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Washington, D.C. 20545

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Mr. Paul S. Check, Director
CRBR Program Office
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Check:

RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION - QUESTION 110.78

Reference: Letter, T. P. Speis to L. W. Caffey, "CRBRP Request for Additional Information," dated December 1, 1976.

This letter formally responds to your request for additional information contained in the referenced letter.

Enclosed is a response to Question 110.78 which contains current information concerning the dynamic and static analysis used to determine the structural and functional integrity of selected seismic Category I components. This response was prepared from the actual structural evaluation plans for the components and demonstrates satisfaction of ASME code requirements. Please note, Question 110.78 was the only question outstanding at the time the licensing process was resumed in September 1981.

John R. Longenecker

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Acting Director, Office of the
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Office of Nuclear Energy

Enclosure

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Question 110.78

The response to Question 110.58 is unsatisfactory. The staff must be assured that the methods to be used in dynamic and static analysis to determine the structural and functional integrity of Seismic Category I components and supports are adequate. Of principal concern is the assurance that the analytical models will adequately represent the physical situations of concern, i.e., proper failure modes (static and creep-fatigue rupture, vibrational distortions, stability and deformations), adequate constituative relationships (elastic, inelastic, viscoelastic, degradation with time), compatible boundary conditions, realistic component material properties.

Also of concern to the staff is the adequacy of the computer programs to produce sound quantitative results. Some recognized computer programs are capable of producing excellent results for one class of component models and possibly not provide accurate results for others. Convincing evidence must be presented to demonstrate that the computer programs used really are adequate.

Supporting tests are generally required to directly verify the structural capabilities of components, and to confirm the analytical methods used. Such tests can be either component model or prototype tests. The staff must be assured that such tests indeed accomplish their purpose.

Include the information in Items 1 through 5 below for the following HTS components:

Reactor Vessel

Piping Systems

PHTS Pump

IHX

IHTS Pump

Superheater

Evaporator

Line Valves

Pressure Relief Valves

1. Identify the specific failure modes which are expected to dominate the component design and the loading conditions associated therewith. For larger and more complicated components several critical areas will arise. Identify the failure modes for each of these areas.

2. Indicate the degree to which elastic, simplified inelastic, detailed inelastic, and visco elastic (creep) methods of analysis will be used in design interactions. Also, summarize the time dependent and cyclic structural analysis that will be performed, i.e., vibration, stability, and creep-fatigue analysis. Describe the basic details of these methods. State the primary assumptions associated with each analysis. Indicate how component degradation over life of the component will be treated in the analytical methods.

3. Identify and summarize those structural tests that will be performed in support of the analysis methods or the actual verification of the component structure in lieu of analysis.

4. Indicate how analysis or testing of components from other programs, such as the FFTF, will be adapted into the overall procedure to verify the adequacy of CRBR component design. Summarize or reference the methods used, assumptions made, and the results of such analysis or tests. If the analysis or test has not been performed, summarized the approach to be used in these programs.

5. Identify and briefly describe the major computer programs which will be used in the various analyses (Ref. Question 110.27). The adequacy of these programs for specific application must be provided.

Response:

The following material in this response deals with satisfaction of ASME Code Requirements. These components also have been analyzed for Structural Margin Beyond the Design Base (SMBDB) conditions as discussed in Reference 10a of PSAR Section 1.6.

Response for Reactor Vessel:

The methods used in the static and dynamic analyses of the Reactor Vessel (RV) to determine the adequacy of the structural and functional integrity are summarized in this response.

The RV is a top ring-supported cylindrical structure with a torispherical bottom head. It is roughly 57 feet long with a diameter of about 20 feet. The sodium-containing portion is all stainless steel designed for 900°F in the outlet plenum region and 775°F in the inlet plenum region. The top flange of the vessel and the vessel support ring are fabricated of SA 508 Class 2 low-alloy forgings. There is an Inconel 600 transition section between the low-alloy forgings at the top and the stainless steel in the remainder of the vessel.

The vessel walls and outlet, makeup, and overflow nozzle penetrations are cooled by primary sodium coolant bypass flow to keep the steady-state metal temperature below or equal to 900°F during normal operation and to reduce the rate of vessel wall temperature change during operation transients.

The RV is supported from its upper end. The vessel support system accommodates dead weight, seismic loads, and forces hypothesized under margin loading conditions from the assembled reactor vessel and closure head to the reactor cavity wall through the support ledge.

The RV is designed and analyzed to the Class 1 requirements of the ASME Code, Section III, and Code Case 1592. In addition, simplified inelastic and detailed inelastic methods that are used conform to the requirements of RDT Standard F9-4T and the guidelines of RDT Standard F9-5T.

FAILURE MODES

Analyses of the RV reflect both time-independent and time-dependent materials properties and structural behavior (elastic and inelastic) by considering the following failure modes:

- Ductile rupture from short-time loadings
- Creep-rupture from long-term loadings
- Creep-fatigue failure
- Gross distortion due to incremental collapse and ratchetting
- Buckling due to short-term loading

Specific failure modes critical to the various regions of the vessel are addressed later in the description of the corresponding analyses.

LOADING CONDITIONS

The loading conditions which mostly control the design of the RV are the seismic loadings and the thermal loadings (transient and steady-state conditions). The seismic loads primarily affect the sizing of the upper assembly and the core support cone. The thermal loading is critical for the elevated temperature parts; the vessel thermal liner, makeup nozzle bridge liner, and the outlet nozzle assembly. These parts will experience through-thickness and axial temperature gradients both during steady-state and transient conditions.

ANALYSES

Analysis of the RV has been subdivided into overall system analyses and analyses of several different regions or components of the RV. In addition, analyses have been sequenced as sizing or conceptual design verification, preliminary detailed, and final analyses. The principal features and anticipated critical failure modes associated with each of these analyses is discussed in detail below.

Design Conditions

This analysis covers the basic sizing for all the parts of the RV. The loading conditions to be considered for this analysis are the design and test conditions of Subsection NB AND Code Case 1592 of the ASME Code. Paragraph NB-3112 defines the design conditions for the low temperature parts of the assembly as design pressure, design temperature, and design mechanical loads (e.g., design pipe loads). The design conditions for the elevated temperature parts are defined in Paragraph 1592-3113.1 as the design parameters for normal conditions. The effects of earthquake are not considered as a design condition load for elevated temperature parts. Test conditions are defined in NB-3114 and 1592-3113.7.

The analysis consists of dividing the vessel into simple shell, plate, and beam segments and calculating the primary membrane and bending stresses using conventional, elastic, hand techniques. Nozzle reinforcing calculations are included. The effects of pipe loads on the nozzle and shell are considered. The stress limits are the allowable stresses defined in NB-3221 and 1592-3222.1 of the Code. Appropriate environmental effects are considered.

Highest stressed areas are the nozzles (pipe attachment area) and the nozzle-to-shell junctures. Design piping loads are the significant stress contributors.

Seismic Analysis

This analysis considers the detailed seismic and stress analysis for the total RV assembly. It is analyzed with the response spectra developed from the response motion at the location of the support ring. The reactions imposed upon the RV nozzles by the piping are determined by using the stiffness matrices due to the piping system. A mathematical model of the lower reactor is used to generate loads for all seismic conditions. The design criteria are established in accordance with that stated in Appendix A to Section 3.7 of the PSAR.

The RV assembly is analyzed by a detailed dynamic analysis using the response spectra loading. The 3-D finite element method is used to establish a mathematical model of the RV assembly. The structure is divided into a finite number of appropriate elements, such as beam and plate elements, which are interconnected at a finite number of joints or nodal points. These individual finite elements are then assembled into a simplified mathematical model under the variational principle preserving the shock energy absorption capacity of the total system.

The seismic analysis is performed considering the seismic motion to be acting in the vertical direction and in two orthogonal horizontal axes. The analysis is performed independently in each of the two horizontal directions and vertical directions. Finally, the combined modal responses obtained for each of the vertical and horizontal siesmic loads are combined individually by the square root of the sum of the squares.

Fluid-induced vibration is investigated at this stage for the liner, outlet nozzle sleeve, makeup nozzle sleeve, and inlet nozzle flow deflector to determine the potential for vibration due to fluid flow.

The adequacy of the design is determined in accordance with Section III of the Code. The RV assembly is designed to insure a safe shutdown during and after an SSE. To meet this condition, the RV shall not exceed the limits of Section III of the Code for faulted conditions.

Highest seismic stresses are found in the upper stainless steel shell courses and the Inconel transition section.

Thermal Analysis

This analysis consists of a 2-D axisymmetric finite element thermal analysis to determine the basic thermal gradients in the various aras where potential high thermal stresses can exist.

The analysis includes the evaluation of all the normal, upset, and steady state conditions identified in the equipment specification. The transients are conservatively combined considering coolant flow, maximum temperature ranges, temperature ramp rates, and number. From the resulting bounding transients, film coefficients are calculated and temperature profiles obtained using finite element techniques. This data is subsequently used to determine the time and location of significant thermal stresses. This analysis also determines the metal temperatures from which the allowable stress can be determined.

Thermal-Mechanical Analysis fo Cover Gas Nozzles

This analysis considers the cover gas inlet and outlet nozzles.

The loading conditions considered are the normal, upset, emergency and faulted operating condition thermal and flow transients to determine the maximum primary plus secondary stress range. In addition, loads due to deadweight seismic and thermal expansion are evaluated. Pressure stresses were found to be small.

A 2-D finite element method (FEM) analysis using constant strain triangular ring element is performed. A single mesh is generated for both the thermal and stress analyses. The thermal analysis yields temperature distributions in the nozzles based on gas flow and associated shell temperatures. A special purpose program is used to evaluate the asymmetric pipe loads. The stresses are calculated on a completely elastic basis.

The analysis is performed per NB-3000, para. 3228.3, of the Code. The critical areas are the nozzle-to-shell juncture and the nozzle-to-pipe juncture.

Thermal-Mechanical Analysis of the Lower Head, Shell and Core Support Assembly

This analysis of the lower head, shell, and core support assembly considers the thermal-mechanical loads for operating conditions, normal, upset, emergency, and faulted. The analysis includes evaluation of transient and steady state temperature distributions for all significant transients. Also included are the mechanical stresses due to pressure, seismic, deadweight (weight of the core) and core support plate thermal motions.

The analysis presents an evaluation of transients for the inlet plenum and determines how the transients are combined for analytical consideration. The combining of transients into a lumped transient is based on coolant flow, maximum temperature changes, rate of change and number of cycles. Based on the lumped transient, fluid temperatures and film coefficients are determined. Metal temperature distributions are then determined by FEM. Stresses are calculated for the above thermal and mechanical loads using a 2-D FEM. For perturbed loop transients, the thermal response is approximated by composite

solutions. Asymmetric stress conditions are determined using a 2-D asymmetric FEM with Fourier series thermal distributions about circumference.

Buckling is investigated in the areas of the core support cone and the lower torispherical head using analytical procedures based on conservative current state-of-the-art practice.

High stressed areas are the juncture of the core support cone to the shell, knuckle region in the torispherical head and the torispherical head-to-shell juncture.

Thermal-Mechanical Analysis of Upper Assembly

This analysis covers the upper assembly, including the stainless, Inconel shells, the ferritic flange, the radiological shield, and the support ring and the dip seal access ports. The loadings of normal, upset, emergency, and faulted conditions including seismic are considered.

The heat transfer analyses include the determination of transient and steady state thermal distributions. Thermal stresses considered include those due to radial and longitudinal gradients and thermal discontinuity at the juncture of the flange and the tapered shell. Superimposed on these thermal loads are pressure loads, deadweight acting on the flange, seismic loads, and all other externally applied loads.

The evaluation of the design is made in accordance with Section III of the Code and Code Case 1592. Environmental effects are considered.

The highest stressed areas are the stainless to Inconel shell juncture and the upper shell (stainless) courses which are subjected to large longitudinal thermal gradients. The temperatures in the carbon steel parts are below 800°F, therefore the acceptance criteria is NB-3000. In the lower part of this assembly (stainless shells) temperatures are above 800°F, hence Code Case 1592 is used for evaluation of the stresses. Inelastic analysis is performed to demonstrate adequacy in the region where the axial gradient in the shell begins.

Buckling due to seismic loading was investigated in the upper shell courses. The analysis was based on conservative analytical methods.

The analysis considered the basic sizing and design of the dip seal maintenance port. The loading conditions considered include interal and external pressure, deadweight, seismic and temperature effects.

The analysis determines or validates tube wall thickness, gap size between the tube and bore, weld size and type of weld at the vessel flange, flange size and the design of any additional supporting system. Hand calculations are used to perform the analysis. The highest stressed area is the weld at the vessel flange-to-pipe juncture.

The analysis considered the design of the radiological shield, its attachment and its interaction with the vessel flange. The loading conditions are deadweight, seismic, thermal conditions and natural frequency calculations. The seismic analysis is based on a static seismic loading of 1.5 times the maximum OBE response. The analysis uses hand calculations for seismic analysis and a combination of computerized interaction analysis and hand calculations for the thermal evaluation.

Thermal-Mechanical Analysis of the Inlet Nozzle Assembly

This analysis considers the inlet nozzle assembly. The loading conditions considered in this analysis are all the thermal and flow transients for normal, upset, and emergency conditions, and the thermal and siesmic pipe loads.

A 2-D FEM analysis is performed. The grid from the inlet nozzle analysis previously described is utilized in this analysis. The thermal analysis yields temperature distributions throughout the assembly for steady-state and transient conditions. The stresses are determined for most areas using an elastic or inelastic material model. In addition to the thermal stresses, stresses due to pressure are included in the axisymmetric analysis. Pipe loads and the flow deflector loads are also analyzed by FEM using a special program for asymmetric loads. Supporting this analysis is a limited 3-D elastic FEM analysis of the assembly to validate the 2-D assumptions used. This model is also utilized in evaluating the effects of the lower head on the nozzles.

In using a 2-D technique to analyze the juncture between a cylinder and a nozzle, the cylinder is assumed to act as either a sphere or a flat plate, both of which can be modeled as symmetric about the nozzle centerline while a cylinder cannot be so represented. When a small diameter nozzle is inserted into a relatively large diameter cylinder, the approximations used in 2-D analysis are obviously close to the true geometry; however, when the nozzle diameter is large relative to the cylinder a check on the accuracy of stress distribution at their juncture is appropriate. For the inlet nozzle, the ratio of cylinder diameter to nozzle diameter is only 9.44; this low ratio makes a check on the assumptions necessary. Also, the vessel lower head is less than $2.5(Rt)^{1/2}$ from the inlet nozzle; this effect is not considered in the axisymmetric analysis, but is checked by the 3-D test case.

The critical area occurs at the nozzle-to-shell juncture and the pipe-to-nozzle juncture. The adequacy of the assembly is determined with respect to Subsection NB. The environmental effects are considered.

Thermal-Mechanical Analysis of the Outlet Nozzle and Outlet Nozzle Liner

This analysis considers the outlet nozzle assembly. The loading conditions considered in this analysis are the thermal and flow transients for normal, upset, and emergency conditions, and the thermal and seismic pipe loads. The majority of this nozzle will be at temperatures near 800°F; however, outboard of the thermal sleeve and in the sleeve itself, temperatures will exceed 800°F. Therefore, time-dependent effects are considered.

A 2-D axisymmetric FEM analysis using constant strain triangular ring elements is performed. A single mesh is generated for both the thermal and stress analyses for each of the major subassemblies. The thermal analysis yields detailed temperature distributions through the nozzle and sleeve, based on fluid temperature and flow through the outlet and behind the liner and sleeve. Both two and three loop flow conditions are evaluated thermally and, based on results, the decision is made whether to make stress evaluations for one or both conditions.

Thermal distributions are obtained for the transients and stresses are determined using an elastic and/or inelastic material model of the assembly. In addition to the thermal stresses, pipe loads and the effects of the relative motion of the vessel thermal liner are factored into the analysis. Stresses due to these loads are determined using a FEM program for asymmetric loading. Supporting this analysis is a limited 3-D elastic FEM analysis of the assembly to validate the 2-D assumptions used.

The critical stress areas are in the nozzle liner, the nozzle-to-shell juncture, sleeve-to-vessel liner juncture, and the sealing discs. The stresses are compared to the limits of Subsection NB and Code Case 1592. The environmental effects are considered.

Analysis of the Makeup and Overflow Nozzles for Operating Conditions

This analysis considers the sodium makeup and overflow nozzles. The loading conditions considered are the thermal and flow transients for operating conditions transient events, flow rates, and outlet plenum conditions, and thermal and seismic pipe loads. The overflow nozzle is exposed only to bypass flow. The makeup nozzle has a thermal liner to consider and is affected by outlet plenum temperatures. Analysis of the makeup nozzle liner includes the local region of the vessel liner.

The geometries for both these nozzles are modeled axisymmetrically for FEM analysis. For both nozzles, thermal distributions as well as stress distributions are considered axisymmetrically. Asymmetric pipe loads are evaluated and superimposed at critical locations. The stresses are computed on a completely elastic basis.

The acceptance criteria is Code Case 1592 for those areas where significant temperatures above 800°F occur. Environmental effects are considered.

The critical stress areas are the nozzle-to-piping junctures and the shell-to-nozzle junctures.

Thermal-Mechanical Analysis of the Makeup Nozzle Liner

This analysis considers the makeup nozzle liner. The loading condition is the same as described for the makeup nozzle. The 2-D finite element model for the bridge liner is evaluated for convergency capability for the inelastic/creep behavior.

The acceptance criteria is ASME Code Case 1592. Environmental effects are considered.

The critical area is the juncture of the makeup nozzle liner to vessel thermal liner.

A sleeve of 718 material is installed on the makeup nozzle to enable the assembly to withstand the striping caused by incoming cooler sodium.

Thermal-Mechanical Analysis of the Vessel Thermal Liner Attachment Region

This analysis considers the thermal mechanical loading on the thermal liner forging including the adjacent shell and the baffle support ledge. The loading conditions considered in this analysis are the thermal and flow transients for normal, upset, and emergency conditions, and the seismic loads on the attachment pins.

The analysis includes a heat transfer evaluation of both steady state and transient conditions. Due to the complexity of the design, thermal stresses are considered for both radial and longitudinal gradients as well as the thermal discontinuity which exists at the thermal liner forging. Superimposed on these stresses are the mechanical load stresses due to pressure and seismic events.

The attachment region adjacent to the shell complies with the NB-3000 rules for material below 800°F. The vessel thermal liner portion adjacent to the vessel thermal liner support forging reaches a temperature above 800°F and is analyzed to the criteria of Code Case 1592. The stresses and strains in this area are not critical.

Thermal-Mechanical Analysis of the Vessel Thermal Liner

This analysis considers the thermal mechanical loading of the vessel thermal liner. The first phase includes a total evaluation of the radial gradient through the liner to identify operating temperature limits. No discontinuities are considered in this phase. The second phase is an evaluation of the liner stiffening ring, the liner and the bypass flow penetrations. The loading conditions considered are the normal, upset, and emergency conditions. Seismic stresses are also considered.

The analysis includes a heat transfer evaluation of steady state and transient conditions. The maximum thermal stresses are caused by the radial gradient which will exist in the thermal liner. The effect of longitudinal gradient is also evaluated. This location also requires stresses calculated for thermal discontinuity.

This assembly operates normally at elevated temperatures. Therefore, it requires a time-dependent analysis. The major potential failure mechanism is creep-fatigue interaction. The method of analysis is 2-D FEM. The structural program has inelastic and creep capability. The adequacy of the design is evaluated according to Section III and Code Case 1592. The environmental effects are considered.

The critical areas are the vessel thermal liner shell in the vicinity of the sodium level and the striping potential in the bypass flow penetration area.

MATERIAL PROPERTIES

The environmental conditions of the RV also influence the design. Sodium exposure is the only effect of significance and is applicable for the high temperature stainless steel regions, specifically, the vessel liner, outlet nozzle liners, nozzle stub ends, and makeup nozzler liner. There are no environmental effects on material properties for the carbon steel and Inconel 600 low temperature portions of the reactor vessel.

The elastic material properties used in the structural evaluation of the RV are specified in the ASME Code documents. The Nuclear Systems Materials (NSM) Handbook TID-26666 is used as the authoritative source for material properties not specified in the applicable Code documents. All material properties used in the design and analyses of the RV are specified in the Code documents or the NSM Handbook.

A collection of computer files containing material property data, routines for interpolation and routines for material models, which are based on the material data given in the NSM Handbook and the ASME Code, were used for the analysis of the RV.

Where material properties are significantly uncertain, consideration is given to the use of minimum, average or maximum properties as appropriate to obtain a conservative result. This selection of appropriate properties is guided by RDT Standard F9-5T.

Material Degradation

Most of the data used to define the allowable design stresses in the ASME Code were obtained from tests conducted in air. No attempt is made in the Code to account for the effects of other service environment. The LMFBR development program has focused attention on the mechanical behavior of reactor materials when exposed to high-temperature liquid sodium, in addition to fast neutron irradiation and to long time aging at elevated temperatures. A brief discussion of the environmental effects is given in the following paragraphs.

Thermal Aging Effects on Mechanical Properties

Types 304 and 316 stainless steels are non-age hardenable alloys. Thus, no significant changes in strength or hardness of annealed material would accrue from long-term aging at temperatures up to 1200°F, unlike the precipitation-hardened stainless steels. Some slight increases in strength and decreases in ductility may occur due to carbide formation, together with a reduction in the room temperature impact strength. Of more significance, is the fact that these alloys will sensitize during long-term service in the temperature range from 800°F to 1500°F.

In this phenomenon, carbide precipitation occurs at the grain boundaries, the adjacent matrix becomes depleted in chromium and the grain boundary regions become susceptible to attack by corrosive media. Such attack is not likely to occur in sodium, which, if pure, is a relatively inert environment. However, cracking may initiate during fabrication and the other pre-operation periods when the component is not exposed to sodium due to the environmental conditions (presence of water and halides). Because of this, precautions must be taken during such periods to ensure that contact between sensitized material and potentially corrosive media is minimized, if not entirely avoided. Hence, no allowances have been made for the effects of thermal aging on the properties to types 304 and 316 stainless steels. This did, however, demand that control be specified and exercised during the fabrication process to prevent stress corrosion and intergranular attack.

Neutron Irradiation Effects on Mechanical Properties

The effect of neutron irradiation on the mechanical properties of a material are generally to increase the tensile and yield strengths, and to decrease the ductility. The actual magnitude of the effect is dependent on several parameters, such as the temperature of irradiation, the test temperature, the neutron energy spectra and the neutron fluence.

Two alternate procedures have been used to account for the effects of neutron irradiation on the structural integrity of components. The comprehensive approach characterizes the effects of neutron irradiation upon each material response and failure mode considered by the ASME Code. When necessary, additional failure modes are considered. The alternate approach involves finding the threshold where irradiation effects first become measurable (in terms of structural response integrity). The irradiation levels are then held below these threshold levels by shielding.

For austenitic stainless steels (Types 304 and 316), measurable loss of ductility (total elongation) can first be detected at about 10^{21} nvt total fluence for temperatures in the range of 600°F to 1100°F. The reactor vessel end-of-life fluence is less than 6×10^{20} nvt and hence no fluence effects are expected.

Effects of (Nitrogen + 2% Oxygen) Atmosphere on Mechanical Properties

The selection of nitrogen gas as the atmosphere for the reactor cavity was based on the desire to prevent chemical reactions should molten sodium leak into the cavity from any source. However, the exposure of austenitic stainless steel to pure nitrogen for extended periods of time at elevated temperatures may lead to the formation of a thin nitrided layer. This is considered undesirable because of the brittleness of such layers. To minimize the formation of such a layer, a small percentage of oxygen (2%) will be introduced into the nitrogen.

Effects of (Argon-Plus-Sodium Vapor) Atmosphere on Mechanical Properties

Very little is known of the effects of exposure to an argon-plus sodium-vapor atmosphere on the mechanical properties of a material. It is possible that, if the sodium vapor is continually condensing on the material surface and rejoining the main reactor coolant, there could be some interstitial transfer. However, because of the scarcity of data, it is not possible to provide quantitative assessments of such effects at this time. Practically, the potential for significant mass transfer via condensation is insignificant. It is judged that exposure to the cover gas should be considered the same as exposure to liquid sodium without loss of interstitials.

Surface Effects of Liquid Sodium on Mechanical Properties

Compared with air testing, liquid sodium may cause certain metallic elements to be transferred from the hotter to the cooler regions of the system. In addition, surface oxidation in liquid sodium is greatly reduced when compared to air testing. It is believed that these surface effects are insignificant in their influence on short-term tensile properties.

For time-dependent deformation, such as stress-rupture and fatigue, the effects of a liquid sodium environment are complex and need to be considered in detail. In the case of stress-rupture, it has been shown that for a given temperature and stress, rupture times in air are longer than those in liquid sodium. A sodium environment correction factor is applied to the rupture strength data specified in ASME Code Case 1592 for Types 304 and 316 austenitic stainless steel. This effect is used in all evaluations where stress to rupture is involved.

Fatigue properties of materials can be greatly affected by the environment in which the properties are measured. The avoidance of excessive surface oxidation by testing in sodium (or inert gas) instead of in air increases the cycles-to-failure for a given strain range. No increase in the design fatigue limits due to exclusion of oxygen effects is permitted.

Interstitial Transfer Effects on Material Properties

In the reactor system, interstitial carbon and nitrogen are transferred from the hotter to the cooler regions. This leads to weakening in the decarburized and denitrided regions and to strengthening in the carburized and nitrided areas. In the case of fatigue behavior, however, the effects of interstitial absorption at the surface are complicated because of two concurrent mechanisms. On the one hand carburization can lead to enhanced crack nucleation at carbide particles and, on the other, surface strengthening during strain-controlled fatigue will increase the proportion of elastic straining which is less damaging than plastic deformation. Studies indicate that, in general, the austenitic materials will be carburized and the ferritic materials will lose interstitials. However, the crossover from carburization to decarburization is system dependent, and it is likely that in certain systems at least some of the austenitic material will be decarburized. Procedures have been established by which the extent of interstitial transfer for Types 304 and 316 stainless steel can be determined and from this the

effects on mechanical behavior is calculated. The procedures include calculations of surface and average interstitial concentrations and interstitial gradients under decarburizing and denitriding conditions. Because of the shortage of data on nitrogen diffusion, the rates of nitrogen transfer are estimated from available carbon transfer data.

TESTS

No structural tests, other than those required by the ASME Code, have been performed in support of the RV analysis methods.

COMPUTER PROGRAMS

The following computer programs were used in the analysis of the RV. These codes are all proprietary to Babcock and Wilcox.

Code	Used For
ABSA	Axisymmetric Body Stress Analysis
ABTA	Axisymmetric Body Thermal Analysis
ALAS	Axisymmetric Load, Axisymmetric Body Stress Analysis
FESAP	See PSAR Appendix A
FETAP	General Configuration Thermal Analysis
CREEPABSA	Elastic Plastic Creep, Axisymmetric Body Stress Analysis
BIJLARRD	Bijlarrd Shell Stress Analysis
INTERACTION	General Interaction Analysis for Shells of Revolution with Axisymmetric Loading

Response for IHX:

The methods used in the static and dynamic analysis of the Intermediate Heat Exchanger (IHX) to determine structural and functional integrity are summarized in this response.

The IHX provides the thermal link between the primary and intermediate heat transport piping. The IHX is a straight tube flexible downcomer design using an essentially counterflow arrangement of heated and cooled sodium. Figure 110.78-IHX-1 depicts the salient features of the IHX design. The main support for the IHX is the hanging support cylinder which is fabricated from type 304 stainless steel at the top and type 316 stainless steel at the bottom. It consists of a cylindrical shell that is welded to the IHX shell and tube bundle through a "Z" shape junction forging at the lower edge and has an upper flange which is anchored to the operating floor. The shell is fabricated from type 304 stainless steel in the bottom portions and type 316 stainless steel in the top areas where it is welded directly to the lower edge of the cylindrical hanging support through the "Z" junction. The bottom portion of the shell assembly consists of a lateral support ring with spacer guides to restrain the tube bundle, the lower tubesheet, the hemispherical head, and the primary outlet nozzle. The tube bundle is comprised of two major sub-assemblies: (1) the bundle, consisting of tubesheets, tubes, support plates, tierods and spacers, outer shroud, hemi-head, downcomer, strongback and by-pass seal, and (2) the channel assembly consisting of replaceable bellows, upper head, intermediate outlet nozzle, intermediate vent, inner and outer channel cylinders, upper downcomer pipes and the "Z" forging. The uppermost portion of the channel contains a removable IHX bellows assembly. The bellows permits the differential axial thermal growth between the downcomer and straight tubes and also serves as a portion of the pressure boundary between the primary and intermediate systems. A detailed description of the IHX is included in Chapter 5 of the PSAR.

The IHX was designed and constructed to the Class 1 requirements of the ASME Code, Section III and the supplementary requirements of RDT E15-2NB-T. Design and construction of parts and components for design temperatures exceeding 800°F were in accordance with Code Case 1592 and the supplemental requirements of RDT F9-4T.

LOADINGS CONSIDERED

Two major types of general loading were considered, mechanical and thermal. Mechanical loads consist of internal pressure, nozzle loads (due to piping weight, thermal expansion and seismic effects), dead weight of the component and its content, seismic dynamic loads in the component itself, vibratory dynamic loads from various sources, and rapid high pressure loads as impact dynamic load effects. Thermal loads consist of many thermal transients in the sodium of varying degrees of severity, duration, and temperature change direction, as well as steady state high temperature effects. Some parts of the unit operate at temperature below the creep regime but many parts operate in the creep regime. These loads apply to all pressure boundaries and internal parts.

FAILURE MODES

Analyses were performed on the IHX to reflect both time-independent and time-dependent material properties and structural behavior (elastic and inelastic) by considering all the modes of failure listed below:

1. Ductile rupture from short-term loadings

2. Creep-rupture from long-term loadings

3. Creep-fatigue failure

4. Gross distortion due to incremental collapse and ratchetting

5. Loss of function due to excessive deformation

6. Buckling due to short-term loadings

7. Creep buckling due to long-term loadings

Critical failure modes for specific areas of the IHX are identified in the discussion of analysis methods.

ANALYSIS METHODS

The following paragraphs provide a brief summary of the considerations involved in the identification of highly loaded areas and the analysis methods applied to show compliance with applicable criteria.

Stress Analysis

The intermediate channel, upper tubesheets, lower portion of the hanger, lower tubesheet complex and the upper portion of the primary shell were included in a single finite element thermal and stress model. The thermal transient analysis was conducted on two separate sub-models composed of the lower tubesheet complex and the intermediate channel complex. The stress analysis was conducted on the combined model through the use of substructuring methods. The stress analysis methods used for the different areas of the IHX are described below:

Lower Tubesheet Complex: For this region, the governing failure mode is fatigue. Creep strain and stress rupture damage are of minor concern as this area operates above 800°F for less than 100 hours during its 30 year design life. While the rules of RDT F9-4T, which permit exemption from satisfying strain limits, can be used, the added restriction of the elastic shakedown limits of ASME Code, Section III presented difficulties for a few of the upset and emergency transients where the $3S_m$ limits were exceeded. In such cases, inelastic analysis based on the approach given in Paragraph NB-3228 of Section III was performed to show that the amount of accumulated strain was within acceptable bounds. The remaining transient cycles were treated using elastic rules.

Intermediate Channel Complex: This area is composed of the intermediate channel, upper tubesheet, lower portion of the hanger and upper portion of the primary shell. Creep-fatigue was the major failure mode with strain accumulation only a secondary concern. The creep damage was evaluated with material properties being modified to account for decarburization which reduces the stress rupture strength of the material. Gross deformations due to creep were not of particular concern as the normal operating temperature is 975°F. A creep buckling analysis of the inner cylinder was performed to confirm that it had adequate thickness.

Several lumped thermal transients were used for creep-fatigue evaluations, including worst up, worst down, moderate up, and moderate down. The moderate thermal transients were used to envelope the large-number-of-occurrence transients, while the most severe transients were used to envelope all transients which are worse than moderate transients. This general transient lumping procedure and usage was employed for transient analysis in the other parts of the IHX also. The total number of lumped transients used is the same as the total number of actual transients.

In addition to elastic analysis, extensive simplified inelastic analysis was employed on the upper tubesheet and outer "Z" and inner "Wye" junctions of the intermediate channel complex to optimize the design prior to performing a detailed inelastic analysis to confirm the design. Detailed inelastic analysis was performed using two dimensional axisymmetric models of these three areas. This general technique of proceeding from an elastic to a simplified inelastic to a detailed inelastic analysis was employed in other areas where necessary.

The detailed inelastic analysis of the upper tubesheet involves the evaluation of several cycles composed of worst up and down thermal shocks and moderate up and down thermal shocks. An equivalent set of material properties was developed and both plastic and creep correlations were made for the solid region used in the model in place of the actual perforated region. The model used contains the tubesheet and the attached cylinders.

For the inelastic analysis of the outer "Z" junction, many cycles composed of severe and moderate up-down thermal shocks were evaluated. Also, several cycles composed of severe and moderate up-down thermal shocks were used in the inelastic analysis of the inner "Wye" junction.

Hanger: The lower portion of the hanger, which operates above 800°F during normal operation, is considered an integral attachment to the ASME Code Class 1 IHX pressure boundary and hence subject to the same design rules as the IHX. The upper portion of the hanger including the anchor bolts was designed to the rules of Subsection NF of the ASME Code, Section III. A jurisdictional boundary between the two areas was established, based upon the temperature level. The major consideration involved the adequacy to withstand primary stresses, the important contributors to these stresses being seismic loading and deadweight. The affect of the axial temperature gradient from the IHX shell to the support flange was taken into account.

Primary Shell: The primary shell is divided into three regions. The upper region involves the primary shell forging and is considered with the intermediate channel complex. The middle region involves the high temperature [illegible] inlet area. Here the critical failure mode was creep-fatigue. The creep damage was evaluated with material properties being modified to account for decarburization. Strain limits were not a problem as large thermal discontinuity stresses were not present. This region was evaluated with simplified inelastic analysis using an infinitely long thick walled cylinder model. The lower region consists of the seal ring, lateral support ring, head and primary outlet nozzle. Here, the critical failure mode was fatigue and the evaluation was handled in the same manner as the lower tubesheet complex.

Additional considerations in the analysis of the primary shell included worst-case weld configurations and their effect on creep-fatigue evaluations. This involved considering the increase in secondary stresses due to maximum mismatch between sections that were joined. In addition, the peak stresses due to the local discontinuity in a weld were considered. Another consideration was dry and wet heat up and cooldown of the primary shell in the area of the primary closure. These cycles control the design of the primary closure seal, and hence reasonable heating rates were established and the effect of local loss of heaters was considered. Also, evaluation of the non-axisymmetric temperature distributions due to maldistribution of flow, such as at the primary vent elevation, was done.

Nozzles: The primary inlet nozzle, the intermediate outlet nozzle, the vent nozzles and the hand hole nozzle including its cap were evaluated in detail. Three vent nozzles were evaluated. The primary shell vent has sodium flowing through it during operation while the other vent nozzles do not. The critical failure modes for the primary inlet, intermediate outlet and hand hole nozzles were creep-fatigue and strain accumulation. The creep damage was evaluated with material properties being modified to account for decarburization. Several lumped thermal transients were analyzed using axisymmetric model approximations. The nozzle loads were evaluated using axisymmetric approximations as subjected to non-axisymmetric loads.

In addition to elastic analysis, simplified inelastic analysis was used to optimize the nozzle configuration so that a minimum of detailed inelastic analysis was required to confirm the design. The detailed inelastic analsis involved the evaluation of several lumped transients composed of severe and moderate up-down thermal shocks.

Internals: The support plates, shroud, tie rods, nuts, spacers, primary by-pass seal complex, primary inlet plenum baffle, top baffle plate and strong-back are included in this category. The mandatory rules of Code Case 1592 were applied even though these components are not part of the pressure boundary. These rules cover the limits on primary stress. Dynamic loadings due to fluid-borne pressure transients and flow-induced vibrations were considered.

Tube and Tube-to-Tubesheet Weld: The critical failure mode was creep-fatigue for both the tube and the tube-to-tubesheet weld. In addition, all loadings on the tube were considered to evaluate the potential for column buckling. As in the case of the intermediate channel complex and the lower tubesheet complex, several thermal transients were evaluated. The tube was modeled using an infinitely long cylinder and simplified inelastic methods were then applied. An elastic analysis of the tube-to-tubesheet junction was performed using an axisymmetric model. As both the tube and tube-to-tubesheet junction are subject to decarburization, creep damage was evaluated with modified material properties. However, excessive strain accumulation was not of concern.

Additional considerations include the buckling of the straight tubes due to radial variation in bulk tube temperature during dry heatup and cooldown of the tube bundle. This consideration includes the stress-strain characteristics of the tubes due to loss of carbon and nitrogen and contributes to fatigue damage in the tubes and imposes deflection requirements on the expansion joint. Also, flow maldistribution is of importance in the area of the tube and lower tubesheet to downcomer junction. A nonaxisymmetric bulk temperature distribution in the tubes caused significant fatigue damage in the junction between the downcomer and tubesheet. In addition, compressive axial thrusts on the tubes were accounted for in the tube buckling potential assessment.

Expansion Joint Complex: This area is composed of the expansion joint (bellows), attachments, intermediate inlet nozzle, hand hole and outer cylinder. The critical failure mode is fatigue for all of these components. The intermediate inlet nozzle, hand hole and outer cylinder operate below 800°F for a considerable fraction of the design life. Thus, the rules of RDT F9-4T providing an exemption from the strain limits were used. Several lumped thermal transients were evaluated. For the expansion joint and attachment region, various loading conditions for detailed inelastic analysis were developed. Even though the expansion joint operates below the creep range for most of its design life, the inability to demonstrate elastic shakedown necessitated the use of inelastic analysis. Many cycles of various axial deflections were analyzed. The plastic strain ranges obtained from the inelastic analysis were used to establish the fatigue life of the expansion joint.

SEISMIC ANALYSIS

Seismic analysis of the IHX was performed by the response spectrum method, using the ANSYS dynamic-seismic capability. The hanging support flange was modeled using continuum type finite elements. This accounted for some additional flexibility of this region. Both SSE and OBE vertical and horizontal cases were analyzed. Non-linear effects were factored into the analysis where applicable. The results of the seismic analysis provided input to the structural evaluations described in the previous section of this response.

VIBRATION AND DYNAMIC ANALYSIS

Other dynamic and vibration considerations which were evaluated involve sodium-water reaction, check valve slam, fluid and structural borne vibrations and flow induced vibrations.

The expansion joint was analyzed under the action of the pressure transient entering the intermediate inlet nozzle due to a sodium water reaction. The effect of this pressure transient was also considered for the tubes, as they have low flexibility. The approach was to use a static analysis with an amplification factor, which was determined by comparing the natural frequencies of the bellows and tubes in the appropriate modes to the time rate of change of the pressure.

The transient pressure resulting from check valve slam was analyzed for its effect on the shroud, tubes and expansion joint using an analysis procedure similar to that for the sodium-water reaction.

Calculations for fluid and structural borne vibrations were made as well as assessments for flow induced vibrations. It was found that fluid borne and structural borne vibrations (e.g. from the pump through the cross over piping to the IHX primary inlet nozzle) were insignificant. The effect of flow induced vibration was verified by tests as discussed later.

MATERIAL PROPERTIES

The elastic material properties used in the structural evaluation of the IHX are specified in the ASME Code documents. The Nuclear Systems Materials (NSM) Handbook (TID-26666) was used as the authoritative source for material properties not specified in the applicable Code Documents. All material properties used in the design and analyses of the IHX are specified in the Code Documents or the NSM Handbook.

Thermal and mechanical properties were considered in the selection of materials for use in the IHX. Further, consideration was given to material properties in connection with fabrication procedures as noted below in the section on thermal aging effects. A thickness allowance was provided, in the manner described in the ASME Code, Section III, Subsection NB-3120, to account for the effects of corrosion and erosion.

Where material properties are significantly uncertain, minimum, average, or maximum properties were used as appropriate to obtain a reasonably conservative result. For example, in certain critical situations the evaluations of deformation limits were based upon minimum stress-strain curves. The selection of appropriate properties was guided by RDT F9-5T.

Material Degradation

Most of the data used to define the allowable design stresses in the ASME Code were obtained from tests conducted in air. No attempt is made in the Code to account for the effects of other service environment. The LMFBR development program has focused attention on the mechanical behavior of reactor materials when exposed to high-temperature liquid sodium, in addition to fast neutron irradiation and to long time aging at elevated temperatures. The effects of the service environment upon the response and failure characteristics of the structural materials are summarized in the following paragraphs.

Thermal Aging Effects on Mechanical Properties

Types 304 and 316 stainless steels are non-age hardenable alloys. Thus, no significant changes in strength or hardness of annealed material accrue from long term aging at temperatures up to 1200°F, unlike the precipitation-hardened stainless steels. Some slight increases in strength and decreases in ductility may occur due to carbide formation, together with a reduction in the room temperature impact strength. Of more significance is the fact these alloys will sensitize during long term service in the temperature range from 800° to 1500°F. In this phenomenon, carbide precipitation occurs at the grain boundaries, the adjacent matrix becomes depleted in chromium and the grain boundary regions become susceptible to attack by corrosive media. Such attack is not likely to occur in sodium, which, if pure, is a relatively inert environment. However, cracking may initiate during fabrication and the other pre-operation periods when the component is not exposed to sodium, due to the environmental conditions (presence of water and halides). Because of this, precautions must be taken during such periods to ensure that contact between sensitized material and potentially corrosive media is minimized, if not entirely avoided. Hence no allowances have been made for the effects of thermal aging on the properties of types 304 and 316 stainless steels used in the IHX. This did, however, demand that control be specified and exercised during the fabrication process to prevent stress corrosion and intergranular attack.

Neutron Irradiation Effects on Mechanical Properties

Neutron shielding is provided between the reactor cavity and the HTS cells containing the IHX. Neutron fluences in the vicinity of the IHX are therefore negligible and no fluence effects on mechanical properties of IHX materials are expected.

Effects of (Nitrogen + 2% Oxygen) Atmosphere on Mechanical Properties

The selection of nitrogen gas as the atmosphere for the reactor cavity and HTS cells was based on the desire to prevent chemical reactions should molten sodium leak into the cavity and HTS cell from any source. However, the exposure of austenitic stainless steel to pure nitrogen for extended periods of time at elevated temperatures may lead to the formation of a thin nitrided layer. This is considered undesirable because of the brittleness of such layers. To minimize the formation of such a layer, a small percentage of oxygen (<2%) will be introduced into the nitrogen.

Effects of (Argon-Plus-Sodium-Vapor) Atmosphere on Mechanical Properties

Very limited information is available on the effects of exposure to an argon-plus-sodium-vapor atmosphere on the mechanical properties of a material. It is possible that, if the sodium vapor is continually condensing on the material surface and rejoining the main reactor coolant, there could be some interstitial transfer. However, because of the scarcity of data, it is not possible to provide quantitative assessments of such effects at this time. Practically, the potential for significant mass transfer via condensation is insignificant. It was judged that exposure to the cover gas should be considered the same as exposure to liquid sodium without loss of interstitials. Loss of interstitials due to liquid sodium exposure in other circumstances is discussed below.

Surface Effects of Liquid Sodium on Mechanical Properties

Compared with air testing, liquid sodium may cause certain metallic elements to be transferred from the hotter to the cooler regions of LMFBR systems. In addition, surface oxidation in liquid sodium is greatly reduced when compared to air testing. It is believed that these surface effects are insignificant in their influence on short-term tensile properties.

For time-dependent deformation, such as stress-rupture and fatigue, the effects of a liquid sodium environment are complex and need to be considered in detail. In the case of stress-rupture, it has been shown that for a given temperature and stress, rupture times in air are longer than those in liquid sodium. A sodium-environment correction factor was applied to the rupture strength data specified in ASME Code Case 1592 for type 304 and 316 austenitic stainless steel. This effect was used in all evaluations where stress rupture was involved.

Fatigue properties of materials can be greatly affected by the environment in which the properties are measured. The avoidance of excessive surface oxidation by testing in sodium (or inert gas) instead of in air increases the cycles-to-failure for a given strain range. No increase in the design fatigue limits due to exclusion of oxygen effects was employed in the analyses as a conservative approach.

Interstitial Transfer Effects on Material Properties

In the Heat Transport System, interstitial carbon and nitrogen are tranferred from the hotter to the cooler regions. This leads to weakening in the decarburized and denitrided regions and to strengthening in the carburized and nitrided areas. In the case of fatigue behavior, however, the effects of interstitial absorption at the surface are complicated because of two concurrent mechanisms. On the one hand carburization can lead to enhanced crack nucleation at carbide particles and, on the other, surface strengthening during strain-controlled fatigue will increase the proportion of elastic straining which is less damaging than plastic deformation. In general, the austenitic materials will be carburized and the ferritic materials will lose interstitials. However, the crossover from carburization to decarburization is system dependent and it is likely that in certain systems at least some of the austenitic material will be decarburized. Procedures have been established for the CRBRP by which the extent of interstitial transfer for types 304 and 316 stainless steel can be determined and from this the effect on mechanical behavior was calculated. The procedures include calculations of surface and average interstitial concentrations and interstitial gradients under decarburizing and denitriding conditions. Because of the shortage of data on nitrogen diffusion, the rates of nitrogen transfer were estimated from available carbon transfer data. Thus, the effects of interstitial transfer on the mechanical behavior of structural materials used were taken into account in the analysis or shown to be insignificant in effect at the region involved mainly due to thickness considerations. For example, the effects of decarburization of the thin walled tubes was considered because of the thin section of metal involved.

STRUCTURAL VERIFICATION TESTS

IHX Expansion Bellows Development Program

The straight tube design of the IHX required that a flexible joint be provided in the intermediate inlet region to accommodate differential thermal expansion. The bellows is thermally isolated from the primary sodium by virtue of its location and because the stagnant primary sodium on its exterior is cooled by the intermediate sodium in the downcomer. This keeps the operating temperature below the creep range, at about 635°F.

A development test program was conducted to verify the structural calculations, design parameters and fatigue life of the IHX expansion bellows. The testing consisted of three parts: a squirm test, a strain gage test and a fatique test. The squirm test was performed in accordance with NC-3649.4 of the ASME Code, Section III and the fatigue test was performed in accordance with Appendix II of Section III. The fatigue test consisted of cycling the bellows through a prototypical plant histogram in a 100 PSI nitrogen atmosphere at 635°F. The tests confirmed the adequacy of the bellows for the IHX service requirements.

IHX Model Flow Induced Vibration Test Program

A model flow test of the IHX tube bundle was conducted to determine the tube vibration characteristics. The objectives were:

1. To determine the amplitude and frequency of flow induced tube vibrations at various elevations of the IHX tubes.

2. To ascertain that the maximum amplitude of tube vibration does not exceed 25% of the nominal distance between the outer surfaces of adjacent tubes.

3. To ascertain that peak tube deflection stress levels do not exceed the allowable tube material endurance limits.

4. To ascertain that unsupported tube span natural frequencies are at least 50% higher than the calculated vortex shedding frequencies.

A full scale replica of a 30^{o} sector of the tube bundle was used to establish geometric similarity. The test results verified analytical predictions and confirmed that the tube bundle would not experience flow induced vibration problems in service.

COMPUTER PROGRAMS

Responses to NRC Questions 110.27 and 110.58 provided information relating to the computer programs used for the static and dynamic analyses of seismic Category I structures. Of those, the following computer programs were used for the analyses of the IHX:

1. ANSYS - For thermal, stress and seismic analyses in all areas of the IHX.

2. CHERN - For simplified inelastic analysis to optimize design of those areas where elastic analysis was not adequate and detailed inelastic analysis was eventually necessary, and for use in those areas where the program was applicable and adequate by itself (mainly tubular configurations).

3. MARC - For detailed inelastic analysis of those areas where required (primary inlet nozzle, Wye junction, "Z" junction, upper tubesheet, etc.).

A description of each of these programs is included Appendix A of the PSAR and hence is not repeated in this response. Appendix A also provides information relating to the adequacy of these codes and verifications that have been completed. Both ANSYS and MARC are extensively used throughout the nuclear industry. The CHERN program has been verified for use on the FFTF-IHX with a high level of confidence.

INFORMATION USED FROM OTHER PROGRAMS

The design of the IHX for CRBRP used information developed in the design of the IHX for the FFTF. Relative to structural assessments, the stress analysis of the FFTF IHX components required the development of analytical techniques and computer programs (e.g., the CHERN program for simplified inelastic analysis was developed for use in the FFTF IHX structural analysis). Analytical techniques for evaluating the effects of thermal transients by lumping and for appropriate application of simplified and detailed inelastic analysis were forthcoming. The use of complex thermal and structural finite element models to represent the physical situations in complicated geometries was also developed. The information and expertise gained from the FFTF IHX design and analysis was used and expanded for application to the CRBRP IHX design and analysis. Since the type of service required for both of these IHX components was very similar, the carry-over and use of techniques established for FFTF was a natural consequence for CRBRP.

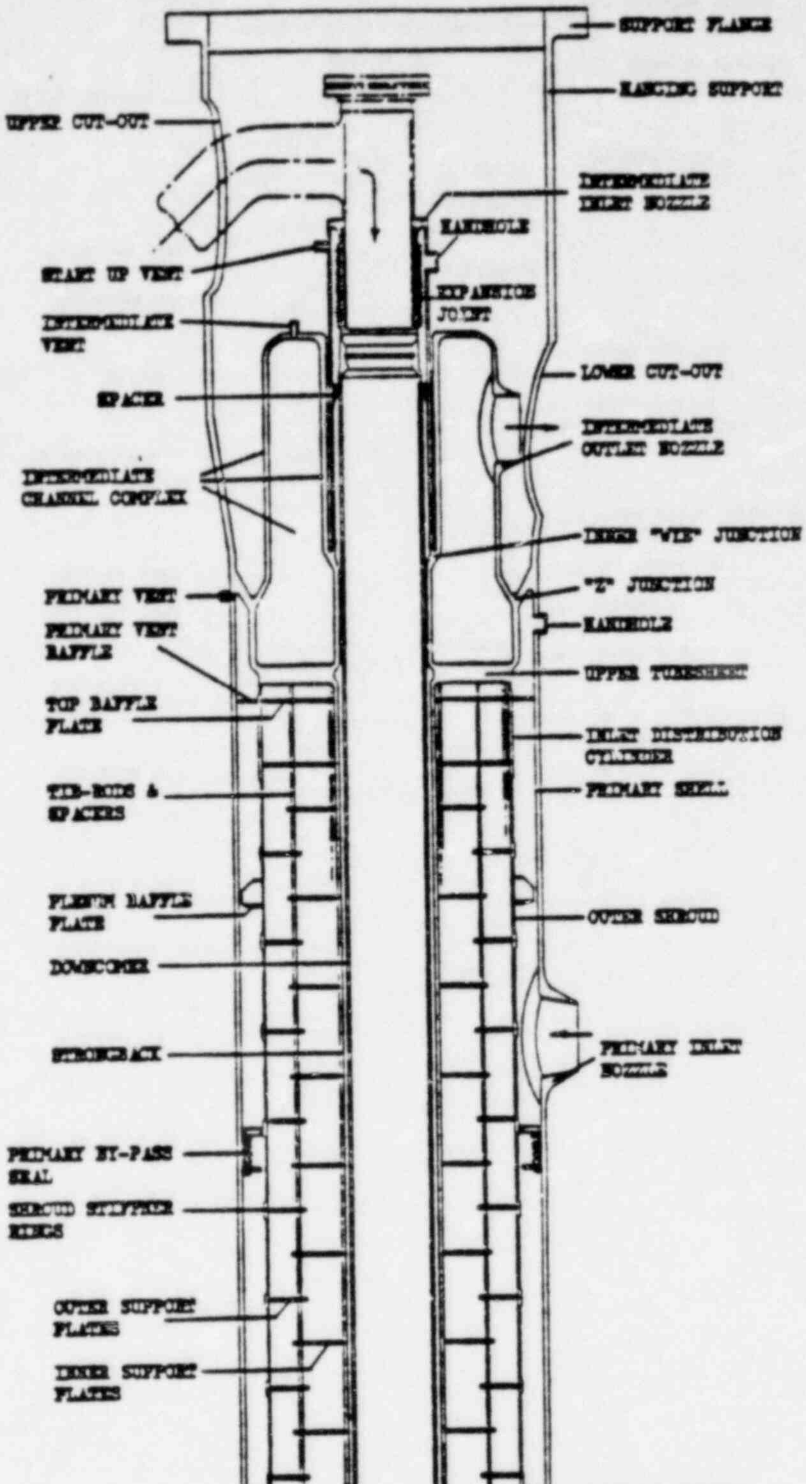

Figure Q110.78-IHX-1 General Arrangement of the IHX

Response for Evaporator and Superheaters:

Revisions have been made to plant unit evaporator and superheater designs. The structural evaluation plan (SEP) is currently in the process of being updated to incorporate:

- o The latest plant unit design
- o Revisions to the structural design criteria, analysis guidelines in RDT Standards, and the availability of new materials data in NSMH
- o Availability of materials development program results
- o Availability of the Few Tube Model test results
- o Revisions to computer codes and the introduction of new codes

The SEP will be transmitted by September 1, 1982.

Response for HTS Pumps:

Primary and Intermediate Sodium Pumps

The information presented below is based on that currently available in the pump structural evaluation plan. In general, these plans provide for the overall philosophy and analytical approach to be followed in the structural analysis and identify the conditions under which certain supplemental analysis may be required.

Components operating above 800°F are considered "elevated temperature components" and have strain limits and creep-fatigue damage limits established by Code Case 1592.

Primary and Intermediate Sodium Pump

1.0 Failure Modes and Loading Conditions

For the purposes of loads and analysis the pump (see Figure Q110.78-PU-1) is divided into four subcomponents: Subcomponent 1 - the pump tank; Subcomponent 2 - upper inner structure including the pressure bulkhead; Subcomponent 3 - the rotating machinery; Subcomponent 4 - the static hydraulics section. The predominant failure modes and associated loading conditions for each subcomponent are addressed in Section 2.0.

2.0 Structural Evaluation Criteria

2.1 Subcomponent 1 - Pump Tank

The pump tank is designed to the ASME Boiler and Pressure Vessel Code Section III, Subsection NB Class 1 and Code Case 1592, where applicable. The cone and cylinder are designed mainly by dynamic stiffness requirements. These include seismic loads and the necessity of keeping the natural frequency of the structure above the operating speed of the impeller to avoid critical resonance during operation. STARDYNE and ANSYS computer codes are used for this analysis.

The lower end of the pump tank will operate above 800°F on the primary pump, whereas all portions of the intermediate sodium pump normally operate below 800°F. Creep effects for the intermediate pump will be shown to be insignificant. The evaluation of that portion of the primary pump above 800°F will utilize methods of finite element coarse model inelastic analysis. These methods have been used on the FFTF intermediate heat exchanger as well as the intermediate heat exchanger of CRBRP.

The pump tank is divided into two groups for analytical purposes; namely, nozzles and the pump tank assembly.

Nozzles

For structural integrity of the pressure boundary, axisymmetric ANSYS models of the various nozzles will be used. Detailed time dependent temperature distributions will be determined with these models. Elastic piping loads will be evaluated using Fourier Series and axisymmetric ANSYS models. Because of the proximity of the discharge and suction nozzles in the pump tank sphere, a coarse three dimensional model will be used to assess their interaction for both mechanical and thermal loads. This work will be used to develop and justify a conservative set of boundary conditions for the axisymmetric analysis. The suction, discharge, and IHX-vent return nozzles and transition ring of the primary pump are creep-fatigue and strain limit critical.

The creep damage problem is magnified due to material decarburization which reduces the time-dependent allowable stress for a given time at 1015^{O}F by 11%. Strain limit problems occur in the weld between the nozzle forgings and the pump tank sphere. These nozzles cannot pass the simplified elastic rules of Code Case 1592-1. Coarse model inelastic analysis using axisymmetric MARC models with axisymmetric loads will be used to demonstrate compliance with the design criteria of Code Case 1592-1. The unit histogram to be used will include six subcycles and will be run for six unit cycles. It is anticipated that the histogram will be composed of two normal cooldown conditions, two U-1a transients, and one U-1b transient on one U-8 and E-5 transient (see PSAR Appendix B for definition of transients).

An additional functional requirement of the discharge nozzles involves the slip fit with the discharge duct. This slip fit must be shown to remain open during the design life and not to enlarge to the point where leakage degrades pump performance to an unacceptable level. The problem will be evaluated using an axisymmetric model of the nozzle.

The standpipe bubbler nozzle of the primary pump is not subject to transients and significant pressure. Simplified methods will be used to demonstrate its structural adequacy. The drain nozzle will be shown acceptable by comparing it to the suction and discharge nozzles. The cover gas vent nozzle is not subject to transients and significant pressure. Simplified elastic methods will be used to demonstrate its structural adequacy.

As noted earlier, the intermediate pump does not involve creep design considerations. Except for U-11a and E-4a*, the transients of the intermediate pump nozzles are very mild. The elastic shakedown limits and fatigue damage will be evaluated using twice the stress range from the E-4a transient. The severity of transients U-11a and E-4a, are such that plastic design evaluation procedures (Paragraph NB 3228 of Section III) must be used to assess distortion and total strain range (for fatigue damage). The MARC models developed to evaluate the primary pump suction and discharge nozzles will be used. The histogram will consist of transient E-4a and will be run for four cycles.

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* E-4a was subsequently deleted as a plant transient, but it has been retained as a pump design requirement since it umbrellas other emergency transients in its severity.

Pump Tank Assembly

The pump tank assembly consists of the remaining parts of the tank (sphere, sealing cone support attachment junction, sphere-to-cone transition piece, cone, cylinder, and mounting flange). These parts can have an effect on the system requirement related to peak-to-peak nozzle vibrations. In addition, deformations of the sphere-to-cone transition piece are directly related to the pump tank impedance requirement.

A three dimensional (180°) thermal and elastic ANSYS finite element model of the tank will be used to assess the three dimensional effects for mechanical and thermal loads on the sphere-to-cone transition piece. The results of this three dimensional analysis will be used to develop and justify axisymmetric models of the transition piece which will be used to evaluate the pressure boundary for safety requirements. This work will involve detailed thermal analysis for two thermal transients and eight mechanical load runs. Also the model will be used to develop the foundation stiffness of the trunnion type supports for the sealing cone assembly.

The axisymmetric analyses and structural evaluation of the sphere-to-cone transition piece and the sealing cone support attachment junction will follow the same general procedure described for the nozzles. The number of transients considered, the unit histogram, and the number of unit cycles run in the coarse model inelastic analyses will be the same. The cone and cylinder sections of the tank are not subject to severe thermal transients. Their design is based upon load controlled considerations (pressure and seismic) and the peak-to-peak nozzle motions. In the sphere the areas which are far from local discontinuities will be shown acceptable using one dimension CHERN inelastic analyses.

The analysis and evaluation of the closure and support flange complex will involve an equivalent axisymmetric interaction model. The model will use the gap element capability of ANSYS to assess the changing configuration effects due to surfaces moving in and out of contact. Sliding with friction will be considered. The bolts will be modeled with beams and local flexibility at the nut face and threaded areas will be considered. Non-axisymmetric over-turning loads (seismic and rocking vibration) will be evaluated using the model with Fourier Series. In this instance, the gap element will not be used to simulate the circumferential ring joint. The stiffnesses determined will be available for inclusion in the seismic and pump dynamics models. In addition, the dynamic pressure pulse for the SMBDB and sodium-water reaction will be evaluated.

2.2 Subcomponent 2 - Upper Inner Structure

The upper inner structure will conform to the same code requirements as the pump tank. The design of the upper closure plate and radiation shield is controlled by the design pressure and temperature requirements. Elastic failure is the predominant mode. The thermal shield will have steady state thermal gradients which will be determined by a 2D ANSYS axisymmetric model. The motor stand will be designed by the stiffness requirements of the motor

and seismic loads. The principle failure mode will be buckling under SSE seismic load. Parts of the primary pump upper inner structure will operate above 800°F; none of the intermediate pump upper inner structure operates above this temperature.

2.3 Subcomponent 3 - Rotating Machinery

The rotating machinery can be removed and inspected after an emergency or faulted event and repaired before the plant is placed in service again. Therefore, this equipment will be designed and analyzed to the ASME Boiler and Pressure-Vessel Code, Section III, Subsection NB for Class 1 Components and Code Case 1592 where applicable. However, for emergency events when Code Case 1592 is used, the design rules for load controlled stresses (Section 3227) will apply. Strain deformation and fatigue analysis need only be performed up to the emergency event and the limits will apply only to the pumps' ability to operate at pony motor speed after the event. The shaft will be designed by critical frequency requirements, inertial loads, torque and thermal transients. Failure modes will be fatigue, shear failure and creep fatigue in the shaft. The upper journal has a local area which will be analyzed inelastically with a 2D ANSYS axisymmetric model. Loads caused by bearing misalignment will be accounted for. Portions of the rotating machinery in the primary pumps operate above 800°F; all rotating machinery of the intermediate pumps normally operate below 800°F.

2.4 Subcomponent 4 - Static Hydraulics Section

The hydraulic section consists of the lower removable region of the pump inner structure and the mating sealing cone mounting in the pump tank. It will be analyzed to same code rules as Subcomponent 3 (rotating machinery). The principle loads will be thermal transients, hydraulic pressure, containment of a failed impeller, reaction loads against the hydraulic machinery due to deformation of the sphere during the thermal transients and bearing loads due to axisymmetrical heating. Creep and creep-fatigue are the predominant failure modes. Portions of the static hydraulics section in the primary pumps operate above 800°F; all of the static hydraulics section of the intermediate pumps normally operate below 800°F.

For purposes of analyses, the static hydraulics section has been divided into two parts, the sealing cone assembly and the pump case assembly.

Sealing Cone Assembly

In order to satisfy the functional requirements (operability and performance) and to supply structural characterization (stiffnesses) for establishing adequacy with respect to system requirements (peak-to-peak nozzle motions), extensive three dimensional analysis of the assembly's support on the pump tank is required. With respect to the functional requirements, the following gross distortions must be considered:

a) Time dependent (steady state loads and residual stress from plastic action during thermal transient and/or seismic DBE events).

b) Time independent (plastic action during steady state and transient conditions).

c) Time independent (elastic action during steady state and transient conditions).

With respect to system requirements and the pump seismic analysis, the load path and stiffness characteristics between the inner structure and pump tank are needed. The interaction of the sealing cone assembly with its support on the pump tank and the pump case will be established.

A full three dimensional (360°) model of the sealing cone will be used (elastic ANSYS). The gudgeon sleeve and supports will be substructured and included. Gross thermal distributions including circumferential variations due to low flow rate conditions will be determined. The detailed three dimensional analysis will be used to justify two dimensional models which will in turn be used to establish time dependent distortion and stresses.

Two elastic-plastic-creep MARC analyses will be used. The first will be a two dimensional (Rz) analysis to assess the axial distortion of the cone. The second will be a two dimensional (RG) analysis to assess the ovalization of the sealing cone at different elevations. As stated above, the three dimensional analyses will be used to justify the conservative two dimensional models. For the primary pump, a unit histogram of three subcycles will be run for six unit cycles for each of the three models. For the intermediate pump, the potential plastic ratcheting from the severe U-11a transient will be assessed using the same models with plastic action only. An objective of this analysis is to show that the sealing cone/hydraulic assembly radial gap does not increase in a manner which would degrade pump performance with respect to functional requirements.

The structural adequacy (code-type evaluation) will be evaluated for the following:

a) The discharge duct-to-sealing cone junction (modeled as an equivalent axisymmetric problem).

b) The support assembly is basically the same as the discharge nozzle and therefore can be shown adequate by comparison.

c) The cone - the 2D and 3D elastic models will be used for regions far from discontinuities.

<u>Pump Case Assembly</u>

Extensive three dimensional analysis of the pump case assembly is required in order to satisfy the functional requirements (operability and performance) and to supply structural characterization (stiffness) for establishing adequacy with respect to system requirements (peak-to-peak nozzle motions).

With respect to functional requirements, the following gross-type distortions must be considered:

a) Time dependent events (steady state loads and residual stress from plastic action during thermal transients and/or seismic DBE events). Misalignment of bearing housing due to distortion of the volute in the axial direction, and ovalization of the volute in the circumferential direction.

b) Time independent events (plastic action during thermal transients and seismic events).

c) Time independent events (elastic action during steady state and transient conditions).

d) Ovalization of the bearing housing during thermal transients due to the journal being offset from center under low flow conditions.

With respect to system requirements and the pump seismic analysis, the load path and stiffness characteristics between the inner structure and pump tank are needed. The interaction of the pump case (volute, bearing housings, and cylindrical attachment) with the sealing cone assembly and inner structure will be established. The load transfer across the lugs which connect the attachment cylinder and volute casting is important because plastic action would change the as-manufactured alignment of the two housings.

The structural adequacy (code-type analysis and evaluation) will be evaluated for the following items. The general approach for the items to be analyzed is as given for the nozzles:

a) Lower bearing housing lugs and volute-axisymmetric approximation derived from the above three dimensional analysis will be used to justify this approach.

b) Upper lugs, cylinder and volute-axisymmetric approximation will be used in the three dimensional analysis results above.

c) Attachment cylinder, baffle and bolted joint - the axisymmetric approximation will also be used to determine baffle motions for bubbler impedance.

d) Upper bearing housing attachment cylinder, baffle and bolted junction.

e) Lower bearing housing.

MARC inelastic analyses will be performed to evaluate creep damage and the effects of ratcheting strains on bearing operability. This inelastic evaluation will include axisymmetric 2D models of the upper bearing complex and of the upper case housing.

2.5 Seismic Analysis of the Pump

The pumps will be seismically analyzed using both the response spectra and the time history methods. Response spectra solutions will provide upper bound seismic loads for use in general stress analysis. Time history analysis will be performed for evaluation of more critical regions and of interaction effects such as journal/bearing impact during seismic events. Also interactions occur through the pump case and sealing cone assemblies which are critical with respect to functional and system requirements. The interaction is nonlinear due to the gaps which will open and close during the seismic event. The local impacts which result when the gaps close will be considered. The model will be developed using the dynamic options of the ANSYS and STARDYNE computer programs. ANSYS will employ axisymmetric conical shell and continuum elements with non-axisymmetric loads. The STARDYNE model will be a 3 dimensional beam representation. The steps which will be carried out are as follows:

a) Local stiffnesses will be developed at points of internal support. This will be done by means of small static computer models or by hand.

b) The remainder of the linear dynamics model will then be developed. This includes the addition of any fluid masses and external mechanical masses such as the motor and/or piping.

c) The time-history input loadings will be developed on tape from the support foundation time-history acceleration for the DBE and SSE events.

d) The size of the above model will be reduced by substructuring techniques in order to lower solution run times.

e) The STARDYNE model will be run simultaneously in all three directions. The ANSYS model will be run in each of three directions and the results stored on tape. The results will be scanned to determine the maximum response points at various critical points.

f) Internal forces and/or stresses will be derived for use in subsequent stress evaluation.

g) Final results will be developed and tabulated for the entire unit. The results of the analysis along with the details of the model will be summarized in a final report.

2.6 Overall Pump and Foundation System Dynamic Analyses

For the overall system analyses of the pump and the drive motor system, the model will include the coupling effects of the foundation and interconnecting piping. The system is analyzed with the finite element HASTRAN, ANSYS and STARDYNE codes. A detailed model of both the drive motor and pump that includes the foundation elements and main piping spring mass elements will be used.

3.0 Structural Test to Support Analysis

At present it is planned to design by analysis. However, half scale and full scale water tests have been run to determine and adjust the pump performance characteristics. A dynamic analysis of the pump operating in the water test setup was made and the water test results confirmed the analysis in all cases. The pump shaft's mid-span deflection was measured and confirmed the maximum T.I.R. of 0.017" as predicted in the dynamic analyses. The test results indicated hydrostatic bearing lift-off at all operating conditions as predicted by the dynamic analysis and confirmed the hydrostatic bearing load capability of the pump. A prototype pump will be tested in sodium for the upset thermal transients identified in the pump specification, up to the facility capability (temperature increase of 400°F up to 1000°F and decreases of approximately 500°F). Full scale water tests will be run on the plant pumps to determine and adjust their performance characteristics.

4.0 Relevant Programs from Other Facilities

Experience gained from the FFTF sodium pump tests has been applied to the design of the CRBRP pumps where applicable. In particular, bearing clearances in the CRBRP pump are being adjusted to compensate for Type 304 stainless steel shrinkage as observed in the FFTF tests.

5.0 Computer Programs

Computer codes used in the pump dynamics analysis are: ANSYS, HASTRAN and STARDYNE.

The computer codes used in the pump structural analysis are: ANSYS, HAFMAT, LPGEN, MARC, N-1045, N-1050, N-2050, N-2060, PRI[illegible]P AND SINDA.

ANSYS, HAFMAT and MARC codes are described in Appendix A of the PSAR. The remaining codes will be added in an upcoming PSAR amendment.

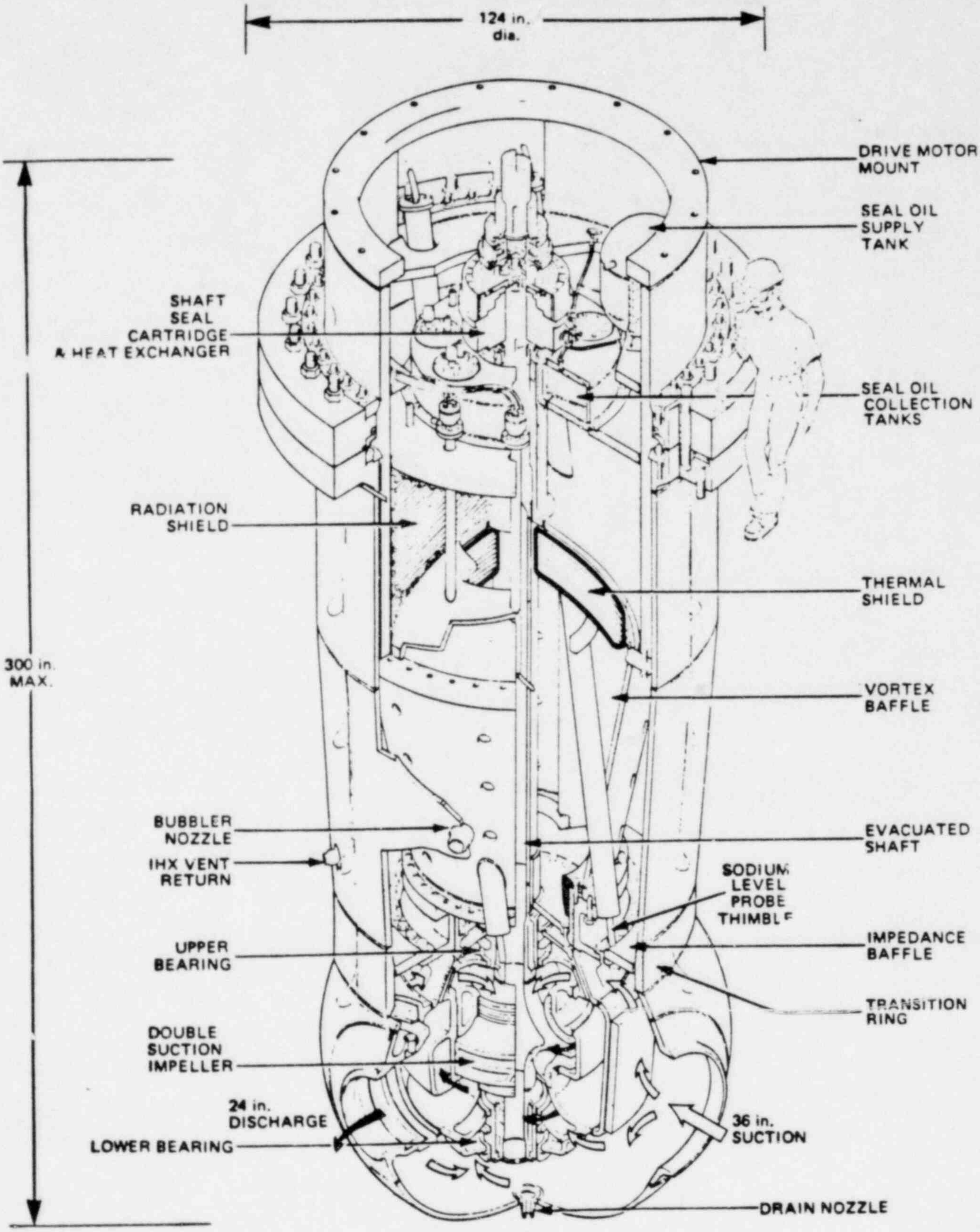

FIGURE Q110.78-PU-1 PRIMARY PUMP ISOMETRIC

Response for HTS Piping:

The methods used in the static and dynamic analyses of the primary and intermediate HTS piping to determine structural and functional integrity are summarized in this response.

The Heat Transport System (HTS) consists of piping and components required to transport reactor heat to the steam generators. The system is comprised of three approximately identical cooling circuits, each of which includes a Primary Heat Transport System (PHTS) loop and an Intermediate Heat Transport System (IHTS) loop thermally coupled by an Intermediate Heat Exchanger (IHX). The PHTS and IHTS piping within containment are located within shielded and inerted cells (nitrogen atmosphere with a maximum of 2 percent oxygen). A detailed description of the PHTS and IHTS piping is provided in Chapter 5 of the PSAR.

The HTS Piping shall be designed, constructed and stamped in accordance with the rules for Class 1 (ANS Safety Class 1) Nuclear Components in the ASME Boiler and Pressure Vessel Code, Section 111, 1974 Edition with Addenda through Summer 1975 and Code Case Interpretations 1592-7, 1593-1, 1594-1, 1595-1 and 1596-1 supplemented by RDT Standards F9-4T (dated January 1976) and E15-2NB-T (dated November 1974, Amendments 1, 2 and 3). The piping will be designed to assure that the stresses, strains and deformations are within the applicable Code criteria, and to meet the system functional requirements. In addition, simplified inelastic and detailed inelastic methods that are to be used will conform to the requirements of RDT Standard F9-4T and the guidelines of RDT Standard F9-5T (dated September 1974).

FAILURE MODES

Analyses will be performed on the piping to reflect both time-independent and time-dependent material properties and structural behavior (elastic and inelastic) by considering all the modes of failure listed below:

1. Ductile rupture from short-term loadings

2. Creep-rupture from long-term loadings

3. Creep-fatigue failure

4. Gross distortion due to incremental collapse and ratchetting

5. Loss of function due to excessive deformation

6. Buckling due to short-term loadings

7. Creep buckling due to long-term loadings

LOADS

It is convenient in the context of the structural analysis and stress evaluation of the HTS piping to separate the loadings into two categories; System Loads and Piping Component (Local) Loads. Requirements regarding the combination and application of loadings are specified in the applicable ASME Code, RDT Standard documents, NRC Regulatory Guides and CRBRP criteria documents. (See PSAR Section 3.9)

System Loads

System design loads are comprised of internal pressure, deadweight, earthquake loads, thermal expansion, Sodium/Water Reaction (SWR) loads and system thermal transients. The combination or treatment of the system loadings in the analysis process for the HTS piping and support systems is shown on Figure Q110.78-P-1. These loads are described in detail in the following:

1. Internal Pressure

   System pressures include the piping internal pressures for Design, Normal, Upset, Emergency and Faulted Conditions. Local membrane and bending stresses resulting from system pressures in the piping are determined by standard practices and are combined with other calculated stresses.

2. Deadweight

   The deadweight loading imposed by the piping on itself and on the supports consists of the dry weight of the HTS piping and the weight of the sodium contained in piping during the operating conditions. The total weight of the insulation and trace heaters around the piping provides an additional deadweight loading as do the weight of valves, clamps and portions of the restraining devices such as snubbers.

3. Earthquake Loads

   The intensity and character of the earthquake motion which produces forced vibration of the equipment mounted within the containment building are specified in terms of the floor response spectrum curves or time-histories at various elevations within the containment building. These response spectra or time-histories are developed from a three-dimensional multi-mass elastic dynamic model of the reactor containment and steam generator buildings. The forcing function applied to this model is the site seismic ground motion.

The subsequent motion throughout the buildings at various elevations is the basis for the Operational Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE) floor response spectrum curves.

4. Thermal Expansion

The vertical and lateral growth of piping and the main HTS components as temperature rises above the ambient temperature impose loads in the piping.

5. Sodium/Water Reaction Loads (IHTS Piping)

A possible event considered is the Design Basis Leak (DBL) within the Steam Generator. Large pressure peaks reverberate through the IHTS pipin when sodium and water react in the steam generator under the postulated rupture of steam/water tubes. As pressure increases the rupture disks fail and sections of the IHTS piping are rapidly evacuated. Both the pressure transients and inertial loading of evacuation produce responses in the IHTS piping.

6. System Thermal Transient Loads

System operating transients such as plant heatup, cooldown, reactor scram, etc. cause changes in thermal expansion loading as described above and in addition may cause large through wall thermal gradients which must be considered in the evaluation. From heat conduction analyses, system thermal transients are analyzed to determine local thermal stresses in the piping system which in turn are combined with the other local calculated stresses.

Piping Component (Local Loads)

The pipeline flexibility analyses under system loadings generate data on displacements, forces and moments at selected points along the piping resulting from deadweight, thermal expansion, seismic conditions and other dynamic conditions such as for sodium/water reaction (SWR) loadings. Local membrane and bending stresses resulting from system pressures in the piping are determined by standard practices. From heat conduction analyses, system thermal transients are analyzed to determine local thermal stresses in the piping system.

The flexibility loads are combined in an appropriate manner and applied in the stress analysis of a local region of the piping system to determine the induced stresses and strains at the piping component level. These are added to the pressure and thermal stresses to obtain the total stresses for comparison with criteria.

Maximum allowable interface loads between the HTS piping and certain attached components such as the reactor vessel and the IHX are specified at the component nozzles. The nozzle loads determined from the flexibility analyses in terms of weight, thermal expansion, seismic, etc. (or combinations thereof) must be within these maximum allowables or redesign of the piping becomes necessary.

In the design of the piping, the interface interaction between components and piping is considered in one of two ways. Either the displacements of the component nozzles are imposed upon the piping or the component is included in the analysis model of the piping. When components are included in flexibility models it is necessary to consider the loads introduced by the relative motion of component support locations. For example, under seismic conditions it may be found that supporting floors have movement relative to each other. Loadings caused by such interface conditions shall be identified and considered in the structural evaluation.

ANALYSES

The evaluation of the HTS piping design is made in accordance with the methods outlined in recognized nuclear industry codes and standards, namely the ASME B&PV Code and RDT Standards. The governing Code and Standards for the piping are identified in the introductory paragraphs of this response.

The evaluation of the HTS piping includes flexibility analyses, heat transfer analyses, and stress analyses; these types of analyses are described in the following subparagraphs.

Flexibility Analyses

The objectives of the flexibility analyses are to determine moments, forces and deformations induced in a piping system due to the types of loadings discussed previously. To a large extent the flexibility analyses consider elastic formulations; the piping is designed, wherever practical, such that the stresses are sufficiently low to ensure elastic behavior. In regions where inelastic behavior is expected, non-linear flexibility analyses are made.

Procedures for constructing elastic flexibility models are based on finite element techniques, using matrix displacement methods. The specific computer finite element model or flexibility model for each piping system is composed of a series of pipe elements of the appropriate flexibility character with an appropriate lumping of mass at the intersection of each element (node point). The nodes are selected at changes of sections, at locations of equipment support, at equipment centers of gravity, at points of restraint, at special locations where response is desired and at intermediate locations to limit the length of the elements so that the model will adequately represent the actual system. The number of lumped masses or degrees of freedom shall be such as to insure compliance with requirements of PSAR Section 3.7.2.3. Other assumptions common to this type of analysis include:

- o Deflections are small in proportion to the size of the configuration so that changes in position and shape of a member are ignored in their effect on flexibility of the whole, and

- o effects of direct axial compression or extension, or of shear deflection, are negligible in comparison with bending and torsional effects.

The influence of localized effects on deflections and rotations is provided by the inclusion of flexibility factors in the formulations. Guidelines for the calculation of the flexibility factors are given in Subparagraph NB-3687 of the ASME B&PV Code, Section III. It is noted that the formulations tend to overestimate the stiffness, and therefore are conservative. This same guideline is employed in constructing the flexibility indices for items such as nozzles and anchors for which no ASME Code procedures are specified.

To the maximum practical extent, the HTS piping flexibility analysis models are defined so as to include the connecting component, pipe or auxiliary equipment. This minimizes the number of points at which seismic inputs must be determined. This also avoids over conservatism at interfaces between items when the stiffness of one is not negligible relative to the other. Further, this approach minimizes the number of flexibility analysis models and leads to a consistency among the models used for the several types of static and dynamic loadings.

Representations which are included in the piping system models to represent the connected components (e.g., Reactor Vessel) are checked against more detailed component models to assure correct dynamic response prediction. Piping-type stick elements and lumped masses are used for modeling components just as for piping sections. Component support stiffnesses are included in such models and where appropriately defined, equivalent support of floor masses are included. Models also include modeling of shell nozzle flexibility.

Elastic flexibility analysis for the PHTS and IHTS in-containment piping are made with the WECAN or WESTDYN computer programs. For deadweight and thermal expansion analyses, linear elastic models of the piping from the component nozzle anchors are used. For seismic analyses, extensive use is made of the response spectrum method in accord with the Appendix A to PSAR Section 3.7. Time-history analyses are used wherever the response spectrum method is judged to be overly conservative. For sodium/water reaction (SWR) and SMBDB conditions, the response of the IHTS and PHTS piping, respectively, is determined by integrated time-history analysis, using forcing functions that are prescribed as force-time histories at change-in-direction and flow restriction locations in the piping system.

The piping seismic flexibility analysis for the PHTS 36" Hot Leg includes the reactor vessel, the outlet downcomer and the pump. The PHTS 24" Hot Leg model includes the pump and IHX. The PHTS 24" Cold Leg model includes the IHX, check valve, reactor vessel and inlet downcomer. The in-containment IHTS 24" Hot and Cold Leg models include the IHX and models of the RCB penetration seals. For the SWR analysis of the in-containment IHTS piping, a portion of the ex-containment piping is also added to models. The seismic models for the small-diameter PHTS piping (IHX vent, pump bubbler, and pump drain lines) include the connecting component models (IHX and Pump) as well as the guard vessels when the piping is supported off a guard vessel.

The elastic flexibility analyses for the IHTS ex-containment piping are made with the SAP computer program. Post processing programs are used to made the stress calculations in accordance with the ASME Code. The models for the flexibility analyses of the IHTS ex-containment piping are briefly described as follows:

Hot Leg

The Hot Leg model includes the superheater inlet and outlet, the evaporator inlet and an anchor at the penetration of the HTS cell of the Reactor Containment Building. Normally 3 to 5 thermal expansion cases are performed. These expansion cases will envelope all of the thermal operating conditions. The displacement of the equipment nozzle depends on the particular thermal expansion case being analyzed.

The superheater inlet nozzle is treated as an equivalent pipe that is carried to the superheater shell; at the shell the equivalent pipe is rotationally fixed.

At the superheater outlets, the superheater nozzles (two) and the superheater shell are treated as equivalent pipes. The shell equivalent pipes (one for each side of the shell) are carried to the vertical centerline of the superheater. At this point, the equivalent pipes are rotationally fixed.

The nozzle equivalent pipe is rotationally fixed at the shell.

At the evaporator inlet the evaporator nozzle and the evaporator shell are treated as equivalent pipes. The shell equivalent pipe is carried to the vertical centerline of the evaporator. At this point the same equivalent pipe is rotationally fixed. The nozzle equivalent pipe is rotationally fixed at the shell.

At the anchor of the RCB penetration, the piping is geometrically fixed both with respect to rotational and linear displacements.

Cold Leg

The cold leg model includes the evaporators (outlets), the pump (inlet and outlet) and an anchor at the penetration of the HTS cell of the Reactor Containment Building.

At the outlets of the evaporators, the evaporator nozzle and shell are treated as equivalent pipes. The shell equivalent pipe is carried to the vertical centerline of the evaporator. At this point the same equivalent pipe is rotationally fixed and the thermal displacement imposed. Also, the nozzle equivalent pipe is rotationally fixed at the shell.

The pump inlet is treated in a similar manner. At the inlet, the pump nozzle and shell are treated as equivalent pipe. The shell equivalent pipe is carried to the vertical centerline of the pump. At this point the equivalent pipe is rotationally fixed and the thermal displacement imposed.

At the pump outlet, the pump nozzle is treated as an equivalent pipe. This equivalent pipe is rotationally fixed at the pump shell.

At the anchor at the penetration of the Reactor Containment Building, the cold leg is geometrically fixed - both with respect to rotation and displacement.

Nonlinear flexibility analysis is required for fill and drain loading conditions for the PHTS large piping. This need arises from the use of constant load hangers to support the piping. The hanger load values are set as appropriate for the filled condition. When empty these forces lead to excessive stress and deformation. Devices to limit the travel of the hangers are required and the determination of appropriate limiting values involves a flexibility analysis which is nonlinear due to the changing free/fixed conditions of the hangers during fill and drain.

An inelastic flexibility analysis is required for the PHTS 24-inch hot leg where the calculation of induced forces on an elastic basis is excessively conservative because stress relaxation is not accounted for. The use of an inelastic flexibility analysis to calculate the forces applied to local regions is not considered to invalidate the use of elastic analysis rules in evaluation of the local region for compliance with applicable structural integrity requirements. The inelastic flexibility analysis is performed with the MARC computer program using the curved pipe finite element model specifically developed for such analyses.

No significant design analyses for short-term primary or long-term creep buckling of the in-containment piping is required. Load-controlled forces that can lead to buckling due to short-term loadings are kept small by the piping support arrangements. The predominant operating stresses on the piping are due to thermal expansion and thermal transients (or deformation-controlled loading). Buckling in straight pipe sections under deformation-controlled loadings does not pose a problem because of the low axial load levels and the limited deformations that could result. Also, the buckling or plastic collapse of the elbows in the HTS large-diameter piping is not a practical mode of failure because rotations of the elbows are limited by the piping support system.

Heat Transfer (Thermal Transient) Analysis

Thermal transients are the source of some of the largest variations of stress in the HTS piping. Thermal analysis of piping temperature distributions during such occurrences are therefore an important part of the structural integrity assessment for the piping. In this section, the procedure and principles employed for HTS piping temperature distribution analyses are described.

The transient events used as the basis for piping design/analysis are specified in the piping design specification for each section of piping loop in the piping system. Thermal hydraulic data, in the form of temperature, flow and pressure time plots, are given for each thermal transient in the specification.

The heat transfer analysis of the piping components is carried out with finite element programs because these analyses can become complex. Some examples of when a detailed analysis are necessary include:

(1) When axial heat flow as well as through-the-wall flow is significant such as in a branch connection.

(2) when the specified sodium transient is complex.

(3) When the radiation mode of heat transfer is significant along with convection and conduction.

ANSYS, WECAN and TFEATS are the basic computer programs used to solve temperature distribution problems for the HTS in-containment piping system. Geometry generators are internal to these programs which are used to prepare models and input for both one-dimensional and two-dimensional heat transfer problems.

The computer programs have the capacity to determine through-wall temperature gradients in the piping as a function of time for time-dependent input functions of mass flow rate and bulk fluid temperature. They have the capability of decomposing the through-wall temperature distribution into three components as described in sub-paragraph NB-3653 of the ASME B&PV Code, Section III. These three components are the wall average temperature (T_a), the moment generating equivalent linear distribution (ΔT_1) and the nonlinear portion with zero average value and zero first moment with respect to the mid-thickness (ΔT_2). These quantities are used with ASME code formulas to determine secondary and peak stresses for use in the ratchetting and fatigue evaluation of the piping components.

Several locations in the piping system required special thermal analysis such as at nozzle-to-pipe joints, flued heads, tapers, branch connections, etc. For these general thermal analyses, the large finite elements programs are readily applicable. For nozzle-to-pipe joint discontinuities, the thermal response of the structure on each side of the interface is determined by calculating the radial temperature distribution at various time periods during the various thermal transients and then calculating the average temperature (T_a and T_b as defined in the ASME Code) as a function of time for each region. The maximum temperature difference ($T_a - T_b$) between these two quantities during each transient is used to determine peak thermal discontinuity stresses at the interface in accord with the ASME Code formulas.

Stress (ASME Code Evaluation) Analysis

The technical approach taken in analyzing and evaluating piping components for compliance with structural integrity requirements follows the procedure outlined in Figure Q110.78-P-2 (Blocks 1 through 9). The process starts off with the through-wall temperature results ($\Delta T_1, \Delta T_2$ and $T_a - T_b$) obtained from the heat transfer analysis as discussed previously and as shown in Block 1. elastic flexibility analysis loads (forces, moments and displacements) are then obtained for all the piping system load conditions as indicated by Blocks 2 and 3.

In all cases the analysis and evaluation of the piping components proceeds on an elastic basis as shown in Block 4. The ELTEMP computer code is used to analyze and evaluate piping components on an elastic basis in accord with Code Case 1592 and RDT Standard F9-4T.

The ELTEMP computer program is operational and the calculations performed by ELTEMP have been verified. This computer program is considered to be satisfactory for use in elastic evaluation of HTS piping.

The ELTEMP computer program will be documented, revised and maintained as a part of the structural evaluation program for the HTS piping and will be used in the preparation of final stress reports for CRBRP Class 1 piping. At present, the applicable ASME Codes and RDT Standards do not provide specific rules for piping at elevated temperature; only general rules in accord with NB-3200 of the code are provided. To assure consistency, the preparation of the ELTEMP computer program is coordinated with other efforts to prepare special rules for elevated temperature piping for inclusion in the applicable Codes and Standards.

A number of fallback approaches are used to assess piping components which are not shown to be satisfactory on an elastic basis using Blocks 3 and 4. if the reason for noncompliance is judged to result from high thermal transient stresses, the procedure is modified to use an elastic flexibility analysis and an inelastic analysis of the piping component (Blocks 3 and 6). If the reasons for noncompliance is judged to result from excessive flexibility analysis forces, the procedure is modified to use an inelastic flexibility analysis and an elastic piping component analysis (Blocks 5 and 4). In some cases both the flexibility and component analyses need to be inelastic (Blocks 5 and 6).

It is anticipated that the foregoing four alternatives will be adequate for the design/analysis of most of the HTS piping components. However, the applicability of the CHERN computer program must be verified for use under nonaxisymmetric conditions.

Block 7 identifies an inelastic analysis approach of last resort. This type of analysis is required for piping systems that are highly loaded by thermal expansion and thermal transient stresses such as the PHTS 24-inch hot leg between the pump and IHX. Block 8 is included in Figure Q110.78-P-2 to indicate that some individual discontinuity regions may require detailed multi-dimensional inelastic analysis. In addition, limited indirect use of these types of analyses is anticipated in the verification of simpler design analysis procedures.

The scope of analysis as described above does not include consideration of vibration. The potential for excitation of vibration is considered in the structural evaluation program. The effects of vibration induced by the pump impellor are considered for the PHTS hot leg piping connected to the pump.

An analysis checklist for the piping is included in Figure Q110.78-P-3. This checklist will be expanded in size and detail as the analyses progress.

MATERIAL PROPERTIES

The elastic material properties used in the structural evaluation of the HTS piping are specified in the ASME Code Documents. The Nuclear Systems Materials (NSM) Handbook (TID-26666) is used as the authoritative source for material properties not specified in the applicable Code Documents. Where material properties are required which are not available in the Nuclear Systems Materials Handbook or the ASME Code, action will be taken using procedures approved by the CRBRP Project Office to obtain the required material properties.

A collection of computer files containing material property data, routines for interpolation and routines for material deformation models, which are based on the materials data given in the Nuclear Systems Materials Handbook and the ASME Code, are used for analysis of the HTS piping (and other CRBRP components).

Thermal and mechanical properties are considered in the selection of materials for use in the HTS piping. Further, consideration is given to material properties in connection with fabrication procedures. For example, the need and procedure for accounting for the effects of cold work in the design analysis is examined. A thickness allowance is provided, in the manner described in the ASME Code Section III Subsection NB-3600, to account for the effects of corrosion and erosion.

For material properties critical to the design/analysis process, consideration is given to the use of minimum, average or maximum properties as appropriate to obtain a reasonably conservative result. For example, in certain critical situations the evaluation of deformation limits is based upon minimum stress-strain curves. The selection of appropriate properties is guided by RDT F9-5T.

Material Degradation

Most of the data used to define the allowable design stresses in the ASME Code were obtained from tests conducted in air. No attempt is made in the Code to account for the effects of other service environment. The LMFBR development program has focused attention on the mechanical behavior of reactor materials when exposed to high-temperature liquid sodium, in addition to fast neutron irradiation and to long time aging at elevated temperatures. Guidance for establishing the effects of the service environment upon the response and failure characteristics of the structural materials is summarized in Table Q110.78-P-1. A brief discussion of the environmental effects is given in the following paragraphs.

Thermal Aging Effects on Mechanical Properties:

Types 304 and 316 stainless steels are non-age hardenable alloys. Thus, no significant changes in strength or hardness of annealed material would accrue from long term aging at temperatures up to 1200°F, unlike the precipitation-hardened stainless steels. Some slight increases in strength and decreases in ductility may occur due to carbide formation, together with a reduction in the room temperature impact strength. Of more significance, is the fact that these alloys will sensitize during long term service in the temperature range from 800° to 1500°F. In this phenomenon, carbide precipitation occurs at the grain boundaries, the adjacent matrix becomes depleted in chromium and the grain boundary regions become susceptible to attack by corrosive media. Such attack is not likely to occur in sodium, which, if pure, is a relatively inert environment. However, cracking may initiate during fabrication and the other pre-operation periods when the component is not exposed to sodium, due to environmental conditions (presence of water and halides). Because of this, precautions must be taken during such periods to ensure that contact between sensitized material and potentially corrosive media is avoided. Hence, no allowances have been made for the effects of thermal aging on the properties of types 304 and 316 stainless steels used in the HTS piping. This did, however, demand that control be specified and exercised during the fabrication process to prevent stress corrosion and intergranular attack.

Neutron Irradiation Effects on Mechanical Properties

The effect of neutron irradiation on the mechanical properties of a material are generally to increase the tensile and yield strengths, and to decrease the ductility. The actual magnitude of the effect is dependent on several parameters, such as the temperature of irradiation, the test temperature, the neutron energy spectra and the neutron fluence.

Two alternate procedures have been used to account for the effects of neutron irradiation on the structural integrity of components. The comprehensive approach characterizes the effects of the neutron irradiation upon each material response and failure mode considered by the ASME Code.

When necessary, additional failure modes are considered. The alternate approach involves finding the threshold where irradiation effects first become measurable (in terms of structural response and integrity). If irradiation levels are held below these threshold levels, no fluence effects will take place.

For austenitic stainless steels (Types 304 and 316), measurable loss of ductility (total elongation) can first be detected at about 10^{21} nvt total fluence for temperatures in the range of 600°F to 1100°F. The pipe wall end-of-life fluence for the HTS piping within the reactor cavity is less than 1×10^{20} nvt and hence no fluence effects are expected.

Effects of (Nitrogen + 2% Oxygen) Atmosphere on Mechanical Properties)

The selection of nitrogen gas as the atmosphere for the reactor cavity and HTS cell was based on the desire to prevent chemical reactions should molten sodium leak into the cavity and HTS cell from any source. However, the exposure of austentic stainless steel to pure nitrogen for extended periods of time at elevated temperatures may lead to the formation of a thin nitrided layer. This is considered undesirable because of the brittleness of such layers. To minimize the formation of such a layer, a small percentage of oxygen (<2%) is introduced into the nitrogen.

Effects of (Argon-Plus-Sodium-Vapor) Atmosphere on Mechanical Properties

Very little is known of the effects of exposure to an argon-plus sodium-vapor atmosphere on the mechanical properties of austenitic stainless steel. It is possible that, if the sodium vapor is continually condensing on the material surface and rejoining the main reactor coolant, there could be some interstitial transfer. However, because of the scarcity of data, it is not possible to provide quantitative assessments of such effects at this time. Practically, the potential for significant mass transfer via condensation is insignificant. It is judged that exposure to the cover gas should be considered the same as exposure to liquid sodium without loss of interstitials.

Surface Effects of Liquid Sodium on Mechanical Properties

The interactions of the sodium environment with the material, excluding interstitial transfer effects, may be defined as surface effects. Compared with air testing, liquid sodium may cause certain metallic elements to be transferred from the hotter to the cooler regions of HTS systems. In addition, surface oxidation in liquid sodium is greatly reduced when compared to air testing. It is believed that these surface effects are insignificant in their influence on short-term tensile properties.

For time-dependent deformation, such as stress-rupture and fatigue, the effects of a liquid sodium environment are complex and need to be considered in detail. In the case of stress-rupture, it has been shown that for a given temperature and stress, rupture times in air are longer than those in liquid sodium. Figure Q110.78-P-4 gives a sodium-environment correction factor which applied to the rupture strength data specified in ASME Code Case 1592 for Types 304 and 316 austenitic stainless steel. This effect is used in all evaluations where stress-to-rupture is involved.

Fatigue properties of materials can be greatly affected by the environment in which the properties are measured. The avoidance of excessive surface oxidation by testing in sodium (or inert gas) instead of in air increases the cycles-to-failure for a given strain range. These increased cycles-to-failure values observed when testing in sodium are being independently verified. No increases in the design fatigue limits due to exclusion of oxygen effects is permitted.

Interstitial Transfer Effects on Material Properties

In the HTS piping, interstitial carbon and nitrogen are transferred from the hotter to the cooler regions. This leads to weakening in the decarburized and denitrided regions and to strengthening in the carburized and nitrided areas. In the case of fatigue behavior, however, the effects of interstitial absorption at the surface are complicated because of two concurrent mechanisms. On the one hand, carburization can lead to enhanced crack nucleation at carbide particles and, on the other, surface strengthening during strain-controlled fatigue will increase the proportion of elastic straining which is less damaging than plastic deformation. Studies indicate that, in general, the austenitic materials will be carburized. However, the crossover from carburization to decarburization is system dependent and it is likely that in certain systems at least some of the austentitic material will be decarburized. Procedures have been established for the CRBRP piping by which the extent of interstitial transfer for Types 304 and 316 stainless steel can be determined and from this the effects of mechanical behavior can be calculated.

ASME Code Case 1592 requires a minimum carbon content of 0.04 percent for austenitic stainless steels. To compensate for any interstitial transfers, the material is being ordered with a minimum carbon content of 0.055 percent for the primary hot-leg piping. This additional carbon percentage is considered sufficient to account for carbon depletion in the high temperature regions of the primary loop.

Although some carbon depletion is expected in the intermediate HTS piping, the specified minimum carbon content of 0.04 percent is considered adequate.

STRUCTURAL VERIFICATION TESTS

The planned technical approach for the design/analysis of the HTS piping includes the use of some methods, procedures, designs, etc. that are not fully developed, substantiated or verified. To account for this, appropriate testing and verification will be carried out as part of the HTS piping design/analysis effort and/or LMFBR base technology programs which are considered relevant to the structural evaluation of the HTS piping. Table Q110.78-P-2 provides a list of completed and ongoing base programs which will contribute to verification of design methods and, hence verification of the adequacy of the HTS piping.

Of specific importance is the qualification testing of the CRBRP HTS piping support system identified as Items 3 and 12 on Table Q110.78-P-2. These programs will qualify the load carrying capability of the vertical and horizontal pipe clamp designs. They will also evaluate and assess the mechanical snubbers and constant load hangers when used in combination with the pipe clamps as a complete pipe support and restraint system. Under these programs, models also will be developed and verified for piping restraints for use in the design/analysis of LMFBR piping systems.

To determine the performance capabilities of the pipe clamps, testing has been done at various temperatures up to 1015°F and under various static and dynamic loadings. The test articles were instrumented with thermocouples, strain gages, accelerometers, load transducers and displacement transducers to gather data from which stresses and strains were calculated. The clamps were inspected during testing to ensure proper fit during thermal expansion movements of the pipe test section and to assure load carrying capability during seismic-type shocks and vibrations.

Testing was performed on 24-inch pipe clamps. Shock loadings at forty different frequencies from 5.64 Hz to 62.98 Hz and with corresponding forces between 2 lbs. and 19635 lbs. were used.

Results from all the direct CRBRP test programs and appropriate base technology programs for piping will be used to provide assurance that designs are structurally adequate and analysis calculations reasonable in the certified ASME stress report and FSAR.

COMPUTER PROGRAMS

Responses to the NRC questions 110.27 and 110.58 provide information relating to the computer programs used for the static, heat transfer, and dynamic analysis of Seismic Category I structures. Of these, the following computer programs will be used for the analyses of HTS piping within containment:

1. WECAN

2. WESTDYN

3. MARC

4. ELTEMP

5. CHERN

6. ANSYS

7. TFEATS

All the above programs have been described in Appendix A of the PSAR and hence are not repeated in this response. Appendix A also provides information relating to the adequacy of these codes and verifications that have been completed or planned. Where verification studies are in progress, the results will be provided in the FSAR.

TABLE Q110.78-P-1 SUMMARY: ENVIRONMENTAL EFFECTS UPON ANNEALED TYPE 304 AND 316 SST

Stress Intensity Category	Specific Item	Sodium Exposure	Loss of Interstitials: Effect	Loss of Interstitials: Basis+
Primary Limits	S_r	Degrading	Degrading	Ave
	S_y	-*	Degrading	Ave
	S_u	-	Degrading	Ave
	Creep Eqn	-	DNI	Ave
	Onset Tertiary Creep	-	DNI	Ave
Primary & Secondary (and Buckling)	S_r	Degrading	Degrading	Ave
	S_y	-	Degrading	Ave
	S_u	-	Degrading	Ave
	Creep Eqn	-	DNI	Ave
	Onset Tertiary Creep	-	DNI	Ave
	Creep Hardening	-	DNI	Ave
	Stress-Strain Eqn	-	Modification	Ave
	Cyclic Hardening	-	DNI	Ave
	ϵ_{total}	-	Improvement	Ave
Peak	S_r	Degrading	Degrading	Point***
	S_y	-	Degrading	Point
	S_u	-	Degrading	Point
	Creep Eqn	-	DNI	Point
	Onset Tertiary Creep	-	DNI	Point
	Creep Hardening	-	DNI	Point
	Stress-Strain Eqn	-	Modification	Point
	Cyclic Hardening	-	DNI	Point
	Fatigue Curve	DNI**	DNI	DNI
	Creep-Fatigue Interaction	-	DNI	DNI
	Stress Rupture	-		
	Notch Effect	-	DNI	DNI
	Fatigue Notch Effect	-	DNI	DNI
	Saturation of Hold Time Effects	-	DNI	DNI

*No significant effect expected
**DNI - Design information not included
***Point - Instantaneous value or peak, not average values.

+ Basis - Denotes whether point (C+N) content or average content is used as the basis to establish the effect.

TABLE Q110.78-P-2

BASE TECHNOLOGY PROGRAMS IN SUPPORT OF THE HTS PIPING DESIGN EFFORT

Item	Title (With Objective)	Status
1	Thermal Transient Facility (Analysis and test to verify inelastic predictions of ratchetting of piping - welded pipe and Croloy-to-304/316 SS joints)	Ongoing
2	Transition Weld Development	Ongoing
3	Piping Supports (Establish design of piping supports using load bearing insulation - FFTF type)	Complete
4	Mixing Tee Studies	Complete
	a. Hydraulic Tests of SPTE Mixing Tee Model (Water Tests)	Complete
	b. Mixing Tee Considerations for FFTF (Water and Sodium Tests)	Complete
	c. CRBRP IHTS Mixer Thermal-Hydraulic Model Tests	Complete
5	Fracture Mechanics Studies (To prove leak-before-break assumption)	
	a. Characterize Crack Propagation, Critical Crack Size & Crack Leakage	Complete
	b. Sodium Effects on Fracture Mechanics	Complete
	c. Corrosion Study of Sodium Leaking to Air	Complete
6	Evaluation of Formed & Welded Pipe	Ongoing
7	Multi-Loading-Test Facility (MLTF) (inelastic response of piping, straight pipe, elbow and tee sections)	Ongoing
8	Simplified inelastic design analysis procedure for piping systems, PIRAX-2	Complete

TABLE Q110.78-P-2 (Continued)

BASE TECHNOLOGY PROGRAMS IN SUPPORT OF THE HTS PIPING DESIGN EFFORT

Item	Title (With Objective)	Status
9	High Temperature Time-Dependent Characteristics of Materials in Sodium (Mechanical properties of stainless steels and Inconel 718 in air and sodium)	Ongoing
10	Simplified methods (Program for qualification of analysis models of reduced complexity and dimension)	Complete
11	Piping Restraint Effects	Ongoing

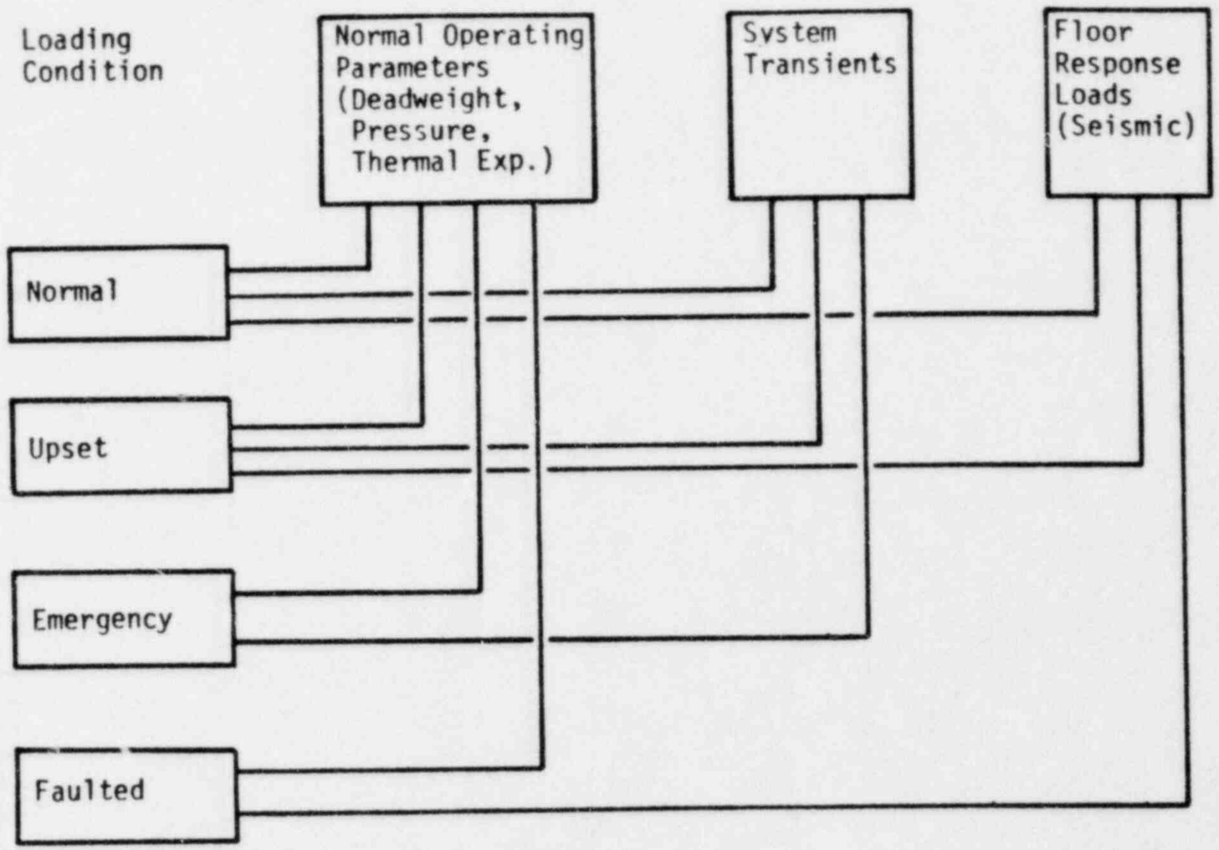

Figure Q110.78-P-1. HTS Piping and Support System Design and Analysis Process

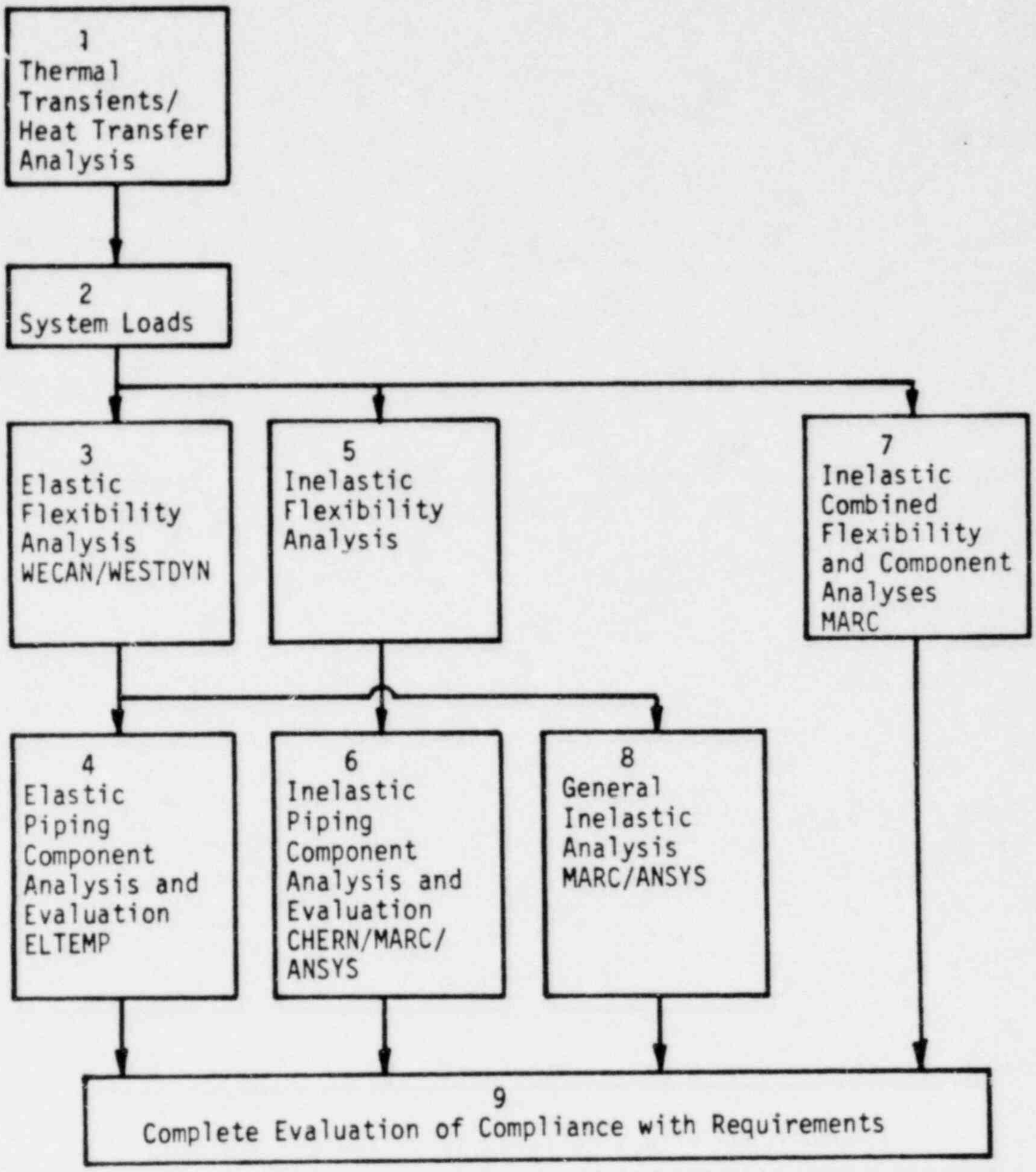

Figure Q110.78-P-2. HTS Piping Analysis Procedures

	PHTS 36" Hot Leg From Downcomer Outlet Elbow To Pump Inlet Nozzle	PHTS 24" Hot Leg From Pump Vessel Outlet Nozzle To IHX Vessel Primary Inlet Nozzle	PHTS 24" Cold Leg From IHX Vessel Primary Outlet Nozzle To Check Valve Inlet Nozzle	PHTS 24" Cold Leg From Check Valve Outlet Nozzle To Downcomer Inlet Elbow	IHTS 24" In-Containment Hot Leg From IHX Vessel Intermediate Outlet Nozzle To Hot Leg Containment Penetration	IHTS 24" In-Containment Cold Leg From Cold Leg Containment Penetration To IHX Vessel Intermediate Inlet Nozzle	PHTS 2" IHX Vent Line Between Pump Nozzle And IHX Nozzle	PHTS 6" Pump Bubbler Line Between Pump Nozzle And Inert Gas System	PHTS 2" Pump Drain Line Between Pump Nozzle And Auxiliary Liquid Metal System
Load Conditions									
A. Design	x	x	x	x	x	x	x	x	x
B. Normal/Upset	x	x	x	x	x	x	x	x	x
C. Faulted	x	x	x	x	x	x	x	x	x
D. Testing	x	x	x	x	x	x	x	x	x
E. Special	x	x	x	x					
Types of Analysis									
A. Thermal	x	x	x	x	x	x	x	x	x
B. Elastic	x	x	x	x	x	x	x	x	x
C. Inelastic									
1. One-D									
2. Two-D					x	x			
3. Three-D		x							
D. Dynamic	x	x	x	x	x	x	x	x	x
E. Buckling		x							
Design Criteria									
A. Sec. III									
1. Low Temp.									
2. High Temp.	x	x	x	x	x	x	x	x	x
B. Other									

Figure Q110.78-P-3 Analysis Checklist for System 51A Piping

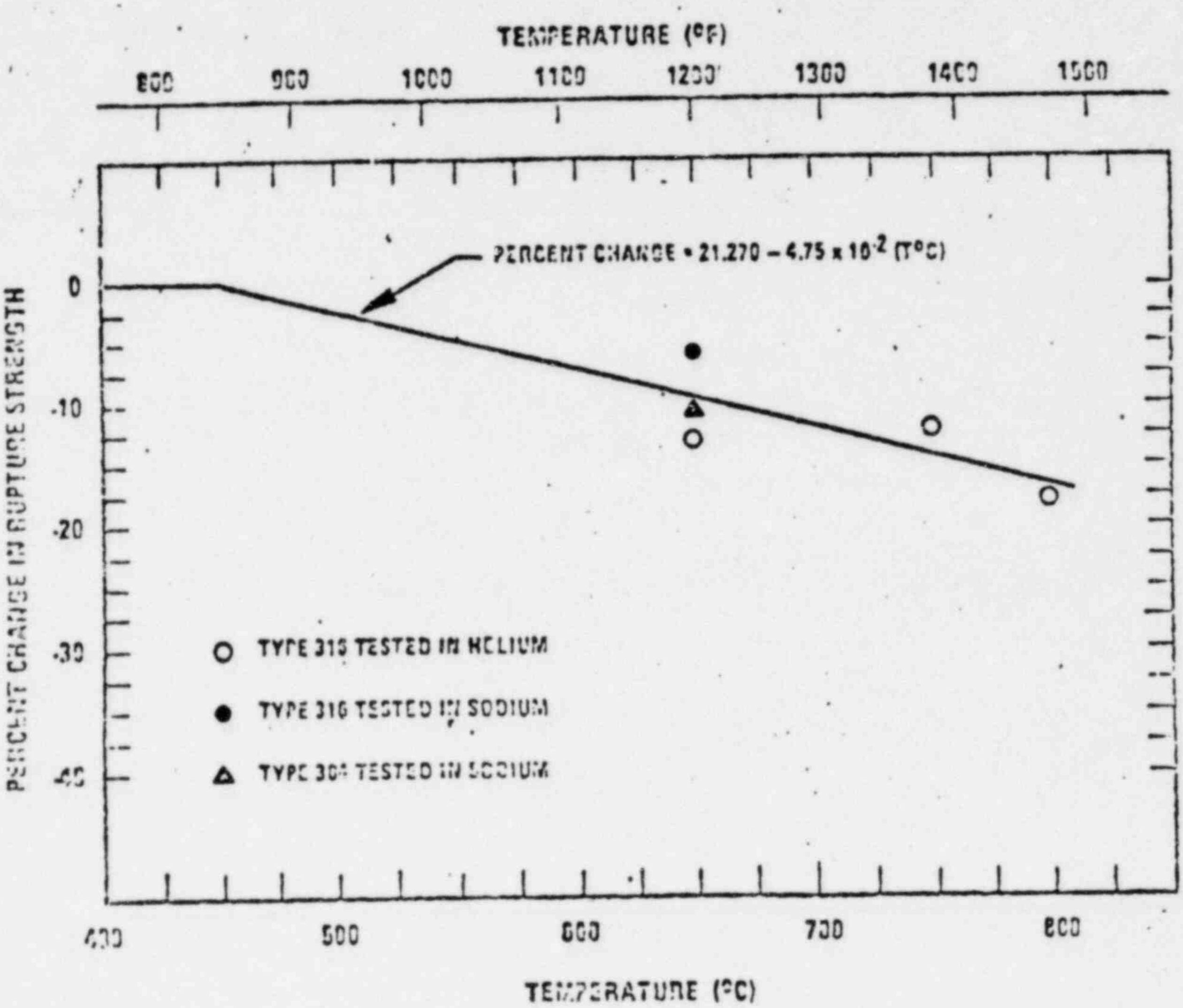

Figure Q110.78-P-4. Decrease in Rupture Strength of Type 304 and 316 SS Due to a Sodium Environment

Response for Line Valves

The only large-diameter Seismic Class 1 valves in the PHTS and IHTS are the cold leg check valves in the PHTS. The design limits and rules for these valves are given in PSAR paragraph 5.3.2.3.3 and the analytical methods are given in PSAR paragraph 3.9.1.6.