RECEIVED BY DTIC DEC 24 1969

MASTER

GEAP-10072
AEC RESEARCH AND
DEVELOPMENT REPORT
JULY 1969

**REACTOR PRIMARY COOLANT SYSTEM
RUPTURE STUDY
QUARTERLY PROGRESS REPORT NO. 17
APRIL - JUNE 1969**

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

ATOMIC POWER EQUIPMENT DEPARTMENT
GENERAL ELECTRIC
SAN JOSE, CALIFORNIA

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
QUARTERLY PROGRESS REPORT NO. 17

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

Printed in U.S.A. Available from the
Clearing House for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia
Price: \$3.00 per copy

ATOMIC POWER EQUIPMENT DEPARTMENT
GENERAL ELECTRIC
SAN JOSE, CALIFORNIA

5957-Dev.Eng.-34
225-AG-11/69

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission: A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe upon privately owned rights; or B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person" acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, in the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or*
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.*

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

TABLE OF CONTENTS

1. Introduction	1
2. Summary	2
2.1 Task A—Probability Study	2
2.2 Task B—Stress Analysis	2
2.3 Task C—Fracture-Mechanics	2
2.4 Task D—Fatigue	2
2.5 Task K—Effect of BWR Environment	2
3. Task A—Probability Study (<i>S. A. Wilson</i>)	3
3.1 Objectives	3
3.2 Summary	3
3.3 Estimating C and B in Low-Cycle Fatigue Crack Growth Rate Equation: Testing for Independence of Successive Transformed Raw Data Points . . .	3
3.4 References for Section 3	5
4. Task B—Stress Analysis	5
4.1 Objective	5
4.2 Task B-1 — Computer Program Development (<i>E. North</i>)	5
5. Task C—Fracture-Mechanics	7
5.1 Objective	7
5.2 Summary	7
6. Task D—Fatigue	7
6.1 Objective	7
6.2 Task D-1—Fatigue Crack Growth Studies (<i>A. J. Brothers</i>)	7
7. Task K—Effect of Environment (<i>D. A. Hale</i>)	15
7.1 Objective	15
7.2 Summary	15
7.3 DNPS-1 Related Activity	15
7.4 Hot Shakedown Testing at San Jose	15
7.5 Fatigue Specimen Evaluation	15
7.6 Specimen Material Procurement and Preparation	15
Distribution	24

LIST OF ILLUSTRATIONS

Figure	Title	Page
3-1	Mean-Square Successive Difference Ratios	4
6-1	Correlation of Crack Growth Rate and Total Strain Range for 2-1/4 Cr-1 Mo Steel at Room Temperature	9
6-2	Surface Crack Growth Curves for Part-Through Crack Specimens and Through-Crack Plate	10
6-3	Comparison of Surface and Depth Crack Growth Curves	11
6-4	Fracture Appearance of Part-Through Crack Specimens	12
6-5	Correlation Between Measured and Predicted Crack Growth	14
7-1	Axial Hole Specimens, Final Fracture Surfaces	20
7-2	Measured Strain Range versus Cycles to Crack for 304 Stainless Steel	21
7-3	Dynamic Test Specimen	22
7-4	Task K—Specimen Orientation, 1-inch Plate Material	23

1. INTRODUCTION

The Reactor Primary Coolant System Rupture Study is being conducted for the Safety Branch, Division of Reactor Development and Technology, USAEC. This seventeenth quarterly report documents progress for the period of April 1 to June 30, 1969. 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 is proceeding on the following tasks:

- Task A - Probability Study,
- Task B - Stress Analyses,
- Task C - Fracture Mechanics,
- Task D - Fatigue, and
- Task K - Effect of BWR Environment.

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 below.

- GEAP-4445- A Survey of Water Reactor Primary System Conditions Pertinent to the Study of Pipe Rupture.
- GEAP-4446- A Review of Fracture Modes as Related to Reactor Primary Coolant Pipe Rupture.
- GEAP-4474- Experimental and Analytical Program Recommendations-Reactor Pipe Rupture Study.
- GEAP-4574- Survey of Piping Failures for the Reactor Primary Coolant Pipe Rupture Study.
- GEAP-4578- Mechanical Design Considerations in Primary Nuclear Piping.
- GEAP-4678- Fracture Mechanics and the Stability of Engineering Structures.
- GEAP-4911- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 1, April-June 1965.
- GEAP-4964- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 2, July-August 1965.
- GEAP-5014- Fracture Toughness of Some Engineering Alloys.

- GEAP-5082- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 3, October-December 1965.
- GEAP-5147- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 4, January-March 1966.
- GEAP-5192- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 5, April-June 1966.
- GEAP-5279- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 6, July-September 1966.
- GEAP-5410- Low-Cycle Fatigue Strength Reduction in Notched Flat Plates.
- GEAP-5427- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 7, October-December 1966.
- GEAP-5471- PAPA-Structural Analysis of Plates and Shells Using Trapezoidal and Triangular Plate Elements.
- GEAP-5474- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 8, January-March 1967.
- GEAP-5512- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 9, April-June 1967.
- GEAP-5553- PAPA-The Digital Computer Program for the Static Analysis of Structures Made Up of Plate and Panel Elements.
- GEAP-5554- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 10, July-September 1967.
- GEAP-5557- Stress Intensity Factor for a Circumferential Through-Wall Crack in a Straight Pipe, January 1968.
- GEAP-5587- Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 11, October-December 1967.
- 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-5622— A Failure Diagram for Axially Flawed Pipes, April 1968.

GEAP-5637— Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 12, January–March 1968.

GEAP-5653— Status of Pipe Rupture Study at General Electric—II, July 1968.

GEAP-5680— Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 13, April–June 1968.

GEAP-5714— Notched High-Strain Fatigue Behavior of Three Low-Strength Structural Steels, September 1968.

GEAP-5716— Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 14, July–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-5770— Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 15, October–December 1968.

GEAP-10024— Reactor Primary Coolant System Rupture Study Quarterly Progress Report Number 16, January–March 1969.

2. SUMMARY

2.1 TASK A—PROBABILITY STUDY

In the estimation of A and B in the low-cycle fatigue crack growth rate equation, the independence of successive transformed raw data points (on a log da/dN scale) was examined. There was evidence of some lack of independence, but in directions of both positive and negative correlation. It was concluded that the model is not entirely perfect—some cracks grow faster or slower for varying periods than predicted by the model—but that it is satisfactory for reconciling results from the 44 runs. It was also concluded that the present estimate of variance of slope is the most rational estimate available.

2.2 TASK B—STRESS ANALYSIS

A paper, "Analysis of Thin-Wall Shells Using the PAPA Computer Program," was presented at the annual ORNL information meeting in April. The subject of the meeting was *Studies in Applied Solid Mechanics*, in two parts:

- a. Structural Design Criteria for Piping, Pumps, and Valves, and
- b. Experimental and Analytical Investigations of Structural Behaviors of Nozzle-to-Shell Attachments.

The sessions included a number of papers on finite element computer codes, and afforded an excellent opportunity for initiating the evaluation of computer codes similar to PAPA which are in various stages of development. Work is currently in progress to evaluate the PAPA/EPS code as well as

other codes with similar objectives. Brief comments are given in this report on the finite element computer codes reported on at the ORNL meeting.

2.3 TASK C—FRACTURE-MECHANICS

No work was performed during this report period.

2.4 TASK D—FATIGUE

The experimental results of crack growth in part-through surface cracked plates of 2-1/4 Cr-1 Mo at room temperature were compared with those obtained on through-cracked specimens for identical conditions of tension-compression, strain-controlled loading. The observed effect of flaw geometry can be reconciled and estimated from flaw shape effects predicted by fracture mechanics considerations.

2.5 TASK K—EFFECT OF BWR ENVIRONMENT

The fatigue machine was given initial, hot (530°F) shake-down testing in a loop at San Jose, and had accumulated about 2000 cycles at the close of the period. The shaft-packing gland leakage was negligible when cycling at the planned rate of two per hour. All necessary items are at the DNPS-1 site for loop piping installation scheduled for completion during August. Several weeks are scheduled for startup and operating checks prior to the 3-month plant outage commencing in September. The fatigue specimen with an axial hole has been selected for the program, based on the results of testing 19 axial hole specimens and 9 transverse hole specimens.

3. TASK A—PROBABILITY STUDY

(S. A. Wilson)

3.1 OBJECTIVES

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

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

3.2 SUMMARY

In the estimation of A and B in the low-cycle fatigue crack growth rate equation, the independence of successive transformed raw data points (on a log da/dN scale) is examined. There is evidence of some lack of independence, but in directions of both positive and negative correlation. It is concluded that the model is not entirely perfect—some cracks grow faster or slower for varying periods than predicted by the model—but that it is satisfactory for reconciling results from the 44 runs. It is concluded that the present estimate of variance of slope is the most rational estimate available.

3.3 ESTIMATING C AND B IN LOW-CYCLE FATIGUE CRACK GROWTH RATE EQUATION: TESTING FOR INDEPENDENCE OF SUCCESSIVE TRANSFORMED RAW DATA POINTS

Subject equation is $da/dN = A(\Delta K)^B$, or as mean-adjusted, $da/dN = C(\Delta K/\overline{\Delta K})^B$. The previous work in estimating C and B appears in the following sections, which should be referred to:

Subsection 3.4, Twelfth Quarterly Report, GEAP-5637, and

Subsection 3.5 and Appendix A, Fourteenth Quarterly Report, GEAP-5716.

Therein, estimates are made of slope B and intercept log C for each of 44 runs in the following equation, found by taking logs of subject mean-adjusted equation.

$$\log da/dN = \log C + B(\log \Delta K - \overline{\log \Delta K}).$$

Then, estimates are made of mean and variance of slope and intercept within material-temperature groups, i.e., the mean

line and variability among lines within these groups. If the residuals (y-deviations from the line) of successive transformed raw data points ($y = \log \Delta a/\Delta n$, $x = \log \Delta K$) are not independent, then estimates of mean slope and intercept for individual lines are still unbiased but estimates of variance of residuals may be too low, if residuals (errors) are positively correlated (runs on same side of line); or too high if residuals are negatively correlated (points tend to reverse sides with excessive frequency), and thus variance of estimates of intercept and slope for individual lines will be correspondingly too low or too high. We did not use variance of estimates of intercept of individual lines (only variance among lines), but we did use a grand average variance of estimate of slope of individual lines (0.608, step 17, subsection 3.5.3, Fourteenth Quarterly) to subtract from the apparent variance of slopes among lines to give this latter variance without estimating error. Thus, whether or not successive transformed raw-data points are independent will affect our estimate of variance of slopes among lines; the estimate is too high if successive residuals are positively correlated, too low if negatively correlated. Note that we are interested in an estimate of variance of slope among lines, not variance of estimate of slope of individual lines.

While successive raw data points (a versus n) are certainly not independent, the value of some a depending on what the previous a value was, differences between successive a values will in general be independent, will permit successive transformed raw data values ($\log \Delta a/\Delta n$) to be independent, and thus lead to unbiased variances of estimates of slope and intercept (Ref. 1, 2). Nevertheless, this independence should be verified.

The test for independence of successive transformed raw-data points is the mean-square successive difference ratio test (Ref. 3, 4). It can be shown that, if values are drawn at random from a standardized normal distribution, having mean $\mu = 0$ and variance $\sigma^2 = 1$, the mean square of differences between successive values will be $\delta^2 = 2\sigma^2$. One may form the ratio $R = \delta^2/\sigma^2$, which will have expected value 2 if draws are random (independent). If successive draws tend to cluster ("errors" from 0 positively correlated), R will be less than 2; and if they tend to oscillate excessively between low and high values ("errors" negatively correlated), R will exceed 2. The distribution of R can be approximated, and thus confidence intervals for it can be formed, which depend on number of samples drawn.

Figure 3-1. Mean-Square Successive Difference Ratios

An R value for each run, along with 90% confidence limits, is plotted in Figure 3-1. Nine points fall outside these confidence limits, six below and three above; 4.4 points would be expected, but 9 are not significantly high even at the 10% level (binomial). The pattern of transformed raw data points for the six runs having low R was that they tended to form a wavy line of points, through which we fitted a straight line. Thus crack growth rate tended to vary, faster or slower than the model predicts. For the three runs having high R, successive points tended to oscillate excessively about the line; this could be caused by measurement error, where one crack length measured too short would reflect as too low a crack growth rate first, then too fast a rate. Possibly, also, the period of genuine faster-and-slower crack growth rate variation was shorter for these runs and happened to synchronize with the data-taking intervals. While the foregoing does suggest that the basic crack growth rate model is not always followed for every cycle, it still appears as a satisfactory way of representing the results of the 44 runs. Also, it appears that

the present estimate of variance of slope among lines (1.106) is the most rational estimate available.

3.4 REFERENCES FOR SECTION 3

1. Mandel, John, "Fitting a Straight Line to Certain Types of Cumulative Data," *Journal of the American Statistical Association*, December 1957, pp. 552-566.
2. Jaech, J. L., "A Note on the Equivalence of Two Methods of Fitting a Straight Line Through Cumulative Data," *Journal of the American Statistical Association*, September 1964, pp. 863-866.
3. Brownlee, K. A., "Statistical Theory and Methodology in Science and Engineering," Wiley, 1960, pp 161 ff.
4. Bennett, C. A., and Franklin, N. L., "Statistical Analysis in Chemistry and the Chemical Industry," Wiley, 1954, pp. 677 ff.

4. TASK B—STRESS ANALYSIS

4.1 OBJECTIVE

The purpose of the stress analysis task is to develop a method for the stress and strain analyses of those piping components which have been intractable problems. The designer must be able to determine the detailed stress and strain distributions in complex piping geometry under complex loadings for avoidance of leaks and severance in piping, and to take into account low-cycle fatigue, corrosion, and critically sized flaws.

4.2 TASK B-1 — COMPUTER PROGRAM DEVELOPMENT (E. North)

The objective of the computer code development is to develop the analytical tools required to define the state of stress and strain in complex piping in service.

4.2.1 SUMMARY

A paper, "Analysis of Thin-Wall Shells Using the PAPA Computer Program," was presented at the annual ORNL information meeting in April. The meeting subject was *Studies in Applied Solid Mechanics*, in two parts:

- a. Structural Design Criteria for Piping, Pumps, and Valves, and
- b. Experimental and Analytical Investigations of Structural Behaviors of Nozzle to Shell Attachments.

The sessions included a number of papers on finite element computer codes and afforded an excellent opportunity for initiating an evaluation of other computer codes similar to PAPA but in various stages of development. Work is currently in progress to evaluate the PAPA/EPS code, as well as other codes with similar objectives. Brief comments are given on the finite element computer codes reported on at the ORNL meeting.

4.2.2 PAPERS ON FINITE ELEMENT ANALYSIS PRESENTED AT ORNL MEETING

Discussion is limited to those papers that dealt with finite element analysis.

4.2.2.1 Finite Element Analyses of Piping Tee Configurations

R. W. Clough, University of California, Berkeley

This was an hour-long talk given by the originator of the constant stress, linear strain finite element. His general comments and conclusions were as follows.

- a. The geometric idealization is no more severe than the displacement function assumed in flat-plate analysis.
- b. The work done on constant strain triangles (membrane elements) has led to the conclusion that the formulation was wrong. The lowest order for membrane elements

should be at least a linear variation of strain across the element. The conclusion was based on the fact that when analyzing flat plates under biaxial or uniaxial loads, the answers seemed reasonable; however, any deviation from the simplest of geometries was reflected in erroneous calculations.

- c. To handle plate bending, a cubic displacement function was used. This resulted in 3 degrees of freedom at each

node (2 translation, 1 bending). Since this was difficult to work with, a new bending element with intermediate nodes was introduced (see Sketch A), which resulted in the ability to use a quadratic displacement relationship for the plate element (18 degrees of freedom). It is felt that this is a minimum allowable for reasonable accuracy.

Sketch A

- d. Following the same reasoning, a 12-equation membrane element with 2 degrees of freedom at 6 nodes was then used.

- e. From the bending element, a quadrilateral that has 33 degrees of freedom was formulated (see Sketch B).

Sketch B

By eliminating the central nodes, one ends up with 20 degrees of freedom.

- f. Results obtained:

1. Curved partial shell shows poor results using the membrane element. If the bending quadrilateral is used, the results are good.

2. Tee analysis ($d/D = 0.5$) was compared with some preliminary strain gage data from ORNL. Deviations were in the order of 50 to 75% and showed varying divergence between the analytical and experimental results. (When the test has been completed, ORNL will send strain gage data to E. North at Evendale. This should make an interesting comparison for the PAPA program.)

- g. Work now in process, or soon to be started:
 1. Further work on improving the basic finite element,
 2. Incorporate shear effects into the formulation,
 3. A 3-D element; however, there is uncertainty regarding strain assumptions, and
 4. Thermal effects not now included will be done in the near future.
- h. For analysis of large tee problems, a mesh or coordinate generator must be developed.
- i. Regarding nonlinear analysis (elastic-plastic), the method of performing this is to take into account:
 1. Material property changes,
 2. Incremental loading (elastic-linear plastic),
 3. Element stiffnesses (problems expected in formulating), and
 4. Strain variations through the thickness. No attempt will be made to incorporate strain variations across the length of the element.

Of interest is that Clough's approach—disregarding the element stiffness formulation—is exactly the course of action chosen for PAPA/EPS.

4.2.2.2 Analytical Considerations for LMFBR Valve Technology from Applied Aerospace Techniques

R. T. Reid, Aerojet-General Corporation

The presentation of Aero-Jet General on a pump casing showed results that differed by less than 2% when compared with experimental findings. No explanation of the elements was offered. Considering the complexity of the structure, with thick- combined with thin-walled sections, the excellence of these results—where a 50% deviation would be expected—is remarkable.

4.2.2.3 Comparison of Theoretical and Experimental Stress Analysis Results for a Pump Casing

A. Hopper, Franklin Institute Research Laboratories

This covered the axisymmetric code FEBOR, with extensive plot routines for input, deformed structure, and isobars of stress. A pump volute was analyzed by taking radial cuts around the circumference and treating each section as an axisymmetric section. Correlation with experimental findings showed as much as 3-to-1 differences.

5. TASK C—FRACTURE-MECHANICS

5.1 OBJECTIVE

The objective of this task is the determination of the relationship between flaw configuration and pressure load limit in piping components used in nuclear coolant circuits.

Experiments to date have been limited almost entirely to ASTM-A106B pipe of 12-inch or less nominal diameter.

5.2 SUMMARY

No work was performed during this report period.

6. TASK D—FATIGUE

6.1 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.

6.2 TASK D-1—FATIGUE CRACK GROWTH STUDIES (A. J. Brothers)

6.2.1 SUMMARY

The experimental results of crack growth in part-through surface cracked plates of 2-1/4 Cr-1 Mo at room tem-

perature are compared with those obtained on through-cracked specimens for identical conditions of tension-compression, strain-controlled loading. The observed effect of flaw geometry can be reconciled and estimated from flaw shape effects predicted by fracture mechanics considerations.

6.2.2 CRACK GROWTH OF PART-THROUGH SURFACE CRACKS UNDER FULLY REVERSED, STRAIN-CONTROLLED, TENSION-COMPRESSION LOADING

Previous tests under fully reversed strain-controlled loading to determine basic crack growth rate properties have utilized either through-cracked plates tested in tension-compression (Quarterly Report No. 12) or

part-through surface cracked plates under fully reversed bending tension-compression (Quarterly Report No. 14). In both these configurations, it was observed that crack growth rates were generally independent of, or a weak function of, crack length and related exponentially to the strain range. This is illustrated in Figure 6-1 for the 2-1/4 Cr-1 Mo alloy. However, it was determined from preliminary tests in tension-compression of part-through surface cracked plates (Quarterly Report No. 13) that there was an apparent effect of flaw geometry.

To systematically investigate the influence of part-through crack (PTC) geometry, additional tests have been performed on nominally 5-inch-wide by 0.8-inch-thick plates of 2-1/4 Cr-1 Mo steel containing part-through electric-discharge machined surface slots of various depth and length-to-depth ratios. All tests were cycled under equally balanced, reversed tension-compression with constant strain range control.

The results of these tests, including a previous test of a 5-inch-wide by 0.25-inch-thick specimen containing a 0.5-inch-wide through-crack are shown in Figure 6-2. With the unaccountable exception of a single test (PTC 0.5 x 0.1 inch), all specimens shortly before and after through-thickness penetration exhibit very similar and constant crack growth rates; e.g., the slope of the curves of Figure 6-2. However, during initial growth, the growth rate is an apparent function of crack length and/or depth.

The relation of crack length to depth in these tests is illustrated in Figure 6-3 and shown qualitatively in the fracture surface photographs of Figure 6-4. The data of Figure 6-3 were derived from either beach marks induced by understressing techniques or by dye penetrant marking. Comparison of the curves of Figure 6-3 indicates nearly identical growth rates in the surface and the depth directions. Also, inspection of Figure 6-4 for two specimens with flaw sizes less than the thickness suggests that incipient flaws or cracks tend to assume an equilibrium length to depth of

about 3.0. This is generally consistent with previous observations of growth of PTC flaws under cyclic loading (GEAP-5607).

Since it was shown earlier (Quarterly Report No. 15) that crack growth rates under strain-controlled loading correlated well with stress-controlled tests on the basis of stress intensity factor, and since this latter quantity has provisions to account for geometry effects of PTC cracks, an attempt was made to correlate the incipient crack growth rates in these PTC tests with those measured on through-crack specimens. This correlation, if successful, will provide a means of rationally estimating flaw growth of PTC cracks under strain-controlled loading conditions.

From consideration of the general expressions for stress intensity factor, one notes factors of stress, geometry, and crack length; i.e.,

$$K = f(\sigma) \times (f) a, c \times (f) (a, t, c \text{ or } W),$$

where

a = crack depth,
c = surface half-crack length,
t = thickness, and
W = plate width.

Specifically, for a center-slotted plate,

$$K = \sigma_g \times (\pi c)^{1/2} \times \left(\frac{2W}{\pi c} \tan \frac{\pi c}{2W} \right)^{1/2} \quad (\text{see footnotes})$$

or modification thereof [see footnote (a)].

For a part-through surface cracked plate,

$$K = \sigma_g \times (\pi a)^{1/2} \times \frac{1 + 0.12 (1 - a/c)}{\phi_0} \times \left[\frac{2t}{\pi a} \tan \frac{\pi a}{2t} \right]^{1/2} \quad [\text{see footnote (b)}]$$

(a) Brown, W. F. and Srawley, J. E., "Plane Strain Crack Toughness Testing of High Strength Metallic Materials," *ASTM STP 410*.

(b) Paris, P. C. and Sih, G. C., "Stress Analysis of Cracks," *Fracture Toughness Testing and Its Applications, ASTM STP 381*.

Figure 6-1. Correlation of Crack Growth Rate and Total Strain Range for 2-1/4 Cr-1 Mo Steel at Room Temperature

Figure 6-2. Surface Crack Growth Curves for Part-Through Crack Specimens and Through-Crack Plate

Figure 6-3. Comparison of Surface and Depth Crack Growth Curves

PART-THROUGH CRACK, 0.5 x 0.2 in.

1X

PART- THROUGH CRACK, 0.5 x 0.1 in.

1X

Figure 6-4. Fracture Appearance of Part-Through Crack Specimens

For a constant stress or corresponding strain level, it is possible to determine the relative or effective K or strain level for a given surface crack length in a PTC specimen in terms of that for a center-slotted plate of equal crack length. Since correlations of crack growth rate versus K or strain range are available for through-cracked plates, the growth rate corresponding to the effective strain range in the PTC specimen can then be determined.

The results of such an analysis for specimens PTC 1 X 0.2 and PTC 0.5 X 0.2 inch are shown in Table 6-1, and summarized in Figure 6-5 which plots both the measured and predicted surface crack growth rate as a function of crack depth. The estimated rates were obtained from Figure 6-1,

using the effective strain range for the PTC specimens and considering two possible lines representing the maximum and minimum growth rates measured at a strain range of 0.4%. The correlation, shown in Figure 6-5 is reasonable for crack depths less than about 75% of the thickness, and suggests that this is a reasonable analytical procedure for compensating for geometry effects. However, in view of the great scatter possible with exponential relationships, it would be desirable to base a design relationship on a more statistically representative group of data. Also, application of this procedure to service or design cases for which the crack length-to-depth ratio is unknown will require either the assumption of various length-to-depth ratios or, more reasonably, assumption of an equilibrium length-to-depth ratio of 3.0.

TABLE 6-1
SUMMARY OF ANALYSIS OF STRAIN-CONTROLLED CRACK GROWTH SPECIMENS

PTC 0.5 X 0.2 in.

Crack Depth a (in.)	a/t	Crack Half Length c (in.)	a/c	ϕ_0	$\{K/\sigma\}$ PTC $\sqrt{(\text{in.})}$	Measured da/dN ($\mu\text{-in./Cycle}$)	Estimated da/dN($\mu\text{-in./cycle}$) (Max.) (Min.)	
0.395	0.49	0.413	0.957	1.54	0.823	479	630	225
0.495	0.62	0.588	0.842	1.45	1.075	735	850	305
0.565	0.706	0.695	0.812	1.42	1.30	1125	1300	450
0.645	0.806	0.820	0.786	1.41	1.66	1390	3400	820
0.740	0.93	0.990	0.747	1.38	2.92	1400	-	-

PTC 1.0 X 0.2 in.

0.338	0.422	0.563	0.601	1.28	0.916	358	475	165
0.395	0.494	0.700	0.565	1.25	1.065	680	530	195
0.483	0.604	0.810	0.594	1.28	1.20	938	610	225
0.662	0.827	0.950	0.697	1.34	1.89	1000	3100	720

Determination of Effective Strain in PTC Specimens

	Crack Half Length c (In.)	c/W	$\{K/\sigma\}_c$ ($\sqrt{\text{in.}}$)	$\{K/\sigma\}$ PTC/ $\{K/\sigma\}_c$	Effective Strain Range in PTC Spec. ϵ_T (%)
PTC 0.5 X 0.2 in.	0.413	0.083	1.155	0.711	0.284
	0.588	0.118	1.410	0.763	0.305
	0.695	0.139	1.55	0.839	0.335
	0.820	0.410	1.72	0.965	0.386
PTC 1.0 X 0.2 in.	0.563	0.112	1.375	0.666	0.266
	0.700	0.140	1.560	0.683	0.273
	0.810	0.163	1.705	0.704	0.282
	0.950	0.190	2.020	0.936	0.374

Effective strain in PTC spec = $\{K/\sigma\}$ PTC/ $\{K/\sigma\}_c \times \epsilon_T$; $\epsilon_T = 0.4\%$.

Figure 6-5. Correlation Between Measured and Predicted Crack Growth

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

7.1 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 cycle-to-failure will be obtained employing a specially-designed fatigue testing unit in an experimental piping loop at a boiling water reactor. The planned test duration is 2-1/2 years, allowing time for corrosion, if any, to affect crack initiation and growth.

7.2 SUMMARY

The fatigue machine was given initial, hot (530°F) shakedown testing in a loop at San Jose, and had accumulated about 2000 cycles at the close of the period. The shaft-packing gland leakage was negligible when cycling at the planned rate of two per hour. All necessary items are at the DNPS-1 site for loop piping installation scheduled for completion during August. Several weeks are scheduled for startup and operating checks prior to the 3-month plant outage commencing in September. The fatigue specimen with an axial hole has been selected for the program, based on the results of testing 19 axial hole specimens and 9 transverse hole specimens.

7.3 DNPS-1 RELATED ACTIVITY

7.3.1 LOOP PIPING AND VESSELS

Approval of the loop cubicle design package, subject to several minor changes, was received from Commonwealth-Edison. The changes were concerned mainly with improving the instrumentation of the loop safety system, and have been incorporated in the final loop design.

The first shipment of material (including the static test vessel) required for the actual installation of the loop cubicle piping left Vallecitos in late June for the Dresden site. Actual installation work is scheduled to begin the week of July 14, with completion scheduled for the week of August 18.

Present plans call for starting up the loop (minus the fatigue test vessel) to check out instrumentation and safety system operation, calibrate the chemistry sample station, and verify predicted loop operating parameters as soon as installation is completed. This will permit about 2 weeks of loop operation prior to the scheduled September 7 plant outage. The fatigue test vessel at Vallecitos is scheduled for fatigue machine assembly (with test specimens) in October preparatory to shipment to the site.

7.3.2 LOOP INSTRUMENTATION

The loop operating console is now being used to monitor the hot shakedown tests (see subsection 7.4). Present plans call for returning the console to Vallecitos for a final system calibration of the console and its attendant flow, pressure, and temperature transducers prior to shipment to the Dresden site in late July.

7.3.3 LOOP CHEMISTRY CHARACTERIZATION

The Loop Chemistry Sample Station consoles are virtually complete. Final operational checks are under way at Vallecitos: the consoles will be transferred to the Dresden site in late July.

7.4 HOT SHAKEDOWN TESTING AT SAN JOSE

Preliminary hot shakedown testing began in May. Several minor problems were encountered with the hydraulic loading circuitry for the fatigue test machine, which were corrected by redesign of the components involved.

The unit was cycled approximately 2000 cycles, at cyclic rates varying from 2 to 5 cpm while immersed in 530°F, 1050 psig, demineralized water.

A condenser was connected to the lantern ring cavity between the inner and outer chevron packing ring sets to measure steam leakage through the gland which seals the fatigue test jig support shaft. Measured leak rates were found to be negligible for the lower cyclic rates and 10 to 15 ml/min for the higher ones. These preliminary measurements indicate that the Teflon packing gland would be adequate for use at relatively low cyclic rates approximating those planned for the actual environmental testing (2 cph) at Dresden 1. As a further precaution, however, a packing gland leak-off line will be added to the loop piping to allow any condensate which does collect in the gland to be vented to the contaminated drain header provided for the effluent from the loop chemistry sample station.

7.5 FATIGUE SPECIMEN EVALUATION

7.5.1 ROOM TEMPERATURE TESTING IN AIR

Testing was completed on the final group of 11 axial hole specimens (room temperature, constant deflection tests). The pertinent test parameters are listed in Table 7-1. This

Table 7-1
TEST RESULTS: AXIAL SPECIMENS

Specimen	Initial Strain Range	Crack Initiation	Failure	Remarks
MT-D-22	7100 $\mu\epsilon$ ($\pm 3550\mu\epsilon$)	Full width crack noted on bottom surface of reduced thickness section and 22,400 cycles.	Water leakage noted on bottom surface of reduced thickness section at 22,449 cycles.	Post-mortem exam indicates: (a) crack initiated on outer surface, propagated inward. (b) final fatigue crack geometry unaffected by presence of axial hole.
MT-D-23	5100 $\mu\epsilon$ ($\pm 2550\mu\epsilon$)	No cracks detected prior to water leakage.	Water leakage noted on top surface of reduced thickness section at 204,264 cycles.	Value for cycles-to-failure questionable due to shape of final fatigue crack which suggests crack may have initiated on bore of axial hole.
MT-D-24	5100 $\mu\epsilon$ ($\pm 2550\mu\epsilon$)	No cracks detected visually, or with dye penetrant at conclusion of test (229,981 cycles)	---	---
MT-D-25	4900 $\mu\epsilon$ ($\pm 2450\mu\epsilon$)	Crack $\approx 1/2$ width detected top surface of reduced thickness section at 118,542 cycles.	Water leakage noted on top surface of reduced thickness section at 119,822 cycles.	Post-mortem exam indicates: (a) crack initiated on outer surface, propagated inward; (b) final fatigue crack geometry unaffected by presence of axial hole.
MT-D-26	6900 $\mu\epsilon$ ($\pm 3450\mu\epsilon$)	No cracks detected prior to water leakage.	Water leakage noted on top surface of reduced thickness section at 90,744 cycles.	Value for cycles-to-failure questionable due to shape of final fatigue crack geometry which suggests crack may have initiated on bore of axial hole.
MT-D-27	Strain gage failed on first loading cycle, unable to measure any peak-peak strains.	No cracks detected prior to full section failure.	Specimen failed by full section failure between 2000 and 2400 cycles.	Unable to relate cycles-to-failure to measured strain range.

Table 7-1 (Continued)

Specimen	Initial Strain Range	Crack Initiation	Failure	Remarks
MT-D-28	10,500 $\mu\epsilon$ ($\pm 5250\mu\epsilon$)	Crack detected in center of reduced thickness section on top surface at 6768 cycles, edges not cracked.	Water leakage noted on bottom surface of reduced thickness section at 7350 cycles.	Post-mortem exam indicates: (a) crack initiated on surface propagated inward, and (b) final fatigue crack geometry unaffected by presence of axial hole.
MT-D-29	10,300 $\mu\epsilon$ ($\pm 5150\mu\epsilon$)	Crack detected in center of reduced thickness section on bottom surface at 9875 cycles, edges not cracked.	Water leakage noted on bottom surface of reduced thickness section at 10,500 cycles.	Post-mortem exam indicates: (a) crack initiated on surface propagated inward, and (b) final fatigue crack geometry unaffected by presence of axial hole.
MT-D-30	11,000 $\mu\epsilon$ ($\pm 5500\mu\epsilon$)	No cracks detected prior to water leakage.	Water leakage noted on bottom surface of reduced thickness section at 4700 cycles.	Post-mortem exam indicates that even though only one crack was present directly over axial hole, shape of crack suggests crack had initiated on outer surface and propagated inward.
MT-D-31	5900 $\mu\epsilon$ ($\pm 2950\mu\epsilon$)	No cracks detected prior to water leakage.	Water leakage noted on bottom surface of reduced thickness section at 106,005 cycles.	Post-mortem exam indicates: (a) crack initiated on surface, propagated inward, and (b) final fatigue crack geometry unaffected by presence of axial hole.
MT-D-32	5800 $\mu\epsilon$ ($\pm 2900\mu\epsilon$)	Crack detected near edge in reduced thickness section on top surface at 72,480 cycles.	Water leakage noted on top surface of reduced thickness section at 73,000 cycles.	Post-mortem exam indicates: (a) crack initiated on surface, propagated inward, and (b) final fatigue crack geometry unaffected by presence of axial hole.

brings the total number of specimens tested to 35 (9 transverse hole, 19 axial hole, 7 miscellaneous), and concludes the room temperature phase of the dynamic specimen evaluation test program.

Axial Hole Specimen Concept, Summary

Of the 19 axial specimens tested, 11 cracked and ultimately failed (i.e., detectable water leakage from pressurized axial activity) in the reduced thickness test section; 4, tested at the lowest strain ranges, showed no signs of cracking at the termination of dynamic testing; and 4, representing prototype "trial" efforts, were not considered in the final data analysis.

Measurements were completed on all the axial specimens tested to determine how accurately the axial hole was centered in the reduced thickness test section. The results of these eccentricity measurements are summarized in Table 7-2, and discussed in the following paragraphs.

Dye penetrant checks were performed on the four fatigued but uncracked specimens to ensure that no incipient surface cracks were present. These specimens were then pulled apart to determine whether any fatigue cracks had started in the interior of the specimen in the vicinity of the axial hole; none were found.

The final fracture surfaces of the 11 specimens which did crack were examined macroscopically to characterize the geometry of the fatigue crack front that existed when dynamic testing was terminated (i.e., at specimen failure). The appearance (Figure 7-1), combined with the observations which had been recorded during the dynamic tests, indicated that in 9 of these 11 specimens the fatigue crack which ultimately signalled specimen failure had started on the outer surfaces of the specimen and had grown into the specimen thickness until it reached the axial hole. However, in two cases (23, 26) it was impossible to determine where the final crack had started. The eccentricities associated with these two specimens were large (0.010 and 0.013 inch); none of the seven specimens with eccentricities of 0.010 inch or less showed internal crack initiation.

The fatigue data strain range versus cycles for the nine "good" specimens (omitting 23 and 26) are summarized in Figure 7-2. The ASME Section III "Air Line" has been included for comparison, and a straight line has been fitted to the nine data points using the least-squares technique.

7.5.2 FINAL SPECIMEN QUALIFICATION AT SYSTEM CONDITIONS

A group of seven Type-304 stainless steel test specimens conforming to the proposed final dynamic specimen geometry (Figure 7-3) has been machined and is being instrumented for testing in the hot shakedown loop in San Jose during the next quarter.

Several pressure switches will be connected via capillary tubes to the specimens so that the complete dynamic specimen-pressure switch system can be evaluated under actual operating conditions. When a crack grows from the specimen surface and intercepts the axial hole, 1000 psi is impressed on the pressure switch. An electrical signal then stops a cycle counter. This testing will be done at the same time as the shakedown testing of the fatigue test machine itself.

7.6 SPECIMEN MATERIAL PROCUREMENT AND PREPARATION

All the plate material for specimen machining is on hand. Metallographic studies were performed on all four plate materials to establish the rolling direction and characterize the microstructure of the material. The dynamic, static WOL, and stress bend specimens will be oriented with respect to the rolling direction of the plate material, as shown in Figure 7-4.

Preparation of the fatigue specimen blanks is in progress. Final machining will begin late in July.

Table 7-2
MEASUREMENTS OF AXIAL HOLE LOCATION

$$\text{CALCULATED ECCENTRICITY } (\epsilon) = \frac{-Y_t + Y_b}{2}$$

SPECIMEN I.d.	AXIAL HOLE DIAMETER d_o (inches)	BOTTOM MIN. LIGAMENT THICKNESS Y_b (inches)	TOP MIN. LIGAMENT THICKNESS Y_t (inches)	SPECIMEN THICKNESS T (inches)	ECCEN- TRICITY ϵ (inches)	LOCATION OF FINAL FAILURE
MT-D-32	0.028	0.0391	0.0338	0.1008	+ 0.003	TOP
MT-D-31	0.021	0.0360	0.0449	0.1010	- 0.004	BOTTOM
MT-D-30	0.028	0.0219	0.0521	0.1018	- 0.015	BOTTOM
MT-D-29	0.027	0.0309	0.0448	0.1018	- 0.007	BOTTOM
MT-D-28	0.022	0.0347	0.0448	0.1005	- 0.005	BOTTOM
MT-D-27	0.034	0.0354	0.0332	0.1012	- 0.001	$\gamma^{(a)}$
MT-D-25	0.019	0.0529	0.0321	0.1011	+ 0.010	TOP
MT-D-23	0.023	0.0495	0.0283	0.1005	+ 0.010	TOP ^(b)
MT-D-22	0.020				+ 0.010	BOTTOM
MT-D-26	0.023				+ 0.013	TOP ^(b)

(a) EXPERIENCED FULL SECTION FAILURE BEFORE LEAKAGE WAS DETECTED.

(b) CYCLES-TO-FAILURE DATA SUSPECT DUE TO APPEARANCE OF FINAL FRACTURE SURFACE.

Figure 7-1. Axial Hole Specimens, Final Fracture Surfaces

Figure 7-2. Measured Strain Range versus Cycles to Crack for 304 Stainless Steel

Figure 7-4. Task K Specimen Orientation, 1-inch Plate Material

DISTRIBUTION

	Copies		Copies
Aerojet General Engineering Division Sacramento Plant Sacramento, California 95801 Attn. Dr. F.J. Climent	1	Mr. Lombard Squires c/o Mr. F.P. Allen Explosives Department E.I. DuPont de Nemours & Co. Wilmington, Delaware 19898	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 Mr. Harold G. Mangelsdorf 78 Knollwood Road Short Hills, New Jersey 07078	1
Advisory Committee on Reactor Safeguards Mr. Harold Etherington 84 Lighthouse Drive Jupiter, Florida 33458	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. William L. Faith 2540 Huntington Drive San Marino, California 91108	1	Advisory Committee on Reactor Safeguards Dr. Arlie A. O'Kelly 2421 West Rowland Avenue Littleton, Colorado 80120	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. 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. Stephen H. Hanauer Professor of Nuclear Engineering 606 Dougherty Hall University of Tennessee Knoxville, Tennessee 37916	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. Joseph M. Hendrie Nuclear Engineering Department Brookhaven National Laboratory Upton, New York 11973	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. Herbert S. Isbin Department of Chemical Engineering University of Minnesota Minneapolis, Minnesota 55455	1	Advisory Committee on Reactor Safeguards Dr. Carroll W. Zabel Director of Research University of Houston Cullen Boulevard Houston, Texas 77004	1

DISTRIBUTION (Continued)

	Copies		Copies
Mr. Raymond F. Fraley Executive Secretary Advisory Committee on Reactor Safeguards U.S. Atomic Energy Commission Room 1034-H Washington, D.C. 20545	3	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Col. R.L. Ednie Asst. Director for Army Reactors	1
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Mr. Paul G. Shewmon	1	Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: Mr. M.A. Rosen Asst. Director for Plant Engrg.	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		
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Attn: Dr. L. Baker	1	Atomic Energy Commission Division of Compliance Washington, D.C. 20545 Attn: Mr. L. Kornblith, Jr.	1

DISTRIBUTION (Continued)

	Copies		Copies
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: Mr. S.A. Szawlewicz	5
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. R.R. Newton	1
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. M. Bolotsky	1	Atomic Energy Commission Division of Production Washington, D.C. 20545 Attn: Mr. George B. Pleat	1
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. A.B. Holt	1	Atomic Energy Commission c/o Gulf General Atomic, Inc. P.O. Box 608 San Diego, California 92112 Attn: Mr. Russell H. Ball	1
Atomic Energy Commission Division of Reactor Standards Washington, D.C. 20545 Attn: Mr. R. Waterfield	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: Dr. G. Burley	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: Mr. R. Impara	1	Babcock & Wilcox Company P.O. Box 1260 Lynchburg, Virginia Attn: Mr. Robert Wascher	1
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.N. Sunderman	2
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: Dr. D.L. Morrison	1
Atomic Energy Commission Division of Reactor Development and Technology Washington, D.C. 20545 Attn: A.J. Pressesky	7	Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Mr. S. Paprocki	2

DISTRIBUTION (Continued)

	Copies		Copies
Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attn: Mr. A.R. Duffy	1	IIT Research Institute 10 W. 35th Street Chicago, Illinois 60616 Attn: Mr. E.V. Gallagher	1
Brookhaven National Laboratory Upton, Long Island, New York 11973 Attn: A.W. Castleman	1	Idaho Operations Office Atomic Energy Commission P.O. Box 2108 Idaho Falls, Idaho 83401 Attn: Mr. D. Williams	2
University of California Institute of Engineering Research Berkeley, California 94704 Attn: Prof. V.E. Schrock	1	Liquid Metal Engineering Center c/o Atomics International P.O. Box 309 Canoga Park, California 91304 Attn: R.W. Dickinson	1
University of California Institute of Engineering Research Berkeley, California 94704 Attn: Prof. H.A. Johnson	1	Los Alamos Scientific Laboratory P.O. Box 1663 Los Alamos, New Mexico 87544 Attn: Mr. J.H. Russel, K Division	1
Canoga Park Area Office P.O. Box 591 Canoga Park, California 91305 Attn: Mr. R.L. Morgan RDT Senior Site Rep.	1	MPR Associates, Inc. 1140 Connecticut Avenue, N.W. Washington, D.C. 20036 Attn: Mr. T. Rockwell III Chairman AIF Safety Task Force	1
Combustion Engineering, Inc. Nuclear Division P.O. Box 500 Windsor, Connecticut 06095 Attn: Mr. M.F. Valerino	1	National Bureau of Standards Washington, D.C. 20545 Attn: Dr. C. Muehlhause	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

DISTRIBUTION (Continued)

	Copies		Copies
Oak Ridge National Laboratory Nuclear Safety Information Center P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. Joel Buchanan	1	Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. L. Schwendiman	1
Chemical Technology Division Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. D. Ferguson	1	Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. E.R. Astley, Mgr. FFTF	1
Chemical Technology Division Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee 37830 Attn: Mr. R. Blanco	1	Phillips Petroleum Company P.O. Box 1259 Idaho Falls, Idaho 83401 Attn: Mr. Curt Haire	1
Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: HTGR Safety Program Office	2	Phillips Petroleum Company P.O. Box 1259 Idaho Falls, Idaho 83401 Attn: Dr. S. Forbes	2
Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: Mr. W. B. Cottrell	4	Phillips Petroleum Company P.O. Box 1259 Idaho Falls, Idaho 83401 Attn: Mr. T.R. Wilson	2
Oak Ridge National Laboratory P.O. Box Y Oak Ridge, Tennessee Attn: Mr. P. Rittenhouse	1	Phillips Petroleum Company P.O. Box 1259 Idaho Falls, Idaho 83401 Attn: Mr. N.K. Sowards	1
Pacific Northwest Laboratories P.O. Box 999 Richland, Washington 99352 Attn: Mr. G. Rogers	1	Phillips Petroleum Company P.O. Box 1259 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

DISTRIBUTION (Continued)

	Copies		Copies
San Francisco Operations Office Atomic Energy Commission 2111 Bancroft Way Berkeley, California 94704 Attn: Mr. C.V. Backlund	1	Holmes & Narver, Inc. 828 South Figueroa St. Los Angeles, California 90017 Attn: B. Shimizu	1
Savannah River Laboratories E.I. duPont deNemours and Company Aiken, South Carolina 29802 Attn: Mr. A.H. Peters	1	Mr. Edward T. Wessel Research and Development Center Westinghouse Electric Corporation Beulah Road, Churchill Boro Pittsburgh, Pennsylvania 15235	1
TRW Inc. TRW Systems Group One Space Park Redondo Beach, California 90278 Attn: Dr. D. B. Langmuir	1	William E. Cooper Lesselle and Associates 303 Bear Hill Road Waltham, Massachusetts	1
TRW Inc. TRW Systems Group One Space Park Redondo Beach, California 90278 Attn: Mr. S.M. Zivi	1	Roger W. Staehle Metallurgy Department Ohio State University Columbus, Ohio	1
Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Mr. R.A. Wiesemann	1	Mr. Ralph Jones Division of Reactor Development U.S. Atomic Energy Commission Washington 25, D.C.	1
Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Dr. D. Fletcher	1	Mr. H.K. Marks Room 2N83 Department of the Navy Washington, D.C.	1
Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Dr. E. Beckjord	1	H. Thielsch 140 Shaw Avenue Cranston 5, Rhode Island	1
Westinghouse Electric Corporation Atomic Power Division P.O. Box 355 Pittsburgh, Pennsylvania 15230 Attn: Dr. E. Beckjord	1	Mr. F.M. Moschine Westinghouse Electric Company Atomic Power Department P.O. Box 355 Pittsburgh, Pennsylvania 15230	1
Westinghouse Electric Corporation P.O. Box 19218 Tampa, Florida 33616 Attn: Mr. A. Lohmeier	1	Robert Cloud Bettis Atomic Power Laboratory P.O. Box 79 West Mifflin, Pennsylvania 15122	1
Southern Nuclear Engineering, Inc. P.O. Box 10 Dunedin, Florida 33528 Attn: Mr. Gilbert Brown	1	Professor C.E. Taylor Department of Theoretical and Applied Mechanics University of Illinois Urbana, Illinois	1

DISTRIBUTION (Continued)

	Copies		Copies
Mr. E. Beauchamp-Nobbs U.S. Marine Engineering Laboratory Annapolis, Maryland	1	United Kingdom Atomic Energy Authority Reactor Materials Laboratory Wigshaw Lane, Culcheth Warrington, Lancs. England Attn: R. W. Nichols	1
U.S. Atomic Energy Commission Division of Technical Information Extension P.O. Box 62 Oak Ridge, Tennessee	3		
U.S. Atomic Energy Commission Division of Reactor Licensing Washington, D.C. 20545 Attn: S.S. Pawlicki	1	Atomic Energy of Canada Limited Chalk River Nuclear Laboratories Chalk River, Ontario, Canada Dr. George Pon	1
USAEC Site Representative General Electric Company Sunnyvale, California 94086 Attn: Joel Levy, Senior Site Rep.	1	Mr. Robert D. Wylie Department of Materials Engineering Southwest Research Institute 8599 Culebra Road San Antonio, Texas 78228	1
Mr. B.L. Greenstreet P.O. Box Y Oak Ridge National Laboratory Oak Ridge, Tennessee	1		
Mr. F.J. Witt P.O. Box Y ORNL - Oak Ridge, Tennessee	1	O.A. Kellerman Institut Fur Reaktorsicherheit Der Technischen Uberwachungs Vereine, e.V. 5 Koln - Ehrenfeld, Lukasstr. 90 West Germany	1
Commonwealth Edison Company Dresden Nuclear Power Station Rural Route 1 Morris, Illinois 60450 Attn: H.K. Hoyt	2		
Commonwealth Edison Company System Mechanical and Structural Engineer 72 West Adams Street Chicago, Illinois 60690 Attn: N.A. Kershaw	3	C. A. G. Phillips U.K.A.E.A. Safeguards Division Authority Health & Safety Branch Risley, Warrington, Lancashire England	1