259
11-30-74
NRC-5
F.40 up to Callwell

Dr. # 552

GEAP-10207-36
U.S. NUCLEAR REGULATORY COMMISSION
SEPTEMBER 1976

REACTOR PRIMARY COOLANT SYSTEM PIPE RUPTURE STUDY PROGRESS REPORT NO. 36

APRIL—JUNE 1976

U.S. NUCLEAR REGULATORY COMMISSION
CONTRACT E(04-3)189 PROJECT AGREEMENT 37

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

GENERAL ELECTRIC

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 PIPE RUPTURE STUDY
PROGRESS REPORT NO. 36
APRIL—JUNE 1976**

Approved:

D. H. Imhoff, Manager
Development Engineering

Approved:

J. S. Armijo, Manager
Fuel Materials and Mechanics Development

Approved:

T. L. Gerber, Manager
Applied Mechanics Development

Approved:

D. A. Hale
Project Engineer

Prepared for the
U.S. Nuclear Regulatory Commission,
Metallurgy and Materials Research Branch of
Division of Reactor Safety Research
Under Contract E(04-3)-189
Project Agreement No. 37

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, 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.

Printed in U.S.A. Price ^{3.50}~~\$5.00~~

Copies available from National Technical Information Service
U.S. Department of Commerce, Springfield, VA 22151

BOILING WATER REACTOR SYSTEMS DEPARTMENT • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

GENERAL ELECTRIC

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *leg*

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, 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

	Page
ABSTRACT.....	v
1. INTRODUCTION.....	1-1
2. SUMMARY.....	2-1
2.1 Task K — Effect of BWR Environment	2-1
2.2 Task G — Effect of Sensitization on Type-304 Stainless Steel.....	2-1
3. TASK K — EFFECT OF BWR ENVIRONMENT.....	3-1
3.1 Objective	3-1
3.2 Summary.....	3-1
3.3 Fatigue Crack Initiation (Tasks $K_a + K_b$).....	3-1
3.4 Fatigue Crack Growth Testing in Simulated BWR Water Environment (Task K_d).....	3-1
3.5 Electrochemical Potential Measurements.....	3-5
4. TASK G — EFFECT OF SENSITIZATION — TYPE-304 STAINLESS STEEL.....	4-1
4.1 Introduction	4-1
4.2 Summary.....	4-1
DISTRIBUTION.....	1

ABSTRACT

The pipe rupture study is designed to extend the understanding of failure-causing mechanisms and to provide improved capability for evaluating reactor piping systems to minimize the probability of failures. Following a detailed review to determine the effort most needed to improve nuclear system piping (Phase I), analytical and experimental efforts (Phase II) were started in 1965. This progress report summarizes the recent accomplishments of a broad program in (a) basic fatigue crack growth rate studies focused on LWR primary piping materials in a simulated BWR primary coolant environment, and (b) studies directed at quantifying weld sensitization in Type-304 stainless steel.

1. INTRODUCTION

The Reactor Primary Coolant System Pipe Rupture Study is being conducted for the Metallurgy and Materials Research Branch of Division of Reactor Safety Research, USNRC. This Progress Report No. 36 documents work done in the period April 1, 1976 to June 30, 1976. 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 G — Effect of Sensitization on Type-304 Stainless Steel

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 as follows:

QUARTERLY REPORTS

GEAP-4911	Reactor Primary Coolant System Rupture Study Quarterly Progress Report No. 1, April — June 1965.
GEAP-4984	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.
GEAP-10207-24	No. 24, January — June 1971.
GEAP-10207-25	No. 25, July — September 1971.
GEAP-10207-26	No. 26, October 1971 — March 1972.
GEAP-10207-27	No. 27, April — June 1972.
GEAP-10207-28	No. 28, July — December 1972.
GEAP-10207-29	No. 29, January — June 1973.
GEAP-10207-30	No. 30, July — December 1973.
GEAP-10207-31	No. 31, January — June 1974.
GEAP-10207-32	No. 32, July — December 1974.
GEAP-10207-32	No. 32, July — December 1974.
GEAP-10207-33	No. 33, January — June 1975.
GEAP-10207-34	No. 34, July — December 1975.
GEAP-10207-35	No. 35, January — April 1975.

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.
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-5614	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.
GEAP-10452	Estimating Pipe Reliability by the Distribution of Time-to-Damage Method, March 1972.
GEAP-10763	Low-Cycle Fatigue of Prototype Pipe Components, January 1973.
GEAP-20662	Effect of Constraint and Loading Mode on Low-Cycle Fatigue Crack Initiation — Comparison with Code Design Rules, October 1974.
GEAP-20615	Estimating the Relative Probability of Piping Severance by Fault Cause.
GEAP-21382	Detection of Sensitization in Stainless Steel Using Electrochemical Techniques.

2. SUMMARY

2.1 TASK K — EFFECT OF BWR ENVIRONMENT

Work continued on a topical report summarizing the work done to date on the effect of a BWR primary water environment fatigue crack initiation.

Preparations are nearly complete for two multispecimen, fatigue crack growth tests which will be conducted in a simulated BWR water environment.

2.2 TASK G — EFFECT OF SENSITIZATION ON TYPE-304 STAINLESS STEEL

A topical report summarizing the work done to date was completed.

3. TASK K — EFFECT OF BWR ENVIRONMENT (D. A. Hale, D. Vogelhuber)

3.1 OBJECTIVE

The objective of this task is to generate quantitative data on the effects of a high pressure/temperature water environment on crack initiation and growth under steady and cyclic loads. Typical light water reactor materials are being investigated—Type-304 and -304L stainless steel, Inconel 600 and A-516 carbon steel plus A533 and A508 low alloy vessel steels. Testing is currently being done in a simulated BWR water environment (550°F, 1150 psig, no radiation) and is focused on fatigue crack growth.

3.2 SUMMARY

Work continued on a topical report summarizing the work done to date on the effect of a BWR primary water environment fatigue crack initiation.

Preparations are nearly complete for two multispecimen, fatigue crack growth tests which will be conducted in a simulated BWR water environment.

3.3 FATIGUE CRACK INITIATION (Tasks K_a + K_b)

Work was conducted under Tasks K_a and K_b during previous report periods, to obtain fatigue crack initiation data needed to determine whether existing ASME fatigue design rules adequately account for the effect of a BWR primary water service environment. This work focused on fatigue crack initiation in light water reactor (LWR) primary piping materials (Types-304 and -304L stainless steel, Inconel 600, and A516 carbon steel) with testing done in both a BWR primary water environment (a special test loop at Dresden 1)* and a 500°F laboratory air environment.

A final statistical analysis of all the data obtained under this part of the program was concluded. The topical report, GEAP-20224, incorporating this analysis should be completed during the next report period.

3.4 FATIGUE CRACK GROWTH TESTING IN SIMULATED BWR WATER ENVIRONMENT (Task K_c)

Work continues, under Task K_c , to provide fatigue crack growth data in a simulated BWR primary water environment.**

Two test vessels, accommodating up to 11 1T-WOL test specimens (Figure 3-3), are committed to this program. A schematic of these vessels and the GE environmental test loop which provides the controlled high pressure/temperature water environment for testing is shown in Figure 3-4. This loop is a flowing loop capable of supplying up to 10 gpm of 550°F, 1150 psig water to this vessel while constantly monitoring and controlling the conductivity and oxygen content of the water.

Efforts during the report period were primarily aimed at readying both of the autoclaves, which are available for use with this BWR test loop, for testing. The larger test autoclave, Test Vessel IV (TV-IV), which accommodates eight 1T-WOL specimens, will be used for a long-term, slow frequency test. The eight specimens are listed in Table 3-1. Note that both piping and reactor pressure vessel (RPV) steels are included. All eight specimens will be equipped with capillary holes (Figures 3-1, 3-2) as the primary method for monitoring fatigue crack propagation in each individual specimen.

Two specimens will also be equipped with high temperature/pressure displacement transducers for monitoring the change in specimen compliance with crack length. These transducers will be evaluated to determine whether they have the accuracy and reliability needed to provide specimen compliance measurements during testing. The use of compliance to

*Commonwealth Edison Company, Morris, Illinois.

**550°F, 1130 psig demineralized water, 300 ppb O_2 , conductivity <1 μ mho, no radiation.

Table 3-1
TASK K_d
ENVIRONMENTAL FATIGUE CRACK GROWTH TEST PARAMETERS

Test Environment: 1150 psig, 550°F demineralized water, 300 ppb dissolved O₂, conductivity <1 μ mho

Test Specimen: 0.9T or 1T WOL

I. Slow Frequency Test

Loading Parameters: R Ratio = 0.6, $f = 0.3$ cpm, skewed sawtooth waveshape*

Specimen Layout:

1. T-304 SS, As Received
2. T-304 SS, Furnace Sensitized
3. T-304 SS, Cast
4. T-304L SS, As Received
5. Inconel 600
6. A516 Gr. 70, CS, As Received
7. A508-2 CS, As Received
8. A508-2 CS, Sub Arc Weld HAZ

II. Moderate Frequency Test

Loading Parameters: R Ratio = 0.6, $f = 1.25$ cpm skewed sawtooth waveshape*

Specimen Layout:

1. T-304 SS, As Received
2. A-516 CS, As Received
3. A508-2 CS, As Received

*Special waveform details

Figure 3-1. Capillary Tube Attached Details for 0.9T-WOL Specimen

Figure 3-2. Specimen Details

monitor crack propagation in the WOL specimen is a fairly standard technique used by many investigators. Its success, however, is directly dependent upon availability of transducers suitable for high temperature/high pressure operation. Present plans are to evaluate these particular transducers concurrent with tests planned during the next 6 months. Any compliance/crack growth data obtained will be used to augment the capillary hole data.

The smaller three-specimen autoclave will be used for a moderate frequency test. All three specimens will be equipped with capillary tubes. One specimen will also be provided with an experimental compliance transducer.

Both these tests will begin early in the next report period.

3.5 ELECTROCHEMICAL POTENTIAL MEASUREMENTS (M. Indig)

Electrochemical potential measurements were made during the environmental fatigue crack growth test concluded during the previous report period. Potential measurements were made between four metal working electrodes (see Figures B-2, G-2, GEAP-10207-33) (304 and 304L SS, Inconel 600 and A-516 carbon steel), and a Ag/AcCl reference electrode (GEAP-10207-33, Figure B-2, G-1) using a Digital Voltmeter. These are the same type electrodes previously used to make this same type measurement in the Dresden 1 test loop (see Appendix B, GEAP-10207-33).

These measurements were made over a period of 10 days. The original plans were to make them using a high impedance electrometer; however, the unit would not respond properly forcing substitution of a Digital Voltmeter (DVM). Studies made subsequent to these measurements, indicate that use of the DVM biases the results. The data obtained, though admittedly biased, support the following qualitative conclusions:

1. The initial measurements showed a significant effect of oxygen addition: a shift of approximately +0.18 volts was noted on increasing the dissolved oxygen level in the 545°F, 1150 psig water from 0 to ~200 ppb.
2. The initial corrosion potentials for the four working electrode materials, in 545°F, 1150 psig water, were the same (~0.02 volts referenced to a standard hydrogen electrode).

It also appears that the reference electrode changed on the fifth day of operation when a large, otherwise unexplainable, shift in potential was noted. Further measurements will be required to determine reproducibility before any quantitative correlations can be made.

A new electrometer has been procured and checked out. In addition, several changes in the Ag/AgCl electrode design have been made which should improve its performance. These measurements will be repeated in conjunction with the two previously mentioned simulated, BWR water tests during the next report period.

PART No.	SPEC No.	B	W	C	D	E	F	G	H	L	M	N	O	P	R	S
3	1T-B	1.000 $\pm$ 0.010	2.55	3.200	0.094	0.767	0.650	1.240	2.480	0.050	0.047	0.175 $\pm$ 0.020	0.500 $^{+0.005}_{-0.000}$	—	YES	NO
4	0.9T-B	0.900 $\pm$ 0.010	2.55	3.200	0.094	0.767	0.650	1.240	2.480	0.050	0.047	0.175 $\pm$ 0.020	0.500 $^{+0.005}_{-0.000}$	—	YES	NO

NOTES:

1. 0.007 in. MAX. RADIUS (EDM)
2. LAY MARKS TO FALL PARALLEL TO AXIS OF RADIUS SURFACE FINISH TO BE 32.

Figure 3-3. WOL Specimen for Crack Growth Rate Study

Figure 3-4. Simulated BWR Water Test Loop Schematic

4. TASK G — EFFECT OF SENSITIZATION — TYPE-304 STAINLESS STEEL (W. L. Clarke, J. C. Danko, V. Romero)

4.1 INTRODUCTION

The purpose of this task is to develop a nondestructive field test for evaluating the degree of sensitization (DOS) of welded Type-304 stainless steel. The electrochemical approach utilizes the polarization behavior of a material to evaluate its DOS. This potentiokinetic reactivation method has been described in GEAP-10207-33.

4.2 SUMMARY

A comprehensive topical report (GEAP-21382, "Detection of Sensitization of Stainless Steel Using Electrochemical Techniques") summarizing the results achieved to date was prepared.

Details were finalized for the next phase of this work. Efforts during the next contract year will be directed toward development of a working electrochemical cell and procedures to allow this cell to be evaluated on field type pipe welds.

DISTRIBUTION

Darrell Butcher
General Electric Company
2015 Spring Rd.
Oak Brook, IL 60521

L. F. Coffin
General Electric Company
1 River Road
Schenectady, NY 12345

E. V. Giaquinto, M&P Lab
General Electric Company
1 River Road, Bldg 55-Rm 219
Schenectady, NY 12345

R. E. Hanneman
CR&D, General Electric Company
1 River Rd., Bldg K-1, Rm 3-B4
Schenectady, NY 12345

D. R. Johnson
General Electric Company
1 River Road, Bldg 55-Rm 119
Schenectady, NY 12345

R. B. McCalley
Machinery Apparatus Operation
PO Box 1021
Schenectady, NY 12301

F. S. Rothe
General Electric Company
Fairfield Pouch

N. J. Lipstein
General Electric Company
1 River Road
Schenectady, NY 12345

GENERAL **ELECTRIC**