundamental heat transfer theory have been satisfactorily substantiated by experimental data for liquid metals flowing through round tubes and annuli. However, these methods have proved entirely inadequate for predicting liquid metal heat transfer performance in heat exchanger shells. Generalized equations found to be satisfactory for normal fluids in shells frequently predict Nusselt numbers for liquid metals which may differ from experimental results by as much as a factor of 10. This inadequacy is of little consequence in the design of heat exchangers where the heat transfer is between liquid metal and some other fluid which has a low heat transfer coefficient in comparison with the liquid metal. However, in the design of liquid metal-to-liquid metal heat exchangers and liquid metal heated steam generators, the liquid metal heat transfer coefficient may be a significant factor in determining heat exchanger dimensions required to meet specified operating conditions. In the case of liquid metal steam generators, it is usually preferable for structural design reasons to carry the high pressure steam in the tubes with the liquid metal in the shell. Where liquid metal shell side performance is an important factor, it has been necessary to develop an empirical relationship from experimental data obtained for the particular shell side geometry being considered. At this time, it is impossible to reliably evaluate by analytical methods liquid metal heat transfer performance for a wide variety of shell side geometries. If such an evaluation were possible, it would strongly aid in the selection of the shell side geometry best suited for any particular liquid metal heat exchanger application.

III. Scope

The organizations submitting proposals should be requested to outline the approach they intend to take and the scope and cost of the work. The initial work should include the accumulation by literature search and personal contacts of as much available data and analytical work as possible. Following review of the material gathered, the problem might be approached on a fundamental analytical basis supported by experimentation designed to study the various variables independently, or on an empirical basis where the effort is directed toward establishing empirical equations which best fit the existing data, or by a combination of these approaches.

IV. Suggested Parametric Limits for the Experimental Work

In order to more clearly define the scope of the investigation, the following factors (parameters) shall be considered within the limits specified.

A. Liquid Metals

The investigation shall include correlation of data for (1) Sodium, (2) NaK (56-44), (3) NaK (22-78), (4) _____, (5) _____.

The weight rate of flow of the liquid metals shall be of the magnitude required to produce a wide range of Reynolds numbers (or modified Reynolds numbers if necessary for good correlation).

The mean temperature of the liquid metals shall vary from _____°F to _____°F.

B. Coolants

The investigation shall include correlation of data using both sensible and latent heats of coolants. Thus the effects of a constant vs variable tube temperature will be considered.

C. Heat Exchanger Geometry

All heat exchanger designs investigated shall be of the shell and tube design incorporating all necessary features required for the safe use of liquid metals. The size of the heat exchanger shall be such that it will be capable of transferring between _____ and _____ megawatts equivalent of heat.

The effect of the following geometric parameters shall be considered:

1. Tube size (_____ to _____ OD)
2. Transverse pitch (_____ to _____)
3. Longitudinal pitch (_____ to _____)
4. Internal baffling
 - a. Longitudinal
 1. Number (_____ to _____)
 2. Type (X, Y, Z, etc.)
 - b. Cross
 1. Spacing (as function of S/D)
 2. Size (as function of free flow area)
5. Length to diameter ratio (_____ to _____)

METER FOR CONTINUOUS INDICATION OF SODIUM
OXIDE CONTENT IN SODIUM

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for the development of a meter that will give a continuous indication of the concentration of sodium oxide in a 1200°F sodium system.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume^e of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel that will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of current major Government contracts and other work of this general nature.

7. The organization's current financial statement.
8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by 1959, to Mr. Thomas P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

Thomas P. Heckman
Thomas P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Sodium Oxide Concentration MeterBACKGROUND INFORMATION

Sodium oxide in liquid sodium represents a major problem in the operation of sodium cooled reactors. High concentrations of the oxide impurity can lead to plugging in portions of the sodium heat transfer apparatus. To date no commercial instrument has been developed which will give the reactor operator a continuous indication of the oxide concentration in the system. A "relative (Na_2O) indicator" has been constructed under direction of L. R. Blake, United Kingdom authority and shows promise of usefulness.

Considerable experience has been accumulated in the general area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 O-351326.

NATURE AND SCOPE OF WORK

The contractor will design, fabricate, and deliver to the Commission an instrument capable of continuous measurement of sodium oxide impurity in high temperature sodium. The instrument will be subjected to conditions and will meet specifications listed in Functional Requirements. It is expected that the contractor will familiarize himself with technology to date on sodium oxide detection and will conduct necessary development work to design the instrument. The instrument design shall be approved by the contracting officer prior to fabrication by the contractor. A report will be submitted to the Commission at the end of the contract period which will include the following:

1. Analysis of the basic problems involved in measurement.
2. Justification for selection of a particular method.
3. Preliminary design of practical instrument.
4. Fabrication history (if any).
5. Test data (if any).
6. Cost of first unit including complete supporting apparatus.
7. Cost of special tools.
8. Estimated cost of subsequent units.
9. Expected operating cost.
10. Anticipated useful operating life.
11. Predicted performance under operating conditions.

Interim reports will be submitted at reasonable intervals to show the progress of noteworthy developments.

FUNCTIONAL SPECIFICATIONS

The sodium oxide concentration measuring device will be capable of operating under the conditions and specifications listed here:

1. Operation in sodium from 208°F to 1200°F.
2. Must withstand rate of change of sodium temperature of 70°F per second for three seconds.
3. Measure sodium oxide concentration in sodium over two ranges: 0-10 ppm and 10-500 ppm.
4. Accuracy and sensitivity of instrument $\pm$ 10% of reading.
5. Capable of continuous measurement of oxide with a system time constant of no more than five minutes.
6. Measurements must be transmitted to remote display and recording device.
7. Essential parts must be removable from a radioactive space for ease of maintenance.
8. Trouble free long life is of primary importance.

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

HYDROGEN DETECTOR FOR SODIUM SYSTEMS

UNITED STATES
ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
P. O. Box 59
LEMONT, ILLINOIS

February 16, 1959

Gentlemen:

The U. S. Atomic Energy Commission is sponsoring a research and development program directed toward providing reliable economical non-nuclear components for use in a sodium cooled nuclear power plant operating at an outlet temperature of 1200°F. In addition, this program will explore certain areas of advanced sodium technology which will be of benefit to both existing and proposed sodium reactor projects. The Sodium Components Development Program is expected to be a continuing effort, subject to the availability of funds.

At this time the Commission wishes to contract for the development of a rugged and sensitive device that can detect hydrogen in a minute quantity from a water-sodium reaction in a flowing stream of high temperature sodium.

The proposer shall include in the response to this invitation the following information:

1. Availability of proposer owned facilities to accomplish this effort, with location and general description.
2. Brief history of the company and a resume' of experience in work allied to the proposed effort.
3. The names and qualifications of key personnel who will be assigned to contract.
4. The proposer's tentative time schedule and anticipated manpower schedule for completion of this project.
5. A statement as to what extent the work will be done with the proposer's own forces and to what extent outside assistance will be used.
6. A list of current major Government contracts and other work of this general nature.
7. The organization's current financial statement.
8. Any additional information which you feel may be of interest to the Commission in evaluating your interest in and your capability for undertaking this work.

You are invited to review the Nature and Scope of Work and the Functional Specifications as outlined in the following pages and submit a proposal with six copies by March 16, 1959, to Mr. Thomas P. Heckman, Secretary, Sodium Components Development Program Contract Selection Board, U. S. Atomic Energy Commission, Chicago Operations Office, Post Office Box 59, Lemont, Illinois.

Very truly yours,

A handwritten signature in cursive script that reads "Thomas P. Heckman".

Thomas P. Heckman, Secretary
Sodium Components Development Program
Contract Selection Board

Enclosure:
As Noted Above

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Instrument for DeterminingHydrogen or Water in Liquid SodiumBACKGROUND INFORMATION

A considerable number of the nuclear power plants under construction include in the primary heat cycle a sodium-H₂O steam generator. A mixture of sodium and water will react violently resulting in the generation of heat, Na₂O, NaOH, NaH, and hydrogen gas. The early detection of a leak from the high pressure H₂O to the sodium is vital to the life of this component and possibly to the operation of the entire plant.

Considerable experience has been accumulated in the general area of proposed work. The Genie Project, the MSA High Temperature System, and the EBR Heat Transfer Experiences are described in Chapter VI of the Liquid-Metals Handbook, Third Edition, 1955. This reference handbook is unclassified and available for purchase through the U. S. Government Printing Office by the number, 1955 0-351326.

NATURE AND SCOPE OF WORK

The various existing techniques for measuring the individual products of a Na-H₂O reaction should be surveyed. A device that appears most promising shall be fabricated and tested in a facility provided by the Commission. The device shall be designed for nuclear power plant use.

FUNCTIONAL SPECIFICATIONS

The instrument for detecting the presence of hydrogen in sodium shall be capable of the following:

1. Measure hydrogen from a H₂O-sodium reaction in the range of 0-30 ppm
2. Accuracy $\pm$ 1% of range
3. Response time 5 seconds
4. Pressure -14.7 to 175 psig
5. Sodium temperature 1200°F maximum
6. Sodium velocity 30 fps
7. Total sodium in loop 10,000 gal.
8. Sodium system flow rate 5,000,000 lb./hr.
9. Inert gas blanket A, He, or N
10. Design life 10 years
11. No plugging permissible
12. Easily maintained or replaceable as a unit

13. Remote reading and recording of generated signal
14. Must comply with Section VIII of ASME boiler and pressure vessel code including methods of attachment to or sampling from code vessels.

SODIUM COMPONENTS DEVELOPMENT PROGRAM

Reference Center

In 1956 a reference center was installed at the Technical Information Service Extension, Oak Ridge, Tennessee, for use of industrial firms. Material available to them includes a complete collection of Commission-developed reports, both classified and unclassified; a master card catalogue; bibliographies; lists of available documents; and other reference aids.

Literature Search Service

For firms that do not wish to send literature search teams to Oak Ridge and do not have independent library sources, the Commission established in 1956 a literature search service at a cost of six dollars an hour, supplying on any requested topic either literature titles or specific tabulated data.

Other Supporting Programs for Industry

Numerous other supporting programs for industry are listed in the Semi-annual Reports of the Atomic Energy Commission under the heading of "Supplying Technical Information."

The following industries received letters of invitation on:

Instrument for determining hydrogen or water in liquid sodium

Mr. Robert S. Stevenson, President
Allis-Chalmers Manufacturing Company
1126 S. 70th Street
Milwaukee 1, Wisconsin

Mr. George L. Irvine, Regional Vice President
General Electric Company
840 South Canal Street
Chicago, Illinois

Mr. John R. Menke, President
Nuclear Development Corporation of America
5 New Street
White Plains, New York

Atomation, Inc.
5959 S. Hoover Street
Los Angeles 44, California

General Scientific Equipment Company
7516 Limekiln Pike
Philadelphia 50, Pennsylvania

Gow-Mac Instrument Company
100 Kings Road
Madison, New Jersey

Thiokol Chemical Corporation
Hunter-Bristol Division
Bristol, Pennsylvania

Johnson-Williams, Inc.
2625 Park Boulevard
Palo Alto 36, California

Kruger Instruments, Harold
P. O. Box 164
San Gabriel, California

Mr. Davis R. Dewey II, President
Baird-Atomic, Inc.
33 University Road
Cambridge 38, Massachusetts

Mr. Philip S. Fogg, President
Consolidated Electrodynamics Corporation
300 N. Sierra Madre Villa
Pasadena, California

Devtron Engineering
1 Winslow Street
Redwood City, California

Mr. John Carter, President
Fairchild Camera & Instrument Corporation
Defense Products Division
Robbins Lane
Syosset, New York

Gelman Instrument Company
Chelsea
Michigan

Mr. Sameul S. Auchincloss, President
Tracerlab, Inc.
1601 Trapelo Road
Waltham 54, Massachusetts

Mr. Mark W. Cresap, Jr., President
Westinghouse Electric Corporation
Post Office Box 2278
3 Gateway Center
Pittsburgh 30, Pennsylvania

Mr. Phillip W. Zonne, President
American Electronics, Inc.
1025 W. Seventh Street
Los Angeles 17, California

Mr. Arnold O. Beckman
Beckman Instruments, Inc.
Beckman/Scientific & Process Instruments Div.
2500 Fullerton Road
Fullerton, California

Liquid Metals, Inc.
Box 266
Westford, Massachusetts

Mr. Charles Weeks, President
Menlo Research Laboratory
Post Office Box 522
Menlo Park, California

Mr. Richard S. Morse, President
National Research Corporation
70 Memorial Drive
Cambridge 42, Massachusetts

New Jersey Safety Equipment Company
Park Ave. at Garden State Pkwy.
East Orange, New Jersey

Universal Winding Company
Patterson Moos Division
90-28 Van Wyck Expressway
Jamaica 18, New York

Resitron Laboratories, Inc.
2908 Nebraska Avenue
Santa Monica, California

Mr. Moses Cammer, General Manager
Specialty Engineering & Electronics Co.
79 Clifton Place
Brooklyn 38, New York

Taller & Cooper, Inc.
75 Front Street
Brooklyn, New York

APPENDIX E

QUESTIONNAIRE SENT TO CONTRACTORS AND REPLIES

OAK RIDGE NATIONAL LABORATORY

OPERATED BY

UNION CARBIDE CORPORATION

NUCLEAR DIVISION

POST OFFICE BOX Y
OAK RIDGE, TENNESSEE 37831

April 16, 1965

At the request of Glen Wensch, I am preparing a history of the Sodium Components Development Program from its inception. The period covered will probably be January 30, 1957, to July 1, 1965.

The records indicate that your organization participated as a contractor or subcontractor in the program. To achieve agreement on events of technical significance and progress and to identify who did what and when, would you please provide the information requested in the enclosure. The listing in the questionnaire is not all-inclusive and should be augmented or modified to suit your particular case. Administrative details having no technical significance may be omitted.

Each contract or subcontract for which you have been responsible should be itemized separately.

I would very much appreciate receiving this information as soon as convenient, since a preliminary draft of the history is desired by July 1, 1965.

Very truly yours,

A handwritten signature in cursive script that reads "H. Wesley Savage".
H. Wesley Savage

HWS:sj

Enclosures

SCDP History Contractor Technical Questionnaire

on

"Chronology of Technical Events, Progress, and Documentation"

(Please provide separate itemization for each contract or subcontract)

I. General Contract Information

1. Contract number, title, and authorization date (if subcontract: cross reference to basic contract).
2. Organization and address.
3. Project manager, organizational title, and basic technical profession.
4. Key project technical personnel and consultants, organizations and addresses (if different than (2) above), project responsibilities, organizational titles, and basic technical professions.
5. Present addresses of project manager and key personnel, if different than above.
6. If item I.1 is basic contract: list subcontract numbers, titles, authorization dates, organizations, addresses, and basic purpose of each.

II. Contract Work Scopes and Schedules

1. Initial basic work scope, objectives, and schedules (summary only-- bar graphs and tables acceptable).
2. Work scope and schedule modifications, dates effective, and basic reasons.
3. Contract completion or termination dates.
4. Expected date for completing current work.
5. Future work required, if known.

III. "Chronology of Technical Events, Progress and Documentation":

- A. For Events, list chronologically, giving key dates, key participants, or attendees, objectives, accomplishments, reasons, and so forth.
- B. For documentation, list chronologically, giving dates, titles, authors, identifying notations, locations of file copies, and so forth.

The following list, augmented or modified as needed, applies to both III-A and III-B:

1. Preliminary proposals
2. Reviews or conferences
3. Request for Bid
4. Bid proposals
5. Contract technical specifications
6. Contract authorization and work scope
7. Contract technical modifications, divisions, extensions
8. Subcontracts
9. Reviews, conferences, or meetings--organized or informal
10. Progress reports--issued or anticipated by July 1, 1965
11. Topical reports--issued or anticipated by July 1, 1965
12. Technical reviews--issued or anticipated by July 1, 1965
13. Patents
14. Important technology contributions
15. Important techniques developed
16. Hardware delivered or perfected
17. Test results and evaluations
18. Other

PLEASE NOTE: The intent of the foregoing is to establish contractual facts, inter-contractual relationships, and a factual chronology of events and documentation. Explanations and prose should be summary statements only, brief, terse, and non-controversial. Identification and location of key documents is important. Each contract or subcontract should be itemized individually.

ATOMICS INTERNATIONAL

Shell Side Heat Transfer

Hydrogen Detector Development

Sodium Components Test Installation

Modular Steam Generator

SHELL SIDE HEAT TRANSFER

I. General Contract Information

1. Contract AT-(11-1) GEN-8; subaccount 4468, authorized 1 July 1961.
2. Atomics International, Division of NAA, P. O. Box 309, Canoga Park, California.
3. J. S. McDonald, Senior Engineer, Sodium Components Development Group, Sodium Reactors Department (Mechanical Engineering).
4. Professor B. E. Snort, University of Texas, Austin, Texas--Consultant (Heat Transfer and Fluid Flow).
5. Same
6. See 1 above

II. Contract Work Scopes and Schedules

1. To obtain, through a statistically designed set of experiments utilizing specially constructed tube bundles in a 1 megawatt regenerative sodium loop, the shell side heat transfer coefficients of liquid metal to liquid metal heat exchangers. The information gained, as a function of tube size, tube pitch, and angle of attack, is to be used in refining the shell side heat transfer calculations of plant-size heat exchangers.

2. Work Scope Modifications:

The original work scope, which proposed a maximum of 5166 experiments on 13 tube bundles, was modified in August 1961 to require additional studies on theoretical heat transfer, and reduction of the test program initially to three bundles, by AEC letter dated 24 August 1961. This redirection stemmed from inability of some of the "Ad Hoc" review committee members (Savage, Goldmann and Morabito) to agree on the experimental approach proposed, favoring instead a theoretical derivation prior to embarking on experiments. Facility construction was, however, authorized.

A verbal request to "close out the project in an orderly fashion" was received from the AEC 20 October 1961.

AEC approval to test one "basic bundle" was received 29 November 1961, in response to an AI proposal to utilize the completed test facility to verify predicted performance of this bundle, which was in hand. This test was performed. Authorization to fabricate and test two additional bundles was received from the AEC October 2, 1962.

The program was terminated by the AEC on 30 June 1963, prior to test completion of more than the three bundles authorized.

3. Terminated by AEC 30 June 1963, officially.

4. Not applicable
5. Equipment is still available for pursuing the program, in the event that predictions of shell side performance on large units now in test prove sufficiently inaccurate that further experimental work is required.

III. Chronology of Technical Events, Progress and Documentation

In response to Sodium Component Working Group discussions, the AEC in March of 1960 requested AI to prepare a technical specification for later bidding to perform the shell side heat transfer coefficient determinations.

Over a period of 15 months, the proposed specifications were reviewed intensively by the Working Group, primarily Messrs. Savage and Goldmann. The program was assigned to AI under the Advanced Sodium Cooled Reactor Program 1 January 1961, with the understanding that the scope of work was subject to review by the Working Group.

An experimental plan satisfactory to all interested members of the Working Group was not obtained, and a Review Group of Messrs. Savage (Chairman), Goldmann and Morabito was appointed to resolve this issue. The Review Group met in Canoga Park, July 27, 1961, after receiving and studying requested documents. Results of this meeting were reported to the Commission by the Chairman's (Savage) letter of 1 August 1961. This report recommended completion of the test facility as designed, development of "rigorous" theory of heat transfer, redesign of the basic bundle, and fabrication and test of three bundles of different "attack angles" of sodium. This recommendation was implemented by AEC letter to AI of 24 August 1961.

On 26 October, 1961, the AEC directed that the project be discontinued and the work brought to a "logical conclusion" pending clarification of funding. The AEC was apprised of the status of the program, which by that time had progressed to the point where the test facility was nearly complete and the first bundle fabricated.

Authorization to proceed with test of one bundle was received 20 March 1962. The program was reactivated, the test loop rehabilitated, and water testing of the first bundle was begun. At the same time, Professor Short (University of Texas) was re-engaged as a consultant to perform theoretical analyses.

Work proceeded on the basic bundle satisfactorily, and the AEC authorized construction of two additional bundles 2 October 1962. Fabrication and test proceeded until a failure occurred in the sodium cooler obtained surplus from MSA Research. This failure occurred in February 1963 and the program was effectively terminated due to lack of funds to replace the cooler.

The program was officially terminated 30 June, 1963, by failure to include authorization or funding in the basic contract (AT 11-1 GEN-8) for GFY 1964. The remaining equipment and data obtained have been preserved in the event technical interest in the program is revived in the future.

Monthly, informal project progress reports were mailed to all members of the Working Group; copies are on file at Atomics International. Various plans of action and work statements prepared during the program are similarly on file. (It should be noted that the basic plan of action and work statement encompassed 84 pages.) One technical data report "Analysis of Some of the Edge Effects in Shell Side Heat Transfer" by J. S. McDonald, TDR 6593 of 19 July 1961, is on file at Atomics International.

No topical reports were prepared, as the information gained during the program was not deemed worthy of publication, due to its lack of completion as a result of cooler failure and subsequent shutdown of the test equipment.

HYDROGEN DETECTOR DEVELOPMENT

I. General Contract Information

1. General Contract AT (11-1) GEN-8; project authorized 1 July 1960
2. Atomics International Division, North American Aviation,
P.O. Box 309, Canoga Park, California
3. H. Strahl, Senior Engineer, Development Group, Sodium Reactors
Dept., Mechanical Engineer
4. None; test and construction personnel only
5. Same as 3
6. Subaccount 4871, authorized 1 July 1960

II. Contract Work Scopes and Schedules

1. To develop a device for the continuous detection, down to 10 ppm, of hydrogen in liquid sodium, suitable for the secondary system of a reactor system, to indicate the onset of steam generator leakage. Initial authorization for 9 months development.
2. Schedule modified January, 1961, to provide an additional three months effort to produce an "engineered" model suitable for general installation. Initial authorization covered feasibility model only; as feasibility became assured, it was considered desirable to convert the laboratory device into a practical instrument.
3. Effort was terminated 30 June, 1961, with the completion of the project.
4. Not applicable
5. No further effort, except possible "product improvement" as a result of operational experience, is known to be required.

An existing 2" pumped sodium loop was modified to provide for injection of hydrogen and water, with the design permitting injection ten feet upstream of the detecting device. The device itself was a nickel diaphragm, coupled with a Pirani gage to detect hydrogen which diffused through the nickel. A modest vacuum of about 10 mm Hg was maintained to enhance diffusion and permit operation of the gage.

As a result of feasibility demonstration, AEC approval was granted to design and construct an instrument capable of being installed on any loop. This three-month effort commenced April 1, 1961, and was successfully concluded June 30, 1961.

SODIUM COMPONENT TEST INSTALLATION

I. General Contract Information

1. Atomics International contract AT-(11-1) Gen 8
2. Atomics International Division, North American Aviation, Inc.
3. Project Managers - January 1961-July 1962 Roman Cygan, Research
 Specialist; Mechanical Engineering
 July 1962-July 1963 Ralph Jones, Research
 Specialist; Mechanical Engineering
 July 1963-November 1964 Thomas Withers, Senior
 Engineer, Mechanical Engineering
 November 1964 - Present James Leppard, Eng.
 Supervisor, Mechanical Engineering
4. Same as 3 above

5. Same as 3 above
6. Major subcontracts
 - a. N1-S-1317: Cooling tower and control building erection, May 1, 1962, R. M. Lane Co., Los Angeles, California
 - b. N2-S-1509: Sodium Heater Erection, October 1, 1962, Commercial Contracting Co., Los Angeles, California
 - c. N2-S-81-1698: Steam System and Equipment Installation, July 1, 1962, Commercial Contracting Co., Los Angeles
 - d. N2-S-81-1728: Sodium Piping and Equipment Installation, October 1, 1962, Commercial Contracting Co., Los Angeles
 - e. N30581A-001892: Installation of Preheating, Electrical and Instrumentation System, August 19, 1963, Technical Construction Co., Los Angeles

II. Contract Work Scopes and Schedules

1. To provide a 35 Mwt sodium heated steam generator test facility, generally in accordance with the performance requirements specified in APDA-134, utilizing the maximum amount of existing facilities and equipment. Original completion date as proposed 4 January 1961 was July 30, 1962.
2. Major revisions to work scope and schedule modifications.
 - a. April 1, 1961: All effort suspended for 30 days while site location re-evaluated with renewed consideration given to CANEL. Effort renewed at AI approximately 15 May. Completion date revised to October 1962.
 - b. January 1962: Revised estimates of availability of major items of surplus equipment, notably the sodium heater (ex-KAPL) and main condenser (ex-Navy), and the effort required to place them in operating condition for the SCTI, required revision of completion date to July 1963. Extensive repairs and alterations were required to these items of equipment.
 - c. January 1963: Significant changes in engineering requirements, chiefly in the area of transient capability, were made during 1962 by AEC. These requirements were generally more stringent than originally noted in APDA 134 and the AI proposal; a large amount of re-engineering resulted from required increases in the flow rate and temperature, which necessitated change in pipe size from 8" to 10", increasing temperature capability from 1200°F max. to 1300°F max., and sodium system design pressure from 100 to 125 psig. Other changes, such as an increase in secondary pump head and incorporation of capability to operate directly from sodium heater to steam generator (bypassing the IHX)

were also required. Completion date rescheduled to January 1964 as a result of successive changes requiring complete redesign and substantial reordering and reinstallation of equipment.

- d. January 1964: Delivery delays of major equipment (pumps, feedwater heaters, boiler feed apparatus) delayed final construction completion to April 1964.
 - e. May 1964: Test item (Alco steam generator) delayed in delivery until September 1964; installation proceeded at that time.
 - f. November 1964: Addition of sodium fill and drain capacity required; modifications complete, after general system review, April 1965.
 - g. May 1965: Secondary pump motor failed by internal short circuit on system startup; repairs and corrective action currently in process.
- 3. Contract Completion: Construction officially completed April 1964; start-up and operating contract continuing.
 - 4. Expected Date for Completing Current Work: Three steam generators currently scheduled for test (Alco, AI modular, B&W). Each test approximately one year duration. Present schedule calls for completion July 1968.
 - 5. Future Work: Steam generator, component and system test as directed by AEC.

III. Chronology of Technical Events, Progress and Documentation

- 1. Chronology of major events.
 - a. Title I submitted January 10, 1961, including NAA-SR-5993.
 - b. Start of first construction work May 22, 1961.
 - c. Sodium heater erection began October 23, 1961.
 - d. Steam and feedwater construction started July 18, 1962.
 - e. Sodium piping installation started October 26, 1962.
 - f. Completion of sodium heater January 15, 1963.
 - g. Start of preheating and instrumentation contract August 19, 1963.
 - h. Completion of steam and feedwater piping October 17, 1963.
 - i. Completion of sodium system piping October 18, 1963.

- j. Completion of preheating and instrumentation contract April 30, 1964.
 - k. Alco steam generator delivered September 1, 1964.
 - l. Alco steam generator installed December 15, 1964.
 - m. Modifications to sodium fill and drain system complete April 15, 1965.
 - n. System start-up June 1, after completion of preoperational tests; secondary sodium pump motor shorted.
2. Documentation
- a. APDA-134; original specifications - Available from TID, ORNL
 - b. NAA-SR-5993; SCTI Title I proposal - " " " "
 - c. Monthly "Cost Budget Narrative and Program Status Report", submitted to COO, USAEC. Classified, filed at COO, and Atomics International Classified Library.
 - d. "SCTI Preoperational Procedures" and "SCTI Operational Procedures" to be published after final approval by USAEC.
 - e. Atomics International Quarterly and Annual Progress Reports, January 1961 to present, available from TID, ORNL.
 - f. Meeting notes, Sodium Components Working Group, 1961-1963, filed with COO, USAEC.

MODULAR STEAM GENERATOR

I. General Contract Information

1. AT 11-1 (GEN-8), Subaccount 7519-4493, "Supercritical Modular Steam Generators".
2. Atomics International Division, NAA, P.O. Box 309, Canoga Park, Calif.
3. Dr. D. T. Eggen, Manager, Sodium Cooled Reactor Program, Experimental Physicist.
4. Donald F. Casey, Project Engineer (directly responsible), Heat Transfer Specialist.
Leo Bogaert, Manufacturing Engineer.
William F. Anderson, Specialist, Stress Analysis.
Dr. M. M. Lemcoe, Specialist, Experimental Stress Analysis.
5. Atomics International
6. Not applicable

II. Contract Work Scopes and Schedules

1. Basic Work Scope

To design and develop a once-through, single wall sodium heated supercritical steam generator. The project program will involve:

- a. The design of a unit to furnish 3500 psi, 1050° steam at turbine throttle.
- b. Module optimization studies to determine minimum installed cost.
- c. Design of a representative steam generator and reheater installation for a 400 Mwe (nameplate) plant.
- d. Development of a tube-to-tube sheet, internal butt welding procedure and the necessary tooling and equipment to make the weld.
- e. Conducting an experimental stress program to determine optimum tube wall thickness and tube sheet geometry.

Original completion date 30 June 1963.

2. Work Scope Modifications

- a. 17 May 1962: Received authorization for design and development phases only (II-1-a and d above).

- b. 1 July 1963: Received authorization for design only of a two evaporator - two superheater module for test in SCTI. These 37 tube units were to generate 2400 psi, 1050°F steam. Completion date 30 December 1963.
- c. 28 January 1964: Received authorization to proceed with material procurement and fabrication of two evaporators and two superheater modules as in (b) above. Completion date 30 October 1964.
- 3. Contract completion date: 30 June 1965.
- 4. Expected date for completing current work: 30 June 1965.
- 5. Future work required: Test of steam generators in SCTI following completion of test of BLH unit.

III. Chronology of Technical Events, Progress and Documentation

1. Events

As indicated in II-2 above, the original project was authorized in stages. Authorizations were keyed to completion of technical work in each phase, which resulted in an orderly, if extended, development program.

The design and development feasibility studies were completed 30 June, 1963, and are reported in NAA-SR-8508, "Design, Performance and Economic Evaluation of Sodium Heated, Modular Supercritical Steam Generator", August 19, 1963.

Authorization to proceed with a specific design, received 1 July 1963, resulted in a detailed design of a 2400 psi, 1050° set of modules, with approximately 20 Mwt capacity, for test in the SCTI. This design, with supporting experimental work on stress analysis and welding development was completed on schedule, and was summarized in NAA-SR-9826, "Final Design of Sodium Heated, Modular Steam Generators for the SCTI", dated 1 February 1965. Numerous supporting reports on weld development, stress analysis and instrumentation were also published as noted in Section III-2.

Assembly of material and commencement of fabrication was initiated 28 January 1964. The original completion date of 30 October 1964 was not met, due primarily to welding difficulties in three of the tubes, which necessitated repair welds. In one tube, two repair welds were made as a result of insertion of a 3" replacement tube section between the tube sheet and the damaged tube. This was most instructive, as it demonstrated that fabrication errors could be corrected without scrapping the whole unit, or plugging off a tube, and reducing the capacity of the module. There was no particular pressure to complete the modules, as neither the BLH steam generator, scheduled for test first in the SCTI, nor the SCTI itself, were ready for test. Consequently, the fabrication was accorded less priority, the primary bench mark being completion before the end of GFY 1965. This has been accomplished, and the completed units are in dry storage, filled with pressurized nitrogen, awaiting test after completion of SCTI tests on the BLH unit which was first installed.

2. Documentation, Presentations, and Technology Contributions

a. Documentation

- 1) D. F. Casey, et al "Design, Performance and Economics Evaluation of Sodium - Heated, Modular, Supercritical, Steam Generators", NAA-SR-8508, August 19, 1963.
- 2) G. Kazlauskas, "A Device for Internal T.I.G. Arc Welding of Tube to Tube Sheet Joints", NAA-SR-8541, to be issued.
- 3) M. M. Levin, "Photoelastic Determination of Stresses in the AI Steam Generator", NAA-SR-8515, January 30, 1964.
- 4) M. M. Lemcoe, "Experimental Stress Analysis of 37-Tube Modular Steam Generator Head", NAA-SR-8514, January 30, 1964.
- 5) M. M. Lemcoe, "Fatigue Testing of 37-Hole Modular Steam Generator Head", NAA-SR-9827, to be issued.
- 6) D. F. Casey, et al "Final Design of Sodium-Heated, Modular Steam Generators for the SCTI", NAA-SR-9826, February 1, 1965.
- 7) D. F. Casey, et al "SCTI - Modular Steam Generator Control System Study", NAA-SR-TDR-10994, February 4, 1965.
- 8) L. T. Bogaert, et al "Fabrication of the Modular Steam Generator", NAA-SR-11410 to be issued.
- 9) AI Quarterly Technical Progress Report, AEC Unclassified Programs, from July 1962 to and including June 1965.

All foregoing reports are, or will be, available through Technical Information Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

b. Presentations

- 1) "Modular Steam Generators", D. F. Casey.
AEC Sodium Component Working Group Information Meeting,
April 14, 15 and 16, 1964, Hollywood, California.
- 2) "Fabrication of the Modular Steam Generator", L. T. Bogaert.
AEC Sodium Technology Information Meeting, June 16 and 17,
Chicago, Illinois.

c. Patents

- 1) "Heat Exchanger", D. F. Casey and W. F. Anderson,
Patent #3176761.
- 2) "Internal Weld Head", G. Kazlauskas, patent applied for.

d. Important Technology Contributions

- 1) Internal tube to tube sheet welding of chrome moly and austenitic steels.

ATOMIC POWER DEVELOPMENT ASSOCIATES

Sodium Heated Steam Generator Summary
 Study of Optimum Steam Conditions and Cycles for Large
 Sodium-Cooled Nuclear Power Plants
 Small Leak Sodium-Water Reaction Test Program
 APDA Sodium Technology Loop
 Ultrasonic Scanner
 Compilation of Fermi Operating Experience
 Sodium Boiler Development Contract
 Sodium Components Test Facility

SODIUM HEATED STEAM GENERATOR SUMMARY, TID-18072

AT (11-1)-865 TASK I

I. General Contract Information

- A. AEC Contract No. AT (11-1)-865 Task 1 Sodium Heated Steam Generator Summary approval given by letter from the Chicago Operations Office to APDA, July 17, 1962.
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: J. J. Morabito, Fermi Project Engineer, APDA
Basic Technical Profession: Mechanical Engineering
- D. The following Sodium Components Working Group members and their colleagues contributed to this report:

J. J. Morabito, Editor	APDA
H. Muenchow, Associate Editor, (nonmember)	APDA
F. Smith	AEC-CH
T. Heckman	" "
R. Dickinson	AI
W. Simmons	ANL
K. Goldmann	UNC
R. Lockhart	GE
H. Bowers (nonmember)	LASL

II. Contract Work Scopes and Schedules

- A. The letter of July 17, 1962, from Chicago Operations Office to APDA requested J. J. Morabito to "review all comments and edit the report into final draft form for publication by the Commission."
- B. Work has been completed, and the report TID-18072, "Sodium Heated Steam General Summary" was issued under date of September 19, 1962.

III. Chronology of Technical Events, Progress and Documentation

Drafts of the report were sent to all who contributed to the writing of this document. After receipt of comments, the report was written up in final form.

STUDY OF OPTIMUM STEAM CONDITIONS AND CYCLES FOR
LARGE SODIUM-COOLED NUCLEAR POWER PLANTS (TID-21292)

AEC CONTRACT NO. AT(11-1)-865, PROJECT 1

I. General Contract Information

- A. AEC Contract No. AT(11-1)-865, Project 1
Study of Optimum Steam Conditions and Cycles for Large Sodium-Cooled Nuclear Power Plants
This study was requested by the Chicago Operations Office in a letter to APDA on June 10, 1964. Approval of costs involved was given by COO to APDA in a letter dated July 16, 1964.

- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: J. J. Morabito, Fermi Project Engineer
Basic Technical Profession: Mechanical Engineering

Assistant Project Engineer: J. A. Ford, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
- D. Key Project Technical Personnel and Consultants
 - 1. V. Lomuller, Staff Engineer, APDA
Basic Technical Profession: Construction Engineering
Project Responsibility: Cost data.
 - 2. T. P. Ross, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Rough plant layouts.
 - 3. P. E. Heidman, Senior Engineer, The Detroit Edison Company,
2000 Second Ave., Detroit, Michigan 48226
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Steam cycle conditions and costs.

II. Contract Work Scopes and Schedules

A. Scope

The scope was defined in the Chicago Operations Office letter of June 10, 1964 to APDA as follows:

" . . . assessment of the optimum pressure and arrangement for operating a sodium-heated steam generator as a function of both size and need for reheat."

The introduction to the report states that the study was made to determine the economically optimum steam conditions and cycles for large sodium-cooled nuclear power plants. The introduction further states " . . . the analysis was to encompass the effect of steam pressure, steam temperature, reheat, and fuel cost on plant economics."

B. Completion

This study was completed with the issuance of APDA report "Study of Optimum Steam Conditions and Cycles for Large Sodium-Cooled Nuclear Power Plants," J. A. Ford and J. J. Morabito, September 14, 1964. Later this report was numbered TID-21292.

III. Chronology of Technical Events, Progress and Documentation

A. Topical Report

Report TID-21292 referred to above was the topical report for this project.

B. Test Results and Evaluations

The optimum steam conditions of those considered were steam temperature at 950 F, steam pressure at 3500 psig, and single reheat cycle. These conditions were found to be economically optimum for plants with fuel costs of both 10 and 30 cents per million Btu. Increasing the steam pressure from 1450 to 3500 psig, the range considered, gave a higher

capital credit for all corresponding cases. A steam temperature of 950 F was economically more favorable than a temperature of 1050 F for most corresponding cases considered. Single reheat as opposed to no reheat was also more favorable for most cases, especially at the lower pressures.

SMALL LEAK SODIUM-WATER REACTION TEST PROGRAM

(PROJECT 10)

I. General Contract Information

- A. AEC Contract No. AT(11-1)-865 Project Agreement No. 10
Small Leak Sodium-Water Reaction Test Program
Effective date: Febraury 1, 1964 (entered into March 4, 1964).
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer; Herbert O. Muenchow, APDA
Basic Technical Profession: Chemical Engineering
- D. Key Project Technical Personnel and Consultants
 - 1. Wayne L. Chase, Head, Systems Section, APDA
Basic Technical Profession: Chemical Engineering
Project Responsibility: Technical direction to Project Engineer.
 - 2. R. C. Williams, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Assistant Project Engineer.
 - 3. Raymond H. Costello, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Operations Engineer.
 - 4. Joseph Bucki, Design Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Equipment and process design.

E. Subcontracts

- 1. Solar Engineering Corp., 3140 Hilton, Ferndale, Michigan, has provided engineering personnel under Purchase Order No. G-3193. The original term of this agreement was April 9, 1964 through July 31, 1964. COO approved this agreement in a letter to APDA dated April 10, 1964. The term of this agreement has been changed by three Change Orders. Change Order 1 extended the termination date to October 17, 1964. Change Order 2 extended the agreement to October 24, 1964, and Change Order 3 extended the termination date to October 31, 1964.
- 2. APDA Purchase Order No. G-3261 required Solar Engineering to supply the services of drafting and design personnel from April 27, 1964 through July 31, 1964. COO approved this Purchase Order in a letter to APDA dated April 29, 1964. Change Order 1 changed the termination date of the Purchase Order to October 17, 1964, and Change Order 2 extended the termination date to April 30, 1965.

3. APDA Purchase Order No. G-3844 required Diehl & Diehl, Architects, Inc., 120 Madison Avenue, Detroit, Michigan 48226, to furnish APDA with certain professional services in connection with a test stand structure to support and enclose pressurized vessels and equipment.

Specifically, the Purchase Order requires Diehl & Diehl to: "Make necessary on site inspection survey. Prepare final architectural and structural working drawings and specifications to be used for competitive bidding for the erection of the structure. Furnish all necessary copies of blueprints and specifications required for bidding purposes. Check all shop drawings prepared by future erection contractor. Prepare an erection cost estimate of the test structure. Furnish necessary field inspection and supervision."

4. Construction Subcontract No. G-4036 between APDA and James & Savage Corporation, 300 E. Seven Mile Road, Detroit, Michigan 48203, effective December 4, 1964, called for James & Savage to construct a small-leak test rig.
5. Subcontract No. G-5338 between APDA and Construction Pipe Company, Inc., 661 Southfield Road, Lincoln Park, Michigan, effective March 30, 1965, requires the contractor to erect piping for the small-leak, sodium-water test rig.
6. APDA anticipates signing a Subcontract with Hall Engineering Co., 21200 Telegraph Road, Southfield, Michigan in June 1965 for the electrical and instrumentation work on this job.

II. Contract Work Scopes and Schedules

A. Scope

1. Design, procure, construct and operate a small leak sodium water test loop containing a reaction vessel, sodium pump, oxide removal system, sodium water reaction trigger mechanism and required instrumentation.
2. Conduct a series of twelve (12) small leak tests covering a range of small water leaks to determine the effect of leak rate on tube wastage. Some parameters to be investigated are water leak rate, exposure time, distance of adjacent tube surface from leak, water leak velocity, and reaction temperatures.
3. Analyze all test data.
4. Present this test data analysis through informal monthly reports and through a final report which shall include appropriate conclusions and recommendations.

B. Schedules

Originally this Project Agreement was to run from February 1, 1964 through July 31, 1964. A modification, effective July 31, 1964, extended the contract through September 30, 1965. This modification was approved by the Chicago Operations Office on August 20, 1964.

C. Expected Date for Completing Current Work

September 30, 1965

D. Future Work Required

Continuation of testing.

III. Chronology of Technical Events, Progress and Documentation

A. Contract Technical Specifications

Diehl & Diehl Specification for "Test Stand Structure for Atomic Power Development Associates, Inc. at Sibley Quarries, Trenton, Michigan" dated October 22, 1964. (Diehl & Diehl Job No. 999.)

APDA 60-22 - Specification for an Entrainment Separator for Small Leak Sodium-Water Reaction Test Program

APDA 60-23 - Specification for a Reaction Water Supply Vessel for Small Leak Sodium-Water Test Program

APDA 60-25 - Specification for a Filter Tank for Small Leak Sodium-Water Test Program

APDA 60-26 - Specification for a Sodium-Water Reaction Test Unit for Small Leak Sodium-Water Test Program
Original issue: June 26, 1964
Revision 1: September 2, 1964

APDA 60-27 - Specification for a Forced Air to Water Cooler

APDA 60-28 - Specification for Preparation of Site for Small Leak Test Structure

APDA 60-29 - Specification for a Water Pressurizer Vessel for Small Leak Sodium-Water Test Program

APDA 60-30 - Specification for a Test Stand Structure to Support and Enclose Pressurized Vessels and Equipment for Small Leak Sodium-Water Test Program
Original issue: August 17, 1964
Revision 1: September 17, 1964

APDA 60-32 - Specification for a Cold Trap Vessel for Small Leak Sodium-Water Test Program
Original issue: September 10, 1964
Revision 1: October 27, 1964

APDA 60-34 - Specification for a Cold Trap Cooling System for Small Leak Sodium-Water Test Program

APDA 60-35 - Specification for Piping Systems for Small Leak Sodium-Water Test Program
Original issue: March 10, 1965
Revision 1: April 12, 1965

APDA 60-36 - Specification for Thermal Insulation for Small Leak Sodium-Water Test Program

APDA 70-13 - Specification for Electrical Systems for Small Leak Sodium-Water Test Program

APDA 70-14 - Specification for Heater Control and Instrument Panels for Small Leak Sodium-Water Test Program

B. Meetings

1. A Sodium Components Development Program Information Meeting was held in California on April 14, 1964. Among those in attendance were Messrs. Herbert O. Muenchow (APDA), Thomas (Ethyl Corp.), Goldman (UNC), Bane (ANL), Hobart of CANEL (P&W), Wise (AEC).

and Dutina (GE). Among the topics discussed were production of sodium, corrosion effects of sodium, and carbon analysis. A report was also given on the round-robin analysis of carbon in sodium by twelve laboratories.

2. A meeting is scheduled to be held in Chicago on June 16, 1965.

C. Reports

Monthly progress reports have been issued for the term of the contract to date. A report for the first quarter of 1965 has been written.

D. Technical Reviews

AEC personnel have visited Detroit for technical reviews. Several reviews took place in 1964. Reviews also were held in January, February, March, and April 1965.

E. Hardware Delivered Perfected

1. Test unit
2. Structure erected
3. Piping erected
4. Cold Trap system erected
5. Instrumentation on hand

F. Test Results and Evaluation

Testing has not taken place yet.

APDA SODIUM TECHNOLOGY LOOP

(PROJECT 11)

I. General Contract Information

- A. AEC Contract No. AT(11-1)-865 Project Agreement No. 11 APDA Sodium Technology Loop
Effective date: March 1, 1964 (entered into April 21, 1964)
Previous contract: AT(11-1)-865 Project Agreement No. 3, Blake Resistivity Meter, January 1, 1961 - March 1, 1964
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: Ralph H. Jones, APDA (January 1, 1961 - July 6, 1962)
Organizational Title: Head, APDA Test Operations Section
Basic Technical Profession: Electrical Engineering
Present Address: Liquid-Metal-Cooled Reactors Branch, Division of Reactor Development and Technology, USAEC, Washington, D.C. 20545
Project Engineer: Peter S. Lindsey (July 7, 1962 - December 31, 1964)
Organizational Title: Staff Engineer, APDA
Basic Technical Professional: Chemical Engineering
Project Engineer: Eugene F. Hill (January 1, 1965 to date)
Organizational Title: Supervisor, Laboratory Operations, APDA
Basic Technical Profession: Chemical Engineering

D. Key Project Technical Personnel and Consultants

1. J. J. Morabito, Fermi Project Engineer, APDA Basic Technical Profession: Mechanical Engineering Project Responsibility: Provided program direction, checked reports, and initiated most of the changes in the scope of the project during the period that Mr. Lindsey served as Project Engineer.
2. David Boltz, Consultant: Head, Analytical Chemistry Department, Wayne State University, Detroit, Michigan 48202. Consultant Agreement No. C-3082, March 5, 1964 - September 30, 1965. Project Responsibility: Advising on instrumentation and analytical procedures.

E. Subcontracts

Subcontract No. G-3593 with Johns-Manville Sales Corp., Industrial Insulation Division, 832-4 Fisher Building, Detroit, Michigan 48202 calls for the services of insulator mechanics. Subcontract approved by Chicago Operations Office, August 7, 1964.

Subcontract No. G-3526 with James W. Partlan Company, Inc., 283 E. Robinwood Avenue, Detroit, Michigan 48203, calls for the services of pipe-fitting and welding personnel. Subcontract approved by Chicago Operations Office, July 15, 1964.

Subcontract No. G-3826 with Taylor Engineering Corp., 14333 Woodrow Wilson, Detroit, Michigan, covers obtaining fabrication services. Due to the small amount of money involved, no specific AEC approval was required.

Subcontract No. G-3195 with Solar Engineering Corp., 2141 Hilton Road, Detroit, Michigan 48220, covers drafting and design personnel services. Subcontract approved on April 8, 1964, by Chicago Operations Office.

II. Contract Work Scopes and Schedules

A. Initial Scope

Under Project Agreement No. 3:

In connection with the Commission's Sodium Components Development Program, the Contractor will perform the following work and services to evaluate the efficiency of specified devices for determining impurities in sodium in the range of 1 to 100 parts per million:

1. The Contractor will test and evaluate a sodium contaminants monitor developed by R. L. Blake of the United Kingdom Atomic Energy Authority. The tests and evaluations will compare the results of the Blake meter with results obtained under the present procedures for determining impurities in sodium which consist of the use of plugging indicators, chemical analyses and with a meter designed by the Contractor. The tests outlined below will be conducted in a sodium loop owned and operated by the Contractor.
2. The Contractor will conduct the following tests:
 - Phase I - Oxygen Tests
 - Phase II - Gas Entrainment Tests
 - Phase III - Carbon Tests
3. The Contractor will furnish the Commission monthly letter progress reports and a final summary report.

B. Modifications

The Contract was originally scheduled to run from January 1, 1961, until December 31, 1961. On January 11, 1962, it was extended to December 31, 1962. Additional work requested by the Commission necessitated the extension of the Contract until September 1, 1963, (agreed upon January 1, 1963). A further extension to September 30, 1963, was agreed upon on August 28, 1963. Further extensions were made as follows:

<u>Date Extended</u> <u>To</u>	<u>Date Agreement</u> <u>Reached</u>	<u>Reason</u>
December 31, 1963	October 4, 1963	
January 31, 1964	November 15, 1963	Scope Changed
March 15, 1964	February 17, 1964	
March 31, 1964	March 30, 1964	

On January 1, 1963, the Scope of the Contract was amended as follows:

Redesignate Section 3. as Section 4. and add a new Section 3. reading as follows:

"3. In addition to the above, the Contractor shall perform the following work and services:

Phase I

- a. Addition of a temperature compensation resistor to the meter bias circuit to improve the temperature stability. Loop operation to test operation.
- b. Addition of a thermostatic control to anticipate rate of change of temperature designed to eliminate the effects of loop temperature transients. Loop operation to demonstrate operation.
- c. Modification of meter to accommodate sodium temperature of 900° F. and modification of the range of the temperature compensation to compensate for sodium temperature changes up to 900° F. Loop operation to demonstrate operability of change.
- d. Determination of the possibility of self-calibration of the instrument and increasing of the range of the meter to concentration equivalent of 500-ppm oxygen.
- e. Incorporation of a variable orifice in the present loop to determine if a more accurate calibration of the Blake Meter is possible in concentration of oxide below 10 ppm.

Phase II

- a. Determination of the reaction of the meter to reaction products of sodium and CO, CO₂, and CH₄. A separate calibration of meter response on a calibration run with solid Na₂CO₃.
- b. Determination of the response of the meter to gaseous additions of hydrogen. The meter should be calibrated for NaH and NaOH where the NaH and NaOH are introduced in controlled and measured amounts. If possible, the efficiency of the loop cold trap in removing NaH and NaOH should be obtained.

On June 24, 1963, the scope of the contract was amended as follows:

In the paragraph entitled "Scope", Section 3., Phase II, add a new subsection "c" reading as follows:

c. Upon completion of the scheduled modifications and temperatures compensation of the meter, the scope of this work shall also include:

- (1) A determination of the reaction of the test Blake Meter to the introduction of measured amounts of liquid H_2O into the loop sodium.
- (2) A determination of the effects of the H_2O -Na chemical reaction to the loop system. The effects to be noted shall include pressure rise, temperature rise, oxygen content of the sodium, hydrogen content of the cover gas, and physical changes to the H_2O injection equipment.

On November 15, 1963, the scope of the contract was again amended as follows:

1. In the paragraph entitled "Scope", Section 3., Phase II, add a new subsection "d" reading as follows:
- d. A second hydrogen gas injection run will be conducted to approach a contamination level of approximately 300 ppm of sodium hydride, to establish the response of the upgraded rhometer and the improved plugging meter to sodium hydride contamination. As a part of this run, preliminary information on the rate of dissociation of sodium hydride versus temperature for a 300 ppm concentration of the hydride will be obtained. The contamination run will be followed by a closely monitored temperature ramp to detect any breakpoint in sodium hydride dissociation in the 570-970 F. range. The loop will be held at this breakpoint (if one exists), and at one or more higher temperature levels to establish the pattern of sodium hydride dissociation in loop environment. More recent analytical techniques will be used on sodium samples taken during the experiments to attempt to validate the determination of hydride levels. Surveillance will be maintained of the cover gas, by means of chromatographic inspections, to provide a material balance in the event dissociation occurs or the injected hydrogen should fail to react.

Under Project Agreement No. 11, the scope was defined as follows:

The Contractor shall design, procure and install in the APDA sodium technology loop, components necessary to conduct loop operations through the current program, and shall furnish laboratory equipment required for the supporting analytical effort. The Contractor shall operate the loop in a continuing R & D program designed to cover the following associated activities:

- a. Instrumentation for Sodium Systems, including the development and evaluation of in-line instruments for the detection and determination of impurities in sodium.
- b. Sodium System Cleanup Processes, including the development and evaluation of sodium purification techniques and devices.
- c. Chemical and Physical Behavior of Sodium Impurities, including the investigation of the chemical and physical behavior of impurities in sodium loop environment.
- d. Laboratory Analysis, including complementary development and refinement of analytical techniques for the determination of sodium contaminants.

On December 21, 1964, it was agreed to extend the Contract from September 30, 1964, to September 30, 1965.

A change in scope now requires APDA to issue quarterly reports in addition to monthly reports and a final summary report.

Another change in scope calls for a supercentrifuge study to be made. Authorization for this study is contained in a teletype message from COO to APDA dated May 12, 1965.

III. Chronology of Technical Events, Progress and Documentation

A. Meetings

A Sodium Components Development Program Information Meeting was held in California on April 14, 1964. Among those in attendance were Messrs. Eugene F. Hill (APDA), Thomas (Ethyl Corp.), Goldman (UNC), Bane (ANL), Hobart of CANEL (P&W), Wise (AEC), and Dutina (GE). Among the topics discussed were production of sodium, corrosion effects of sodium, and carbon analysis. A report was also given on the round-robin analysis of carbon in sodium by twelve laboratories.

A meeting is scheduled to be held in Chicago on June 16, 1965, at which Mr. Hill will present a paper.

B. Topical Reports

For Project 3 the following reports were issued:

APDA-149 - "Evaluation of the Blake Sodium Resistivity Meter," October, 1962.

APDA-163 - "Operation of the Sodium Technology Loop for Contamination Meter Evaluations," March, 1964.

The following reports were issued under Project 11:

APDA-164 - "Determination of Carbon in Sodium by a High-Temperature Combustion Method Utilizing Gas Chromatography", H. Bradley and S. A. Meacham, November 25, 1964.

APDA-166 - "Determination of Carbonate Carbon in Sodium Metal," D. F. Boltz and S. A. Meacham, January 15, 1965.

APDA-168 - "Determination of Oxygen in Sodium," D. F. Boltz, J. O. Kermoshchuk and S. A. Meacham. This report will be issued in June or July, 1965.

Summary reports under Contract No. AT(11-1)-865 Project 11 have been issued monthly starting in April, 1964.

C. Important Contributions to Technology and Techniques Developed

1. Primarily the important technology contributions and techniques developed have taken place in the area of chemical analysis and instrumentation development. The significant developments are as follows:

- a. Development of a new method for analyzing carbon in sodium.
- b. Development of a new method for analyzing carbonate carbon in sodium.
- c. Development of a new method for analyzing oxygen in sodium.
- d. Development of a new method for analyzing hydroxide hydrogen in sodium.

- e. Development of a new method for analyzing non-hydroxide hydrogen in sodium.
 - f. Development of a new method for analyzing total hydrogen in sodium.
 - g. Feasibility studies on a new in-line hydrogen detector for sodium systems.
 - h. Determination of the solubility of sodium carbonate in sodium.
2. In the area of improving and modifying existing in-line instrumentation the response of the Blake Rhometer to a variety of sodium impurities has been evaluated. As a result of this study a basis has been established for redesigning this instrument to make it suitable for reactor use. Similar studies are also under way on the United Nuclear oxygen meter.

D. Hardware Delivered or Perfected

Much of the information on hardware is covered under Part I, Item E, Subcontracts. In addition, the following hardware has been delivered or perfected:

- 1. Cold Trap
- 2. Hydroclone
- 3. Filter
- 4. Modified rhometer temperature compensator

Laboratory equipment developed and perfected is not included in this category.

E. Test Results and Evaluations

This information is reported in the topical reports listed above and in the monthly reports.

ULTRASONIC SCANNER

AT (11-1)-865 PROJECT AGREEMENT NO. 14

I. General Contract Information

- A. AEC Contract No. AT(11-1)-865 Project Agreement No. 14 Ultrasonic Scanner.
December 1, 1964 (entered into January 25, 1965)
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: C. C. Scott, Head, Electrical and Instrumentation Section, APDA
Basic Technical Profession: Mechanical Engineering.
- D. Key Technical Personnel and Consultants
 - 1. Shuh-Pan Ying, Instrumentation Physicist, APDA
Basic Technical Profession: Physics
Project Responsibility: Principal Investigator

2. Bensor Carlin, Ph D, Consultant
Basic Technical Profession: Electrical Engineer
(Author of several articles on ultrasonics and the book,
Ultrasonics, Mc Graw-Hill Book Company, Inc.,
New York, 1960 - Second Edition)

E. Subcontracts

APDA expects to enter into a formal subcontract with Dr. Carlin in June 1965.

II. Contract Work Scopes and Schedules

A. Objective of the Program

The objective of this program is to develop an image-scanning device for operation in liquid sodium for viewing fuel handling and for locating foreign objects. The approach to be used by the Contractor in developing such a device shall be dependent upon the results obtained from testing transducers in sodium.

B. Scope of Work

The Contractor shall perform the following work:

1. Establish the feasibility of operation of ultrasonic transducers in sodium;
2. Based on the information derived under 1 above, develop a conceptual design of a practical method for viewing objects immersed in sodium;
3. Prepare and submit to the Commission a time schedule and cost estimate for development and fabrication of an "undersodium scanning" device or devices, recommended to be feasible;
4. Submit to the Commission informal monthly letter reports and a final informal written report at the conclusion of this phase of the work.

C. Schedules

The terms of the Contract is from December 1, 1964 through September 30, 1965.

D. Expected Date for Completing Current Work
September 30, 1965

E. Future Work Required

Executing the work outlined under number 3 of "Scope of Work".

III. Chronology of Technical Events, Progress and Documentation

Monthly progress reports have been issued on this Project. In addition, a Quarterly Report was issued in April 1965 and another is expected to be issued in July 1965.

COMPILATION OF FERMI OPERATING EXPERIENCE

AT(11-1)-865 PROJECT AGREEMENT NO. 15

I. General Contract Information

- A. AEC Contract No. AT(11-1)-865, Project Agreement No. 15, Compilation of Fermi Operating Experience (between AEC and APDA)
Effective date: January 1, 1965 (entered into January 28, 1965)

- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: Evan C. Kovacic, APDA
Basic Technical Profession: Chemical Engineering
- D. Key Project Technical Personnel and Consultants
 - 1. J. W. Hess, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibilities: Reporting on Fermi safety and control rod drives and fuel handling in the Fermi reactor.
 - 2. C. Robert Nash, Consultant: Engineer, Commonwealth Associates, Inc., 209 E. Washington Ave., Jackson, Michigan (formerly, Head, Mechanical Handling Section, APDA)
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Consulting on experience with safety and control rod drives.
 - 3. James Seward, Consultant: Engineer, Toledo Edison Company, Edison Building, Madison and Superior Streets, Toledo, Ohio (formerly, Head, Mechanical Handling Section, APDA)
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Consulting on experience with safety and control rod drives and fuel handling experience in the Fermi reactor.
 - 4. Jack Stader, Consultant: Project Engineer, Commonwealth Associates, Inc., 209 E. Washington Ave., Jackson, Michigan (formerly, Staff Engineer, APDA)
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Consulting on fuel handling experience in Fermi reactor.
 - 5. Peter S. Lindsey, Staff Engineer, APDA
Basic Technical Profession: Chemical Engineering
Project Responsibility: Compiling information on Fermi primary system development.
 - 6. Norman T. Peters, Assistant Fermi Project Engineer
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Compiling information on Fermi primary system development.
 - 7. Robert H. Anderson, Consultant: Engineer, United Engineers & Constructors, Inc., 1401 Arch Street, Philadelphia, Pennsylvania 19105 (formerly, Head, Liquid Metals and Steam Section)
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Reporting on the evaluation of the design and operation of the steam generators for the Enrico Fermi reactor plant.
 - 8. George L. Ball, Physicist, APDA
Project Responsibility: Reporting on low-power nuclear test results.
 - 9. Robert E. Mueller, Physicist, APDA
Project Responsibility: Reporting on over-all Nuclear Test Program.
 - 10. George H. Reicks, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibilities: Reporting on sodium system flow meters and sodium system level detectors.

11. Raymond A. MacLeod, Design Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Reporting on fuel and blanket subassemblies.
12. Saul Siegel, Staff Engineer, APDA
Basic Technical Profession: Chemistry
Project Responsibility: Reporting on sodium sampling

E. Subcontracts

1. Subcontract No. G-5508 has been signed with Sherwood Publications, Inc., 19970 Sherwood, Detroit, Michigan 48234, for art work services. The Contract runs from May 3, 1965 through June 30, 1965.
2. Subcontract No. G-5593 covers United Engineers & Constructors, Inc., engineering and clerical services.

II. Contract Work Scopes and Schedules

The contractor shall conduct an internal literature search of available reports, records, and other internal data related to the operating experience and evaluation of systems and component performance of the Enrico Fermi reactor, and shall compile the experience in to a report acceptable for publication.

This work consists of two phases:

Phase I: Review all available internal APDA-PRDC data and identify a number of components or systems of the Enrico Fermi Atomic Power Plant, about which a compilation of experience would be useful to reactor designers. Submit a list of above components or systems to the Commission for review and approval of final selection.

Phase II: During this phase the contractor shall compile the experience regarding the components or systems selected and approved under Phase I and present them in a report acceptable for publication.

The contract was originally scheduled to run from January 1, 1965 through September 30, 1965. A change in the scope and the completion date has been agreed upon. The change in scope calls for completion of the steam generator report. The new completion date is September 30, 1966. These changes are outlined in a letter from APDA to Chicago Operations Office dated May 18, 1965, and they will be incorporated in a formal agreement soon.

III. "Chronology of Technical Events, Progress and Documentation"

A. Meetings

APDA personnel met on December 4, 1964, with John Wimber, and another meeting at COO with J. Purcell on April 6, 1965.

B. Progress Reports

APDA monthly reports were issued in April, May, and June of 1965. The APDA Quarterly Report issued in April 1965 also contains information on progress made on this project.

C. Important Technology Contributions

Reporting of all noteworthy technical experience gained during the design, construction, and operation of the Enrico Fermi Atomic Power Plant.

D. Test Results and Evaluations

Results and evaluations of tests conducted during installation, pre-operational testing, and operation of individual systems and components in the Enrico Fermi plant will be reported.

B & W SUBCONTRACT 1, PRIME CONTRACT NO. AT(11-1)-1280

SODIUM BOILER DEVELOPMENT CONTRACT

I. General Contract Information

- A. Prime Contract, AT(11-1)-1280, is between Babcock and Wilcox Company and the U.S. Atomic Energy Commission. Subcontract No. 1 is between APDA and Babcock and Wilcox.
Title of the Subcontract: Sodium Boiler Development Contract
Effective date: February 13, 1964
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: Wayne L. Chase, Section Head, Systems Section, APDA
Basic Technical Profession: Chemical Engineering
- D. Key Project Technical Personnel
 - 1. John A. Ford, Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Assistant Project Engineer, detailed engineering analysis.
 - 2. James E. Meyers, Staff Engineer, APDA
Basic Technical Profession: Chemical Engineering
Project Responsibility: Air-water tests and analysis.
 - 3. Lewis R. Kovac, Metallurgist, APDA
Basic Technical Profession: Metallurgical Engineering
Project Responsibility: Sodium-water tests (design and testing).
 - 4. Aaron J. Friedland, Head, Engineering Analysis Section
Basic Technical Profession: Chemical Engineering
Project Responsibility: Revising mathematical model for detailed analysis, temperature-softening problems, and leak-propagation rates.
 - 5. H. V. Chamberlain, Staff Engineer, APDA
Basic Technical Profession: Chemical Engineering
Project Responsibility: Participating in engineering analysis of prototype steam generator.

II. Contract Work Scopes and Schedules

- A. The scope of work under this Subcontract consisted of performing a mathematical analysis of the sodium-water reaction problem and design consultation on the Babcock and Wilcox Company's 30-MWt Prototype Steam Generator and Full-Size Steam Generator using existing sodium-water test data. Specifically, the scope required that the Subcontract would -
 - 1. Summarize existing sodium-water reaction data and write a mathematical model based on this data.

2. Using the mathematical model, analyze the problems, with regard to safety, of a sodium-water reaction in the B & W 30-MWt Prototype Steam Generator.
 3. Update the mathematical model in light of any new available data resulting from sodium-water reaction studies in progress during the course of this work.
 4. Using the modified mathematical model described above, analyze the problems, with regard to safety, of sodium-water reaction in the B & W Full-Size Steam Generator.
 5. Consult when and as necessary with the Contractor on sodium-water reaction problems related to the design of the Full-Size Steam Generator and the 30-MWt Prototype Steam Generator.
- B. This Contract was originally scheduled to run from February 13, 1964 through October 31, 1964. Modification No. 1 entered into December 31, 1964, amended the termination date to read June 30, 1965, and changed the scope to read:

The Subcontractor will:

- a. Conduct a literature search for information pertaining to sodium-water reactions, will utilize this information to develop relationships used in evaluating the capability of sodium-heated steam generators to withstand water leaks.
- b. Undertake a preliminary review of the B & W Full-Size Steam Generator based on previous experience and a limited amount of mathematical analysis. This review is to determine obvious problem areas from the standpoint of sodium-water reactions.
- c. Establish analytical procedures and determine areas where evaluations are necessary.
- d. Scope, design, and conduct the tests necessary to give a reasonable degree of assurance that the assumptions to be used in the detailed analyses are conservative.
- e. Carry out, concurrent with the test program (Item d), an extensive analysis of the Full-Size B & W Steam Generator to ascertain whether the integrity of the shell of this steam generator will be maintained during a sodium-water reaction.
- f. Undertake a preliminary review of the B & W 30-MWt Prototype Steam Generator to determine obvious problem areas from the standpoint of sodium-water reactions.
- g. Carry out, concurrent with the test program (Item d), an extensive analysis of the 30-MWt Prototype Steam Generator to ascertain whether the integrity of the shell of this steam generator will be maintained during sodium-water reaction.
- h. Once prior to the completion of the Subcontract, Subcontractor will update the information furnished in the light of any new sodium-water reaction data that has become available.

- i. Consult, when and as necessary, with the Contractor on sodium-water reaction problems in the design of the Full-Size Steam Generator and the 30-MWt Prototype Steam Generator.
- C. Expected date for completing current work: Paragraph (i) of the Scope requires APDA to "Consult, when and as necessary." The present Subcontract may be extended for the same term as B & W's Contract with the AEC.

III. Chronology of Technical Events, Progress and Documentation

A. Meetings

1. A meeting was held at the AEC Chicago Operations Office on November 16, 1964. At this meeting APDA personnel presented the status and scope of the APDA Subcontract with B & W concerning the analysis of sodium-water reaction problems in the B & W Full-Size and Prototype Steam Generators. The following AEC personnel attended this meeting:

G. Wensch	J. Purcell
R. H. Jones	G. Power
J. Wise	J. Wimberg
J. P. Holliday	L. Redeke

In addition, the following persons attended this meeting:

O. E. Dwyer (BNL)	F. Perrera (B & W)
W. R. Wykoff (LASL)	G. Skinkle (B & W)
R. MacPherson (ORNL)	J. J. Morabito (APDA)
A. E. Mravca (ANL)	W. L. Chase (APDA)
P. Probert (B & W)	J. A. Ford (APDA)
G. Clark (B & W)	

2. On May 25, 1965, a meeting was held at Babcock & Wilcox offices at which the following people were in attendance:

G. Gower (COO)	F. Perrera (B & W)
K. Kuczen (ANL)	T. P. Farrell (B & W)
R. MacPherson (ORNL)	R. C. Barnett (B & W)
L. Whinery (IASL)	W. L. Chase (APDA)
P. Probert (B & W)	J. A. Ford (APDA)
J. Hocking (B & W)	A. Friedland (APDA)

3. A meeting will be held on June 18, 1965 at the Chicago Operations Office. Persons from APDA and B & W will be in attendance.

B. Documentation

1. Monthly progress reports have been issued starting in May 1964 and continuing up to the present.
2. The following reports have been issued by APDA:
 - a. APDA-167 - "Literature Review of Sodium-Water Reactions," J. A. Ford, March 15, 1965.
 - b. "Preliminary Review of the Babcock & Wilcox Full-Sized Steam Generator," J. A. Ford, December 1, 1964.
 - c. "Preliminary Review of the Babcock & Wilcox Prototype Steam Generator," H. V. Chamberlain and J. A. Ford, April 7, 1965.

3. The following report is now being prepared:

"Status Report of the Sodium-Water Reaction Analysis of the B & W Full-Sized Steam Generator," J. A. Ford.

C. Patents

J. A. Ford (APDA) has submitted an invention disclosure form on "Heat Exchanger Leakage Control." A copy of this disclosure was sent from APDA to Mr. George Lee of the COO Patent Office on March 18, 1965.

D. Test Results and Evaluations

There are no test results to report at present.

APDA-134 - SODIUM COMPONENTS TEST FACILITY

I. General Contract Information

- A. AEC Contract No. AT(11-1)-772
Sodium Components Test Facility
Effective date: May 18, 1959 (entered into June 19, 1959)
- B. Atomic Power Development Associates, Inc.
1911 First Street
Detroit, Michigan 48226
- C. Project Engineer: Robert H. Anderson, formerly, Head, Liquid Metals Section, APDA
Basic Technical Profession: Mechanical Engineering
Present address: United Engineers and Constructors Inc.,
1401 Arch Street, Philadelphia, Pennsylvania 19105.

D. Key Technical Personnel and Consultants

In addition to the Project Engineer, Robert H. Anderson, the following persons contributed to the report covered by this contract:

- 1. J. J. Morabito, Fermi Project Engineer, APDA
Basic Technical Profession: Mechanical Engineering
- 2. Herbert O. Muenchow, Project Engineer, APDA
Basic Technical Profession: Chemical Engineering
- 3. Donald Lutz, formerly Staff Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Present address: Argonne National Laboratory, Argonne, Illinois
- 4. V. Lomuller, Staff Engineer, APDA
Basic Technical Profession: Construction Engineering
Project Responsibility: Cost estimates
- 5. Joseph Bucki, Design Engineer, APDA
Basic Technical Profession: Mechanical Engineering
Project Responsibility: Preparation of drawings

6. Harry L. Smith, Jr., Design Engineer, APDA
 Basic Technical Profession: Mechanical Engineering
 Project Responsibility: Preparation of drawings

E. Subcontracts

A subcontract between APDA and United Engineers and Constructors, Inc., calling for UE&C to provide APDA with the services of one mechanical engineer (Robert H. Anderson), and one cost engineer (V. Lomuller), was entered into on August 11, 1959. This agreement was approved by the Chicago Operations Office on September 4, 1959.

By a Supplemental Agreement, effective September 30, 1959, entered into February 29, 1960, APDA and UE&C extended the above Contract through December 31, 1959. COO approved this agreement on April 1, 1960.

A Subcontract between APDA and Commonwealth Associates, Inc., 209 East Washington Avenue, Jackson, Michigan, calling for CAI to provide APDA with the services of one mechanical engineer, effective July 1, 1959, was entered into on September 3, 1959. This Agreement was approved by Chicago Operations Office on October 23, 1959.

A Supplemental Agreement, effective October 31, 1959, entered into on March 3, 1960, between APDA and CAI extended the above Contract through December 31, 1959. COO approved this Agreement on April 1, 1960.

A Subcontract between APDA and LaDriere, Inc., 17th Floor Cadillac Tower, Detroit, Michigan 48226, calling for artwork and 35-mm slides was entered into on April 11, 1960.

II. Contract Work Scopes and Schedules

The work consisted of undertaking a conceptual study of a sodium components test facility that would be capable of subjecting certain types of sodium components to both steady state and transient conditions (which were determined as part of the study) expected in full-sized nuclear power electric generating stations.

The Contract was scheduled to be in force from May 18, 1959, through October 31, 1959.

Modification No. 1, effective October 31, 1959, extended the Contract through December 31, 1959. Modification No. 2 extended the Contract through June 30, 1960.

Work was completed on or before June 30, 1960.

III. Chronology of Technical Events, Progress and Documentation

APDA-134 entitled "Sodium Components Test Facility" was issued under date of November 1959.

THE BABCOCK & WILCOX COMPANY

Sodium-Heated Steam Generator Program

SCDP HISTORY

B&W SODIUM-HEATED STEAM GENERATOR PROGRAM

I. General Contract Information

1. Contract number: AEC Contract: AT(11-1)-1280

B&W Contract: 610-0067

Title: Sodium-Heated Steam Generator Development

Authorization Date: March 20, 1963

2. Organization and address: The Babcock & Wilcox Company, Barberton, Ohio
and Alliance, Ohio.

3. Project manager, organization title, and basic technical profession:

P.B. Probert, Project Manager, Mechanical Engineer

4. Key project technical personnel and consultants:

(a) T.M. Campbell, B&W Research Center; Alliance, Ohio; in charge of
materials R&D for this Contract; Chief, Metals Engineering
Section, Alliance Research Center, Mechanical Engineer

(b) J.G. Clark, B&W Barberton, Ohio; in charge of Functional Engineering
on this Contract, Mechanical Engineer

(c) J.E. Hocking, B&W Barberton, Ohio; in charge of Stress Analysis
on this Contract, Mechanical Engineer

(d) F.A. Perrera, B&W Barberton, Ohio; consultant on special stress
problems, Group Leader Stress Analysis Section, Mechanical
Engineer

(e) A.L. Evans, B&W Barberton, Ohio, in charge of Mechanical Design

5. Present addresses of project manager and key personnel:

Same as above.

6. Subcontracts under this contract:

Subcontract Number 1

Title: Analysis of the Sodium-Water Reaction Problems in B&W Full-Size
and Prototype Steam Generator.

Authorization Date: February 13, 1964, Organization: Atomic Power

Development Associates, Detroit, Michigan.

Basic Purpose: To analyze the consequences of a Sodium-Water Reaction in the B&W Steam Generator as a consequence of an initial failure of one tube. By experimental and analytical techniques APDA will predict pressures, velocities, and temperatures to assist B&W in analyzing the structural adequacy of the Full-Size and Prototype Steam Generator to withstand the Sodium-Water Reaction.

II. Contract Work Scopes and Schedules

1. Initial basic work scope, objectives, and schedules:

Objective: The overall objective of the steam generator project is to develop the technology necessary to permit industry to supply a large Sodium-Heated Steam Generator of improved design. This technology would be available for use in the nuclear industry in large, sodium-cooled central station, nuclear plants. The objective is to be achieved by:

- (a) Developing the design of a Full-Size Sodium-Heated Steam Generator System which is based on reasonable extrapolations of current technology and the assumed successful conclusion of an improved program of research and development,
- (b) Fabrication of a Prototype Steam Generator (maximum 30 Mwt),
- (c) Testing of the Prototype by others in a Commission-owned facility,
- (d) Evaluation of the degree of success of this project by analyses of the test and operating data.

Schedule:

(a) Contract Signed	March 20, 1963
(b) Complete Preliminary Design,
Full Size Steam Generator	July 1, 1964
(c) Complete Preliminary Design,
Prototype Steam Generator	July 1, 1965
(d) Complete Fabrication, Prototype	November 1, 1966
(e) Final Report Following Testing
at SCTI	December, 1967

2. Work scope and schedule modifications:

Modification No. 1, May 8, 1963.

The size of the Full-Size Steam Generator being designed under this Contract was changed from 1000 MWt in three units to 1000 MWe in three units to bring the steam generator design into closer agreement with the size of sodium-cooled reactors being developed. The steam pressure was raised from 2200 psig to 2400 psig to agree with the "preferred standard" pressures for steam turbines. This will make the steam pressure available from the steam generator agree with the steam pressures for which turbines are easily available.

Modification No. 2, December 30, 1963.

This modification brought up-to-date some of the contract terms relating to allowable and unallowable costs and also decreased the feedwater temperature for which this steam generator was being designed from 600F to 530 F. This change in feedwater temperature was requested by B&W as a result of an optimization study that showed that the cost of the high pressure heater required to produce 600F feedwater was significantly higher than the saving resulting from the higher efficiency of the plant due to the higher feedwater temperature.

Modification No. 3, March 24, 1964.

This modification merely extended the term of the Contract from November 30, 1964 to March 31, 1964. There were no other changes in the scope of work under the Contract.

Modification No. 4, February 23, 1965.

This modification extended the term of the Contract from November 30, 1964 to June 30, 1965, adjusted the funding of the Contract, and expanded the scope of work to include additional research and development work on the Sodium-Water Reaction Problems in the Full-Size and Prototype Steam Generator.

Modification 1 to Subcontract 1, September 19, 1964.

This modification increased the scope of work being done by APDA and changed the term of the Subcontract to agree with the term of the prime contract.

3. Contract completion or termination date: At the present time the term of this Contract extends until June 30, 1965.
4. Expected date for completion of current work:

Preliminary design of Prototype Steam Generator: June, 1965

Fabrication of Prototype Steam Generator: November, 1966

Testing of B&W Prototype Steam Generator: September, 1967

Analysis and Final Report, December, 1967
5. Future work required:

III. "Chronology of Technical Events, Progress and Documentation:"

A. Events:

Pre-Proposal Conference, Argonne National Laboratory, September 20, 1962

Proposal Review Meeting, Argonne National Laboratory, January 8, 1963

Sodium Components Development Information Meeting

Palo-Alto, California August 18, 1963

Presentation to Visitors from United Kingdom Fast

Reactor Team, Argonne National Laboratory, October 17, 1963

Sodium Components Development Information Meeting

Hollywood, California April 14, 1964

Complete Preliminary Design Full-Size Steam

Generator July 1, 1964

Complete R&D Project - "Heat Transfer" - Effect

in Heat Transfer and Two Phase Flow of

Coiling Tube July 21, 1964

Complete R&D Project "Flow Model of Sodium

Distributor" July 1, 1965

Complete Preliminary Design of Prototype Steam

Generator July 1, 1965

B. Documentation:

Invitation to Bid August 20, 1962

Proposal November 26, 1962

Patents, Case No. 3395, 3396, Steam

Generator Arrangement, February 28, 1963, Ammon, et al

Contract Effective Date	March 20, 1963	
Contract Modification #1	May 8, 1963	
Progress Report 1	May, 1963	P.B. Probert
Progress Report 2	June, 1963	P.B. Probert
Progress Report 3	July, 1963	P.B. Probert
Progress Report 4	August, 1963	P.B. Probert
Progress Report 5	September, 1963	P.B. Probert
Progress Report 6	October, 1963	P.B. Probert
Progress Report 7	November, 1963	P.B. Probert
B&W Research Report 4413, November 22, 1963, Heat Transfer in Coiled Tubes, Carver and Kakarala		
Progress Report 8	December, 1963	P.B. Probert
Contract Modification #2, December 30, 1963		
Progress Report 9	January, 1964	P.B. Probert
BW 67-1, January 22, 1964, Interim Status Report, P.B. Probert		
Subcontract #1, February 13, 1964, APDA Detroit, Michigan, Sodium-Water Reaction		
Progress Report 10	February, 1964	P.B. Probert
Progress Report 11	March, 1964	P.B. Probert
B&W Research Report 5452, March 6, 1964, Progress Report, Model Sodium Steam Generator Test, D.W. Koch		
Contract Modification #3, March 24, 1964		
Progress Report 12	April, 1964	P.B. Probert
Progress Report 13	May, 1964	P.B. Probert
Progress Report 14	June, 1964	P.B. Probert
BAW-1280-15, Progress Report, July, 1964, P.B. Probert		
BW-67-2, July 1, 1964, Preliminary Design Report Full-Size Steam Generator		
B&W Research Report 4438, July 21, 1964, Heat Transfer in Coiled Tubes, Carver, Kakarala, Slotnik		
BAW-1280-16, Progress Report, August, 1964, P.B. Probert		
Modification 1 - Subcontract 1 - September 19, 1964, APDA, Detroit, Michigan		
BAW-1280-17, Progress Report, September, 1964, P.B. Probert		

BW-67-3, September, 1964, Materials Selection, Austine

BAW-1280-18, B&W Research Report 5455, December 31, 1964, Second Progress

Report on Model Sodium Heated Steam Generator, Campbell and Koch

Patent, Case No. 3469 - Tube Support Design, October, 1964, Evans

BAW-1280-20, Progress Report, October, 1964, P. B. Probert

BAW-1280-21, Progress Report, November, 1964, P.B. Probert

BAW-1280-22, Progress Report, December, 1964, P.B. Probert

BAW-1280-23, Progress Report, January, 1964, P.B. Probert

BAW-1280-24, Progress Report, February, 1964, P.B. Probert

Contract Modification #4, February 23, 1965

BAW-1280-25, Progress Report, March, 1965, P.B. Probert

BAW-1280-26, Progress Report, April, 1965, P.B. Probert

BAW-1280-27, Progress Report, May, 1965, P.B. Probert

BAW-1280-28, Progress Report, June, 1965, P.B. Probert

Note:

Copies of all documentation above are located at the offices of USAEC, Chicago Operations Office, and at The Babcock and Wilcox Co., Barberton, Ohio. In addition, copies of all reports are on file at USAEC Technical Information Service Extension, Oak Ridge, Tennessee.

BALDWIN-LIMA-HAMILTON CORPORATION

Sodium Heated Steam Generator and Intermediate
Exchanger Preliminary Design Study

ALCO/BLH Sodium Heated Steam Generator Research and
Development Contract Including Fabrication and
Testing of Components

Analysis and Evaluation of Performance Data on ALCO
Steam Generator and Intermediate Heat Exchanger

SCDP History

G-R, BLH Sodium Heated Steam Generator & Intermediate
Exchanger Program

I. General Contract Information

1. Contract Number: AEC Contract: AT(11-1)-664
G-R Order: #18030
Title: Steam Generator & Intermediate Exchanger Preliminary
Design Study
Authorization Date: June 26, 1958
2. Organization and Address: The Griscom-Russell Co.,
Massillon, Ohio (Now the Baldwin-Lima-Hamilton Corporation,
Philadelphia, Penna. 19142)
3. Project Manager, organization title and basic technical
profession: R. W. Schroeder, Manager - New Product
Development - Mechanical Engineer
4. Key project technical personnel and consultants:
 - (a) R. A. Tidball - Manager Special Products Engineering,
Chemical Engineer
 - (b) P. S. Otten - Manager Special Products Sales,
Chemical Engineer
 - (c) M. A. Chionchio - Project Engineer - Mechanical Engineer
 - (d) F. Boni - Engineering Supervisor - Mechanical Engineer
 - (e) K. A. Gardner - Chief Engineer - Chemical Engineer
 - (f) J. G. Gaydos - Applications Engineer - Mechanical Engineer
5. Present address of key personnel:

R. W. Schroeder	- NASA, Cleveland, Ohio
J. G. Gaydos	- BLH, Philadelphia, Pa. 19142
R. A. Tidball	- BLH, Philadelphia, Pa. 19142
P. S. Otten	- Merritt, Inc., Flemington, N.J.
M. A. Chionchio	- Perfex Corp., Milwaukee, Wisconsin
F. Boni	- Yarnall Waring Co., Philadelphia, Pa.
K. A. Gardner	- Kellogg Corp., New York, N.Y.
6. Subcontracts under this Contract: None

II. Contract Work Scopes and Schedules

1. Objective: Conceptual design of a less expensive, more
reliable heat exchanger and steam generator of
advanced design and improved performance for use
in sodium-cooled reactor systems.
- Scope:
- (a) Selection and preparation of a preliminary
design for a 70 Mw steam generator and for
a 70 Mw heat exchanger meeting the performance
specifications of Part A and Part B attached
herewith.
 - (b) Report on alternate designs which were
discarded.
 - (c) Optimization, sizing, stress analysis, and
material selection for the design selected under
(a) above.

(d) Economic evaluation of the design selected.

(e) Outline of R&D proposed to develop and prove the preliminary design.

Schedule: Work to be completed and final report presented February 28, 1959.

2. Objective changed by Sodium Components Development Working Group in September, 1958 to emphasize decreased stress levels, possibly at the expense of an increase in cost of the heat exchanger and steam generator. No change in schedule. Resulted in submission of a total of 4 alternate designs in final report, Item 16.
3. Contract completed by submission of Final Report (Item 16) on February 25, 1959. Addendum to Final Report, presenting calculated stresses for the heat exchanger and steam generator, submitted March 13, 1959.
4. There is no current work.
5. Future work was proposed by Griscom-Russell in letters to the Chicago Operations Office of the AEC dated 9-9-59 and 3-17-60 (Exhibits #14 and 16, respectively,) requesting funding for the design, construction, and testing of an offset-tube-type of steam generator. The testing was to have been performed by Mine Safety Appliances by modifying an existing sodium test loop.

III. Chronology of Technical Events, Progress, and Documentation

1. 4-22-58 - Letter to G-R from J. J. King, Secretary, Sodium Components Selection Board, DRD, USAEC.

Invitation to bid on design, develop, manufacture and test-operate steam generators for use in Na-cooled reactor systems. Lists operating conditions, also transients.
2. 5-29-58 - Proposal to AEC.
3. 6-12-58 - TT to G-R from USAEC setting up agenda for meeting 6/16 to discuss G-R proposal.
4. 6-26-58 - G-R order sheet says AEC has awarded CPFF contract in amount of \$40,000. Covers development of steam generator preliminary design and intermediate heat exchanger preliminary design. Terms and Conditions per Contract AT(11-1)-664 and Supplementary Letter from Robert S. Gruhn, AEC to G-R dated 6-18-58.
5. 7-1-58 - Memo Schroeder to K. Gardner. Materials - Intermediate Heat Exchanger - 316 SS a/c compatibility with remainder of primary circuit.
Steam generator and superheater - Croloy (2 $\frac{1}{4}$ Cr, 1 Mo) a/c high allowable working stresses. Design basis:

Primary Na	1200°F to 800°F
Secondary Na	1100°F to 750°F
Steam	Incoming feed 600°F
	Boil at 650°F
	Superheat to 1050°F
6. 7-3-58 - Letter from COO re orientation meeting at Germantown on 8-5-58.

7. 9-3-58 - Agenda of Meeting with AEC on September 10-11
8. 9-17-58 - Memo of Conference on meeting September 10-11 with Liquid Metals Committee. Confirms 1100°F temperature for Na entering the steam generator. Emphasizes importance of thermal stresses.
9. 10-24-58 - Memo, Schroeder to File re meeting at ORNL. OR reported no effect of molten Na on creep tests and displacement strain cycle performance of metals except that impure Na causes some loss in creep strength resulting from de-carburization of metals.
10. 10-27-58 - Report to AEC - "Optimization of Terminal Temperature, Fluid Flow Rates, and Pumping Power."
Intermediate Heat Exchanger (IHX) - 500#/sec./ft.² optimum on tube side, 210 optimum on shell side. Changes in mass velocity of + 20% increased combined cost of IHX and capitalized fluid H.R. by only +1% referred to tube side, +2% referred to shell side.
Total heat exchanger cost varies approximately 10% from the mean when terminal temperature of IHX varies from 750 to 900°F and flow rates vary from 9.5 to 14.3'/sec. (primary) and 10.6-17.0'/sec. secondary.
11. 11-5-58(?) - Meeting in Massillon with working group.
12. 12-3-58 - Interim Report submitted.
13. 2-16-59 - Letter from COO inviting proposals for an engineering study of a sodium components test facility (non-nuclear.)
14. 2-18/19-59 - AEC meeting Chicago (no Minutes in file).
15. 2-24-59 - Letter G-R to COO declining to participate in the test facility study.
16. 2-25-59 - Final report submitted.
17. 3-10-59 - Letter to COO transmitting forms bearing design data on offset, U-tube, and involute exchangers and steam generators.
18. 3-13-59 - Letter to COO transmitting Addendum to Final Report - Structural Design-Part C." Tabulates values of calculated stresses in IHX and steam generator.
19. 4-23-59 - *Letter to COO suggesting revisions to COO's proposed contract draft of 4/17 and submitting a cost breakdown.
20. 9-9-59 - Letter to COO from G-R detailing proposal for further development work. (Apparently a revision of Exhibit (13) above.)
21. 3-17-60 - Letter to COO, adding to Exhibit (14) above, a proposal for design, construction, and testing of an offset-tube-type steam generator (tests to be performed by MSA.)

*Not in file - COO letter to G-R, 4-17-59, including a contract draft re steam generator design.

22. 3-23-60 - Minutes of Meeting of 3/16 with MSA re Exhibit (16) above. Shows proposed test loop: NaK to Na in IHX, Na to H₂O in steam generator.
23. 6-6-60 - Cost estimate to COO per modified proposal to construct a 30 Mw (instead of 70 Mw) offset-tube steam generator.
24. 6-21-60 - Memo of meeting at COO for extension of contract.
25. 6-28-60 - Letter to COO re contract terms.

SCDP History

ALCO/BLH Sodium Heated Steam Generator

I. General Contract Information

1. Contract Number: AEC Contract: AT(11-1)-1213
BLH Order: 770-1049
Title: Research and Development Contract
including Fabrication and Testing of Components.
Authorization Date: June 27, 1962
2. Organization and Address:
Baldwin-Lima-Hamilton Corporation, Philadelphia 19142, Pa.
3. Project Manager, Organizational Title & Basic Technical Profession: P.S. Otten-Chemical Engineer, Manager Of Sales of Nuclear & Special Products
4. Key Project Technical Personnel & Consultants:
 - (a) R. B. Abderhalden, Project Engineer- Mechanical Engineer
 - (b) C. H. Diehl, Manager Research & Development- Mechanical Engineer
 - (c) B. F. Love, Heat Transfer Specialist-Mechanical Engineer
 - (d) M. A. Chionchio, Engineering Supervisor-Mechanical Engineer
 - (e) R. A. Tidball, Manager Heat Transfer Engineering-Chemical Engineer
5. Present address of key personnel:

P. S. Otten - Merritt Incorporated, Flemington, New Jersey
C. H. Diehl - Hale Pumps, Conshohocken, Pa.
B. F. Love - Combustion Engineering, Windsor, Connecticut
M. A. Chionchio- Perfex Corporation, Milwaukee, Wisconsin
6. Subcontracts under this Contract: None

II. Contract Work Scopes and Schedules

- (1a) Complete manufacture and testing of steam generator using ALCO design drawings and material already procured by ALCO, for delivery November, 1963.
- (1b) Restore a high pressure, high temperature test loop at BLH using equipment from ALCO. Run test using sine-wave bi-metallic tube as used on the steam generator and other tubes as directed by the AEC. The objective was to obtain certain heat transfer information and to obtain metallurgical and chemical effects on

tubing when operated for extended periods at high temperature, high pressure conditions with tubing in contact with water and steam. Loop expected to be restored three months after receipt of material at B.L.H.

(2) Work Scope and Schedule Modifications:

Modification #1 - October 24, 1964

Contract changed to add requirement that BLH bend into sine-wave and Hydro test tubing for 30 Megawatt steam generator. Fixed fee increased \$450.00 and obligated funds by \$7,000.

Modification # 2 - April 3, 1963

Term of Contract extended without change in funds.

Modification #3 - October 28, 1963

Term of Contract extended from December 31, 1963 to June 30, 1964 without additional funds.

Modification # 4 - April 22, 1964

Increased obligated funds by \$50,000 with no change in scope or fixed fee.

Modification #5 - May 5, 1964

Increased obligated funds by \$36,650 with no change in scope or fixed fees.

Modification #6 - June 26, 1964

Ambient Temperature and pressure stress evaluation added increasing obligated funds by \$5,892.00 and fixed fee by \$569.00.

Modification #7 - August 13, 1964

Obligated funds increased by \$20,000.

Modification #8 - October 8, 1964

Obligated funds increased by \$8,000.00.

Modification #9 - December 21, 1964

Extended term of Contract from November 30, 1964 to January 31, 1965.

Modification #10 - January 11, 1965

Obligated funds increased by \$4,000.00.

Modification #11 - February 4, 1965

Extended term of Contract from January 31, 1965 to February 28, 1965.

Schedule Modifications for test loop,

Original date for restoration of test loop was January, 1963, Due to assembly problems, required modifications, late arrival of equipment (March and April, 1963), and poor gas-keting closure design loop was not in, finished, and set-up for full scale test until November 1963. After completion of set-up for full scale test, Contract was cancelled.

Schedule Modifications for Steam Generator:

Original scheduled shipping date November, 1963.

Revised date of May, 1964 resulted from manufacturing delays for renewal of baffles, outside vendor problems with tubesheet drilling, slippage by BLH and unrealistic original shipping date. Final shipping date extended to August, 1964. This extension resulted from excessive tube to tube sheet welding difficulties including dye penetrant and mass spectrometer examination of root weld passes, minor manufacturing problems during assembly and time required for strain gage test.

- (3).
Test loop cancelled by AEC on January 9, 1964
Steam Generator shipped August 21, 1964, Contract expired February 28, 1965.

- (4).
Current work completed.

- (5).
None anticipated.

III. " Chronology of Technical Events, Progress & Documentation".

1. June 20, 1962 - Proposal, Transfer of Steam Generator Fabrication from ALCO Products, Incorporated to B-L-H (Submitted by ALCO to AEC).
2. June 27, 1962 - SUBCONTRACT effective date (BLH)
3. June 28, 1962 - Coordination meeting on SCTI test program. Parties present: ALCO, B-L-H (Mr. Otten) AEC and A.I.
4. July 3, 1962 - ALCO recommends elimination of ultra-sonic test requirements for tubing. AEC request B-L-H concurrence.
5. July 5, 1962 - B-L-H concurs with ALCO recommendation provided tubing meets all other requirements of ALCO Spec. NA-666-30-MW-1 Revision 6/6/62.
6. August 2, 1962 - Received authorization from A.E.C. to begin shipment of Steam Generator components from ALCO to BLH.
7. August 8, 1962 - Mr. R. Abderhalden replaced Riley as Project Engineer.

8. August 17, 1962 - Supplement #3 order #8-42207-5 to Sup. Tube Company gives final agreed to ultrasonic test requirements for Tubing.
9. August 15, 1962 - Submission of Contract No. AT(11-1)-1213 by AEC to BLH for approval.
10. August 21-22, 1962- A Meeting at A.I. in California. Purpose: "To resolve the final test program as proposed by ALCO. Parties present: AEC, A.I.; ALCO and B-L-H (Abderhalden and Riley)."
11. August 23, 1962 - Contract No. AT(11-1)1213. Accepted, copies signed and returned to A.E.C.
12. August 31, 1962 - Request from AEC to issue Purchase Orders for Transfer of Property.
13. September 4, 1962- Material received from ALCO- For Test Loop.
14. September 12, 1962 - A Meeting was held at ALCO- Schenectady for purpose of reviewing the status of Steam Generator and to discuss transfer of material and information to B-L-H.
15. September 27, 1962 - Meeting at B-L-H with Dr. Lemcoe of A.I. discussing strain gage location and testing.
16. September 28, 1962 - Monthly Progress Report-RBA
17. October 4, 1962 - A.E.C. supplements Contract. B-L-H to Sine-wave bend tubes at additional cost.
18. October 10, 1962 - Mr. Otten of B-L-H attended meeting of the Sodium Components Development Program at Oak Ridge National Laboratory.
19. October 11, 1962 - Purchase Orders issued by B-L-H to transfer property accountability of AEC equipment from ALCO.
20. October 24, 1962 - Modification 1 - Agreement adds requirement that B-L-H bend into sine-wave and hydrostatic test tubing for 30 Megawatt Steam Generator; adds \$450.00 to fixed fee and increases obligated funds by \$7,000.00.
21. October 24, 1962 - A Meeting was held at ALCO, Dunkirk. Reviewed Quality Control aspects and agreement reached on method of transfer and type of information to be transferred to BLH. (See Monthly Progress Report for October).
22. October 31, 1962 - Monthly Progress Report(R.B.A.)
23. December 20, 1962 - Mr. M. W. Steffens appointed Contract Administrator for BLH.

- 24. December 20, 1962 - BLH requests approval from AEC for the placement of fixed price Purchase Orders for the procurement of the Test Loop Heat Sources and Associated Control and Protective Equipment.
- 25. December 31, 1962 - Monthly Progress Report on Test Loop
- 26. January 18, 1963 - Approval for Purchase of Test Loop Heat Sources and Associated Control and Protective Equipment received from AEC.
- 27. January 31, 1963 - Monthly Progress Report(R. B. Abderhalden).
- 28. February 4, 1963 - Meeting with ALCO to discuss High Pressure Test Loop.
- 29. February 5, 1963 - Meeting at A.N.L., Chicago, to discuss status of Order including ALCO Progress in tube to tubesheet weld development. Parties present: AEC and B-L-H (P.S. Otten, R. B. Abderhalden, M. Steffens).
- 30. February 28, 1963 - Monthly Progress Report(R. B. Abderhalden).
- 31. March 6, 1963 - Mr. Smith of AEC visited B-L-H to view Test Loop progress and alterations (See March Progress Report).
- 32. March 12, 1963 - BLH requests Contract extension.
- 33. March 20, 1963 - BLH submits to AEC proposal addition to scope of work.
- 34. March 26, 1963 - Consistency weld test on tube joints performed at ALCO with BLH in attendance. (See March Progress Report).
- 35. March 31, 1963 - Monthly Progress Report(R. B. Abderhalden).
- 36. April 3, 1963 - Modification 2 of Contract- extends term of Contract without additional funds.
- 37. April 25, 1963 - Mr. Fred A. Smith of A.E.C. Reactor Engineering Division visited B-L-H to review status of work conducted by AEC.
- 38. April 30, 1963 - Monthly Progress Report(R.B. Abderhalden)
- 39. May 13-14, 1963 - Working Review Meeting with AEC in Washington.
- 40. May 23, 1963 - Mr. Mattmueller and Mr. Smith of AEC visited BLH to view Progress and discuss Schedule.
- 41. May 31, 1963 - Monthly Progress Report
- 42. June 25, 1963 - AEC visited BLH to view progress and review Schedule. (See June Progress Report).

43. June 30, 1963 - Monthly Progress Report(R. B. Abderhalden).
44. July 30, 1963 - AEC visited BLH to review progress and Schedule.
(See July Progress Report).
45. July 31, 1963 - Monthly Progress Report(R. B. Abderhalden).
46. August 5, 1963 - AEC gave approval to A.I. to procure and install Strain Gages on the Steam Generator at B.L.H.
47. August 8,20,21,1963- Sodium Components development meeting at Polo Alto to report Progress and status of Contract.
48. August 31, 1963 - Monthly Progress Report(R. B. Abderhalden).
49. September 11, 1963 - Mr. Gower of AEC visited BLH for progress review.
(See September Progress R^Eport).
50. September 19, 1963 - Dr. Lemcoe of A.I. visited B.L.H. to discuss strain gauge attachments by A.I.
(See September Progress Report).
51. September 30, 1963 - Monthly Progress Report(R. B. Abderhalden.)
52. October 15, 1963 - AEC and AI visited BLH to review status of all items and discuss schedule.
(See October Progress Report).
53. October 28, 1963 - Modification No. 3 - AEC extends term of Contract from December 31, 1963 to June 30, 1964 without additional funds.
54. October 31, 1963 - Monthly Progress Report (R. B. Abderhalden).
55. November 20, 1963 - Meeting at BLH with AEC and AI to review progress and schedule.
(See November Progress Report)
56. November 30, 1963 - Monthly Progress Report(R.B. Abderhalden).
57. December 13, 1963 - B-L-H requests approval to have tube sheets drilled at I.P.E.
58. December 31, 1963 - AEC approves tube sheets be drilled at I.P.E.
59. December 31, 1963 - Monthly Progress Report(R. B. Abderhalden).
60. January 9, 1964 - AEC advised B-L-H to suspend work on Test Loop
61. January 17,1964 - AEC authorizes " a maximum of \$2,800.00 to prepare reports on Test Loop.
62. January 31, 1964 - Monthly Progress Report(R. B. Abderhalden).
63. February 29, 1964 - Monthly Progress Report(R. B. Abderhalden).

- 64. March 5, 1964 - AEC visit to BLH to review Test Loop inventory.
(See March Progress Report).
- 65. March 13, 1964 - A.E.C. instructs BLH to dismantle Test Loop. Part of Loop is to be shipped to Argonne Laboratory and others to be scrapped.
- 66. March 31, 1964 - Monthly Progress Report(R. B. Abderhalden).
- 67. April 22, 1964 - Modification No. 4 - this modification increased obligated funds by \$50,000.00 fixed fee remained same.
- 68. April 30, 1964 - Monthly Progress Report(R. B. Abderhalden).
- 69. May 5, 1964 - Modification No. 5 - This Modification increase obligated funds by \$36,650.00 fixed fee remained same.
- 70. May 27, 1964 - AEC notified BLH to obtain and install room temperature strain gages
(See Monthly Report).
- 71. May 30, 1964 - Monthly Progress Report(R. B. Abderhalden).
- 72. June 26, 1964 - Modification No. 6 - This Modification add's an ambient Temperature press stress evaluation. Increasing obligated funds by \$5,892.00. The fixed fee increased \$569.00.
- 73. June 30, 1964 - Monthly Progress Report(R. B. Abderhalden)
- 74. July 31, 1964 - Monthly Progress Report(R. B. Abderhalden).
- 75. August 13, 1964- Modification No. 7 - This Modification increased obligated funds by \$20,000.00.
- 76. August 20, 1964- Received authority to ship Steam Generator via Motor Carrier to A.I.
- 77. October 8, 1964- Modification No. 8 - This Modification increases obligated funds \$8,000.00.
- 78. December 1, 1964- Strain Gage Test Report submitted to AEC.
- 79. December 21, 1964- Modification No. 9 - This modification extended term of Contract from November 30, 1964 to January 31, 1965.
- 80. January 11, 1965 - Modification No. 10 - This Modification increased obligated funds \$4,000.00.
- 81. February 4, 1965 - Modification No. 11 - This Modification extended term of Contract from January 31, 1965 to February 28, 1965.
- 82. February 28, 1965- Contract expired.

November 1, 1964 - Fabrication and Inspection Report
 C00-1213-26 submitted to AEC.
 (This report covers all sequences of
 Fabrication including problems
 encountered and recommendations.
 Therefore Fabrication details have
 not been included in the above list.)

SCDP History

G-R, BLH Sodium Heated Steam Generator & Intermediate
 Exchanger Program

I. General Contract Information

1. Contract Number: AEC Contract: AT(11-1)-1501
 BLH Order: 360-50223
 Title: Analysis & Evaluation of Performance Data on the
 Alco Steam Generator & Intermediate Heat Exchanger
 Authorization Date: June 15, 1965
2. Organization and Address: Baldwin-Lima-Hamilton Corp.
 Philadelphia, Pa. 19142
3. Project Manager, organization title and basic technical
 profession:
 Project Manager (original) - P. S. Otten, Manager of Sales of
 Nuclear & Special Products
 (Present) Project Manager - John G. Gaydos, Senior Engineer -
 Heat Transfer Products
 Mechanical Engineer
4. Key project technical personnel and consultants:
 - (a) R. A. Tidball - Chief investigator supervising
 engineering work. Manager, Heat Transfer
 Engineering - Chemical Engineer
 - (b) P. S. Otten - Engineering Consultant - Chemical Engineer
 Formerly Project Manager
 Presently with Merritt, Inc., Flemington, N.J.
 - (c) N. Xanthopoulos - Analyze strain gage data and determine
 actual stresses
 Stress Analyst - Mechanical Engineer
 - (d) D. R. Bosley - Engineering Consultant & Computer Solutions
 Mechanical Engineer
 Engineering Supervisor, Heat Transfer
 - (e) H. Hall - Metallurgical Consultant
 BLH Metallurgist
5. Present address of key personnel: Same as above
6. Subcontracts under this Contract: None

II. Contract Work Scopes and Schedules

1. Initial scope and schedule - To perform approximately 3,260 man hours of work to analyze and evaluate performance data on the Alco Steam Generator and Intermediate Heat Exchanger. Work to be completed by June 20, 1967.
2. No modifications of scope or schedule.
3. Not completed.
4. June 20, 1967.
5. None

III. Chronology of Technical Events, Progress, and Documentation

1. 4-23-65 - Proposal to AEC
2. 5-11-65 - Notice of award of contract
3. 6-15-65 - Authorization of Contract
4. 6-29-65 - Authorization for SCDP History

BATTELLE MEMORIAL INSTITUTE

Determination of Oxygen in Sodium at
Concentrations Below 10 ppm

DETERMINATION OF OXYGEN IN SODIUM

I. GENERAL CONTRACT INFORMATION

1. Contract No.: W-7405-eng-92, Budget Activity Nos. 4105.1, 040103191

Title: Determination of Oxygen in Sodium at Concentrations
Below 10 ppm.

Program Initiation: July 1, 1959

2. Organization: Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
3. Project Manager: Daniel R. Grieser, Senior Scientist, Physicist
4. Key Project Personnel: Dr. G. G. Cocks, formerly Assistant Chief,
Physics of Solids Division (presently an Associate Professor at
Cornell University) investigations using ellipsometry.

Dr. E. H. Hall, Senior Chemist, investigations using mass
spectrometry.

W. M. Henry, Supervisor of Analytical Spectroscopy, investigations
using arc emission spectroscopy.

Dr. J. McCallum, Research Fellow, Electrochemical Engineering
Division, investigations using coulometry and polarography.
5. All personnel at BMI with exception noted in Item 4.
6. No subcontracts.

II. CONTRACT WORK SCOPE

The basic scope of the program was to study the feasibility for determination of oxygen in sodium at concentrations below 10 ppm by techniques other than those based primarily on chemical analysis.

Request for proposal from T. P. Heckman (then SCDP Secretary) dated January 23, 1959.

Proposal from BMI submitted February 26, 1959.

III. CHRONOLOGY AND DOCUMENTATION

Contract Initiation: July 1, 1959

Contract Completion: June 30, 1961

SCDP meetings at which progress reports were presented orally:

<u>Location</u>	<u>Date</u>
BMI	March 11, 1960
AI	May 6, 1960
AI	March 16, 1961

Progress reported in the BMI Monthly and Quarterly Reports to the AEC on Civilian Reactor Applications.

No patents.

No hardware perfected or delivered.

Development of a technique was not successful; research served to pinpoint additional work needed to develop selected techniques. Work was discontinued when chemical methods being investigated elsewhere began to show substantial promise.

Topical Report: Daniel R. Grieser, et. al., "Determination of Oxygen in Sodium at Concentrations Below 10 ppm," BMI 1538, August 23, 1961.

UNITED NUCLEAR CORPORATION

Measurement of Oxygen in Sodium Below 10 ppm
Electrochemical Meter for Continuous Measurement
of Oxygen in Sodium

SCDP History Contractor Technical Questionnaire

on

Consultant Services to SCDP Working Group

I) General Contract Information

- 1) Consultant Services to SCDP Working Group -
Contract Nos.: AT(30-3)-256
AT(30-1)-2303
AT(30-1)-2834
- 2) United Nuclear Corporation, Development Division,
5 New Street, White Plains, New York
- 3) K. Goldmann, Engineer
- 4) K. Goldmann, Engineer
- 5) Same as above

II) Contract Work Scopes and Schedules1) Work Scope

Provide consultant services, as directed by the Contracting Officer, for the AEC Sodium Components Development Working Group. These services will include, but not be limited to, attendance at Working Group meetings, preparation for such meetings, and assignments on sub-committees.

Schedule

February 27, 1958 through April 22, 1963

- 2) There were no modifications
- 3) April 22, 1963
- 4) No current work
- 5) No future work contemplated

III) "Chronology of Technical Events, Progress and Documentation"

These have been submitted to you as "SCDP History Questionnaire for Kurt Goldmann", (PS-499), under cover letter PS-501, April 15, 1965.

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SCDP History Contractor Technical Questionnaire

on

"Chronology of Technical Events, Progress, and Documentation"

I. General Contract Information

1. Contract number, title, and authorization date:

AT(30-1)-2303 Project XV
Scope 1 - Measurement of Oxygen in Sodium Below
10 ppm
Scope 2 - Consultant Services to SCDP Working Group
March 21, 1960 - August 30, 1961

2. Organization and address

United Nuclear Corporation
Development Division
5 New Street
White Plains, New York 10601

(Prior to June 1961 - Nuclear Development Corporation
of America)

3. Project Manager, organizational title, and basic
technical profession

Scope 1 - G. Stern - Manager, Materials Research
Department
Metallurgist

Scope 2 - K. Goldmann - Manager, Liquid Metal
Systems
Mechanical Engineer

4. Key project technical personnel and consultants,
organizations and addresses, project responsibilities,
organizational titles, and basic technical pro-
fessions.

Scope 1 - H. Steinmetz - Project Scientist
(Chief Chemist)
Chemist

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5. Present addresses of project manager and key personnel.

G. Stern - same
H. Steinmetz - deceased
K. Goldmann - same

6. If Item I.1 is basic contract, list subcontract numbers, titles, authorization dates, organizations, addresses, and basic purpose of each.

No subcontracts.

II. Contract Work Scopes and Schedules

1. Initial basic work scope, objectives, and schedules.

The objectives included the development of a high sensitivity chemical method for the determination of oxygen in sodium in the 0 to 10 ppm of oxygen range.

Another objective was the determination of the carbon content of three samples of sodium submitted to UNC for analysis.

2. Work scope and schedule modifications, dates effective and basic reasons.

None

3. Contract completion or termination dates.

August 30, 1961

4. Expected date for completing current work.

DNA

5. Future work required, if known.

At the completion of the contract, it was recommended that "This analytical method should be developed so that it can be used for routine analysis." This was never done.

III. "Chronology of Technical Events, Progress and Documentation"

- A. For events, list chronologically, giving key dates, key participants, or attendees, objectives, accomplishments, reasons, and so forth.

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Work started - March 21, 1960
Work completed - August 30, 1961

Important technology contributions - A method for the determination of oxygen in sodium in the 0-10ppm range was developed.

Important techniques developed - An amalgamation method followed by a reaction of the sodium oxide with alcohol and then reacted with an organic acid to convert the sodium oxide to an equivalent amount of water was developed. The water was then titrated with Karl Fischer reagent. The method has the advantage of not requiring a complete separation of the sodium from the sodium oxide.

Test results and evaluations - The analysis of a series of samples of zirconium - gettered sodium gave a mean value of 3 ppm of oxygen with a standard deviation of ± 1.5 ppm.

- B. For documentation, list chronologically, giving dates, titles, authors, identifying notations, locations of file copies, and so forth.
1. "Development of a High Sensitivity Analytical Method for Oxygen in Sodium Metal" - NDA-2154-2, Quarterly Progress Report for the Period June 27, 1960 to September 30, 1960, H. Steinmetz, October 30, 1960.
 2. "Development of a High Sensitivity Analytical Method for Oxygen in Sodium Metal" - NDA-2154-3, Quarterly Progress Report for the Period October 1, 1960 to December 31, 1960, H. Steinmetz, March 1, 1961.
 3. "Experimental Determination of Contaminants in Sodium" - NDA-2154-5, Quarterly Progress Report for the Period January 1, 1961 to March 31, 1961, H Steinmetz, May 1, 1961.
 4. "Experimental Determination of Contaminants in Sodium" - NDA-2154-6
H. Steinmetz - August 30, 1961
B. Minushkin

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SCDP History Contractor Technical Questionnaire

on

"Chronology of Technical Events, Progress, and Documentation"

I. General Contract Information

1. Contract number, title, and authorization date.

AT(30-1)-2877
Development of Electrochemical Meter for
Continuous Measurement of Oxygen in Sodium
September 1, 1961

2. Organization and address.

United Nuclear Corporation
Development Division
5 New Street
White Plains, New York 10601

3. Project manager, organizational title, and basic technical profession.

G. Stern - Manager, Materials Research Department
Metallurgist

4. Key project technical personnel and consultants, organizations and addresses, project responsibilities, organizational titles, and basic technical professions.

H. Steinmetz - Project Scientist (Chief Chemist)
Chemist
September 1, 1961 - December 1963 (deceased)

B. Minushkin - Project Engineer - Sr. Engineer
Chemical Engineer
January 1964 - Present

M. Kolodney - Consultant
Professor of Chemical and Metallurgical
Engineering
City College
Amsterdam Avenue and 137th Street
New York, New York

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5. Present addresses of project manager and key personnel.

G. Stern - same
H. Steinmetz - deceased
B. Minushkin - same
M. Kolodney - same

6. If item I.1 is basic contract: list subcontract numbers, titles, authorization dates, organizations, addresses, and basic purpose of each.

None

II. Contract Work Scope and Schedules

1. Initial basic work scope, objectives, and schedules.

The objective was the development of a continuous, direct-reading instrument capable of operating in the temperature range of 800-1200°F, and measuring oxygen content in sodium from 100 ppm down to a few ppm. The meter was to be insensitive to impurities commonly found in the sodium stream, other than oxygen.

The first phase (8/31/61 - 8/31/62) was to include:

- Experimental demonstration of the principle of the instrument.
- Measurement of the effect of temperature and impurity variation on the readings obtained.
- Initiation of work leading to the design, fabrication, and testing of a "breadboard" model of the instrument.

The extension covered the period 9/1/63 - 10/1/65 and included:

- The design and construction of a pumped loop to make quantitative measurements beyond those needed for feasibility.
- A development program for the selection of a reference electrode.
- The design of a first prototype.
- Evaluation of the prototype.
- Final design, specification, and construction of prototypes and the field testing of these units.

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- Design and construction of three instrumentation packages to be used with the electrochemical cells.
 - Field testing of the electrochemical cells.
 - Preparation of a final report.
2. Work scope and schedule modifications, dates effective, and basic reasons.
- Program extended from 3/31/65 to 10/31/65 - Decision made May 1965 - Reason:
- Delay in initiating field tests.

3. Contract completion or termination dates.

October 31, 1965

4. Expected date for completing current work.

October 31, 1965

5. Future work required.

There should be an effort on the continued development of the electrochemical oxygen monitor aimed at determining radiation effects on its performance.

III. "Chronology of Technical Events, Progress and Documentation".

- A. For Events, list chronologically, giving key dates, key participants, or attendees, objectives, accomplishments, reasons, and so forth.

Work started - September 1, 1961

Work to be completed - October 31, 1965

Reviews, conferences or meetings -

1. "Development of a Continuous Meter for Oxygen in Sodium" - A Progress Report prepared for the Sodium Components Development Program Information Meeting
August 21, 1963 - Palo Alto, California
H. Steinmetz - G. Stern

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2. "Plugging Meter and Continuous Oxygen Meter",
B. Minushkin - Prepared for Panel Discussion-
"On-line Monitoring Techniques", Sodium Com-
ponents Development Program-Information
Meeting, Hollywood, California
April 14, 1964
3. "Liquid Metal Oxygen Meter", B. Minushkin
AEC Sodium Components Development Program
Meeting
Chicago, Ill.
June 16 & 17, 1965

Important technology contributions - An instrument, specific for oxygen, and suitable for use in sodium or potassium, has been developed. It can be used to monitor a flowing liquid metal system.

Patents - Disclosure by M. Kolodney and B. Minushkin now being updated for government controlled patent.

Hardware delivered or perfected - Oxygen Monitors were delivered to ANL, APDA, LASL in May of 1965 along with an instrument package to each installation. Test results and evaluations - APDA is currently evaluating the electrochemical oxygen monitors in their pumped sodium loop. ANL and LASL are about to start their tests.

- B. For documentation, list chronologically, giving dates, titles, authors, identifying notations, locations of file copies, and so forth.
 1. "Development of a Continuous Meter for Oxygen in Sodium" - UNC-5000
Quarterly Progress Report for the period
September 1 to December 1, 1961
H. Steinmetz - January 15, 1962
 2. Same title - UNC-5010
Quarterly Progress Report for the period
December 1961 to February 28, 1962
H. Steinmetz - April 15, 1962
 3. Same title - UNC-5028
Quarterly Progress Report for the period
March 1962 to May 31, 1962
H. Steinmetz - July 15, 1962

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4. Same title - UNC-5032
Quarterly Progress Report for the period
September 1, 1961 to July 31, 1962
H. Steinmetz - August 24, 1962
5. Same title - UNC-5050
Quarterly Progress Report for the period
September 1, 1962 to December 31, 1962
H. Steinmetz - January 25, 1963

WESTINGHOUSE ELECTRIC CORPORATION

Design of Large Sodium Pump Test Facility

Examination of Contents of Fermi Reactor Cold Trap

DESIGN OF LARGE SODIUM PUMP TEST FACILITY

I. General Contract Information

1. AT(30-1)-3123

Large Sodium Pump Requirements and Problem Areas; Design of
Large Sodium Pump Test Facility

November 1, 1962

2. Westinghouse Electric Corporation

Atomic Power Division

P. O. Box 355

Pittsburgh, Pa. 15230

3. J. H. Wright, Manager

Advanced Systems Section

Chemical Engineer

4. J. H. Wright

Project Manager

Manager, Advanced Systems Section, Atomic Power Division

Chemical Engineer

C. C. Randall

Project Engineer

Senior Engineer, Advanced Systems Section, Atomic Power Division

Chemical Engineer

B. Cammetti

Responsible Charge for Tasks 2.2; 2.3; 2.4

Consultant, Westinghouse Atomic Equipment Division

Mechanical Engineer

R. L. Whitney

Responsible Charge for Tasks 3.1

Supervisor Engineer, Plant Development, Westinghouse, Atomic Power Division

Mechanical Engineer

5. Same

6. United Engineers & Constructors

Philadelphia, Pa.

Subcontract for Architect-Engineering design services in conjunction
with conceptual design and cost estimate of pump test facility, Task 3.1.

Authorization Date: June 1963

II. Contract Work Scopes and Schedules

1. Initial Work Scope and Objectives

Phase I - Formulation of a Development Program for Large Sodium
Pumps and Establishment of Test Facility Functional
Requirements

- a. Identification of sodium pump requirements for large
(1000 - 1500 MWe) sodium cooled power reactors and

establishment of their criteria and limits by consideration of the pertinent technological and economic factors.

- b. Identification and definition of sodium pump problem areas.
- c. Formulation of a pump development program, including an estimated schedule of accomplishment, to resolve the problem areas and to provide information to support the design, fabrication and testing of pumps meeting the criteria established. A "PERT" network for said development program shall also be developed covering events through the complete detailed design and specifications for a prototype pump or pumps.
- d. Establish requirements for a pump test facility capable of supporting the formulated development program and accomplishing the required testing.

Phase II - Test Facility Design, Site Survey and Cost Estimates

- a. Preparation of a design, sufficient for estimation of reliable capital and operating costs, for a sodium pump test facility capable of meeting the technical and functional requirements established in Phase I. The design shall consider the buildings, utility services, related auxiliaries, test loop and components, and separate test rigs required for performance of the development program formulated in Phase I.
- b. Comparative evaluation of alternate test facility sites based on inspection of sites, including Government-owned sites specified by the Commission.
- c. Cost estimates and estimated construction schedule for a test facility constructed at a Commission designated site. The estimates shall include costs for construction, annual maintenance, and annual test operation. In addition, a "PERT" network shall be developed covering events from initiation of Architect-Engineering design through completion of construction of the test facility.

Initial Schedule: Attachment 1

2. Work Scope and Schedule Modifications

Schedule Revision #1 January 4, 1963 Attachment 2
Revision of schedule based on adjustments necessary to compensate for delays in initiating work.

Schedule Revision #2 July 1, 1963 Attachment 3
Extension of completion from Aug. 31, 1963 to Oct. 30, 1963 primarily due to delays in obtaining approvals for architect-engineering contract.

Scope changed to delete Site Evaluation, Task 3.2.

3. Contract Termination: April 4, 1964

4. No current work
5. Future work required includes engineering design and construction of pump test facility and implementation of research and development work for development of large pumps.

III. Chronology of Technical Events

August 1962	Proposal submitted to AEC
November 1, 1962	Contract awarded
March 1963	Review meeting with Dr. Wensch and staff at Germantown
May 14, 1963	Review of current status at Working Review Meeting of Sodium Components Development Committee
August 1963	Presentation of current status of program at Sodium Information Meeting by Dr. J. H. Wright
October 1963	Presentation of Status and objectives of program to United Kingdom Fast Reactor Team at meeting at ANL
December 16, 1963	Discussion of Sodium Pump Development Program with representatives of major pump manufacturers, AEC contractors associated with sodium components program and AEC staff at meeting held at NYOO.
June 1964	Reviewed cost estimate of Sodium Pump Test Facility NYOO project review board (J. Allentuck, S. Hack, R. Garnet).

Documentation

	Progress Report No.	Period ending	WCAP-
February 1963	1	1/31	2190
March	2	2/28	2236
April	3	3/31	2259
May	4	4/30	2286
June	5	5/31	2324
July	6	6/30	2338
August	7	7/31	2367
September	8	8/31	2388
October	9	9/30	2405
November	10	10/31	2528
December	11	11/30	2539

Topical Reports

June 1963	Survey of Sodium Pump Technology; D. R. Nixon, WCAP-2255
August 1963	Sodium Pump Development and Pump Test Facility Design; C. C. Randall, et al; WCAP-2347
November 1963	Conceptual Design and Cost Estimate for Sodium Pump Test Facility; J. R. Blanchfield, Jr.; WCAP-2526

PROJECT SCHEDULE
SODIUM PUMP DEVELOPMENT & TEST FACILITY DESIGN
CONTRACT NO. AT(30-1)-3123

Attachment No. 1

11/7/62

PROJECT SCHEDULE
 SCCIM PUMP DEVELOPMENT & TEST FACILITY DESIGN
 CONTRACT NO. AT(30-1)-3123

Attachment 2

7/30/63

SODIUM PUMP DEVELOPMENT AND TEST FACILITY DESIGN

CONTRACT AT(30-1)-3123

REVISED SCHEDULE FOR PERIOD 7/1/63 - 10/30/63

	July	August	September	October
1.0 <u>Project Management</u>				
Phase I Report Submit for Approval		•		
Phase II Report Submit for Approval				•
3.0 <u>Pump Test Facility Design</u>				
3.1 <u>Conceptual Design & Cost Estimate</u>				
System & Controls Design	—			
Component Specifications	—			
Release Spec for Quotes	—			
Quotations Complete			•	
A-E Design Work				
A-E Report Received			•	
Report Preparation			—	
Initial Draft				•
Review and Revise				—
3.2 <u>Facility Operating Cost Estimate</u>			—	

EXAMINATION OF CONTENTS OF FERMI REACTOR COLD TRAP

I. General Contract Information

1. AT(30-1)-3186

The Analysis of the Sodium Cold Trap of the Enrico Fermi Reactor.
Authorized March 4, 1963

2. Westinghouse Electric Corp.

Atomic Power Division

P. O. Box 355

Pittsburgh, Pa. 15230

3. Project Manager is Dr. J. H. Wright, Manager of Advanced Systems Section. He is a chemical engineer.

4. The present key project person is Mr. John Herb who reports to Dr. Wright.

II. Contract Work Scope and Schedules

1. The initial objective of the program was to examine and analyze the Enrico Fermi primary sodium cold trap in order to:

a. Determine the chemical and physical composition of the trap contents.

b. Determine the spatial distribution of the chemical species in the trap and determine their physical form.

c. Evaluate the operational performance of the trap with particular regard to maldistribution of flow and flow bypassing.

d. Develop criteria for sodium cold trap design.

The initial scope of work included:

a. Transportation of the cold trap to Westinghouse facility.

b. Disassembly to the extent necessary for sampling.

c. Removal of samples.

d. Disposal of sodium and cleaning of tank for salvage.

e. Preparation of samples for analyses.

f. Analyses of samples.

g. Correlation and reporting of results.

h. Check by independent analytical laboratory.

The initial schedule, shown in Figure 1, was 9 months long.

2. About one year after the program had begun it was apparent that taking a representative sample of sodium and mesh was a very difficult task. The work program was revised as shown in Figure 2.

In August 1964 a minor change was made which extended the work program by one month. In September 1964, the results of the round robin analytical samples were reviewed and the AEC decided on extra outside analyses which resulted in the work program in Figure 3.

The extra delay caused by the outside analyses caused about a two month delay. The final report was written and submitted to the AEC for approval in March 1965. When the AEC comments are received the report will be changed and reissued. This may take until June or July 1965.

III. Chronology

October 1962 - Proposal to do Sodium Cold Trap Analysis

March 4, 1963 - Contract between AEC and Westinghouse

Monthly progress reports WCAP-4301 to WCAP-4320, (March 1963 - December 1964)

Sodium Cold Trap Studies Final Report by J. Herb (being reviewed by AEC)

March 1964 - WCAP-2540, "An Annotated Bibliography for Analytical Methods for Alkali Metals" by E. E. Garcia and B. D. LaMont

April 1964 - The Analysis of the Sodium Cold Trap of the Enrico Fermi Reactor, J. Herb, Sodium Components Development Program, Hollywood, California, April 15, 1964

June 17, 1965 - Analysis of Enrico Fermi Primary Sodium Cold Trap, J. Herb, to be presented at Sodium Components Development Program, Chicago, Ill.

IV. The abstract from the final report is as follows:

Under AEC Contract AT(30-1)-3186 Westinghouse sampled, analyzed and evaluated the performance of a non-radioactive cold trap removed from the Enrico Fermi Atomic Power Plant at Lagoona Beach, Michigan. The trap, a 500 gallon vessel containing stainless steel wire mesh, was operated for 3700 hours in the primary sodium system. The trap was prematurely removed from service so that a new one could be installed prior to nuclear operation of the plant.

A simple and effective method was developed for removing suitable sodium-mesh samples from the cold trap. Fifty-five representative samples were taken from selected areas of the trap. Methods for the determination of the impurities of interest in the cold trap were adapted from procedures described in the technical literature. Based on the chemical analyses of the cold trap contents, less than 20% of its designed oxygen removal capability was realized. The major portion of the contaminants was concentrated in the lower mesh area. The trap contained an estimated 50 pounds of oxygen and 0.9 pound of carbon. The carbonate, hydrogen, and nitrogen values were relatively low. Spectrographic analyses for metallic impurities revealed relatively high concentrations of copper (up to 360 ppm) and iron (up to 110 ppm).

Even though the innermost cylindrical wall had collapsed and the lower mesh area was displaced upwards, the cold trap operated satisfactorily. Flow maldistribution was not evident. Radial flow pattern and a pressure drop monitor are proposed improvements for the Fermi cold trap design. General design criteria for future cold traps are listed. The following tasks are recommended for future studies:

- (1) Development of more specific analytical methods.
- (2) Generation of reliable solubility data for impurities in sodium.
- (3) Evaluation of cold trapping as a process for fission product removal from sodium.
- (4) Examination of cold traps removed from EBR II, Hallam, and SRE.

ERRICO FERRI COLY VAP STUDIES

Contract No. AT(30-1)-3186

WAPD FORM # 154

Figure 1

J. Herb is responsible for all items.

Figure 2

WAPD FORM # 154

BERICO FERM Cold Trap Studies

Contract AT(30-1)-3186

PROJECT SCHEDULE 1964

Figure 3