VALIDATION OF HIGH TEMPERATURE DESIGN METHODS
AND CRITERIA
QUARTERLY PROGRESS REPORT FOR PERIOD ENDING
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SECTION 1 INTRODUCTION

1.0 OBJECTIVES

The objectives of the program are to design and physically test hardware models of increasing complexity necessary to:

1. Determine the inelastic (plastic plus creep) behavior and strain tolerances of 304 and 316 stainless steel base materials and types of configurations under complex stress distributions.
2. Validate inelastic methods of analysis for complex structures already developed or under development by ORNL and others.

1.1 BACKGROUND

This report covers the work performed during the period from March 1, 1972 to May 31, 1972 and is the second progress report since the inception of the program at Westinghouse in November 1971. The program is divided into the following technical tasks:

Project Management (Section 2)

Core Design Methods (Section 3)

Basic Specimen Testing (Section 4)

Tubular Specimen Testing (Section 5)

Structure Testing (Section 6)

Code Validation Analysis (Section 7)

Quality Assurance (Section 8)

This program is directly related to the high temperature design criteria development efforts ranging from the LMFBR and FFTF designers and subcontractors and the national laboratories to code committees and similar groups. ORNL will provide coordination and guidance to the ARD program, which complements and supports the national effort in this field.

1.2 SUMMARY OF TECHNICAL OBJECTIVES

1.2.1 Core Design Methods

The purpose of this task is to document the design criteria for core structural components, exclusive of the reactor vessel and fuel rod cladding. This requires updating of the existing structural design criteria for core structures, the incorporation of the latest material data, and identification of the research and development needs to verify the assumptions on which the design is based.

1.2.2 Basic Specimen Testing

The objectives of this task are to design and physically test uniaxial models of increasing complexity necessary to determine the inelastic behavior and strain tolerances of Type 304 and 316 stainless steel base materials under complex stress distributions.

1.2.3 Tubular Specimen Testing

The objectives of the task are to design and test tubular hardware models of increasing complexity necessary to determine the inelastic behavior and strain tolerances of Types 304 and 316 stainless steel base materials under complex stress distributions.

1.2.4 Structure Testing

The object of this task is to study the interaction of mechanical, pressure, and thermal loads on elbows, tees, pipe, reducers and cross-sectional discontinuities. The configurations are representative of the type of complex structures requiring tests to validate the design methods. It is a basic necessity for the LMFBR program to test and analyze the ability of typical structures to sustain the total strains in creep and fatigue anticipated over the lifetime of each component.

1.2.5 Code Validation Analysis

The objective of this task is to utilize all test data obtained from the other tasks to validate inelastic methods of analysis for complex structures already developed or under development by ORNL and to develop information on inelastic behavior and strain tolerances of Types 304 and 316 stainless steel materials under complex stress distributions.

1.3 SUMMARY OF PRIOR WORK

The original 189a document was submitted in November 1971. A review of the program by RDT and ORNL resulted in modifications and the need for a resubmittal in March 1972. The latest scope represents a coordinated effort which is consistent with the national program for high temperature technology in the design of nuclear energy power plants.

1.3.1 Core Design Methods

A list of material data needing updating and a tentative table of contents for the design criteria were written. The research and development needs to verify the assumptions on which the design is based were identified in a letter released to ORNL in February.

1.3.2 Basic Specimen Testing

The details of the program were formulated, specimens designed, and special furnaces and fixtures ordered. The following two types of tests were initiated:

1. Life tests of the specimen and grid marks
2. Life tests of strain gages

1.3.3 Tubular Specimen Testing

The detailed test plans were formulated, test equipment needs identified, and quotations for two special furnaces and strain measuring systems were received.

1.3.4 Structure Testing

Since standard creep machines limit the size of test specimens, a conceptual layout of a special loading rig was started and preliminary design requirements established. Requests for quotes for some of the hardware were released, and other quotations on the fabrication of elbows, tees and reducers using the standard heat of Type 304 stainless steel were requested.

1.3.5 Code Validation Analysis

Cognizance of the ORNL finite element programs, CREEP-PLAST and EPACA, was maintained; efforts to secure the CREEP-PLAST computer code were initiated; and the manuals for CREEP-PLAST and EPACA were received.

1.4 SUMMARY OF CURRENT PROGRESS

1.4.1 Project Management

The revised 189a, No. 04165, (Old #08619), covering efforts to be performed in FY-1972 was transmitted on March 3, 1972. This revised 189a reflected the modifications to the work scope that were requested by ORNL and RDT. In subsequent meetings on March 10 and April 27, 1972, progress on the approved work scope was reviewed and concurrence was obtained on continuing effort.

The first quarterly progress report covering the work performed during the period from December 1, 1971 to February 29, 1972 was issued.

1.4.2 Core Design Methods

A first draft of the core design criteria has been prepared. The steady state and transient loading conditions for the reactor internals have been updated, based on a recent study of normal, upset and emergency conditions during commercial reactor operation.

Stress, strain and deformation limits of structural core components are being defined for core components in the high and relatively low fluence areas.

Short-time tensile property data for both Types 304 and 316 stainless steels were evaluated and plotted. For the annealed condition, a considerable volume of data has recently become available, so that substantial improvement in the design criteria will result. For the 20 percent cold worked, Type 316 stainless steel, there was much less new information available, especially for the irradiated condition. Such data are being generated, but will not be obtained in time to impact the current effort.

The most recent data on high temperature mechanical properties of Type 304 and Type 316 stainless steel have been compiled and analyzed statistically where quantity and quality of the data were sufficient. All data will be used to establish design curves and the associated confidence limits. A report, which contains the materials data and the design curves, is being prepared.

The design stress and strain limits as a function of irradiation damage have been defined and must be checked against the available material data. A preliminary report containing this information was written. Properties data on irradiated and unirradiated materials were considered. Relevant figures are being drafted and the accompanying text is being typed. Preliminary sets of data and computer-fitted equations have been established.

A final report identifying additional development needs for irradiated materials in structures is in preparation.

1.4.3 Basic Specimen Testing

The A type test* at 21,000 psi stress and 1100°F is in the third stage of creep after 1500 hours.

* Reference First Quarterly Report WARD-3045-T2C-1

A-Type specimen is a flat plate, 1/3-inch-thick, 2/3-inch wide with a 3-inch-long gage length.

The test of another A type specimen, at 10,000 psi stress and 1100°F, is still exhibiting a slightly decreasing creep rate after 1000 hours.

The B type test* of the wide plate specimen at 21,000 psi stress and 1100°F was initiated.

The new split furnace and loading rigs have been received and assembled. Preparation has started for the thermal calibration of the setup.

The suggested welding specifications, procedures, specimens, and material characteristic requirements were submitted on May 16, 1972 in response to the agreements and commitments from the meeting at ORNL on April 27, 1972.

1.4.4 Tubular Specimen Testing

An order was placed with Satec Systems Incorporated for the furnace and extensometer system to measure creep strains.

The specimen design and loading conditions have been established.

Thirty feet of Type 304 stainless steel from the ORNL standard heat was received.

1.4.5 Structure Testing

Conceptual drawings of the test stand, dump tank and test specimens were completed.

Material requirements for fabricating test specimens were submitted on May 16, 1972 in response to the agreements and commitments from the ORNL meeting on April 27, 1972.

The preparation of a System Design Description and a thermal and mechanical design analyses of the Multi-Loading Facility were initiated.

1.4.6 Code Validation Analysis

Both the research and production versions of the ORNL two dimensional, elastic/plastic/creep computer program CREEP-PLAST have been received and conversion to the ARD-CDC 7600 computer was initiated.

The elastic-plastic and creep property data from the standard heat of Type 304 stainless steel have been compared with typical values.

* Reference First Quarterly Report WARD-3045-T2C-1

B-Type specimen is a flat plate, 1/3-inch-thick, 3-1/3 inches wide with a 3-inch-long gage length.

Since the CREEP-PLAST computer code is not yet operational, the work of analyzing the initial test specimens using the Westinghouse code, WRDC-PEPLR has continued.

Individual limit loads and displacements for the proposed structural piping components to be tested in the multiloading test facility were determined.

SECTION 2

PROJECT MANAGEMENT

E. C. Bishop, E. Mullan, J. H. Saling

2.0 OBJECTIVES

The objectives of this task are to assure that the project is successfully completed, on schedule, within budget, and to the satisfaction of the Atomic Energy Commission; to assure compliance with contracted obligations; and to coordinate this project with other AEC-sponsored and Westinghouse-sponsored LMFBR development projects.

Overall project direction and day-to-day administration will be provided under this task. Plans and control will be established and maintained; periodic reviews will be held with the Commission; correspondences and reports will be coordinated; and day-to-day technical and administrative liaison with the Commission will be provided.

2.1 PRIOR WORK

The original proposal submitted in November 1971 was reorganized and modified to be more compatible with the total national effort under the cognizance of the Oak Ridge National Laboratory.

2.2 CURRENT PROGRESS

The revised 189a/Work Plan was submitted in early March 1972. Scheduling and purchasing studies were made to insure completion of this task within the allotted time period and funding limits. The program was redirected in accordance with the notice of reduced funding received on April 20, 1972. A summary of the significant events during the report period is shown in Table 2-1.

Table 2-1. Significant Events During Quarter

EVENTS	MARCH			APRIL			MAY		
PROJECT									
First quarterly report									
Drafted									
To publications									
Review of final document at ARD									
Revised 189a program document released									
Program review meeting at ARD									
Agreements & commitments released									
Program review meeting at ORNL									
Agreements & commitments released									
Release of responses to items 2 & 7									
Received standard heat of plate and pipe from ORNL									
CORE DESIGN METHODS									
Steady state and transient loading condition updated									
First draft of core design criteria completed									
Report identifying material property data and design curves completed									
Report identifying development needs for radiated materials completed									
BASIC SPECIMEN TESTING									
Creep tests of first specimen A initiated									
Creep test of second specimen A initiated									
Creep test of first specimen B initiated									
Two split furnances received									
Welding specifications for test specimen established									
TUBULAR SPECIMEN TESTING									
Standard heat of 304 stainless steel received									
Furnaces, extensometers and controller hardware ordered									
STRUCTURE TESTING									
Conceptual layout of test stand completed									
Conceptual layout of piping components completed									
Assembly layout of test stand completed									
Initiate the preparation of a System Design Description									
CODE VALIDATION ANALYSIS									
Elastic, plastic and creep properties of Type 304 stainless steel reviewed									
Advanced copy of CREEP-PLAST received									
Production version received									
First two flat plate specimens analyzed using WRDC-PEPCR									
Test Condition established for tubular specimen testing in 1973									
Yield and buckling loads for structure test specimens identified									

SECTION 3

CORE DESIGN METHODS

H. Garkisch, J. F. Patterson, P. Soo, K. C. Thomas

3.0 OBJECTIVES

The purpose of this task is to document the design criteria and methods for LMFBR core structural components. This requires updating of the existing Westinghouse Demonstration Plant structural design criteria for the core structure, incorporation of the latest material data, and identification of the research and development needs to verify the assumptions on which the design is based.

3.1 PRIOR WORK

3.1.1 Core Support Structures

On-going research and development for the verification of high temperature design criteria is applicable for the non-irradiated material properties of core structures. For the structures supporting and surrounding the core where the flux is relatively low, a modified elastic-plastic creep analysis, which accounts for the irradiation enhanced creep relaxation, is sufficient. The only additional restraints must account for the reduction in ductility due to irradiation. Type 304 stainless steel is the preferred material for the relatively thick-walled core support structures. Additional development requirements are identified in the following areas:

1. The effect of radiation on the basic material properties.
2. Comparative tests of welds in irradiated and unirradiated conditions are required to determine creep and fatigue behavior and ductility limits of welds.
3. Shakedown loads, ratchetting parameters, and creep buckling behavior of structures inside the reactor due to the enhanced creep and creep relaxation of irradiated material.
4. Sodium and other reactor environment effects on fatigue strength and fracture strength.

3.1.2 In-Core Structures

For components in the high flux region of the core, which includes primarily fuel assembly components, the irradiation induced swelling and creep deformation must be delineated from elastic-plastic creep deformation. The

information obtained so far on these phenomena is from thin-walled fuel rod cladding and very small test specimens. Irradiation swelling and creep correlations have been tentatively formulated from such tests, which allow prediction of the deformation behavior in the core under simple load conditions. Large uncertainties exist in these predictions.

Almost no information is available on how irradiation creep and swelling affect the strength and the ductility of materials. Present thinking is that irradiation induced creep and swelling deformation is not ductility limited. In order to verify this hypothesis additional tensile, creep rupture, and fatigue tests of test specimens are required. Tests have been identified to confirm present assumptions and obtain data on the strength and ductility of material in the core.

Presently, only cold-worked, Type 316 stainless steel is intended to be used as structural material in the core of the Westinghouse LMFBR. The thickness of the in-core structural components ranges from 0.3 inch to 0.01 inch. The thin sections of structural components are affected by the sodium environment which results principally in carbon depletion from the surface. Therefore, metallurgical changes of the structural components must be taken into account by exposing specimens to flowing sodium under conditions which simulate the mass transfer conditions in a reactor.

3.2 CURRENT PROGRESS

3.2.1 Criteria

Design criteria have been prepared to provide guidelines for structural analysis and design of liquid metal fast breeder core components. These design criteria are applicable to temperature and loading conditions where creep effects are significant and where the design and analysis must guard against time-dependent failure modes, and to service conditions where neutron fluence produces significant changes in material properties. Therefore, the methods of analysis and design limits must reflect the dependence of material behavior on both time and irradiation.

The proposed design criteria are similar to the ASME Code Case 1331-5 and FRA 152. The proposed design criteria reflect to some extent the methods presently being used in analyzing core structures.

Since the proposed design criteria provide guidelines for the design of irradiated structures, the design criteria proposed for high temperature design must be expanded where radiation effects have deleterious effects on the structural behavior. This was carried out for the following:

3.2.1.1 Strain Limits

Irradiation reduces the time dependent stress and strain limits because of the following effects:

1. The ductility in a short-term tensile test is reduced, although the yield strength and the ultimate strength are generally increased.
2. The rupture strain in long-term tests is reduced.
3. The time to rupture is reduced.

A design limit of one percent on accumulated material strain caused by primary membrane stress has been set in the ASME Code Case 1331-5 to assure that rupture strains under uniaxial and multiaxial stress states are not exceeded.

For reactor core structures which accumulate significant high energy fluence, the rupture strain due to short-term loading decreases with increasing fluence. A lower limit for rupture strain has not been determined. Since data on irradiated material properties are insufficient to define general strain limits for high fluence levels, the following guidelines for design of LMFBFR components will be used in the interim:

1. Non-replaceable core components which receive fluences below a defined level retain a 10 percent strain limit (uniform elongation) in a short-term tensile test. Damage effects caused by those defined fluence limits are considered in the design limits for ductility limited strain of non-radiated material.
2. For materials of replaceable core components which are irradiated to high fluences, the assumed low limit for time dependent creep strain (ϵ_t) is 0.2 percent ($\dot{\epsilon}_t < 10^{-1}$ in/in/hr). The limiting strain (ϵ_s) for short-term tensile elongation is 0.1 percent.
3. For material of replaceable components which receive fluences greater than the limiting fluences defined for non-replaceable components, tentative long-term strain limits (ϵ_t), short-term strain limits (ϵ_s), will be defined as a function of the fluence. For materials for which no fluence dependent strain limits are given the strain limits of 2 above shall also be used.

Methods for determining irradiation damage are being developed which more properly account for the effects of the flux energy. Preliminary results show that better correlation between fluence of a certain spectrum level and irradiation damage of material properties can be obtained.

Once the irradiation fluence damage of tested materials has been correlated with the fluence spectrum at which the tested materials have been irradiated, different fluence limits can be set for each reactor component depending on the flux spectrum at this location.

3.2.1.2 Stress Limits

The unirradiated ASME Code Time Independent Stress Limits are to be used for both unirradiated and irradiated components. It is recognized that radiation increases the ultimate tensile strength and the yield strength, and decreased the ductility. However, loss of ductility could make the material more susceptible to brittle fracture. Design rules for brittle fracture of irradiated material will be supplied as data become available. In the meantime, an effective increase of the safety factors on the ultimate and yield strengths beyond the values selected by the code will not be considered.

3.2.1.3 Strain and Deformation Limits

Design against gross distortion and fatigue at temperatures where creep effects are significant generally requires an inelastic analysis. However, elastic methods can be used to establish conservative bounds for deformation and to reduce the number of locations in a structure requiring an inelastic analysis. Strains and deformations resulting from specified operating conditions must be evaluated, including ratchetting, interaction between creep and fatigue, and buckling deformations. Preliminary rules for the evaluation of these potential failure modes are described in the ASME Code Case 1331-5; the proposed design criteria generally follows these rules. However, for the analysis of core structures, additional rules are defined which account for irradiation effects on the functioning, dimensional stability, and structural integrity of the reactor components.

3.2.1.4 Ratchetting

The strain limits for structural integrity using elastic analysis are based upon ratchetting criteria. The ASME Code Case 1331-5 requires that the sum of primary and secondary stresses shall not exceed the elastic limits. By limiting the stresses to the elastic range of the Bree ratchetting diagram, plastic deformation is avoided even when cyclic stresses are completely released.

In the proposed design criteria the stresses are also limited to the elastic range if shakedown stresses are significantly relaxed. However, when the residual shakedown stresses relax by approximately 10 percent or less during the average cycle because the temperature is low or the change in thermal cycles is short, the design area on the Bree diagram has been increased. A tentative method is proposed which gives a criteria when stress relaxation is insignificant.

The ratchetting criteria of non-radiated structures may be applicable and even conservative for radiated core components. Since the increased yield strength of such materials is neglected when ratchetting criteria are applied, the effective elastic area of the Bree ratchetting diagram increases. Irradiation creep increases stress relaxation and therefore enhances ratchetting. However, radiation creep is not considered to be ductility limited and does not add to structural damage accumulation.

3.2.2 Multi-Dimensional Stresses and Flow Rules

In inelastic analysis, the following rules are currently being used:

1. The von Mises or the Tresca yield criterion for plastic strain
2. Isotropic plastic hardening for noncyclic loading
3. Bi-linear stress strain curves or a multilinear representation of the temperature dependent stress strain curves
4. Linear superposition of plastic and thermal creep strain, radiation creep strain, and neutron swelling
5. Creep modelled by empirical equations. Changes of stress during creep are generally modelled by a life fraction rule.

For the analysis of non-replacable core structures, the modified kinematic hardening model, which has been proposed by ORNL, will be employed in the future. The kinematic hardening will be applied only when strain cycling occurs. For non-replaceable core components, the analysis will not be different from the other LMFBR system components except that small radiation creep enhancement will be considered in the thermal creep equation.

For replaceable core components, irradiation creep and neutron swelling is significant and must be considered as separate strain components. Neutron swelling is treated as a non-reversible thermal expansion. Irradiation creep increases proportionally with stress. For multiaxial states of stress, the von Mises flow rule is applied to the uniaxial radiation creep equation. This practice may not simulate the actual structural behavior.

3.2.3 Development Needs For Verification of Design Criteria

A separate report is being prepared which identifies the development needs to verify the failure modes discussed above and other failure modes which are effected by radiation (e.g., creep rupture, fatigue failure, buckling, and weld failure). The report discusses the effect of radiation on those failure modes and gives in some cases a justification for the selected design rules. Some alternate design rules are discussed which have not been included in the proposed design criteria because data to support these design rules are not available.

The current practice in analyzing reactor core structures is explained and the tools required to improve the analytical methods are compiled.

3.2.4 Evaluation of Irradiated Material Property Data For Types 304 and 316 Stainless Steels

A report was prepared in which available data for irradiated Types 304 and 316 stainless steels at elevated temperatures were compiled and evaluated.

Recent literature and available technical reports were searched for pertinent experimental data. The general categories of information sought were short-term tensile properties, uniaxial and biaxial rupture strength and ductility, secondary creep rate, irradiation creep, fatigue strength, irradiation-induced swelling, interaction effects of sodium environment, and irradiation on properties. The majority of collected data were for temperatures of 800 or 1200°F. Where new data were supplemental to data previously available, the two sets were examined separately and in the aggregate. Where new data were not found for properties or conditions previously reported in WARD 4135-7, the earlier presentation in that document is still applicable.

In order to ensure validity, guidelines were adopted in selecting appropriate data for analysis. The following criteria were observed in the data selection:

1. MATERIALS

Annealed or solution-treated Types 304 and 316 stainless steels in either the annealed or 20 percent cold worked condition were the only materials considered. Uncertainty as to composition or cold work was grounds for exclusion of the data. Some specimens thermally aged as unirradiated controls were accepted.

2. TEST TEMPERATURE

Data between 800 and 1200°F were accepted. In some cases, test temperatures as low as 700°F or as high as 1560°F were also plotted, but not statistically analyzed.

3. IRRADIATION TEMPERATURE

For tensile properties, irradiation temperatures within 200°F of the test temperature were accepted. For creep-rupture properties, only irradiation temperature within 100°F of the test temperature were accepted.

4. NEUTRON FLUX

Where sufficient data were available, fast flux irradiations were considered exclusively; in other cases it was necessary to utilize data from thermal reactor irradiations, either alone or in conjunction with fast flux data.

5. DATA SEGREGATION

In general, an attempt was made to minimize the number of variable factors represented within a given set of data; additional data sets were then prepared as needed to show the effects of the other variables.

Where the quantity and quality of data were sufficient, the data were analyzed with a multiple regression technique to obtain equations for the mean, with an estimated standard deviation of the dependent variable. The statistically derived equation should not be extrapolated beyond the ranges shown. Being empirical in origin, and not in a theoretically ideal form, the equations provide useful expressions that adequately represent the available data.

In case extrapolation should be unavoidable, better guidance will be obtained from the plotted curves, which represent most probable values estimated independently of the statistical analysis, and thus reflect the incorporation of weight factors not included in the statistical analysis.

The material information compiled in the report is used to define stress and strain limits in structural design criteria for core components.

The available information is insufficient to allow a systematic presentation of data in form of design charts. For any design of irradiated structures, the available material data must be compared with the most recent material data. Also the interpretation of material property damage due to neutron irradiation is currently being revised.

SECTION 4

BASIC SPECIMEN TESTING

N. J. Ettenson, M. Manjoine (Westinghouse R&D)

4.0 OBJECTIVES

The objective of this task will be to design and physically test uniaxial models of increasing complexity necessary to determine the inelastic behavior and strain tolerances of Types 304 and 316 stainless steel base materials under complex stress distributions.

4.1 PRIOR WORK

During the first quarter the details of the program were formulated, specimen design developed, and special furnaces and fixtures ordered.

4.1.1 Specimens

The specimens were designed to conserve the characterized material and facilitate the special processing.

4.1.2 Furnace

Two special split furnaces with observation ports to facilitate photographing the grid lines at temperature during the testing were designed and ordered.

4.1.3 Fixtures

Fixtures for specimen fabrication were fabricated. A fixture for specimen loading and alignment was designed and two units were ordered. With the completion of these units, machines will be available for testing the wide flat plate specimens,

4.1.4 Strain Measurements

LIFE TESTS OF GRID MARKS - A method was developed at the Westinghouse Research Center for measuring the surface strain distributions. This method utilizes a rectangular grid of lines which are applied to the surface without any significant damage. Life tests were initiated to determine the duration of accurate strain measuring ability of these grid lines at 1100°F in air when applied to Type 304 stainless steel. Photographs of the lines exposed at temperature for 2472 hours were clear and well defined.

LIFE TESTS OF STRAIN GAGES - A tensile creep test of a flat plate to evaluate the characteristics of welded strain gages at 1100°F was initiated. Six gages were indicating satisfactorily after 2154 hours, although some drift variations were noted during the first 200 hours. The maximum strain was about 2500 micro-inches.

4.2 CURRENT PROGRESS

4.2.1 Specimen (A)*

4.2.1.1 First Specimen (A1)

Creep tests have been initiated and the results to date are summarized in Table 4-1. Specimen A1 with a gage section of 1/3-inch-thick, 2/3-inch wide, by 3-inch-long is essentially under plane stress. The test stress was 21,000 psi which was selected to give a life of about 2000 hours based on the earlier ORNL data. The actual failure time was 1826 hours and final elongation was about 11.9 percent. A photograph of the fractured specimen (Figure 4-1) shows that the grid lines are about 80 percent readable. The nearly parallel transverse lines verify the uniform stress conditions. The fracture is practically at the middle of the gage length which had an' original constant width and thickness. Numerous grainboundary fissures are near the fracture, but no adverse effect of the grid lines was noted. Measurement of the grid spacing along the gage length will be made on the final photograph and those taken earlier during the interruptions listed in Table 4-1. These interruptions were made by cooling the specimen under load to prevent recovery effects. The specimen was then unloaded and photographed. Reloading was initiated when temperature was re-established. The loading stress-strain curves (Figure 4-2) illustrates the low proportional limit of of this specimen, the elastic behavior on reloading after the strain hardening of the initial plastic flow of 4.66 percent, and the creep straining. No significant break or first stage of creep was measured on reloading.

On the initial loading, the welded strain gage failed after a strain of greater than 9000 micro-inches. (These gages are not intended for strains greater than this.) After the specimen had crept about one percent additional strain after loading (Table 4-1), the test was interrupted and a new welded gage installed. The second loading curve (Figure 4-2) shows that this gage functioned well and gave a good modulus reading. This gage remained operative for about three percent strain, but the gage factor started to change after about 0.9 percent strain. This particular type of welded gage, therefore will not be reliable for strains greater than about one percent. The third loading (Figure 4-2) utilized the overall strain of the indicating extensometer (a motor driven micrometer type).

* Reference First Quarterly Report WARD-3045-T2C-1

A-Type specimen is a flat plate 1/3-inch-thick by 2/3-inch wide with a 3-inch long gage length.

B-Type specimen is a flat plate 1/3-inch-thick by 3-1/3-inches wide with a 3-inch long gage length.

Table 4-1. Summary of Creep Data of Type 304 Stainless Steel at 1100°F
(Specimens from 3/8 Plate of H.T. 9T2796, 2000°F Anneal)

Test Item (Gage Section)	Stress (ksi)	Plastic Loading Strain (%)	(a) Intercept (%)	Creep Rate		Creep Strain		Rupture	
				(%/hr)	@hr	(%)	@hr	@hr	(e)
A1 (1/3 x 2/3 x 3)	21 0	0 66	0 45	2.2×10^{-3}	303	1.10	303 ^(a)	-	-
				2.2×10^{-3}	706	1.99	706 ^(b)	-	-
						2.61	980 ^(c)		
				4.4×10^{-3}	1201 ^(d)	3.02	1201		
						~7.2	1828	1826	~11.9
A2 (1/3 x 2 2/3 x 3)	10 0	0 21	N A.	10^{-4}	1500	0 19	1500	Test in Progress	
B1 (1/3 x 10/3 x 3)	21 0	5 3	N.A.	1.3×10^{-3}	540	1 65	504	Test in Progress	

(a) Intercept at zero time does not include loading strains

(b) Test interrupted for photographic recording

(c) Initiation of third stage of creep

(d) Transition point - creep rate doubled minimum rate

(e) Permanent elongation, plastic & creep

DUMMY GRID
(UNLOADED)
DURING TEST)

Figure 4-1. Basic Specimen (A1) Fractured in
1826 Hours at 21 ksi and 1100°F

Figure 4-2. Loading Curves of Specimen A1, Type 304 Stainless Steel at 1100°F

4.2.1.2 Second Specimen (A2)

The limited range of the welded gage caused a change in the testing program. Since Specimen A2 was already gaged, it was decided to explore the creep indicating capability of the welded gage for longer times. This specimen was, therefore, loaded to only 10,000 psi so that the initial plastic strain would be in the measuring range. On loading (Figure 4-3) the modulus was 19.8×10^6 psi, the proportional limit was about 8000 psi (higher than that shown in Figure 4-2), and the plastic strain at final load was 0.21 percent. An additional 0.19 percent creep has accumulated to date (Table 4-1) and satisfactory readings have been obtained on active and dummy gages so that the drift can be characterized.

4.2.1.3 Comparison of Results From A1 and A2 Tests

The complete loading curves for specimens A1 and A2 are given for comparison in Figure 4-4. This curve illustrates how the small inelastic strains are concealed by the gross strain scale but does confirm the slightly higher yield strength of specimen A2.

4.2.2 Specimen B

4.2.2.1 First Specimen (B1)

Specimen B1 with a gage section of 113-inch thick, 1013-inch wide, by 3 inches long was loaded to 21,000 psi. The plastic strain was 5.3 percent. No welded strain gages were installed. The overall extension is being indicated by strain gage deflectometers at each of the four corners of the flat plate. This specimen will follow a loading cycle similar to Specimen A1.

4.2.2.2 Second Specimen (B2)

Another flat plate specimen (B2) is being prepared for test. It will follow a loading similar to A2 and, therefore, has gages in the gage section as well. The instrumentation (gages, extensometers, grid, and thermocouples) is shown in Figure 4-5, and a close-up of the gage section in Figure 4-6 indicates the location of the gages at the center and the grid lines of 30 per inch.

4.2.3 Test Specimen with Welds

The specifications for welding of specimen blanks were written. The following three welding processes were reviewed:

1. Combustion Engineering process using ORNL designated F21 electrode to weld 1/2-inch thick plate.
2. Commercial Grade 308 filler metal using tungsten arc process to weld 1/2-inch thick plate.

Figure 4-3. Loading Curve of Specimen A2, Type 304 Stainless Steel at 1100°F

Figure 4-4. Loading Curves of Type 304 Stainless Steel at 1100°F HT 9T2796, 2000°F Anneal

5096-5

4-9

Figure 4-5. Instrumentation of Basic Specimen (B2)

5096-6

Figure 4-6. Close-up of Welded Strain Gages and Grid Lines of Basic Specimen (B2)

3. The above Combustion Engineering process to weld one inch plate and machine to the required thickness.

4.2.3.1 Criteria for Process Selection

Each of the three processes exhibit certain advantages and disadvantages which were compared to the program objectives. The criteria for selection were :

1. Process must produce a weldment capable of being described mathematically for use in future computer predictions of test configuration.
2. Process should make maximum use of existing property data, thereby minimizing the effect of cost to fully characterize the weld joint materials.
3. The joint design should represent an LMFB or FFTF weldment.

4.2.3.2 Selected Welding Specification

The Combustion Engineering process using 1/4-inch diameter F21 electrodes was selected. The root opening of the specimen plates will be approximately 3/4 to 7/8-inch wide. The backup strip will be recessed by machining a pocket at the weld joint. The weld rod chemistry and weld procedure are consistent with the matrix property study being performed by R. King at ORNL. This condition corresponds to the outer layer of the FFTF reactor vessel.

4.2.3.3 Weld Procedure

The initial weld should be performed to establish the degree of distortion encountered for each specimen configuration. Using the information, the two plates are to be clamped before welding and the backup strip tack welded to the specimen. The flatness should be targeted to be within 1/2 degree. Since the specimen thickness is greater than 0.3 inch, M. J. Manjoine should be consulted on the flatness which was achieved. After welding, a minimum amount of material will be removed and the weldment will not be heat treated.

4.2.3.4 Specimen Blanks for Transverse Weld

1. Twelve blanks are required
2. Weld joint is to be perpendicular to the direction of rolling
3. Size of each blank is to be 5 x 6 x 1/2-inch with the 6 inch side welded.

4.2.3.5 Specimen Blanks for Axial Weld

1. Six blanks are required
2. Weld joint is to be parallel to direction of rolling
3. Size of each blank is to be 10 x 3 x 1/2-inch with the 10-inch side welded.
4. If distortion occurs in axial direction, weld the center 4 inches and back weld the balance to minimize any out-of-flatness.

4.2.3.6 Specimen Blank for Weld Notched Bars

1. Two blanks are required
2. Weld joint is to be perpendicular to direction of weld
3. Size of each blank is to be 6 x 3-1/2 x 1 inch with the 6 inch side welded

4.2.3.7 Material Characterization

Stress-strain and creep rate data which characterize the weld material over the stress range from 15 to 25 ksi are essential for analyzing and predicting the weld specimen response to uniaxial loads.

SECTION 5

TUBULAR SPECIMEN TESTING

L. S. Heard, R. E. Horner, E. J. Tarby, K. C. Thomas

5.0 OBJECTIVES

The objectives of this task are to design and test tubular hardware models of increasing complexity necessary to determine the inelastic behavior and strain tolerances of Types 304 and 316 stainless steels under complex stress distributions.

5.1 PRIOR WORK

A series of tests will be carried out on biaxially loaded cylindrical tubes to study strain behavior of the base materials and weldments in the creep regime at various temperatures and complex states of stress. These tests will be coordinated with complementary efforts at Babcock and Wilcox and Brown University under sub-contract from ORNL. The ARD program will use Type 304 stainless steel before concentrating on Type 316 stainless steel, including welds and fracture studies.

During the last period, plans were formulated for testing 2-inch OD x 0.1 inch wall tubular specimens having an 8-inch gage length. The samples will be loaded axially by dead weight means and internally by argon gas pressure. Testing will be conducted in a clam shell furnace and will utilize an LVDT extensometer for measurement of creep strains. The two types of loading sequences to be used in the plan will be:

1. Constant load and temperature with varying biaxial stress rates
2. Variable load-time history at constant temperature

5.2 CURRENT PROGRESS

An order was placed with Satec Systems, Incorporated, for the furnace and extensometer system for the measurement of creep strains. The furnace design is an 18-inch-long, three-zone controlled resistance heater. The extensometer set up consists of a quartz rod and tube design used in conjunction with an LVDT having a sensitivity of 2×10^{-5} inch/inch.

The specimen design was detailed (Figure 5-1) and sent to Satec to aid in the construction of the extensometer system.

Thirty feet of pipe from the ORNL standard heat of Type 304 stainless steel was received. Test samples will be machined from this material,

SPECIMEN PROPERTIES

TEST NO.	OUTSIDE DIA (in.)	INSIDE DIA (in.)	WALL THICKNESS (in.)	CROSS-SECTIONAL AREA (in. ²)	D/t
1	2.0	1.90	0.05	0.3063	40
2 THRU 15 (d)	2.0	1.80	0.10	0.5969	20

Figure 5-1. Specimens For Tubular Testing

The test sample dimensions are shown in Figure 5-1. Table 5-1 gives a listing of the loads for the Type 304 stainless steel samples which will be tested.

Test Number	Stress Ratio σ_{θ}/σ_z	Test Duration (hr)	Loads to Obtain Desired Stresses	
			Pressure (psi)	Axial (lbs)
1	0	100	0	7,558
2	0	2000	0	5,969
3	0	2000	0	11,938
4	2.0	2000	1,238	0
5	2.0	2000	1,925	0
6	2.0	2000	2,566	0
7	1.5	2000	1,260	579
8	1.5	2000	1,890	868
9	1.5	2000	2,520	1,142
10	1.0	2000	1,110	1,532
11	1.0	2000	1,667	2,297
12	1.0	2000	2,222	3,063
13a	1.5	500	1,260	579
13b	1.5	500	1,890	868
13c	1.5	500	2,520	1,142
13d	1.0	500	2,222	3,063
14a	2.0	500	1,925	0
14b	1.5	500	1,890	868
14c	1.0	500	1,667	2,297
14d	2.0	500	1,925	0
15a	2.0	500	1,283	0
15b	1.5	500	1,890	868
15c	1.0	500	2,222	3,063
15d	2.0	500	2,566	0

Recent creep data from the standard RDT heat of stainless steel have shown the creep strength to be lower than expected for an average Type 304 stainless steel. It was therefore decided to reduce the first test stress level to 25,000 psi which would give the desired creep strain in approximately 100

hours. Since the upper load limit of the creep machine is 12,000 pounds, the wall thickness of the first test sample will be reduced to 0.05 inch so the cross sectional area will be sufficiently low for the machine capability.

SECTION 6

STRUCTURE TESTING

E. C. Bishop, N. J. Ettenson, F. E. Peters, C. R. Smith

6.0 OBJECTIVES

The object of this task is to study the interaction of mechanical, pressure, and thermal loads on pipe, elbows, tees, reducers, and cross-sectional discontinuities. These configurations are representative of the type of complex structures requiring tests to validate design methods.

6.1 PRIOR WORK

The complementary studies in the other tasks of this program on plates and tubes form the bases for planning the structure test efforts. The function of the multiloading test stand is to provide a facility in which forces can be applied to typical power plant components at temperatures and pressures affecting the creep response of the material. Although selected components have been used as the basis for establishing physical limits of the facility, adaptors and auxiliary loading stands can easily be added for future configurations, such as spheres with nozzles, discontinuities on standard components, and mock ups of multi-component assemblies.

The control system will consist of four independent subsystems: temperature, pressure, mechanical force, and displacement. Similarly, the auxiliary system will include subsystems such as sodium handling, argon cover gas supply, data acquisition, material handling, and safety.

6.1.1 Multi-Loading Test Rig

The final design based on the conceptual drawing was started. Concurrently with this effort, possible long lead time items, including the components for tests, were discussed with vendors.

6.1.2 Hardware Models

A preliminary review for the procurement of hardware made from Types 304 and 316 stainless steel resulted in the receipt of the raw material requirements from two piping component manufacturers.

6.2 CURRENT PROGRESS

6.2.1 Facility

Drawings were completed of: facility concept (3457295), test specimens (ED-SK 345758J), and a detailed layout of selected components to be tested and force actuators mounted to the test stand (7665445). The latter two drawings were reviewed at the ORNL meeting on April 27. Since the configurations listed in Table 6-1 are representative of the size fittings used in the FFTF and LMFBR order. These drawings are being used as the bases for detailed thermal and mechanical analyses of the facility.

Table 6-1. Test Specimen Material to be
Procured From FFTF Orders for Structure Testing

Configuration	Quantity	Material (Stainless Steel)	Nominal Dimensions	
			Diameter (in.)	Thickness (in.)
Elbows	1	316	28	3/8
	1	316	16	3/8
	1	304	16	3/8
	1	304	8	3/8
Tee	2	304	16	3/8
Reducer	2	304	16 to 8	3/8
Pipe	50 f t	316	28	3/8
	50 f t	316	16	3/8
	50 f t	316	8	3/8
	120 f t	304	16	3/8
	100 f t	304	8	3/8

The preparation of a System Design Description was initiated. The contents and format will be in accordance with the latest RDT Standard (F1-2T, March 1972). The document will identify the requirements and describe each of the subsystems shown in the attached schematic "System Flow Diagram", Figure 6-1.

6.2.2 Mechanical Design

The suggestion by ORNL that the test stand should be capable of applying limit and buckling loads to the selected piping components is being reviewed. The loads and displacements were calculated for these conditions and are discussed in Section 7 of this report. The initial conclusions indicate that the complexities introduced into the design through the large loads and displacements exceed the immediate program requirements. The validation

Figure 6-1. System Flow Diagram

of the design methods can be achieved by applying several loads simultaneously on the specimen. The interaction of these various loads, shown in Figure 6-2, will result in lower individual loads to investigate the desired stress distribution. Therefore, the test stand that is presently envisioned will be used to apply loads of sufficient magnitude to assess the adequacy of the design methods. Auxiliary reaction frames can be planned for applying limit loads. Calculations are being performed to evaluate the simultaneous loading matrixes for achieving the limit and buckling conditions. The detailing of the test stand will be done when the results of this study are available,

6.2.3 Thermal Design

Design effort was initiated on the sodium system. The sodium provides a heat transfer medium for maintaining a uniform temperatures over the test specimens operating in a static mode.

A system schematic was developed (Figure 6-3) and a parts list started. The system is equipped with a filter to remove particulates from the sodium before entering the test article. The capability of replacing the filter is provided by isolation and bypass valves. An automatic valve is placed in the dump line to ensure immediate draining of the test article in the event of an accident. To prevent delays in dumping, the cover gas system is provided with automatic valves which cut the high pressure gas supply, vent cover gas pressure over test article and dump tank, and equalizes cover gas pressures in the test specimen and dump tank.

Check valves have been added to the automatic vent lines to prevent air contamination in the test article or dump tank during an automatic venting operation. Since vapor traps can become plugged, spare traps are provided and differential pressure (AP) transducers will automatically open the spare traps in the event of a plug, thus ensuring a free path in the cover gas system.

A preliminary alarm action control has been included to monitor smoke, temperature, and pressure with the following devices:

Smoke:	Open dump valve Vent pressure off test specimen and dump tank Audio/visual alarm Turn off main heater Close high pressure supply line Equilibrate pressures
High Temperature:	Turn off main heater Audio/visual alarm Vent test specimen pressure
High Pressure:	Audio/visual alarm Vent test specimen Close high pressure supply line Equilibrate pressure with dump tank.

Figure 6-2. Moment Vector Loadings on Components

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Figure 6-3. Sodium System Schematic For Multi-Load Test Stand

High AP between Audio/visual alarm
Specimen and Open auxiliary specimen vapor trap
Vapor Trap:

High AP between Audio/visual alarm
Dump Tank and Open auxiliary dump tank vapor trap
Vapor Trap:

A dump tank for the facility has been designed (drawing 628F733) to handle the maximum possible conditions to 1000°F and 100 psig while normally operating at 300°F and 10 psig.

An analysis on the load rod has been performed to determine the temperature profile along the rod. With six inches of insulation, a total rod length of 16 inches is sufficient to insure that the load cells on the load rods would operate at less than 270°F.

Analysis of the cooling characteristics of the test specimen has been performed assuming a straight cylindrical geometry. The resulting characteristics for a 28 inch diameter test piece at 1100°F appears in Table 6-2.

Pipe Size (in.)	Insulation Thickness (in.)	Specimen Temperature after 1 Hour (°F)
28	3	1079
28	2	1071
28	1	1052
28	0	899

Stress analyses on possible piping layouts were performed using the WESTDYN computer code. Due to the nature of the test, a piping run with 12 inch movement in any one direction has been studied. To date, a suitable configuration has not been selected.

SECTION 7

CODE VALIDATION ANALYSIS

J. J. Buggy, R. M. Mello

7.0 OBJECTIVE

The objective of this task is to utilize all test data obtained in the over-all program to:

1. Validate inelastic (plastic plus creep) methods of analysis for complex structures already developed or under development by ORNL.
2. Develop information on inelastic (plastic plus creep) behavior and strain tolerances of Types 304 and 316 stainless steel materials under complex stress distributions.

7.1 PRIOR WORK

A review was conducted to identify material response formulation and material property needs which are critical to the application of the analytical methods. At the request of the Hanford Engineering Development Laboratory, ORNL has prepared a document (ORNL-TM-3602^[1]) which provides the currently recommended constitutive equations for inelastic design analysis for Types 304 and 316 stainless steels. These constitutive equations will be used in the initial applications of CREEP-PLAST and EPACA at ARD. Since initial test specimens will be fabricated from the ORNL standard heat of Type 304 stainless steel, required material properties for analysis must be obtained from this heat. The quarterly report ^[2] issued by ORNL contains all the material property data for the Type 304 standard heat obtained to date.

The ORNL finite element programs - CREEP-PLAST (Rashid) and EPACA (Zudans) - were discussed and reviewed at a joint ARD-ORNL meeting at ORNL. The CREEP-PLAST code has been completed and the final versions delivered to ORNL. ORNL agreed to make the code available to ARD after some preliminary checkout. The final version of EPACA will not be ready until June, but a draft of the User's Manual has been obtained. Due to the delay in receiving the ORNL code, CREEP-PLAST, and by agreement with ORNL, ARD began to analyze the initial test specimens to be tested by Westinghouse R&D using the Westinghouse proprietary inelastic computer code, WRDC-PEPCR.

7.2 CURRENT WORK

7.2.1 ORNL Finite Element Codes

Both the research and production versions of the ORNL two-dimensional, elastic/plastic/creep computer program CREEP-PLAST have been received. All attempts to get the research version adapted to the Westinghouse CDC 7600 computer have failed. The problem is in the format of the magnetic tape containing the program rather than in the preparation or condition. It was decided that no attempt would be made to recopy the research version of CREEP-PLAST, since the production version was available from ORNL. The production version of CREEP-PLAST was written for the UNIVAC 1108 computer and is more easily converted to the CDC 7600 than the research version which was written for the IBM 360. The production version is geared to the more efficient handling and solution of realistic problems at the expense of less versatility with respect to the constitutive equations than can be handled in the research version.

An effort is now underway to convert the production version of CREEP-PLAST to the Westinghouse CDC 7600 computer system. Since the active storage core of the CDC 7600 is smaller than for the computer for which the program was originally written, core overlays are required. To date, the code has been compiled on the CDC 7600 and an overlay scheme is being prepared in order to load the program on the computer. Once loading has been accomplished, then execution of the program can be attempted. Test cases and example problems will be run after conversion to the CDC 7600.

7.2.2 Material Properties

Data on the elastic-plastic and creep properties of Type 304 stainless steel have been reviewed and will provide a bases for material behavior input needs for the inelastic computer codes to be used. The stress-strain and creep-time curves for the RDT standard heat of Type 304 stainless steel (heat 9T2796) at 1100°F have been determined from the limited experimental data collected to date at ORNL (reference ORNL-TM-3736[2] and ORNL-TM-3550[3]). Comparisons are shown in Figure 7-1 between the stress-strain curves for the standard heat and typical Type 304 stainless steel values. Note that the yield strength is lower and the elastic-plastic deformations are larger for the standard heat. The re-annealing treatment for the purpose of standardizing the material properties of the standard heat contributes to these values.

Using the Blackburn equations,^[4] the creep curves for Type 304 stainless steel have been generated and compared to the experimental data for the standard heat. Figures 7-2 and 7-3 show that the creep resistance of the standard heat has been reduced drastically from that predicted by the Blackburn creep equations. The large elastic-plastic and creep deformations of the standard heat will cause difficulty in trying to measure deflections of the test specimens with strain gages.

To carry out meaningful analyses, proper formulation of the standard heat material behavior must be determined. For the Westinghouse code, WRDC-PEPCR, this is no problem since material behavior can be input in curve form.

Figure 7-1. Type 304 Stainless Steel Stress-Strain Curve at 1100°F

Figure 7-2. Creep Curves for Type 304 Stainless Steel at 1100°F

Figure 7-3. Creep Curves for Type 304 Stainless Steel at 1100°F

7.2.3 Specimen Analysis

Since the ORNL code, CREEP-PLAST, is not yet operational, ARD has continued the work of analyzing the initial test specimens using the Westinghouse code, WRDC-PEPCR. The standard heat elastic-plastic and creep properties have been input into the code in curve form. Analyses of the first two flat plate specimens (1/3 inch x 2/3 inch x 3 inch and 1/3 inch x 4 inch x 3 inch) with monotonic increasing load have been carried out.

The finite element models of the two specimens are shown in Figures 7-4 and 7-5. Each model represent a quarter segment of the specimen. This can be done since any part of the specimen may be considered as cut away and analyzed as a separate entity while retaining the effect of the whole specimen by applying the proper boundary conditions at the cuts. For the two models, appropriate boundary conditions were applied along the horizontal and vertical cuts to retain the structural behavior of the complete specimen.

Along the top edge of the models, the uniaxial load on the test specimens is applied as a uniform distributed load. Also the top edge is restrained laterally to account for the effects of the rigid clamping of the specimen by the test machine attachment grips. By restraining the top edge of the specimen, a biaxial stress state is introduced in the specimen. Near the restrained edge this biaxiality is the greatest, and it decreases as one moves away from the restrained edge. For the first specimen, the biaxiality ratio is reduced essentially to zero at the centerline or midpoint of the test specimen. Figures 7-6 and 7-7 show the stress results for this specimen for an equivalent stress level of 10,000 psi after a 500 hour period. These results confirm the uniaxiality of the test specimen at its midsection.

Figures 7-8 and 7-9 show the stress results for the second specimen after a 500 hour period. The state of biaxial stress produced by restraining the top edge of this specimen is retained through a greater length of specimen, but is reduced to approximately 5 percent at the mid-section of the specimen. Further analysis of the wide plate specimen for stress levels between 10,000 to 21,000 psi applied for a 500 hour noninterrupted time period shows that there is little stress redistribution in the specimen as the stress level is increased.

7.2.4 Test Support

Limit loads and displacements for the proposed structural components to be tested in the multi-loading test facility were determined. These loads were to be used to design for necessary strength capabilities for the facility and to select proper test equipment and instrumentation. In most cases, these limit loads would exceed limits allowed by Code Case 1331-5^[5] for the individual components.

The limit (collapse) loads for the straight pipes, elbows, tee, and reducer were based on the assumption of an elastic-perfect plastic material. The tensile yield stresses used were based on the 0.2 percent offset values obtained from uniaxial stress-strain curve for Type 304 stainless steel at

X
TEST 2 CREEP-RUPTURE FLAT PLATE W/T=10

ELEMENT GEOMETRY NODAL POINT

Figure 7-5. Finite Element Model, Specimen B
5096-15

NO,	STRESS
1	0
2	750
3	1500
4	2250
5	3000
6	3750
7	4500
8	5250
9	6000
10	6750
11	7500
12	8250
13	9000
14	9750

X
TEST 1 CREEP-RUPTURE FLAT PLATE W/T=2

Figure 7-6. Specimen A, Axial Stress Contours
5096-16

X
TEST 1 CREEP-RUPTURE FLAT PLATE W/T=2

**Figure 7-7. Specimen A, Transverse Stress Contours
5096-17**

**Figure 7-8. Specimen B, Axial Stress Contours
5096-18**

NO.	STRESS
1	-4000
2	-3500
3	-3000
4	-2500
5	-2000
6	-1500
7	-1000
8	-500
9	0
10	500
11	1000
12	1500
13	2000
14	2500
15	3000
16	3500
17	4000
18	4500
19	5000

TEST 2 CREEP-RUPTURE FLAT PLATE W/T=10

X STRESS

Figure 7-9. Specimen B, Transverse Stress Contours
5096-19

room temperature and at 1100°F. To obtain the torsion limit loads, the von Mises yield criteria were used.

Table 7-1 gives the limit loads in bending, torsion, axial loading (buckling is excluded) and internal pressure for the three sizes of pipe. Tables 7-2 and 7-3 give the limit loads for the elbows, tee and reducer. Presently, there is no general accepted analysis method to determine limit (collapse) bending moments for curved pipe. From some limited test data, a very conservative estimate is that the collapse moment is 4/3 of the moment to produce a local bending stress of the material. Hence, the limit loads for curved pipe are estimated by dividing the straight pipe values by the ASME Code B₂ factor. The same is true for limit internal pressures.

Table 7-2 gives the rotations and displacements of the test elbows under room temperature limit bending moments. The flexibility of the elbows is accounted for by reducing elbow stiffness. Values are given under the assumption of pure elasticity and also under the assumption that the elbows have yielded completely. The probable deformation will be in between these values.

Test conditions were determined and reported for the specimens given in the tubular test matrix proposed by ORNL on April 27, 1972. Table 7-4 gives the test conditions for all the proposed specimens. Effective stress, stress ratio, hoop stress, axial stress, and expected strains are given for each test, assuming that the standard heat material will be used. By definition, the effective stress is the same as the von Mises yield function and it serves the purpose of correlating a multi-state of stress to a single curve of stress versus strain (uniaxial tensile curve). Table 5-1 has presented the pressure and axial loads required to obtain the desired hoop and axial stresses in each specimen.

7.3 References

1. "Currently Recommended Constitutive Equations for Inelastic Design Analysis of FFTF Components," ORNL-TM-3602 (Draft), ORNL, Oak Ridge, Tennessee, October 15, 1971.
2. W. L. Greenstreet, J. M. Corum, and C. E. Pugh, "High-Temperature Structural Design Methods for LMFBR Components, Quarterly Progress Report for Period Ending December 31, 1971," ORNL-TM-3736, March 1972. (Distribution of the document is limited to AEC offices and AEC contractors)
3. P. Patriarca, "Fuels and Materials Development Program Quarterly Progress Report for Period Ending September 30, 1971," ORNL-TM-3550, December, 1971.
4. "Materials Design Handbook," WARD-44. (Westinghouse Advanced Reactors Division, Proprietary Class 11).
5. "Nuclear Vessels in High Temperature Service," Interpretations of ASME Boiler and Pressure Vessel Code, Case 1331-5, August 4, 1971.

Component	At Room Temperature			
	M _L (in.-lb)	T _L (in.-lb)	P _L (lb)	P _L (psi)
28 in. SCH 20	8,585,000	7,788,000	976,000	815
16 in. SCH 30	2,747,000	2,491,000	552,000	1,440
8 in. SCH 60	766,000	694,000	292,000	2,730
	At 1100°F			
	M _L (in.-lb)	T _L (in.-lb)	P _L (lb)	P _L (psi)
28 in. SCH 20	4,189,000	3,801,000	476,000	398
16 in. SCH 30	1,341,000	1,216,000	269,000	703
8 in. SCH 60	374,000	338,400	142,500	1,330

$$T_L \text{ (Limit Torsional Moment)} = \frac{2\pi}{\sqrt{3}} tr$$

$$P_L \text{ (Limit Axial Load)} = 2\pi tr S_Y$$

$$P_L \text{ (Limit Pressure Load)} = t/r S_Y$$

AND t = pipe thickness (0.375 in. ALL CASES)

r = pipe mean radius

S_Y = pipe material yield strength

Note: Each Limit Load is Calculated, Assuming Applied by Itself.

Component						
	M _L (in-lb)	TL(in-lb)	P _L (lb)	P _L (psi)		
28 in. SCH 20	1,113,000	1,009,600	--	655		
16 in. SCH 30	524,200	475,400	--	1,160		
8 in. SCH 60	215,800	195,500	--	2,150		
28 in. SCH 20	At 1100°F					
	543,000	492,700	--	320		
	255,900	232,100	--	565		
	105,350	95,330	--	1,050		
Component	Elastic Deformations			Plastic Deformations		
	Rotation (degrees)	Vert. (in.)	Horiz. (in.)	Rotation (degrees)	Vert. (in.)	Horiz. (in.)
28 in. SCH 20	1.030	1.356	0.297	9.640	12.891	2.591
16 in. SCH 30	0.905	0.696	0.159	8.060	6.347	1.248
8 in. SCH 60	1.065	0.829	0.175	6.657	5.674	0.600

$\overline{B}_2$

$$P_L = \frac{1}{\overline{B}_1} (P_L) \text{ Straight Pipe}$$

where B_2 , B_1 = stress intensity factors from Section III, ASME Code

Table 7-3. Standard Tee And Reducer Limit Loads

Component	At Room Temperature			
	M _L (in.-lb)	T _L (in.-lb)	P _L (lb)	P _L (psi)
16 in. Tee	722,000	654,000	--	1,440
16 in. x 8 in. Reducer*	766,000	694,000	292,000	1,440
At 1100°F				
16 in. Tee	352,400	319,000	--	703
16 in. x 8 in. Reducer*	374,000	338,400	142,500	703
Values based on straight pipe values				

Table 7-4. Conditions for Tubular Test

Test Number	Effective Stress* (psi)	Stress Ratio (σ_{θ}/σ_z)	Hoop σ_{θ} (psi)	Axial Stress (psi)			% Effect Creep Stain	% Effect Elastic + Plastic Strain
				σ_z^P	$\sigma_z^T=$	Total		
1	25,000	0	0	0	25,000	25,000	2.	5.8
2	10,000	0	0	0	10,000	10,000	0.145	0.16
3	20,000	0	0	0	20,000	20,000	3.18	3.5
4	10,000	2.	11,547	5,774	--	5,774	0.145	0.16
5	15,000	2.	17,321	8,660	--	8,660	0.73	1.60
6	20,000	2.	23,094	11,547	--	11,547	3.18	3.50
7	10,000	1.5	11,339	5,670	1,889	7,559	0.145	0.16
8	15,000	1.5	17,008	8,504	2,835	11,339	0.73	1.60
9	20,000	1.5	22,678	11,339	3,730	15,119	3.18	3.50
10	10,000	1.	10,000	5,000	5,000	10,000	0.145	0.16
11	15,000	1.	15,000	7,500	7,500	15,000	0.73	1.60
12	20,000	1.	20,000	10,000	10,000	20,000	3.18	3.50
13a	10,000	1.5	11,339	5,670	1,889	7,559	0.091	0.16
13b	15,000	1.5	17,008	8,504	2,835	11,339	0.360	1.60
13c	20,000	1.5	22,678	11,339	3,730	15,119	1.35	3.50
13d	20,000	1.0	20,000	10,000	10,000	20,000	1.35	3.50
14a	15,000	2.	17,321	8,660	--	8,660	0.36	1.60
14b	15,000	1.5	17,008	8,504	2,835	11,339	0.36	1.60
14c	15,000	1.	15,000	7,500	7,500	15,000	0.36	1.60
14d	15,000	2.	17,321	8,660	--	8,660	0.36	1.60
15a	10,000	2.	10,547	5,774	--	5,774	0.091	0.16
15b	15,000	1.5	17,008	8,504	2,835	11,339	0.36	1.60
15c	20,000	1.	20,000	10,000	10,000	20,000	1.35	3.50
15d	20,000	2.	23,094	11,547	--	11,547	1.35	3.50

$$^*\text{Effective stress} = \frac{1}{\sqrt{2}} [(\sigma_{\theta} - \sigma_z)^2 + \sigma_{\theta}^2 + \sigma_z^2]^{1/2}$$

SECTION 8 QUALITY ASSURANCE

C. A. Meyers

8.0 OBJECTIVES

The purpose of this task is to establish a Reliability and Quality Assurance program, as detailed in a Division Quality Assurance Plan, supported with the necessary facilities which will provide inspection capabilities to support the program, as well as the verification of training and certification of fabrication and inspection personnel. In addition, procedures shall be established in support of the Division Quality Assurance Plan which will verify the "fitness-for-use" of purchased or manufactured parts, components, assemblies, or equipment.

8.1 PRIOR WORK

The Quality Control Laboratory has basic dimensional equipment and dimensional characterization and inspection to support the contract. Dye penetrant inspection equipment for the fluorescent penetrant inspection and Non-Destructive Testing (NDT) Equipment (i.e., ultrasonic, eddy current, and air gaging equipment) is now in use on other contract programs. Quality Methods and Procedures (QMP's) and the Division Quality Assurance Plan are in operation at ARD.

8.2 CURRENT PROGRESS

Product Reliability has participated in program activities through review and approval of drawings, purchase requisitions and work plans. Receiving inspection and release to controlled stores and end use has been accomplished on all materials and components received to date.