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SODIUM TECHNOLOGY
TECHNICAL PROGRESS REPORT
APRIL, MAY, JUNE
1975

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company
A Subsidiary of Westinghouse Electric Corporation

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J. M. Atwood

December 1975

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Hanford Engineering Development Laboratory

Operated by the
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for the United States
Energy Research and
Development Administration
Contract No. E(45-1)2170

SODIUM TECHNOLOGY
HEDL QUARTERLY TECHNICAL REPORT

J. M. Atwood

ABSTRACT

This report was prepared at the Hanford Engineering Development Laboratory operated by Westinghouse Hanford Company, a subsidiary of Westinghouse Electric Corporation, for the United States Energy Research and Development Administration, Division of Reactor Research and Development, under Contract No. E (45-1) 2170. It describes technical progress made during the reporting period by Westinghouse Hanford Company and supporting contractors.

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SODIUM TECHNOLOGY QUARTERLY REPORT

APRIL, MAY, JUNE 1975

J. M. Atwood

INTRODUCTION

This is the second in a series of Sodium Technology Quarterly reports. The initial report, TME-75-3, covered the first three months of 1975. Previously, Sodium Technology progress was incorporated in HEDL Technical Quarterly Reports.

Progress is reported by the four organizational components within Sodium Technology:

- Radioactivity Control Technology
- Sodium Systems Development
- Sodium Systems Engineering
- Sodium Systems Analysis

Major topics covered include:

- Corrosion product release, transport, and deposition
- Tritium control in LMFBFR's
- Decontamination of LMFBFR components
- Design and procurement of the FFTF Sodium Characterization System and initial work on SCS for CRBR
- Design and performance analysis of FFTF cold traps
- Sodium removal process development
- Liaison with off-site sodium technology programs
- Investigation of flow impedance phenomena
- Chemical analysis and instrumentation
- Development of a protective suit for sodium emergency personnel
- Fuel failure monitoring systems for FFTF and CRBR

RADIOACTIVITY CONTROL TECHNOLOGY

R. J. Cash

Radioactivity Control Technology (RCT) is concerned with developing methods and technology to predict, measure, control, and remove radionuclide deposits on heat transport system piping and components. These radionuclides consist of the corrosion products ^{60}Co , ^{58}Co , and ^{54}Mn and the various fission products released when operation with failed fuel is permitted. Because of the complexity and magnitude of radionuclide transport, several methods are being investigated. Five parallel approaches for reduction or control of radionuclide release and deposition are being pursued for application to LMFBFR's.

- Coolant impurity control
- Radionuclide traps
- Sodium additives
- Decontamination
- Fuel cladding alloy modifications

At LMFBFR operating temperatures, radioactivity from corrosion product transport and deposition will be sufficiently high to severely limit access time for maintenance of system components unless control measures are instituted. Results from on-going development programs, plus data from operating sodium cooled reactors show that radiation levels in the range of 1 to 15 R/hr can occur. If the reactors are operated with failed fuel, fission products will further increase radiation levels.

This report discusses work currently underway and planned as part of the RCT program.

Improved Model for Corrosion Product Transport

W. L. Kuhn

Objective

In order to identify and characterize potential maintenance problems of the FFTF Heat Transport System (HTS), the rate of release of activated corrosion products from the core and their subsequent accumulation in the

HTS piping and components must be estimated. This subtask provides for an improved model for estimating corrosion product activity levels for the FFTF Heat Transport System.

Summary

The heat transport system (HTS) radionuclide inventories for the FFTF reported in Reference 1 have been updated as a result of refinements to the analytical model. The latest calculations predicted the HTS inventories using different model assumptions and operating conditions as a function of elapsed time. Model parameters inferred from radionuclide release data collected by the RCT Section over the past two years are used, and the resulting predicted inventories are similar to those reported in Reference 2.

The analytical model and its predictions under various parameters assumed for FFTF operation will be combined with the computer program ISOSHL D to yield dose rates for various locations in the HTS cells. These predictions will culminate in a HEDL-TME report.

Discussion

The radionuclide transport model and the computational technique used are those described in References 1 and 3, with some modification. The current work uses corrosion rates and solid state diffusivities obtained partly from the literature and partly from data obtained from the operation of the RCT non-isothermal sodium loop STCL-1 (Source Term Control Loop).

Bagnall and Jacobs (Reference 4) report a correlation for the corrosion rate of Type 316 stainless steel in sodium as a function of temperature, sodium oxygen concentration, and sodium velocity. The dependence on oxygen concentration is taken to be linear; however, most of the data used for the correlation was for concentrations substantially above the 0.5 to 2.5 ppm range of interest here. Consequently, the Bagnall-Jacobs temperature and velocity dependence behaviors are adopted, but the magnitude of the correlation is adjusted separately at the 0.5 and 2.5 ppm oxygen concentrations to agree with STCL-1 data. The correlation is also multiplied by a factor of 2 to account for the anticipated higher corrosion rate in

rapidly increasing temperature zones, as suggested by Bagnall and Jacobs. The resulting forms of the corrosion rate "u" in mils per year are:

0.5 ppm oxygen, velocity >9.5 feet/sec

$$u = \exp(18.338 - 18120/T, ^\circ K)$$

0.5 ppm oxygen, velocity <9.5 feet/sec

$$u = (1.1704 + 0.3496 V) \exp(16.438 - 18120/T, ^\circ K)$$

2.5 ppm oxygen, velocity >9.5 feet/sec

$$u = \exp(19.247 - 18120/T, ^\circ K)$$

2.5 ppm oxygen, velocity <9.5 feet/sec

$$u = (1.1704 + 0.3496 V) \exp(19.247 - 18120/T, ^\circ K),$$

where V = sodium velocity in feet per second.

Smith and Hales (Reference 5) report a correlation for the diffusivity of manganese in Type 316 stainless steel, which is assumed here to be accurate for the diffusion of chromium, as well. The calculated diffusivity at the STCL-1 test temperature (1120°F) is found to be roughly an order of magnitude lower than that obtained from an analysis of radio-nuclide concentration profiles in STCL-1 corrosion specimens obtained by sectioning. The apparent discrepancy is attributed partly to the uncertainty of the literature correlation and partly to the roughening of the corrosion specimens, which presents an increasing diffusion area. For this work Smith and Hales' temperature dependence is adopted, but the diffusivity correlation is adjusted to yield the STCL-1 value of $3.26 \times 10^{-15} \text{ cm}^2/\text{sec}$ at 1120°F. The resulting form for the diffusivity, D, is

$$\text{Smith and Hales: } D = 0.412 \exp(-31253/T, ^\circ K)$$

$$\text{STCL-1: } D = 8.278 \exp(-31253/T, ^\circ K).$$

During sodium corrosion, cladding tends to develop a surface ferrite layer of enhanced diffusivity. Assuming the ferrite diffusivity is much greater than that of the 316 SS, then the effective moving interface for computing "diffusive release" (i.e., ^{54}Mn and ^{51}Cr) is the ferrite/austenite interface rather than the sodium/ferrite interface. Therefore, the sum of the metal corrosion rate and the ferrite layer growth rate is

used as an effective corrosion rate "u" for the computation of ^{54}Mn and ^{51}Cr release.

The FFTF fuel cycle is divided into three sequences of 100 days at full power followed by 32 days "down" to refuel a third of the core. The HTS radionuclide inventories are computed for times falling at the end of the 100 day periods, except for the first computation at 50 days. Three conditions are assumed for the computations: 800°F core inlet and 0.5 ppm oxygen, 800°F core inlet and 2.5 ppm oxygen, and 600°F core inlet and 0.5 ppm oxygen. The results are presented in Tables 1, 2 and 3, respectively.

TABLE 1

HTS RADIONUCLIDE INVENTORIES IN CURIES.
800°F CORE INLET, 0.5 PPM OXYGEN

Time, days	^{54}Mn	^{60}Co	^{58}Co	^{51}Cr	^{59}Fe
50	33.7	0.14	6.78	117.7	1.32
100	94.6	0.56	20.0	192.5	3.32
232	217.2	1.80	34.4	207.1	4.52
364	324.1	3.32	39.6	207.8	4.73
760	508.2	7.48	41.5	"	4.76
1156	584.7	11.1	41.6	"	"
1552	616.6	14.2	"	"	"
1948	629.8	16.9	"	"	"
3928	639.1	25.9	"	"	"
7888	639.3	32.5	41.6	207.8	4.76

TABLE 2

HTS RADIONUCLIDE INVENTORIES IN CURIES.
800°F CORE INLET, 2.5 PPM OXYGEN

Time, days	^{54}Mn	^{60}Co	^{58}Co	^{51}Cr	^{59}Fe
50	37.6	0.35	16.8	129.6	3.26
100	109.8	1.38	49.7	217.4	8.23
232	261.8	4.46	85.3	235.4	11.2
364	398.2	8.24	98.2	236.2	11.7
760	639.9	18.6	103.1	"	11.8
1156	730.5	27.5	103.2	"	"
1552	771.1	35.2	"	"	"
1948	788.0	42.0	"	"	"
3928	799.9	64.3	"	"	"
7888	800.1	80.6	103.2	236.2	11.8

TABLE 3

HTS RADIONUCLIDE INVENTORIES IN CURES.
600°F CORE INLET, 0.5 PPM OXYGEN

<u>Time, days</u>	<u>⁵⁴Mn</u>	<u>⁶⁰Co</u>	<u>⁵⁸Co</u>	<u>⁵¹Cr</u>	<u>⁵⁹Fe</u>
50	1.79	0.006	0.25	7.10	0.054
100	4.93	0.025	0.74	11.5	0.14
232	11.1	0.080	1.27	12.3	0.19
364	16.4	0.15	1.46	12.4	0.20
760	25.6	0.33	1.53	"	"
1156	29.4	0.49	"	"	"
1552	31.0	0.63	"	"	"
1948	31.7	0.75	"	"	"
3928	32.1	1.15	"	"	"
7888	"	1.44	1.53	12.4	0.20

The inventories found in Tables 1 or 2 are indicative of HTS radiation fields and attending maintenance problems comparable to those predicted in Reference 2. Table 3 indicates approximately a twenty-fold decrease in the inventories when the coolant temperature is decreased 200°F.

The potentially important contribution of grain boundary diffusion to radionuclide release from fuel cladding has not been considered. This problem appears to be mathematically quite difficult and will be addressed as part of the program at a later time.

Expected Accomplishments Next Quarter

The distribution of radionuclides among the HTS components is being investigated in order to translate the computed inventories to dose rates at selected locations about the HTS. This work will culminate in a HEDL-TME report updating HEDL-TME 72-71.

Radioactive Corrosion Product Release

W. F. Brehm

Objective

The objective of radioactive corrosion release studies is to characterize the release and transport of radionuclides in flowing sodium as a function of system operational parameters. The results of this study will

be used to specify LMFBF temperature and coolant purity limitations, if required, and also to predict deposition locations of nuclides in reactor primary heat transport systems. The data from this study are used in the improved analytical model for corrosion product transport described in the previous section.

Summary

The tests in STCL -1, 2, and 3, as described in Reference 1 and also herein in Table 4, ran without interruption. Gamma-scanning of STCL-1 (no accumulation trap) showed considerable activity buildup in the regenerative heat exchanger and a lesser amount in the hot trap. The oxygen level in the zirconium hot-trapped test in STCL-1 has remained essentially stable at about 1 ppb or less.

Discussion

The results of two separate 6000-hour tests to determine radionuclide releases at 1120°F (604°C) for 2.5 and 0.5 ppm oxygen levels, respectively, have been reported previously.⁽¹⁾ Briefly, the experiments showed that a slight reduction in ⁵⁴Mn release and a factor of 3 reduction (considerable scatter in the data) in ⁶⁰Co release were attained at the lower oxygen level. This phase of the program is being continued in STCL-1 at an oxygen level of approximately 1 ppb using a zirconium hot trap to achieve the low oxygen activity.

Since the effect of oxygen level on radionuclide transport is important to establish reactor purification system operational requirements, independent experiments are being conducted at WARD under a subcontract from HEDL. These experiments are outlined in Table 5, and results are reported in the WARD Quarterly Reports. Additional corrosion and materials performance data are being obtained in the trap development tests in STCL-2 and 3, discussed elsewhere in this report.

Test Matrices. A status report on the test matrix for corrosion product transport studies is shown in Table 4. Interim shutdowns of all

TABLE 4

RADIOACTIVITY CONTROL TECHNOLOGY TEST MATRICES

Loop	Specimen Temp./ Min. Temp.	Oxygen ppm		Specimen* Materials	Radionuclide Trap	Test Duration	Status and Remarks
STCL-1	1120°/800°F	< 0.01 (hot trap)		I 316, CW U 316, CW U 316, SA	No	6,000 h	3000 hours complete 6-24-75. Interim shutdown for replace- ment of one specimen and detailed gamma scanning of piping.
STCL-2 -3	1120°/800°F	0.5	Test Section I	I 316, CW U 316, CW U Ni, AR	Yes	3,000 h	3000 hour trap evaluation complete 7-13-75. Test plan being developed.
			Test Section II	U 304, AR U Ni, AR			
			Test Section III	U 304, AR (cold leg)			
RCL-C**	1120°/800°F	2.5		I 304, SA	No	6,000 h	6000 hour test will begin in 6-75. Interim shut-
RCL-H**	1120°/800°F	< 0.01 (hot trap)		I 304, SA	No	6,000 h	downs for pipe gamma scanning planned for 2000 hr intervals.

* I = Irradiated

AR = As Received

316 = 316 Stainless Steel

U = Unirradiated

SA = Solution Annealed

304 = 304 Stainless Steel

CW = 20% Cold Worked

** WARD, being operated on HEDL subcontract.

three STCL loops being utilized in this program will take place during June and July. A test plan for the use of the STCL loops after the present experiments are completed is being developed. Preliminary plans for STCL-1 provide for removing the entire main line piping system and using the material for decontamination specimens. Some of this material will have seen 21,000 hours' service when it is finally cut out of the loop. Some of the options for a rebuilt loop are a 920°F source rate test, experimental deposition modeling, and a fission product distribution/deposition study. If possible, a rebuilt STCL-1 test system will be designed and built that will accomplish all three goals.

STCL-1 Operations. Nuclide buildup in the piping system is monitored during operation with the Ge(Li) detector on the movable positioner.⁽⁶⁾ The loss in sensitivity from the relatively large distance between piping and detector and the background from the nuclide sources in the loop is offset somewhat by heavy lead shielding and narrow collimation around the detector, and by using long counting times. The multichannel analyzer is equipped with automatic live-time correction and an integration circuit coupled to a high-speed printer, so the long counts can be automatically acquired overnight. This procedure makes the detector and analyzer available for other work during the day.

There is special interest in the nuclide buildup along the new economizer (points 19, 21, 23, 24; see Figures 1 through 4) and the hot trap (points 200 and 300; see Figures 6 and 7) since these regions are being exposed to sodium for the first time in Run 7. Figures 1 through 4 show a steady buildup of ^{54}Mn and ^{60}Co in the new economizer. The ^{60}Co buildup appears to be faster in the high-temperature region (position 19) while the ^{54}Mn buildup is extremely heavy in the lower temperature regions and the cooler (positions 21, 23, 24). The counts reported before the start of the run (2-19-75) were obtained during the system checkout and can be used as the "background" reference point. Buildup of both ^{54}Mn and ^{60}Co is still being observed in the cooler (position 30) as shown in Figure 5. The cooler is just downstream from the economizer and has seen

HEDL 7507-156.1

FIGURE 1. Position 19 - Economizer High Temperature Section.

HEDL 7507-156.2

FIGURE 2. Position 21 - Economizer Midpoint.

HEDL 7507-156.3

FIGURE 3. Position 23 - Economizer Low Temperature Section.

HEDL 7507-156.4

FIGURE 4. Position 24 - Economizer Outlet.

HEDL 7507-156.5

FIGURE 5. Position 30 - Cooler.

HEDL 7507-156.6

FIGURE 6. Position 200 - Hot Trap Body.

FIGURE 7. Position 300 - Hot Trap Economizer.

17,000 hours' operation in STCL-1. These observations are in close agreement with previously observed distributions of ^{54}Mn and ^{60}Co (References 1, 6, 7, 8). Measurable ingress of ^{54}Mn and ^{60}Co into the cold trap economizer and body is also being observed as shown in Figures 6 and 7. At the high temperature of the economizer and trap body, it is expected that any radioactivity that impacts on the metal surfaces would be adherent. The hot trap branch line is downstream from the economizer and cooler so the presence of deposited activity in the hot trap shows that not all of the activity deposits in economizer and cooler.

Since ^{54}Mn is known to migrate from previous deposition sites in high temperature locations,⁽⁹⁾ it will be interesting to determine whether the ^{54}Mn deposited in the hot trap steadily increases or if the amount of activity reaches a maximum and then migrates away. More quantitative information will be obtained during a system gamma-scan with the sources removed. This is planned for the interim shutdown at the 3000-hour midpoint of the test.

Expected Accomplishments Next Quarter

1. Conduct interim shutdown of STCL-1, obtain weight change data, remove one radioactive specimen for incremental analyses, and gamma-scan all non-radioactive specimens. Remove insulation and perform a quantitative gamma-scan of the STCL-1 piping.
2. Develop a test plan for STCL-1 after completion of Run 7 in December 1975. Begin design for rebuild of piping system.
3. Measure corrosion rates on specimens in STCL-2 and 3. Develop test plan for continuation of runs in those facilities.

Radionuclide Trap Development

J. C. McGuire and J. L. Bevan

Objective

One division of the Radioactivity Control Technology research effort is the development of trapping materials and trap designs suitable for the

removal of long-lived gamma emitting radionuclides from the primary loop sodium of the FFTF/LMFBR.

Summary

The prototype nuclide traps in STCL 2 and 3 have been in operation for approximately 2000 hours. The results to date have been very encouraging, with trapping efficiencies approaching the theoretical limit. A preliminary assessment of the feasibility of putting a prototype test in EBR-II was made and plans have been formulated for proceeding with such an experiment in Fiscal Years 1976 and 1977. An assessment of using a by-pass radionuclide trap was made. Because of the small fraction of flow which would normally be diverted to such a device in an LMFBR and the tendency for radionuclides to plate out on the first pass, the bypass trap concept is not promising as a removal device for corrosion product activity in LMFBR primary circuits.

Discussion

Radionuclide Traps. Source Term Control Loops 2 and 3 have been in operation for ~2000 hours in the present test series. Each of these loops is fitted with a nuclide trap which provides an effective cross sectional area of 0.4 in.^2 — equivalent to the area available to one fuel pin in an FFTF driver assembly. Within the first 200 hours of loop operation, both traps showed definite activity peaks on the upstream edges. Periodic surveys have been taken during the test to date. These surveys show a gradual increase in peak amplitude with some activity migrating very slowly down the trap length. The activity scans are based upon gamma scans with a GeLi detector through a 0.5" by 3.0" lead collimator. Because close access to the traps is not possible while the loops are running, a true activity distribution must await loop shutdown and removal of the irradiated source specimens upstream of the traps.

The present radionuclide trap concepts now undergoing tests appear to be very promising for incorporation into future LMFBR's. Therefore, the RCT Section has made preliminary plans to test a full-scale device in

EBR-II under conditions of a fast neutron flux field for a constant replenishment of the supply source of the corrosion product radionuclides. Although such an experiment does not lend itself to a comparative evaluation of upstream and downstream activity deposition, the trap itself can be disassembled and counted incrementally. These data should yield good information on axial and radial activity distribution within the trap matrix. In addition, corrosion or erosion rates, activity penetration, and mass transport can be determined by metallographic, gravimetric, incremental, and Auger analysis.

After conferences with cognizant personnel at both HEDL and ANL, the following ground rules were laid down for a prototype trap test in EBR-II.

1. Test temperature to be 1000°F+.
2. Sodium flow rate to be as high as possible but not over 22 fps.
3. Trap size to be scaled to the surface area of driver fuel pins available.
4. Trap to be designed with minimum pressure drop but maximum internal turbulence as the trade offs.
5. Trap to have the maximum surface area practicable.

Formal feasibility documentation of the EBR-II trap test and a request for Approval-in-Principle will be submitted in Fiscal Year 1976 in accordance with the instructions contained in the "Guide for Irradiation Experiments in EBR-II".

Feasibility of Bypass Radionuclide Trap. The feasibility of a hot-leg, bypass radionuclide trap (similar to a sodium cold trap) has been evaluated. This evaluation shows that for a typical LMFBR coolant loop with a bypass trap in place (see Figure 8), the fraction of the total nuclide inventory, " α ", accumulating in the trap is

$$\alpha = \frac{1}{1 + \frac{1-\alpha}{\alpha} \frac{\epsilon_L}{\epsilon_T}}$$

MAIN FLOW, "f" Kg/SEC
 CORE SOURCE, "S" C_i/SEC
 TRAP EFFICIENCY, "ε_T"
 HTS AND PIPING EFFICIENCY, "ε_L"
 CONCENTRATIONS "C" C_i/Kg

FRACTION DEPOSITING IN TRAP IS:

$$\gamma = \frac{\alpha}{\alpha + (1 - \alpha) \frac{\epsilon_L}{\epsilon_T}}$$

HEDL 7507-156.14

FIGURE 8. Rationuclide Trap Bypass Schematic.

where α = the fraction of total reactor flow diverted through the trap,
 ϵ_L = the fraction of radionuclides deposited in the main reactor
heat transport system,
 ϵ_T = the fraction of the radionuclides deposited in the trap.

For large reactor systems such as FFTF and CRBR, $\alpha \ll 1$. If the nuclide trap approaches 100% efficiency, $\epsilon_T \approx 1$; hence,

$$\alpha = \frac{1}{1 + \frac{\epsilon_L}{\alpha}}$$

The fraction of the total inventory, α , accumulating in the trap will be large only if $\epsilon_L \sim \alpha$. Since α is very small the deposition rate in the loop would have to be correspondingly small. Unfortunately, this is not the case since most of the deposition occurs during the first circuit of the sodium through the heat transport system. Thus, a bypass hot trap for radionuclide accumulation would not be very effective.

Expected Accomplishments Next Quarter

1. Gamma scanning will continue on the STCL 2 and 3 nuclide traps together with associated cold zone locations to observe any possible changes in activity buildup.
2. Further preparations will be made for the formal documentation of feasibility and Approval-in-Principle necessary to place a prototype nuclide trap in EBR-II.

Tritium Control Program

J. C. McGuire, E. O. Badgett, J. L. Bevan

Objective

A tritium control program was formulated consisting of two areas:
1) model development for tritium transport in an LMFBR and 2) an experimental program to measure hydrogen/deuterium/tritium diffusion rates through stainless and Croloy with surfaces prototypic of those in an LMFBR.

Summary

Modeling. Several changes have been suggested for the tritium models developed independently at ANL and HEDL (References 10 and 11). A meeting was held at ANL in May at which it was agreed that one basic model would be developed jointly with input from ANL, EBR-II, and HEDL. Parametric constants would also be mutually agreed upon.

Experimental. The vacuum equipment necessary for hydrogen and deuterium diffusion studies has been assembled, leak checked, and calibrated to determine exact volumetric capacities. Procedures have been prepared and permission was granted for using hydrogen species in the laboratory.

Discussion

A tritium coordination meeting was held at ANL in May to outline the joint tritium program to be conducted at ANL and HEDL. It was agreed that a mutual tritium behavior and control plan would be submitted to ERDA-RRD which includes requirements and development needs of the CRBRP. It was further agreed that the modeling effort would be discussed further in a meeting early in FY-1976 so that a mutually agreeable analytical expression could be defined. Agreement on the parameters used in the model for the three reactor systems of interest (i.e., FFTF, EBR-II, and CRBRP) is also required. ANL has the overall responsibility for coordination of the tritium program.

The experimental equipment for the hydrogen/deuterium diffusion-rate studies consists of a vacuum manifold evacuated by a two-stage mercury diffusion pump, the diffusion cell, calibrated diffusion reservoirs, and a vacuum manometer capable of accurate digital readings of pressures from 10 to 10^{-4} torr.

The diffusion cell, shown in Figure 9, is a fused quartz furnace tube containing a spiral diffuser fabricated of 1/8" OD x 0.016" wall 304L stainless steel tubing 30 inches long which is wound in a tight spiral. The bulk gas is supplied to the quartz tube and the diffused gas is detected on the inside of the diffuser tube. This tube is connected to a

HEDL 7507-156.15

FIGURE 9. Spiral Diffuser in the Diffusion Cell.

calibrated volume fitted with the vacuum manometer. The diffusion cell is heated by a 9" x 1" I.D. clam shell tubular furnace capable of temperatures to 1850°F. End heat losses are minimized by quartz wool packing. The diffuser tube is also connected by grease free stopcocks to a time-of-flight mass spectrometer.

For diffusion rates at high temperatures (600°C) or high ΔP 's, pressure rise will be recorded as a function of time in a calibrated volume. For the lower diffusion rates, the diffused gas will be swept into the mass spectrometer by a known volume of argon and the comparative mass peaks determined. The mass spectrometer is being reconditioned and will be checked out with known mixtures before use.

Expected Accomplishments Next Quarter

1. HEDL input for the tritium behavior and control plan will be forwarded to ANL.
2. A meeting will be held to arrive at a mutually agreeable analytical expression for tritium behavior in the FFTF, EBR-II, and CRBRP.
3. Shakedown runs for deuterium diffusion through clean stainless steel will be done at a gas pressure of 1 torr.
4. Comparison runs will be made for the same pressure of deuterium brought to 760 mm pressure with argon.
5. Diffusion rates will be determined for gas pressures of 1, 0.1, and 0.01 Torr at 600, 550, 500, and 450°C.

Radioactivity Decontamination Program

R. P. Colburn, H. P. Maffei, and E. O. Badgett

Objective

The objective of this program is the development of decontamination processes for application to LMFBR primary HTS components which will permit contact maintenance and requalification of the component.

Summary

Screening of various types of candidate decontamination solutions was performed by beaker tests on solution annealed and sensitized 304 SS specimens. Oxalic acid/ammonium citrate and acetic/formic acid mixtures gave the most uniform metal removal with minimum intergranular attack of the sensitized material.

Auger analysis and incremental analysis of STCL-1 hot leg, cold leg, and economizer surfaces show significant chromium deposition in all three regions with the maximum Cr concentration occurring on the surfaces in the middle of the economizer. Nickel deposition occurs in the cooler half of the economizer and cold leg while manganese tends to be severely leached from the hot leg and most of the economizer with net deposition only occurring at the economizer outlet and in the cold leg.

Discussion

Surface Characterization. Surface characterization of STCL-1 components continued. The economizer, removed after 15,000 hours of sodium exposure, was sectioned under an inert atmosphere and the pieces will be stored in a glove box for protection of the surfaces. Short specimens taken from several regions along the length of the economizer were examined metallographically. Typical metallographs of the inside and outside surfaces of the heat transfer tube and economizer shell are shown in Figures 10 and 11. The shell-side surface shows isolated localized pitting to a depth of 0.003" but no significant grain boundary attack of the type seen in the hot leg pipe.⁽¹⁾ The internal heat transfer tube showed no significant attack on either the inside or outside surfaces, both of which were exposed to flowing sodium.

FIGURE 10. Typical Metallographs of STCL-1 Economizer Shell After 15,000 Hours Exposure to Flowing Sodium at 1090°F (Mag X500). (Photo No. 4751203)

FIGURE 11. Typical Metallography of STCL-1 Economizer Heat Transfer Tube After 15,000 Hours Exposure to Flowing Sodium at 1090°F (Mag X500). (Photo No. 4751202-4751201)

Incremental analyses were performed on specimen surfaces immediately adjacent to the metallography samples. The composition profiles for the shell surface at five positions along the economizer are shown in Figures 12 through 16. The changes in the surface layer composition for the economizer shell and loop sections immediately upstream and downstream from it are shown in Figure 17. These data show Cr enhancement at the surface in all regions reaching a maximum near the middle of the economizer, where the surface composition is 77 wt% Cr (4.5 times the base metal concentration). Slight Ni surface depletion found in the economizer inlet changes to Ni enrichment in the cooler portion of the economizer. Manganese, severely depleted in the hot leg and most of the economizer, changes to surface enrichment at the economizer outlet. These trends are in good agreement with other sodium mass transfer system observations reported in the literature.^(8,12)

Auger analyses of the hot leg and cold leg STCL-1 piping generally confirm the composition profiles obtained by incremental analyses reported last quarter.⁽¹⁾ However, the Auger analysis indicates more severe depletion of Ni from the hot leg and substantially greater deposition of Mn in the cold leg than previously reported.

Typical profiles obtained by sputtering areas approximately 4 x 6 mils are shown in Tables 5 and 6. These results indicate negligible leaching of Cr from the hot leg surface; however, high carbon levels and significant depletion of Ni were found. Auger analyses of the cold leg deposits show the depth of the deposit layer to be approximately 1 μ m thick; relatively large fractions of C, O, Cr, Ni, and Mn and low concentrations of Fe relative to the base metal composition were observed.

Screening Tests. Screening tests were performed in small beaker experiments consisting of weight-loss measurements on 304 stainless steel specimens immersed in the candidate solutions for 48 hours at various temperatures.

HEDL 7507-156.8

FIGURE 12. Concentration Profiles of Metallic Species in the STCL-1 Economizer Shell.

HEDL 7507-156.9

FIGURE 13. Concentration Profiles of Metallic Species in the STCL-1 Economizer Shell.

HEDL 7507-156.10

FIGURE 14. Concentration Profiles of Metallic Species in the STCL-1 Economizer Shell.

HEDL 7507-156.11

FIGURE 15. Concentration Profiles of Metallic Species in the STCL-1 Economizer Shell.

HEDL 7507-156.12

FIGURE 16. Concentration Profiles of Metallic Species in the STCL-1 Economizer Shell.

HEDL 7507-156.13

FIGURE 17. Composition of Surface Layer Along the Economizer Shell.

TABLE 5

AUGER ELECTRON SURFACE ANALYSIS AND PROFILE
FOR SAMPLE H-6-A*

Depth A°	C	O	Na	Cr	Fe	Ni
100	5.66	1.35	4.76	15.7	74.1	0.59
500	4.02	1.49	0.67	16.8	75.4	0.48
1000	3.21	1.75	-	18.9	74.2	0.52
3500	1.97	2.80	-	21.8	71.8	0.56
6500	2.01	0.27	-	22.9	73.3	0.56

* STCL-1 hot leg piping: 15,000 hours sodium exposure at 1120°F.

TABLE 6

AUGER ELECTRON SURFACE ANALYSIS AND PROFILE
FOR SAMPLE C-2-C*

Depth A°	C	O	Na	Cr	Mn	Fe	Ni
100	11.1	16.1	2.6	38.6	6.31	4.87	13.9
500	5.22	14.3	1.62	45.5	7.62	4.91	16.0
1000	4.18	14.5	0.41	47.6	8.38	6.08	15.2
2000	3.30	12.9	-	46.5	10.4	7.60	15.7
4000	3.03	10.7	-	41.8	10.1	14.0	17.1
8000	2.60	5.9	-	32.0	5.98	32.6	18.6
1.03 μ m	2.69	4.0	-	30.0	3.80	40.1	17.7
1.28 μ m	2.77	3.0	-	29.7	-	47.3	15.7

* STCL-1 cold leg piping: 15,000 hours sodium exposure at 800°F.

Six types of solutions were investigated at temperatures ranging from 55 to 80°C. The 304 SS specimens used were either solution annealed or sensitized. Solution-annealed specimens were prepared by sealing 0.75" diameter tubing in Quartz under vacuum and then heating the assembly to 1950°F for 20 minutes. The assembly was then water quenched. The sensitized specimens

were prepared in the same manner except they were allowed to furnace cool overnight.

The results of the screening tests and the various solutions investigated are shown in Table 7. In addition to nitric acid, which was used as a reference solution, five different groups of solutions were tested. All of the solutions except the nitric acid and the phosphoric acid removed measurable amounts of metal from the 304 stainless steel coupons over a 48 hour period, whether they were sensitized or solution annealed. Two of the solutions were found to cause intergranular penetration of the sensitized specimens. These were Solutions IV (oxalic acid, sodium fluoride, aluminum nitrate) and VI (sulfamic acid). The intergranular penetration was as much as 0.0045" with Solution IV (Figures 18 and 19) and 0.006" with Solution VI (Figure 20).

Solution III (oxalic acid - ammonium citrate) demonstrated metal removal ranging from 0.0001" to 0.0003" in 48 hours for both sensitized and solution-annealed 304 stainless steel. The most effective concentration was 0.1 M oxalic acid - 0.5 M ammonium citrate. Figure 21 shows that there was no measurable intergranular penetration.

Another solution which showed uniform metal removal was Number V (acetic acid - formic acid). Solution VC (30% acetic acid - 5% formic acid) demonstrated uniform metal removal to depths of 0.005" for both heat treatments of stainless steel with no intergranular penetration (Figure 22). These mixtures appear to be sensitive to the acetic acid concentration (Table 7).

Expected Accomplishments Next Quarter

This program will become a joint effort with Atomics International (AI) starting in FY 1976. The division of work scope provides for continuation of the screening tests and process optimization effort at AI while HEDL will: 1) continue corrosion product deposit characterization, 2) monitor the screening tests and process development, and 3) build and operate a

48 HOUR EXPOSURE AT 75⁰ C

SOLUTION ANNEALED

(200X)

OUTSIDE DIA

(50X)

INSIDE DIA

(200X)

→ 5 MIL ←

SENSITIZED

(200X)

OUTSIDE DIA

(50X)

INSIDE DIA

(200X)

HEDL 7507-156.20

FIGURE 18. Reaction of 0.1 M Oxalic Acid - 0.1 M Sodium Fluoride - 0.1 M Aluminum Nitrate on 304 SS. (Photo No. 416612)

48 HOUR EXPOSURE AT 80° C
SOLUTION ANNEALED

(200X)

OUTSIDE DIA

(50X)

INSIDE DIA

(200X)

SENSITIZED

(200X)

OUTSIDE DIA

(50X)

INSIDE DIA

(200X)

HEDL 7507-156.18

FIGURE 19. Reaction of 0.5 M Oxalic Acid - 0.1 M Sodium Fluoride -
0.1 M Aluminum Nitrate on 304 SS. (Photo No. 416354-416352)

48 HOUR EXPOSURE AT 80° C
SOLUTION ANNEALED

SENSITIZED

HEDL 7507-156.16

FIGURE 20. Reaction of 0.5 M Sulfamic Acid on 304 SS.
(Photo No. 416369-416370)

48 HOUR EXPOSURE AT 80⁰ C
SOLUTION ANNEALED

SENSITIZED

HEDL 7507-156.17

FIGURE 21. Reaction of 0.1 M Oxalic Acid - 0.5 M Ammonium Citrate on 304 SS.

48 HOUR EXPOSURE AT 80° C
SOLUTION ANNEALED

SENSITIZED

HEDL 7507-156.19

FIGURE 22. Reaction of 30% Acetic Acid - 5% Formic Acid on 304 SS.
(Photo No. 416356-416359)

TABLE 7

SCREENING TESTS ON VARIOUS POSSIBLE DECONTAMINATION SOLUTIONS

Solution Number	Solution Composition	Solution Temperature (°C)	Metal Removed in 48-hr Exposure Calculated from Weight Loss (mils)		Depth of Intergranular Attack Measured by Metallography (mils)
			Sensitized 304 SS	Solution Annealed 304 SS	
IA	5% Nitric Acid	70	< 0.01	--	--
B	15% Nitric Acid	70	< 0.01	--	--
C	50% Nitric Acid	70	< 0.01	--	--
D	100% Nitric Acid	70	< 0.01	--	--
IIA	10% Phosphoric Acid 0.1% EDTA	55 to 80	< 0.01	--	--
B	20% Phosphoric Acid 0.1% EDTA	65 to 80	< 0.01	--	--
IIIA	0.1 M Oxalic Acid 0.1 M Ammonium Citrate	65 to 75	< 0.01	< 0.01	--
B	0.1 M Oxalic Acid 0.5 M Ammonium Citrate	70 to 80	0.2	0.3	0
C	0.4 M Oxalic Acid 0.1 M Ammonium Citrate	70 to 80	0.2	0.1	--
IWA	0.1 M Oxalic Acid 0.1 M Sodium Fluoride	65 to 75	0.05	0.06	--
B	0.5 M Oxalic Acid 0.1 M Sodium Fluoride	65 80	0.2 0.3	0.2 --	0 0.5
C	0.1 M Oxalic Acid 0.1 M Sodium Fluoride 0.1 M Aluminum Nitrate	65 to 75	0.09	0.08	~4.5 on sensitized
D	0.5 M Oxalic Acid 0.1 M Sodium Fluoride 0.1 M Aluminum Nitrate	55 to 80	0.22	0.21	~1.5 on sensitized
VA	10% Acetic Acid 5% Formic Acid	65 to 75	< 0.01	< 0.01	--
B	10% Acetic Acid 10% Formic Acid	65 to 75	< 0.01	< 0.01	--
C	30% Acetic Acid 5% Formic Acid	80	0.5	0.5	0
D	30% Acetic Acid 10% Formic Acid	55 75	0.1 0.5	< 0.01 < 0.01	0 --
E	50% Acetic Acid 10% Formic Acid	65 to 80	< 0.01	< 0.01	--
VIA	0.1 M Sulfamic Acid	60 to 70	< 0.01	< 0.01	--
B	0.5 M Sulfamic Acid	65 to 80	0.7	0.4	6 on sensitized 0 on solution annealed

pilot-scale decontamination facility. To make efficient use of the existing decontamination program and facilities at HEDL, the current screening test program will extend through July using the refluxing condenser facilities.

Electrochemical measurement techniques for corrosion rates will be developed and applied to in situ measurements of the corrosion conditions during decontamination tests in the glass/teflon loops. These loop tests will demonstrate promising decontamination procedures recommended by AI on well-characterized radioactive specimens taken from the STCL-1 economizer.

The surface characterization will continue on STCL-1 surfaces. Incremental analysis will be completed on the economizer shell and on the inside and outside heat transfer tube surfaces. The radionuclide penetration profiles for these surfaces will also be determined.

A document will be issued summarizing the literature searches performed in the areas of surface characterization of sodium mass transfer deposits and the state-of-the-art of LMFBR component decontamination.

An Interim Report will be issued covering the analytical modeling of mass transfer deposition in an LMFBR.

Radioactivity Control Technology Operations

L. E. Chulos and R. R. Rake

Objective

The primary purpose of the Source Term Control Loops (STCL) is the gathering of data for Radioactivity Control Technology (RCT) programs with a maximum of efficiency and a minimum of systems downtime. The STCL's will also be utilized in various capacities of conducting tests to determine operating characteristics of different system components.

Summary

STCL-1 had logged over 2500 hours of operation as of 6-3-75 in Run No. 7 with the oxygen level holding at about 1.0 ppb with 1120°F hot leg/ 800°F cold leg temperatures.

STCL-2 and 3 passed the 2000-hour test point on 6-2-75 at 1120°/800°F temperatures, 0.5 ppm oxygen. A failed oxygen meter tube with over 10,000 hours of test operation was replaced on STCL-2. A new vanadium-wire equilibration was completed to calibrate the new tube.

STCL-4 completed Run 1A of 500 hours on 5-30-75 for the Advanced Alloy Program at loop temperatures of 1292°/977°F, 1.0 ppm oxygen. A pneumatic operated valve on the dump tank was replaced prior to Run 1A. The valve bellows had failed because of incorrect operating procedures which did not allow pressure relief from thermal expansion when the loop temperatures were changed.

Discussion

STCL-1 has logged over 18,000 hours of operation since its initial startup in June 1972. Since that time there have been no shutdowns of the loops because of mechanical or equipment failure. This can be attributed to three items: 1) well-planned design and construction, 2) reliable electrical and electronic control systems and valving, and 3) dedicated and efficient operating personnel. The oxygen meter tube now in service has logged over 10,000 hours of operation and still appears to be operating well. The previous total for an oxygen meter tube is about 5000 hours. It appears that the new type of ceramic tubes available are much more reliable than the earlier version. This once more points to the fact that oxygen meters are commercial, state-of-the-art instruments which are highly reliable; their dependability and usefulness is unquestionable.

The computerized control system for STCL-2, 3, and 4 has operated without problems for several months. Some of the earlier control system failures have been attributed to improperly written software or lagging of insulation over heater leads which caused them to short out and destroy their solid-state relays. All in all it is now evident that the computer system is doing a good job in controlling the multiple STCL loops.

STCL-2 has been operating without problems except for an oxygen meter tube failure after 10,704 hours which is noteworthy in itself as discussed above. STCL-3 has also been operating trouble free.

During shutdown of STCL-4 after shakedown tests at new higher temperatures of 1292°/977°F, it was discovered that one of the dual dump tank valves had failed because of an improper operating procedure. The bellows had been forcibly ruptured due to thermal expansion of sodium caught between the two valves when loop temperatures were elevated. The sodium dead-leg between the two valves was heated from 600° to 977°F without relief of the pressure; hence, the bellows failed. The procedures have now been rewritten to allow cycling open and then closed for each 100°F temperature change. The valves will also be maintained at 600°F instead of the normal cold leg temperature of the loop. The valve was cut out of the loop and replaced with one of the same design without delay in the loop test schedule.

Expected Accomplishments Next Quarter

STCL loop and computer operations will continue in support of the experimental Radioactivity Control Technology program.

SODIUM SYSTEMS ENGINEERING

D. W. Bennett

FFTF System 85 Procurement

D. W. Bennett, A. J. Karnie, V. P. Kelly, T. J. Owen, and J. A. Yount

Objective

Sodium Technology has provided the specifications and design drawings for hardware procurement and is actively providing the technical supervision of the procurement contract with the fixed price contractor. The present objective is to complete the procurement of System 85 Sodium Characterization System (SCS) components, including delivery at the FFTF site, and then participate in the installation and startup phases as required.

Accomplishments

Milestones achieved this quarter include:

- The System 85 Design Report, Rev. 2, was issued for use.
- Pressure boundary fabrication was initiated.
- Delivery of government-furnished equipment to the mechanical contractor was expedited.
- System 85 gas distribution piping preliminary design was completed.

Discussion

The System 85 Design Report was updated by adding final stress and other design information, and issued for use. The two-volume document was completely edited to improve readability.

Module floor-anchor loadings and piping heat losses were calculated using the latest seismic response spectra and thermal insulation conductivity values, respectively.

Pressure boundary fabrication of System 85 Plugging Temperature Indicators and Multipurpose Samplers was initiated by the fixed price

contractor. All piping has been cut to length and the bends have been made. Welding on Multipurpose Sampler internals has commenced.

All government-furnished materials for pressure boundary construction of the Sodium Characterization System, with the exception of small sodium valves, have been shipped to the contractor. The valves, which are the critical-path item on the delivery schedule, were delayed due to damaged bellows during valve assembly welding. Valve delivery is now scheduled for December 1975.

Other government-furnished materials that do not constitute a portion of the pressure boundary are either previously delivered to the vendor or are on well-substantiated and acceptable manufacturing schedules. Many of these items, such as thermocouples, trace heaters and thermal insulation, are being provided as a part of large, combined procurements along with other FFTF system requirements. This arrangement assures lowest costs and maximum commonality of systems from maintenance and spare-parts aspects.

System 85 gas distribution system preliminary design was completed and drawings were issued for approval. These piping systems transport argon from outdoor gas bottle racks to the various Multipurpose Samplers located throughout the FFTF. The design will be completed by Sodium Technology and then transmitted to Bechtel for field procurement and installation.

Expected Accomplishments

Fabrication of System 85 components will be 75% complete. Receiving and installation requirements for System 85 control panels will be defined and documented.

CRBRP System 85

J. A. Yount and D. W. Bennett

Objective

Finished specifications for the CRBRP Sodium Characterization System, complete with attendant drawings, stress analysis, and design report, will be provided.

Accomplishments

- Detailed technical discussions were held with the Atomics International (AI) Cognizant Engineer for CRBRP System 85. SCS design concepts and configuration management were discussed, and the operating history of the Plugging Temperature Indicator, Multipurpose Sampler and Oxygen-Hydrogen meters was reviewed.
- Piping arrangement drawings were developed and initial computer runs were performed on the four SCS Systems to scope the thermally induced expansion stresses.
- Control Panel front drawings were prepared.
- Cost estimates for CRBRP hardware (based on FFTF equipment costs) were formally transmitted to AI.

Discussion

HEDL personnel met on several occasions with CRBRP System 85 counterparts from AI. HEDL acts as a subcontractor to AI in this instance with ARD providing direction to AI. HEDL Sodium Systems Engineering's primary contact will be with AI.

Detailed technical discussions with AI representatives provided a comprehensive transfer of information regarding operating history of the Plugging Temperature Indicator, Multipurpose Sampler and the Oxygen/Hydrogen Meter. All of the Sodium Characterization equipment is well tested and refined and should definitely have a place in any state-of-the-art LMFBF.

Preliminary arrangement drawings of the various systems were completed and transmitted to AI for use in the CRBRP design review scheduled for July 1975.

The arrangement that is proposed for the CRBRP Sodium Characterization Systems utilizes a "building block" concept which employs three different standardized piping subassemblies--one each for the Plugging Temperature Indicator, the Multipurpose Sampler and the Oxygen/Hydrogen meter. These subassemblies can be installed, as required, in each of the reactor sodium sampling stations. An example of this arrangement is shown in Figure 23.

Sufficient stress analysis has been completed to prove the viability of the concept. Final stress analysis will be initiated next quarter.

Control Panel front drawings were also prepared and transmitted to AI.

A detailed breakdown of estimated costs for mechanical fabrication, Government Furnished Equipment (GFE), Process Instrumentation and heat trace control panels for CRBRP-SCS components was transmitted to AI. These estimates were based on FFTF Contract prices, with suitable allowance for design simplification and CRBRP requirements.

Expected Accomplishments

Detailed stress analysis will be initiated.

Sodium Technology will participate in the CRBRP Preliminary Design review and present the System 85 design package.

FIGURE 23. CRBRP System 85 Intermediate Sodium Characterization System.

SODIUM SYSTEMS DEVELOPMENT

J. L. Ballif

Sodium Removal

Objective

This work has the objective overall to provide a safe, reliable and viable method for the removal of sodium from wetted components used in HEDL test facilities and LMFBR components. HEDL is working on the water vapor nitrogen (WVN) method. AI is assigned to work on the alcohol cleaning method. This section covers the work at HEDL and is divided into three areas of effort. These are:

- I. Corrosion Control
- II. Process Control
- III. Process Demonstration

Each individual section will describe its specific objectives and will cover its details for discussion.

I. Corrosion Control

G. B. Barton and C. W. Funk

Objective

The work on this task reported for this quarter has concentrated on the following:

- A. Determination of the relationship of surface defects observed (previously reported) in the Process Qualification test specimens and the test method that exposed those defects.
- B. Investigation of the relationships between time, temperature, sodium hydroxide concentration, and atmosphere to the development of stress corrosion cracks.
- C. Investigation of damping capacity as a non-destructive method for detecting stress corrosion cracks.

Summary

Examination of control specimens subjected to the same thermal cycle as the Process Qualification specimens and then strained to fracture indicated surface defects of the same magnitude as observed in the Process Qualification specimens previously tested. Straining only 10% did not produce significant surface defects in the control. Similar treatment of H₂ charged specimens demonstrated that 10% straining did develop some surface defects while straining to rupture developed many surface defects similar to those observed in the Process Qualification test. The effects on mechanical properties were not measurable.

Presently metallography is considered the most positive method of identifying stress corrosion cracking, hence crack initiation was re-examined on a more conservative basis using metallography. The more conservative basis was to look for smaller cracks than had been previously used to define the onset of stress corrosion cracking. The criterion of significance was that they would have to exceed one mil to even tend to be significant. Thus, in the 250°F, 50% NaOH tests, it required 6 days to reach this level. At 210°F it required 22 days.

The question of the test atmosphere, as it relates to the validity of the specimen sensitivity tests conducted in air, has been addressed. The effect of the atmosphere of air versus nitrogen at 12 psi over the 50% NaOH solution was investigated. No significant change was observed by the exclusion of oxygen.

Examination of photomicrographs from specimens exposed at different depths in the NaOH solution showed that the greater tendency toward cracking occurred near the bottom of the container. Corrosive attack and cracking tends to be more intense in the triaxially loaded region near the section transition (root radius).

Measurements have been made by an NDT contractor of the damping capacity or internal friction of cracked tensile specimens and as machined controls. It is suggested by these results that this NDT method has merit. The results are preliminary, but indicate promise.

Discussion

Surface Defects

Surface defects were observed⁽¹³⁾ in Process Qualification specimens that had been strained 10% after completion of the processing cycle. They were strained with the objective of opening up any existing cracks so they would be more visible. Metallographic examination of sections through the defects showed they did not look like stress corrosion cracks. It had been reported in the literature^(14,15) that hydrogen charging produced surface cracks so this was considered as a possible contributor to the observed defects. The reaction of sodium with water releases hydrogen so it is present in the sodium removal process. The relation of mechanical strain to the generation of surface defects was examined for controls subjected to the same thermal cycle as the Process Qualification specimens but with exposure only to an argon atmosphere or vacuum prior to mechanical straining. In addition, specimens were hydrogen charged by electrolysis in a poisoned sodium hydroxide solution and then mechanically strained.

The data for the surface defects measured on the two Process Qualification runs previously reported plus that on controls are presented in Table 8. The defects observed in the fractured specimens are all of the same order of magnitude whether they be controls or "Test" specimens. The control specimens strained 10% did not develop significant surface defects. The type of surface defects developed in the fractured specimens is illustrated by Figure 24.

A summary of the mechanical properties of controls is presented in Table 9. Comparison of these data shows the thermal cycle used has little effect on the properties. Comparison with the previously reported data⁽¹³⁾ on the "Test" specimens shows the process does not significantly affect the properties either.

Hydrogen Charging

The effect of hydrogen charging was surveyed by subjecting 0.5 dia. tensile bars made of 304 SS to electrolysis for 24 hours in a solution of 50% NaOH poisoned with Na AsO₂ at a temperature of 150°F and a current density of 0.005 amp/cm² using a platinum anode. (The current density is equivalent to a sodium recession rate of 0.02 in./hr). All specimens had been heat treated in argon at 1050°F for 4 days. The post charging conditions of storage, examination and straining are tabulated in Table 10 with results of the appearance of the surface and fracture after pulling as well as mechanical properties in Table 11. The effects of hydrogen charging and post charging conditions on surface defects are illustrated in Figure 25 for the shank of specimen and Figure 26 for the necked region of the specimen. Metallography of the surface defects in the shank is shown in Figure 27 and splitting of the as-ruptured heat treated specimen is seen in Figure 28. The effect of 10% strain on surface defects of hydrogen-charged specimens is shown in Figure 29.

TABLE 8

EFFECT OF STRAIN ON SURFACE DEFECTS

Metallographically Measured Defect Depth in Inches

Strain Condition	1st WVN Process Qual. Run	2nd WVN Process Qual. Run		Control Specimens Simulating Process Qual. Run - No Na or WVN Exposure
	304 SS (A)	304 SS (A)	316 SS (A)	304 SS (B)
Zero Strain	N/A	.00025	<.0002	<.0002
		.0002	<.0002	<.0002
		.0002	<.0002	<.0002
			<.0002	<.0002
			<.0002	<.0002
10% Elong. Strain	0.0008 0.0003	N/A	N/A	0.00025
				0.00025
				0.00025
				0.0002
				0.0002
Fractured	0.005 0.004	0.003 0.002	N/A	0.005
				0.0025
				0.002
				0.0035
				0.0015

A = As previously reported for WVN process qualification tests.

B = Simulated dry process qualification

No WVN exposure

Sensitize - 1050°F/48 hr. in vacuum

Reheated - 1050°F/48 hr. in argon

N/A = Data not available or measured.

As-machined surface penetrations approach 0.0002 in.

CONCLUSION: Surface defect size is proportional to amount of applied strain such as zero, 10%, 100% to rupture.

SPECIMENS SHANK

SPECIMENS NEAR FRACTURE

0.001"

HEDL 7505-165.5

FIGURE 24. Etched Microstructure at 500X of 5 Standard Specimens After Pulling to Rupture Showing Strain Induced Fissures. No Exposure to WVN Process. (Photo No. 753877-2)

TABLE 9

EFFECT OF HEAT TREATMENT CONDITIONS ON MECHANICAL
PROPERTIES OF CONTROL SPECIMENS (304 SS)

<u>Condition</u>	<u>Reduction of Area (%)</u>	<u>Elongation in 2 in. (%)</u>	<u>0.2% Offset YTS (KSI)</u>	<u>Ultimate Tensile Stress (KSI)</u>
As-Manufactured	72.9	65.0	42.8	96.2
	73.3	66.0	41.6	95.0
	75.8	67.0	44.3	93.7
	69.7	54.0	47.1	101.1
	<u>76.1</u>	<u>66.0</u>	<u>42.2</u>	<u>93.7</u>
	Avg 73.6	63.6	43.6	95.9
Sensitized 1050°F/2 days in vacuum	74.0	67.0	39.2	92.0
	73.9	56.0	44.7	97.7
	76.3	67.3	39.0	91.4
	74.8	66.9	39.1	90.5
	<u>75.5</u>	<u>65.3</u>	<u>39.8</u>	<u>90.8</u>
	Avg 74.4	64.5	40.4	92.5
Sensitized as above plus 1050°F/ 2 days in argon at strain equivalent to 100% YTS	64.2	49.8	52.1	103.4
	64.1	55.7	47.9	102.1
	61.5	54.3	45.8	99.8
	73.9	63.4	43.1	93.5
	<u>70.6</u>	<u>61.6</u>	<u>43.5</u>	<u>94.5</u>
	Avg 66.9	57.0	46.5	98.7

Strain Rate: 0.002 in./min.

CONCLUSION: Sensitization heat treatment does not affect significantly
mechanical properties.

TABLE 10

EFFECT OF HYDROGEN CHARGING AND STORAGE
ON SURFACE DEFECTS AND FRACTURE

0.5 in. Round 304 SS Bar Specimens

Process Conditions			Results			
H.T. 1050°F 4 Days Argon	H ₂ Charging 1 Day 150°F 50% NaOH + Pt Anode	Storage	Surface Appearance	Fracture Appearance	Metallog. Maximum Depth (inches)	Spec. #
None	None	None	Smooth	Normal cup + cone	.00025	104
Yes	None	None	Smooth	Split	.0005	71 77 128
Yes	Yes	Pulled to fracture in 4 hr.	Many Fissures	Split	~.005	64
Yes	Yes	Pulled post 7 days @ RT	Many Fissures	Split	~.005	51
Yes	Yes	Pulled post 7 days @ 200°F in air	OK	Split	<.001	78
Yes	Yes	10% Strained post 2 hr	Few Fissures	N/A	.005	?

- CONCLUSION:
1. Hydrogen charging increases surface defect population and penetration depth even after 7 day storage at room temperature.
 2. Hydrogen effects are removed by 7 days storage at 200°F.
 3. Sensitizing heat treatment at 1050°F/4 days causes splitting of normal tensile fracture.

TABLE 11

EFFECT OF H₂ CHARGING AND STORAGE ON MECHANICAL PROPERTIES
OF TYPE 304 SS 0.5 IN. DIA. ASTM ROUND TENSILE SPECIMENS

Material & Treatment	Reduction of Area (%)	Elongation In 2 in. (%)	0.2% Offset YTS (KSI)	Ultimate Tensile Strength (KSI)	Specimen #
As manufactured, 304	76.8	67.1	37.8	89.4	(104)
	76.4	66.9	40.6	91.5	(122)
Heat treated 1050°F 4 days	75.1	64.4	37.3	90.7	(71)
	75.0	64.0	37.3	89.5	(77)
	76.0	67.6	36.1	91.1	(128)
H ₂ Charged, Pulled within 4 hours	73.2	65.0	37.6	91.0	(64)
H ₂ Charged, Pulled after 7 days storage at 200°F	76.2	68.2	37.0	89.4	(78)
H ₂ Charged, Pulled after 7 days storage at room temp.	72.4	67.3	38.2	90.5	(51)

Strain Rate: 0.002 in./min.

CONCLUSION: Mechanical properties are not significantly affected by sensitizing heat treatment, hydrogen charging or storage.

DEFECT FREE
SURFACE OF SPECIMEN
AS MANUFACTURED

DEFECT FREE
SURFACE OF SPECIMEN
HEAT TREATED
1050°F/4 DAYS IN ARGON

SURFACE DEFECTS IN
HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED,
FRACTURED WITHIN 4 HR. AT
ROOM TEMP. AFTER REMOVAL
FROM BATH

SURFACE DEFECTS
OF HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGES,
STORED 7 DAYS AT ROOM TEMP.
AFTER REMOVAL FROM BATH

DEFECT FREE SURFACE
OF HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED,
STORED 7 DAYS AT 200°F
AFTER REMOVAL FROM BATH

6X

HEDL 7505-165.1

FIGURE 25. Showing Effect of H₂ Charging in 50 wt% NaOH and Post Conditions on 304 SS 0.5 inch Diameter. (Photo No. 753877-5)

DEFECT FREE SURFACE
AS MANUFACTURED
SPECIMEN

DEFECT FREE
SURFACE SPECIMEN
HEAT TREATED
1050°F/4 DAYS IN ARGON

SURFACE DEFECTS IN
HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 4 HR. AT ROOM TEMP.
AFTER REMOVAL FROM BATH

SURFACE DEFECTS IN
HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 7 DAYS AT ROOM TEMP.
AFTER REMOVAL FROM BATH

DEFECT FREE
SURFACE SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 7 DAYS AT 200°F
AFTER REMOVAL FROM BATH

6X

HEDL 7505-165.2

FIGURE 26. Showing Effect of H₂ Charging in 50 wt% NaOH and Post Charging Conditions on Pulled 304 SS 0.5 Inch Tensile Specimen Surface Defects. (Photo No. 753877-4)

DEFECT FREE SURFACE
AS MANUFACTURED
SPECIMEN

DEFECT FREE SURFACE OF
SPECIMEN HEAT TREATED
1050°F/4 DAYS IN ARGON

SURFACE DEFECTS OF HEAT
TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 4 HR. AT ROOM TEMP.
AFTER REMOVAL FROM BATH

SURFACE DEFECTS OF
HEAT TREATED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 7 DAYS AT ROOM TEMP.
AFTER REMOVAL FROM BATH

DEFECT FREE SURFACE
OF SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 7 DAYS AT 200°F
AFTER REMOVAL FROM BATH

100X

HEDL 7505-165.3

FIGURE 27. Showing Effect of H₂ Charging in 50 wt% NaOH at 150°F and Post Charging Condition on 304 SS 0.5 Inch Diameter Tensile.
(Photo No. 753877-3)

100X

SPLITTING OF
FRACTURE SPECIMEN
HEAT TREATED
1050°F/4 DAYS IN ARGON

⊥ 0.001"
⊥

100X

SPLITTING OF
FRACTURED SPECIMEN
ELECTROLYTICALLY H₂ CHARGED
STORED 7 DAYS AT 200°F
AFTER REMOVAL FROM BATH

⊥ 0.001"
⊥

FIGURE 31. Showing Effect of Sensitizing Heat Treatment on Splitting of Fracture of Ruptured Tensile Specimen

500X

SURFACE DEFECTS OF
SPECIMEN STRAINED
TO 10% ELONGATION
AFTER 2 HR. AT ROOM TEMP.
FOLLOWING ELECTROLYTICALLY
CHARGING IN 50% NaOH
AT 150°F FOR 24 HR.

⊥
0.001"
⊥

HEDL 7505-165.4

FIGURE 29. Showing Effect of 10% Strain on Surface Defects After Electrolytically H₂ Charging. (Photo No. 753877-1)

Cracking Conditions

A parametric examination of the primary variables of temperature and sodium hydroxide concentration on the induction and growth rate of cracks is underway. Herein are reported the results for 50% NaOH solution.

The experimental procedure consisted of exposing stressed sleeved tensile bars of 304 SS in the solution of NaOH contained in an Inconel 600 pot 4 in. dia. x 19 in. deep. The specimen assemblies were suspended from wires. Measurements were also made of the effect of replacing the air over the solution with nitrogen at 12 psig.

The specimens were sectioned and polished for metallographic examination after removal from the solution. Selected views are presented in Figures 30, 31 and 32 and the measurements summarized on Table 12.

In the sections of the 3-day 250°F exposed specimens examined metallographically, there were no discernible cracks but there were many "fingers". After six days the "fingers" were deeper and wider and a few shallow cracks were observed. It should be pointed out that the probability of observing the deepest crack is quite low. For example, if a crack has a length of 0.050 in. on the surface of a 0.25-in. diameter tensile bar the probability that a section through the bar (across a diameter) will intersect it is:

$$p = \frac{2\ell}{\pi d} = \frac{2 \times 0.05}{\pi \times 0.25} = 0.127$$

or about one chance in 8 that the crack will be intersected.

The probability that the measured depth of the crack will be greater than 3/4 of the actual depth is of the order of 0.8 if the crack is a semi-circular segment originating at a point on the surface of the specimen. (This was the observed shape of a number

3 DAYS

250°F

6 DAYS

7 DAYS

210°F

22 DAYS

HEDL 7506-18.1

FIGURE 30. Micrographs at 500X Showing Effect of Temperature and Exposure Time of 304 Sleeved Tensile Specimens Stressed to 100% of YTS in 50 wt% NaOH, Specimens Located 2 inches Below Surface.

(Photo No. 754358)

IMMERSED 6 DAYS NEAR BOTTOM OF VESSEL

IMMERSED 6 DAYS NEAR BOTTOM OF VESSEL

IMMERSED 25 DAYS NEAR BOTTOM OF VESSEL

1 MIL

HEDL 7506-18.2

FIGURE 31. Micrograph at 500X Showing Effect of Inert Cover Gas N_2 of 304 Sleeved Tensile Specimen Stressed to 100% YTS in 50 wt% NaOH at 250°F. (Photo No. 754358)

IMMERSED 6 DAYS AT BOTTOM OF VESSEL

IMMERSED 6 DAYS 2 INCHES BELOW SURFACE UNDER SLEEVE NEAR CENTER

IMMERSED 6 DAYS 2 INCHES BELOW SURFACE NEAR RADIUS

1 MIL

HEDL 7506-18.3

FIGURE 32. Micrographs at 500X Showing Effect of Specimen Location in Vessel of 50 wt% NaOH at 250°F for 304 Type SS Sleeved Tensile Specimens Stressed to 100% of YTS.
(Photo No. 754378-2)

TABLE 12

COMPARISON OF RECENT CORROSION PENETRATION MEASUREMENTS ON
TENSILE BARS OF 304 SS EXPOSED TO 50 WT% NaOH (SLEEVED
AND STRESSED TO 100% YTS IN)

Temp. (°F)	Atmosphere over 50% NaOH	Specimen Location	Corrosion Penetration (in.)				Remarks	Spec #
			3 days	6 days	7 days	22 days		
250	Air	2 in. below surface	<0.0001	-	-	-	<1 mil SCC	775
250	"	"	-	<0.0015	-	-	>1 mil SCC	774
210	"	"	-	-	<0.0001	-	"	1908
"	"	"	-	-	-	<0.00045	"	2022
250	12 psig N ₂	Near bottom	-	<0.0013	-	-	Same penetration	1327
"	"	"	-	-	-	<0.004	as #774 under equal condition	1328
250	Air	2 in. below surface	-	<0.0002	-	-	Under sleeve	773A
"	"	"	-	<0.00065	-	-	Near radius less deep than #774	773B
210	"	"	-	-	-	<0.0011	Near radius	2022A
"	"	"	-	-	-	<0.00045	Under sleeve	2022B
250	"	Near bottom	<0.0002	-	-	-	Deeper than #775	776

of cracks in bars that were fractured.) Thus, the probability that the deepest measured crack in a section is at least $3/4$ of the depth of the deepest crack in the specimen is about 5% (taking into account that it has been the practice to examine only $1/2$ the length of a given tensile bar).

If many cracks or "fingers" occur, a statistical method of predicting maximum crack depth from measurements on a single specimen could be developed; but if only a few cracks occur, then more specimens must be measured to get a large enough population of crack depth measurements to estimate the maximum depth. Since such an analysis and method of measurement have not been worked out, the results are presented as qualitative or ranking of conditions as more or less severe.

In three days at 250°F, the attack appears to be negligible; in six days attack (cracking) appears to be less than 2 mils.

When a nitrogen blanket at 12 psig was used over the solution, the rate of attack may have been reduced (see Figure 10). Delays in equipment fabrication prevented the performance of planned experiments on the effect of bubbling various gases (air, nitrogen, and Ar-H₂) through the NaOH solution. Cracks up to ~2 mil were observed in the 25 day 50 w/o NaOH exposed specimen at 250°F.

When the temperature is reduced to 210°F, the rate of attack is reduced. After seven days' exposure there is very little attack (Figure 30), after 22 days there is significant attack (>1 mil) (Figure 30), and a few cracks could be seen in the section examined. Only one crack was observed to develop from a "finger" or pit. A few cracks were observed to originate from the surface as can be seen.

These data make it more apparent that cracking conditions cannot be characterized on a yes-no basis. They need to be determined on a rate of growth basis. From a rate of growth basis (and induction times, if they can be satisfactorily determined) and allowable loss of section, the design engineer could make a more reasonable estimate of the life of a component subjected to various exposures.

Crack Propagation

Since surface defects are a concern in selection of a sodium removal process, a fracture mechanics analysis was prepared to calculate the exact depth propagation of hypothetical flaws for specific components. This analysis has been completed and shows that 5 mil deep defects are not of engineering significance in the two specific FFTF hardware cases analyzed.

Consultation with the component design group handling the FFTF pump and IHX established two specific cases for analysis by fracture mechanics. The sections selected were those where sodium removal would be most difficult and at points of maximum stress. Examples of this would be the locking pin in the IHX and the female sleeve of the pump journal bearing. Stress conditions identified by WARD for these specific components are tabulated in Table 13. Details of the calculations are included in the writeup.

Conclusions of the analysis were: 1) Extension of about 1.45×10^{-6} in. of a hypothetical 5 mils deep crack in the Type 304 SS locking pin is not of engineering significance based upon 20 years of service, which includes 725 cycles of bending stress to a maximum stress of 36,000 psi., and 2) The extension of a hypothetical 5 mil deep crack in the Type 304 SS journal housing is not of engineering significance because the stress intensity factor ($3870 \text{ psi}\sqrt{\text{in}}$) is an order of magnitude (24,900 to 39,280 $\text{psi}\sqrt{\text{in}}$.) less than specimens that exhibit no crack extension after Na exposure to moist nitrogen.

Fracture Mechanics Analysis of FFTF Components

Taking first the problem of the IHX Locking Pin, the component is shown in Figure 33 and a schematic of the assumed crack is shown in Figure 34.

A flaw depth (a) of 5 mils was assumed in the analysis. The crack length (2c), which is considerably less important in the analysis

TABLE 13

CONDITIONS FOR FRACTURE MECHANICS CALCULATIONS OF FFTF COMPONENTS

<u>Condition</u>	<u>FFTF Pump</u>	<u>FFTF IHX</u>
Component	Lower ID corner of the pump journal	Locking pin
Stress state outer fiber	28,000 psi hoop tension constant load during operation in 1050°F sodium	37,700 psi bending thermal cycling load RT to 1050°F (sodium) 725 cycles/20 years
Material	304 SS forged grain size less than 5	304 SS bar grain size less than 5
Section	1.75 in. thick with 15 in. ID	9/32 in. OD round reduced section
Finish Estimated	RMS 16 coated with 3/16 in. of Stellite 6	RMS 125

a = crack depth
(assumed to be 0.005 in.)

FIGURE 33. IHX Locking Pin.

a = crack depth = 0.005 in.
2c = crack length = 0.100 in.

FIGURE 34. Schematic of Assumed Crack.

than the depth, was assumed to be 0.100 in. The fracture mechanics* parameter K (K is called the stress intensity factor) has been shown to be the rate-controlling parameter in the propagation of fatigue cracks and can be used in the analysis for estimating the crack extension during service loadings. An approximate K-solution for a surface crack would be as follows:

$$K = \left[\sigma_t M_k + \sigma_b M_b \right] \sqrt{\frac{\pi a}{\Phi}} \quad \text{Eq. (1)}$$

where σ_t = uniform tensile (or compressive stress)

σ_b = maximum bending stress

M_k = finite boundary correction factor for uniform stress (Ref. 16)

M_B = finite boundary correction factor for bending stress (Ref. 16)

a = crack depth

Φ = complete elliptic integral of the second kind

$$= \int_0^{\pi/2} \left[1 - \left(\frac{c^2 - a^2}{c^2} \right) \sin^2 \beta \right]^{1/2} d\beta$$

(Φ ranges between $\pi/2$ for $a = c$ to 1.00 for $a \ll c$)

For the case of IHX Locking Pin, the uniform stress component is zero and the maximum bending stress is 37,700 psi. Equation (1) therefore reduces to

$$K = \frac{\sigma_b M_B \sqrt{\pi a}}{\Phi} \quad \text{Eq. (2)}$$

*Linear-elastic fracture mechanics techniques could not be rigorously applied to a case where the grain size was greater than the crack size because of the anisotropy present in such a local stress field. However, in the present case, the mean grain diameter corresponding to an ASTM Grain Size 5 is 0.002 in., and, as will be seen, our crack would be therefore at least two grain diameters deep.

From Reference 16, it is found that $M_B = 1.12$ for $a/c = 0.1$ and $a/t \approx 0$. The elliptic integral Φ may be found in any standard mathematic handbook (e.g., Reference 17), and for $a = 0.005$ and $2c = 0.100$, the value of $\Phi = 1.0167$. Therefore, from Equation (2)

$$K_{\max} = \frac{(37,700)(1.12)(\sqrt{.005\pi})}{1.0167} = 5202 \text{ psi}\sqrt{\text{in}}$$

We will assume that the minimum stress in the fatigue cycle is zero, therefore $\Delta K = 5202 \text{ psi}\sqrt{\text{in}}$.

The fatigue-crack growth behavior of Type 304 SS in low-oxygen flowing sodium at 800°F and 1000°F has been determined (see Reference 18). Little difference in crack growth behavior was noted between 800 and 1000°F, and it is therefore reasonable to assume that the 1000°F data may be used in the present analysis at a temperature of 1050°F. Extrapolating* the data of Reference 18 to a value of $\Delta K = 5205 \text{ psi}\sqrt{\text{in}}$, one obtains a fatigue-crack growth rate (da/dN) of approximately $2 \times 10^{-9} \text{ in./cycle}$. Since the component is expected to sustain a maximum of 725 cycles in a 20-year lifetime, the calculated crack extension would be

$$\begin{aligned}\Delta a &= (da/dN)(\Delta N) \\ &= (2 \times 10^{-9} \text{ inch/cycle})(725 \text{ cycles}) \\ &= 1.45 \times 10^{-6} \text{ inch.}\end{aligned}$$

It will be noted that this is a negligible amount of crack extension. It should be pointed out, however, that the crack growth rate data was generated in relatively pure sodium and that the possibility exists for residual corrosion products remaining in the crack after the cleaning process. Data for the fatigue

*Extrapolation to lower values of ΔK is conservative since slope transitions, if they occur, would be toward steeper slopes which would produce even lower crack growth rates.

behavior of cracks containing residual corrosion products does not exist. However, a conservative estimate would be that corrosion products would not accelerate the crack growth rate more than two orders of magnitude. If this were the case, the estimated crack extension would be 1.45×10^{-4} in., which is still negligible compared to the initial crack depth of 0.005 in.

Considering next the case of the Pump Journal, the component is illustrated in Figure 35.

Assume $a = 0.005$ in.
 $2c = 0.100$ in.

FIGURE 35. Pump Journal.

The K-solution would be similar to Equation (1) with an added factor to account for the curvature of the journal. Therefore:

$$K = \left[\sigma_t M_k + \sigma_b M_B \right] \left[f(\lambda) \right] \frac{\sqrt{\pi a}}{\phi} \quad \text{Eq. (3)}$$

where $f(\lambda)$ = curvature correction factor (Ref. 19)
 $= 1 + (0.481 \lambda + 0.386 e^{-1.25\lambda} - 0.386) \left(\frac{a}{t} \right)$

and $\lambda = [12(1 - \nu^2)]^{1/4} \sqrt{\frac{c}{vt}}$

ν = Poisson's Ratio = 0.282

For $a = 0.005$, $c = 0.05$, $\rho = 7.50$, and $t = 1.75$ inch, the value of $f(\lambda)$ is 1.0017. The uniform (hoop) stress for this case is

$\sigma_t = 28,000$ psi, and the bending stress is zero. From Reference 16 the value of M_k is 1.12. The value of ϕ is the same as in the previous calculation. Therefore:

$$\begin{aligned}
 K &= \left[\sigma_t \ M_k \right] \left[f(\lambda) \right] \sqrt{\frac{\pi a}{\phi}} \\
 &= \frac{(28,000)(1.12)(1.0017)(\sqrt{.005\pi})}{1.0167} \\
 &= 3870 \text{ psi} \sqrt{\text{in}}
 \end{aligned}$$

Reference 20 studied the exposure of precracked and preloaded fracture mechanics specimens in liquid sodium with an intermediate moist nitrogen cleaning. Five specimens were preloaded to K-levels ranging between 24,960 and 39,280 psi $\sqrt{\text{in}}$. They were exposed to static sodium for 10 days at 1050°F, removed from the sodium and given a cleaning treatment of 30 minutes 30% steam 70% N₂ at 230°F followed by 4 hours 100% steam at 230°F. The specimens were then reinserted in static sodium at 250°F and the temperature was slowly increased to 1050°F over a 45-day period. No crack extension was noted at the end of this exposure. Since the K-levels in Reference 20 were, in some cases, an order of magnitude greater than the K-level calculated for the pump journal, it is concluded that crack extension in the pump journal would be minimal under these conditions.

D. Nondestructive Detection of Defects

Damping capacity or internal friction measurements were completed by Daedalean Associates on typical HEDL standard ASTM 0.25 in. round tensile specimens. The condition of these specimens are noted in Table 14. Specimens represented the as-machined un-heat treated condition for comparison with specimens with gross cracks and those exposed to caustic for certain periods of time. Additional specimens were exposed to the water vapor nitrogen processing conditions and then strained 10% to improve ability to see surface defects.

Comparison of the results in Table 14 show the following: The damping capacity was reproducible on the two as-machined specimens. The range of the signal response of the measured characteristic was a five decade range from control to complete crack conditions.

TABLE 14

RESULTS OF DAMPING CAPACITY TESTS BY DAEDALEAN ASSOC. INC.

Specimen Number	Wetting Media	Conditions Of specimens	Accoustic Energy Attenuation $\Delta W/W$	Fm (Hz)	Remarks
1.	Air	AM (controls)	7.7×10^{-4}	8700	No visible cracks
5.	Air	AM	7.7×10^{-4}	8700	do
* 6.	Sodium	AM + Wet + WVN + Rewet + Clean	8.8×10^{-4}	8300	do
* 7.	do	do	9.4×10^{-4}	8300	do
* 8.	do	do	9.1×10^{-4}	8300	do
* 9.	Sodium	AM + Wet + WVN + Rewet + Clean + 10% Elong.	18.1×10^{-4}	7700	No visible cracks
* 10.	do	do	14.0×10^{-4}	8000	Visible cracks
* 11.	do	do	14.4×10^{-4}	7700	No visible cracks
** 2.	50% NaOH	AM + NaOH Encapsulated 10 days @ 250 F	8.5×10^{-4}	7700	No visible cracks
** 3.	do	AM + NaOH Encapsulated 7 days @ 325 F	20.0×10^{-4}	8300	do
** 4.	do	AM + NaOH Encapsulated 2 days @ 400 F	$1000. \times 10^{-4}$		Visible crack

Legend

AM = as machined specimens

Wet & Rewet = 1050 F in sodium for 48 hours @ 50 F/hour up and down.

WVN = Water vapor nitrogen cleaning process with H₂O 7v/0 in 160 F Nitrogen carrier gas.

Clean = drain and mechanical cleaning prior to examination.

* = Process qualification coupons in which sodium was the media.

** = Specimen sensativity specimens in which 50 % NaOH (caustic) was the media ...under pressure.

W = A derived quantity representing accoustical energy attenuation.

- CONCLUSIONS:
- (1) There is no significant difference between controls & processed WVN coupons.
 - (2) There is a significant difference between the elongated specimens and controls.
 - (3) In two out of three cases there is a significant difference in 3 & 4 (cracked ?).

Surface Contamination

Because component crevices could contain residue from the cleaning processes, it was decided to look at some of the sleeved stressed tensile (SST) specimens. Those used had been cleaned with ethyl alcohol prior to sodium rewetting to determine whether or not significant quantities of carbon would be added to the stainless steel. Auger electron spectroscopy indicated that the surface film was not sufficiently enriched in carbon to constitute a significant source for carburization of the underlying metal.

Applied Chemistry performed the Auger Electron Spectroscopy analysis on two tensile bars. The two bars had been wet at 1050° F for 48 hours, loaded to 100% yield strength, then cleaned in ethanol at room temperature until bulk sodium was removed, then held at 140° F for 100 hours. One specimen was then water rinsed while the other was vacuum dried, then both were re-wet in sodium at 1050° F for 48 hours in separate capsules. The objective was to determine whether or not carbon could be measured in the surface layer and if so was there more in the specimen that had not been water washed.

Tables 15 and 16 are the analytical reports. There are several things of interest shown. 1) Unless a handling mixup occurred, the water rinsed sample retained more carbon than the unrinsed one, contrary to expectation. 2) The film was largely chromium oxide. 3) The presence of Ca, K, Cl indicates possible ion exchange properties of the film. 4) The variation in composition with depth is interesting and may be significant in interpreting the corrosion process.

The indicated quantities of carbon are not high enough to raise a question about the suitability of an alcohol based cleaning process.

TABLE 15

AUGER ELECTRON SURFACE ANALYSIS
OF BLACK FILM ON STEEL BAR NO
WATER-RINSE BEFORE HEATING IN Na

		Approximate Wt. % Corrected For C														
Atmosphere and Handling Contamination		Depth	C	N	O	Na	S	Cl	K	Ca	Cr	Fe	Ni	Mg	Li	Si
		0	14.6	.89	20.8	4.38	.45	1.30	.73	2.04	22.2	6.56	20.8	About 1 %		
		25Å	3.95	.30	25.7	.78	.21	.80	2.04	2.62	44.8	6.13	10.3			
		60	1.99	.30	26.5	1.46	.07	.66	1.87	1.91	52.4	4.52	6.33			
		100	1.65	.42	27.4	.66	.11	.37	1.41	1.79	56.6	3.40	4.04			
		300	.75	.26	26.7	.67	.062	.73	2.39	1.43	60.1	2.32	1.86			
		900	.85	.28	25.8	1.67	.062	.53	2.91	.63	63.1	3.29	6.68			
		1800	.93	.25	23.1	2.80	.023	.29	1.09	.21	58.7	10.9	1.46			
		3000	1.13	.25	20.6	4.90	.039	.082	1.28	.097	40.8	27.5	3.63			
		4010	1.28	.30	14.1	4.78	.053	--	.94	--	23.6	50.5	4.18			
		5000Å	2.40	.15	20.0	4.34	.028	--	.70	--	9.03	52.3	9.62			

Film was very rich in Cr; weak in Fe and Ni. The K occurs at the position of a weak C line. Perhaps the C environment is changed in the Na--but I have never seen such a change before. I did not get all the way through the film.

TABLE 16

AUGER ELECTRON SURFACE ANALYSIS OF BLACK FILM
ON STEEL BAR WATER RINSED BEFORE
REHEATING IN Na

Atmosphere and Handling Contamination	Depth	Approximate Wt. % Corrected For C											Ca	Cr	Fe	Ni	Mg	Al	Si
		C	N	O	Na	S	C	K											
	0	26.4	1.32	23.0	2.96	1.01	1.56	--	1.30	34.3	4.70	1.51							
	25Å	5.40	.47	26.9	1.78	.35	.40	--	3.30	49.2	5.78	.86	1.30	.82	1.49				
	60	3.03	.41	27.0	1.17	.33	.45	--	2.72	55.5	.90	1.41							
	100	2.37	.48	26.3	.83	.32	.58	--	2.59	57.1	6.40	1.05							
	250	1.46	.39	24.6	.86	.17	.51	.27	1.97	60.6	6.63	.56							
	500	1.01	.26	25.1	1.70	.19	.49	.53	1.73	58.9	7.32	.73							
	1000	1.31	.27	22.2	1.05	.13	.25	.87	1.09	58.2	11.4	1.26							
	1500	2.07	.34	18.8	1.61	.030	.18	--	.54	48.3	25.5	2.61							
	2500	2.41	.30	6.07	1.88	.033	--	--	.08	21.2	59.8	6.12							
	4000	4.66	.32	2.37	1.39	.024	--	--	--	13.7	68.2	7.96							
	5000	6.32	.30	1.96	1.94	--	--	--	--	12.5	66.6	8.42							
6800Å	2.09	.42	.90	1.28	--	--	--	--	16.5	67.9	8.98								

This surface contained more C than the one from which the alcohol was not rinsed off. Film is rich in Cr + O; weak in Fe + Ni. Weak Fe line at 47 eV indicates film is very nearly penetrated at 6800Å--but there is still some C, Ca, and Na.

II. Process Control

J. M. Lutton

Objective

The purpose of this subtask is to determine the factors affecting the WVN process stability and to establish on a firm basis techniques for positive process control.

Summary

During this report period techniques were developed and measurements made of the reaction rates and the reaction rate temperature coefficient for a wide range of temperatures and water vapor compositions. The basic mechanism of the water vapor sodium reaction for the water vapor nitrogen process has been experimentally established.

Conclusions drawn from this work to date are the following: 1) the sodium reaction rate with water vapor is a linear function of the water concentration. 2) the temperature coefficient of the reaction rate is very small and apparently negative near 200°F. 3) the mechanism of the reaction involves the slow diffusion of water through a film of solid NaOH from a saturated solution of NaOH on the sodium surface, followed by rapid reaction at the sodium surface.

Discussion

Reaction Rate Measurement

Previous work showed that the sodium WVN reaction rate is determined primarily by the water vapor concentration. In tests with a closed cup configuration it has also been found that the rate is strongly affected by the initial condition of the surface of the sodium. To determine the rates involved, experiments with continuously drained samples were conducted. A typical result is seen in Figures 36 and 37 which shows the hydrogen evolution and sodium temperatures during the run. The hydrogen evolution is a direct measure of the reaction rate. Results from these tests demonstrate that stable reaction rate increased at a near linear rate with water vapor concentration. In a further series of tests, the sodium samples were cast around a small coil of tubing, through which coolant could be circulated.

FIGURE 36. Hydrogen Evolution vs Time for Run 34 A.

FIGURE 37. Sodium Temperature vs Time for Run 34 A.

In these experiments the sodium could be maintained at nearly constant temperatures regardless of the reaction heat generation rate. Thus the effect of water concentration and temperature on the reaction rate could be studied independently. Results show the same dependance on water concentration nearly independent of temperature. The linear relation was confirmed. Experiments were also conducted over the range of 100 to 208°F for the sodium sample temperature. Results indicate rather small variations in rate throughout the range which shows the temperature coefficient of the reaction rate is near zero. Results shown in Figure 38 show that the lines for each temperature are very close and that the rates for 165-175°F are higher than those for 200 - 210°F indicating that the temperature coefficient is actually negative. Data indicate that the coefficient becomes positive at from 150 to 170°F.

The results are significant in relation to the control technique selected. The negative temperature coefficient implies that the reaction should be self stabilizing above the temperature where the coefficient changes sign. Thus it is desirable to maintain the operating sodium temperature as high as possible below the melting point of the sodium. When the closed cup configuration is involved there is a tendency for the reaction rate to fall off with time. The buildup of the reaction product increasingly restricts the access of the water to the sodium surface by increasing the fluid diffusion length. However, the operating temperature in a cup (pot) is determined by the heat being generated and the process gas temperature. The upper limit for this temperature is 205°F for a process gas temperature of 160°F. Thus stable conditions should prevail in the early stages of the process. As the reaction rate falls off however, the long term trend is for the sodium temperature to fall and this can be corrected by increasing the process gas temperature. The main point is that the reaction will be more stable, the higher the temperature. Further, temperature changes produce a modest effect compared to the much more drastic effect on the rate of water concentration changes. Control could probably be maintained by very small gradual increases in the water concentration but changes required are obviously minute when compared to the small effects associated with the relatively crude temperature changes.

In view of the importance of the sign of the temperature coefficient, tests were run to verify this. Figure 39 shows the information from which Figure 38 was derived and expresses them directly as reaction rates for 15 minute intervals.

Reaction Mechanism

The small reaction rate temperature coefficient proves that the reaction is not controlled by a chemical kinetic process. In previous work it was shown that solution concentration of NaOH is essentially the same as that in closed cups where the solution accumulates over the sodium. These results have now been extensively confirmed by the controlled temperature plug tests discussed in this report. These observations suggest that the rate controlling mechanism is a condensed phase diffusional process. The controlled temperature test provided good evidence of the actual nature of the process.

Exploratory tests covering the operating temperature range indicated an abrupt increase in the rate of about 20% when the temperature increases through 150°F. A run was conducted to investigate this effect and it was found that this phenomenon occurs reproducibly at 146°F. Since this is the transition temperature for the reaction $\text{NaOH} \cdot \text{H}_2\text{O}(\text{s}) \rightarrow \text{NaOH}(\text{s}) + \text{H}_2\text{O}(\text{l})$, it clearly indicates solid phases of NaOH or its hydrate must be present on the sodium surface. The effect was dramatically observable by setting the control near the transition where sodium blob temperatures would oscillate back and forth with a period of 10 to 15 minutes because of the change in heat generation rate when the reaction rate changes. Changing the control temperature either up or down by one or two degrees abruptly stops the oscillation.

Visual observation of the sodium surface during the oscillatory behavior shows the thin coating of liquid caustic solution normally present dries up during reaction. Change from moist transparent liquid to white opaque solid is abrupt, dramatic, and correlates directly with the hydrogen meter surges. Further confirmation of this point is provided by the observation that liquid dripping from a reacting plug of sodium immediately forms a solid upon hitting a cooler surface. These solid spots soon liquify in the moist gas showing that the solution is essentially saturated.

FIGURE 38. Sodium-WVN Reaction Rates in Controlled Temperature Tests.

FIGURE 39. Sodium-WVN Reaction Rates.

These observations collectively suggest that the mechanism of the reaction involves a rapid reaction of water molecules at the sodium surface and a slow transport of water by diffusion through a thin layer of solid NaOH. The surface of the NaOH layer is in contact with a layer of saturated solution from which water diffuses into the solid layer. As water diffuses through the saturated solution and reaches the solid NaOH surface, the caustic gradually dissolves. That the same mechanism is operative in closed cups is confirmed by direct sampling. This mechanism provides a rational explanation of the small negative reaction rate temperature coefficient. The solubility of NaOH increases very slowly with temperature above 150°F which means the concentration of water, which is the diffusional driving force for the reaction, declines. The mechanism also explains the effect of surface condition on reaction rate which is observed in closed cups, since here any foreign material will be incorporated and retained in the solid caustic film and can modify its characteristics. In the drained condition such modifications are quickly washed away.

Pool Tests

A series of tests has been conducted to verify the temperature manipulation as a means of control. Three experiments were conducted at initial temperatures of 140, 150 and 180°F. All reactions proceeded normally and eventually showed instability. Since no corrective action was taken all three spiked (by design). In comparison similar reaction tests were conducted at an initial temperature of 170°F and 5 v/o H₂O. Temperature increases were applied when the instability showed up and the reaction was completed smoothly. Finally a run was made at 160°F and 5 v/o H₂O. Temperature increases to 170 and 185 °F were successfully applied to correct oscillations. When a third oscillation was noted the temperature was increased only to 188°F and the reaction subsequently spiked. The implication is that you must continue your correction until oscillations stabilize, and the system provides the feedback to do this.

The results confirm the earlier conclusions that control of the pool reaction is best accomplished by substantially raising the gas temperature at least 10°F when the oscillations are noted.

III. Process Demonstration

M. D. Crippen

Objective

The objective of this talk is to demonstrate the water vapor nitrogen (WVN) process on prototype components. In some cases full-scale components are also cleaned by the WVN process.

Summary

HEDL has not observed stress corrosion cracking on any test specimen or component cleaned by WVN. To date, the process has been successfully demonstrated on a number of sodium system components, a Fermi secondary pump, several two- and three-inch valves, a CLIRA subassembly, and HTSF cold trap economizer and a multi-purpose sample. Sodium removal was successful in all cases; removal was complete and no control problems or stress corrosion cracking has been observed.

Discussion

IHX Tube Bundle

The purpose of these tests was to demonstrate the effectiveness of the WVN process in removing sodium from full-scale crevices of the IHX. These tests demonstrated that sodium could be completely removed from plant scale crevices of the IHX by application of the WVN process with sufficient hot water rinsing of the tube bundle model.

All residual sodium was reacted within 48 hours of vapor processing at 10 vol/o H_2O concentration. A minimum rinse time of 160 hours at 165-185° was required to provide rinse water with a resistivity of Grade B water (50×10^3 ohm-cm) or better after 6 hours (minimum) of circulation. No sodium or its reaction products was evident on any surface of the model after processing by the WVN process (see Figure 40).

CLIRA Module

The CLIRA subassembly was processed for disassembly, inspection, and eventual reuse. Half a pound of sodium was successfully removed from the many complex crevices in the assembly. The WVN process was effective in removing sodium from narrow, complex annuli.

A total of 45 hours at 165°F was used with an initial water vapor concentration of 3 vol/o, later increased to 15 vol/o. Five rinses requiring

HEDL 7505-135.4

FIGURE 40. IHX Tube Bundle Model Close-up of the Partially Disassembled 304 SS Model After Processing With Water Vapor - Nitrogen.

109 hours at 175-180°F were used to attain a resistivity of the final rinse of 980×10^3 ohm-cm which exceeded Grade A water specifications. Figure 41 shows the component before insertion into the process vessel.

Sodium removal was incomplete in an inverted 18 inch deep, .5 to 10 mil annuli. (Access of the reactants was from the bottom only.) Details of this annuli are shown in Figure 42. Disassembly was accomplished without incident and the unit was returned to the test service.

Multipurpose Sampler (MPS)

The MPS was processed to remove sodium prior to disassembly for repair. All sodium was removed even though a 0.2 lb. volume of Na could not be drained from the baffle plate.

Heating to 280°F for 66 hours in dry N_2 was not able to melt the residual sodium (0.2 lb from the baffle plates) because of air and moisture reaction products accumulated during transfer, disassembly, handling and photographing. However, this did not affect the ability of the WVN process to remove it except by increasing the time. WVN processing required 93 hours at 170°F with H_2O concentration initiating at 2% and increasing to 10%. Three rinses required 68 hours to remove all reaction products from the 0.46 lb of sodium estimated to be originally present. The final rinse resistivity was 106×10^3 ohm-cm.

Hydrogen Meter

The AMCF hydrogen detection meter to be used for dynamic control and end point detection was received and installed on SRDA.

The meter is currently undergoing calibration and checkout on SRDA. Preliminary results indicate that it responds very quickly, within a few seconds, to changes in hydrogen concentration and has little or no hysteresis or equilibrium lag effects. A malfunction of the amplifier circuit has required rework and prevented completion of this effort.

HEDL 7505-135.5

FIGURE 41. CLIRA Subassembly Immediately Before Water Vapor - Nitrogen Processing in SRDA-12 (Background).

FIGURE 42. CLIRA Subassembly Details of Inverted Annulus Found to Still Contain Sodium After Water Rinse Processing.

Process Control Analysis

A mathematical analysis has been made of the reaction dynamics for processing of undrained sodium pools. The analysis has shown the nature and extent of reaction instabilities and heat transfer problems. Guidance has been obtained in solving these problems and the results have been substantiated by lab data.

The model developed shows how the sodium pool temperature can oscillate with time. (See Figure 43). The amplitude can increase or decrease depending on the parameter λ which is a complex function of physical properties (heat capacity, heat of reaction, etc.) and the temperature and concentration derivatives of various rates of the system involved. Although a quantitative solution to the equations is not possible with the present state of knowledge of the physical parameters, it does illustrate the effect of adjusting parameters to increase the system stability. For instance, it shows that increasing the feed temperature and/or the heat transfer from the pool will decrease the value of λ thereby promoting a more stable system.

A heat transfer model of an undrained pot shows that there is a maximum effective height (for heat transfer purposes) of a heat dissipating member (pot wall). This height is about 11 in. for a 0.5 in. thick wall and increases with the square root of thickness (see Figure 44). This in turn leads to a chart of expected pool temperatures for various pot diameters and thicknesses (see Figure 45). This chart shows that thin walled pots 12 in. or less in diameter are thermally equivalent to what may be expected in real components with large diameters but much thicker walls.

SRDA Modification

Sodium Technology has continued to improve and increase the flexibility of the SRDA system. A number of recent changes have improved control and reliability of unattended operation.

Specific improvements are as follows: 1) The control panel was rearranged to improve data interpretation. 2) An automatic water-vapor feed system valve was installed on the steam addition line to automate control and record water vapor concentration in the feed. 3) A bypass has been added to permit nitrogen purge during addition and circulation of rinse water, which

CONVERGING TO STABILITY

REGULAR INSTABILITY

DIVERGING INSTABILITY

HEDL 7404-135.3

FIGURE 43. Temperature Component Instabilities - Illustration of How The Value of λ Affects Stability. Theoretical Model Shows That λ May be Decreased by Increasing Temperature and/or Heat Transfer.

HEDL 7505-135.2

FIGURE 44. Effective Height - The Maximum Wall Height (Independent of Diameter) That is Effective for Dissipating Heat.

FIGURE 45. Maximum Temperatures - The Maximum Expected Sodium Temperatures for Various Pot Diameters and Wall Thicknesses.

increases safety and improves hydrogen monitoring and recording. 4) A gas sample pump has been replumbed to permit continuous extraction of gas for hydrogen analysis from either short SRDA I or tall SRDA 12 process vessels. 5) The hydrogen meter has been reworked to improve reliability and unattended operation. 6) High and low level trips have been provided on the hydrogen recorder to permit unattended operation by the feedback control method. 7) A timer has been added to permit unattended changes in operating temperatures. This will save time by making unattended changes at night in operating conditions possible that can be at equilibrium by morning. 8) The large vessel was equipped with internal gauge marks for use during rinsing. 9) Lock-out was provided to prevent inadvertent closing of the vent line on the large vessel.

National Program Liaison

C. W. Funk

Objective

The objective of this work is to direct the effort of the offsite sodium technology programs toward the timely input of data for the FFTF design and operational programs.

Summary

Alcohol process development has quantified reaction rates for cylindrical crevices and bolt specimens at an ethanol temperature of 140°F. A series of tests have been conducted indicating only a moderate reaction of Jaysol 55 with sodium frost. Tests using ethyl acetate additions to buffer to less than pH 7 were not successful.

Work in process quality control and inspection has included completion of specification and ordering of required pilot process equipment. Corrosion specimens processed in ROH showed no evidence of SCC. Regeneration effort has explored filtration and other modes of distillation with only limited success. The design of the pilot cleaning facility was completed and orders placed. The report on evaporation development work is being prepared.

Discussion

Sodium Removal Work at Atomics International

A. Alcohol Process Development

1. Reaction Rate Tests - Cylindrical Specimens in Tubes - Horizontal and open-end-up orientations of 0.85 inch dia. tubes show no difference in reaction rates of sodium with anhydrous 140°F Jaysol 55. The same result is apparent for 140°F Jaysol 55 containing 10 v/o H₂O (Table 17).
2. Reaction Rate Tests - Crevice Specimens - Processing times for sodium removal from crevices decreased significantly with the gap size of the crevice for both ethanol and hot water. However, for 1 mil gaps the

TABLE 17

SUMMARY OF TUBE SODIUM REACTION RATES

Reaction Rate in Na/hr	Tube Orient.	Tube Dia.(in.)	Reagent	Diluent (%H ₂ O)	React. Temp. (°F)
.016	Invert	0.85	Ethanol	0	140
.018	Invert	0.85	Ethanol	5	73
.023	Invert	0.375	Ethanol	10	75
.024	Invert	0.375	Ethanol	10	137
.024	Invert	0.85	Dowanol pm	0	99
.024	Invert	0.85	Dowanol pm	0	99
.11	Invert	0.85	Ethanol	0	140
.12	Vertical	0.85	Dowanol pm	0	73
.49	Horiz.	0.85	Ethanol	0	87
.51	Horiz.	0.85	Ethanol	5	90
2.42	Horiz.	0.85	Ethanol	10	98

180°F hot water rinse process removal rate was 25 times that of ethanol at 140°F. At gap sizes of 6 to 7 mils the 180°F water was about 10 times faster than for 140°F ethanol as shown in Table 18.

3. Reaction Rate Tests - Bolt Specimens - Sodium removal from bolt threads by 140°F Jaysol 55 was incomplete on the last 2 to 4 threads even after processing for 150 hours. This is in contrast to the 100% effective removal of sodium from bolts on the IHX tube bundle and IVHM subscale model after 130 to 160 hours using 180°F liquid water (Table 19).

4. Reaction Rate Tests - Sodium Frost - The reaction of loose frost with anhydrous Jaysol 55 at an undefined temperature was effervescent and moderately active and resulted in a temperature excursion of 36 to 57°F.

5. Additives for Buffering - Five vol % ethyl acetate additions to the Jaysol 55 for buffering were not successful because of the several hour delay in going from basic to acidic.

B. Process Quality Control and Inspection

1. Process Control and Inspection - Ordering specifications were completed and requisitions were released for a 1) differential refractometer to detect/control Na ion concentration, 2) an automatic Karl Fischer instrument for measuring water content of alcohols, 3) a paramagnetic oxygen analyzer for detecting O₂ and N₂ in the inerting gas, and 4) a gas chromatograph for detection of H₂ in the exhaust gas. Two reports on this topic were published but have not yet been received by HEDL.

2. Process Reliability and Replication - Thirty-two specimens were examined for corrosion following Jaysol 55 processing without detecting changes in mechanical properties due to processing or evidence of SCC. Surface defects that were observed metallographically were determined to be caused by mechanical straining.

3. Reagent Chemistry and Regeneration -

(a) Solvent Recovery - Filtration - A high volume precipitate was formed when sodium ethoxide was treated with CO₂. The process stream flow was blocked when the filter container was filled with a "thick buttery cake" of sodium ethyl carbonate. Although the filtrate was clear, it was still colored by aldehyde condensation products.

TABLE 18

SUMMARY OF CREVICE SODIUM REMOVAL RATE

Reaction Rate in Na/hr	Reaction Duration (hr)	Annular Crevice Gap (mils)	Reagent	Diluent	Max. Temp. (°F)
0.016	165	1	Jayso1	0	140
0.66	3	6	Jayso1	0	140
2.36	1.5	13	Jayso1	0	140
0.25	10	1	H ₂ O	-	180
6.2	0.4	7	H ₂ O	-	180

TABLE 19

EFFECTIVENESS OF SODIUM CREVICE REMOVAL

Effective Sodium Removal (%)	Process Duration (hrs)	Reagent	Reagent Temp. (°F)	Gap Mils	Hardware
90	100	Jayso1 SS	140	1	AI bolt
95	100	Jayso1 SS	140	1	AI bolt
95	150	Jayso1 SS	140	1	AI bolt
100	50	H ₂ O (ℓ)	180	4	HEDL Economizer Type III
100	160	H ₂ O (ℓ)	180	0	HEDL IHX Tube Bundle
100	130	H ₂ O (ℓ)	180	0	HEDL IVHM Sub Scale

(b) Solvent Recovery - Laboratory Distillation - Acetic Acid Addition - A two stage distillation of 100 ml of Jaysol 55 containing 10 g of Na/l and 2.25 vol % of H_2O yielded 30 ml of alcohol with 2.1 v/o H_2O and a subsequent sample of 1.98 v/o H_2O . Addition of 2.5 ml of glacial acetic acid to the 22 ml of the bottoms which was dark brown and viscous was made to make up a third stage of distillation. Continuation of the distillation yielded 17 additional ml of distillate to recover a total of 95% of the alcohol by a three-stage process.

4. Review of Distillation Recovery Data showed a 30% yield of ethanol containing 90 g of sodium ethoxide per liter by using an 80°C end point (2°C above initial boiling) to minimize carrying-over of contaminants. Distillation to dryness yielded 95% of the ethanol, but the determination of the contaminate carry-over is not yet available.

C. Solvent Recovery - Bulk Distillation

The still uses pressurized steam at 40 psig and produces 7-8 gal/hr of distillate. The water content of a 55 gal run changed from 5.5 to 6.0 gram/liter.

D. Pilot Cleaning Facility

Drawings were completed and released and delivery of equipment has begun.

E. Hot Gas Lance

Preliminary runs with the lance have demonstrated inadequate suction. Sodium was melted and blown out of a 4-inch diameter vessel. A portion of the sodium was blown into the box.

F. Evaporative Removal of Sodium

The time, pressure, and temperature conditions for evaporating 0.11 gram samples were measured. Experiments have removed about 1/50th of the sodium theoretically possible based on a flat, pure film of a precisely known temperature. Evaporation tests on bolt threads and shrink fits appear to be yielding encouraging results.

Seals Technology at Atomics International

The technical requirements for development and application of cover gas seals in support of FFTF, CRBR and future LMFBR's were examined, and coordinated with WARD and HEDL. Recommendations to meet these requirements were prepared, documented and forwarded to RRD. Subsequently, the Seal Development Program at AI was reviewed in a meeting at RRD-HQ on April 22-23 to integrate user requirements with the development program.

The recommendations to meet identified technical requirements included, 1) development of new seal materials for longer service life at elevated temperatures, 2) application of design data to drawings, 3) feedback of operating and maintenance and quality control experience into the development and design efforts.

The AI effort for FY-76 is proposed to 1) continue testing of inflatable and dip seals in support of CRBRP, 2) measure permeability and viscoelastic mechanical properties to screen new seal elastomers and lubricants, 3) explore the compatibility of seal materials with environments of sodium vapor, elevated temperature and gamma radiation. WARD and HEDL also recommended that 1) application of halogen containing elastomers be investigated, 2) emphasis be placed on traceability of formulation, 3) identification of acceptable storage conditions, and 4) that new vendors be developed for inflatable seals.

The current manufacturer of inflatable seals has advised AI they are no longer interested in development or manufacture of FFTF type seals because of the low volume and low profit of the item.

In-leakage tests of oxygen and water permeability requested by WARD and HEDL have been delayed at AI by apparatus modifications. These data are needed to estimate frost formation rates and potential blockage in purged reactor head annuli.

A design guide has been prepared and transmitted by AI and is available in HEDL technical files (Ref.21). This document is intended to assemble seal development data for future application and procurements.

The application of EBR-II experience with elastomer seals was investigated as a possible projection of requirements of irradiation exposure. Conversations indicated that elastomer seals were not generally used in the EBR-II design. Radiation dose was too modest to be significant to FFTF application. However, Buna N and silicone seals in valve operators require replacement every 3 to 12 months.

Flow Impedance Phenomena

W. H. Yunker and W. W. Yuan

Objective

The objectives of the Flow Impedance Phenomena Program are to determine (1) whether surface deposits can occur in the fuel and the plenum regions of LMFBR cores; and (2) if they occur, can they be controlled or eliminated.

Summary

This report period was used to calibrate the test system instrumentation, to remedy component operational problems, and to tie the loop into the building safety system. The data handling system has likewise had problems that required solving before startup. The first test for the loop is now underway covering the Phase I to reproduce and characterize any FIP that can be seen.

PAL Test Program

J. J. McCown, G. W. Mettler and R. F. Keough

Objective

This work has two objectives: (1) to provide analytical chemical support to the Sodium Technology Work area both in service and consultation and (2) to continue to upgrade the chemical instrumentation and analytical chemical methods for the characterization of sodium used in large systems.

Discussion

Oxygen Meter Performance PAL/SCS and HTSF

One probe failed in service on PAL during the report period. The service period was six months which included a number of shutdowns and restarts. The HTSF meter probe failed in service after six months of operation. Both probes were replaced and both meters are now back in service providing routine surveillance of the oxygen level.

The commercial ppm oxygen readout device was obtained and has been in use for two months without problem. The prototype unit previously tested in PAL will be tested also on the HTSF system to provide large system experience.

Oxygen meters are no longer considered by HEDL to be developmental devices. They are presently used as routine monitoring devices. The probe life expectancy is presently six to nine months.

Carbon Meter Development

The combination diffusion membrane/emf half cell type carbon meter (COCO meter) has been in test on PAL for three months. No further problems have been encountered with gas leaks or erratic emf readings. The output of the signal follows loop and cold trap operations and indicates carbon changes due to impurity additions, startup of new loop sections and changes in cold trapping temperatures. Several measurements of the carbon level by the FE-CR-Ni foil equilibration method in the MPS have been within 15% of the values indicated from the meter readings via the theoretical calculations provided by ANL, i.e., emf signal versus carbon activity.

Sodium Sampling-Multipurpose Sampler (MPS)

The first test of a new particulate filter and its holding assembly resulted in the filter section collapsing due to gas pressure generated during the MPS blowdown performed at the conclusion of the MPS runs. A second filter unit with an internal support has been fabricated and tested. The filter was again successful in removing particulates from the sodium and did not collapse on blowdown. Some minor changes in the design of the connect - disconnect part of the assembly are now being considered in order to allow for easier disassembly after sampling.

RDT Standards Program - Sodium and Cover Gas

A complete revision of RDT F3-40F has been completed and sent out for review by the National Analytical Standards Working Group prior to its formal submittal for publication.

Several sets of vanadium wires have been exposed in the PAL/MPS and equilibrated with oxygen for use in a inter-laboratory exchange. The results will be used in evaluating the performance of the various sodium analysis laboratories in the use of the vanadium wire method for measuring of oxygen in sodium.

Alkali Metal Protective Suit

W. W. Yuan

Objective

The objective of this work is to provide a suit to protect workers during emergency operations or rescue efforts involving leaking or burning sodium.

Summary

Results of two additional burning sodium spray tests of candidate suit parts indicate suit fabrication can proceed using state-of-the-art materials.

Discussion

Two additional test series have been completed. These were suit parts fabricated by ILC Industries, the only responding vendor. The first series was composites that were judged to be the best available. The second series was parts modified in light of the first set of test results, and reflected improvements. Table 20 indicates the composite materials tested in both series of tests.

All tests were conducted using the HEDL standardized test procedure using 1000°F sodium sprayed in a conical pattern at a 15 in. distance from the nozzle for a time of three seconds. The burning of the sodium on the test piece often lasted from one to two minutes.

The conclusions from these tests were essentially the same for both series and were the following:

1. The nickel foil barrier (0.001") was successful in stopping the penetration of the sodium.
2. The heat generated from the burning sprayed sodium on the surface is the major problem. This heat must be dissipated and reduced to an acceptable level.
3. Several material combinations showed ability to resist both the sodium and reduce the heat load to within the 165°F maximum suggested, and maintain this for several minutes.

4. Coating of the foil with either teflon or polyimide improved the sodium run-off capability.

The results of these materials tests are very encouraging and suit materials and construction appear to be within the present state-of-the-art.

TABLE 20

MATERIALS TESTED FOR THE FIRE SUIT

Test No. Materials of Construction (outside layer listed first)

April 28, 29 1975 Tests

1. Graphatized Polyvinyl Chloride (PVC)
 Nickel Foil (.001")
 Kapton Kynol (3.5 oz.)
2. Aluminized Kynol (3.5 oz.)
 Treated Nomex Felt
 Alumized Kynol (3.5 oz.)
3. Lead Loaded PVC
 Nickel Foil (.001)
 Kynol (3.5 oz.)
4. Fluorel Coated Copperwire
 Kynol (3.5 oz.)
 Aluminized Kapton Kynol (3.5 oz.)
5. Polyimide Coated Nickel Foil (.002")
6. Teflon Coated Nickel Foil (.002")

May 30, 1975 Tests

1. Nickel Foil (.001")
 Owens Corning Insulation (yellow, 0.5" thick)
 Durette
2. Nickel Foil (.001")
 Fiber Frax (white, National Carbon, 0.5" thick)
 Aluminized Kynol (3.5 oz.)
3. Polyimide Coated Nickel Foil (.001")
 Kaowool (0.5" Thick)
 Treated Cotton
4. Polyimide Coated Nickel Foil (.001")
 Owens Corning Insulation (light green 0.5" thick)
 Durette
5. Polyimide Coated Nickel Foil (.001")
 Cera Felt Type 400 (light brown)
 Treated Cotton
6. Polyimide Coated Nickel Foil (.001")
 Owens Corning insulation (yellow 0.5" thick)
 Aluminized Kynol (3.5 oz.)

All tests were conducted with three second exposure to 1000°F sodium spray at a distance of 15 inches resulting in a 9-inch diameter cone.

SODIUM SYSTEMS ANALYSIS

J. J. McCown

The focal point within the Sodium Systems Analysis section is the development, design, demonstration, and procurement of subsystems and components for FFTF System 94, Fuel Failure Monitoring. In addition the section is also establishing a technical base which will provide reactor test data and operational assistance to the FFTF operating staff. During this quarter development work also commenced on the fuel failure monitoring system (detection, location, and characterization) for CRBRP.

The major accomplishments for this quarter are listed below:

Purchase orders were placed for the three major System 94 equipment packages: process instrumentation; piping and mechanical; and gamma counting electronics. Equipment required for upgrading the Failure Characterization Spectrometer/Computer was also ordered. Supporting lab tests of the sample column cooling system and absorber/collimator devices were continued.

Both major interferences (argon and hydrocarbons) were eliminated in the analysis of gas tags by the mass spectrometer. Several determinations were made on "blind" tags at the ppb level and the correct tag was identified in all cases.

The Cover Gas Monitoring Proof test on EBR-II responded to several additional fission gas releases. An absorber mechanism was installed to prevent system saturation at high counting rates ($>15,000$ c/sec). The ratios of the fission gas nuclides during gas releases is being studied for "fingerprints" which will indicate sodium-fuel contact events, age of failed pin and leak location (plenum vs. fuel zone).

The fabrication of the lab sparger mechanical components was completed. Electrical panels are still being fabricated. The EBR-II sparger system stress analysis (ASME Section III, Class 2) was completed and the EBR-II sparger mechanical drawings were finished.

Work was started on the evaluation of the FFTF CGMS and Gas Tag System for use on CRBRP with continuous gas leakers present in the core. A design review of the CRBR systems together with calculations of expected gas activities as a function of reactor conditions and a variable gas number of on-line gas leakers was completed. A gas tag system evaluation indicates that by using modified tag ratios and spacings and by using an on-line mass spectrometer for daily analyses, a gas tagging system for CRBR can be developed.

Cover Gas Monitoring System

D. V. Archer, F. E. Holt, and W. C. Miller

Objective

This task provides for the development, design, procurement and implementation of the FFTF FFM Cover Gas Monitoring (CGM) System.

Summary

- Purchase orders were placed for the three major System 94 procurements: HWS-2507, process instrumentation; HWS-2509, piping and mechanical; and HWS-1917A, CGM Failure Detection Subsystem (gamma counting electronics).
- Purchase orders were placed for all equipment modifications and additions to the FFTF CGM Failure Characterization Subsystem Spectrometer/Computer.
- HEDL approval of the design of the CGM gas mass flowmeter to the rules of the ASME Boiler and Pressure Vessel Code, Section III, Class 2, was given. Procurement of the flowmeters was initiated.
- The first issue of the CGM Design Report, Volume 2, which encompasses the ASME Nuclear Code design verification, was released.
- Additional testing of the prototypic absorber/collimator mechanism and gamma ray subtraction device substantiated the adequacy of the designs of these pieces of equipment.
- The testing of the CGM sample column cooling system continued without any malfunctions. Design adequacy of this system was verified.

Discussion

Procurement

Emphasis of this task has shifted from the design and development stages to the procurement stage. Purchase orders were placed for the three major System 94 procurements, and all equipment for upgrading the existing Spectrometer/Computer was ordered.

Weston Hydraulics was chosen as the fabricator for the System 94 piping and mechanical equipment (HWS-2509) with a purchase order placed on May 16, 1975. Honeywell, Inc. was the successful bidder for the process electronics (HWS-2507). A purchase order was placed with Honeywell on April 22, 1975. The fabricator chosen for the CGM Failure Detection Subsystem (HWS-1917A) was Nuclear Controls and Electronics. A purchase order was placed on April 22, 1975. Delivery of all this equipment at FFTF should be before or near the designated December 15, 1975 site need date.

The work completed on these three orders this quarter consisted of the writing and submittal of fabrication documentation, ordering of equipment and materials, and completion of quality assurance procedures. Fabrication will commence in the next quarter. Specific activities completed this quarter for each procurement are summarized below.

1. HWS-2509, Piping and Mechanical: Revision 2 of the specification was approved by HEDL and a minor contract alteration was made reflecting the changes involved. Weston submitted their quality assurance plan, cleaning procedures, packing procedures, and other documentation for HEDL review or approval. All government furnished equipment (GFE) was ordered and several GFE items were received. Manufacturing release was given to Weston.
2. HWS-2507, Process Instrumentation: Addendum 1 to the specification was written and approved by HEDL. Various documentation was submitted by Honeywell for HEDL review or approval and Honeywell ordered all necessary equipment and materials.
3. HWS-1917A, CGM Failure Detection Subsystem: Addendum 1 to the specification was written and approved by HEDL. Much of the required documentation was submitted by NCE for HEDL review or approval. All materials and equipment were ordered by NCE.

The existing Spectrometer/Computer is being upgraded for use in FFTF. The upgrading consists of improving the input/output peripherals, expanding the computer memory, adding signal routers, timer modules, and a multiplexer

to allow the system to analyze up to six gamma ray detector inputs, and adding controller interfaces which allow the Spectrometer/Computer to communicate with all of the CGM Failure Detection Subsystems and the main FFTF computer (DDH & DS). All of this equipment has been ordered with delivery scheduled for the early part of next quarter. Delivery of the upgraded system at FFTF should occur near the designated site need date of February 15, 1976.

Prototype Absorber/Collimator Mechanism and Gamma Ray Subtraction Device

After several minor modifications were made to the prototype absorber/collimator mechanism and gamma ray subtraction device, a series of tests were run to verify the adequacy of their designs. The absorber/collimator mechanism was cycled through various positions several thousand times. At the end of this run, which is equivalent to several years of operation at FFTF, the mechanism was still operating satisfactorily with no measurable loss of positioning accuracy, a critical consideration in its design.

In addition to providing the gamma ray subtraction function for four different fission gases, i.e., subtraction of baseline (noise) from an individual isotope countrate to derive a true net isotopic countrate, the gamma ray subtraction device also controls the position of the absorber/collimator mechanism. As indicated above, this control function was shown to be satisfactory in the tests run on the absorber/collimator mechanism. Initial tests to verify the background subtraction function of the device were successfully completed.

A complete system performance test of the laboratory prototypic cover gas monitor was initiated to verify the correctness of specifications given for the FFTF Cover Gas Monitor Acceptance Tests. In the midst of these tests the planar Ge detector failed, temporarily ending all testing. After the detector is repaired by the manufacturer, these tests will be completed.

Sample Column Cooling Testing

The insulation used on the prototypic FFTF CGM sample column cooling system (thermoelectric device) was improved to achieve a better hermetic

seal. The system was then operated continuously at a temperature of 5-6°F for a period of over three months with no apparent reduction in performance, effectively showing that the system can operate satisfactorily a minimum of one FFTF reactor cycle (100 days). Indications are that the system should be able to perform satisfactorily significantly longer than one reactor cycle.

Expected Accomplishments Next Quarter

Procurement of FFTF System 94 equipment will be the primary task for next quarter. Fabrication of equipment for each of the three major procurements will be initiated and a major portion of each fabrication should be completed. Assembly of the purchased components into the existing Spectrometer/Computer for the purpose of upgrading that system for use on FFTF should be completed.

Gas Tag Sampling Trap (GTST) Design and Testing; Gas Tag Sample Analysis

D. V. Archer, W. C. Miller, K. B. Sowa, M. W. Goheen and C. E. Plucinski

Objective

This task provides for the development, design, verification, testing, and procurement of the FFTF Gas Tag Sampling Trap (GTST) and Cart Assembly for both characterization and location of absorber and fuel pin failures.

Summary

The design and development work required in support of the GTST procurement has been completed and was reported last quarter. All GFE material has been ordered and the major procurement packages have been placed.

The FFTF prototype GTST was used in the analysis of a "blind" tag by the gas tag analysis laboratory.

Discussion

Gas Analysis Laboratory (Mass Spectrometer)

The mass-80 residual argon peak problem was finally eliminated by using a neon purge to remove traces of argon from the charcoal trap containing the Xe and Kr tag gases. The hydrocarbon interference problem was traced to back diffusion from a mercury pump. A double pump arrangement was used to lower the hydrocarbons and remove their interference. Five analyses were performed on the "blind" tag both directly and after separation onto the GTST from argon. All data (even at the 0.07 ppb Kr level) clearly identified the correct tag.

Expected Accomplishments Next Quarter

Prepare the design of an LN₂ fill system for FFTF Building 491S.

EBR-II Prooftesting

D. V. Archer, F. E. Holt and W. C. Miller

Objectives

This task provides design verification and performance evaluations of the FFTF Fuel Failure Monitoring System components on an operating fast reactor.

Summary

- The Charged Tape Detector (CTD) prooftest experiment was terminated after 2 years of operation.
- The Ge(Li) Cover Gas Monitor (CGM) Prooftest responded to each of the gas escapes that occurred during the quarter.
- An automatically insertable graded absorber was installed on the Ge(Li) Prooftest.
- The relationships among consecutive Ge(Li) Prooftest analyses, gas escapes from EBR-II's sodium to the cover gas, and cover gas purge rates were elucidated and written in mathematical form.

Discussion

The CTD experiment began operating on a continuous basis on March 15, 1973. During this report period the experiment was terminated, removed from the Experimental Equipment Building (EEB), packaged and returned to HEDL.

The Ge(Li) Prooftest responses to the many EBR-II fuel pin gas escapes that occurred in March and April were both informative and enigmatic. Figures 46 and 47 are plots of the relative concentrations of eight of the sixteen nuclides monitored versus time. Six distinct gas escapes are evident. The increase at about hour 51 is due to the escape of gas from a pin out of reactor but stored in the basket. That conclusion is arrived at from the fact that only the long-lived Xe-133 and Xe-133^m were seen in the escaped gases. The increase just before hour 46 differs markedly from the other increases in that the ratio of Xe-133/Xe-135 is reversed relative to

FIGURE 46. Ge(Li) Proof test Responses to Fission Gas Escapes.

FIGURE 47. Ge(Li) Prooftest Responses to Fission Gas Escapes.

the earlier escapes and by the presence of short-lived Xe-138 and Xe-137. The gas escape that occurred at that time was reportedly caused by the failure of one of EBR-II's driver elements in assembly XX07. The earlier escapes appear to be due to the failure of two other elements. Differences in the various nuclide ratios lead one to that conclusion. Additional correction of the data to arrive at gas escape values versus time are expected to shed light on some apparent anomalies.

The automatically insertable, graded absorber designed and fabricated during the last quarter was installed on the Ge(Li) proof test experiment during this period. The total spectrum count rate trip point for insertion of the absorber for initial operation was set at 15,000 c/sec. The necessary correction factors to be applied when the absorber is "in" were calculated and will be included in the program which is used to decode the data from magnetic tape.

The counting data from the Ge(Li) proof test can be used to estimate gas escape rates from EBR-II's sodium coolant to the cover gas. The necessary mathematical relationships were derived to arrive at those escape rates and are to be included in the computer program "EBR" so that escapes versus time can be plotted. The relationships include the effects of: the sample column; the delay time from the cover gas to the sampling point; the dilution of the gases by increasing purge rates. The escape rates are inferred from differences between successive sample analyses.

Expected Accomplishments Next Quarter

The electronic equipment used in the Ge(Li) Proof test will be recalibrated. The data handling and analysis capabilities will be expanded to derive and plot escape rates from the counting data.

Sodium Sparger Development

R. Kolowith, F. E. Holt and L. J. Fishel

Objective

This task provides for the development, design, procurement and implementation of the Sodium Sparger System for reactor application. The work currently includes the design and testing of a Lab Sparger and the design of a batch type sparger for EBR-II application.

Summary

- All major procurements have been placed for the EBR-II Sparger System.
- All EBR-II Sparger System drawings have been completed.
- An ASME Section III, Class 2, stress analysis of the EBR-II sparger sodium module piping has been completed and minor design changes have been made in problem areas.
- All drawings of the Lab Sparger were completed.
- A Design Review of the Lab Sparger was completed.
- Fabrication of all Lab Sparger mechanical components has been completed. Fabrication of the electrical panels is scheduled for completion in July.

Discussion

The test plan for the HEDL sparger development program has been approved. The objectives of the HEDL development program are as follows:

1. Determine sparge efficiency in degassing ^{131m}Xe from liquid sodium. The ^{131m}Xe will be present in the sodium as single atoms born through decay of ^{131}I .
2. Determine the effects of localized iodine plateout on sparger radio-xenon counting accuracy.
3. Demonstrate the design and operation of the sparger gas analysis system.

4. Develop a continuous sparger concept that minimizes cyclic valve actuations, while providing failure data comparable to the present batch sparger concept.

A Design Review of the static sodium sparger test facility was held on May 1 and the Design Review Report was issued on May 14.

Fabrication was completed on the Lab Sparger, support structure and gas system to be used in achieving objectives 1, 2 and 3 above. Fabrication of the electrical panels for this installation is scheduled for completion in July. Installation of this hardware in the laboratory is scheduled for July with testing to begin in August.

In addition to efforts on the Lab Sparger, work has proceeded on the EBR-II Batch Sparger Design. The design package, including all drawings and stress analyses, for the EBR-II sparger experiment has been completed and a Design Review Meeting with EBR-II personnel is scheduled for July 1975. The EBR-II batch sparger design is based on installation of this experiment in the RSCL, Cell A area of EBR-II.

A sample source alternative study for the EBR-II facility has also been completed for the sparger. This study compared the cost, schedule and technical impact of installing the current batch sparger design on the RSCL loop versus installing it on the FERD loop or running FERD sodium to the RSCL Test area.

Expected Accomplishments Next Quarter

Installation of the HEDL lab sparger static sodium test facility shall be completed and testing shall begin.

The design review of the EBR-II batch sparger design package shall be completed and fabrication contracts shall be placed.

CRBR Fuel Failure Monitoring System Development

F. E. Holt and R. Kolowith

Objectives

Design and develop a cover gas monitoring system that will be able to detect and characterize failed pins in the presence of earlier failures that remain in core.

Summary

Work began this quarter on the design of a Cover Gas Monitoring (CGM) System for the CRBR plant. Table 21 lists important parameters that affect the performance of the CGM System and shows differences between FFTF and CRBR.

The first stage of this effort was to estimate the specific activities present in CRBR's cover gas at the monitoring station versus various reactor conditions. Tables 22, 23 and 24 list the many factors used to arrive at estimates of cover gas activities, i.e., countrates, with no failed fuel in the core. An uncertainty factor of ~ 20 exists around the estimate of the fissions/sec from "tramp" fuel. A sampling and counting system identical to that designed for FFTF was assumed, to arrive at countrate values.

Estimates were made of the expected countrates from failed pins, assuming steady-state production and leakage of the gases. Production rates were taken to be the appropriate fraction of the total fission rate, e.g., 1 pin's production rate would be $2.93 \times 10^{19} \div 42,966$ fissions/sec $\times$ fission yield. Table 25 lists the steady-state countrates and the $\pm 10 \sigma$ precision values around those countrates expected at the monitoring station versus the number of failed pins and two background cases.

Expected Accomplishments Next Quarter

- Determine the number of failed pins that can be in core, N, and still be able to detect the N + 1 failure using reasonable assumptions.

- Determine the failed pin "fingerprint" that will indicate a gas escape condition requiring a reactor shutdown.
- Determine the suitability of the FFTF Cover Gas Monitoring System for CRBR use.

TABLE 21

REACTOR PARAMETERS, FFTF AND CRBR

<u>Parameter</u>	<u>Units</u>	<u>FFTF</u>	<u>CRBR</u>
<u>1. General</u>			
Thermal Power	MW	400	975
Fission Rate	Fiss/Sec, 10^{19}	1.19	2.93
Driver Assemblies	No.	73	198
Pins/Assy.		217	217
No. of Driver Pins		15,841	42,966
Burnup/Ultimate Goal	MW/MT	80,000	100,000
Refueling Cycle	Days	102	360
<u>2. Cover Gas</u>			
Volume	ScC	6E6	1.2E7
Purge Rate	ScC/Day	1E8	7E7
Purge Constant	Sec ⁻¹	2.1E(-4)	7.E(-5)
Temperature	°F	858	(700)*
Dilution By Pump Purge	%	9	0
Transit Time to Sys. 94	Min.	9.3	(10)*
Flow To Sys. 85	SCFM	1.0	1.0
<u>3. Coolant</u>			
Volume In Core	Gms., 10^5	3.5	(8.5)*
Flow Rate Thru Core	10^6 lbm/hr	14.2	33.2
Velocity Out of Core	ft/Sec.	22-30	40 (Max.)
Plenum Inlet Temp.	°F	785	735
Plenum Outlet Temp., Design	°F	1035	1015
Plenum Outlet Flow, Each	lbm/hr.	6E6	13.8E6
Turnaround Time	Min.	1	(~1)*
Height, Top of F.A. to C.G.	Ft.	16	21.4
<u>4. Vortex Suppression Plate</u>			
"Free-Flow" Area/Core Area	%	10.6	(~10)*
Na Velocity Thru Openings	ft/Sec.	10	~10
Distance from Na/C.G. Inter-face	in.	6	24

* () Estimated Values.

TABLE 22

CRCRP COVER GAS ACTIVITIES, NO FAILED FUEL

Nuclide	Fiss. Yield ⁽⁴⁾	Decay Cons. (Sec ⁻¹)	De-Entrain. Factor	Dis./Sec-Cm ³ , S _i (1,2,3)*		
				Cover Gas	RSB	
				@ F=6.8E10	@ t=5	@ t=10
Kr-85 ^m	0.0064	4.35E(-5)	0.96	13.7	13.5	13.4
Kr-85	0.0014	2.04E(-9)	1.0	2E(-4)	2E(-4)	2E(-4)
Kr-87	0.0111	1.52E(-4)	0.86	38	36	35
Kr-88	0.0137	6.88E(-5)	0.93	37	36	36
Kr-89	0.0139	3.61E(-3)	0.24	18	6	2
Xe-131 ^m	0.00025	6.71E(-7)	1.0	0.014	0.014	0.014
Xe-133 ^m	0.00195	3.54E(-6)	1.0	0.54	0.54	0.54
Xe-133	0.0682	1.51E(-6)	1.0	8.4	8.4	8.4
Xe-135 ^m	0.0190	7.41E(-4)	0.55	57	46	36
Xe-135	0.0745	2.09E(-5)	0.98	98	97	96
Xe-137	0.0582	2.96E(-3)	0.26	87	36	15
Xe-138	0.0371	6.60E(-4)	0.58	115	94	77
Ne-23	9E5 Ci ⁽⁴⁾	0.0182	0.09	2.6E8	1.1E6	4.7E3
Ar-41	45 Ci ⁽⁴⁾	1.05E(-4)	0.90	7.7E4	7.2E4	7.2E4

1. From TC-39: $S_i = \lambda_i F Y_i / (\lambda_i + \rho) V$ $R + \frac{s(1-R)}{\lambda_i + s} \Big] e^{-\lambda_i t}$ 2. $F = 2.8E10 \times 2.4$, $R = 0.05$, $s = 0.05/60$

3. From CRBR's SDD-82: $V = 1.16E7 \text{ scc}$, $\rho = 7.11E(-5)/\text{Sec}$ 4. From WA30026

*@ $F = 7.5E11 \times 2.4$,
all S_i 's = 27 x list.

TABLE 23

CRBR COVER GAS EMISSION RATES @ F = 2.8E10 X 2.44 FISS./SEC. (LOW "TRAMP")

Nuclide Ni	S _i (dis/sec-cm ³)* @ _i RSB, t = 5 min.	Energy (MeV)	γ/D	γ/Sec-Cm ³ (Ri)**	γ/Sec on 1 gr. Charcoal @ 50°F & F = 1000 sccm (A _i)**	
					t = 5 Min.	t = 10 Min.
Kr-85M	13.5	0.15	0.74	10	910	900
Kr-85	2(-4)	0.511	0.004	8(-7)	7(-5)	7(-5)
Kr-87	36	0.403	0.84	30	2730	2600
Kr-88	36	0.19	0.35	13	1180	1200
Kr-89	6	0.21	0.25	1.5	130	40
		0.59	0.21	1.3	110	40
Xe-131 ^m	0.014	0.16	0.919	3(-4)	0.3	0.3
Xe-133 ^m	0.54	0.22	0.098	0.05	60	60
Xe-133	8.4	0.081	0.37	3	3700	3700
Xe-135 ^m	46	0.527	0.80	37	4.2E4	3.4E4
Xe-135	97	0.250	0.91	88	1.1E5	1.1E5
Xe-137	36	0.455	0.33	12	1.2E4	4900
Xe-138	94	0.434	0.24	23	2.6E4	2.1E4
Ne-23	1.1E6	0.44	0.33	3.6E5	3.6E6	1.5E4
Ar-41	7.2E4	1.29	0.99	7.1E4	1.4E6	1.4E6

* From Table 23.

$$^{**}A_i = \frac{FR_i}{\lambda_i + F/mK}$$

$$F/mK = \frac{1000/60}{1 \times 100} = 0.0139/\text{Sec for Xe}$$

$$= 16.67/90 = 0.1833/\text{Sec for Kr}$$

$$= 16.67/20 = 0.833/\text{Sec, Ar}$$

$$= 16.67/10 = 1.667/\text{Sec, Ne}$$

TABLE 24

CRBR COUNT RATES FROM 1 GRAM CARBON^(a) VS. BKG. AND FAILED FUEL

Nuclide N_i	E (MeV)	Effic. (b) (c/ γ)	A _i @ t = 10 Min. (c) (γ 's/Sec)		Bkg.	C _i (Counts/Sec)	
			Bkg.	1 Pin (d)		30XBkg.	1 Pin ($\pm 10\sigma$) (e)
Kr-85 ^m	0.15	5E(-4)	900	1.4E6	0.45	13.5	700 (10)
Kr-87	0.40	6E(-5)	2500	1.2E6	0.16	4.8	70 (3)
Kr-88	0.19	3.5E(-4)	1200	1.1E6	0.4	13	390 (8)
Kr-89	0.21	2.5E(-4)	40	900	0.01	0.3	0.2 (0.2)
	0.59	2.5E(-5)	40	750	1E(-3)	0.03	0.02
Xe-131 ^m	0.16	4 (-4)	0.3	3 E3	1.2(-4)	4(-3)	0.8 (0.4)
Xe-133 ^m	0.22	2.2(-4)	60	5.1E6	0.01	0.4	110
Xe-133	0.081	2 (-3)	3700	3.4E7	7.4	220	6.6E4 (100)
Xe-135 ^m	0.53	3 (-5)	3.4E4	3.3E6	1.0	30	96 (4)
Xe-135	0.25	1.8(-4)	1.1E5	3.3E8	20	600	5.9E4 (100)
Xe-137	0.46	4.2(-5)	4900	4	0.2	6	1700 (17)
Xe-138	0.43	4.5(-5)	2.1E4	2.1E6	1.0	30	95 (4)
Ne-23	0.44	4.5(-5)	1.5E4		0.7	0.7	0.7
Ar-41	1.29	5 (-6)	1.4E6		7	7	7

(a) Column @ 50°F and flow @ 1000 SCCM.

(b) Using 200 mm² x 5 mm thick Ge located ~2" from column.

(c) From Table 24. (d) 1/430 of SDD'-82's Table I-3 Values used in Formulas to obtain Table 23 & 24 failed pin values.

(e) $\pm 10 \sigma$ is based on
600 Second Count.

TABLE 25

CRBR COUNT RATES + 10 σ VS. NO. FAILURES

<u>N_i</u>	Nuclide	E (MeV)	<u>Bkg.</u>	<u>30xBkg</u>	Counts/Sec From Column, ($\pm 10\sigma$) *		
					<u>1 Pin</u>	<u>10 Pins</u>	<u>100 Pins</u>
	Kr-85 ^m	0.15	0.5	14	700 (10)	7000 (30)	7E4 (100)
	Kr-87	0.4	0.2	5	70 (3)	700 (10)	7E3 (35)
	Zr-88	0.2	0.4	13	390 (8)	3900 (30)	4E4 (80)
	Kr-89	0.2	0.01	0.3	0.2 (0.2)	2 (1)	20 (2)
		0.6	0.001	0.03	0.02	0.02 (0.2)	2 (0.6)
	Xe-131 ^m	0.2		4 (-3)	0.8 (0.4)	8 (1)	80 (4)
	Xe-133 ^m	0.2	0.01	0.4	110 (4)	1100 (15)	1E4 (40)
	Xe-133	0.1	7.4	220	6.6E4 (100)	6.6E5 (330)	7E6 (1000)
	Xe-134 ^m	0.5	1	30	96 (4)	960 (13)	1E4 (40)
	Xe-135	0.3	20	600	5.9E4 (100)	5.9E5 (315)	6E6 (990)
	Xe-137	0.5	0.2	6	1700 (17)	1.7E4 (50)	2E5 (170)
	Xe-138	0.4	1	30	95 (4)	950 (13)	1E4 (40)

* Based on 600 Sec. Count. $10\sigma = \frac{\sqrt{c/\text{Sec} \times 600}}{60}$

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