3 up

GEAP-10207-24
AEC RESEARCH AND
DEVELOPMENT REPORT
JULY 1971

RECEIVED BY DTIC OCT 13 1971

MASTER

**REACTOR PRIMARY COOLANT SYSTEM
STUDY
PROGRESS REPORT NO. 24
JANUARY-JUNE 1971**

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
PROJECT AGREEMENT 37

GENERAL ELECTRIC

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REACTOR PRIMARY COOLANT SYSTEM RUPTURE STUDY

PROGRESS REPORT NO. 24

JANUARY—JUNE 1971

Approved:

S. R. Vandenberg
S. R. Vandenberg
Project Engineer

Approved:

D. H. Imhoff
D. H. Imhoff, Manager
Development Engineering

Prepared for the
U.S. Atomic Energy Commission
Contract AT(04-3)-189
Project Agreement 37

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ATOMIC POWER EQUIPMENT DEPARTMENT • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TABLE OF CONTENTS

1.	INTRODUCTION	1-1
2.	SUMMARY	2-1
2.1	Task A—Probability Study	2-1
2.2	Task D—Low Cycle Fatigue	2-1
2.3	Task D-5—Fatigue Data for Piping Code	2-1
2.4	Task k—Effect of BWR Environment	2-1
3.	TASK A—PROBABILITY STUDY	3-1
3.1	Objectives	3-1
3.2	Summary	3-1
3.3	Contributions to the Variance of Cycles to Leak	3-1
4.	TASK D—LOW CYCLE FATIGUE	4-1
4.1	Objective	4-1
4.2	Task D-3—Prototype Pipe Fatigue	4-1
4.3	Task D-5—Fatigue Data for Piping Code	4-1
5.	TASK K—EFFECT OF BWR ENVIRONMENT	5-1
5.1	Objective	5-1
5.2	Summary	5-1
5.3	Dresden 1 Test Loop Operation	5-1
5.4	Fatigue Specimen Test Data	5-1
5.5	Metallurgical and Surface Condition Effects	5-2
5.6	High Temperature Air Test Facility	5-19
5.7	Third Test Vessel	5-22
5.8	Inspection Equipment	5-22

LIST OF ILLUSTRATIONS

Figure	Title	Page
3-1	Nominal and Two Random Cracks, Showing Improper Pivoting at $\text{Log } \Delta K = 0$	3-2
3-2	Nominal and Two Random Cracks, Showing Proper Pivoting at $\text{Log } \Delta K = \text{Mean Log } \Delta K$	3-2
5-1	Dynamic Test Specimen	5-9
5-2	Equivalent Stress Amplitude (psi) versus Cycles to Failure for Type-304 Stainless Steel	5-11
5-3	Equivalent Stress Amplitude (psi) versus Cycles to Failure for Type-304L Stainless Steel	5-13
5-4	Equivalent Stress Amplitude (psi) versus Cycles to Failure for Inconel-600 Carbon Steel	5-15
5-5	Equivalent Stress Amplitude (psi) versus Cycles to Failure for Type A516 Carbon Steel	5-17
5-6	"I-T" WOL Specimen, Type B	5-21

LIST OF TABLES

Table	Title	Page
3-1	Expected Values and Variances	3-5
3-2	Contributions to Variance of $\text{Log } n_t$	3-6
4-1	Test Parameters	4-3
4-2	Comparison of Average Through-Wall Crack Growth Rate for BWR and PWR Tests	4-4
5-1	Dresden Test Loop Operating Summary	5-2
5-2	Task K Fatigue Specimen Layout	5-3
5-3A	Fatigue Test Results from Dresden Loop (Operating Period I)	5-5
5-3B	Fatigue Test Results from Dresden Loop (Operating Period II)	5-6
5-3C	Fatigue Test Results from Dresden Loop (Operating Period III)	5-7
5-3D	Fatigue Test Results from Dresden Loop (Operating Periods IV, V, VI and VII)	5-8
5-4	Calculated Fatigue Life Reduction Factors, Carbon Steel Data	5-20
5-5A	Shakedown Test Parameters	5-22
5-5B	Fatigue Specimen Test Plan, Series II Air Test	5-23

1. INTRODUCTION

The Reactor Primary Coolant System Rupture Study is being conducted for the Division of Reactor Development and Technology, USAEC. This Progress Report No. 24 documents work done in the period, January 1 to June 30,* 1971. The overall objective of the program is to improve the reliability of reactor system piping by increasing current knowledge of failure-causing mechanisms and by enhancing capability for design evaluation and analysis.

Toward the attainment of this objective, work was continued on the following tasks:

- Task A—Probability Study
- Task D—Low-Cycle Fatigue
- Task K—Effect of BWR Environment

No further work is planned for Task B—Stress Analysis, and Task C—Fracture Mechanics, which terminated at the close of the previous contract year.

The specific objectives of the tasks and technical progress are covered in the following sections. Previous reports issued as a part of this program are listed as follows:

Quarterly Reports

GEAP-4911	Reactor Primary Coolant System Rupture Study Quarterly Progress Report No. 1, April—June 1965.
GEAP-4964	No. 2, July—August 1965.
GEAP-5082	No. 3, October—December 1965
GEAP-5147	No. 4, January—March 1966.
GEAP-5192	No. 5, April—June 1966.
GEAP-5279	No. 6, July—September 1966.
GEAP-5427	No. 7, October—December 1966.
GEAP-5474	No. 8, January—March 1967.
GEAP-5512	No. 9, April—June 1967.
GEAP-5554	No. 10, July—September 1967.
GEAP-5587	No. 11, October—December 1967.
GEAP-5637	No. 12, January—March 1968.
GEAP-5680	No. 13, April—June 1968.
GEAP-5716	No. 14, July—September 1968.
GEAP-5770	No. 15, October—December 1968.
GEAP-10024	No. 16, January—March 1969.
GEAP-10072	No. 17, April—June 1969.
GEAP-10120	No. 18, July—September 1969.
GEAP-10143	No. 19, October—December 1969.
GEAP-11069	No. 20, January—March 1970.
GEAP-10207	No. 21, April—June 1970.
GEAP-10207-22	No. 22, July—September 1970.
GEAP-10207-23	No. 23, October—December 1970.

Topical Reports

GEAP-4445	A Survey of Water Reactor Primary System Conditions Pertinent to the Study of Pipe Rupture, January 1964.
GEAP-4446	A Review of Fracture Modes as Related to Reactor Primary Coolant Pipe Rupture, May 1964.
GEAP-4474	Experimental and Analytical Program Recommendations—Reactor Pipe Rupture Study, January 1965.
GEAP-4574	Survey of Piping Failures for the Reactor Primary Coolant Pipe Rupture Study, May 1964.

*A quarterly report for the period January-March was not issued.

GEAP-4578	Mechanical Design Considerations in Primary Nuclear Piping, March 1964.
GEAP-4678	Fracture Mechanics and the Stability of Engineering Structures, September 1965.
GEAP-5014	Fracture Toughness of Some Engineering Alloys, March 1966.
GEAP-5410	Low-Cycle Fatigue Strength Reduction in Notched Flat Plates, January 1967.
GEAP-5471	PAPA—Structural Analysis of Plates and Shells Using Trapezoidal and Triangular Plate Elements, March 1967.
GEAP-5553	PAPA—The Digital Computer Program for the Static Analysis of Structures Made up of Plate and Panel Elements, October 1967.
GEAP-5557	Stress Intensity for a Circumferential Through-Wall Crack in a Straight Pipe, January 1968.
GEAP-5607	Fatigue Crack Growth in Nuclear Reactor Piping Steels, March 1968.
T&AM-677	A Three-Dimensional Photoelastic Study of Stress Near Cracks in Shell Structures, University of Illinois, March 1968.
GEAP-5620	Failure Behavior in ASTM A 106-B Pipes Containing Axial Through-Wall Flaws, April 1968.
GEAP-5622	A Failure Diagram for Axially Flawed Pipes, April 1968.
GEAP-5653	Status of Pipe Rupture Study at General Electric—II, July 1968.
GEAP-5714	Notched High-Strain Fatigue Behavior of Three Low-Strength Structural Steels, September 1968.
GEAP-5724	BWR Primary Piping Stresses for System Reliability Analysis, September 1968.
GEAP-5726	Influence of Stress/Strain Concentration and Mean Stress on the Low-Cycle Fatigue Behavior of Three Structural Steels at Room Temperature, September 1968.
GEAP-10007	Restart for the PAPA Program, March 1969.
GEAP-10090	The 550°F Notched High-Strain Fatigue Behavior of Three Low-Strength Structural Steels, August 1969.
GEAP-10135	Low-Cycle Fatigue of Prototype Piping, January 1970.
GEAP-10140	The Effect of Cyclic Strain Aging on the Embrittlement of a Plain Carbon Steel Plate, July 1970.
GEAP-10170	The Effect of Stress Concentration on the Low-Cycle Fatigue of Three Low-Strength Structural Steels at Room Temperature and 500°F, March 1970.
GEAP-10181	Low Cycle, Strain Controlled Fatigue Crack Propagation in Nuclear Piping Steels, May 1970
GEAP-10205	Status of Pipe Rupture Study at General Electric Company, Part III, June 1970.
GEAP-10236	Failure Behavior of Flawed Carbon Steel Pipes and Fittings, October 1970.

2. SUMMARY

2.1 TASK A—PROBABILITY STUDY

In earlier reporting of the Distribution of Time to Damage Method, the consideration of mean $\log \Delta K$ in the equation for cycles to grow an initiated crack through the wall of a pipe by low-cycle fatigue led to an empirical equation for predicting n_t , cycles to grow through. The variance of this empirical equation considering mean $\log \Delta K$ is reported and a revised table of the contributions of the variances of the participating variables (initial crack depth, stress and parameters A and B) is presented. The contribution of slope B is negligible, and the other three important as before. Thus, to reduce the probability of leakage it is necessary to reduce the variabilities of initial crack depth, and/or stress, and/or parameter A, with priority to initial crack depth, based on the distributions assumed.

2.2 TASK D-3—LOW CYCLE FATIGUE

Testing was completed on the following prototype piping specimens:

1. CSS-111—Room temperature, carbon steel, circumferentially-notched, specimen tested at PWR conditions (2200 psig).
2. CSANS-160-1—Room temperature stainless steel, axially-notched specimen tested at PWR conditions.

Testing was started at room temperature on specimen CCANS-160-2, a carbon steel, axially-notched specimen at PWR pressure.

2.3 TASK D-5—FATIGUE DATA FOR PIPING CODE

Review of ASME Code rules for low-cycle fatigue was made and a test program presented in Quarterly Report No. 22 (GEAP-10207-22). The objective is to provide data that can be used to confirm or improve nuclear vessel and piping fatigue design procedures for nominal stress ranges at and above $3 S_m$. The effects of stress concentration, constraint, mode of loading, and type of load on cycles to produce crack initiation or ratchet failure, will be investigated. When possible, local strains and crack growth rates will be measured. Analytical and experimental results will be compared with current and proposed design procedures. To provide experience in supplying input and interpreting output from a computer program, a sample problem is being prepared.

2.4 TASK K—EFFECT OF BWR ENVIRONMENT

Since initial startup in September* the Dresden test loop accumulated 2200 hours of operation (8800 fatigue cycles) at test conditions (510°F, 1000 psig). A total of 75 of the 149 fatigue specimens in the loop have "failed," i.e., signaled crack initiation, including 27 plain carbon steel, 2 Inconel-600, 34 Type-304 stainless steel and 12 Type-304L stainless steel. Shakedown testing of the test facility for baseline curves was completed with two weeks of successful operation. Instrumented test specimens are being added to the facility for testing. Modifications have been made to the initial design concept of the "third test vessel" for fatigue crack growth rate measurement in the Dresden 1 test loop. Transducers will be used to measure specimen loads and crack opening displacements in the BWR environment.

* 1970.

3. TASK A—PROBABILITY STUDY (S. A. Wilson)

3.1 OBJECTIVES

The objectives of the probability study task are to develop methods for:

- Estimation of the reliability of a reactor primary piping system in terms of leak rate and time of reactor service.
- Identification of the principal sources of real variability or uncertainty in service life.

3.2 SUMMARY

In earlier reporting of the Distribution of Time to Damage Method, the consideration of mean $\log \Delta K$ in the equation for cycles to grow an initiated crack through the wall of a pipe by low-cycle fatigue led to an empirical equation for predicting n_t , cycles to grow through. The variance of this empirical equation considering mean $\log \Delta K$ is reported and a revised table of the contributions of the variances of the participating variables (initial crack depth, stress and parameters A and B) is presented. The contribution of slope B is negligible, and the other three important as before. Thus, to reduce the probability of leakage it is necessary to reduce the variabilities of initial crack depth, and/or stress, and/or parameter A, with priority to initial crack depth, based on the distributions assumed.

3.3 CONTRIBUTIONS TO THE VARIANCE OF CYCLES TO LEAK

In Quarterly Report No. 20 (GEAP-11069) consideration was given to mean $\log \Delta K$ in the low-cycle fatigue cycles to leak equation. That document should be consulted for details, but to summarize, in the basic fracture mechanics crack growth rate equation,

$$da/dn = A \Delta K^B \quad (1)$$

The sensitivity of the function to A and ΔK may be investigated independently, but not the sensitivity to B, which is not independent of A. This may be seen when logs are taken to linearize the equation, giving

$$\log da/dn = \log A + B \log \Delta K \quad (2)$$

This equation is of the form

$$y = a + bx, \quad (3)$$

in which, in general, slope is not independent of intercept a. Such an equation implies a far greater sensitivity of y to changes in b than is in fact the case, as illustrated in Figure 3-1.* This problem is remedied by writing equation (3) in mean-adjusted form,

$$y = c + b(x - \bar{x}). \quad (4)$$

Now when b is changed, the line pivots at $x = \bar{x}$, at value c on the y scale; previously it pivoted at $x = 0$, at value a on the y scale. Now changes in b may be made, independent of c, as illustrated in Figure 3-2.*

The problem is made more complicated for the crack growth rate equation because of how $\bar{x}$ must be chosen. If equation (2) is modified by including the $\bar{x}$ term, it becomes, say,

$$\log da/dn = \log C + B (\log \Delta K - \overline{\log \Delta K}), \quad (5)$$

where $\overline{\log \Delta K}$ is mean $\log \Delta K$, $\log C = \log A + B \log \Delta K$.

Ordinarily, $\bar{x}$ is the mean of x values in an experiment in which parameters a and b are estimated, resulting in an equation for predicting a y value at a given x value, the uncertainty in a predicted y reflecting the variances of estimate of a and b. But in the crack growth rate problem we are not interested in predicting a crack growth rate value at some stress intensity factor, but rather, in the number of cycles for a crack to grow from an initial depth a_0 through wall

* Figures 3-1 and 3-2 reproduced from GEAP-11069.

Figure 3-1. Nominal and Two Random Cracks, Showing Improper Pivoting at $\text{Log } \Delta K = 0$

Figure 3-2. Nominal and Two Random Cracks, Showing Proper Pivoting at $\text{Log } \Delta K = \text{Mean Log } \Delta K$

thickness t ; that is, between starting and stopping ΔK values denoted $\Delta K(a_0, \sigma)$ and $\Delta K(t, \sigma)$, along a line defined by B and $\log C$ at $\log \Delta K$, being subjected to a slightly larger da/dn value on each cycle. How much the number of cycles to leak might vary depends on the variability in parameters A and B , seen experimentally *among specimens*, that is, among *different* crack growth lines, and these variabilities have been used. But the appropriate $\log \Delta K$ is not the one which happened to occur among such lines as fixed by some experiments, but is characteristic of each crack grown, i.e., the combination of a_0 , t , σ and B chosen to represent the crack and its location. It was appropriate to find $\log \Delta K$ for this crack, as if an experiment had been run under these conditions. For a random crack, $\log \Delta K$ was found for every cycle, and these values were averaged to find $\log \Delta K$. In practice, $\log \Delta K$ was found iteratively, starting at the mean of the means of the Schenectady testing. $\log \Delta K$ depends on a_0 , σ and B , very slightly on t , and not at all on A .

We are interested in the variance of cycles to leak. To find, first, an equation for cycles to leak, take antilogs of equation (5), resulting in

$$da/dn = C(\Delta K / \bar{\Delta K})^B, \quad (6)$$

where $\bar{\Delta K}$ is the antilog of $\overline{\log \Delta K}$, which, as before, is the mean of the $\log \Delta K$'s of all the cycles to which the crack is subjected. Inverting, and integrating with respect to crack depth, gives

$$n_t = \frac{1}{C} \int_{a_0}^t \left(\frac{\Delta K}{\bar{\Delta K}} \right)^B da, \quad (7)$$

wherein ΔK must be calculated for the values chosen for B , a_0 , t ; and σ in ΔK . In doing this, and calculating n_t values, it became possible to write an empirical equation for n_t , linear in its coefficients, valid at least over an ample range of values of the variables near those of interest, as illustrated in Figures 3.7 to 3.10 of GEAP-11069. This equation was written first for B constant at $B = 4.45$, appearing as equation (6) in GEAP-11069. The following expression should be added for B :

$$0 = 0.1623 - 2.47 e^{-B} - 0.03 B, \quad (8)$$

resulting in the following equation for n_t in terms of all four major variables:

$$\log n_t = 27.4687 - 1.0084 (\Delta \log C) - 4.5069 (\log \sigma_{PM}) - 6.2615 \sqrt{a_0/t} - 2.47 e^{-B} - 0.03 B, \quad (9)$$

where

n_t = Cycles to leak at the selected piping study section.

$\Delta \log C$ = Random deviation from the nominal intercept $\log C$, at some $\log \Delta K$; the equation is written for $\log C = -3.962$ at $\log \Delta K = 4.786$, the grand mean $\log \Delta K$ of the Schenectady testing.

$\log \sigma_{PM}$ = Primary membrane stress per Table 3.1 of Quarterly Report No. 13 (GEAP-5680).

$$\sigma_{PM} = S_{exp} \times S_{exp}^* + S_{hoop}/2$$

$$S_{exp} = \text{expansion stress}$$

$$S_{exp}^* = \text{uncertainty coefficient on expansion stress}$$

$$S_{hoop} = Pd/2t = 1000 \times 6.624/(2 \times 0.432) = 7667 \text{ psi.}$$

$$a_0/t = \text{Initial crack depth ratio to wall thickness.}$$

$$B = \text{Slope parameter}$$

$$\log \equiv \log_{10}$$

This equation is valid for a_0/t values chosen from the distributions of (a_0/t) max with or without ultrasonic testing.

Now we may find the variance of this equation in terms of the variances of the variables to see which variables have variances which contribute most to that of the function, thereby identifying them as making the largest contributions to the probability of leakage. The variance of this function will be found by the usual propagation of errors approximation described in Quarterly Report No. 14 (GEAP-5716), equation (14), obtaining adequate accuracy by retaining only the first summation, as follows. For any equation

$$Y = g(X_1, X_2, \dots, X_n) \quad (10)$$

where the X_i , $1 \leq i \leq n$, are independent random variables, the variance equation is as follows, the E notation indicating that each partial derivative is to be evaluated at the expected value (mean) of the variable:

$$\text{Var } Y \approx \sum_{i=1}^n \left(\left. \frac{\partial Y}{\partial X_i} \right|_{EX_1, EX_2, \dots, EX_n} \right)^2 \text{Var } X_i. \quad (11)$$

For the case at hand where the function $g(\cdot)$ is a simple linear sum (of independent random variables),

$$g(\cdot) \approx \sum_{i=1}^n a_i X_i, \quad (12)$$

equation (11) leads to

$$\text{Var } Y = \sum_{i=1}^n a_i^2 \text{Var } X_i. \quad (13)$$

Equation (13) may be used to find the variance of equation (9).

Contributions to $\text{Var } \log n_t$ will be in proportion to those to $\text{Var } n_t$, and numerically smaller by a factor of approximately n_t^2 by equation (11).

Using equation (13), the variance of equation (9) is

$$\begin{aligned} \text{Var } \log n_t &\approx 1.0084^2 \text{Var } \Delta \log C \\ &+ 4.5069^2 \text{Var } \log \sigma_{PM} \\ &+ 6.2615^2 \text{Var } \sqrt{a_0/t} \\ &+ 2.47^2 \text{Var } e^{-B} \\ &+ 0.03^2 \text{Var } B. \end{aligned} \quad (14)$$

A 5000-trial Monte Carlo estimate of the variance contribution of the two B terms alone verified exactly the amount found by finding the variance of equation (8) using equation (11).

Using equation (11), the required variance expressions are as follows:

$$\text{Var } \log \sigma_{PM} \approx (\log e)^2 \text{Var } \sigma_{PM} / (E\sigma_{PM})^2 \quad (15)$$

$$\text{Var } \sqrt{a_0/t} \approx \text{Var } (a_0/t) / 4E(a_0/t) \quad (16)$$

$$\text{Var } e^{-B} \approx e^{-2EB} \text{Var } B \quad (17)$$

The required values for variances and expected values are shown in Table 3-1, from the sources indicated.

Substituting these values into equations (15) to (17), and into equation (14), gives in Table 3-2 the contributions of the variances of the variables to that of $\log n_t$, for the initial crack size distributions assumed, with and without ultrasonic testing.

Thus it is seen that, using the uncertainty distributions assumed, variability in slope B now makes a negligible contribution to the overall variance, whereas, without ultrasonic testing, initial crack depth makes the major contribution, and with ultrasonic testing makes an equal contribution with stress, reducing the variance of the function about 2/3 for this case. The foregoing implies that a reduction of some percentage of the variance assumed in the maximum initial crack depth distribution would reduce the variance of the function more than the same percent reduction in the variance of the other variables. And further, while the relationship is not exact due to different shapes for the uncertainty distributions of the variables, such a reduction would also reduce the probability of leakage more than a comparable reduction for the other variables. Finally, it is seen at the bottom of Table 3-2 that consideration of mean $\log \Delta K$ has resulted in a considerable reduction in the variance of $(\ln) n_t$. The leakage probabilities given in Table 3-2 of Quarterly Report No. 20 (GEAP-11069) are based on the lower values.

Table 3-1
EXPECTED VALUES AND VARIANCES

Variable	Expected Value	Source	Variance	Source	Remarks
$\Delta \log C$	(0)		0.138	(1) (2)	
σ_{PM}	25042	(1) (2)	57×10^6	(1) (2)	
$a_o/t \text{ max.}$	0.0364	(1)	0.007	(1)	Without ultrasonic testing.
$a_o/t \text{ max.}$	0.0146	(2)	0.000531	(2)	With ultrasonic testing.
B	4.45	(1) (2)	1.016	(1) (2)	

(1) Table 3-2, Quarterly Report No. 14 (GEAP-5716)

(2) Table 3-1, Quarterly Report No. 15 (GEAP-5770)

Table 3-2
CONTRIBUTIONS TO VARIANCE OF LOG n_t

	Without Ultrasonic Test		With Ultrasonic Test	
		Percent		Percent
Δ Log C, material property intercept, change from nominal	0.1403	5.9	0.1403	16.5
σ_{PM} , primary membrane stress	0.3488	14.7	0.3488	41.2
a_0/t max., initial crack depth	1.8830	79.3	0.3568	42.1
B, material property, slope	0.0018	0.1	0.0018	0.2
Total Var Log n_t	2.3739	100.0	0.8477	100.0
Var In n_t (1)	12.5864		4.4945	
Replaces Value in Ref. shown	18.9944	(2)	11.9005	(3)

- (1) $\ln n_t = (\ln 10) (\log n_t)$
 $\text{Var } \ln n_t = (\ln 10)^2 \text{Var } \log n_t$, by Equation (14)
- (2) Table 3-2, Quarterly Report No. 14 (GEAP-5716).
- (3) Table 3-1, Quarterly Report No. 15 (GEAP-5770)

4. TASK D—LOW CYCLE FATIGUE

4.1 OBJECTIVE

The objectives of the Fatigue Task are (a) to extend the understanding of low-cycle fatigue cracking in high pressure piping components which have mechanical or defect flaws, and (b) to apply this knowledge in developing rational design bases for prevention or control of fatigue crack initiation and growth in reactor piping systems.

4.2 TASK D-3—PROTOTYPE PIPE FATIGUE (J. D. Heald)

4.2.1 Summary

Testing was completed on the following specimens during the report period:

1. CSS-111—Room temperature, carbon steel, circumferentially-notched, specimen tested at PWR conditions (2200 psig).
2. CSANS-160-1—Room temperature, stainless steel, axially-notched specimen tested at PWR conditions.

Testing was started on specimen CCANS-160-1, a room temperature, carbon steel, axially-notched specimen at PWR pressure. A summary of the test data is given in Table 4-1.

4.2.2 Data Obtained

The series of tests now being completed is to determine whether or not circumferential or axial notches in straight pipe sections pressurized to PWR conditions and fatigue tested would leak or break. Average crack growth rate data was obtained and crack initiation detected visually when possible.

1. Circumferentially Notched Specimens

Two circumferentially notched specimens, one carbon steel and one stainless steel, have been fatigue tested at PWR pressure until leakage occurred. The number of stress cycles to crack initiation and leakage were not appreciably different compared to a previous test at BWR pressures. The average crack growth rates to penetrate the wall are given in Table 4-2.

2. Axially Notched Specimens

Two axially notched specimens have been tested and a third is now in progress. The first axially notched specimen was tested at BWR pressure. It leaked at a point approximately 3 in. from the axial notch. The crack where leakage occurred was oriented in the circumferential direction. Postmortem analysis of the axial machined notch showed no indications of any axial crack growth either in depth or length. The second test was run at PWR pressure and leakage occurred at a weld approximately 6 in. away from the machined notch. Postmortem analysis of the second specimen also showed no signs of axial crack growth. The last test at PWR pressure is now in progress and will be completed in the next quarter.

4.2.3 Future Work

The scope-of-work for the period from April 1, 1971 to March 31, 1972, shows that there are five tests at BWR conditions remaining to be completed:

1. To obtain additional data on the behavior of Type-304 stainless steel with butt (or girth) welds at 550°F. Three specimens are planned and are now being fabricated.
2. To test elbow specimens with combined cyclic pressurization and bending. Two specimens are planned.

4.3 TASK D-5—FATIGUE DATA FOR PIPING CODE (T. L. Gerber and P. N. LeFort)

Review of the ASME Code rules for low-cycle fatigue has been made and a test program has been formulated.* The objective is to provide data that can be used to confirm or improve nuclear vessel and piping fatigue design procedures for nominal stress ranges at and above $3 S_m$. The effects of stress concentration, constraint, mode of loading, and type of load on cycles to produce crack initiation or ratchet failure, will be investigated. When possible, local strains and crack growth rates will be measured. Analytical and experimental results will be compared with current and proposed design procedures.

The finite element program chosen to be used for the analyses of the test specimens is one being developed by Y. R. Rashid of the General Electric Company under an AEC subcontract. While the creep option of this program is not yet finalized, all the routines required for an elastic-plastic study are complete.

* Outlined in detail in Quarterly Report No. 22 (GEAP-10207-22).

To provide experience in supplying input and interpreting output from this program, a sample problem is being prepared. This sample problem is of a notched round bar specimen previously used on Task D-2 for which experimental data and the results of an analysis by another finite element code are available for comparison.

Materials will be ordered, specimens fabricated, and material properties measured during the next period.

**Table 4-1
TEST PARAMETERS**

Sample Description	Test Temperature (°F)	Internal Pressure (psig)	Nominal Stress Range (psi)	Cantilever End Deflection (in.)	Cycles to Crack Initiation (N_I)	Cycles to Fully Penetrate Wall (N_w)	Test Termination (N_ϕ)
CSS-111 ASTM A-106 Grade B Carbon Steel Schedule 160	R.T.	2200	86,200	±9.38	<799	5150 (3156)*	8500 (5506)**
CSANS-160-1 ASTM A-312 Type 304 Stainless Steel Schedule 160 Axial Notch	R.T.	2200	83,000	±9.56	1099	7450 (6351)	7450 (0)
CCANS-160-1 ASTM A-106 Grade B Carbon Steel Schedule 160 Axial Notch	R.T.	2200	83,000	Test in Progress			

* Values in () are Full Amplitude Cycles during Through-Wall Growth ($N_w - N_I$)

** Values in () are Full Amplitude Cycles after full wall penetration

Table 4-2
COMPARISON OF AVERAGE THROUGH-WALL CRACK GROWTH
RATE FOR BWR AND PWR TESTS

Description	BWR Tests	PWR Tests
Specimen Number	CSS-25	CSS-124
Material	304 Stainless Steel	304 Stainless Steel
Schedule	160 Pipe	160 Pipe
Stress Range	70,460 psi	70,500 psi
(da/dN) average	53.2 μ in./cycle	49.6 μ in./cycle
Specimen Number	CSS-11	CSS-111
Material	Carbon Steel	Carbon Steel
Schedule 1	160 Pipe	160 Pipe
Stress Range	89,000 psi	86,200 psi
(da/dN) average	873 μ in./cycle	192 μ in./cycle

5. TASK K—EFFECT OF BWR ENVIRONMENT (D. A. Hale)

5.1 OBJECTIVE

The objective of Task K is to determine quantitatively the effect of BWR primary coolant on the low-cycle fatigue life of piping steels. Measurements of cycles to failure will be obtained, employing a specially designed fatigue testing unit in an experimental piping loop at the Dresden 1 boiling water reactor. The planned test duration is 2-1/2 years, allowing time for corrosion, if any, to affect crack initiation and growth.

5.2 SUMMARY

Since initial startup in September the Dresden test loop has accumulated 8800 fatigue cycles at test conditions (510°F, 1000 psig). A total of 75 of the 149 fatigue specimens in the loop have "failed," i.e., signaled crack initiation, including 27 plain carbon steel, 2 Inconel 600, 34 Type-304 stainless steel, and 12 Type-304L stainless steel. Shakedown testing of the air test facility was completed after two weeks of successful operation. Instrumented test specimens are being added to the facility for testing. Modifications have been made to the initial design concept of the "third test vessel" for fatigue crack growth rate measurement loads and crack opening displacements in the BWR environment.

5.3 DRESDEN 1 TEST LOOP OPERATION

The Dresden test loop was shut down and restarted several times during the report period; the operating history is summarized in Table 5-1.

A loop air monitor was purchased and installed early in May prior to the start of operating period VII. This monitor continually samples the air at various locations throughout the test cubicle and alarms whenever the airborne contamination level exceeds normal background levels.

New chevron packing rings and a redesigned spring-loaded packing gland flange were installed on the fatigue test unit to stop the water leakage noted on several previous occasions during transient startup conditions. Several minor valve packing leaks were also repaired during the cycle VI-VII shutdown.

The loop was returned to service on June 4 marking the start of operating period VII. Both the air monitor and the repacked DTV sliding shaft seal functioned properly. The loop continued to operate smoothly at the close of the report period.

5.4 FATIGUE SPECIMEN TEST DATA

A total of 149 fatigue specimens (Figure 5-1) representing four materials, 31 different metallurgical test conditions, and four specimen loadings are included in the basic Task K test program. Table 5-2 shows the test plan, reproduced from Quarterly Report No. 18 and indicates which specimens have failed. The plan was designed to allocate the fatigue specimen positions among the selected test conditions to maximize chances of detecting differences in cyclic fatigue life which might be caused by these conditions when the specimens are in the environment.

During the first seven periods of test loop operation, failure was indicated for 75 specimens; pertinent test parameters are summarized in Table 5-3, parts a, b, c, and d. Note that because of the geometry of the Task K fatigue specimen (i.e., thin specimen loaded in bending) and the unique method used to define and detect specimen failure, these failure data represent cycles to initiation; very little (~ 5–10%) specimen life is devoted to fatigue crack growth. The distribution of these 75 failures among the four material groups and 31 test conditions is shown at the bottom of Table 5-2.

The values of initial surface strain range in Table 5-3 are based on room temperature, strain-deflection calibration curves generated for each material and represent the shakedown strain ranges corresponding to given specimen deflections. These were measured using miniature strain gages mounted in the reduced thickness test section of each specimen. Although one might expect the strain range in the thin test section to depend only on tip deflection, these strain-deflection relationships could be influenced by temperature and hold times under load as a result of redistribution of strain between the thin and thick portions of the specimen under the test conditions (temperature and long hold time) compared to the room temperature, no-hold-time conditions used in calibration. Therefore, in order to determine the true strain range during test, preparations are being made to rerun the strain-deflection curves at 500°F, in air at 4 cph.

The cycles-to-failure data for these 75 specimens are compared to the ASME Section III fatigue design curves in Figures 5-2, 5-3, 5-4 and 5-5. The upper line on Figures 5-2, 5-3, and 5-5 represents an ASME best fit curve of experimental

**Table 5-1
DRESDEN TEST LOOP OPERATING SUMMARY**

Loop Operating Period	Startup	Shutdown	Cumulative Operating Time	Fatigue Cycles (Cumulative)		Fatigue Test Specimen Failure Indications Received	Remarks
				Start	Finish		
I	Sept. 16	Oct. 2	17 days	0	1900	23	Loop shutdown in anticipation of scheduled plant maintenance outage
II	Oct. 22	Nov. 5	32 days	1901	3250	18	Loop shutdown in anticipation of scheduled plant maintenance outage
III	Nov. 25	Dec. 31	69 days	3251	6494	19	Loop shutdown to repair leaking fitting
IV	Jan. 7	Jan. 14	76 days	6495	7174	2	Loop secured after reactor scram
V	Jan. 27	Feb. 3	84 days	7175	7891	9	Loop shutdown for scheduled plant outage
VI	Feb. 17	Feb. 18	85 days	7892	7960	1	Loop secured to repair steam leaks and install cubicle air monitor
VII	June 3			7961		3	Loop still in operation at end of report period

failure data; the upper line on Figure 5-4 is based on a best fit of failure data from Snow, et al.¹ The lower line on Figures 5-2 through 5-5 represents the ASME recommended fatigue design curve which is derived from the ASME best fit curves by applying a safety factor of 20* on cycles (i.e., $N_{\text{Design}} = N_{\text{Data}}/20$).

5.5 METALLURGICAL AND SURFACE CONDITION EFFECTS

5.5.1 Type-304 Stainless Steel

Seven additional Type-304 stainless steel specimen failure indications were received during the most recent four loop operating periods bringing the total number of Type-304 stainless steel failure indications to date to 34.

Detailed analysis of these data will be deferred until data from the 40 as yet unfailed Type-304 stainless steel specimens become available. However, several preliminary trends are evident (Figure 5-2):

1. As previously noted (Quarterly Report No. 23) there appears to be a significant fatigue life reduction associated with the fully furnace sensitized condition (material condition code 5**) as compared to the "as-received" condition (material condition code 1**): 19 of the 21 furnace sensitized specimens have failed compared to 7 of 20 as-received specimens.
2. The fatigue life reduction previously attributed to the zero-tension loading condition in the furnace sensitized specimens seems to also be establishing itself for the as-received material condition.

¹ Snow, Langer and Gibbons, WAPD-T-2093, September 1967.

* See ASME Boiler and Pressure Vessel Code, Section III "Criteria"

** Refer to Section 7.5.1.1, Quarterly Report No. 20 (GEAP-11069).

Table 5-2
TASK K FATIGUE SPECIMEN LAYOUT

Test Condition Number	1	2	3	4	5	6(a)	7(b)	8	9	10	10A	11	12	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Material																															
Type-304 Stainless Steel	x	x	x	x	x	x	x	x	x	x	x	x	x																		
Type-304L Stainless Steel														x	x	x	x	x	x												
Inconel-600																				x	x	x	x	x							
Carbon Steel																									x	x	x	x	x		
Material Condition																															
Material Condition Code	1	8	3	4	5	2	2	1	5	1	5	1	5	1	8	4	5	1	5	1	4	5	1	5	2	6	4	7	6		
Welded—Low Heat (Normal)				x												x					x						x	x			
Welded—High Heat (Block)			x																												
Machined	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Surface Cold Work		x													x																
Solution Annealed	x				x			x	x	x	x	x	x	x			x	x	x	x		x	x	x							
Pickled	x				x			x	x	x	x	x	x	x			x	x	x	x		x	x	x							
Sensitized(c)					x				x		x		x	x			x	x	x	x		x	x	x							
Stress-Relieved																	x		x												
Simulated Crack Preparation																															
Mechanical								x	x										x	x											
Chemical										x	x																				
Number of Specimens Loading																															
OT(d) (Initial Surface Strain Range)																															
0.5%												2	2																		
												○	●																		
												●	●																		
0.75%												2	2																		
												●	●																		
												●	●																		
CT(d) (Initial Surface Strain Range)																															
0.5%	5	2	2	2	5	2	2	2	2	2	2			4	2	2	4	2	2	4	2	4	2	2	4	2	2	2	2		
	○	○	○	○	○	○	○	○	●	○	●			○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○		
	○	○	○	○	○	○	○	○	●	○	●			○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○		
	○				●	</																									

Table 5-3A
FATIGUE TEST RESULTS FROM DRESDEN LOOP (OPERATING PERIOD I)

Specimen Number	Cycles to Failure	Material	Shakedown Surface Strain Range*	Loading Mode**	Test Condition Code***	Description
1059	797	Carbon Steel	1.0%	C-T	29	Welded, stress relief
1060	909	Carbon Steel	1.0%	C-T	29	Welded, stress relief
1010	996	Carbon Steel	1.0%	C-T	27	As machined, stress relief
1009	1027	Carbon Steel	1.0%	C-T	27	As machined, stress relief
131	1027	Type-304 SS	0.5%	O-T	12	As machined, furnace sensitized
57	1066	Carbon Steel	1.0%	C-T	26	As machined, no stress relief
64	1123	Carbon Steel	1.0%	C-T	26	As machined, no stress relief
48	1176	Carbon Steel	1.0%	C-T	26	As machined, no stress relief
179	1365	Type-304 SS	0.75%	O-T	12	As machined, furnace sensitized
1008	1378	Carbon Steel	0.75%	C-T	27	As machined, stress relief
53	1380	Carbon Steel	1.0%	C-T	26	As machined, no stress relief
1053	1423	Carbon Steel	1.0%	C-T	28	Welded, no stress relief
1052	1455	Carbon Steel	1.0%	C-T	28	Welded, no stress relief
188	1493	Type-304 SS	0.5%	C-T	10A	As machined, furnace sensitized, mechanical notch
170	1506	Type-304 SS	1.0%	C-T	5	As machined, furnace sensitized
1017	1524	Carbon Steel	0.75%	C-T	29	Welded, stress relief
165	1651	Type-304 SS	0.5%	C-T	5	As machined, furnace sensitized
1061	1708	Carbon Steel	0.75%	C-T	29	Welded, stress relief
1024	1738	Type-304 SS	0.5%	C-T	9	As machined, furnace sensitized, mechanical notch
180	1771	Type-304 SS	1.0%	C-T	5	As machined, furnace sensitized
128	1778	Type-304 SS	0.5%	O-T	12	As machined, furnace sensitized
166	1838	Type-304 SS	0.75%	C-T	5	As machined, furnace sensitized
185	1896	Type-304 SS	0.75%	O-T	12	As machined, furnace sensitized

* Based on Room Temperature Strain-Deflection Calibration Curves

** C-T = Compression-Tension; O-T = Zero to Tension Loading

*** Reference: Table 2

Table 5-3B
FATIGUE TEST RESULTS FROM DRESDEN LOOP (OPERATING PERIOD II)

Specimen Number	Cycles to Failure	Material	Shakedown Surface Strain Range*	Loading Mode**	Test Condition Code***	Description
157	1917 ⁽¹⁾	Type-304 SS	0.5%	C-T	5	As machined, furnace sensitized
189	1919 ⁽¹⁾	Type-304 SS	0.75%	C-T	5	As machined, furnace sensitized
1080	1920 ⁽¹⁾	Type-304 SS	0.75%	C-T	5	As machined, furnace sensitized
1085	1922 ⁽¹⁾	Type-304 SS	1.0%	C-T	5	As machined, furnace sensitized
1079	1922 ⁽¹⁾	Type-304 SS	1.0%	C-T	5	As machined, furnace sensitized
1084	1919 ⁽¹⁾	Type-304 SS	1.0%	C-T	5	As machined, furnace sensitized
147	2132	Type-304 SS	0.5%	C-T	5	As machined, furnace sensitized
38	2242	Type-304L SS	1.0%	C-T	18	As machined, furnace sensitized
36	2286	Type-304L SS	1.0%	C-T	18	As machined, furnace sensitized
34	2488	Type-304L SS	0.75%	C-T	18	As machined, furnace sensitized
197	2706	Type-304 SS	0.5%	C-T	10A	As machined, furnace sensitized, mechanical notch
50	2813	Carbon Steel	0.75%	C-T	26	As machined, no stress relief
1018	2821	Carbon Steel	0.5%	C-T	29	Welded, stress relieved
1144	2868	Type-304 SS	1.0%	C-T	7	Dresden equalizer line weld material, as machined
1051	2998	Carbon Steel	0.5%	C-T	30	As machined, stress relieved, mechanical notch
1048	3144	Carbon Steel	0.5%	C-T	30	As machined, stress relieved, mechanical notch
1019	3231	Carbon Steel	0.5%	C-T	29	Welded, stress relieved
1007	3235	Carbon Steel	0.5%	C-T	27	As machined, stress relieved

(1) Failed during cycle No. 2 loop startup on 10/22/70

* Based on Room Temperature Strain-Deflection Calibration Curves

** C-T = Compression-Tension; O-T = Zero to Tension Loading

*** Reference: Table 2

Table 5-3C
FATIGUE TEST RESULTS FROM DRESDEN LOOP (OPERATING PERIOD III)

Specimen Number	Cycles to Failure	Material	Shakedown Surface Strain Range*	Loading Mode**	Test Condition Code***	Description
1058	3556	Carbon Steel	0.75%	C-T	28	Welded, no stress relief
195	3683	Type-304 SS	0.5%	C-T	9	As machined, furnace sensitized mechanical notch
82	3766	Carbon Steel	0.5%	C-T	27	As machined, stress relieved
26	3990	Type-304L SS	0.5%	C-T	18	As machined, furnace sensitized
81	4007	Carbon Steel	0.5%	C-T	26	As machined, no stress relief
1055	4015	Carbon Steel	0.5%	C-T	28	Welded, no stress relief
1146	4093	Type-304 SS	0.75%	C-T	7	Dresden equalizer line, weld material, as machined
1092	4418	Type-304 SS	1.0%	C-T	6	Dresden equalizer line base material, as machined
22	4724	Type-304L SS	0.5	C-T	18	As machined, furnace sensitized
201	5215	Type-304 SS	0.75%	O-T	11	As machined
72	5292	Carbon Steel	0.5%	C-T	26	As machined, no stress relief
29	5359	Type-304L SS	1.0%	C-T	15	As machined
40	5435	Type-304L SS	0.5%	C-T	20	As machined, furnace sensitized, mechanical notch
5	5617	Type-304L SS	0.5%	C-T	20	As machined, furnace sensitized, mechanical notch
42	5859	Type-304L SS	1.0%	C-T	15	As machined
190	5920	Type-304 SS	0.75%	O-T	11	As machined
187	6110	Type-304 SS	1.0%	C-T	1	As machined
1121	6140	Type-304 SS	0.5%	C-T	2	As machined, heavy cold work
1148	6157	Type-304 SS	1.0%	C-T	7	Dresden equalizer line weld material, as machined

* Based on Room Temperature Strain-Deflection Calibration Curves

** C-T = Compression-Tension; O-T = Zero to Tension Loading

*** Reference: Table 5-3

Table 5-3D

FATIGUE TEST RESULTS FROM DRESDEN LOOP (OPERATING PERIODS IV, V, VI AND VII)

Specimen Number	Cycles to Failure	Material	Shakedown Surface Strain Range*	Loading Mode	Test Condition Code**	Description
1147	6532	Type-304 SS	0.75%	C-T	7	Dresden equalizer line weld material, as machined
1056	6915	Carbon Steel	0.5%	C-T	28	Welded, no stress relief
76	7161	Carbon Steel	0.5%	C-T	26	As machined, no stress relief
177	7756	Type-304 SS	1.0%	C-T	1	As received
1132	7891	Type-304L SS	0.5%	C-T	16	As received + heavy cold work
1042	7891	Inconel	1.0%	C-T	22	Welded, as machined
98	7891	Inconel	0.5%	C-T	23	As machined, furnace sensitized
181	7891	Type-304 SS	1.0%	C-T	1	As received
1076	7891	Type-304L SS	1.0%	C-T	17	Welded, as machined
1123	7891	Type-304 SS	0.75%	C-T	2	As received + heavy cold work
1004	7891	Type-304L SS	0.75%	C-T	17	Welded, as machined
142	7930	Type-304 SS	0.5%	C-T	11	As received
184	8040	Type-304 SS	1.0%	C-T	1	As received
1095	8048	Type-304 SS	1.0%	C-T	6	Dresden equalizer line, base material, as machined
75	8869	Carbon Steel	0.5%	C-T	26	As machined, no stress relief

Total failure indications received to date, 75 → (34 Type-304 SS, 12 Type-304L SS, 2 Inconel, 27 Carbon Steel)

* Based on Room Temperature Strain-Deflection Calibration Curves

** Reference: Table 2

NOTES:

1. $.029 \pm .027$ DIA. HOLE CENTERED IN REDUCED SECTION WITHIN $.006 (\pm .003)$
2. CENTERLINE OF WELD TO BE LOCATED IN MIDDLE OF REDUCED THICKNESS SECTION FOR WELD SPECIMENS

Figure 5-1. Dynamic Test Specimen

Figure 5-2. Equivalent Stress Amplitude (psi) versus Cycles to Failure for Type-304 Stainless Steel

Figure 5-3. Equivalent Stress Amplitude (psi) versus Cycles to Failure for Type-304L Stainless Steel

Figure 5-4. Equivalent Stress Amplitude (psi) versus Cycles to Failure for Inconel 600

Figure 5-5. Equivalent Stress Amplitude (psi) versus
Cycles to Failure for Type A516 Carbon Steel

3. The difference in fatigue life between the as-received and furnace sensitized specimens seems to be of the same magnitude for both the fully reversed and zero-tension loading modes.
4. There is a reduction in fatigue life associated with the equalizer line weldment material as compared to the as-received material; however, it is not as great as that previously noted for the furnace sensitized material. Also, this material displays a greater sensitivity to strain range than the furnace sensitized material.

5.5.2 Type-304L Stainless Steel

Seven of the 12 Type-304L specimen failure indications received to date occurred in furnace sensitized material. The remaining five were divided among three material test conditions as noted below:

1. Two "as-received" specimens tested at the 1.0% strain range.
2. Two "welded" specimens—one each at the 1.0% and 0.75% strain range.
3. One "cold worked" specimen tested at the 0.5% strain range.

Detailed analysis of these data will be deferred until data from the 18 surviving Type-304L specimens become available.

5.5.3 Inconel-600

The number of Inconel specimen failure indications received to date is two (Figure 5-4). Both occurred during loop operating cycle V and represent two different material conditions tested at two strain ranges:

1. As welded material tested at the 1.0% strain range.
2. Furnace sensitized material tested at the 0.5% strain range.

5.5.4 Carbon Steel

All of the 27 carbon steel fatigue specimens have failed; the data are summarized in Figure 5-5.

The data were analyzed to determine whether any statistically significant differences could be detected among the various material conditions; five cases were selected for study (Table 5-4):

- Case I As Mach* (No S.R.***) vs. As Mach (S.R.)
- Case II Welded (No S.R.) vs. Welded (S.R.)
- Case III As Mach (S.R.) vs. Welded (S.R.)
- Case IV As Mach (No S.R.) vs. Welded (No S.R.)

The analysis, based on a pooled-mean statistical technique, must be regarded as preliminary and the following conclusions treated accordingly:

1. There is a relatively small reduction in fatigue life associated with the stress relieved condition for both the as-machined (Case I) and the welded (Case II) materials.
2. No significant difference in fatigue life is detected between the as-machined and welded materials in either the stress relieved (Case III) or the non-stress relieved (Case IV) condition.

All of the carbon steel data lie on the conservative side of the ASME design curve.

5.6 HIGH TEMPERATURE BASELINE TEST FACILITY

A fatigue test unit similar to the Dresden Fatigue Test Facility is in place in San Jose. It has the capacity to load up to 12 of the Task K fatigue specimens (Figure 5-6) in the same manner as their Dresden counterparts. The air inside the test vessel is maintained at 500°F and 700 psi which allows specimen failure to be defined in the same manner for both groups of specimens.

Two Task K fatigue specimens (one each Type-304 stainless steel and carbon steel) were instrumented with high temperature strain gages and installed in the fatigue test fixture on the test vessel. The tip deflections selected for these two specimens were the same as those imposed on the Dresden fatigue specimens tested at the highest strain range (see Table 5-5A).

The object of the initial testing was to evaluate test facility equipment, instrumentation techniques and experimental testing procedures under actual test conditions prior to committing a large group of fatigue specimens to the test.

Maximum operating pressure was limited to 700 psig due to heat transfer limitations; however, 700 psig should be more than adequate to allow specimen failure to be defined in the same manner for these specimens as their Dresden counterparts.

* Machined, wrought material

** Stress relief

Table 5-4
CALCULATED FATIGUE LIFE REDUCTION FACTORS, CARBON STEEL DATA

Case Number	Column A Reference Condition	Column B Study Condition	Mean Cycles To Specimen Failure		Mean Fatigue Life Reduction Factor $FLRF^* = 1 \div N_{IB}/N_{IA}$	95% Confidence Interval on FLRF*	Remarks
			N_{IA}	N_{IB}			
I	As-machined (no stress relief)	As-machined (stress relieved)	2708	1695	1.60	+0.33 -0.27	To estimate the effect due to stress relief in the as-machined material
II	Welded (no stress relief)	Welded (stress relieved)	3010	1610	1.87	+0.57 -0.44	To estimate the effect due to stress relief in the welded material
III	As-machined (stress relieved)	Welded (stress relieved)	1695	1610	1.05	+0.12 -0.10	To estimate the effect due to welding process when both materials have been subjected to post-weld stress relief
IV	As-machined (no stress relief)	Welded (stress relieved)	2708	1610	1.68	+0.34 -0.28	To estimate the combined effect of welding and post-weld stress relief referenced to as-machined material
V	As-machined (no stress relief)	Welded (no stress relief)	2708	3010	0.90	+0.34 -0.28	To estimate the effect due only to the welding process

* Fatigue Life Reduction Factor

Figure 5-6. "I-T" WOL Specimen, Type B

**Table 5-5A
SHAKEDOWN TEST PARAMETERS**

Specimen Number	Material	Tip Deflections*	Testing Rate	Remarks
SS-130	304 Stainless	±0.094 inch	8 cph	Testing suspended at 4602 cycles—no failure indications received—no cracks detected during postmortem inspection on both specimens
CS-1015	Carbon Steel	±0.086 inch	8 cph	Testing suspended at 4602 cycles—no failure indications received—no cracks detected during postmortem inspection on both specimens

*Corresponds to deflections imposed on Dresden specimens tested at highest strain range (1.0%)

Testing was suspended after two weeks and 4600 test cycles of successful operation so that eight additional instrumented fatigue specimens could be added to the test. Neither of the two original "shakedown" specimens had signaled specimen failure prior to the suspension of testing. Both were subsequently examined under 50X magnification to determine whether any fatigue cracks were present—none were detected.

All test facility equipment performed satisfactorily during this Phase I testing demonstrating the ability to operate unattended for extended periods of time.

The second series of air tests will begin shortly; pertinent test parameters are summarized in Table 5-5B.

5.7 THIRD TEST VESSEL (DRESDEN TEST LOOP)

Design work on the third test vessel is progressing. It will be added to the Dresden test loop to generate crack growth rate data in the BWR environment.

The original design concept (Figure 5-5, GEAP-10207-22) has been modified based on experience gained during operation of the Dresden test loop. The bellows "load-capsule" concept has been eliminated in favor of sliding, chevron shaft seals and an externally mounted hydraulic cylinder. This approach would require some type of an internally mounted load cell for measuring the true load (i.e., independent of seal friction loads) applied to the specimen train. In addition, the compact tension specimen geometry originally proposed for this application will be abandoned in favor of the 1-T "WOL" Type B (Figure 5-6) specimen geometry. The relationship between stress intensity and fatigue crack length (i.e., change in K per unit change in crack length) is less severe for the WOL geometry making it more attractive for fatigue crack growth rate studies.

Various techniques for measuring the cyclic crack opening displacements (COD) of these WOL specimens are being investigated. These COD measurements are necessary in order to establish the fatigue crack length as a function of load cycles which, in turn, yields the desired crack growth rate information.

5.8 INSPECTION EQUIPMENT

An inspection shield for use during future inspections of the Dresden fatigue specimens has been fabricated and is presently stored in San Jose awaiting transfer to the Dresden site. A borescope was purchased for use with this shield. These two items will allow highly contaminated specimens to be examined in detail minimizing the radiation exposure to inspection personnel.

A portable positioning fixture for measuring crack propagation in WOL specimens has been designed (Ref. Drawing No. 10504523), and has been placed in the shop for fabrication. Checkout of the fixture utilizing special calibration samples should be completed by July 2, 1971. The fixture utilizes an immersed, focused ultrasonic transducer which is mounted beneath the specimen. The specimen is then moved through the focused sound beam via an X-Y microscope stage. Readout can be obtained mechanically by observing the ultrasonic instrument and taking direct length measurements from the fixture or on an X-Y recorder, where length can be plotted against the amplitude of reflections from the cracked area. A best estimate of the accuracy of the system is ±0.005 inch of true crack length.

Table 5-5B
FATIGUE SPECIMEN TEST PLAN, SERIES II AIR TEST

Specimen Number	Material	Tip Deflections*	Testing Rate	Remarks
SS-130	304 Stainless	± 0.094 inch	8 cph	Specimen accumulated 4602 cycles during Series I Testing with no indication of failure received
CS-1015	Carbon Steel	± 0.086 inch	8 cph	Specimen accumulated 4602 cycles during Series I Testing with no indication of failure received
SS-134	304 Stainless	± 0.094 inch	8 cph	New Specimen
SS-136	304 Stainless	± 0.094 inch	8 cph	New Specimen
SS-144	304 Stainless Furnace Sensitized	± 0.094 inch	8 cph	New Specimen
SS-1023	304 Stainless Furnace Sensitized	± 0.094 inch	8 cph	New Specimen
IN-110	Inconel 600	± 0.100 inch	8 cph	New Specimen
IN-111	Inconel 600	± 0.100 inch	8 cph	New Specimen
CS-78	Carbon Steel	± 0.086 inch	8 cph	New Specimen
CS-1012	Carbon Steel	± 0.086 inch	8 cph	New Specimen

* Corresponds to deflections imposed on Dresden specimens tested at highest strain range (1.0%)

DISTRIBUTION

Aerojet General Engineering Division Sacramento Plant Sacramento, California 95801 Attn. Dr. F.J. Climent	1	Advisory Committee on Reactor Safeguards Dr. Harry O. Monson, Senior Engineer Laboratory Director's Office Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois 60439	1
Advisory Committee on Reactor Safeguards Dr. Spencer H. Bush Consultant to the Director Battelle Memorial Institute Pacific Northwest Laboratory Richland, Washington 99352	1	Advisory Committee on Reactor Safeguards Dr. Arlie A. O'Kelly 2421 West Rowland Avenue Littleton, Colorado 80120	1
Advisory Committee on Reactor Safeguards Mr. Harold Etherington 84 Lighthouse Drive Jupiter, Florida 33458	1	Advisory Committee on Reactor Safeguards Dr. David Okrent, Senior Physicist Laboratory Director's Office Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois 60439	1
Advisory Committee on Reactor Safeguards Dr. William L. Faith 2540 Huntington Drive San Marino, California 91108	1	Advisory Committee on Reactor Safeguards Dean Nunzio J. Palladino College of Engineering The Pennsylvania State University 101 Hammond Building University Park, Pennsylvania 16802	1
Advisory Committee on Reactor Safeguards Dr. Chester P. Siess Department of Civil Engineering 3129 Civil Engineering Bldg. University of Illinois Urbana, Illinois 61801	1	Advisory Committee on Reactor Safeguards Dr. William R. Stratton Los Alamos Scientific Laboratory P. O. Box 1663 Los Alamos, New Mexico 87544	1
Advisory Committee on Reactor Safeguards Dr. Stephen H. Hanauer Professor of Nuclear Engineering 606 Dougherty Hall University of Tennessee Knoxville, Tennessee 37916	1	Advisory Committee on Reactor Safeguards Dr. Carroll W. Zabel Director of Research University of Houston Cullen Boulevard Houston, Texas 77004	1
Advisory Committee on Reactor Safeguards Dr. Joseph M. Hendrie Nuclear Engineering Department Brookhaven National Laboratory Upton, New York 11973	1	Mr. Raymond F. Fraley Executive Secretary Advisory Committee on Reactor Safeguards U.S. Atomic Energy Commission Room 1034-H Washington, D.C. 20545	3
Advisory Committee on Reactor Safeguards Dr. Herbert S. Isbin Department of Chemical Engineering University of Minnesota Minneapolis, Minnesota 55455	1	Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Mr. Paul G. Shewmon	1

Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. P. Lottes	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. M.J. Whitman Asst. Director for Program Analysis	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. C.E. Dickerman	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Dr. E.E. Sinclair Asst. Director for Reactor Technology	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. R.O. Ivins	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. A. Giambusso Asst. Director for Project Management	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. S. Fistedis	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. E.E. Kintner Asst. Director for Reactor Engineering	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. R.C. Vogel	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. J. W. Crawford Asst. Director for Engineering Standards	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: LMFBR Program Office	1	Atomic Energy Commission Division of Compliance, Region IV 10395 West Colfax Avenue Denver, Colorado 80215 Attn: Mr. John W. Flora	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Mr. A. Amorosi	2	Atomic Energy Commission Division of Compliance Washington, D.C. 20545 Attn: Mr. L. Kornblith, Jr.	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. L. Baker	1	Atomic Energy Commission Division of Operational Safety Washington, D.C. 20545 Attn: Mr. H. Gilbert	1
Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Col. R.L. Ednie Asst. Director for Army Reactors	1	Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. E.G. Case	10
Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. M.A. Rosen Asst. Director for Plant Engineering	1	Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. M. Bolotsky	1

Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. A.B. Holt	1	Atomics International P.O. Box 309 Canoga Park, California Attn: Dr. H. Morewitz	2
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. R. Waterfield	1	Babcock & Wilcox Company Washington Operations Office 1725 I Street, N.W. Washington, D.C. 20006	1
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Dr. G. Burley	1	Babcock & Wilcox Company P.O. Box 1260 Lynchburg, Virginia Attn: Mr. Robert Wascher	1
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. R. Impara	1	Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Dr. D.N. Sunderman	2
Atomic Energy Commission Water Projects Branch Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. W.H. Layman	1	Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Dr. D.L. Morrison	1
Atomic Energy Commission Naval Reactors Branch Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. R.S. Brodsky	2	Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Mr. S. Paprocki	2
Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: A.J. Pressesky	3	Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Mr. A.R. Duffy	1
Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. S.A. Szawlewicz	5	Brookhaven National Laboratory Upton, Long Island, New York 11973 Attn: A.W. Castleman	1
Atomic Energy Commission Division of Production Washington, D.C. 20545 Attn: Mr. George B. Pleat	1	University of California Institute of Engineering Research Berkeley, California 94704 Attn: Prof. V.E. Schrock	1
Atomic Energy Commission c/o Gulf General Atomic, Inc. P.O. Box 608 San Diego, California 92112 Attn: Mr. Russell H. Ball	1	Canoga Park Area Office P.O. Box 591 Canoga Park, California 91305 Attn: Mr. R.L. Morgan RDT Senior Site Rep.	1
	1	Combustion Engineering, Inc. Nuclear Division P.O. Box 500 Windsor, Connecticut 06095 Attn: Mr. M.F. Valerino	1

Chicago Operations Office Atomic Energy Commission 9800 South Cass Avenue Argonne, Illinois 60439 Attn: Mr. D.M. Gardiner	1	Naval Ordnance Laboratory White Oak Silver Spring, Maryland Attn: Mr. James Proctor	1
Douglas United Nuclear Richland, Washington Attn: Mr. John Riches	1	North Carolina State University Department of Mechanical Engineering Raleigh, North Carolina 27607 Attn: Prof. M.N. Ozisik	1
Harvard Air Cleaning Laboratory Harvard University 665 Huntington Avenue Boston, Massachusetts 02190	1	Nuclear Fuels Services West Valley, New York 14171	1
IIT Research Institute 10 W. 35th Street Chicago, Illinois 60616 Attn: Dr. T.A. Zaker	1	Oak Ridge Operations Office Atomic Energy Commission Oak Ridge, Tennessee 37830 Attn: Mr. W.L. Smalley	1
IIT Research Institute 10 W. 35th Street Chicago, Illinois 60616 Attn: Mr. E.V. Gallagher	1	Oak Ridge National Laboratory Nuclear Safety Information Center P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. Joel Buchanan	1
Idaho Operations Office Atomic Energy Commission P.O. Box 2108 Idaho Falls, Idaho 83401 Attn: Mr. D. Williams	2	Chemical Technology Division Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. D. Ferguson	1
Liquid Metal Engineering Center c/o Atomics International P.O. Box 309 Canoga Park, California 91304 Attn: R.W. Dickinson	1	Chemical Technology Division Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. R. Blanco	1
Los Alamos Scientific Laboratory P.O. Box 1663 Los Alamos, New Mexico 87544 Attn: Mr. J.H. Russel, K Division	1	Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: HTGR Safety Program Office	2
MPR Associates, Inc. 1140 Connecticut Avenue, N.W. Washington, D.C. 20036 Attn: Mr. T. Rockwell III Chairman AIF Safety Task Force	1	Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: Mr. W. B. Cottrell	4
National Bureau of Standards Washington, D.C. 20545 Attn: Dr. C. Muehlhause	1	Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: Mr. P. Rittenhouse	1

Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. G. Rogers	1	Idaho Nuclear Corporation P. O. Box 1845 Idaho Falls, Idaho 83401 Attn: Water Reactor Safety Program Office, Mr. G. O. Bright, Mgr.	3
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. J.C. Spanner	1	Richland Operations Office P.O. Box 500 Richland, Washington 99352 Attn: Mr. C. Robinson	1
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Dr. J. Batch	1	Richland Operations Office P.O. Box 500 Richland, Washington 99352 Attn: Mr. A.S. Waterhouse	1
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. R. Nightingale	2	Richland Operations Office P.O. Box 500 Richland, Washington 99352 Attn: Mr. A. Brunstad	1
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. L. Schwendiman	1	San Francisco Operations Office Atomic Energy Commission 2111 Bancroft Way Berkeley, California 94704 Attn: Mr. C.V. Backlund	1
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. E.R. Astley, Mgr. FFTF	1	Savannah River Laboratories E.I. duPont deNemours and Company Aiken, South Carolina 29802 Attn: Mr. A.H. Peters	1
Idaho Nuclear Corporation P.O. Box 1845 Idaho Falls, Idaho 83401 Attn: Mr. Curt Haire	1	TRW Inc. TRW Systems Group One Space Park Redondo Beach, California 90278 Attn: Dr. D. B. Langmuir	1
Idaho Nuclear Corporation P. O. Box 1845 Idaho Falls, Idaho 83401 Attn: Mr. S. O. Johnson	2	TRW Inc. TRW Systems Group One Space Park Redondo Beach, California 90278 Attn: Mr. S.M. Zivi	1
Idaho Nuclear Corporation P.O. Box 1845 Idaho Falls, Idaho 83401 Attn: Mr. H. L. Coplen	2	Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Mr. R.A. Wiesemann	1
Idaho Nuclear Corporation P. O. Box 1845 Idaho Falls, Idaho 83401 Attn: Mr. O. F. Brockett	1	Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Dr. D. Fletcher	1
Southern Nuclear Engineering, Inc. P.O. Box 10 Dunedin, Florida 33528 Attn: Mr. Gilbert Brown	1		

Westinghouse Electric Corporation
Atomic Power Division
P.O. Box 355
Pittsburgh, Pennsylvania 15230
Attn: Dr. E. Beckjord

1 Dr. P. L. Pfenningwerth
Bettis Atomic Power Laboratory
P.O. Box 79
West Mifflin, Pennsylvania 15122

1

Westinghouse Electric Corporation
P.O. Box 19218
Tampa, Florida 33616
Attn: Mr. A. Lohmeier

1 Professor C.E. Taylor
Department of Theoretical and Applied Mechanics
University of Illinois
Urbana, Illinois

1

Holmes & Narver, Inc.
828 South Figueroa St.
Los Angeles, California 90017
Attn: B. Shimizu

1 Mr. E. Beauchamp-Nobbs
U.S. Marine Engineering Laboratory
Annapolis, Maryland

1

Mr. Edward T. Wessel
Research and Development Center
Westinghouse Electric Corporation
Beulah Road, Churchill Boro
Pittsburgh, Pennsylvania 15235

1 U.S. Atomic Energy Commission
Division of Technical Information Extension
P.O. Box 62
Oak Ridge, Tennessee

3

1 U.S. Atomic Energy Commission
Division of Reactor Licensing
Washington, D.C. 20545
Attn: S.S. Pawlicki

1

Dr. William E. Cooper
Teledyne Materials Research
303 Bear Hill Road
Waltham, Massachusetts

1 USAEC Site Representative
General Electric Company
Sunnyvale, California 94086
Attn: Russell H. Ball, RDT Sr. Site Rep.

1

Roger W. Staehle
Metallurgy Department
Ohio State University
Columbus, Ohio

1 Mr. B.L. Greenstreet
P.O. Box Y
Oak Ridge National Laboratory
Oak Ridge, Tennessee

1

Mr. Ralph Jones
Division of Reactor Development
U.S. Atomic Energy Commission
Washington 25, D.C.

1 Mr. F.J. Witt
P.O. Box Y
ORNL - Oak Ridge, Tennessee

1

Mr. H.K. Marks
Room 2N83
Department of the Navy
Washington, D.C.

1 Commonwealth Edison Company
Dresden Nuclear Power Station
Rural Route 1
Morris, Illinois 60450
Attn: H.K. Hoyt

2

H. Thielsch
140 Shaw Avenue
Cranston 5, Rhode Island

1 Commonwealth Edison Company
System Mechanical and Structural Engineer
72 West Adams Street
Chicago, Illinois 60690
Attn: M.H. Goedjen

3

Mr. F.M. Moschine
Westinghouse Electric Company
Atomic Power Department
P.O. Box 355
Pittsburgh, Pennsylvania 15230

1 Department of Material Science & Engineering
Hearst Mining Building
University of California
Berkeley, California
Attn: Mr. William W. Gerberich

1

United Kingdom Atomic Energy Authority Reactor Materials Laboratory Wigshaw Lane, Culcheth Warrington, Lancs. England Attn: R.W. Nichols	1	United Engineers and Constructors, Inc. 1401 Arch Street Philadelphia, Pennsylvania 19105 Attn: Mr. John Crowley	1
Atomic Energy of Canada Limited Chalk River Nuclear Laboratories Chalk River, Ontario, Canada Attn: Dr. George Pon	1	Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Mr. Craig Cheng	1
Mr. Robert D. Wylier Department of Materials Engineering Southwest Research Institute 8599 Culebra Road San Antonio, Texas 78228	1	AEG Telefunken AEC Hochhaus Sued 6 Frankfurt/Main 70 West Germany Attn: Mr. Dieter Ewers	1
O.A. Kellerman Institute Fur Reaktorsicherheit Der Technischen Uberwachungs Vereine, e.V. 5 KOLN 1 Glockengasse 2 West Germany	1	Division of Reactor Development & Technology U.S. Atomic Energy Commission Washington, D.C. 20545 Attn: J. R. Hunter Chief, Reactor Vessels Branch	1
C. A. G. Phillips U.K.E.A. Safeguards Division Authority Health & Safety Branch Risley, Warrington, Lancashire England	1	Asst. Director, Instruction Division U.S. Atomic Energy Commission Chicago Operations Office 9800 South Cass Avenue Argonne, Illinois 60439 Attn: R. M. Moser	1
Knolls Atomic Power Laboratory P. O. Box 1072 Schenectady, New York 12301 Attn: Dr. Robert A. Barnes	1	Mr. T. R. Mager Westinghouse Electric Company PWR Systems Division P. O. Box 355 Pittsburgh, Pennsylvania 15230	1
Reactor Materials Branch Metallurgy Division Naval Research Laboratory Washington, D. C. 20545 Attn: Mr. L. E. Steele	1	Hans A. Maurer Commission of the European Communities RUE DE LA LOI 200 1040 Brussels, Belgium	1
		Atomic Energy Commission Division of Reactor Development & Technology Washington, D.C. 20545 Attn: R. W. Cochran	1