QUARTERLY TECHNICAL PROGRESS REPORT
HIGH-TEMPERATURE
PIPING DESIGN
TECHNOLOGY
APRIL — JUNE 1976

ERDA Research and Development Report

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Rockwell International

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Program: High-Temperature Piping Design Technology

ERDA Task: 21 - High-Temperature Piping Design

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I. PROJECT OBJECTIVES

The overall objectives of the High-Temperature Piping Design Technology Program are:

- 1) To provide design methodology for elevated temperature piping systems based on experiences in FFTF, LMEC, and CRBRP designs and from operating high temperature piping systems.
- 2) To assess the validity of using current high temperature Code Case 1592 design rules on Piping Systems.
- 3) To investigate critical piping system design problems from the design criteria viewpoint.
- 4) To increase the confidence level in high temperature design rules for piping by demonstrating the conservativeness of these rules.

This project has several major tasks, each supportive of one or more of these overall objectives. One of these tasks is the development and updating of a long-range program plan (PIPLAN) to assure piping integrity for current and future LMFBR plants. This plan will identify:

- 1) The design logic used in identifying PIPLAN program areas and needs.
- 2) The specific tasks required to achieve a high level of piping structural reliability.
- 3) Tasks required in support of a probabilistic assessment of piping integrity.
- 4) A schedule for completion and a definition of work under way for each task.

Another major task of this project is to assess and catalog relevant operating experience and failures in piping of SRE, HNPF, Fermi, EBR-II, SCTL, LCTL, other operating sodium systems and foreign reactors. These data will provide:

- 1) A basis for selecting one of more elevated temperature piping loops which were designed to a less stringent criteria than Code Case 1592, yet have been operating successfully without failures
- 2) Support for piping integrity assessments which have taken the position that low level leakage would precede any large rupture
- 3) Substantiation for judgemental assumptions, with regard to causes and modes of piping failures which must be made in a probabilistic reliability evaluation of piping.

Another major task of this project is to survey sodium piping construction records for defects detected at installation. These data will be assessed and cataloged in a manner which can assist the refinement of probabilistic characterizations of initial defects that may be present in LMFBR primary piping at reactor startup.

Another major task of this project is the Code Case 1592 evaluation of selected sodium piping systems which have been operating successfully, yet were designed to a less stringent criteria than contained in Code Case 1592. The results of both elastic and inelastic analyses will be used to demonstrate, based on actual operating experience, that the design rules contained in Code Case 1592 are conservative.

Another major task of this project is the evaluation of the impact on design margins of variations between actual and assumed material geometry and loading characterizations. This will be achieved through data collection, testing and analysis activities. The results will provide:

- 1) An identification of those design parameters whose variations have the greatest impact on design margins
- 2) Guidance for preparing design specifications, selecting fabrication processes, defining critical tests and establishing dimensional tolerances

- 3) The groundwork for future reliability evaluations of the piping integrity obtainable using the current design codes.

Another major task of this project is the experimental evaluation of the creep-fatigue damage produced by high cycle, small amplitude oscillations in the presence of sustained stresses in the creep temperature range. These data will assist in resolving the current questions on the influence of mean stress on the high cycle fatigue life of Code materials and support extension of the Code Case 1592 fatigue curves beyond 10^6 cycles.

Another major task of this project is the development of simplified analysis methods for elevated temperature piping, and eventually, incorporation of these methods into the applicable design codes for LMFBR piping. Primary emphasis will be placed on the development of appropriate elevated temperature stress indices for piping products currently having low temperature stress indices. Other activities will include development of stress indices for additional piping products and joints commonly employed in sodium piping systems, and development of a simplified method to evaluate and control the effects of local overstrain (elastic followup).

Another major detail of this project is the preparation of interpretive reports presenting a methodology for the design of elevated temperature sodium piping systems. These reports will present practical guidelines for the design and required analysis of LMFBR high temperature piping systems. Emphasis will be given to providing practical data in terms of analytical modeling methodologies and Code evaluation techniques.

The final major task of this project, as presently scoped, is the thermal transient and mechanical testing of piping elbows and bare pipe clamps. The elbow tests are intended to clarify the effect of thermal shock damage on mechanical collapse strength and provide experimental verification of the use of piping stress indices for thin walled elbows typical of LMFBR piping. The bare pipe clamp tests are to provide a benchmark against which analytical modeling techniques can be developed for the clamp-pipe interaction.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1976

A. SUBTASK A - PIPLAN DEVELOPMENT

No activities in support of the Piping Integrity Plan (PIPLAN) were performed during the reporting period.

B. SUBTASK BI - COLLECTION OF PIPING FAILURE DATA

A plan for piping failure data acquisition was released as report N146TI350003. It sets up an extensive survey of U.S. and overseas sodium piping facilities using verbal, written, and in-person communications with identified cognizant personnel. The scope of the data acquisition has been expanded to include the data needs identified for the FFTF. Additionally, the plan establishes a format to be followed in soliciting data and reporting data which is accumulated (see Table 1).

A final draft of an AI report (N246TI350002) presenting all failure data collected prior to May 1976 was completed. However, communications from ERDA (May 6, 1976, Letter from Morabito to Thorne) extended the scope of the required data and the report was not released, pending inclusion of the additional data.

A total of 34 piping failures resulting in sodium leaks were located and the failure causes of one-half of these incidents were identified. None of the identified failure causes are positively attributable to defective piping or occurred as a result of normal operating conditions. Leaks have occurred in piping as a result of chloride stress corrosion cracking induced by diffusion of water through chloride containing insulating material. Holes have also been burned through pipe by faulty weld procedures and by arcs from heater short circuits. Table 2 summarizes the sodium piping failure data collected to date.

A draft of a questionnaire was completed. This draft is to be circulated to sodium facilities within the United States. The questionnaire is designed to acquire operating history and failure data for these facilities.

C. SUBTASK BII - SURVEY OF CONSTRUCTION RECORDS

No activities in support of Subtask BII were performed during the reporting period. This subtask is to be initiated in July 1976.

TABLE 1
 FORMAT FOR REPORTING PIPING FAILURE DATA
 (Sheet 2 of 2)

Item	How Addressed
13. LC Design Basis	Cite ASME code class and criteria, RDT standard, or special cases.
14. QA During Fabrication and Installation of Component Which Leaked.	As specifically as possible.
15. In-service Inspection Applied to LC or Similar Components	Include ISI prescribed and ISI actually implemented.
16. LC Design Conditions	Temperature, pressure, coolant velocity, temperature range, design lifetime, stress.
17. LC Design Environment	Constituents of gas especially oxygen and moisture or impurities in sodium.
18. LC Actual Operating Conditions	Same as Number 16.
19. LC Actual Environment	Include any variations or suspected variations with respect to Number 17.
20. Cause of Leak	Details of cause should be included.
21. Consequences of Leak	State whether sodium fire occurred, extent of corrosion damage (if any), difficulty of cleanup.
22. Correction of Leak	Specify repairs made or if LC was replaced, so state.
23. Changes made in facility operation or changes in components as a result of the leak.	Describe.
24. Special comments	Any comments which provide pertinent data which does not fit in categories above.

TABLE 2
SODIUM PIPING FAILURE SUMMARY

No.	Facility	Pipe Size in. (mm)	Operating Temperature °F (°C)	Total Operating (h)	Facility Feet of Sodium Pipe	Credible on Primary		Failure Cause
						Loop	Pool	
1.	BR-5	X	900(482)	X	X		X	Manufacturing overstress
2.	BR-5	X	900(482)	X	X			Heater short
3.	CCTL (ANL)	X	1150(621)	20,000	120		X	X
4.	C. E. L. No. 1	X	>800(>427)	{ 50,000 12,000 ^(†)	X		X	X
5.	DFR	X	>310(154)	X	X			Extensive stress corrosion
6.	DFR	4	310(154)	131,000 ^(†)	X			Weld
7.	DFR	1	310(154)	X	X			Extensive pitting and corrosion
8.	DFR	3/4(19.05)	310(154)	X	X			Extensive pitting and corrosion
9.	DFR	X	310(154)	X	X			Weld
10.	DFR	2	310(154)	44,000 ^(†)	X			Extensive pitting and corrosion
11.	EBR II	1/2(12.7)	~800(~427)	120,000	{ 277 P 1242 S			X
12.	Fermi	X	X	50,000	{ 909 P 990 S			X
13.	GE	X	X	X	X	X	X	X
14.	GE	X	X	X	X	X	X	X
15.	GPL No. 1	X	X	32,000	250		X	X
16.	GPL No. 2	X	X	18,000	150		X	X
17.	HNPF	X	X	22,000	{ 1500 P 1350 S	X		X
18.	HTSS (AI)	X	X	34,840	250	X	X	X
19.	ITR (LMEC)	X	X	34,944	432	X	X	X
20.	LASL	2-1/2(63.5)	810(432)	13,500	X		X	X
21.	LCTL	3(76.2)	1300(704)	50,000	X			Externally initiated intergranular corrosion
22.	LCTL	1(25.4)	408(209)	60,000	X			Externally initiated intergranular corrosion
23.	MSAR	X	X	X	X		X	Heater arc burn
24.	MSAR	1/2(12.7)	X	X	X			Trace heater failure
25.	MSAR	X	X	X	X	X	X	X
26.	ORNL	X	X	X	X			Corrosion from pipe exterior surfaces
27.	ORNL	X	X	X	X			
28.	PFR	16(406)	X	13,500	X		X	X
29.	Rapsodie	X	X	{ 70,000 P 50,000 S	X			Preheat error
30.	SCTI	10(254)	1300(704)	{ 50,875 1,200 ^(†) 613 ^(†)	650 P 591 S			Inadvertent tack weld
31.	SCTI	2(50.8)	X					
32.	STL	X	X	80,000	75	X	X	X
33.	SRE	2(50.8)	X	72,200	{ 345 P 296 S			Heater short
34.	TTL (HEDL)	X	X	16,000	150	X	X	X
			Totals	~ 10 ⁶	>10,000	26	6	

P = Primary S = Secondary X = Unknown † = Hours to failure = Applicable

D. SUBTASK BIII - ANALYSIS OF SYSTEMS WITH PRIOR SUCCESSFUL OPERATING HISTORY

The Type 316 stainless steel outlet line for the SNAP 8ER reactor was selected for an ASME Code Case 1592 evaluation. It was operated successfully for over 10,000 h with over a year of its life in-service above 1300°F. Its design definition and operational history was reported in N146TI350001. A schematic of this piping line is shown in Figure 1 and a summary of the temperature history is given in Table 3. A plan for evaluating the piping line per Code Case 1592 was released as Report N146TI1250001.

Work was initiated on the formal documentation of a Code Case 1592 elastic analyses of the SNAP 8ER reactor outlet line and preparation for a MARC inelastic analysis of the same line.

E. SUBTASK C - EVALUATION OF SENSITIVITY OF PIPING DESIGN MARGINS TO VARIABILITY IN MATERIALS AND GEOMETRY

The plan for performing a sensitivity study of elevated temperature design margins to variations in material, geometry, and loadings was completed and released as AI Document, N146TI150-001. The efforts will be a combination of data collection, testing, and analysis to be initiated in GFY 1976B, and completed in GFY 1979. The scope of the study will be limited to piping per se (straight pipe, elbows, tees, etc.), and cover dimensional ranges and material selections typical of primary piping in the proposed PLBR and CBR designs. It will quantify, on a failure mode basis, the effect on design margin of variations in those design parameters which affect the piping's tendency to fail or ability to resist failure. A schedule for completing the sensitivity study is presented in Table 4.

F. SUBTASK D - HIGH CYCLE FATIGUE BEHAVIOR AT ELEVATED TEMPERATURE (BNL)

The existing fatigue data with lives greater than 100,000 cycles to failure on 2 1/4 Cr - 1 Mo steel have been reviewed. The data include experiments conducted with temperatures ranging from 77°F (25°C) to 1000°F (538°C). The information will be used in planning the experimental efforts to be conducted in this subtask. Initial interpretations of the data indicate the inelastic

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Figure 1. S8ER Schedule 5 Reactor Outlet Line

TABLE 3
S8ER HOT LEG TEMPERATURE HISTORY

Reporting Period	Temperature Range °F (°C)									Totals
	0 to 200(93)	201(93,8) to 400(204)	401(205) to 600(316)	601(316) to 800(427)	801(427) to 1000(538)	1001(538) to 1200(649)	1201(649) to 1299(704)	at 1300(704)	1301(705) to 1370(743)	
	Time Accumulated in Temperature Range (h)									
<u>1963</u>										
May	0	0	0	0	0	0	0	0	0	0
June	0	186	280	76	92	26	36	0	0	696
July	0	0	0	293	53	55	343	0	0	744
August	252	7	135	245	7	6	92	0	0	744
September	720	0	0	0	0	0	0	0	0	720
October	744	0	0	0	0	0	0	0	0	744
November	426	16	84	100	5	35	54	0	0	720
December	94	121	48	29	151	61	5	193	37	739
<u>1964</u>										
January	0	136	18	75	262	18	52	183	0	744
February	0	206	6	17	43	11	6	105	302	696
March	0	0	0	7	253	20	5	407	52	744
April	0	201	78	31	25	6	0	378	0	719
May	0	0	0	33	497	129	32	53	0	744
June	0	0	0	0	43	4	0	673	0	720
July	0	0	0	0	3	1	0	740	0	744
August	0	0	0	0	0	0	0	744	0	744
September	0	0	3	20	14	8	32	643	0	720
October	0	0	0	0	0	0	0	744	0	744
November	0	0	0	0	0	0	0	720	0	720
December	0	0	0	0	0	0	0	744	0	744
<u>1965</u>										
January	0	0	0	0	0	0	0	744	0	744
February	0	0	0	0	0	0	0	672	0	672
March	0	0	0	0	0	131	0	613	0	744
April	0	0	376	1	2	341	0	0	0	720
May	48	205	491	0	0	0	0	0	0	744
Totals(h)	2284	1078	1519	927	1450	852	657	8356	391	17,514

TABLE 4
SCHEDULE FOR SENSITIVITY STUDY

GFY	76B	1977	1978	1979	1980
Milestones	1	2	3	4	
Phase I - Data Collection and Base Case Selection					
Review piping failure data	_____	_____			
Review piping test data	_____	_____			
Select base cases	_____				
Phase II - Simplified Sensitivity Evaluations					
Establish simplified failure mode models		_____			
Evaluate stress parameter variation		_____			
Evaluate strength parameter variation		_____			
Identify critical design parameters		_____			
Interim Report		_____			
Phase III - Detailed Sensitivity Evaluations					
Establish detailed failure mode models		_____			
Evaluate stress parameter variation			_____		
Evaluate strength parameter variation			_____		
Establish sensitivity of design parameters			_____		
Interim Report			_____		
Final Report				_____	
Phase IV - Verification Testing					
Test Planning			_____		
Prepare AIP and test program			_____		
Testing Efforts			_____		
Interim Report			_____		
Final Report				_____	
Phase V - Safety Margin Definition					
Quantify potential range design parameters			_____		
Characterize safety margins in design codes			_____		
Evaluate "worst case" set of design parameters			_____		
Access adequacy of current design procedures				_____	
Final Report					_____

Milestones

- ▽ - Submit plan for sensitivity study and initiate study
- ▽ - Submit interim report on simplified sensitivity calculation
- ▽ - Submit interim report on detailed sensitivity evaluation and verification testing
- ▽ - Submit final report on sensitivity study.

strain response may be at a small enough level and become cyclically stable soon enough to allow load-controlled testing, provided strain is monitored. The development of an optical strain measurement technique is being considered, as is extended test durations due to a portion or all of the test being performed under strain-control.

One piece (10-1/2 (26.7 cm) x 13-3/8 (34 cm) x 1 (2.5 cm) in. of 2-1/4 Cr - 1 Mo steel plate (Heat 3P5601) was received from the Oak Ridge National Laboratory for use in this subtask. The material was heat treated according to the following specifications:

Austenitize at 1701°F (927°C) $\pm$ 57°F (14°C) for 1 h, cool to 1299°F (704°C) $\pm$ 57°F (14°C) at a maximum cooling rate of 83°C/h, hold at 1299°F (704°C) $\pm$ 57°F (14°C) for 2 h and cool to room temperature at a rate not to exceed 43°F (6°C) min.

Following heat treatment of the material, 34 specimens were machined from the material. Twenty-six of the specimens were taken in the longitudinal direction and eight in the transverse direction of the plate. All specimens were machined to the configuration shown in Figure 2.

Figure 2. Configuration of Test Specimens

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Setup of the experimental apparatus for this subtask has been completed. Experiments will be conducted using a 11.1 kN (2,500 lb) capacity, servo-controlled, electro-hydraulic test system. Specimens will be loaded axially under either load or strain control as appropriate. Strain will be measured using a longitudinal extensometer that operates on a 1.27-cm (0.50 in.) gage length. It consists of two probes of high-purity alumina connected to twin beam supports and hinged by means of a spring steel leaf spring. Changes in axial displacement are mechanically multiplied by a factor of 1.50 before they are measured by a sensitive and magnetically shielded linear variable differential transformer (LVDT)

One experiment has been completed and a second initiated. The test conditions and results of the experiments are summarized in Table 5. The strain range of 0.40% and strain rate of 0.004 s^{-1} were selected for comparison with presently available long-life data in the region of $2 \text{ to } 3 \times 10^5$ cycles to failure. However, the resulting life was about a factor of 10 lower than expected. This may be related to one of several factors: (1) normal data scatter, (2) heat-to-heat material property variation, or (3) test specimen geometry and strain measurement techniques. Possible explanations for this behavior will be explored in future experimental work.

TABLE 5
SUMMARY OF FATIGUE DATA ON ISOTHERMALLY ANNEALED
2-1/4 Cr - 1 Mo STEEL PLATE TESTED IN AIR

Specimen Number	Temperature (°F) (°C)		Strain Rate (s ⁻¹)	Total Axial Strain Range (%)	Stable Axial Strain Range (%)	
					Plastic	Elastic
FL-14	600	316	0.004	0.40	0.11	0.29

Specimen Number	Stable Stress Range		Fatigue Life (Cycles)			Time to Fracture (h)
	(MN/m ²)	(ksi)	N _o	N _s	N _f	
FL-14	606	(87.9)	23,000	26,200	28,400	15.8

G. SUBTASK E – SIMPLIFIED HIGH TEMPERATURE PIPE ANALYSIS

No activities in support of Subtask E were performed during the reporting period. This subtask is to be initiated in October 1976.

H. SUBTASK F – DESIGN METHODS AND CRITERIA FOR LMFBR PIPING

No activities in support of Subtask F were performed during the reporting period. This subtask is to be initiated in April 1977.

I. SUBTASK G – PIPE COMPONENT TESTING

A formal request for Approval-in-Principle (AIP) was given to LMEC to perform piping component testing at the Transient Test Facility (TTF). The proposed testing is to include elbow limit load-thermal transient testing and bare pipe clamp testing. Two phases of testing will be performed: small scale testing first, followed by full size (PLBR and CBR) component tests.

The elbow testing will be initially conducted to assess the behavior under mechanical loads or at slightly below the elbow limit loads. The testing will then be extended to evaluate the effect of thermal transient stress states on the limit load capability.

The bare pipe clamp testing will be used to establish a basis for development of analytical models to predict the clamp-pipe interaction.

III. PROGRESS DURING REPORT PERIOD

This project specifically responds to currently identified tasks in the Piping Integrity Plan. It relates to substantiation and improvement of piping integrity for CRBR, PLBR, and CRB programs.