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AEC RESEARCH AND
DEVELOPMENT REPORT
JULY 1970

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**REACTOR PRIMARY COOLANT SYSTEM
RUPTURE STUDY
QUARTERLY REPORT No. 21
APRIL - JUNE 1970**

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
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**REACTOR PRIMARY COOLANT SYSTEM RUPTURE STUDY
QUARTERLY REPORT NO. 21
APRIL - JUNE 1970**

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1. INTRODUCTION

The Reactor Primary Coolant System Rupture Study is being conducted for the Safety Branch, Division of Reactor Development and Technology, USAEC. This twenty-first quarterly report documents progress for the period of April 1 to June 30, 1970. 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 quarter.

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.

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 A106-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.

2. SUMMARY

2.1 TASK A—PROBABILITY STUDY

A method has been devised for making a preliminary estimate of the probability of full severance occurring in a primary piping system. The method takes into account the various damage mechanisms and the causes and conditions attendant to failures. It assesses completeness of probability information, and identifies any overriding contributions to the probability of severance. The next stage of the analysis will be to obtain initial numbers using the conceptualized structure.

2.2 TASK D—LOW-CYCLE FATIGUE

Fatigue testing was completed on a straight pipe specimen, the first of a series of axially notched assemblies. The plain carbon steel pipe had an internal, machined notch 6 inches long and halfway through the wall thickness. Unexpectedly, the crack that penetrated the wall was oriented circumferentially. Cutting up the assembly for visual inspection revealed a new crack on the inside surface, which lined up with the o.d. crack.

2.3 TASK K—EFFECT OF BWR ENVIRONMENT

2.3.1 Dresden I Test Loop

A replacement motor has been installed in the isolation valve, MOV-1. Installation of the additional piping for the third test vessel was completed. Final preparations for starting up the test loop are underway.

2.3.2 Test Hardware

Assembly of the Fatigue Test Jig with the final group of 150 test specimens was completed. The gap clearances on all 150 specimens were set to load the specimens to the desired levels of strain. The complete assembly was transferred from San Jose to the Dresden I site. The Fatigue Test Jig sustained minor damage during the transfer; the damage was repaired.

Preparations are underway to transfer the Dynamic Test Vessel and fatigue machine equipment into the test loop cubicle inside the Dresden I primary containment building.

2.3.3 Test Specimen Manufacture

Manufacture of all static and dynamic test specimens was completed. Base-line ultrasonic measurements were completed on all the pre-cracked static WOL specimens.

2.3.4 Reference Electrode

For continued electrochemical studies, an Ag/AgCl reference electrode has been proposed, for insertion in the flange immediately downstream of the dynamic fatigue vessel.

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

A method for making a preliminary estimate of the probability of severance in a piping system has been devised.

3.3 PRELIMINARY ESTIMATE OF THE PROBABILITY OF SEVERANCE IN A PIPING SYSTEM

Herein "severance" is regarded as the sudden circumferential parting of a pipe line, or the sudden axial splitting of the line so that a flow area equal to or exceeding the cross-section flow area is created. The method that has been devised for

making the desired preliminary estimate is intended to serve the purposes of giving an appropriate mechanistic structure to the problem, assessing the completeness of probability information available, and identifying any overriding contributions to the probability of severance. The several variables are considered to take on values over two or three discrete ranges or levels. Judgmental probability assignment for the ranges or levels has been used. The distribution of time to damage method developed for estimating the probability of *leakage* used continuous distributions and more advanced analytical methods.

Consideration is given herein to differences between materials, pipe sizes, and periods of reactor service; to stress level and orientation, and whether the stress operates in tension or local bending; to initial crack size (in both length and depth) and orientation; to crack growth as caused by crack size, high stress, high cyclic frequency (relative to frequency of plant shutdowns), brittleness in carbon steel, and material conditions and environments conducive to stress corrosion in stainless steel; to the effectiveness of nondestructive testing; to the relationship of actual stress to the critical stress for severance for a particular crack size; and to whether the outcome is severance, leakage, or no failure.

To reflect properly the restricted circumstances under which many input probabilities apply, the following separate estimate categories were established:

- Size: Large (> 16-inch diameter), small (≤ 16-inch diameter)
- Material: Stainless steel, carbon steel
- Crack orientation: Axial, circumferential
- Period of reactor service: Before startup, first 5 years, last 35 years

It will be possible to make separate estimates of probability of severance for each level of each category.

Because the probability value is small and events causing damage are assumed to occur independently among each other and, at present, among components, the probability of one or more severances is computed as the expected number of severances, using the following conceptual equation:

$$P = \sum N \times L \times E \times G \times F,$$

where

P	=	Probability of severance in the piping system in the chosen service period;
N	=	Number of components (of a material, size, and configuration) in the piping system, based on the reference piping system described in GEAP-5724, "BWR Primary Piping Stresses for System Reliability Analysis;"
L	=	Probability that a stress level occurs in a component;
E	=	Probability that a final crack size occurs in a component;
G	=	Probability that the actual stress level in the component exceeds the critical stress for severance for the final crack size, given both;
F	=	Probability that severance does result, given the conditions of G;

and summation is over the appropriate combinations of terms.

The structure for arriving at the probability estimate is described, first by introducing the idea of fault causes (see Table 3-1a), and then in terms of evaluating each probability term in the foregoing equation. Evaluations of L and E, related to primary fault conditions because the terms appear directly in the equation, are given, followed by evaluations of secondary fault conditions which are related to crack growth. Conditional probabilities, given that related fault causes occur and applicable to individual components on a one-time basis, are assigned to each level of each primary and secondary fault condition, as shown in Tables 3-1b and 3-1c. The absolute probability that any fault condition occurs is the sum of the products of (probability that fault cause occurs) X (probability that fault condition occurs given that fault cause occurs). These products are also given in Tables 3-1b and 3-1c, along with any restrictions of both fault causes and fault conditions to certain levels of the separate estimate categories. Probability terms G and F are evaluated subsequently.

3.3.1 Underlying Fault Causes

As an aid to assigning probabilities to individual fault conditions, 18 "fault causes" were identified and a probability assigned that a component might be subject to each. The fault causes and probabilities are tabulated in Table 3-1a. Also shown are any restrictions of a fault cause to certain levels of the separate estimate categories.

Table 3-1a
FAULT CAUSES AND
SEPARATE ESTIMATE CATEGORIES

Table 3-1a FAULT CAUSES AND SEPARATE ESTIMATE CATEGORIES				FAULT CAUSES																		
				Having been purchased from a marginal raw-material manufacturer	Having been purchased from a marginal piping manufacturer	Being oval (straight sections)	Being oval (elbows)	Having uneven wall thickness (tees)	Having been purchased from a marginal asm fabricator	Being exposed to the elements in transit	Incorrect installation (rerouting)	Unplanned installation and hangar locations	Difficult installation (faulty welding)	Late design changes with unreconciled discrepancies or omissions	Mislocated restraints on pipe whip	Equipment or structures impair flexibility	No fault cause	In-service modification	Frequent local thermal stressing	High-load-non operating conditions (water slugs, etc.)	Use in non-flow legs	
Fault Cause Code				1	2	3	4	5	6 ^a b	7	8	9	10	11	12	13	14	15	16	17	18	
Probability that Fault Cause Occurs to a Component				.1	.1	.03	.03	.03	.1	1	.03	.03	.01	.03	.01	.003	—	.03	.01	.003	.1	
Separate Estimate Categories	Separate Estimate Category Code																					
	Size	Large (> 16 in. diameter)		A1	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.	.	
		Small (≤ 16 in. diameter)		A2	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.	.	
	Material	Stainless steel		B1	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.	
		Carbon Steel		B2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
	Orientation	Axial		C1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
		Circumferential		C2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
	Reactor Service Period	Before startup		D1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
		First 5 years		D2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	X	X	X
		Last 35 years		D3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X	X	X	X
Component Configuration			E	.	.	1	2	3	.	.	.	.	.	.	.	.	.	.	.	.	4	

NOTES:

- All levels of the separate estimate category apply to the fault cause.
X Only the levels marked of the separate estimate category apply to the fault cause.

See subsection 3.3.1 for discussion.

- 1 Straights
2 Ells

- 3 Tees
4 Components in non-flow legs
5 1—Sum of probabilities of other fault causes, if any

Table 3-1b

CONDITIONAL PROBABILITIES FOR STRESS AND THE SECONDARY FAULT CONDITIONS

Variable Code for Total Probabilities		Conditional Probability ¹											Total Probability ²	S.E.C. Exceptions ³		
	Fault Cause Codes ⁴	14														
	Fault Cause Probabilities ⁴	1														
	S.E.C. Exceptions ⁴															
	Primary Fault Condition:															
	Stress Categories ⁵															
L(1,1)	ACCT1	1											1	C2		
L(1,2)	ACHT1	1											1	C2	D1	
	Fault Cause Codes	3	4	5	0	0	11	12	13	15	16	17				
	Fault Cause Probabilities	.03	.03	.03	.03	.02	.03	.01	.003	.03	.01	.003				
	S.E.C. Exceptions	E	E	E						D1	D1	D1				
L(1,3)	ACHB2	.03	1	.1	.03	.03	.03	.3	.03	.03	.1	.01	.0416	C2	D1	E
L(1,4)	ACHB1	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	.1944	C2	D1	E
L(1,5)	AAHT3	0	0	.01	.03	.03	.03	.01	.01	.03	.03	.1	.0046	C1	D1	
L(1,6)	AAHT2	0	0	.1	.3	.3	.3	Δ	Δ	.3	.3	Δ	.0576	C1	D1	
L(1,7)	AAHT1	Δ	Δ	Δ	Δ	Δ	Δ	0	0	Δ	Δ	0	.1738	C1	D1	
	Fault Cause Codes	1	2	a ^{6b}	14	7	18	16								
	Fault Cause Probabilities	.1	.1	.1	*	1	.1	.01								
	S.E.C. Exceptions			A2 A1		B2	D1, E	D1								
	Secondary Fault Conditions: ⁶															
	Transition Temperature															
T(1,2)	T2	.02											.002	B1		
T(1,1)	T1	Δ											.098	B1		
	Sensitization by welding (axial) Y3		.2										.02	A2	B2	C2
T(2,3)	Y2		Δ										.08	A2	B2	C2
T(2,2)	Y1		0										0	A2	B2	C2
	Sensitization by welding (circumferential)															
T(3,3)	Z3			.2 0									.02	B2	C1	
T(3,2)	Z2			Δ .3									.11	B2	C1	
T(3,1)	Z1			0 Δ									.07	B2	C1	
	Surface Cold Work															
T(4,2)	R2				.02								.02	B2		
T(4,1)	R1				Δ								.98	B2		
	Exposure to Elements															
T(5,2)	W2					1							1	B2		
T(5,1)	W1					Δ							0	B2		
	Reactor Environment															
T(6,3)	E3				0		1						.1	B2		
T(6,2)	E2				.5		0						.45	B2		
T(6,1)	E1				Δ		Δ						.45	B2		
	Cyclic Frequency															
T(7,3)	N3				.05			1					.06			
T(7,2)	N2				.02			0					.02			
T(7,1)	N1				Δ			Δ					.92			

NOTES:

1 Conditional probability that fault condition occurs, given fault case.

2 Total probability that fault condition occurs, for a case involving all fault cause codes. The fault causes being approximated as independent and mutually exclusive events, and the sum of conditional probabilities for one fault cause, over the levels of a primary or secondary fault condition, being 1, the sum of Total Probability entries for these levels should be the sum of the conditioning (fault cause) probabilities. If this sum is less than 1 (for the T(2,J) it is 0.1, for example), the remaining difference to 1 is the probability that none of the levels shown for the fault condition applies to a component. Since the complete absence of a fault condition makes no contribution to the tendency for crack growth or severance, no provision is made for these probabilities. Exceptions are by use of

fault cause 14, assigning to it enough probability to make the sum of fault cause probabilities for a case equal to 1, per footnote marked by asterisk. This technique is also used in Table 3-1c for variables T(9,J) and T(10,J).

3 Fault condition applies to all levels of the separate estimate categories except to the level code shown, from Table 3-1a.

4 From Table 3-1a.

5 From Table 3-2.

6 From Table 3-3.

* 1 - sum of probabilities of other applicable fault causes

Δ Conditional probability is (1 - sum of conditional probabilities on immediately higher lines)

See subsections 3.3.2 and 3.3.3 for discussion.

Table 3-1c
CONDITIONAL PROBABILITIES FOR INITIAL CRACK SIZE AND ULTRASONIC DETECTION

Variable Code for Total Probabilities		T(9,J)						T(10,J)						L(2,J)		L(3,J)	
Fault Conditions		Primary												Secondary			
		Initial Crack Size												Not Detected by U/S			
		Axial						Circumferential						Axial		Circumferential	
		Conditional Probability ¹	Total Probability ²	S.E.C. Exceptions ³	Conditional Probability	Total Probability	S.E.C. Exceptions	Conditional Probability	Total Probability	S.E.C. Exceptions	Conditional Probability	Total Probability	S.E.C. Exceptions	Conditional Probability	Total Probability	S.E.C. Exceptions	
Applicable Fault Cause Codes from Table 3-1a		1	2	14				6	10	15	14						
Probability Fault Cause Occurs, from Table 3-1a		.1	.1	*				.1	.01	.03	*						
S.E.C. Exceptions from Table 3-1a										D1							
Crack Size Block Number from Figures 3-1 and 3-2	J= 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	2 ⁴	Δ	Δ	1	.9293	Δ	Δ	Δ	Δ	Δ	1	.9384	C1	1	C1	C1	
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	6 ⁴	Δ	Δ	1	.9293	Δ	Δ	Δ	Δ	Δ	1	.9384	C1	1	C1	C1	
	7	.25	.25	0	.05	.4	.5	.16	0	.05	1	1	1	1	1	1	
	8	.05	.05	0	.01	.032	.04	.013	0	.004	1	1	1	1	1	1	
	9	.01	.01	0	.002	0	0	0	0	0	0	1	1	1	1	1	
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	12	.025	.025	0	.005	.04	.05	.016	0	.005	.1	.1	.1	.1	.1	.1	
	13	.005	.005	0	.001	.0032	.004	.0013	0	.0004	.05	.05	.05	.05	.05	.05	
	14	.001	.001	0	.0002	0	0	0	0	0	.02	.05	.05	.05	.05	.05	
	15	0	0	0	0	0	0	0	0	0	.02	0	0	0	0	0	
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	17	.01	.01	0	.002	.016	.02	.0064	0	.002	.05	.05	.05	.05	.05	.05	
	18	.002	.002	0	.0004	.0016	.002	.0006	0	.0002	.02	.02	.02	.02	.02	.02	
	19	.0005	.0005	0	.0001	0	0	0	0	0	.01	.02	.02	.02	.02	.02	
	20	0	0	0	0	0	0	0	0	0	.01	0	0	0	0	0	
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

- NOTES: 1 Conditional probability that fault condition occurs, given fault cause.
 2 Total probability that fault condition occurs, for a case involving all fault cause codes.
 3 Fault condition applies to all levels of the separate estimate categories except to level code shown, from Table 3-1a.
 4 Blocks 2 and 6 considered as one starting block.
 * 1 - sum of probabilities of other applicable fault causes.
 Δ Conditional probability is (1 - sum of conditional probabilities for all crack size blocks numbered 7 and greater).
 See subsection 3.3.3 for discussion.

Table 3-1d
 CONDITIONAL PROBABILITIES FOR ACTUAL STRESS EXCEEDING CRITICAL, AND FOR SEVERANCE

Variable Code		G(I,J)							F(J)
		Conditional Probability that Actual Stress Exceeds Critical Stress, Given Actual Stress and Crack Size							Conditional Probability that Severance Occurs, Given that Actual Stress Exceeds Critical Stress [Condition of Variable G(I,J)] and Initial Crack Size
		ACCT1	ACHT1	ACHB2	ACHB1	AAHT3	AAHT2	AAHT1	
I =	J =	1	2	3	4	5	6	7	
Axial Crack Size Block Number from Figure 3-1	1	0	0	0	0				0
	2	0	0	0	0				1
	3	0	0	0	0				0
	4	0	0	0	0				0
	5	0	0	0	0				0
	6	0	0	0	0				0
	7	0	0	.5	0				1
	8	0	0	.5	0				1
	9	0	0	.5	0				1
	10	0	0	.2	0				1
	11	0	0	0	0				0
	12	0	0	.1	0				1
	13	0	0	.65	0				1
	14	0	0	.9	.1				1
	15	0	0	.95	.4				1
	16	0	0	0	0				0
	17	0	0	.65	.15				1
	18	.05	.05	.8	.35				1
	19	.3	.3	1	.5				1
	20	.5	.5	1	.7				1
	21	0	0	0	0				0
	22	0	0	1	.3				0*
	23	.6	.6	1	.2				0*
	24	1	1	1	.1				0*
	25	0	0	0	0				0
Circumferential Crack Size Block Number from Figure 3-2	1					0	0	0	0
	2					0	0	0	1
	3					0	0	0	0
	4					0	0	0	0
	5					0	0	0	0
	6					0	0	0	0
	7					.5	0	0	1
	8					.6	.2	0	1
	9					1	.2	0	1
	10					0	0	0	0
	11					0	0	0	0
	12					.3	0	0	1
	13					.8	.3	0	1
	14					1	.6	.1	1
	15					0	0	0	0
	16					0	0	0	0
	17					.9	.6	.2	1
	18					1	.8	.4	1
	19					1	1	.5	1
	20					0	0	0	0
	21					0	0	0	0
	22					1	1	.3	0*
	23					1	1	.8	0*
	24					0	0	0	0
	25					0	0	0	0

* Cracks entering these blocks leak but do not sever.
 See subsections 3.3.4 and 3.3.5 for discussion.

3.3.2 L: Probability of a Stress Level

Reference stress levels were chosen as shown in Table 3-2. Actual stresses were divided, for purposes of probability assignment, into categories related to the reference stress levels, also as shown in Table 3-2. The categories are tensile versus local bending, axial versus circumferential, and arising in cold operation versus hot operation. Actual stresses covering ranges were considered to be uniformly distributed over the ranges. Thus, for example, "AAHT3" is the random variable of "actual axial hot tensile" stress uniformly distributed over the range 54,000 to 72,000 psi and occurring in a component with conditional probabilities shown in Table 3-1b. For all the stress categories, the conditional probabilities assigned—and resulting absolute probabilities—are given in Table 3-1b for variable L(1,J), along with any restrictions to certain levels of the separate estimate categories. Circumferential stresses will operate on axial cracks, and axial stresses will operate on circumferential cracks. For the reactor service periods, only stresses due to pressure will be considered before startup; but pressure, thermal, and nonoperational stresses will be considered for the two service periods during operation.

3.3.3 E: Probability of a Final Crack Size

For the final crack size achieved in a component in the chosen service period, one must consider the probability of an initial crack size for the service period, the probability that such a crack will not be detected ultrasonically, and the effect on growth of stress level and secondary fault causes. Each of these considerations will be discussed in turn.

A distribution of initial crack sizes (in length versus depth) was arrived at by assigning a probability, conditional upon selected fault causes, to each block in Figure 3-1 for axial cracks, and in Figure 3-2 for circumferential cracks. These conditional probabilities are tabulated in Table 3-1c for variables T(9,J) and T(10,J), along with any restrictions to certain levels of the separate estimate categories, and the resulting absolute probabilities are also tabulated in Table 3-1c. The event of the occurrence of an initial crack size within a block is assumed to be uniformly distributed over the block, with total probability equal to the absolute probability just found. The basis for choosing the block sizes is described at the end of this subsection.

A probability that a crack would not be detected ultrasonically, conditional upon its occurrence and selected fault causes, was assigned to each block in Figures 3-1 and 3-2, as shown in Table 3-1c for variables L(2,J) and L(3,J), along with any restrictions to certain levels of the separate estimate categories. The resulting absolute probability for each block is shown in Table 3-1c. The time at which ultrasonic testing was performed was accounted for by the rule that one-half the probability of growing from one block to the next would apply to the first half of the time period, then the probability of no ultrasonic detection was applied, and finally the other half of the probability of growing from one block to the next was applied to undetected cracks in the last half of the time period.

The secondary fault conditions shown in Table 3-3 were identified as contributing to the probability of crack growth, along with stress level and crack size. The conditional probability that each level of each secondary fault condition occurs to a component, given a fault cause, is tabulated in Table 3-1b for variables T(1,J) through T(7,J), along with any restrictions to certain levels of the separate estimate categories.

The effect of secondary fault conditions on crack growth is to be accounted for by a probability that a random crack initially in a block will grow to an adjacent deeper block under the influence of a tensile stress, or to an adjacent longer block under the influence of a local bending stress, both along with the influence of a combination of levels of the secondary fault causes. Provision can be made for a probability of growth to other blocks. A systematic method for assigning a probability for block-to-block growth for all combinations of levels of stress and the secondary fault causes was needed (there are 432 combinations for the maximum case). The two-step method adopted was to form a ranking value for each combination, which is the sum of weights assigned to each level of each variable. These weights were chosen to reflect the degree of effect on crack growth of each level of each variable. These weights are given for the stresses in Table 3-2, and for the secondary fault conditions in Table 3-3. For example, for a combination in which they are included, the highest axial, hot, tensile stress level contributes a weight of 20 to the sum, and the highest sensitization level contributes a weight of 5 times the stress weight, for a subtotal of 120 for the two. The ranking value equation for growing one block in depth due to axial tensile stress in stainless steel pipe, in the first 5 years of service, is as follows:

$$\text{Ranking value} = S + Z + R + W + E + N,$$

where the rank weight codes are identified in Tables 3-2 and 3-3. Other equations apply to other combinations of levels of the separate estimate categories.

Conversion of the ranking values to probabilities was done by selecting certain combinations, assigning to each a probability of crack growth, and noting that these probabilities formed a functional relationship with the ranking values. A satisfactory relationship for the probability, $P \Delta N$, corresponding to the above case was found to be

$$\log_{10} P \Delta N = 3.321 \times \log_{10} (\text{ranking value}) - 8.786.$$

The effect of crack size on crack growth was accounted for by making the crack size blocks for the shallower cracks cover less depth than those for deeper cracks, and correspondingly for length.

Crack-size blocks were chosen for convenience in the length direction: for axial cracks, divisions at lengths of one and three diameters were used, and for circumferential cracks, division at the length of one diameter was used; three diameters, of course, is a full circumference for those cracks. In the depth direction, blocks were defined for less than 0.1 of wall thickness to permit a change in assignment of probability of ultrasonic detection at that depth, which is typical of testing sensitivity. Then another break was taken at 0.3 of wall thickness to provide properly for blocks of increasing range in the depth direction, in accordance with the foregoing paragraph.

3.3.4 G: Probability that Actual Stress Exceeds Critical Stress

To determine the probability that a random actual stress exceeds the critical stress for a random crack size, thus tending to lead to severance, the relationship was examined between actual stress distributions and critical stress distributions revealed by the part-through flaw pipe burst results of Reynolds on Task C of this program, as reflected in Figure 3-2 of the Nineteenth Quarterly Report, GEAP-10143, and modified herein as Figure 3-3 to show the ranges of the stress categories relative to nominal critical stresses. It is assumed for the present that all pipe sizes, both materials, and both axial and circumferential cracks, have the same critical stress diagram for crack sizes in proportion to diameter and wall thickness. The analytical problem of calculating the probability that a random actual stress exceeds the critical stress for a random crack size in a block, for all combinations of actual stress and crack size blocks—the two random variables being uniformly distributed in their respective ranges—was handled by estimating these probabilities by inspection of Figure 3-3. The probabilities are tabulated in Table 3-1d for variable G(I,J).

3.3.5 F: Probability that the Resulting Damage is Severance

The final input required is the probability that severance does occur if the actual stress exceeds the critical stress of a random crack. The simplest assignment has been made for the present: the probability of severance is taken as 1 if actual stress exceeds critical, and as 0 if actual stress is less than critical. These values are assigned to the appropriate blocks for axial and circumferential cracks in Table 3-1d for variable F(J). More detailed consideration will provide some small probability that no failure (by either severance or leakage) will occur if actual stress exceeds nominal critical stress, and also some small probability that severance will occur even if actual stress is less than nominal critical stress, both cases because of variability in critical stress. Some probability of leakage rather than severance can also be provided for some blocks if it becomes clear that steam conditions could prevail which would not produce a running crack upon failure.

3.3.6 Numerical Estimates of Probability of Severance

Numerical estimates using the foregoing structure are anticipated in the following quarter.

Table 3-2
REFERENCE AND ACTUAL STRESS CATEGORIES

Reference Stress:						
Axial Hot:	RAH	(expansion + ½ hoop = 14,000 + 4,000 = 18,000 psi)				
Axial Cold:	RAC	(4,000 psi = ½ hoop)				
Circumferential Hot or Cold:	RC	(8,000 psi = hoop)				
Circumferential Hot (for both sides of elbows):	RCH	(expansion + hoop = 10,000 + 8,000 = 18,000 psi)				
					Rank Weight	
	Level Code		Rank Weight Code	Before Service	First 5 Years	Last 35 Years
Actual Stress:						
			S			
Tensile Stress:						
Axial Hot Tension	AAHT3	$3 \cdot \text{RAH} < \text{AAHT} \leq 4 \cdot \text{RAH}$			20	20
	AAHT2	$2 \cdot \text{RAH} < \text{AAHT} \leq 3 \cdot \text{RAH}$			6	6
	AAHT1	$0 \leq \text{AAHT} \leq 2 \cdot \text{RAH}$			2	2
Axial Cold Tension	AACT1	$\text{AACT} \approx 1 \cdot \text{RAC}$ (negligible)		0		
Cicumferential Hot Tension	ACHT1	$\text{ACHT} \approx 1 \cdot \text{RC}$			1	1
Circumferential Cold Tension	ACCT1	$\text{ACCT} \approx 1 \cdot \text{RC}$		1		
Local Bending Stress:						
Axial Hot Bending	AAHB1	$\text{AAHB} = 0$			0	0
Axial Cold Bending	AACB1	$\text{AACB} = 0$		0		
Circumferential Hot Bending	ACHB3	$\text{ACHB} = 0$ in straights			0	0
	ACHB2	$2\text{RCH} < \text{ACHB} \leq 4 \cdot \text{RCH}$ in elbows			16	16
	ACHB1	$0 < \text{ACHB} \leq 2 \cdot \text{RCH}$ in elbows			2	2
Circumferential Cold Bending	ACCB1	$\text{ACCB} = 0$		0		

NOTE: See subsections 3.3.2 and 3.3.3 for discussion.

Table 3-3
SECONDARY FAULT CONDITIONS

Secondary Fault Conditions and Levels	Level Code	Rank Weight Code	Rank Weight		
			Before Service	First 5 Years	Last 35 Years
Transition temperature:		T			
Temperature at 10 ft-lb by Charpy V $\geq 0^{\circ}\text{F}$	T2		10S	10S	10S
Temperature at 10 ft-lb by Charpy V $< 0^{\circ}\text{F}$	T1		0	0	0
Sensitization by welding (axial, circumferential):		Y, Z			
Highly sensitized	Y3, Z3		5S	5S	5S
Moderately sensitized	Y2, Z2		S	2S	2S
Not sensitized	Y1, Z1		0	0	0
Surface cold work:		R			
Surface cold work $> 40\%$	R2		S	2S	2S
Surface cold work $\leq 40\%$	R1		0	0	0
Exposure to the elements before service (Cl^- , F^-):		W			
Exposed	W2		C*	2C	0
Not exposed	W1		0	0	0
Unfavorable environment chemistry (Cl^- , O_2^-) in service:		E			
Exposed, non-flow line	E3		0	C	2C
Exposed, normal flow line	E2		0	C/4	C/2
Not exposed	E1		0	0	0
Frequency of cyclic loading:		N			
Frequency $> 10/\text{minute}$, stress amplitude $< 0.1 \cdot (\text{actual random stress})$ (high cycle fatigue)	N3		0	S	2S
Frequency $\approx 1/\text{hour}$, stress amplitude = actual random stress (low cycle fatigue)	N2		0	2S	5S
Normal frequency ($\leq 90/\text{year}$), stress amplitude = actual random stress	N1		0	0	0

See subsection 3.3.3 for discussion.

*C = R + Y or R + Z.

Figure 3-1. Axial Crack-Size Blocks

THIS DIAGRAM IS INTENDED ONLY TO ILLUSTRATE RELATIONSHIPS.
SEE SUBSECTION 3.3.3 FOR DISCUSSION.

POSSIBLE STARTING CRACK SIZES — — — — —
POSSIBLE ENDING CRACK SIZES — — — — —

Figure 3-2. Circumferential Crack-Size Blocks

THIS DIAGRAM IS INTENDED ONLY TO ILLUSTRATE RELATIONSHIPS.
SEE SUBSECTION 3.3.4 FOR DISCUSSION.

RCH = RAH

Figure 3-3. Nominal Critical Stresses for Crack Sizes Shown

4. TASK D—LOW-CYCLE FATIGUE (J. D. Heald)

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

4.2.1 Summary

Testing was completed on a straight pipe assembly (Figures 4-1 and 4-2), the first of a series of axially notched specimens to be tested during the current year. The conditions and results of this test are as follows:

Specimen No.	CCANS-80-1
Material	A106 Gr. B carbon steel
Size and schedule	6-inch Schedule 80
Specimen type	Internal axial notch
Test temperature	Room temperature
Internal pressure	1000 psig
Stress range, 0 to 20,400 cycles	60,000 psi
Stress range, 20,400 to 26,934 cycles	90,000 psi
Cycles to initiation (N_i)	Not determined
Cycles to fully penetrate wall (N_W)	26,934
Test termination (N_ϕ)	26,934

4.2.2 Data Obtained

a. Crack Initiation

Since there was some question as to whether or not a sudden fracture might occur, a safety shield was used around the test section. This shield made it impractical to make ultrasonic checks for crack initiation during the test.

b. Leak or Break

Full wall penetration occurred in the pipe at Cycle 26,934. The crack was located on top of the pipe, between the flange weld and the machined notch. The surface crack length when leakage occurred was 1.370 inches and the crack orientation was *circumferential* rather than axial. The crack was located about 1-1/2 inches from the end of the internal flaw—on the higher stressed end toward the flange (see Figures 4-3 and 4-3a). The test was terminated after through-wall failure and leakage had occurred. While it could not be ascertained from the external appearance of the specimen surface whether there was crack growth at the notch, destructive examinations performed showed the presence of a new crack on the inside diameter which lined up with the outside-diameter crack (see Figures 4-3b and 4-3c).

4.2.3 Discussion

The purpose of testing straight pipe with *axial* flaws is to determine whether the fatigue mechanism due to bending will cause crack growth in such a manner as to give rise to a leak or a break failure.

Figure 4-4 makes use of Figure 3-2 from GEAP-10143, Quarterly No. 19, to illustrate the conditions required for axial severance. The initial location of the axial flaw in Specimen No. CCANS-80-1 is shown at point "A" on the diagram.

The gross hoop stress due to internal pressure for this specimen was 7,670 psi and is shown as line CE on the diagram. If crack growth were to occur so as to cause the crack growth line to pass to the left of point "C", a leak-type failure would be expected. If, however, the crack growth line passes to the right of point "C", then a break (axial severance) type of failure would be expected. Also, the probability of a break type failure increases as the distance to the right of point "C" increases.

One of the many possible growth paths is shown as line AD on the diagram. Line AD is a line of constant length-to-depth ratio. Such a path would give rise to an axial severance type failure.

NOTE: RADIOGRAPHIC INSPECT WELDS PER ASME SECTION III PARA. N-624

G2	G1	PART No.	NAME	DESCRIPTION
1	1	1	FLANGE	1500 lb WELD NECK, SCHEDULE 80, CARBON STEEL
	1	2	PIPE	6 in. SCHEDULE 80, CARBON STEEL, 1 ft 6 in. LONG, NOTCHED
	1	3	PIPE	6 in. SCHEDULE 80, CARBON STEEL, 3 ft 6 in LONG
1	1	4	PIPE	6 in. SCHEDULE 80, CARBON STEEL, 15 ft 0 in. LONG
1	1	5	CAP	6 in. SCHEDULE 80, CARBON STEEL
1		6	PIPE	6 in. SCHEDULE 80, 304 STAINLESS STEEL, 1 ft 6 in. LONG
1		7	PIPE	6 in. SCHEDULE 80, 304 STAINLESS STEEL, 3 ft 6 in. LONG

NOTES:

1. ALL CARBON STEEL PIPE PER ASTM A106, Gr B
2. ALL STAINLESS STEEL PIPE PER ASTM A312 TYPE No. 304
3. FLANGES PER ASTM A105, Gr II
4. CAPS PER ASTM A234 WPB

Figure 4-1. Internal Axial Notched Specimen

6 in. SCHEDULE 80 ASTM A106, Gr. B CARBON STEEL PIPE, MATERIAL TO BE SUPPLIED BY GE

NOTES:

1. MEASURE WALL THICKNESS OF PIPE SECTION TO NEAREST 0.001 INCH AT THREE PLACES ON EACH END. MACHINE NOTCH TO A DEPTH OF 1/2 THE AVERAGE WALL THICKNESS ± 0.005 .
2. RECORD AVERAGE WALL THICKNESS AND NOTCH DEPTH TO NEAREST 0.001.
3. ALL SURFACES TO BE PROTECTED IMMEDIATELY FOLLOWING MACHINING USING L.P.S. No. 1.
4. RADIUS AT EACH END OF NOTCH TO BE 1-3/8 INCHES.

Figure 4-2. Test Section Details of Internal Axial Notched Specimen

Figure 4-3. Specimen CCANS-80-1 at Completion of Test—When Leakage Occurred

Figure 4-3a. Actual Size of Outside Diameter-Crack

Figure 4-3c. Actual Size of Inside-Diameter Crack Shown in Figure 4-3b.

NOTE: AXIAL SEVERANCE IS AXIAL OPENING OF PIPE TO AN AREA EQUIVALENT TO THE PIPE CROSS SECTION. A DIAGRAM OF SIMILAR FORM IS REQUIRED FOR CIRCUMFERENTIALLY-ORIENTED CRACKS. THIS DIAGRAM IS INTENDED ONLY TO ILLUSTRATE RELATIONSHIPS.

Figure 4.4. Conditions for Axial Severance

4.3 FUTURE PLANS

Six specimens are planned (the first four will be tested at PWR pressure, 2200 psi). The specimens are described as follows:

Material	Type Notch	Pipe Size	Notch Location
Carbon Steel	Circumferential	6 inch Sch. 160	External
Stainless Steel	Circumferential	6 inch Sch. 160	External
Carbon Steel	Axial	6 inch Sch. 160	Internal
Stainless Steel	Axial	6 inch Sch. 160	Internal
Carbon Steel	Axial	6 inch Sch. 160	?
Stainless Steel	Axial	6 inch Sch. 160	?

The purpose of the low-cycle fatigue tests of the circumferentially notched specimens is to demonstrate whether continued cycling after crack initiation, at PWR operating pressure, will cause leakage or sudden fracture. The first two axial flaw tests will evaluate the low-cycle fatigue mechanism from a fracture diagram point of view, similar to CCANS-80-1 in Figure 4-4. The test conditions for the last two specimens will be decided, based on the results of the other tests.

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 I 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

a. Dresden I Test Loop

A replacement motor has been installed in the isolation valve, MOV-1. Installation of the additional piping for the third test vessel was completed. Final preparations for starting up the test loop are under way.

b. Test Hardware

Assembly of the fatigue test jib with the final group of 150 test specimens was completed. The gap clearances on all 150 specimens were set to load the specimens to the desired levels of strain. The complete assembly was transferred from San Jose to the Dresden I site. The fatigue machine sustained minor damage during the transfer; the damage was repaired.

Preparations are under way to transfer the dynamic test vessel and other test equipment into the test loop cubicle inside the Dresden I primary containment.

c. Test Specimen Manufacture

Manufacture of all static and dynamic test specimens was completed. Baseline ultrasonic measurements were completed on all the pre-cracked static WOL specimens.

5.3 DRESDEN I TEST LOOP

A replacement motor ordered for MOV-1 during the last quarter was installed during the April maintenance outage. The valve was subsequently checked out and accepted for operation at plant operating conditions.

Installation drawings for the test loop main control room alarms were completed and approved by Commonwealth-Edison.

All the additional piping and valves required to allow a third test vessel to be added to the test loop at some future date have been installed. The entire loop was hydro-tested to 1600 psi. The lead shielding for the static test vessel has also been installed.

All the loop operating instrumentation (i.e., flow, temperature, pressure recorders, and transducers) was checked out and recalibrated, where necessary, in anticipation of loop startup.

The dynamic test vessel—with the final complement of 150 fatigue specimens—the specimen failure detection console, and all the miscellaneous equipment required for loop startup and operation were transferred to the Dresden I site early in June. The support fixturing on which the 150 individual pressure switches are mounted was damaged en route to the Dresden site. Necessary repairs were completed late in the report period.

Preparations are under way to transfer the dynamic vessel and associated equipment into the test loop cubicle area located on the 517-foot level of the Dresden I primary containment (Figure 5-1). Plans call for the vessel to be bolted into the loop, insulated and shielded, and ready for operation when the control room alarm wiring installation is completed.

5.4 TEST HARDWARE

5.4.1 Dresden Fatigue Test Equipment

The dynamic fatigue test machine, with the final complement of 150 fatigue specimens, was assembled on the Dresden dynamic test vessel head. Figure 5-2 contains several views of the test machine taken at various stages during the final

Figure 5-1. General Cubicle Layout (No Scale)

assembly. Figure 5-2a shows one of the 25 specimen layers which nest on a common central support shaft. The individual capillary tubes are attached to their respective specimens by a fillet weld which can be seen in the photo. Heavy wall sleeves were installed over the portion of each capillary tube subject to mechanical rubbing; these sleeves can be seen in Figure 5-2b. Also visible in Figures 5-2b and 5-2c are the outer annular plates, spacers, support rods, and threaded machine screws which form the fixed outer annular structure against which the fatigue specimens are loaded. In Figure 5-3, all 150 pressure switches and their associated support fixtures are shown mounted on the top surface of the head; the individual capillary tubes have all been routed through the head via "Conex" sealing glands and are connected to their respective pressure switches.

All test machine parts and fatigue test specimens were double-wiped with reagent-grade acetone to minimize the possibility of any residual chemical contamination. Surgical white-cotton gloves were used by all personnel throughout the assembly procedure, for the same reason.

After installation of the inlet and outlet flow distribution manifolds in the dynamic test vessel (Figure 5-4), the completed fatigue test machine—dynamic test vessel head was assembled to the vessel (Figure 5-5). This complete assembly was filled with high-purity demineralized water (to prevent contamination of the specimens) and pressurized to 1000 psig. The hydraulic loading system was actuated; several full deflection loading cycles were run. (The specimen loading screws were fully retracted to prevent actual loading of the specimens.) The purpose of this "dynamic hydro" was to ensure that all static and dynamic pressure seals remained leaktight under dynamic operating conditions prior to loading the fatigue specimens.

The head assembly was removed from the dynamic test vessel following conclusion of the dynamic hydro. Gap clearances on all the fatigue specimen loading screws were set, based on strain-deflection calibration curves previously run for all four "as-received" material groups. Special fixturing (Figure 5-6) was used to ensure that the final gap settings were within ± 0.0005 inch of the desired values.

Following completion of these final gap clearance adjustments, the hydraulic loading system was again activated. Several full deflection load cycles were run; measurements were made at several points during this dynamic operation to determine whether the desired cantilever deflections were being imparted to the individual fatigue specimens.

Following completion of these measurements, the test machine—head assembly was remounted on the dynamic test vessel and readied for shipment to the Dresden site. The central shaft of the test machine was mechanically blocked to ensure that the fatigue specimens would not be inadvertently loaded by road shock or vibration during transfer to the site. The vessel was then evacuated and backfilled with nitrogen to prevent rusting of the carbon steel test specimens.

5.4.2 "Hi Temp Air" Test Facility

The test facility was raised to full operating temperature (500°F) to verify that the heating equipment functioned properly and to determine whether a reasonably uniform temperature field could be maintained inside the vessel. Actual specimen testing will begin early in the next quarter.

5.5 TEST SPECIMENS

5.5.1 Specimen Manufacturing Program

a. Dynamic Specimens

All the test specimens required for the Dresden test program (150) and for the "air" test program were completed early in the report period.

b. Static Specimens

All the WOL and stress bend specimens required for the Dresden Static Test Program had been machined, heat-treated and, in the case of the WOL specimens, fatigue pre-cracked during the previous quarter.

Special fixturing was designed and fabricated (Figure 5-7) to allow the position of the crack front in the WOL specimens to be monitored using ultrasonic methods. Baseline measurements were completed on all the WOL specimens destined for exposure in the Dresden test loop so that measurements made at any time in the future can be referenced to the initial crack size.

Figure 5-2a. Assembly Detail, Specimen Mounting

Figure 5-2b. Assembly Detail, Near Fatigue Machine Midplane

Figure 5-2c. Detail, Bottom End (Assembly Inverted)

Figure 5-2d. Completed Upper Assembly

Figure 5-2e. Completed Assembly, Ready to Place in Vessel

Figure 5-3. Fatigue Test Machine, Final Assembly

Figure 5-4. Inside View, Dynamic Test Vessel with Flow Distribution Manifolds Installed

Figure 5-5. Overall View, Test Machine—Dynamic Test Vessel Assembly

Figure 5-6. Individual Specimen Gap Adjustment

Figure 5-7. Ultrasonic Test Fixture for Crack Measurement in WOL Specimen

5.6 CRACK GROWTH RATE UNIT

Conceptual designs for the third test vessel and loading system which would be used to stress a string of compact tension specimens in cyclic-load tests have been prepared.

5.7 TASK K-1—ELECTROCHEMICAL STUDY (R. L. Cowan)

5.7.1 Summary

An Ag/Ag Cl reference electrode was proposed for installation in the electrochemical flange immediately downstream of the Task K dynamic vessel.

5.7.2 Theory

The Ag/Ag Cl reference electrode proposed for installation in the flange immediately downstream of the Task K autoclave (Figure 5-8) was developed by the Research & Development Center of General Electric and has been tested successfully under simulated reactor conditions. A stainless steel containment tube will be installed around the electrode and attached to the flange. This electrode will provide thermodynamic data. Present electrode potentials are measured with respect to a bright platinum reference electrode. The potential of this electrode is quite steady with time, but its half-cell potential is not known on the standard thermodynamic scale (Standard Hydrogen Scale). Since the Ag/Ag Cl electrode has been calibrated on this scale by Greeley*, the Ag/Ag Cl electrode can, in turn, be used to characterize the potential of the platinum electrode and the corroding samples on a thermodynamic basis. Hopefully, this information can resolve the difference between E_{corr} values measured in the laboratory and in the test loop flanges. In addition, these potentials should be invaluable in evaluating laboratory stress corrosion data in terms of the actual reactor environment.

* R. S. Greeley, PhD., Dissertation, University of Tennessee, 1959.

Figure 5-8. Silver/Silver Chloride Electrode for Insertion in Electrochemical Flange

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