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UC-25 Metals, Ceramics, and Materials

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SODIUM TECHNOLOGY PROGRAM
QUARTERLY PROGRESS REPORT
FOR THE PERIOD ENDING MARCH 31, 1970

MASTER

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Contract AT(30-1)-4173
U. S. Atomic Energy Commission

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SECTION 1

INTRODUCTION

This is the first quarterly report on the Compatibility of Structural Materials with Sodium being performed during the FY-1970 under AEC Contract AT(30-1)-4173. It covers the work performed from January 1, 1970 to March 31, 1970, and also relates this work to those portions of the Westinghouse Advanced Reactors Division (ARD) program which were in existence prior to this contract and which now fall within USAEC-sponsored scope.

OBJECTIVES

The overall objective of this project is to generate a better understanding of the effect of FFTF and LMFBR sodium environments on the reference structural materials used in those systems and translate that information into data which the designer can use to allow, quantitatively, for sodium-materials incompatibilities.

The project consists of one administrative and four technical tasks as follows:

- NCAA-100 Project Administration
- NCAA-200 Interstitial Transport in Sodium Systems
- NCAA-300 Sodium Corrosion of Weldments and Brazements
- NCAA-400 Mechanical Properties of Structural Materials in Sodium
- NCAA-600 Special Components Mechanical Properties in Sodium

BACKGROUND

The Westinghouse Advanced Reactors Division has maintained an expanding company-sponsored sodium technology program since 1967, with particular emphasis on sodium-materials compatibility studies. By early FY-1970, the sodium-materials compatibility portion of this program encompassed nine small pumped loops and several projects covering:

1. Demonstration plant corrosion mock-up studies
2. Carbon and nitrogen transfer in sodium systems
3. Sodium corrosions of weldments and brazements
4. Effects of sodium on mechanical properties of structural materials

During the second quarter of FY-1970 the Coolant Chemistry Branch of the AEC authorized preparation of a work program under Contract AT(30-1)-4169, which incorporated portions of the above work together with new scope into a five-year plan of sodium-materials compatibility engineering studies. The present contract funds major portions of that plan through the balance of FY-1970.

In so doing, the contract incorporates on-going effort in certain areas detailed in the body of this report under Tasks NCAA-300 and -400. Tasks NCAA-200 and -600 represent new scope. NCAA-200 entails new facilities which are funded in part by Westinghouse and in part by the USAEC.

A clear objective of this contract is to maintain constant liaison with both FFTF and LMFBR design groups to ensure that the data generated will have a maximum utility to these projects. Design requirement reviews and inputs from other sources, such as the LMEC, will be continually monitored. All experimentation will be planned to facilitate extrapolation of results to full scale systems.

A major constraint in the execution of this contract is the need to monitor sodium quality by methods which can be related to other programs and reactor operations. Extensive use will be made of on-line meters, and sodium analytical techniques will be coordinated with the Sodium Technology Group at ANL. They are assigned responsibility for developing reference sodium analytical procedures. Although this phase of the contract effort applies to all tasks, the work will be consolidated and reported under Task NCAA-200, since it has major relevance in that area.

SECTION 2

SUMMARY

NCAA-200 - INTERSTITIAL TRANSPORT IN SODIUM SYSTEMS

Experimental Plans

A detailed experimental program was written for the Carbon Equilibrium Loops (CELs) covering shakedown of the loops and metering systems, carbon meter calibration, and evaluation of C_e and M values.

Facilities

The design of the CELs, including the control panels and tie in of all on-line instrumentation, was completed; and a System Design Description (SDD) was written. The SDD together with the relevant detailed drawings was submitted to RDT, Coolant Chemistry Branch, for approval. Except for minor modifications, the SDD was accepted.

Purchase of control panel equipment was initiated with Westinghouse funds, and control panel construction was begun. All components, except for long lead items, have been installed. Auxiliary power supply equipment has been delivered, and installation initiated.

Ordering of loop components was delayed because of a delay in the release of facility funds by the AEC. All materials are now on order, and fabrication of components has started.

Detailed schedules for the purchase and installation of on-line sodium impurity meters were composed. The AEC owned United Nuclear Corporation (UNC) carbon meter has been transferred from Mine Safety Appliances Research Corporation (MSAR) to ARD. The side arm is heavily carburized and cannot be used. Delivery of a new side arm may take as long as four months.

Currently, bids have been received and are under review for all additional meter and readout equipment.

Control of Hydrogen from the UNC Carbon Meter

A study of methods for hydrogen control was made. Cover gas stripping was compared with cold trapping, and allowances were made for loss of hydrogen by permeation through the loop walls. Even at low trapping efficiencies, cold trapping was much superior to cover gas stripping and will be used as the main method of hydrogen control. It will, however, be supplemented by cover gas stripping, and a gas chromatograph will be installed for cover gas monitoring.

Sodium Sampling and Analysis

An interim policy on sodium sampling and analysis was agreed to by ARD and ANL to be effective until a national policy is established.

Current Status Experimental Program

Suppliers for the thin foil specimen materials were identified and orders were placed with them. Type 316 stainless steel and Armco iron have been delivered and are currently being evaluated.

NCAA-300 SODIUM CORROSION OF WELDMENTS AND BRAZEMENTS

The available information on sodium corrosion of LMFBR weldments and brazements has been reviewed, and a program to study these effects that simulate LMFBR sodium conditions has been designed.

The first section of this task involves a pre-existing program in which the effects of sodium exposure on brazed Inconel 718 fuel pin grid-type samples are being investigated. Weight change and metallography have indicated that at 1200°F, Inconel 718 loses weight due to loss of nickel and chromium; and Microbraz 50 loses nickel and phosphorus when exposed to flowing, low oxygen sodium.

Information on the effects of sodium exposure on spot welded or brazed Type 316 stainless steel fuel pin grid-type samples and spot welded fuel pin end closure welds is being generated in the second section of this task. The second run (WBTL-2) in the sodium corrosion loop testing facility, in which these samples are being exposed to sodium at 1200°F, has accumulated ~1250 hours of operation. Evaluation of these samples will begin in the next period.

In the third part of this work, design requirements for the next run in the weldment and brazement test loop are being examined. Cavitation and cavitation damage effects, which may occur under appropriate sodium conditions in the vicinity of the fuel rod support grids, have been identified for this run. Loop and sample designs to study these effects are being prepared.

NCAA-400 MECHANICAL PROPERTIES OF STRUCTURAL MATERIALS IN SODIUM

Consistent with the work program prepared and submitted for this task, experimental testing and equipment check-out was performed. The sodium Pre-Exposure Loop (PEL-1) operation was terminated after 5049 hours with mechanical property type test samples of Type 316 stainless steel at 1200 and 1325°F. Disassembly is in progress while design and fabrication of components for the second operation of the PEL-1 is proceeding.

Check-out operations of the stress-relaxation and creep-rupture systems with flowing sodium and a test sample at 1200°F have been performed. Modifications to the loop cold trap system are being incorporated due to cover

gas accumulation pulled into the loop as a result of cover gas and sodium mixing in the test chamber. Assembly of the sodium loop for the strain controlled fatigue testing system is in progress. Check-out of the test machine has been performed, and it appears to be satisfactory for a wide variety of test cycles.

NCAA-600 SPECIAL COMPONENTS MECHANICAL PROPERTIES IN SODIUM

Several discussions were held with FFTF and LMFBR mechanical design groups to delineate potential component configurations which would require mock-up testing in sodium. Several pertinent reports (outside Westinghouse) were also reviewed for the same purpose. As a result of these investigations, a number of potential component configurations for evaluation were identified. The component list will be continually revised and enlarged, with the eventual publication of an interim report by the end of FY-1970.

SECTION 3
NCAA-100 PROJECT ADMINISTRATION

F. A. Brassart, W. B. Heubel, and P. Murray

OBJECTIVES

The objectives of this task are to assure that the project is successfully completed, on schedule, within budget, and to the satisfaction of the Atomic Energy Commission; to assure compliance with contracted obligations; and to coordinate this project with other AEC-and Westinghouse-sponsored LMFBF development projects.

Under this task, overall project direction and day-to-day administration will be provided. Plans and controls will be established and maintained; periodic reviews will be held with the Commission; correspondences and reports will be coordinated; and day-to-day technical and administrative liaison with the Commission will be provided.

CURRENT PROGRESS

Authorization for work during FY-1970 was received from the Commission based on the work program submitted in December 1969. Although this is a new USAEC-sponsored program, it picks up on-going effort at WARD in certain tasks.

Internal work authorization and budgets were established.

SECTION 4

NCAA-200 INTERSTITIAL TRANSPORT IN SODIUM SYSTEMS

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D. E. Lohr, S. L. Schrock, and S. A. Shields

OBJECTIVES

The objectives of this program are to provide experimental information and analytical relationships for design data. The rate and direction of carbon and nitrogen transfer and associated mechanical property changes of structural materials within liquid metal systems, representative of primary and secondary circuits of a LMFBR, can then be predicted.

BACKGROUND

Program Philosophy

Even minor changes in carbon and nitrogen contents can produce large alterations in the mechanical properties of the iron-base alloys currently proposed for construction of the LMFBR Systems. A local decrease in carbon level of the 300 series stainless steels, for example, will reduce mechanical strength and impair creep and stress rupture life (see Figure 4-1). The figure shows

Figure 4-1. Equivalent Life or Strength Reduction of AISI 316 Stainless Steel after Loop Exposure
3654-1

the percentage change in rupture time with exposure time when the specimen is subjected to its unexposed 100-hour stress rupture stress. The percentage change in the original carbon content with exposure time is also shown in the figure.

Carburization may severely lower ductility values, although increasing stability of austenite and hence retarding ferrite-sigma reactions, and also increasing mechanical strength. Unlike the surface effects associated with the corrosion and deposition of metallic elements in liquid metal systems, carbon and nitrogen concentration changes can occur to significant depths, since diffusion rates of the latter are relatively high. From a thermodynamic point of view, carbon is expected to move from cold to hot regions within a monometallic system, since carbides of metallic elements are more stable at high temperatures. However, currently available experimental data show that movement is in the opposite direction. It is possible that this is due in part to the fact that the initial "monometallic" character of the system rapidly changes because of selective removal and deposition of certain metallic elements, particularly chromium. It is clear, however, that simple thermodynamic considerations, per se, cannot be used to predict the degree and direction of carbon and nitrogen transfer even in a monometallic loop. The presence of other strong carbide or nitride formers (such as titanium, zirconium, tantalum, niobium, or vanadium) in hot traps, fuel element cladding, or steam generator tubing would also accelerate interstitial transfer in a sodium system.

The proposed experimental program is directed towards the study of system variables and their effect upon carbon and nitrogen transfer. These include alloy composition, time of exposure, temperature, sodium impurity content, and location. Materials used both for construction of experimental loops and for the test specimens will be Types 304 and 316 stainless steel, Incoloy 800, and the 2-1/4Cr-1 Mo ferritic alloy. These are the basic construction materials proposed for actual LMFBR primary and secondary systems, and they will be investigated within their appropriate operational temperature ranges. Analytical relationships developed to describe the transfer of carbon and nitrogen will be applicable not only to long-term steady state conditions but also to short-term impurity transients. These transients would most likely be caused by failure of a reactor component such as the fuel element cladding or steam generator tubing. Even though the duration of the transient in the sodium may be short-term, the time required to remove the impurity from the surface of the containment tubing may be quite lengthy.

The ultimate requirement in this program is to know the rate of interstitial pickup or loss by any material in any part of the system. This rate is governed by three factors:

1. The initial carbon and nitrogen content of the material (C_0).
2. The rate at which the interstitials are transported through the material. This is principally a function of the diffusion coefficients but is also affected by chemical reactions occurring within the material; e.g., precipitation and dissolution of carbides and nitrides. It is also affected by any surface reactions which may

occur. The term "Motivity Coefficient" (M) has been coined to describe the sum effect of these phenomena and will be calculated and used in the same manner as diffusion coefficients.

3. The carbon and nitrogen contents of the steel which are in equilibrium with the sodium environment (C_e) at the wall-liquid interface. This is governed by the activity of the interstitials in the sodium. The difference between C_o and C_e governs the direction of interstitial movement within the material. The variation of C_e with position, material, and temperature within the system governs the overall direction of movement of interstitials within a system.

C_o can be measured by analyzing the as-received material. M is a materials property and should only be dependent on temperature. This value can be determined for the materials in question. C_e , however, depends on the sodium condition at any time and position within an operating system, so some indirect way of determining C_e is required. It is expected that the UNC and BNL carbon meters, which measure the carburizing potential of the sodium, can be used to predict C_e within the system. The meters, however, must be calibrated against C_e values for the various materials in a controllable system prior to use in the main reactor loops.

The purpose of this program, therefore, is to measure the values M and C_e , to calibrate the carbon meters, to predict, using these values, the rate and direction of carbon transport in a system mock-up loop, and to verify these predictions by experimentation. The effect that changes in carbon and nitrogen content has on the mechanical properties of system materials will also be studied.

The program objectives will be approached under three separate subtasks.

1. Calibration of a UNC and a BNL carbon meter against equilibrated tabs of pure iron and the proposed structural alloys will be studied. The work will be conducted in forced convection, isothermal, low sodium velocity loops termed carbon equilibrium loops (CEL). Initially, oxygen concentrations will be kept at typically low levels (<10 ppm), and temperature and carbon activity will be varied. Methods of carbon addition to induce transients will also be investigated, and nitrogen contents associated with the tests will be identified.

A further objective of this task is to determine the "Motivity Coefficients" for carbon (M_c) and for Nitrogen (M_n).

After the carbon standardization tests are completed, methods of nitrogen addition to induce transients in the sodium will also be investigated. Two CELs are planned to accomplish this task; one for determining equilibrium curves, and the other for motivity coefficient measurements.

The two loops can also be used to establish interstitial gradients in mechanical test specimens.

2. Interstitial transfer will be studied in a forced convection loop, or Interstitial Transfer Facility (ITF), which will be a geometric mock-up of a non-isothermal system. It will help determine the positional effects, rates, and transport direction and validate the data extrapolated from Task 1 in a system simulation.

The effect of system variables on interstitial transfer will be studied. The variables will include position, oxygen content, sodium velocity, temperature, and hydrogen content. An empirical model will be developed from these data which will be used for prediction of interstitial behavior in a future scaled-up version of a loop system.

3. The effect of interstitial concentration (or "activity") changes on selected mechanical properties will be investigated for those properties which are more seriously affected by surface composition changes rather than bulk changes (e.g., stress-rupture, creep, fatigue).

Westinghouse Advanced Reactors Division Programs

WARD is conducting an extensive Westinghouse/Utility sponsored program to study the mass transfer of the major metallic elements in LMFBR structural materials. The system Mass Transfer Loops (MTLs) are corrosion potential mock-ups of Westinghouse LMFBR primary and secondary systems and are run with hot leg temperatures up to 1325°F and temperature transients of up to 300°F. Materials used in the primary systems are Type 316 stainless steel hot leg and Type 304 stainless steel cold leg, while the secondary system materials are Type 304 stainless steel hot leg and Incoloy 800 cold leg.[1]

At the end of each loop run, the loop is dismantled and rebuilt with new piping. Only the major components are saved, while the used loop piping is evaluated as part of the experimental material. Loop runs at WARD generally last 2500 hours; however, one run of 10,000 hours has been completed, yielding valuable material information on longer term exposures, and a second run of similar duration is in progress.

Interstitial transport occurs as well as major metallic element transport, and evaluation of the loop materials for changes in carbon and nitrogen levels is expected to yield valuable information concerning the movement of these elements in a real system. Selected sections of the loop piping are thoroughly examined for evidence of carbon and nitrogen transport. This is accomplished by comparing the interstitial gradients in the exposed material with the gradients in the as-received material.

Work Outside Westinghouse

The current AEC sponsored interstitial transfer program is part of an overall national program on sodium technology. The work at Westinghouse interfaces

with, and in some areas complements, work being performed at AI, ANL, BNL, and GE. Programs at MSAR and UNC which have now been terminated are also relevant to the Westinghouse effort.

In the area of carbon meter calibration and operation, the Westinghouse program will benefit from past work at UNC and BNL where the meters were developed and at MSAR where the UNC meter was used successfully in high carbon environments. The ANL program is perhaps the most extensive one outside Westinghouse. They are concentrating primarily on relating carbon transport to chemical species and adapting experimental meters for on-line use in EBR-II.

AI's program interfaces in the area of material properties. They will be investigating the effect of carbon and nitrogen content of stainless steel on mechanical properties.

PRIOR WORK

Preparatory Work

During the first half of fiscal year 1970 extensive preparatory work on the interstitial transport program was performed in anticipation of the current AEC contract. This work involved a preliminary survey of the literature and identification of the key problems in defining interstitial transfer in sodium systems. An experimental approach was decided upon, and a facilities design concept was originated. The program and design philosophies were embodied in the work program which was submitted in November 1969.

A preliminary state of the art review of carbon diffusion data has been completed and documented. The report indicated that diffusivity is as much dependent upon environment and experimental method as on alloy composition. The major difficulties in interpretation and comparison of data arise because of the necessity to extrapolate results obtained above 1400°F to the 1000-1300°F range, because diffusion of carbon has been studied under carburizing or decarburizing conditions, and because of the variations in technique employed for establishing post-exposure carbon concentration gradients.

Reported diffusion coefficients vary by as much as two orders of magnitude at the temperatures of interest (800-1400°F). The difference this variation can make to the carbon gradient in a 1/2-inch wall pipe is shown in Figure 4-2. These curves were computed from the equation:

$$C_{(x,t)} = C_e + \frac{4}{\pi} (C_o - C_e) \sum_{n=1}^{\infty} \left[\frac{(-1)^{n-1}}{(2n-1)} \exp \left[- (2n-1)^2 \frac{\pi^2 D t}{a^2} \right] \frac{\cos(2n-1) \pi x}{a} \right]$$

where:

- $C_{(x,t)}$ = Carbon concentration at a distance x after time t
- C_o = Initial carbon concentration
- C_e = Equilibrium surface concentration
- $a/2$ = Tube wall thickness
- D = Diffusion coefficient

Values of C_o and C_e were arbitrarily taken as 600 ppm and 100 ppm respectively, and curves were computed for a time of 25 years.

A simplified method of determining carbon gradients was also outlined. It involves manipulation of an error function derived from integration of Fick's second law, and avoids the lengthy summations required in the equation given above. The computed curves are shown in Figure 4-2, and are compared with those derived from the mathematical approximations in Figure 4-3.

The success of this program depends to a large extent on the accuracy and finesse when analyzing for carbon. During the initial stages of the work, meter calibration will depend upon analyses of 3-mil foil by the common combustion technique. The required minimum analysis weight of 4 grams necessitates the exposure of rather large specimens measuring approximately 8 x 8 inches. Later work involved with diffusion calculations will rely upon the accurate machining and analyses of thin layers of material machined from areas large enough to provide a similar weight.

Other methods considered for carbon analysis of metallic alloys include the modification to glow-discharge equipment currently available in the analytical laboratories. This would provide carbon concentration data at incremental depths of 1-4 microns, but the expense does not seem justifiable at the present time. Further work is needed to determine the sensitivity of analysis based on density measurements of the 1930.93Å spectral line. An amount of 0.05 Wt % carbon currently appears to be about the lower detection limit.

Radioactive carbon analysis has also been considered but although detection sensitivity problems are not present, it is necessary for accurate mass transfer determinations to have the entire loop system free of non-radioactive carbon. This is because "doped" and "non-doped" species are able to interchange at random.

Facility Design

Two facility designs have been identified: the Carbon Equilibrium Loop (CEL) and the Interstitial Transfer Facility (ITF). Two CEL systems will be built and used to determine values of C_e and M and to calibrate the carbon meters. The ITF will be a ΔT loop mocking-up a real system and will be used to determine the direction and rate of interstitial transfer.

Figure 4-2. Carbon Concentration Curves Through a $\frac{1}{2}$ Inch Tube Wall, for Various Values of Carbon Diffusion at $1050^{\circ}F$ (Type 316 Stainless Steel)

Figure 4-3. Comparison of Computed Concentration Curves and Approximated Curves for Three Values of Carbon Diffusion in Type 316 Stainless Steel at $1050^{\circ}F$

During the first half of the fiscal year a design concept was established in some detail for the CEL systems. The functions of the system are:

1. To supply sodium of known temperature, oxygen content, and carbon activity to the sample tank. The tank contains thin foil specimens which are exposed until they reach equilibrium with the sodium.
2. To enable the evaluation of the UNC and BNL carbon meters under conditions of controlled sodium environment.

In order to fulfill these fundamental loop functions the major design requirements are directed towards establishment of equilibrium, control of loop variables, and suppression of mass transfer of major metallic elements. The necessary design features are outlined below:

1. The system should be as nearly isothermal as possible and capable of operating at any controlled temperature between 850°F and 1400°F. The use of isothermal conditions will reduce mass transfer of major alloying elements and thus minimize their possible interference with carbon transport. Current data indicate that chromium, for example, has considerable influence upon carbon movement.
2. The system must have a large volume-to-surface ratio. The buffering effect of the large sodium volume will allow greater control of the carbon activity.
3. A flowing system is required. The UNC carbon meter to be used for measuring the carburizing potential of the sodium operates at 1400°F and must be located in a side arm. A sodium stream must therefore circulate through this arm.
4. The carbon activity of the sodium, as measured by the UNC and BNL carbon meters, must be controllable, and the system must permit changes in activity from levels causing slight decarburization to levels causing slight carburization.
5. The oxygen and hydrogen contents of the sodium must be controllable and measurable.

The design decided upon is shown schematically in Figure 4-4.

The CEL system is essentially a simple loop containing a pump, flow meter, and specimen tank. The major feature is the relatively large volume (0.8 ft³) specimen tank in which thin foil samples are exposed to the flowing sodium of known temperature, oxygen level, and carbon activity. Oxygen level is controlled by varying the temperature in a by-pass cold-trap line and measured using an electrolytic oxygen meter. Carbon level is controlled by

Figure 4-4. Schematic Diagram of CEL Loop System

either removing carbon with a zirconium hot trap or by adding carbon from a high carbon steel source. Both the carbon source and the carbon sink are in a second by-pass line, and both use the same heater and heat exchangers for temperature control.

Hydrogen level will be governed by the cold trap temperature. As the major portion of the work in the first year will be run at low oxygen (<10 ppm) levels, the resulting hydrogen level will be accepted as the base chemistry condition. The cover gas will be purged at a constant rate to remove hydrogen during operation. This will reduce the possibility of plugging the cold trap.

In the event that plugging does occur, the carbon meter will be shut off and the loop purged of hydrogen until the hydrogen level returns to a manageable level.

Carbon activities will be measured with a UNC and/or a BNL carbon meter. The meters will be located in a third by-pass line.

Work Program Preparation

Extensive effort was expended during the second quarter of the fiscal year on the preparation of the work program under Contract AT(30-1)-4169. The interstitial transfer program was identified in some detail together with cost estimates and milestone charts.

CURRENT PROGRESS

Experimental Plans

An experimental program covering the operation of CEL-1 and -2 was written. The tests, including shakedown, were arranged into five groups, which are to run consecutively. These are:

Group 1	Loop Shakedown
Group 2	Meter Shakedown
Group 3	Proof of Principle and Feasibility of Experimental Program
Group 4	Calibration of Carbon Meters against Iron Tabs
Group 5	Experimental Program. Determination of C_e Values (CEL-1) and Motivity Coefficients M (CEL-2)

The tests within each group and the objectives of the tests are given in Table 4-1. Series C1 and C2 refer to CEL-1 and CEL-2, respectively. Once CEL-2 comes on-line, both series will be run together. The initiation of

Table 4-1. Test Plan for CEL Systems			
Group No.	Test No.	Test Description	Objective
C1/1		<u>Loop Shakedown</u>	To bring loop (CEL-1) to operating status
	C1/1.1	Check flow control and maximum obtainable flow rate	
	C1/1.2	Check isothermality and temperature capability of main loop circuit	
	C1/1.3	Check flow and temperature control of hot and cold trap by-pass lines	
	C1/1.4	Check temperature distribution within sample tank	
C1/2		<u>Meter Shakedown</u>	To bring all impurity monitoring systems to operating status
	C1/2.1	Bring all meters and gas chromatograph into operation at loop nominal conditions. Check control and readout systems	
	C1/2.2	Calibrate oxygen meter against sodium analysis and cold trap temperature Note any response of carbon meters during this procedure	
	C1/2.3	Verify hydrogen control technique by sodium and cover gas analysis	
C1/3		<u>Proof of Principle and Feasibility of Experimental Procedures</u>	To determine that the system will operate and respond to changes as anticipated
	C1/3.1	Check isoactivity of sample tank using Fe tabs	
	C1/3.2	Determine meter response to A_c variations a) Zr Hot Trap followed by High Cold Trap Temp. Low C High O_2 b) Zr Hot Trap Low C Low O_2 c) Carbon Source High Cold Trap Temp. High C High O_2 d) Carbon Source Low Cold Trap Temp. High C Low O_2	
	C1/3.3	Determine time to equilibrium for Type 304 and verify theoretical estimates	
C1/4		<u>Calibration of Carbon Meters Against Fe Tabs</u>	To calibrate and characterize the carbon meters as a function of the carburizing potential and temperature of the sodium
	C1/4.1	Obtain calibration of meters as a function of C_e (Fe Tabs) and Temperature (Const O_2 and H_2 content)	
	C1/4.2	Calibrate BNL carbon meter as a function of meter operating temperature (Constant Loop operating conditions)	
	C1/4.3	Determine the effect of O_2 level on meter calibration	
C1/5		<u>Determination of C_e Values for All Materials</u>	To determine the value of C_e for each material as a function of temperature and carbon meter reading at constant oxygen level and meter operating temperature
	C1/5.1	Determine feasibility of exposing several materials together a) Determine meter reading vs C_e curve for Type 316 SS at one temperature b) Determine meter reading vs C_e curve for Incoloy 800 at one temperature c) Expose Type 316 SS and Incoloy 800. Compare curves with a) and b)	
	C1/5.2	Determine C_e vs meter reading vs temperature for all austenetic materials	
	C1/5.3	Determine C_e vs meter reading vs temperature for all ferritic materials	
C2/1		<u>Loop Shakedown</u> Procedure as for C1/1	Bring CEL-2 to operating status
C2/2		<u>Meter Shakedown</u> Procedure as for C1/2	To bring all impurity monitoring systems to operating status
C2/3		<u>Proof of Principle and Feasibility of Experimental Procedures</u>	To determine that the system will operate and respond to changes as anticipated
	C2/3.1	As for C1/3.1	
	C2/3.2	Determine meter response to A_c variations A limited sequence of tests based on C1/3.2 will be run	
C2/4		<u>Calibration of Carbon Meters Against Fe Tabs</u> Check runs will be made to verify calibration curves from C1/4	Calibration of carbon meters as a function of carburizing potential and temperature of the sodium
C2/5		<u>Determination of 'M' Values for All Materials</u>	To determine motivity coefficients 'M' for all materials as a function of T and to determine the effect, if any, of varying C_e
	C2/5.1	Measure 'M' as a function of temperature at constant carbon activity using two methods a) Measure C for thin tabs as a function of time. (lower temps) b) Measure interstitial gradient in thick tabs. C_e at the surface will be obtained from the equilibrium tabs. (higher temps)	
	C2/5.2	Measure M at different A_c level to identify differences if any	

any group of tests depends on the data from the previous group. If any group of tests indicates that changes in design or technical approach are required, the test plan will be adjusted accordingly.

Facilities

Loop Design and Fabrication - The design of the CEL system was finalized and completed early in this reporting period, and all drawings were detailed. The control panel design and cover gas system designs were also completed. Control panel components were ordered against a Westinghouse capital expenditure order.

A System Design Description (SDD) was written and submitted to the AEC with the appropriate drawings. The SDD covered, in some detail the design philosophy, the objectives and the basic design requirements needed to meet these objectives. Operating procedures and safety requirements were also covered. All loop components and their functions were identified.

An isometric drawing of a CEL system is shown in Figure 4-5. The various components are identified in the figure.

The loading and retrieval system is shown in Figure 4-6. This system consists of two chambers separated by a ball valve. The lower chamber is welded to the upper end of the locating tubes which penetrate the head of the sample tank. The upper chamber is closed by means of a teflon "O" ring. Both chambers are purged with argon.

Thin foil samples ($\sim 9 \text{ in.}^2$) are kept two to a sample holder. The sample holders are stacked three or four high in each of the three locating tubes in the sample tank, allowing exposure of up to 18 specimens at one time.

To load the specimens the top closure is removed and the end of the sample rod is screwed into the threaded hole at the top of a sample holder. The holder is lowered into the upper chamber which is then sealed and purged with argon. The specimen system is then preheated to 300°F before opening the ball valve and lowering the specimen holder into the locating tube. A keyway on the holder prevents rotation while the rod is unscrewed. The rod is withdrawn into the upper chamber and the ball valve is closed. The reverse procedure is followed for specimen removal.

There are several safety devices incorporated in the construction of the loop system which protect it from excessive damage in the event of a component failure. The isometric projection (Figure 4-5) shows how, with appropriate valve settings, the loop will completely drain under gravity into the dump tank. Loop dumping may be triggered by the detection of smoke in the exhaust system, the recording of an excessively high temperature at any one of several critical points around the loop circuit, or the registering of an abnormally low flow rate or low cover gas pressure.

Figure 4-5. Isometric Projection of CEL

Figure 4-6. Loading System for CEL Samples
3654-5

Panel alarms are both audio and visual, and besides indicating the general area of malfunction they will:

1. Automatically shut off all power to a system and "dump" the sodium.
2. Back fill the loop with a continuous supply of low-pressure, high purity argon.

High pressure switches automatically vent excessive pressure from an operating loop, and back-up power supplies prevent a system from dumping for five seconds after a power outage, to guard against momentary mainline fluctuations.

Because of a delay in the release of AEC funds for the procurement of materials and construction of the CEL loops, the program is unavoidably six to eight weeks behind schedule. Construction of the first CEL loop should still be completed before the end of this fiscal year instead of by the end of April as originally scheduled. At this time two dump tanks are under fabrication, one containment framework has been completed, and the second is almost complete.

All components have been installed in the control panels except for the long lead items such as recorders.

Power distribution services are currently being installed and will be available when the loops are installed.

On Line Metering - Detailed schedules for purchase and installation of on-line sodium impurity meters were drawn up. Meters which were originally intended for use were as follows:

1. UNC diffusion carbon meter
2. BNL electrochemical carbon meter
3. Electrochemical oxygen meter
4. UNC electrochemical hydrogen meter

Inquiries showed the first three of these to be available. In the case of the UNC carbon meter, an instrument owned by the USAEC was to be transferred from MSAR. The UNC hydrogen meter was considered at a stage of development that made its use premature in this program.

Panels for control and readout of the meters for CEL-1 and -2 were designed, and requests for purchase of equipment was made.

The present status of various items is as follows:

1. Delivery was made of the UNC carbon meter from MSAR; transportation produced no obvious damage to the two control consoles. Some difficulty was experienced by MSAR during removal of the sensing probe from the side loop. A flow defining orifice broke from the end of the probe, apparently because it was galled in position or held by corrosion products. The entire side loop is heavily carburized, since it has been exposed to sodium of high carbon content for long periods.
2. A firm bid has been received from UNC on two carbon meter side loops and probes. Since this exceeds \$10,000, request for approval by AEC, NYOO has been made.
3. Bids on electrochemical oxygen meters and the BNL electrochemical carbon meters are either under review or awaited.
4. Bids on voltage readout and display equipment for these meters have been reviewed and orders placed.

The critical items at present appear to be the UNC carbon meter side loops which have a quoted delivery date of four months.

On March 23, 1970 a seminar at BNL on the electrochemical carbon meter was attended by WARD personnel. Information on the design, development, and performance of the meter was presented. In subsequent discussions, points relevant to installation of the meters in the Carbon Equilibrium Loops at WARD were discussed.

Control of Hydrogen from the UNC Carbon Meter

Hydrogen insertion into the Carbon Equilibrium Loops via the UNC carbon meter is of some concern. The simplest alternate to cold trapping, as a means of removing this hydrogen, is cover gas stripping achieved by flowing argon over the sample tank sodium surface. Calculations were made on performance and conditions to be expected. An expression for the rate of removal of hydrogen from a sodium loop was derived:

$$\left(\frac{-dC_H}{dt}\right) W = wE(C_H - C_{Hi}) + \frac{P_{HT}}{P_{Ar}} \left(\frac{C_H}{C_{HT}}\right)^2 \frac{273}{T_C} \frac{vMF}{V} - K (C_{H \max} - C_H) + \frac{273}{VTd} \left[\left(P_{HT}\right)^{1/2} \frac{C_H}{C_{HT}} - \left(P_{Hatm}\right)^{1/2} \right] \quad (1)$$

Where:

W = the mass of sodium in the system

w = the mass flow rate of sodium through a cold trap

E = cold trap efficiency = $\frac{C_H - C_{He}}{C_H - C_{Hi}}$

C_H = hydrogen concentration in the main loop

C_{He} = hydrogen concentration at the cold trap exit

C_{Hi} = saturation solubility of hydrogen in sodium at cold trap temperature

T = sodium temperature in the main loop

P_{HT} = dissociation pressure of NaH at temperature T

v = cover gas flow rate at pressure P_{Ar} in the sample tank

C_{HT} = saturation solubility of hydrogen in sodium at temperature T

M = molecular weight of H_2

V = gram molecular volume

T_C = cover gas temperature in the sample tank

F = cover gas stripping efficiency = (fraction of equilibrium hydrogen pressure reached in cover gas)

K is a constant

C_{Hmax} = loop hydrogen concentration at which no hydrogen enters from UNC meter

R = permeability coefficient of steel at temperature T , for hydrogen

A = surface area of steel in the loop

d = thickness of steel in the loop

P_{Hatm} = partial pressure of hydrogen in the atmosphere

At equilibrium, $\frac{-dC_H}{dt} = 0$, and Equation 1 becomes:

$$wE(C_H - C_{Hi}) + \frac{P_{HT}}{P_{Ar}} \left(\frac{C_H}{C_{HT}} \right)^2 \frac{273 \text{ vMF}}{T_C V} + \frac{273 \text{ MRA}}{VTd} \left[\left(P_{HT} \right)^{1/2} \frac{C_H}{C_{HT}} - \left(P_{Hatm} \right)^{1/2} \right]$$

$$= K (C_{H \text{ max}} - C_H) \quad (2)$$

In Equation 2, the first term is a cold trapping removal term, the second a cover gas stripping term, the third covers permeation through steel containment, and the fourth (right hand side) is the hydrogen source term.

In the derivation, uniform hydrogen concentration is assumed throughout the main loop, and it is assumed that hydrogen in sodium obeys Sievert's law. Meacham's data on solubility and dissociation pressure of sodium hydride^[2] is used, and this does conform closely to Sievert's law. An estimate was made of loop surface area, and the data of Bennek and Klotzbach^[3] for hydrogen permeation through steel is used. Hydrogen source term data are taken from the UNC Carbon Meter, Final Report.^[4] Inserting this information and values for anticipated CEL working conditions at 800°F, with cold trap at 240°F and a cover gas flow of 1 ft³/hr, Equation 2 reduces to:

$$(5.074 \times 10^{-5}) C_H^2 F + (1.055 \times 10^{-3}) C_H - (6.33 \times 10^2) E - 6.39 \times 10^{-4} = 0 \quad (3)$$

Equation 3 demonstrates the following points:

1. Cold trap in circuit - Cold trapping determines completely the equilibrium hydrogen content in the loop, even at very low trapping efficiencies (e.g., when $E = 10^{-3}$). If the cold trap is at or below 425°F, hydrogen permeation from air becomes an additional source term.
2. Cold trap out of circuit - With no cold trapping ($E=0$), cover gas stripping and permeation through steel containment both contribute to hydrogen removal. Hydrogen activity in the loop always rises above that in air so that permeation becomes a removal mechanism.
 - a. At 800°F, cover gas stripping is the dominant mechanism, providing the efficiency is high ($F \approx 1$). At 1100°F, cover gas stripping is comparable with permeation, and at 1400°F permeation dominates. These points are illustrated in Figure 4-7 where the hydrogen content of sodium is plotted against cover gas stripping efficiency. The case where permeation is omitted from consideration is also included.
 - b. Hydrogen partial pressure in the cover gas corresponding to the conditions in Figure 4-8 can be calculated from

$$P_{HT} \left(\frac{C_H}{C_{HT}} \right)^2$$

Figure 4-7. Effect of Cover Gas Stripping and Permeation on Hydrogen Content of Sodium

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Figure 4-8. Effect of Stripping Efficiency and Permeation on Cover Gas Hydrogen Content

3654-7

Hydrogen concentrations in the cover gas are plotted against stripping efficiency in Figure 4-8. It is concluded that control of hydrogen level in the sodium could be achieved by cold trapping. For those circumstances when trapping would not be possible, cover gas stripping would be useful, particularly at the lower sodium temperatures. At higher temperatures, permeation usefully supplements hydrogen removal in a region where difficulties might be experienced in excluding sodium vapor from the flowing argon. Monitoring of cover gas by gas chromatography can provide a general guide to conditions in the sodium, but hydrogen in sodium analyses are still required. Purchase of an elaborate instrument is not warranted in view of the acknowledged difficulties of measuring hydrogen in cover gas because of recombination of hydrogen and sodium in cool regions. Purchase of a simple gas chromatograph has been initiated.

Sodium Sampling and Analysis

A trip was made to ANL to determine requirements for control, approval, and implementation of ARD Sodium Analysis Procedures. For background information and as a basis for discussion, a summary of existing ARD procedure was sent to ANL prior to the visit. It was agreed that ARD would submit detailed descriptions of analytical procedures and ANL will acknowledge receipt of these to RDT and review them. Submittals on oxygen analysis by amalgamation, hydrogen analysis by vacuum refluxing, and bypass sampling procedures will be staggered through April. Supporting data are still being obtained for carbon by total combustion, for nitrogen by Kjeldahl distillation, and for oxygen by on-line vacuum distillation. Submittals on these have therefore been deferred to a later date. Establishment of preferred analytical procedures will be by a committee composed of representatives from the industrial contractors and ANL. The need for this committee is considered urgent by ARD.

Status of Program

Vendors were identified for all thin foil specimen materials. Some difficulty was experienced in obtaining 0.003-inch foil of the 2-1/4 Cr - 1 Mo alloy, but Carpenter Steel Corp., Reading, agreed to prepare the foil as a special order. This necessitates accepting up to 500 pounds of the alloy. Such an amount is the minimum billet weight required before hot rolling and subsequent cold rolling can be successfully performed. About 200 pounds will be delivered as 0.003-inch foil, 6 inches wide. The remainder will be accepted as sheet and foil varying in thickness between 0.003 inches and 0.10 inches thick, 0.10 inches being the final hot roll thickness prior to the cold reduction sequence. The materials, suppliers and status of delivery are given in Table 4-2.

The Type 316L stainless steel and the Armco Iron strip have been received and are currently being evaluated chemically and metallographically. Analysis will be principally for carbon and nitrogen, but check analysis will be run on the vendors chemical analysis data.

To date twelve carbon and three nitrogen evaluations have been performed on the Type 316L stainless steel sheet, and one set of carbon data is available for the Armco iron. The Type 316L stainless steel specimens were submitted three at a time. The maximum variation of carbon analysis within any set of three was 26 ppm, and the minimum was 4 ppm. The total variation, however, was 56 ppm. The inference from the analysis data in Table 4-3 is that there is some analytical or operator variation for each set of analyses.

Table 4-2. Delivery Schedule for Specimen Materials

Material	Weight	Supplier	Delivery Date	
Type 316L	52 lbs.	Williams & Co.	2.13.70	Received
Type 304L	100 lbs.	Williams & Co.	4.3.70	
Incoloy 800	55 lbs.	Williams & Co.	4.30.70	
Armco Iron	8.8 lbs.	Hamilton Precision Metals	3.18.70	Received
2-1/4Cr-1Mo	500 lbs.	Carpenter Technology	6.15.70	

Table 4-3. Carbon Analysis For-As Received Type 316L Foil

Specimen	Group and Carbon Content (ppm)			
	1	2	3	4
A	225	181	210	201
	220	181	209	200
B	220	185	---	202
	237	185	208	199
C	213	191	210	197
	211	195	216	200
Mean	223	186	210	200
Variation	26	14	7	4

Nitrogen analyses ranged from 477 ppm to 584 ppm. Further analyses for nitrogen are being run. The carbon content of the Armco iron was determined as 107-113 ppm.

Metallagraphic examination of both normal and low angle taper sections from this Type 316L stainless steel revealed a fine equiaxed grain structure (ASTM grain size 8). The surface appeared clean with no visible contamination at the foil edges. The average hardness was 153 D.P.H.

Examination of polished normal and low-angle taper sections showed an elongated grain structure containing two distinct types of impurity in the Armco iron foil. One was dark, relatively soft and nodal in form, similar to sulphide inclusions common in low-alloy steels. The second type was bright, angular, and much harder than the matrix, standing out in high relief. These latter inclusions were irregular, angular, and appeared to have been fractured during rolling. It is doubtful that these particles were picked up from mill surfaces since they are observed throughout the thickness of the foil. Chemical analysis of the foil is under way, and this will provide further information on the extent and nature of these impurities.

SECTION 5

NCAA-300 SODIUM CORROSION OF WELDMENTS AND BRAZEMENTS

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OBJECTIVES

The purpose of this task is to provide quantitative sodium corrosion data from welded and brazed joints exposed under conditions simulating actual LMFBR sodium environment. The values of the variables of the temperature gradient (ΔT), temperature, oxygen content, and sodium flow rates will be selected so that they bear the maximum resemblance to actual service conditions; i.e., conditions under which material mass transfer would take place.

The principal facility to be used in this program will be the Weldment and Brazement Test Loop, WBTL (see Figure 5-1) which is already operating at WARD. It has been designed with five test section locations capable of operating at five different temperatures to simulate temperature gradients in the LMFBR plant. Sodium flow rates may be varied in each of these test sections up to a maximum of 40 fps, depending on the number of test sections installed and sample geometry. The maximum pumping capacity is 5 gpm.

Jointures to be studied in this program will include the following:

1. Prototypical 316 stainless steel and Inconel 718 welded and brazed fuel pin spacer grid joints.
2. Simulative fuel pin end closure welds (Type 316 stainless steel) made by autogenous TIG fusion welding. Some samples containing deliberate defects will also be evaluated.
3. Flat sheet specimens of welded Type 304 stainless steel and Type 316 stainless steel both with and without filler metal and weld overfill or overpenetration.
4. Simulative tube-to-tubesheet welds for the intermediate heat exchanger (IHX) and steam generator.
5. Butt and fillet brazed samples of core structural materials including Type 316 stainless steel and Type 304 stainless steel.
6. Wire wrap attachments.
7. Instrumentation jointures.

Exposure temperatures will be between 700-1300°F for minimum durations of 2000 hours.

Figure 5-1. Isometric Drawing of the WARD Weldment and Brazement Sodium Loop System (WBTL)

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In the testing program, welded and brazed fuel pin spacer grid joints and simulated end closure welds will be tested initially, since corrosion tests on specific designs have been identified in an existing program, under Task OFBA-313 of Contract AT(30-1)-4135.^(a)

In addition, it is recognized that the tests planned in this Task and Task NCAA-400 Mechanical Properties of Materials in Sodium should be designed to provide inputs for, and correlation with, the tests planned for Task NCAA-600 Mechanical Properties of Components in Sodium.

BACKGROUND

Existing sodium corrosion programs aimed at providing engineering data for LMFBR design optimization are primarily devoted to studies of reference base materials. Particular emphasis is placed on 316 stainless steel and 304 stainless steel because of their obvious importance as reference core and IHX materials. However, since the LMFBR cannot be fabricated without the use of metals joining techniques, there is also an incentive to evaluate sodium corrosion of the joints produced by these techniques in reference LMFBR base materials. A primary classification of metals joining techniques can be made between welding and brazing. Since welded joints will dominate in LMFBR fabrication, these joints will be considered first.

The variety of detail weld configurations that will be exposed to sodium in an LMFBR will range from 3-4-inch thick containment vessel welds to fuel rod end closure welds in tubing of less than 0.015-inch wall thickness. In previous experience with sodium cooled reactors, preferential sodium corrosion of welded regions has not been identified, but only very limited data are available on the sodium corrosion of welds at reference LMFBR temperatures.

Tests have been made at ANL^[5] on butt welded 304 stainless steel pipe with 308 stainless steel filler metal in 1200°F flowing sodium. These tests were very limited and results that were reported could not be used for design purposes. Ratz and Brickner^[6] have also examined samples of welded 304 stainless steel exposed to high temperature sodium, but, again the results were very limited; sodium impurity levels, flow rates, and detailed weld metal observations were not reported. Although qualitative and limited quantitative evidence to date is encouraging, there are still several questionable areas concerning the performance of welded joints in high temperature flowing sodium. This topic is discussed in detail below.

When a welded joint forms a part of a component intended for service in sodium, there may be five major differences between the joint and the surrounding base metal.

1. Where filler metal is used there will usually be a difference in chemical composition; e.g., 308 stainless steel filler metal has a different composition than 304 stainless steel base metal.

^(a) See WARD-4135-8, "Oxide Fuel Element Development Quarterly Progress Report for the Period Ending March 31, 1970."

2. The weld metal will always exhibit a different microstructure than that of the base metal. This will be the case even when no filler metal is used during welding. Segregation and precipitation in the dendritic weld metal structure will give rise to non-uniform composition gradients that could have a marked effect on the sodium corrosion performance of the joint.
3. The heat affected zone structure of the welded joint will exhibit a different microstructure to that of both the weld and base metal. In stainless steels the precipitation of carbides and larger grain size in the heat affected zone may also have an effect on the sodium corrosion rate of the joint.
4. In many welded joints there will be unavoidable geometrical perturbations associated with normally acceptable over-penetration or undercut. Both these features could disturb the local sodium flow path and therefore change the sodium corrosion rate. In the case of over-penetration, turbulent flow may be generated in the joint region to cause an increase in the sodium corrosion rate immediately downstream of the weld. Furthermore, the over-penetrated part of the weld bead may corrode at a faster rate than normal because of its effect on the sodium flow path. If this corrosion occurred by overall surface removal, the over-penetration would be gradually removed, along with its adverse effects on the sodium flow path. However, if corrosion occurred by selective leaching at the dendrite boundaries, the weld would develop cracklike flaws and would still cause a disturbance in the sodium flow path. In the case of undercut, sodium corrosion at the fusion boundary of the weld would have to be considered. The complex composition gradients in this region are therefore added to the problem of predicting the sodium corrosion rate at a notch-like flaw.
5. The residual stress distribution at a welded joint will be different to that of the surrounding base metal. Tensile residual stresses in the heat affected zone are common to many types of welded joints and may increase the corrosion rate in this region.

Having considered the differences between welded joints and base metal, as related to sodium corrosion, it remains to define a program to fill the information gaps that have been identified. It is proposed that most of this program will be concerned with small prototypical welded samples that would simulate the joints in critical reactor components. Particular emphasis will be placed on welds in thin materials. The basic justification for this approach is that since sodium corrosion is principally a surface phenomenon, the corrosion mechanism will be similar for both thick and thin materials; but the weight loss or mass transfer could more easily reduce the effective cross sectional area of thin materials to below design limits.

The approach for providing information on the compatibility of brazing alloys with sodium has been defined in the LMFBR Program Plan^[7] as follows:

"Existing information will be reviewed to determine if additional sodium compatibility data are needed. If so, an experimental program plan will be prepared for AEC approval and performed after such approval." The existing available data on this topic have already been reviewed at ARD. These data have only limited application to materials selection for LMFBR core service because of the differences between the corrosion test conditions and expected LMFBR conditions. Nevertheless, these previous evaluations are extremely useful screening tests and facilitate the selection of potential alloys meriting further investigation.

Unfortunately, sodium corrosion is not the only criterion for selection of brazing alloys for LMFBR. The effects of the brazing thermal cycle on the base metal properties must also be considered, particularly when thin materials are being joined and grain growth could result in single grains across the complete thickness. Furthermore, several of the most attractive alloys, from a sodium corrosion viewpoint, contain small amounts of boron that may cause unacceptable embrittlement of the base material during LMFBR service. On the basis of the above considerations, Nicrobraz 50, 77Ni-13Cr-10P, (Brazing temperature: 1875°F), has been selected as being the most promising brazing alloy for LMFBR service, with Coast Metals 52 and 53 as alternates if boron containing alloys can be used, and, Coast Metals NP as an alternate if higher brazing temperatures (2150°F) can be used without having a deleterious effect on the base material.

In the planning of this corrosion evaluation program, considerable significance will be placed on input from the following sources:

1. The LMEC program, the objective of which is to identify and document materials design requirements in the LMFBR program.
2. A recent BMI report on LMFBR component designs, emphasizing, evaluation of weldments, and brazements in sodium.^[8]
3. Current work at ARD on Contract AT(30-1)-4135 in connection with material properties under LMFBR conditions and weldment and brazement corrosion of sub-assembly grids.
4. Other materials information, particularly on specific weldments and brazements, from LMFBR and FFTF design studies.

PRIOR WORK

The selection of brazing alloys for service in sodium has been studied at ORNL,^[9] AI,^[10] UKAEA,^[11] and CEN-EURATOM.^[12] The main reasons these previous evaluations cannot be applied to brazing alloy selection for LMFBR service are presented in Table 5-1.

A literature survey indicated that several fuel rod support grid brazing alloys, including Nicrobraz 50, were potentially the most suitable for

Table 5-1. Main Reasons Why Previous Brazing Alloy Sodium Corrosion Evaluations Cannot be Directly Applied to LMFBR Materials Selection

Evaluation Reference	Test Conditions Which Invalidate Direct Application of Results to LMFBR Materials Selection	Comments
ORNL ^[9]	<ol style="list-style-type: none"> 1. Test temperature was higher than that expected in LMFBR. 2. No controlled sodium flow was maintained. 3. Tests were essentially isothermal. 4. Test duration was only 100 hours. 5. Oxygen content of sodium was not reported. 	<ol style="list-style-type: none"> 1. Compared to LMFBR conditions these tests would indicate a greater corrosion rate, mainly because of the higher temperature of testing. 2. Since the oxygen content of the sodium was probably higher than expected in LMFBR, then the Fe bearing alloys would be graded pessimistically in comparison to the Fe-free alloys. 3. The static sodium in the tests would not dissolve Ni and Cr as quickly as flowing sodium.
AI ^[10]	<ol style="list-style-type: none"> 1. There was virtually no sodium flow. 2. The oxygen content was estimated to be higher than that expected in LMFBR. 	<ol style="list-style-type: none"> 1. It is thought that these test conditions would be less severe than those in LMFBR because the sodium in the loop was virtually static, thereby, making it comparatively difficult for Ni and Cr dissolution to occur. 2. The higher oxygen content in the tests would facilitate Fe dissolution in comparison to expected LMFBR conditions.
UKAEA ^[11]	<ol style="list-style-type: none"> 1. Temperature gradients were not reported. 	<ol style="list-style-type: none"> 1. These tests probably more closely simulate LMFBR conditions than any of the other tests.
CEN-EURATOM ^[12]	<ol style="list-style-type: none"> 1. Flow rate was lower than that expected in LMFBR. 2. Oxygen content of the sodium was not reported. 	<ol style="list-style-type: none"> 1. The corrosion results were purely qualitative.

further sodium corrosion evaluation, prior to a selection being made for the Westinghouse LMFBR design application. Accordingly, a sodium test loop WBTL-1, was constructed to examine the behavior of small sections of brazed grid joint configurations. The loop is designed to operate at a maximum temperature of 1230°F at flow velocities up to 40 fps and at a maximum pressure up to 70 psig. The dump tank contains ~20 pounds of sodium, but the sodium inventory in the loop during a run is only about 10 pounds. All construction materials, wherever possible, are Type 316 stainless steel.

The WBTL is essentially a simple sodium loop system containing an EM Pump, flow meter, and specimen test sections. The major features are the five stainless steel test sections, in which samples are exposed to flowing sodium at predetermined temperatures, flow rates, and oxygen content.

The piping layout for the WBTL system is shown isometrically in Figure 5-1 and schematically in Figure 5-2. Referring to Figure 5-2, sodium is supplied to the low temperature (900°F) test sections (1 and 2) by an electromagnetic pump, A. It then passes through the tube side of economizer, B, and the main heater section prior to entering the high temperature test sections. After passing through the high temperature test sections (3, 4, and 5), the sodium flows back to the pump via the shell side of the economizer, an air heat exchanger, C, and a flowmeter, D. Trace heaters are attached to all piping in the main circuit. The entire system is drained and filled from the dump tank, E.

The oxygen level is controlled by intermittent cold trapping using the cold trap, F. The cold trapping temperature is achieved by passing the sodium through an air blast heat exchanger, prior to entering the cold trap. The cold-trapped sodium is returned to the mainstream flow between the air-heat exchanger and flowmeter where it regains mainstream temperature. A sodium sample line, G, is also present as a by-pass line just prior to the air heat exchanger. Expansion of the sodium is accommodated by means of the expansion tank, H. The expansion tank also acts as a sodium reservoir which is depleted each time a sodium sample is taken.

In the first loop run, WBTL-1, simulated fuel pin grid type samples illustrated in Figure 5-3 were held in stainless steel sample holders in the stainless steel tubular test sections. There were twenty-four samples in their respective sample holders between each of which was a stainless steel spacer piece. Velocity variation in any one test section is achieved by varying the sample size and cross sectional flow area in the test section. A keyway on the sample holders and spacers prevents rotation within the test section. In Figure 5-4, these components are shown immediately prior to assembly into the loop. Sample retrieval (at the completion of the loop run) was achieved by draining the sodium into the dump tank, backfilling the system with high-purity argon, and physically removing each test section from the loop after the system has cooled to room temperature. Any residual sodium was removed by reaction with alcohol.

The material combination, Inconel 718-Nicrobraz 50 was selected for this initial run (WBTL-1). The respective compositions are Inconel 718: (53-Ni-19Cr-18Fe-5Nb-3Mo-1Ti-0.5Al) and Nicrobraz 50: (77Ni-13Cr-10P). The system parameters investigated were:

Figure 5-2. Weldment and Brazement Sodium Corrosion Loop System (WBTL)-
Schematic Layout

3654-9

DIMENSIONS (in.)			
ITEM	A	B	C
1	0.242	0.260	0.428
2	0.270	0.291	0.459
3	0.445	0.493	0.661

NOTE: ITEMS 1, 2 AND 3 REFER TO HIGH, MEDIUM AND LOW VELOCITY SPECIMENS RESPECTIVELY.

Figure 5-3. Weldment and Brazement Test Loop Specimen Design (WBTL-1)

Figure 5-4. WBTL-1 Test Section and Grid Type Test Samples Prior to Assembly

Maximum temperature	1230°F
Maximum temperature difference	300°F
Sodium velocity	13-1/2, 9-1/2, 3 fps
Time of exposure	3500 hr

During the course of this initial loop run, a reorientation of the weldment and brazement program was made as a result of changes in the grid design philosophy. Emphasis has since reverted to a spot welded Type 316 stainless steel joint configuration. The next loop run WBTL-2, has therefore been redesigned to accommodate the change in emphasis, and work on WBTL-2 has been charged to the Oxide Contract AT(30-1)-4135, Task OFBA-313.

During November/December 1968, a work program detailing scope of work, costs, and schedules for the balance of FY-1970 for this particular task was prepared under Contract AT(30-1)-4169 and submitted as part of the work program on Contract AT(30-1)-4173 to the USAEC. Comments on this document will be used to make any necessary changes prior to submission of the final document.

CURRENT PROGRESS

A System Design Description (SDD) for the Weldment and Brazement Test Loop (WBTL) has been prepared at the request of the USAEC. This report has been submitted to the Coolant Chemistry Group, USAEC for approval.

Work being charged to this task includes evaluation of the brazed grid samples from WBTL-1 and design of the samples and test sections for the next run, WBTL-3, which will commence operation early in FY-1971.

WBTL-1

Due to limited funding in FY-1970, characterization of WBTL-1 samples is limited to evaluation of the validity of the experimental designs used in the loop system as a necessary input to the design of the next run, which must be completed by the end of FY-1970. The weight changes obtained on the WBTL-1, unbrazed Inconel 718 control samples exposed to sodium for 3500 hours at 900 and 1230°F, are shown as a function of sodium velocity in Figure 5-5. Noteworthy features include:

1. The weight changes increase with velocity increase from 3-1/2 to 9 fps, but the weight changes at 13 fps are lower than those observed at 9 fps.
2. This velocity effect is consistent at 900, 1200, and 1230°F.
3. Differences in observed weight changes for two test section samples at the same temperature; e.g., No. 1 and 2, and No. 3 and 4.

Figure 5-5. Relationship Between Weight Change and Flow Rate for Unbrazed Samples of Inconel 718 (3500 hours exposed to <10 ppm Oxygen-Sodium, WBTL-1)

This weight change data for the unbrazed control samples of Inconel 718 may be compared with the data reported by Thorley and Tyzack.^[11] WARD obtained values of -2.6 mg/cm (~ 0.2 mpy) after 3500 hours exposure to sodium (3-1/2 to 13 fps) at 1230°F as compared to anticipated values based on the above mentioned workers data of ~ 2 mpy at 40 fps. The corrosion rate of Nimonic 80A ($\sim 75\text{Ni}$) exhibits a velocity dependence over a range up to 40 fps. If it is assumed that Inconel 718 ($\sim 53\text{Ni}$) exhibits a similar velocity dependence, then Thorley and Tyzack's single data point for an Inconel 718 type alloy (i.e., ~ 50 w/o Ni) (~ 3000 hr at 1200°F - 40 fps, <10 ppm O_2) can be extrapolated to yield a corrosion rate of ~ 0.5 mpy at sodium conditions approaching those in WBTL-1. Downstream effects on corrosion rate further reduce this value. This effect can also be used to satisfactorily explain the observed differences in weight change recorded for specimens at the same and at increasing velocities in WBTL-1 on the basis of distance downstream from the heater exit.

The weight change data on the brazed samples from loop run WBTL-1 indicated that the high temperature samples lost weight, and the low temperature samples gained weight. This data reduction is in progress.

Metallographic characterization of both the sodium exposed and unexposed control samples of Inconel 718 is in progress. This work is aimed at understanding the microstructural changes produced in this alloy as a result of the heat treatment undergone prior to insertion in the loop system. These observations will then be used to evaluate the changes observed in the WBTL-1 samples as a result of sodium exposure. X-ray analysis data obtained during a scanning electron microscopic examination^(a) of these same corroded WBTL-1 samples indicated that nickel and chromium had been removed from the surface, in contact with sodium. Indications were also obtained that nickel and phosphorus had been removed from the Microbraz 50 section of the grid samples; chemical analyses of samples of the braze material are awaited from WARD Technical Service Laboratories. In Figure 5-6 some preliminary metallographic observations are illustrated for typical brazed samples before and after sodium exposure. This work is continuing.

WBTL-2

The second run (WBTL-2) on welded 316 stainless steel grids and fuel rod end closure welds, currently in progress, is being charged to task OFBA-313 on Contract AT(30-1)-4135, Oxide Fuel Element Development, since it is in direct support of a grid design to be utilized in 37-pin grid-type subassemblies to be irradiated in EBR-II. In this run, in addition to the primary task of examining the behavior of spot welded grid-type samples in sodium, a few brazed joints and simulated end closure weld samples are also being tested. All materials are Type 316 stainless steel. This loop system has logged approximately 1250 hours to date under operating conditions. The behavior of welds in both annealed and cold worked stainless steel after exposure is being examined. Unwelded samples are included for comparison purposes. A limited number of end closure welds containing a known defect are also being tested. One test section contains brazed grid samples, for some of which a post brazing sensitization treatment has been included prior to exposure to sodium. Table 5-2 details the type of samples tested under each set of conditions.

(a) Work performed at Westinghouse Research Laboratories by G. A. Whitlow and E. Berkey.

(a) UNEXPOSED

UNETCHED 50X

(b) EXPOSED

UNETCHED 50X

Figure 5-6. Cross Section of Inconel 718-Nicrobraz 50 Fuel Pin Grid-Type Sample (a) Before and (b) After ~3500 Hours Exposure to Flowing Low Oxygen Sodium at 1230°F

3654-13

Table 5-2. Weldment and Brazement Sodium Corrosion Test
Program (WBTL-2) For Type 316 Stainless Steel

Test Section Numbers	Temp. (°F)	Flow Rate (fps)	Samples to be Tested at Each Flow Rate				
			Type	Joint	Condition	No.	Total
3	1230	13-1/2,9-1/2,3	Grid	Welded	CW	3	24
				Welded	A	3	
				Not Welded	CW	1	
				Not Welded	A	1	
2	900	13-1/2,9-1/2,3	Grid	Welded	CW	3	24
				Welded	A	3	
				Not Welded	CW	1	
				Not Welded	A	1	
5	1200	13-1/2	End Closure	Welded	CW	5	16
				Welded	A	5	
				Welded	CW,D	2	
				Welded	A,D	2	
				Not Welded	CW	1	
				Not Welded	A	1	
1	900	13-1/2	End Closure	Welded	CW	5	16
				Welded	A	5	
				Welded	CW,D	2	
				Welded	A,D	2	
				Not Welded	CW	1	
				Not Welded	A	1	
4	1230	13-1/2,9-1/2,3	Grid	Brazed	A	4	24
				Brazed	A+S	2	
				Not Brazed	A	1	
				Not Brazed	A+S	1	
CW: Cold Worked Material. A: Annealed Material. D: Samples with deliberate weld defects. Not Brazed: These samples - same brazing temperature cycle without braze metal. S: After brazing these samples were sensitized (1400°F for one hour-rapid cool argon).							

In addition, control samples have also been fabricated. These are being thermally aged in vacuum for comparison purposes.

WBTL-3

Discussions have been held with staff from WARD Mechanical Development and Thermo Fluids Groups (LMFBR Project) regarding the design requirements for the next run in the Weldment and Brazement Loop (WBTL-3). Considerable interest has been expressed in cavitation and cavitation damage effects, which may occur under appropriate sodium conditions in the vicinity of the fuel rod support grids. Consideration is presently being given to a test section design using a single 37-pin type grid cell equipped with a dummy fuel pin which would be tested at sodium velocities of the order of 40 fps. Other factors such as gas entrainment in the sodium and its effects on the onset of cavitation are being considered. At this stage it seems likely that the redesigned loop system WBTL-3 will be a high velocity system with several short term replaceable test sections or legs and several long term test sections.

SECTION 6

NCAA-400 MECHANICAL PROPERTIES OF STRUCTURAL MATERIALS IN SODIUM

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OBJECTIVES

The objective of this task is to obtain experimental mechanical property data for FFTF and LMFBR structural materials exposed to flowing sodium, such that meaningful corrosion allowance limits may be applied by the designers. Effects of sodium exposure at typical reactor conditions on the mechanical properties of the materials will be evaluated in terms of pre-exposure temperature and time and different surface to volume ratios for the materials. Long term mechanical property tests such as stress relaxation, creep-rupture, and strain-cycle fatigue will be performed primarily in flowing sodium in order to retain the surface condition for the material developed during pre-exposure. Evaluations from this work are intended to provide base line information in support of the Special Components Mechanical Properties in Sodium Program (NCAA-600).

BACKGROUND

Alloys exposed to the dynamic sodium environment expected in FFTF and LMFBR operation are subjected to mass transfer. Selected alloy constituents of the structural and cladding materials are moved from areas of high chemical potential to areas of low chemical potential. The effect of this process is to literally transform the exposed surfaces of structural and cladding materials from one alloy to one of a different composition. The rate at which this process proceeds is the heart of the compatibility or corrosion study programs; but the effects of this process, particularly where high temperature and small cross sectional areas of structural materials are involved, are of particular concern with regard to mechanical behavior.

Recent studies on samples subjected to reasonably long exposure times have shown an influence of sodium on the mechanical properties:

1. At AI, ^[13] pressurized Type 304 stainless steel tubing (0.010-inch wall) was tested in sodium at 1400°F with zirconium foil added to reduce the oxygen level of the sodium. In less than 1000 hours the carbon content was found to be reduced by 30 to 50% (initial value 0.060%C) with the result that the creep rupture strength was reduced by 25% as compared with tests on the same material in a helium environment.
2. Bohm and Schneider ^[14] evaluated the influence of liquid sodium on creep and stress-rupture properties of two austenitic steels at 1292°F. These tests were performed using sodium filled tubes (0.016-inch wall) under uniaxial stress. The secondary creep

rate was not influenced by sodium whereas the tertiary creep stage was shortened, resulting in a 50% reduction of total strain to fracture. For one steel, the time to rupture was also decreased by the sodium exposure.

3. At MSAR, [15] the mechanical properties of Types 304 and 316 stainless steel in sodium at 1200°F have been studied. Initial tests were performed where the velocity was low, the loop ΔT small, and the specimen thickness large (0.065 inch). Comparing results obtained in a clean sodium environment to those obtained in an inert environment, the mechanical properties were not altered appreciably. For sodium with high oxygen or carbon levels, the ductility and fatigue strength were reduced at 1200°F. More recent studies, [16] were performed using clean sodium (<10 ppm O_2) at a velocity of 20 ft/sec and a ΔT greater than 70°F. Using the creep rupture data from materials without prior exposure as the base line, 304 stainless steel specimens exposed to 1200°F produced materials slightly stronger than material in the as-received condition, with 1400°F exposures providing materials with slightly lower strength than the as-received material. For both temperatures, the exposure to the high oxygen-sodium resulted in lower strengths than in helium.
4. GE reports [17] that the results of tests of mechanical properties at 1300°F in two sodium loops show that initial microstructural condition (carbide agglomerated vs. mill annealed) of Type 304 stainless steel does not appear to have an effect on the stress-rupture properties. A reduction in long-term stress-rupture properties in non-isothermal sodium at 1300°F is indicated by comparing the test data to data obtained in other environments. Preliminary data on stress-fatigue in flowing sodium shows a retardation of long term rupture of 304 and 316 stainless steel but compare favorably with constant stress results.

These studies, as well as others, point out that some mechanical properties of structural and core materials may be affected by the sodium environment but that they are also extremely dependent on the associated conditions, such as sodium purity, velocity, and loop ΔT . In addition, the effect of sodium on such properties as stress relaxation and strain cycle fatigue have not been investigated to any great extent.

It is with this background and experimental philosophy that WARD has approached this task.

PRIOR WORK

Over one year ago, ARD initiated an internal program to provide mainly stress-relaxation, creep-rupture, and strain cycle fatigue data in sodium on selected structural alloys. This data was to be used to evaluate the effects

of a dynamic sodium system, approaching those of the FFTF and LMFBR, on the mechanical properties of structural and core materials. Some of the equipment designed and built for this program has reached the operational check-out stage.

This program was centered in the tenet that, since mass transfer in sodium has been shown to result in selective removal and deposition of elements in structural materials, the mechanical properties of these materials are certain to be affected. Moreover, since the interstitial elements, which have a pronounced effect on structural stability and mechanical properties, are more mobile and therefore changed at considerable depth in these materials, the property changes are likely to be substantial. The design of this program, then, was to devise experimental programs which would more nearly simulate the LMFBR conditions which could create these property changes and verify their extent. The program required that:

1. Samples duplicate the surface area to volume ratio, if not the geometry, of the structural components most likely to be affected.
2. The samples are exposed under sodium conditions of temperature, ΔT , flow, and chemistry which approximate reactor operation and produce the expected mass transfer.
3. The tests replicate, to the extent possible, the stress conditions expected in the reactor component.
4. The test results must be compared with those obtained on samples of identical material thermally aged in identical cycles not exposed to sodium.

The types of long term mechanical properties selected (stress-relaxation, creep-rupture, strain cycle fatigue) to evaluate the effects of a dynamic sodium environment were based on a number of considerations. Tests yielding results which were sufficiently sensitive to mass transfer and/or interstitial changes are required. Tests providing the mechanical designers with data so that meaningful corrosion allowance limits may be applied to the structures are also necessary. In addition, tests adaptable to samples where the surface to volume ratio can be changed is desirable.

Basic to this program is a loop designed to pre-expose mechanical property test specimens to sodium under mass transfer conditions for extended periods of time. Such a Pre-Exposure Loop (PEL-1) was designed and fabricated early in CY-1969 and placed in operation on May 22, 1969. This facility, shown schematically in Figure 6-1, exposes test specimens to a turbulent sodium flow (Reynolds No. 15,000) and has a temperature gradient (ΔT) between test specimens and the heat exchanger which simulates actual reactor conditions. A total of six legs are available, three at high temperature (nominally 1325°F) and three at low temperature (nominally 1200°F). All legs are located in corrosion areas of the loop rather than deposition regions. Each leg has an approximate length of 50 inches. A by-pass cold trap line is

Figure 6-1. Schematic Diagram of the Pre-Exposure Loop

located around the E. M. Pump, and the system is continuously cold trapped during operation. A separate by-pass line serves as a sampling section for analytical samples of sodium. A cover gas system is provided to maintain appropriate loop pressures, operate gas-operated valves, and to back-fill the loop system with pure argon in case of a system failure. Controls are provided to permit continuous, unattended operation, yet guarantee automatic, safe shutdown in the event of a loop failure. A photograph of this loop prior to placement of heaters, thermocouples, and insulation is shown in Figure 6-2.

Table 6-1 lists the specimens contained in the legs during the initial run of PEL-1. All sample material was characterized by analytical and metallographic procedures prior to loading into the loop. In addition to the mechanical property specimens, each test leg contains numerous specimen holders, positioners, and corrosion samples. These items are considered to be expendable and will be analyzed chemically and metallurgically to estimate the degree of mass transfer experienced by the mechanical property specimens. A photograph of the un-assembled sample legs, specimens, positioners, and holders is shown in Figure 6-3.

The testing facilities (MPS-1 and-2) designed and fabricated during CY-1969, are presently completing debugging operations. They are designed for stress relaxation and creep-rupture testing, respectively. Test specimens will be exposed to turbulent sodium flow during testing. The facilities consist of a sodium loop shown in Figure 6-4, which supplies sodium to the test chamber shown in Figure 6-5, and maintaining a sodium temperature gradient between test chamber and heat exchanger. The test chamber contains the test specimen. Strain on the test samples is transferred outside the test chamber by extensometer rods through bellows and monitored by LVDTs, while sample load is measured by a load cell. The test chamber is positioned in a two column test rig for stress relaxation or creep rupture testing with motor driven drawheads having an infinitely variable speed range between 0.045 and 0.270 in./min. Present load cell capability is 10,000 lb for both MPS-1 and -2. The electronic control system for MPS-1 maintains a pre-selected strain on the test specimen, while the control system for MPS-2 maintains a pre-selected load. For both systems load, strain and specimen temperature are continuously recorded. The present design allows testing of standard type bar, sheet, and tube type specimens with sodium flowing at high velocity over the specimen gauge section.

A testing facility for strain cycle fatigue (MPS-3) is presently being assembled and will be available for testing early in FY-1971. Testing will be conducted in a dynamic liquid sodium environment. The design of the test chamber (Figure 6-6) will allow controlled low-cycle fatigue tests to be performed. This capability is available in the strain cycle fatigue test machine which has been procured. The electronic controls make available adjustable ramp rates for loading and unloading. On-load dwell time is adjustable from 0.01 seconds to 28 hours to obtain simultaneous creep and fatigue load conditions on the test specimen. A unique failure detection system is incorporated in the controls to terminate the test immediately regardless of the point in the strain cycle when it occurs.

A work program was prepared in November 1969 which described the background, justification, capability, and plans for performing tests to determine the

Figure 6-2. Photograph of Pre-Exposure Loop Prior to Instrumentation

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Table 6-1. Description of Test Specimens in Pre-Exposure Loop (PEL-1)

Temp. (°F)	Test Leg No.	Spec. Type	Number	Specification Description
1200	1	Tube	7	Tubing, 6" long x 0.300" OD x 0.012" wall
1200	2	Sheet	3	Sheet, 7.5" long x 0.018" thick x 0.50" gauge width
1200		Sheet	6	Sheet, 4.5" long x 0.018" thick x 0.50" gauge width
1200	3	Bar	1	Bar, 3.500" overall length x (0.500 - 13 NC-2A) thread size 1.00" long x 0.250" dia. gauge
1200	3	Bar	1	Bar, 3.500" overall length x (0.750 - 10 UNC-2A) thread size 1.00" long x 0.250" dia. gauge
1200	3	Bar	2	Bar, 7.25" overall length x (0.500 - 13 NC-2A) thread size 4.75" long x 0.250" dia. gauge
1200	3	Bar	2	Bar, 7.25" overall length x (0.750 - 10 UNC-2A) thread size 4.75" long x 0.250" dia. gauge
1200	3	Bar	2	Bar, 5.500" overall length x (0.750 - 10 UNC-2A) thread size 2.25" long x 0.500" dia. gauge
1325	1	Tube	7	Tubing, 6" long x 0.300" OD x 0.012" wall
1325	2	Sheet	3	Sheet, 7.5" long x 0.018" thick x 0.500" gauge width
1325	2	Sheet	6	Sheet, 4.5" long x 0.018" thick x 0.500" gauge width
1325	3	Tube	7	Tubing, 6" long x 0.300" OD x 0.012" wall
All material Type 316 Stainless Steel (annealed).				
Tubing exposed to flowing sodium on OD surface and static sodium on ID surface.

Figure 6-3. Photograph of PEL-1 Specimens and Holders Prior to Assembly in Test Legs

Figure 6-4. Sodium Loop for Mechanical Property Testing of Materials in a Dynamic Sodium Environment

Figure 6-5. Test Chamber Design for Stress Relaxation and Creep Rupture Testing in Flowing Sodium

Figure 6-5. Test Chamber Design for Stress Relaxation and Creep Rupture Testing in Flowing Sodium

Figure 6-6. Test Chamber Design for Strain Cycle Fatigue Testing in Flowing Sodium

effect of a dynamic sodium environment on the mechanical properties of FFTF and LMFBR structural materials. This document was forwarded to the Coolant Chemistry Branch of the AEC for review and approval.

CURRENT PROGRESS

Material

The initial material selected to determine the effect of a dynamic sodium environment on the mechanical properties for FFTF and LMFBR structural materials was annealed Type 316 stainless steel in tube, sheet, and bar forms. Selection was made early in CY-1969 so that test samples were available for the Pre-Exposure Loop (PEL-1) start-up in May 1969. At that time the reference fuel cladding material for the LMFBR and FFTF was annealed Type 316 stainless steel. Test samples were also fabricated from the same heats for inert-gas aging tests and unexposed long term mechanical property tests at that same time. More recently, bar samples from the same heat as those identified for stress-relaxation and creep-rupture were fabricated for strain-cycle fatigue tests in sodium for inclusion in the second 5000-hour run of the PEL-1. Chemical and metallurgical characterization of the material has been performed. Based on recent work by others, interstitial gradients through the thickness of as-fabricated tubing has been observed. This will be determined for material used in this program and compared to the material after exposure to sodium and aging. All of the above mentioned test samples have been integrated into a test-plan matrix shown in Tables 6-2 through 6-5. The plan assumes that after pre-exposure to sodium and aging, differences in the mechanical properties will be observed, hence the reason for the number of samples involved. If, after performing a sufficient number of tests to make an evaluation, minimal effects due to sodium exposure can be identified, the mechanical test program for the samples may be curtailed.

Since cold-worked 316 stainless steel is now the fuel cladding reference material, plans are underway to include such material in the test plan matrix. Twenty percent cold-worked 316 stainless steel will be included in the second run of the PEL-1.

Test Plans

The initial mechanical property tests of samples planned, as well as those planned for the PEL-1-2 and the inert-gas aging exposures, are given in Table 6-6. As noted the first stress-relaxation and creep-rupture tests performed in flowing sodium involve unexposed (as-received, annealed) samples at 1200°F. These data will be used as a base reference to evaluate samples tested after a pre-exposure to sodium for 5000 hours at 1200°F and samples aged in an inert-gas for 5000 hours at 1200°F.

Pre-Exposure and Aging

The Pre-Exposure Loop (PEL-1) was shut down on March 25, 1970 after accumulating 5049 hours of operation with three sample legs at 1200°F and three

Table 6-2. 316 Stainless Steel Tube Samples for Mechanical Property Tests In and Out of Sodium											
Temp.	1200°F					1325°F					No. of Samples 62
Gauge Length (in) (a)	2 (b)	2 (c)	2 (d)	5 (e)	5 (f)	2 (b)	2 (c)	2 (d)	5 (e)	5 (f)	
PEL-1-1 5000 hr.	4 ↓	1	1	2 ↓	2 ↓	4 ↓	1	1	2 ↓	2 ↓	20
PEL-1-2 5000 hr.	2	0	0	2+1 ↓	2+1 ↓	2	0	0	2+1 ↓	2+1 ↓	8
AGING-1 5000 hr.	4 ↓	1	1	2 ↓	2 ↓	4 ↓	1	1	2 ↓	2 ↓	20
AGING-2 5000 hr.	2	0	0	1+1 ↓	1+1 ↓	2	0	0	1+1 ↓	1+1 ↓	4
UNEXPOSED	1	1	1	1	1	1	1	1	1	1	10
(a) Two 2-inch GL samples made from one 6-inch tube, and one 5-inch GL sample made from one 6-inch tube Out of Na Tests (b) tensile (c) creep (e) stress relaxation In Na Tests (d) creep (f) stress relaxation											

Table 6-3. 316 Stainless Steel Sheet Samples for Mechanical Property Tests In and Out of Sodium											
Temp.	1200°F					1325°F					No. of Samples 62
Gauge Length (in) (a)	2 (b)	2 (c)	2 (d)	5 (e)	5 (f)	2 (b)	2 (c)	2 (d)	5 (e)	5 (f)	
PEL-1-1 5000 hr.	2 ↓	2	2	0	3 ↓	2 ↓	2	2	0	3 ↓	18
PEL-1-2 5000 hr.	1	0	0	3	1+1 ↓	1	0	0	3	1+1 ↓	8
AGING-1 5000 hr.	2 ↓	2	2	0	3 ↓	2 ↓	2	2	0	3 ↓	18
AGING-2 5000 hr.	1	0	0	3	1+1 ↓	1	0	0	3	1+1 ↓	8
UNEXPOSED	1	1	1	1	1	1	1	1	1	1	10
(a) 2 inch GL samples, Dwg. 500B643 Pt. 2 5 inch GL samples, Dwg. 500B643 Pt. 1 Out of Na Tests (b) tensile (c) creep (e) stress relaxation In Na Tests (d) creep (f) stress relaxation											

Table 6-4. 316 Stainless Steel Bar Samples for Mechanical Property Tests In and Out of Sodium

Temp.	1200°F					1325°F					No. of Samples 59
Gauge 1 (1n)	2-1/4	1		5		2-1/4	1		5		
Thread	3/4-10 ^(a)	1/2-13 ^(b)	3/4-10 ^(c)	1/2-13 ^(d)	3/4-10 ^(e)	3/4-10 ^(a)	1/2-13 ^(b)	3/4-10 ^(c)	1/2-13 ^(d)	3/4-10 ^(e)	
PEL-1-1 5000 hr.	2 ↓	1	1	1	3 ↓	0	0	0	0	0	8
PEL-1-2 5000 hr.	1 ↓	2 ^(f)	1 ^(f)	2 ^(f)	2 ↓	1 ^(f)	2 ^(f)	1 ^(f)	2 ^(f)	2 ^(f)	13
AGING-1 5000 hr.	2 ^(f) ↓	1 ^(f)	1 ^(f)	2 ↓	2 ↓	2 ^(f) ↓	1 ^(f)	1 ^(f)	2 ^(f) ↓	1	15
AGING-2 5000 hr.	1 ↓	2 ^(f)	1	1 ↓	1 ↓	1 ↓	2 ^(f)	1 ^(f)	1 ↓	1	7
UNEXPOSED	1	4 ^(f)	1 ^(f)	1	1	1	4 ^(f)	1 ^(f)	1	1	16

(f) Fabricated as of January 19, 1970.

Out of Na Tests

(a) Tensile, Dwg. 500B641 Pt. 1

(c) Creep, Dwg. 500B642 Pt. 2

(e) Stress Relaxation, Dwg. 500B642 Pt. 1

In Na Tests

(b) Creep, Dwg. 737B002 Pt. 2

(d) Stress relaxation, Dwg. 737B002 Pt. 1

Table 6-5. 316 Stainless Steel Fatigue Samples (Bar) for Testing In and Out of Sodium					
Temp.	1200°F		1325°F		No. of Samples 26
Na Testing	Out	In	Out	In	
PEL-1-1	0	0	0	0	0
PEL-1-2	4	4	4	4	16
AGING-1	2 ↓	2 ↓	2 ↓	2 ↓	6
AGING-2	1 ↓	1 ↓	1 ↓	1 ↓	--
UNEXPOSED	1	1	1	1	4
All samples identical (GL and dia.).					
All samples per drawing: 234C630.					

Table 6-6. Sequence Schedule	
Stress-Relaxation (MPS-1)	
1. Check-out of loop and test system	Check-out of the sodium loop, test chamber, and test machine as a system with a test sample installed has been performed. Satisfactory operation was demonstrated for 500 hours at 1200°F.
2. 316 SS anneal rod	Tests of unexposed and pre-exposed rod type samples will be performed at 1200°F and 0.15% strain for 500 hours to compare their relaxation characteristic. The pre-exposed sample will be subjected to flowing sodium at 1200°F for 5,000 hours.
a. Unexposed sample, 1200°F, 0.15% strain	
b. Pre-exposed sample, 1200°F, 0.15% strain	
3. 316 SS annealed sheet	Tests of unexposed and pre-exposed sheet type samples will be performed at 1200°F and 0.15% strain for 500 hours to compare their relaxation characteristics. The pre-exposed sample will be subjected to flowing sodium at 1200°F for 5,000 hours.
a. Unexposed sample, 1200°F, 0.15% strain	
b. Pre-exposed sample, 1200°F, 0.15% strain	
c. Unexposed sample, 1200°F, multiple strain levels	This test is to determine if multiple tests at various strain levels can be performed using the same sample. ASTM indicated this is possible with some materials.

Table 6-6. Sequence Schedule (Continued)

Creep-Rupture (MPS-2)	
1. Assembly of Test Chamber to loop	Assembly of the test chamber to the sodium loop has been completed. Check-out of the sodium loop, test chamber, and test machine as a system with a test sample installed is in the final stages. Operation at 1200°F after 100 hours appears satisfactory.
2. Check-out of loop and test system	
3. 316 SS annealed rod	Tests of unexposed and pre-exposed rod type samples will be performed at 1200°F and 17,000 psi for comparisons of strain on-loading, primary creep (first stage), secondary creep rate rupture life, and ductility. The rupture life should be on the order of 500 hours. The pre-exposed sample will be subjected to flowing sodium at 1200°F for 5,000 hours.
a. Unexposed sample, 1200°F, 17,000 psi	
b. Pre-exposed sample, 1200°F, 17,000 psi	
4. 316 SS annealed sheet	Tests of unexposed and pre-exposed sheet type samples will be performed at 1200°F and 30,000 psi for comparisons of strain-on-loading, primary creep (first stage), secondary creep rate, rupture life, and ductility. The rupture life should be on the order of 500 hours. The pre-exposed sample will be subjected to flowing sodium at 1200°F for 5,000 hours.
a. Unexposed sample 1200°F, 30,000 psi	
b. Pre-exposed sample 1200°F, 30,000 psi	Test of a pre-exposed sheet type sample at 1200°F and 30,000 psi. Sample pre-exposed to flowing sodium at 1325° for 5,000 hours.
Strain Cycle Fatigue (MPS-3)	
1. Sodium loop installation and check out	Installation check-out, and operation of the sodium loop, test chamber and fatigue machine will be performed in order to strain-cycle fatigue test rod type samples in push-pull with tension and compression capabilities. Variables of ramp rates and hold-time are also included. Initial tests in early FY-71 involve annealed 316 SS samples.
2. Test chamber design, fabrication and installation	
3. Test machine installation and check out	
4. Sodium loop and test machine system check-out	
5. Testing	

Table 6-6. Sequence Schedule (Continued)	
Tensile Tests	
1. Pre-exposed and un-exposed rod at 1200°F	Comparisons of yield strength, ultimate strength and ductility for unexposed and sodium pre-exposed test samples are planned. Sheet, tube and rod forms will be evaluated.
2. Pre-exposed and un-exposed sheet at 1200°F	
Pre-Exposure Loop (PEL)	
1. PEL-1-1	Sheet, tube and rod type samples of 316 SS for mechanical property tests are being pre-exposed to flowing sodium at temperatures of 1200°F and 1325°F after 5,000 hours (near end of FY-70 third quarter), system will be shut-down and some samples removed for testing.
a. Complete 5000 hours at 1200°F and 1325°F	
b. Removal of some test samples	Modification to the loop will be incorporated consisting of adding two new test legs - making four - for high temperature exposure and four for low temperature exposure of test samples for mechanical property testing. Annealed 316 stainless steel samples of sheet, tube, and rod for stress relaxation, creep-rupture, strain cycle fatigue, and tensile will be pre-exposed to flowing sodium for 5,000 hours. Some of the samples from the previous run of the loop will be included to obtain samples with 10,000 hours pre-exposure.
2. PEL-1-2 (New legs)	
a. Design loop modifications	
b. Fabrication of modifications and samples	
c. Installation of modifications	
d. Operational check-out	
e. Pre-exposure test to 5,000 hours	
Thermal Aging	
1. Installation of furnaces and controls	Aging tests of sheet, tube, and rod type (including strain cycle fatigue samples) samples of annealed 316 stainless steel for mechanical property tests will be performed in an argon atmosphere. The aging will be performed at temperatures of 1200°F and 1325°F for 500 hours to determine the effect of time-at-temperature on the mechanical properties and for comparison with the results obtained for samples pre-exposed in sodium.
2. Design capsule assembly for samples	
3. Check-out of capsule and furnaces	
4. Aging test to 5,000 hours	

sample legs at 1325°F, a loop ΔT of 300°F, and a sodium velocity to give a Reynolds Number of 15,000 (turbulent flow) over the test samples. The low temperature section (1200°F) consisted of one leg with bar samples, one sheet samples, and one tube samples for mechanical property type tests to be performed after the pre-exposure. The high temperature section (1325°F) consisted of two legs with tube samples and one leg with sheet samples. One of the tube-sample legs was a replacement for a bar-sample leg which was damaged after 1454 hours. The replaced tube sample leg has accumulated 3595 hours of pre-exposure.

Disassembly of the PEL-1 sample legs has been started, and a detailed characterization of the sample material will be performed prior to initiating the mechanical property testing of some of the pre-exposed test samples. The remainder will be pre-exposed further in PEL-1 along with other new sheet, tube, and bar samples for a second 5000-hour run at 1200 and 1325°F.

A fourth leg with test samples will be added to the high and low temperature sections in order to accommodate all the samples required for the pre-exposure. Design of the necessary modifications and hardware for the second run of PEL-1 is in progress. Included in the system will be an on-line oxygen meter for continuous recording of the oxygen level for the loop.

Installation and check-out of the Aging Furnaces is essentially complete and ready for the first run at 1200 and 1325°F. Test samples for the aging test and tubing for encapsulating the samples are on hand.

Mechanical Properties in Sodium (MPS) Systems

The Stress Relaxation Test System (MPS-1) is currently being operated as a complete unit. Several of the problem areas identified in the previous runs have been cleared, and one new problem area related to the cold trapping of sodium has been identified. A redesign of the cover gas system was performed to prevent sodium vapor from condensing and clogging the cover-gas lines as experienced when operating with a static cover gas system. A slow cover gas bleed is being introduced to the test chamber through the extensometer rods to prevent the sodium vapor from reaching the colder region of the rods outside the test chamber and freeze. The cover gas bleed is discharged through a temperature controlled vapor trap. The modifications on the cover gas system have been completed on MPS-1 and -2 and have been operated satisfactorily on both test systems.

The problem experienced with the sodium cold trapping is caused by an unexpected transport of cover gas from the test chamber into the cold trap by the flowing sodium. The turbulence of the sodium in the test chamber appears to create a fine foam that is pulled through the loop system. This fine foam accumulates in areas of low flow velocities such as the cold trap and the cold trap economizer. The sodium level in the cold trap is gradually lowered to a point where the cold trapping efficiency is affected, and also release of large bubbles into the sodium stream is occurring. When the larger bubbles released from the cold trap reach the pump, flow is normally disturbed or in some cases stopped, and a large and intolerable thermal instability occurs in the sodium system and on the test sample. The redesign of the cold trap loop,

which is presently in progress, will prevent accumulation of cover gas in the cold trap and the economizer.

An improvement in the flow regulation is sought by moving the flow regulator valve downstream from the cold trap and cold trap economizer. The sodium impurity level will be lower and the temperature higher than at the previous location, which will reduce the chances of sodium oxide build-up in the valve.

A welded sodium sample tree consisting of six sample legs will substitute the present one sample-leg arrangement. A cold trap by-pass sodium line will also be added to allow high temperature sodium to pass through the sample line without heating the cold trap to a level where the accumulated impurities are being discharged. This will facilitate the clean-up of the sample line prior to obtaining a sodium sample, and introduce a minimum of disturbance to the existing sodium impurity level during the sodium sampling procedure.

The Creep Rupture Test System (MPS-2) has been operated as a complete unit. It is currently undergoing a modification of the cold trap loop. Upon completion of which the system appears to be ready for a base line data test of 316 stainless steel bar specimen in low oxygen sodium.

The mechanical testing unit purchased from the MTS Systems Corporation for the Strain Cycle Fatigue Test System (MPS-3) was installed with the necessary electrical power, water, and instrumentation connections made. The unit was operated for the first time at WARD by a factory representative with the procedures and capabilities demonstrated. All specifications indicated on the purchase order appear to be satisfied with one exception. That involves the under-peak load-detection module used to detect incipient failure of a test sample during tests involving hold times in excess of 100 seconds. The factory has agreed to make the necessary modifications to provide that detection for periods up to 28 hours. Design of the environmental chamber for strain cycle fatigue testing has been completed and fabrication initiated. Fabrication of the test chamber is approximately 75% complete; assembly, installation and system checkout will follow.

Experimental Results

During the check-out operation of the stress-relaxation system (MPS-1) with flowing sodium through the test chamber, a test sample was included and subjected to stress relaxation conditions. The data presented below are not meant to be used as the characteristic for the material (annealed Type 316 stainless steel bar) but primarily to show the effect of changes on the testing due to changes in various components of the stress-relaxation system. The tests were performed at a nominal sodium temperature of 1200°F and a flow velocity past the gauge section (0.25-inch D x 5.0-inch long) to give a Reynolds Number of 20,000 (turbulent flow). The sample was tested at various values of constant strain and unloaded at intervals of time to determine the amount of permanent or plastic deformation due to excursions in temperature resulting from changes in different components of the system. Table 6-4 gives a summary of the test conditions and results obtained for the operation. Strain values given in Table 6-7 and Figures 6-7 and 6-8 are

**Table 6-7. Evaluation of Stress-Relaxation System
(MPS-1) with Flowing Sodium**

Start Date	Test Type	Sample Temp. (°F)	Hrs.	Elong., in.		Load lbs		Notes
				Start	End	Start	End	
11/21-25/69	-	RT	89.5	.0026	.0026	625	>1000	To determine the effect of RT changes on load at constant strain
12/9-11/69	-	1200	42	0	.0006	30	30	To determine the effect of temp. control on strain with constant load
12/11/69	Stress Relaxation	1200	8	.0025	.0025	455	380	
12/11-12/69	Stress Relaxation	1200	16	.0051	.0051	570	515	
12/12/69	Stress Relaxation	1200	3.7	.0075	.0075	515	500	
12/12/69	Stress Relaxation	1200	<u>1.3</u> 160.5	.0100	.0100	500	510	extensometer rods stuck, shut-down, disassemble, modify.
1/14-15/70	Stress Relaxation	1170	27	.0013	.0013	225	75	Unload, Re-zero
1/20-21/70	Stress Relaxation	1165	17	.0077	.0077	800	598	Unload
1/21/70	Stress Relaxation	1165	23	.0052	.0052	190	190	Unload
1/22-26/70	Stress Relaxation	1165	100	.0102	.0102	980	580	Unload
1/26/70	Tensile	1165	-	.0066	.0114	30	844	
1/26-29/70	Stress Relaxation	1165	67.9	.0127	.0127	904	670	Unload, Re-zero
1/30/70 2/12/70	Stress Relaxation	1165	66.8	.0052	.0052	758	540	Unload
2/2/70	-	1165	29	.0039	.0039	30	30	No load
2/3/70	Tensile	1165	-	.0035	.00525	30	320	Inc. load
2/3-4/70	Stress Relaxation	1165	16.6	.00525	.00525	320	305	
2/4/70	Tensile	1165	-	.00525	.0090	305	918	Inc. load
2/4-5/70	Stress Relaxation	1165	26.8	.0090	.0090	918	715	Unload
2/6/70	Tensile	1165	-	.00325	.0078	30	603	Inc. load
2/6-9/70	Stress Relaxation	1165	68.6	.0077	.0077	600	412	Unload
2/9/70	Tensile	1165	-	.0052	.01025	30	810	Inc. load
2/9-11/70	Stress Relaxation	1165	<u>41.4</u> 484.1	.0102	.0102	805	725	Unload
Run 1 11/21 - 12/12/69								
Run 2 1/14 - 2/11/70

Figure 6-7. Stress-Strain Curves Obtained on Loading Annealed Type 316 Stainless Steel Bar at 1165°F in Flowing Sodium for Stress-Relaxation Tests

3654-18

3654-19

Figure 6-8a. Stress-Relaxation of 316 Stainless Steel Rod (0.25-inch OD x 5-inches long GL) at 1165°F in Flowing Sodium (MPS-1) Showing the Result of Changes in the System Components

Figure 6-8b. Stress-Relaxation of 316 Stainless Steel Rod (0.25-inch OD x 5-inches long GL) at 1165°F in Flowing Sodium (MPS-1) Showing the Result of Changes in the System Components

not absolute but relative, since adjustments to the extensometer system were made from time to time. Figure 6-7 shows the loading curves (stress-strain) yielding essentially a constant value for the elastic modulus (16×10^6) of the material at 1165°F . Each curve was obtained after periods of stress relaxation. Figures 6-8a and 6-8b give stress-relaxation curves obtained at various relative strain values and clearly show the influence of temperature variations due to unstable cold-trap flow, system ΔT , and cover gas flow and pressure fluctuations. Modifications have been incorporated in the system to eliminate or minimize the effect of these variables. These results indicate that satisfactory stress-relaxation data can be obtained for materials at elevated temperatures for extended periods of time in flowing sodium. The effects of the dynamic sodium environment on the stress-relaxation characteristics for materials should be evident when the data become available.

SECTION 7

NCAA-600 SPECIAL COMPONENTS MECHANICAL PROPERTIES IN SODIUM

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OBJECTIVES

The purpose of this task is to isolate and define the effect of prolonged exposure to dynamic sodium under mass transfer conditions on the mechanical behavior of special component configurations required for fabrication of the FFTF and LMFBR demonstration plant.

BACKGROUND

The numerous components of the LMFBR reactor core (cladding and structurals), intermediate heat exchanger (IHX), and steam generator will be subject to stresses of various forms, and also to a flowing liquid sodium environment. The exact nature and magnitude of the stresses will be dependent upon the function and location of the components. To accommodate these requirements in design, it will be necessary to have data on such mechanical properties as tensile, creep, creep-rupture, stress relaxation, and strain cycle fatigue under simulated service conditions, taking into account the special component forms. Some of these components compose a critical area of an assembly whose test state is too complex to allow for a confident design based on standard mechanical property data, and where the effect of the sodium environment on the mechanical behavior is unknown. Examples of such components are: nozzles, bellows, piping configurations, tube-to-tubesheet welds of the IHX and the steam generator, various weldments required for the assembly of many components throughout the reactor system. In cases such as these, the only recourse is to mock-up the particular component configuration and subject it to an environmental test simulating in-service conditions. It should be pointed out, of course, that irradiation effects, which must be separately factored, are beyond the scope of this program.

In order to achieve the overall objective of this task, the following sub-tasks have been identified:

1. Review of LMFBR and FFTF Requirements
2. Evaluation of Weldments and Brazements
3. Special Fixture Design and Fabrication
4. Testing of Specific Component Configurations

Review of LMFBR and FFTF Requirements

The objective of this sub-task is to prepare a report by the end of FY-1970 identifying specific component configurations requiring verification of mechanical behavior in dynamic sodium. This report will also describe the type of test required, test temperature, duration of testing, sodium pre-exposure conditions, as well as parallel out-of-sodium testing requirements. It is recognized that identification of a specific component for testing is contingent upon the development of a detailed design. Because the LMFBR program has not yet advanced to this stage, provisions will be made for updating the report at regular intervals. Typical sources of information for this report will be:

1. Continuous liaison with LMFBR and FFTF mechanical design groups (WARD).
2. The LMEC review of material design requirements for the LMFBR program.
3. The BMI report^[18] entitled "A Survey of LMFBR Component Materials Limitations and Requirements."
4. Such FFTF design projects as Combustion Engineering's design effort on the pressure vessel, including the identification of weldments, etc.
5. Supplementary visits to LMFBR contractors to fill in areas not adequately covered by other sources.

Evaluation of Weldments and Brazements

Although detailed designs of the FFTF and LMFBR Demonstration Plant are not yet fixed, the use of standard weld joint designs during component fabrication will be commonplace. Preliminary designs have also identified brazements for instrumentation lead feedthroughs. Therefore, the mechanical property evaluation of standard weldments and brazements has been selected to initiate the experimental phase of this program. As unique and nonstandard configurations are identified, they will be added to the program. The corrosion behavior of weldments and brazements in flowing sodium has been organized as a separate task and is reported under NCAA-300.

In order to isolate the effect of sodium, both in-sodium and out-of-sodium tests will be performed on unexposed, pre-exposed, and thermally aged weldments. Similar tests will be performed on base materials under the NCAA-400 task. Pre-exposure in flowing sodium is necessary because of the long term nature of some of the tests and the need to optimize on the utilization of the limited number of in-sodium test facilities available. Such a pre-exposure facility for base materials already exists at ARD.

Special Fixture Design and Fabrication

In order to perform the evaluation of complex configurations where the applied loads are not uniaxial, special fixturing will be required to permit testing under dynamic sodium conditions. In many cases, load and strain measurement are difficult and may require non-standard methods. In other cases, techniques will have to be developed and proven reliable under test conditions. The objective of this sub-task is to design fixtures and measuring techniques to permit the generation of required data identified under Subtask 1.

Testing of Specific Component Configurations

Under this subtask the specific configurations and weldments identified under Subtasks 1 and 2 will be tested in the special fixtures designed under Subtask 3. In-sodium test equipment accepting these special fixtures will either be those used for the NCAA-400 task with necessary modifications or new equipment designed to perform the unique tests required. Included in this same category of required test equipment are the pre-exposure (PEL-1) and thermal aging facilities presently in operation. It is anticipated that future pre-exposure requirements for components will require the design and construction of a second pre-exposure facility.

It is anticipated that the need for mechanical property data on base material will diminish as the program progresses and gradually make the equipment available for special component testing.

Related Work

Because of the preliminary nature of the FFTF and LMFBR designs, experimental programs to study the mechanical properties of special component configurations in sodium are virtually nonexistent. Workers at GE^[19] are performing biaxial stress-rupture and stress-fatigue tests on internally pressurized 304 and 316 stainless steel tubing in flowing sodium; however, this is only an approach to the special configuration concept.

ARD has recently performed a sodium corrosion evaluation (unstressed state) test of an innovative tube-to-tubesheet weld with Incoloy 800 tubing butt-welded to a Type 304 stainless steel tubesheet overlaid with Inconel 606. A schematic drawing of the joint is shown in Figure 7-1a. A conventional nuclear type tube-to-tubesheet weld is also shown for comparison purposes in Figure 7-1b. Testing was performed at 1100°F with sodium flowing at 13 ft/sec in the ID of the tube and stagnant sodium on the OD. After 3000 hours the sample was removed from test, and no visible degradation of the base metal or weld joint was observed. Whether or not the results would have been the same if the environmental stresses were applied is not known.

The major reason for developing the butt-welded tube-to-tubesheet weld joint is the potential for crevice corrosion in the conventional nuclear type joint. The cause for concern is the presence of the crevice (Figure 7-1b) between the tube and tubesheet and the concern that this crevice represents an area

Figure 7-1. Schematic of Potential Tube-to-Tubesheet Weld Joints for LMFBR Steam Generator and IHX

of accelerated corrosion and also acts as a stress raiser. ARD is presently implementing preliminary tests in static sodium to better define the scope and severity of the problem. A more thorough investigation has been proposed as part of the FY-1971 work program of the LMFBR steam generator Contract (AT(30-1)-4005).

A survey study has been conducted at BMI identifying LMFBR component materials limitations and requirements and a report has been issued.^[18] Several problems in need of special component configurational testing have been identified and may be potential areas of investigation under this task.

One of the problems discussed, unique to sodium pumps, is the need for screening tests to evaluate materials for potential application in large pump bearings and seals.

Another area of the pump requiring mock-up configurational testing is the impeller tip. Corrosion, erosion, and cavitation behavior of materials in sodium at the high velocities experienced at the impeller tip are lacking.

The need for the development of reliable tube-to-tubesheet weld joints in the IHX and steam generator was also emphasized. This is in complete agreement with the WARD philosophy as evidenced by the previously mentioned sodium corrosion tests.

PRIOR WORK

Equipment capable for use in this program to obtain mechanical property data was designed, built, installed, and checked out during this period. Since its initial use will be for Task NCAA-400, it is described in detail in that program. Involved are systems for measuring the stress-relaxation, creep and creep-rupture, and strain cycle fatigue properties of materials at elevated temperatures with controlled purity flowing sodium. The pre-exposure and thermal aging facilities are also described therein.

CURRENT PROGRESS

During this period a major emphasis has been placed on identifying component configurations for the FFTF and LMFBR that may require an experimental mechanical property evaluation. This is in agreement with meeting the first milestone of this task; i.e., the preparation of a report by the end of FY-1970, documenting problem areas, and identifying the types of tests and test conditions which should be performed to provide solutions to these problems.

Several preliminary meetings have been held with FFTF and LMFBR design groups at ARD during which the objectives and scope of this program were discussed. A request was made of the designers to review their various design requirements for potential problems and submit a list for review. Although the design status of the FFTF and LMFBR is only preliminary, several component configurations have been identified. It should be pointed out however, that these should be considered potential problems that are subject to revision or elimination following detailed design progress.

For FFTF, the reference fuel element assembly design is a wire-wrap type. Designers claim that no mechanical property data is available for the wire-to-end cap and end cap-to-cladding welds of the fuel pin. The use of existing weld quality factors^[20] may be over conservative also. Therefore, stress-rupture tests in sodium on both unexposed and pre-exposed specimens are needed to fix the maximum allowable weld stresses.

The present LMFBR reference core design and the alternate FFTF design, utilizes a grid-type structure for fuel element spacing. A developmental program has been outlined by WARD designers specifying tests and information needed to define and optimize the structural and mechanical performance of the grids. One of the tests identified is low cycle fatigue testing of prototypic full-width spot welds using alternating "peel" type loading. These tests should be performed on both unexposed and pre-exposed samples. The need for prototypic testing is justified by variations in the weld pad geometry and unpredictable stress concentrations at the weld cusp. Low cycle fatigue data is needed because of significant load cycling anticipated for LMFBR service.

Another test essential for grid development is a corrosion-erosion type of test in which small grid segments with dummy fuel rods in place would be exposed to high velocity sodium (~40 fps). The effect of entrained gas on the maximum permissible free stream velocity to preclude cavitation damage is unknown; therefore, prototypic tests are desirable. This work is being performed under Task NCAA-300 and is discussed in more detail therein. Results will aid in fixing wastage allowances for grid strap thickness for a given grid life.

The extent of fretting damage to the fuel rod cladding caused by flow-induced vibrations is also unknown. Prototypic tests utilizing a 37-pin subassembly in a loop are planned. Because this work is in direct support of fuel-assembly design, it is being performed under Task OFBA-313 of AEC Contract AT(30-1)-4135. While it is recognized that these tests are not mechanical property evaluations, they are typical of special configurational testing and are included here for that reason.

Discussions have been conducted by WARD with Combustion Engineering in an effort to identify FFTF reactor vessel weld requirements. Based on the present preliminary design status, a tabulation of items such as weld joint configuration, weld procedure, materials, dimensions, and in-service environment has been made. A similar tabulation of FFTF core structural welding requirements has been made. These listings will be reviewed to identify weldments that may require in-sodium mechanical property evaluations.

It has also been established that the LMFBR tube-to-tubesheet IHX and steam generator welds in several alloy combinations require evaluation. In addition to the Incoloy 800 - Inconel 606 joint of the reference Westinghouse design, various combinations of 2-1/4 Cr-1Mo alloys, such as carbon stabilized or low carbon varieties prepared by ORNL, should be tested. Specimen and test design have not as yet been identified.

One of the common methods of making a seal between liquid sodium and its cover gas is through the use of welded bellows. One possible application

of this type of seal might be in the control rod drive mechanism of a reactor. A literature survey^[21] performed by BNWL has revealed that present sodium-cooled reactor operating experience with bellows seals has met with varying degrees of success. Theoretical calculations have also yielded conservative stress values in disagreement with empirical calculations by a factor of ~ 3 . Experimental data confirms the empirical values. These arguments substantiate the need for prototypic mechanical testing of bellows under simulated environmental conditions.

SECTION 8

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