ENCLOSURE 1

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CRBRP

HEAT TRANSPORT SYSTEM INCONTAINMENT PIPING

RESERVE SEISMIC MARGINS

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SUMMARY

This report provides an evaluation of the inherent reserve seismic capacity of the CRBRP heat transport system incontainment piping. The evaluations have been conducted to assess the capacity of the piping system to accommodate seismic excitation beyond the 0.25g SSE. The evaluations were made using ratios and extrapolations from linear elastic analysis.

Sources of reserve seismic capacity can be divided into the following three broad categories:

(a) Conservative predictions of building and equipment response,

(b) Conservative definitions of structural and functional performance limits, and

(c) Reserve seismic capacity incorporated by means of designer conservatism.

Reserve seismic capacities from Items (a) and (b) were considered in arriving at seismic margins for the piping system. Reserve seismic capacities from Item (c) are listed and discussed, but not quantified.

The approach used to calculate the reserve seismic margin for the HTS piping system is that presented in NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping". The reserve seismic margin is determined by combining the design margin and nominal margin and accounting for the percentage of seismic stress to the total stress. The design margin is defined as follows:

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress}}{\text{Calculated Stress}} = \frac{S_A}{\sigma_c}$$

The allowable stress is based on an applicable industry standard or code that always has a built-in margin of safety on ultimate strength. The margin between the Code allowable and the ultimate strength or failure is called the nominal margin on ultimate strength and is defined as follows:

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress}}{\text{Allowable Stress}} = \frac{S_u}{S_A}$$

The actual or combined margin is given by the product of the above two margins, or

$$\text{Actual Margin (AM)} = \text{DM X NM} = \frac{S_u}{\sigma_c}$$

If k is defined as the ratio of seismic-only stress to total calculated stress (σ_c), the seismic-only margin (SOM) can be defined as follows (see Section 3.1):

$$\text{SOM} = \frac{(\text{NM x DM} - 1)}{k} + 1.0$$

This seismic-only margin was used directly to determine the reserve seismic capacity of the HTS piping system.

The minimum reserve strength capacities obtained for the HTS large and small diameter piping system were calculated for the various piping and support systems components and are as follows:

(a) Piping components (elbows, tees, etc.) = 1.67 (small-diameter piping)
2.71 (large-diameter piping)

(b) Clamps = 3.37

(c) Snubbers = 1.86 (small-diameter piping)
1.89 (large-diameter piping)

(d) Embedments = 4.0

Combining these results with the conservatisms in the predicted seismic piping response (which is 1.45) gives the following overall reserve seismic capacity:

(a) Small Diameter Piping: 1.45 x 1.67 = 2.42

(b) Large Diameter Piping: 1.45 x 1.89 = 2.74

(c) Minimum Reserve Margin Earthquake = 2.42 x 0.25 g = 0.605 g's

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1.0 OBJECTIVE

The purpose of this report is to identify the inherent reserve seismic capacity of the CRBRP heat transport system incontainment piping. Piping designed to withstand the SSE will, by virtue of the design methods, material data and criteria employed, have reserve seismic capacity to accommodate seismic excitations in excess of the SSE. It is the intent to assess the capacity of the CRBRP HTS piping system to accommodate seismic excitation beyond the 0.25g SSE used in the design of the plant.

It is desirable that the combination of seismic design basis and reserve margins in the design be such that seismic events will not cause loss of function of the shutdown heat removal system even for earthquakes larger than the SSE. It will be shown that appreciable seismic margins exist for the large and small diameter PHTS piping that are critical for operation of the shutdown heat removable system. It will also be shown that comparable margins exist for the incontainment IHTS piping which are less critical to the shutdown of the reactor.

2.0 INTRODUCTION AND BACKGROUND

2.1 Introduction and Scope

CRBRP components and piping systems designed to withstand the SSE will have reserve seismic capacity to accommodate seismic excitations in excess of the SSE. Factors which contribute to this reserve seismic capacity include (a) the conservative predictions of building and equipment seismic response, (b) the conservative definition of structural and functional performance limits, and (c) reserve seismic capacity incorporated by means of designer conservatisms. The evaluation procedure used to determine the seismic reserve for the HTS incontainment piping is illustrated in Figure 2-1 which is the approach derived and discussed in References 1 and 2. The lefthand side of the figure addresses the piping system or equipment seismic response conservatism. This consists of five items listed below:

(1) System damping assumptions.

(2) Development of ground accelerogram.

(3) Reduction of floor response spectra due to inelastic action of building.

(4) Development of design response spectra.

(5) Development of design time-histories.

These items have been discussed in detail for the CRBRP plant buildings and systems in Reference 2 and they will not be repeated here.

The righthand branch of Figure 2-1 addresses the reserve seismic capacity of the piping system which is limited by structural reserve capacity of the piping components or the piping support system. The reserve capacity of piping support system must account for the strength of clamps, seismic restraints (or snubbers) and support structures (or embedments).

The total piping system reserve seismic capacity is obtained from the product of the structural strength reserve capacity and the piping system seismic response conservatism.

The structural strength reserve capacity for each structural component of the piping system is determined in accord with the procedure illustrated in Figure 2-2. A structural component reserve capacity is given by the product of the material minimum strength assumptions and the conservatisms provided in the ASME Code allowables. The ASME Code usually dictates that minimum strength values be used to derive allowable stresses. However to determine reserve seismic capacity, it is appropriate in general to use average strengths because stress analyses are used to predict local failure which does not necessarily mean that a gross failure of these highly ductile systems will result. To be conservative, this evaluation of reserve seismic margin will use minimum material properties of the piping components which are loaded by internal pressure.

2.2 System and Piping Description

The CRBRP Heat Transport System consists of three almost identical cooling circuits, each of which includes a Primary Heat Transport System (PHTS) sodium loop and an Intermediate Heat Transport System (IHTS) sodium loop, thermally coupled by an Intermediate Heat Exchanger (IHX). Each PHTS loop contains the following large-diameter piping; a 36" hot leg, a 24" hot leg (crossover) and a 24" cold leg. Each large-diameter IHTS piping loop contains a 24" hot leg and a 24" cold leg within containment.

Various small-diameter piping lines are attached to the PHTS and IHTS piping systems and major components (IHX, check valve, pump, etc.). The primary small-diameter piping includes a 6" bubbler line between the pump and argon gas supply, a 2" pump drain line between the pump and sodium fill system and a 2" vent line between the primary pump and IHX. In addition to these lines, there are other sodium supply/drain lines and argon gas lines attached to the primary system. The incontainment IHTS piping system includes small-diameter piping lines between the IHX and IHTS piping that serve as a startup vent system.

All small and large diameter piping is either elevated or surrounded by guard vessels to ensure a minimum safe level of coolant in the reactor vessel.

The primary sodium loops transport the hot radioactive sodium coolant from the reactor vessel to the intermediate heat exchangers, which thermally link the primary and intermediate loops, and transport cooled primary sodium back to the reactor vessel. The three primary loops have common flow paths through the reactor vessel but are otherwise independent in operation.

The intermediate sodium loops circulate hot non-radioactive sodium from the tube side of the intermediate heat exchangers (located in the reactor containment building) to the steam generators (located in the steam generator build-

ing), the transport cooled intermediate sodium back to the IHX units. The intermediate sodium piping within the containment building runs under the operating floor from the intermediate heat exchangers to the containment building boundary. A rigid seal is provided at each piping penetration through the containment building wall to assure containment integrity relative to leak tightness.

The CRBRP HTS large and small diameter piping systems within containment are made up of the ASME Code Class 1 liquid metal piping configurations, as listed below (see Table 2-1):

1. PRP(A) - PHTS 36-inch hot-leg pipe from the reactor vessel to the pump suction (3 loops).
2. PRP(B) - PHTS 24-inch hot-leg pipe (crossover) from the pump discharge to the IHX primary inlet (3 loops).
3. PRP(C) - PHTS 24-inch cold-leg pipe from the IHX primary outlet to the reactor vessel inlet (3 loops).
4. PRP(D) and PRP(E) - PHTS 2-inch hot-leg pipe, IHX vent return line from IHX to flow restrictor to pump tank (3 loops).
5. PHTS 6-inch hot leg, pump bubbler piping from primary pump tank to argon gas supply system (3 loops).
6. PHTS 2-inch hot leg pipe, pump drain line from primary pump tank to sodium supply system (3 loops).
7. INP(A) - IHTS 24-inch hot-leg pipe from the IHX intermediate outlet to the reactor containment building boundary (3 loops).
8. INP(E) - IHTS 24-inch cold leg pipe from the reactor containment building boundary to the IHX intermediate inlet (3 loops).
9. IHTS 2-inch hot leg, continuous flow running vent connected between the IHX intermediate side outlet high point vent and the IHTS main loop hot leg piping (3 loops).
10. IHTS 2-inch pipe interconnecting line, with a manual valve, between the running vent line and IHTS cold leg main loop piping (3 loops).
11. IHTS 2-inch argon gas/rupture disc piping assembly connected to both the continuous hot leg running vent line and IHTS cold leg main loop piping (3 loops).
12. PHTS 2-inch drain line off of the IHX (3 loops).
13. PHTS 1-inch argon line off of the 36" PHTS high point vent (3 loops).

14. PHTS 1-inch argon line off of the 24" cold leg check valve (3 loops).

15. PHTS 1-inch argon line off of the IHX vent line (3 loops).

The piping structural system includes the piping components such as straights, elbows and tees that make up the loops and its support system (clamps, spring hangers, snubbers, rigid rods, support steel and embedments).

2.3 Structural Design Criteria

The CRBRP Heat Transport System large and small-diameter piping within containment is designed and analyzed as an ASME Class 1, Seismic Category 1 nuclear component in accordance with the following rules:

a. ASME Boiler and Pressure Vessel Code, 1974, Section III, Nuclear Power Plant Components, with Addenda through Summer 1975 and with modifications to Sections NB-2000 and NB-3000 as presented in ASME Code Case Interpretation 1592-7 for design of Elevated Temperature Class 1 components in Section III.

b. RDT Standard E15-2NB-T, Class 1 Nuclear Components (Supplement to ASME Boiler and Pressure Vessel Code, Section III, Subsections NA and NB), November 1974.

c. RDT Standard F9-4T, Requirements for Construction of Nuclear System Components at Elevated Temperature (Supplement to ASME Code Cases 1592, 1593, 1594, 1595 and 1596), September 1974.

d. PSAR, Section 3.7A, Seismic Design Criteria for the Clinch River Breeder Reactor Plant, January 1977.

The consideration of thermal creep effects sets the elevated temperature rules (Code Case 1592) apart from the Section III, Subsection NB rules. Unlike Subsection NB design rules, which basically guard against time-independent failure modes, the elevated temperature rules are applicable for service conditions where creep and relaxation effects are significant. Therefore, the elevated temperature rules require that the design/analysis of a nuclear component consider time-dependent, as well as time-independent, material properties. In addition, Code Case 1592 extends specific rules of Subsection NB to elevated temperature service provided it can be demonstrated that the combined effects of temperature, stress level, and duration of loading do not introduce significant creep effects. This option proves to be applicable to the cold leg piping.

The HTS piping is designed to assure that stresses, strains and deformations are within the applicable ASME Code criteria and system functional limits. As required, the analyses performed to satisfy these limits reflect both time-independent and time-dependent materials properties and structural behavior (elastic and inelastic) by considering the following relevant modes of failure:

a. Ductile rupture from short-term loadings.

b. Creep rupture from long-term loadings.

c. Creep-fatigue failure.

d. Gross distortion due to incremental collapse and ratchetting.

e. Loss of function due to excessive deformation.

For the HTS piping that normally operates at temperatures over 800°F, the elevated temperature criteria given in Code Case 1592 and RDT Standard F9-4T are invoked for the piping evaluation to supplement the ASME Code, Section III criteria. In accordance with Code Case 1592 criteria, the in-containment HTS hot-leg piping is evaluated against the following limits:

a. Load-controlled limits (limits on primary stress intensities).

b. Limit on primary-plus-secondary stress intensities or ratchetting (or strain limits).

c. Limit on creep-fatigue damage.

The primary HTS cold-leg piping normally operates in a temperature range between 400° and 750°F while the intermediate HTS cold-leg piping operates between 400° and 673°F. However, as some thermal transient conditions exceed the 800°F limit for austenitic stainless steels, the elevated temperature criteria, given in ASME Code Case 1592 and RDT Standard F9-4T, are invoked for the evaluation of the HTS cold-leg piping. Code Case 1592 does, however, extend specific rules of Section III, Subsection NB, (as previously discussed) to elevated temperature service if it can be demonstrated that creep effects are insignificant. For the HTS cold-leg piping which operates at temperatures over 800°F for less than 20 hours, creep effects are negligible and a Section III type analysis is sufficient; i.e., ratchetting limits will be satisfied by limiting elastically calculated primary-plus-secondary stress intensities and only elastic fatigue analyses will be required.

2.4 Design Conditions and Loadings

The various types of design loading conditions in the Piping Design Specification have been categorized into design, normal, upset, emergency, and faulted conditions; and organized into a load histogram. The stress analysis is performed on the basis of these loading categories.

For the HTS piping, the steady state and transient events and their frequency of occurrences are identified in the Piping Design Specification. Each transient event is characterized by coolant temperature, flow and pressure variation plots which are given in the piping design specification. Based upon the transient events and steady state conditions, load cycles are constructed such that they begin and end at the same steady state condition. In general for constructing a load cycle, several transient events are used in sequence. Further, the construction is such that the full set of load cycles uses the specified number of occurrences of each type of transient.

From the definition of the loading cycles, the combination of loads acting on the piping system during the plant lifetime was established and used in the stress analysis. The loading combinations in the analyses include the load effects resulting from internal pressure, deadweight, support movements, thermal expansion, seismic, sodium water reaction (IHTS piping), and through wall temperature gradients. The fact that the time phasing of the loads was ignored in the analyses is a significant conservatism.

For the flexibility analyses, a given piping leg between equipment nozzles was modeled using a series of straight and elbow components connected at a finite number of points. A computer analysis was then used to determine elastic displacements, forces and movements in the piping leg. The five basic loading conditions that are considered in the HTS piping flexibility analyses are:

A. Thermal expansion from 70°F to maximum normal operating temperature.

B. Dead weight with the system full of sodium.

C. Seismic motion from the Operating Basis Earthquake.

D. Seismic motion from the Safe Shutdown Earthquake.

E. Motion caused by the Sodium-Water Reaction pressure pulses (IHTS piping).

For elastic thermal flexibility analysis, the thermal motions of the nozzles acting as anchors were imposed on the interfacing piping points. The seismic analysis of the piping was completed using the Response Spectrum Method with response spectra that enveloped the piping attachment points to the building structure, or in some cases, time-history seismic analysis was used. Damping values were selected as per NRC Regulatory Guide 1.61 where two percent and three percent of critical damping are used for OBE and SSE, respectively, for piping of nominal diameter greater than 12 inches, and one percent and two percent of critical damping are used for OBE and SSE, respectively, for piping of nominal diameter smaller than 12 inches.

The dynamic effects of the sodium-water reaction are comprised of time varying loads (force or pressure) applied at either a change in direction or a change in cross-sectional area of the piping. A computer code was used to develop force time histories at the elbows, tees, etc. for input into the dynamic structural analysis code flexibility analysis of the piping loops. This analysis determined peak load responses at features of concern (i.e., pipe fittings, welds, equipment nozzles, penetration anchors, supports/restraints and branch connections).

2.5 Analysis Procedures

To perform the structural evaluation of the HTS piping, the loadings on the piping loop that result from the usual load effects including internal pressure, deadweight, support movements, thermal expansion, seismic, sodium water reaction, and thermal temperature gradients were obtained at particular locations in the piping system (usually at piping components such as elbows, tees, reducers, transition joints, girth welds, etc.).

Computer-aided flexibility analyses (as discussed in the previous section) were used to determine the forces and moments in the piping components. All computer programs used have been verified or are in the process of being verified.

The results of the flexibility analyses were used to formulate the combined stresses for assessment against the ASME Code limits. Moment components for various loadings were combined to determine appropriate moment resultants at the piping components and weld locations between the components. Stress values for moment loadings were computed using the simplified stress indices approach provided in NB-3600. Stress indices at the piping components were computed based on the component nominal geometry using equations or values provided in Table NB-3682.2-1 for ANSI B16.9 butt-welding components. Stress indices for the girth welds were based on the piping dimensions, using the Table NB-3682.2-1 values for a flush girth butt weld.

The following additional assumptions were used to establish and modify the appropriate stress indices:

A. When out of roundness at the piping component did not exceed 0.08t, F_{1a} was assumed unity, otherwise F_{1a} as given by Code was used.

B. Weld shrinkage at the girth welds was 0.02R (the maximum permitted by RDT E15-2NB-T) and the C_1, C_2 indices modifications in RDT E15-2NB-T were employed.

The simplified analysis formulas given in the ASME Code, Section III are used to determine stresses resulting from internal and external pressure.

For simplified analysis, the heat transfer analysis for the individual transients was performed using finite element methods. For the thermal hydraulic data, the thermal response of the piping components was evaluated by calculating the radial temperature distribution at various time intervals during a transient and then calculating the quantities T, ΔT_1, and ΔT_2 as per NB-3653 of the ASME Code, Section III. These quantities are used to obtain the stresses in the piping component due to the temperature gradient through the component wall thickness using the appropriate simplified stress index approach in NB-3600.

TABLE 2-1

PHTS & IHTS PIPING WITHIN CONTAINMENT

PIPING DESIGNATION	DESCRIPTION	O.D. (in)	WALL THICKNESS (NOMINAL) IN.	MATERIAL	ASME CLASS
PRP-A	PHTS - HOT LEG From Reactor Vessel Outlet Nozzle to Primary Pump Inlet Nozzle.	36.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1
PRP-B	PHTS - HOT LEG (Crossover) From Primary Pump Outlet Nozzle to IHX Primary Inlet Nozzle.	24.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1
PRP-C	PHTS - COLD LEG From IHX Primary Outlet Nozzle to Reactor Vessel Inlet Nozzle.	24.0	0.5	PIPE SA-358 GRADE 304 ELBOW SA-403 GRADE WP304	1
INP-A	IHTS - HOT LEG (Within Containment) From IHX Intermediate Outlet Nozzle to the Containment Seal.	24.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1(1)
INP-E	IHTS - COLD LEG (Within Containment) From Containment Seal to IHX Intermediate Inlet.	24.0	0.5	PIPE SA-358 GRADE 304 ELBOW SA-403 GRADE WP304	1(1)

Notes

1. IHTS piping is classified as ASME Class 2 but has been designed and analyzed to meet Class 1 criteria.

TABLE 2-1 (Continued)

PHTS & IHTS PIPING WITHIN CONTAINMENT

PIPING DESIGNATION	DESCRIPTION	O.D. (in.)	WALL THICKNESS (NOMINAL) IN.	MATERIAL	ASME CLASS
PRP(D) & PRP (E)	PHTS IHX Vent Return Line	2.375	0.154	PIPE SA-376 GRADE TP-316 ELBOW SA-403 GRADE WP316	1
-	PHTS Pump Bubbler Line	6.675	0.280		1
-	PHTS Pump Drain Line	2.375	0.154		1
-	IHTS Continuous Flow Running Vent	2.375	0.154		1 (1)
-	IHTS Interconnecting Line Between Running Vent and IHTS Cold Leg	2.375	0.154		1 (1)
-	IHTS Argon Gas/Rupture Disc Piping Line for IHTS Vent System	2.375	0.154		1 (1)

NOTES

1. IHTS piping is classified as ASME Class 2 but has been designed and analyzed to meet Class 1 criteria.

TABLE 2-1 (Continued)

PHTS & IHTS PIPING WITHIN CONTAINMENT

PIPING DESIGNATION	DESCRIPTION	O.D. (in.)	WALL THICKNESS (NOMINAL) IN.	MATERIAL	ASME CLASS
--	IHX Drain Line	2.375	0.154	Pipe SA-376 Grade TP-304H	1
--	Argon Line Off of 36" PHTS High Point Vent	2.375*	0.154	↓	1
--	Argon Line Off of 24" Cold Leg Check Valve	2.375*	0.154	↓	1
--	Argon Line Off of IHX Vent Line	2.375*	0.154	↓	1

*The 2" line is reduced to a 1" line at the sweepolet.

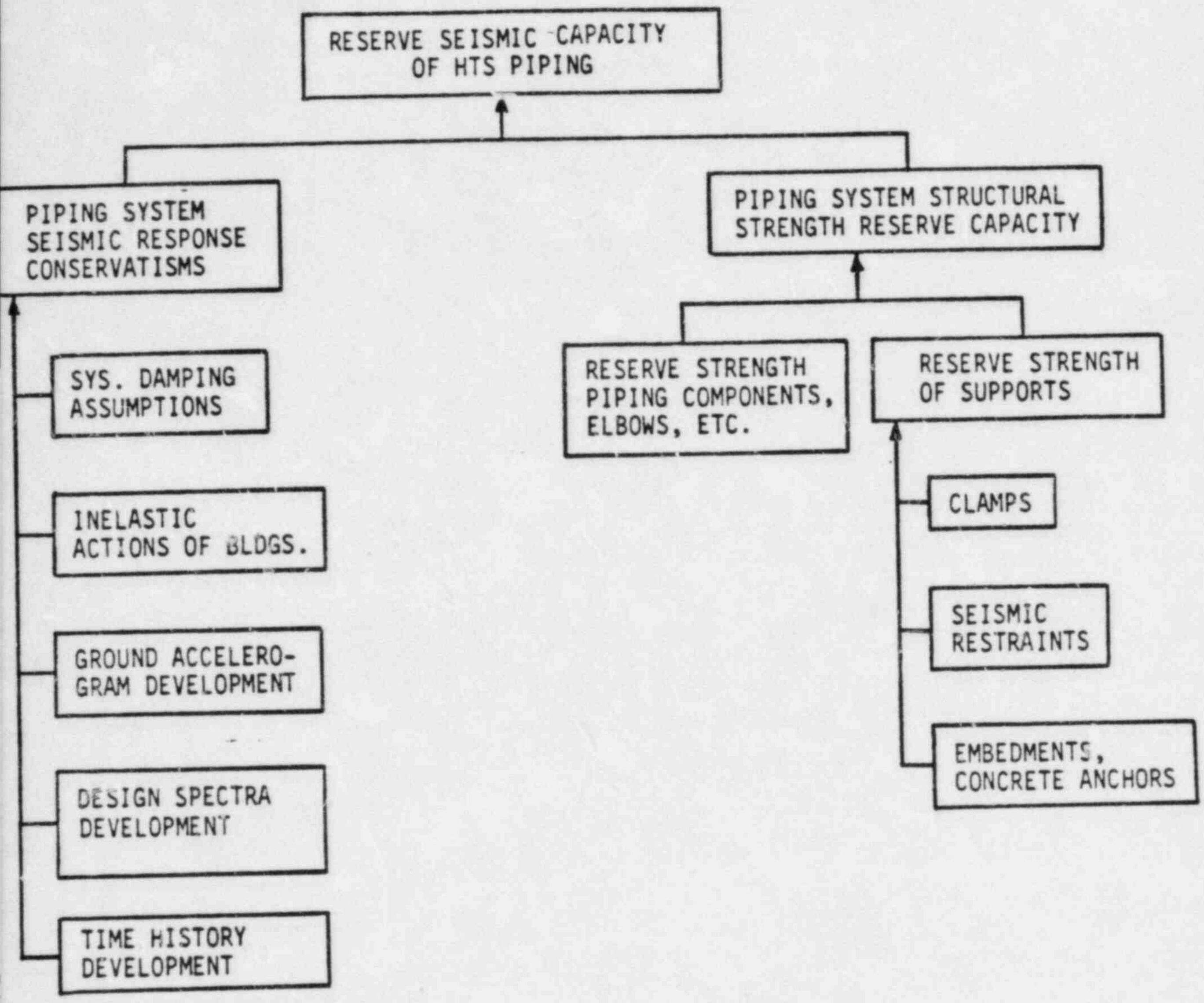


FIGURE 2-1

CRBRP HTS PIPING SYSTEM
RESERVE SEISMIC CAPACITY
EVALUATION PROCEDURE

3.0 SEISMIC MARGIN EVALUATION

3.1 Approach

The approach used to calculate the reserve seismic margin for the HTS piping system is that presented in NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping" (Reference 1).

In safety evaluation reports prepared in support of applications for nuclear power plant licenses, the adequacy of structural components, such as a piping system, to withstand a combination of loads (including seismic) from the SSE event is expressed in the form,

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress/Load}}{\text{Calculated Stress/Load}} = \frac{S_A}{\sigma_C} \quad (1)$$

The allowable stress or load is based on an applicable industry standard or code, such as the ASME Boiler and Pressure Vessel Code, that always has a built in margin of safety on ultimate strength or failure. The calculated stress on the structural component is determined using the operating loads, deadweight loads and SSE loadings on the structure.

For a structural component to be acceptable, the seismic event design margin must be greater or equal to 1.0. If the loads on the component are underestimated such that σ_C is actually higher than calculated, the component may still not fail because of the reserve strength available because the Code allowable is defined to be less than the ultimate or failure stress. This built-in margin of safety is called the nominal margin on ultimate strength or failure and is defined as follows:

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress/Load}}{\text{Allowable Stress/Load}} = \frac{S_u}{S_A} \quad (2)$$

Nominal margins indicate the reserve strength that is available when the seismic event design margin is unity. Nominal margins depend upon the source of the allowable stress or load, S_A, which in turn depends upon material properties, temperature, failure mode, functional limits, etc. For example, a nominal margin based on ultimate strength or breaking must consider the basis used for establishing the ASME Code allowable tensile stresses. The allowable stress is a fraction of the tensile properties of the material used in the construction of the component. This nominal margin would be defined as follows:

$$\text{Nominal Margin} = \frac{S_u}{S_A} \text{ for ultimate strength} \quad (3)$$

If yielding is a primary consideration in order to prevent excessive deformations, the nominal margin may be defined as follows:

$$\text{Nominal Margin} = \frac{S_y}{S_A} \text{ for yielding} \quad (4)$$

In a similar manner, nominal margins may be defined for buckling loads, shear loads, bending loads, and combined loads.

In summary, the nominal margin corresponding to a design margin of 1.0 depends upon the following:

(1) Material

(2) Operating Temperature

(3) Type of Loading

(4) Failure Criteria

(5) Source of allowable stress, S_A, for example, ASME Code Section III, Subsection NB allowable stress for pressure boundary integrity or Subsection NF allowable for piping supports.

The seismic event design margin has been defined by Equation (1) as S_A/σ_c, where σ_c is the calculated stress due to all loads. Because seismic loadings are subject to larger uncertainties, it is pertinent to evaluate the margin that exists for seismic-only loads. If the total calculated stress, σ_c, for the seismic event is separated into the seismic, σ_{cs} and non-seismic stress, σ_{cn} or

$$\sigma_c = \sigma_{cs} + \sigma_{cn} \tag{5}$$

the seismic-only margin may be defined as follows:

$$SOM = \frac{S_u - \sigma_{cn}}{\sigma_{cs}} \tag{6}$$

If k is defined as the ratio of seismic-only stress to total calculated stress ($k = \sigma_{cs}/\sigma_c$), the seismic-only margin given by equation (6) can be written as follows (see Appendix A for the derivation):

$$SOM = \frac{(NM \times DM - 1)}{k} + 1.0 \tag{7}$$

This margin can be used directly to determine the reserve seismic capacity of a structural component or piping system.

3.2 Margin Analysis

3.2.1 Piping System Seismic Response Conservatisms

The resulting system seismic response conservatism margin was determined in Reference 2 and is listed below:

(a) System damping assumptions = 1.2

(b) Development of ground accelerogram = 1.05

(c) Inelastic action of buildings = 1.05

(d) Development of floor spectra or time-histories = 1.1

(e) Combined margin = 1.2 * 1.05 * 1.05 * 1.1 = 1.45

3.2.2 Piping System Structural Strength Reserve Capacity

The structural strength reserve capacity was calculated for the HTS five large-diameter piping legs within containment that make up Loop 1. It is expected that Loops 2 and 3 will give similar results. The analysis of three small-diameter piping legs which are representative of the HTS small piping within containment is presented; the 2-inch IHX vent return line, the 6-inch primary pump bubbler line, and the 2-inch primary pump drain line. These lines were selected because they (1) cover the range of the HTS small-diameter pipe sizes, (2) operate at the highest temperature (1015° F), and (3) their material and construction is representative of all the small diameter piping. In addition, the vent return line is exposed to high pressures and severe thermal transients. The margins obtained from these lines bound the results for all the small-diameter piping connected to the PHTS.

Piping Components (Elbows, Tees, etc.)

For faulted (or Level D) conditions the ASME Code (Reference 3) limits on the calculated primary stress for piping can be expressed as follows (see Section III, Appendix F and Code Case 1592-7):

$$P_L + P_b \leq 3\ S_m \qquad (8)$$

where P_L = membrane stress from pressure, deadweight and SSE loadings

P_b = primary bending stress from pressure, deadweight and SSE loadings

S_m = time independent material allowable

The safe-shutdown earthquake (SSE) event is identified as a faulted loading in the HTS piping design specification.

In terms of Equation (1), the seismic event design margin for the CRBRP HTS piping components can be expressed as follows:

$$DM = \frac{S_A}{\sigma_c} = \frac{3\ S_m}{(P_L + P_b)} \qquad (9)$$

For austenitic stainless steels (Types 304 and 316) the S_m allowable is equal to 0.90 S_y. The ASME Code faulted stress limits allow yielding, but provide margin against breaking or ultimate material strength failure. Therefore, the normal margin for the piping can be expressed as follows:

$$NM = \frac{S_u}{S_A} = \frac{S_u}{3\ S_m} \qquad (10)$$

where S_u is the ultimate strength for the material. The ultimate strengths were obtained from the NSM Handbook (Reference 4) and are based on minimum strength values. From a study of ultimate strengths for austenitic stainless steels, the ratio of average-to-minimum ultimate strengths is approximately 1.10.

However, in the present study, this safety factor is conservatively ignored and the nominal margin is based on the minimum ultimate strength. The nominal margins for the incontainment HTS large-diameter piping components in each pipin, loop are listed in Table 3-1. The table also provides the nominal margins for the three small-diameter piping loops which are representative of the incontainment small piping. The margins are based on the reserve strength between the 3 S_m allowable and the *minimum* ultimate strength of the material.

The piping system flexibility analysis gives a set of forces and moments acting at various locations in the piping system for deadweight, thermal expansion and SSE loadings. These forces and moments along with operating loads such as pressure are converted into stresses using procedures given in Section III of the Code, Subsection NB-3600, for Class 1 piping systems. The Code uses stress intensification factors (B_1, C_1, B_2, C_2, etc.) to indicate the relative strength of a component (such as at an elbow) to the strength of the straight pipe. For Class 1 piping, the combined stresses due to an SSE and associated loads (pressure and deadweight) are limited to 3 S_m or the faulted limit.

The other mode of failure considered in the margin evaluation of the large-diameter piping was plastic collapse of the piping elbows. The piping restraints (or snubbers) as well as the blocks on the hangers constrain the piping system from excessive deformations or rotations under seismic loadings. In the actual piping configurations, the elbows will not be able to rotate sufficiently to cause collapse of the elbows or piping system. Thus, buckling or collapse of a piping elbow is not a practical mode of failure in the CRBRP HTS piping systems.

The stresses at the elbow locations for the five large-diameter piping loops that comprise the CRBRP HTS incontainment piping system are given in Tables 3-2 through 3-6. Each table provides the following information:

(1) Elbow number; the location identified in Figure 3-1 through 3-5.

(2) σ_{cn}; non-seismic membrane-plus-bending stress at the location due to pressure and deadweight.

(3) σ_{cs}; the SSE seismic stress at the location.

(4) σ_c ; the total stress at the location.

(5) k ; the fraction of stresses due to the SSE loadings to the total of all stresses, i.e., σ_{cs}/σ_c.

(6) NM ; the nominal margin presented in Table 3-1.

(7) DM ; the SSE event design margin at each location.

(8) AM ; the actual margin (DM x NM) at each location.

(9) SOM; the seismic-only margin as calculated using equation (7) at each point.

Tables 3-7 through 3-9 provide similar information for the three small-diameter piping loops within the primary heat transport system (PHTS). The stresses at the critical stress locations for the SSE event are given along with the calculated margins. Isometrics of the three piping loops are given in Figures 3-6 through 3-8 which identify the high stress locations. Comparable stresses and margins are expected for the IHTS small-diameter piping within containment.

Stresses due to restraint of thermal expansion are not included in the tables because thermal expansion loads are not considered primary loads. If stresses due to such loads are above the elastic capacity, the higher stressed portions of this very ductile piping yield to accommodate the thermal expansion.

The tables illustrate a typical aspect of piping systems in that only a few points are highly stressed. Typically for thin-walled, high temperature, low pressure piping as used for the HTS piping system, the elbows are usually the highest stressed components in the piping loop. Therefore, the margins have been calculated for the beginning (BEG), middle (MID) and ending (END) for each elbow in the piping system.

A review of the tables show the following ranges of seismic-only margin for the five large-diameter HTS piping loops and the three lines selected as representative of the small-diameter HTS piping loops:

(a) PHTS 36" HL; SOM = 4.25 - 11.37

(b) PHTS 24" HL; SOM = 4.76 - 58.9

(c) PHTS 24" CL; SOM = 2.71 - 14.58

(d) IHTS 24" HL; SOM = 7.72 - 25.2

(e) IHTS 24" CL; SOM = 5.31 - 13.58

(f) PHTS Bubbler; SOM = 1.76 - 19.64

(g) PHTS Vent; SOM = 1.67 - 25.73

(h) PHTS Pump Drain; SOM = 1.98 - 19.43

Piping System - Clamps

A typical piping restraint assembly used on the CRBRP HTS large-diameter piping is shown in Figure 3-9. The assembly included an insulated clamp, snubbers, rigid rods or hangers attached to the clamp, and the embedment or building support structure. The CRBRP pipe clamps and snubbers have been designed and tested to meet the requirements of Subsection NF of the ASME Code for Class 1 supports. Thus they have been designed to satisfy the faulted limits (Level D) for the SSE event.

The CRBRP HTS small-diameter piping support system uses a somewhat more conventional pipe clamp (see Figure 3-10) with mechanical snubbers, rigid rods and hangers. The small pipe clamp assembly provides an insulated clamping surface for standard 3-hole pipe clamps on heated piping. Component parts include load-bearing insulating material wrapped with a stainless steel sheet metal shell retained by metallic straps and pipe clamps.

Detailed stress evaluations have been completed for the pre-loaded, insulated, large-diameter pipe clamp to be used on the HTS piping. The faulted stress limit used to assess the structural integrity of the clamp is as follows:

$$P_L + P_B \leq 2.25\ S_m \tag{11}$$

where P_L, P_b and S_m have been defined previously. Using this equation, the various reserve strength margins can be defined as follows:

$$DM = \frac{S_A}{\sigma_c} = \frac{2.25\ S_m}{P_L + P_b}$$

$$NM = \frac{(S_u)_{aver}}{S_A} = \frac{(S_u)_{aver}}{2.25\ S_m}$$

The large-diameter pipe clamp is constructed using SA-387, Grade 2, Class 1 material. At 300°F, the 2.25 S_m allowable is equal to 52.9 ksi and the minimum ultimate strength is equal to 55.0 ksi. For carbon steels it has been shown in Reference 2 that average ultimate strength properties are at least 120% of the minimum ultimate strengths. Therefore, for this material the NM against ultimate failure is the following:

$$NM = \frac{(S_u)_{aver}}{2.25\ S_m} = 1.20\ \left(\frac{55.0}{52.9}\right) = 1.248$$

The most critically stressed clamp for SSE loadings is the 24" OD by 12" width clamp used on the 24" OD HTS piping. For the SSE event, only seismic loadings introduce primary stresses in the clamp band and the maximum combined membrane plus bending stress was 19.6 ksi. Thus the DM for this clamp was 52.9/19.6 = 2.699. The actual margin (and in this case the seismic-only margin also since only seismic loads are present) is:

$$SOM = (1.248)\ (2.699) = 3.37$$

The small-diameter pipe clamps are designed for a load rating in accordance with the NF requirements of the ASME code. The clamps are being tested to show that they are capable of withstanding at least 4.5 times the rated load. Therefore, for the small-diameter pipe clamps, the NM against ultimate failure is 4.5.

The PHTS and IHTS small-diameter piping use 2-inch and 6-inch size clamp assemblies. The rated load for the 2-inch clamp is 1710 pounds and for the 6-inch clamp is 4770 pounds. The maximum clamp loads and the associated DM's for the three PHTS small-diameter piping loops are given as follows:

PIPE LINE	MAX. CLAMP LOAD (LBS)	DM
IHX Vent	1560	1.096
Pump Drain	978	1.748
Pump Bubbler	4200	1.136

The minimum actual margin for the small-diameter clamps resulting from the normal margin of 4.5 and the design margin is;

AM = 4.5 x 1.096 = 4.932

Since the clamp loads result predominantly from the SSE event, the seismic-only-margin (SOM) for the small clamps is approximately 4.932.

Piping Support System - Snubbers

The snubbers used to restrain the HTS large and small diameter piping are of the mechanical type due to radiation considerations and have many moving parts. The vendors that supply snubbers have established faulted (Level D) loads for their designs and have completed static tests to insure operability at the rated faulted loads. The mechanical snubbers available for use have had detailed stress analyses completed on their structural parts and their capability is certified to ASME Code, Subsection NF requirements for Class 1 supports. Modes of failure considered in the evaluations of the snubber structural parts included ball screw shaft buckling, Brinnelling of the ball screw, buckling of the enclosure cylinder, and failure of the pins, fittings and clevises. From a review of the snubber stress analyses, it was judged that buckling is the likely critical failure mode. Since the ASME Code applies a 1.5 factor to buckling for faulted (Level D) limits, the nominal margin (NM) to failure for the snubbers is at least 1.5.

In addition, there is in most cases for the HTS large and small diameter piping a substantial design margin (DM) between the actual calculated SSE snubber load and the faulted condition rated load because in most cases the size of the snubber selected is based on the SMBDB (structural margin beyond the design base or hypothetical loads) loads for the primary system and on the SWR (sodium water reaction event) loads for the IHTS piping. A review of maximum SSE loads for Loop 1, large-diameter piping of the primary and intermediate systems gives the following margins (it is expected the Loops 2 and 3 will give similar results):

(a) PHTS 36" HL, SSE DM = 1.933

(b) PHTS 24" HL, SSE DM = 1.369

(c) PHTS 24" CL, SSE DM = 1.258

(d) IHTS 24" HL, SSE DM = 1.407

(e) IHTS 24" CL, SSE DM = 2.45

The maximum actual margin (AM), and in this case the seismic-only margin, for the snubbers in the HTS large-diameter piping system is:

SOM = 1.5 x 1.258 = 1.89

The maximum snubber loads and the associated DMs for the PHTS small-diameter piping are listed below:

PIPE LINE		MAX. SNUBBER LOAD (LBS.)	DM
IHX Vent		830	2.771
Pump Drain		846	2.719
Pump Bubbler	(Size 1)	3800	3.079
	(Size 2)	1850	1.243

The minimum actual margin (AM) and in this case the seismic-only-margin (SOM) for the snubbers in the PHTS small-diameter piping system is:

SOM = 1.5 x 1.243 = 1.86

Piping Support System - Concrete Anchor Bolts

The final component of the support train that must be considered is the supporting structure or embedment. A major aspect of seismic capability of piping systems is to assure that they are adequately held to the building structure (see Reference 1). For piping, this means adequately attaching the snubbers to the building. The weak link in attaching supports to the building are usually the concrete anchor bolts.

Embedment connections to concrete can be made either by installing the embedment before pouring the concrete or by drilling a hole in the concrete and inserting an anchor bolt.

Bolts or embedments installed before the concrete is poured have not produced any known field-installation problems. The embedded ends of the bolts can be hooked or installed with large washers; thereby, the tensile and shear strength of bolting like SA-307 Grade B can be developed. However, anchor bolts installed after pouring the concrete have given field-installation problems. Considerable skill and care in the installation process are required to consistently obtain anchor bolts that, as installed, develop the tensile and shear strength indicated by Manufacturers' catalogs.

From review of Reference (1) data, it appears that the tensile and shear strength of anchor bolts given in Manufacturers' catalogs can, with appropriate skill and care, be achieved in field installations. Manufacturers commonly recommend (a) that design loads for anchor bolts should not exceed one-quarter of the manufacturer's tensile or shear strength, and (b) that a linear interpolation should be used for combinations of tensions and shear. If the recommendation is used for both SSE and OBE and associated loadings, the average Nominal Margin would be 4.0.

For CRBRP HTS large and small-diameter piping support anchor or embedment bolts are being designed for installation before the pouring of concrete, thus the use of the recommended nominal margin of four on the seismic-only margin for the embedments given in Reference 1 for anchor bolts in concrete is conservative. The design margin (DM) is also conservatively ignored.

3.3 Designed-in Seismic Reserve Capacity

In the previous section, the reserve seismic margin for HTS piping was quantified on the basis of piping system seismic response prediction conservatisms and the piping structural strength reserve capacity. In addition to these, there are other seismic reserves incorporated in the design of the piping system as a result of designer/analyst conservatisms. These are more difficult to quantify, but from experience it is known that they exist. These seismic reserves are present due to some or all of the following:

(a) Use of linear-elastic dynamic and stress analysis.

(b) Envelope spectra for a multiple-supported piping system.

(c) Use of response spectrum analysis methods versus time-history analysis (in most cases).

(d) Exclusion of non-structural elements.

(e) Structural redundancy of the piping elements.

(f) Absolute combination of seismic loads with other loads.

3.4 Margin Analysis Results Summary

Seismic design margins were calculated as a result of seismic response conservatisms and piping system structural strength reserve capacity. The evaluation procedure used was that as discussed in Section 2.1 and shown in Figure 2-1. The minimum margins obtained for the HTS piping system are identified on Figure 3-11. The results show that the minimum seismic reserve for the small-diameter piping is 1.67 and is governed by the structural strength of the IHX vent return line piping components. The minimum seismic reserve for the large-diameter piping is set by snubber buckling loads and is equal to 1.89.

Accounting for the conservatisms in the predicted piping system seismic response, the overall seismic reserve capacity for the HTS piping system is 2.42 for the small-diameter piping and 2.74 for the large-diameter piping. Thus, the reserve strengths for the small and large diameter pipings are essentially the same. These margin results translate into a reserve margin earthquake of 0.605 g's for the CRBRP large and small HTS piping system within containment. The results obtained for the HTS piping are very comparable to those obtained for the CRBRP building, structures, and equipment in Reference 2.

TABLE 3-1

NOMINAL MARGINS (NM) FOR INCONTAINMENT HTS PIPING

PIPING LOOP	MATERIAL	TEMP. °F	S_A ($3 S_m$) (ksi)	S_u (ksi)	NM
36" PHTS HL	316SS	1015	45.93	57.554	1.253
24" PHTS HL	316SS	1015	45.93	57.554	1.253
24" PHTS CL	304SS	750	46.50	57.480	1.236
24" IHTS HL	316SS	965	46.41	59.772	1.286
24" IHTS CL	304SS	690	47.82	57.818	1.209
6" PHTS Bubbler	316SS	1015	45.93	57.554	1.253
2" PHTS Vent	316SS	1015	45.93	57.554	1.253
2" PHTS P.D.	316SS	1015	45.93	57.554	1.253

TABLE 3-2. PHTS 36" HOT LEG

LOCATION [1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	1.69	13.28	11.59	.8727	3.4586	1.2531	4.3339	4.820
-MID	5.46	12.35	6.89	.5579	3.7190	1.2531	4.6602	7.561
-END	0.92	7.91	6.99	.8837	5.8066	1.2531	7.2761	8.102
2-BEG	0.94	7.45	6.51	.8738	6.1651	1.2531	7.7254	8.697
-MID	1.57	14.76	13.19	.8936	3.1118	1.2531	3.8993	4.245
-END	2.00	11.75	9.75	.8298	3.9089	1.2531	4.8982	5.698
3-BEG	0.78	9.51	8.73	.9180	4.8297	1.2531	6.0519	6.503
-MID	0.85	11.54	10.69	.9263	3.9801	1.2531	4.9873	5.305
-END	1.47	11.60	10.13	.8733	3.9595	1.2531	4.9616	5.536
4-BEG	1.35	10.00	8.65	.865	4.5930	1.2531	5.7554	6.498
-MID	5.14	14.47	9.33	.6448	3.1742	1.2531	3.9775	5.618
-END	1.27	8.49	7.22	.8504	5.4099	1.2531	6.7790	7.796
5-BEG	2.56	9.63	7.07	.7342	4.7695	1.2531	5.9765	7.778
-MID	8.01	14.32	6.31	.4406	3.2074	1.2531	4.0191	7.852
-END	1.13	6.71	5.58	.8316	6.8450	1.2531	8.5773	10.112
6-BEG	1.24	7.65	6.41	.8379	6.0039	1.2531	7.5234	8.785
-MID	1.61	11.90	10.29	.8647	3.8597	1.2531	4.8365	5.437
-END	1.12	6.08	4.96	.8158	7.5543	1.2531	9.4661	11.378
7-BEG	2.40	9.06	6.66	.7351	5.0695	1.2531	6.3525	8.281
-MID	7.55	14.56	7.01	.4815	3.1545	1.2531	3.9529	7.133
-END	.98	7.80	6.82	.8744	5.8885	1.2531	7.3787	8.295
8-BEG	.95	6.99	6.04	.8641	6.5708	1.2531	8.2338	9.371
-MID	1.41	10.81	9.40	.8696	4.2488	1.2531	5.3241	5.973
-END	1.30	9.31	8.01	.8604	4.9334	1.2531	6.1820	7.023

Material: SS316
Temperature: 1015°F
S_U = 57.554 ksi
$S_A = 3 \times S_m$ = 45.93 ksi

1-See Figure 3-1 for elbow locations.

TABLE 3-3. PHTS 24" HOT LEG

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	4.89	6.06	1.17	.1931	7.5792	1.2531	9.4974	45.005
-MID	7.34	12.46	5.12	.4109	3.6862	1.2531	4.6191	9.808
-END	4.47	7.28	2.81	.386	6.3091	1.2531	7.9058	18.891
2-BEG	4.41	8.15	3.74	.4589	5.6356	1.2531	7.0618	14.210
-MID	4.76	10.30	5.54	.5379	4.4592	1.2531	5.5878	9.529
-END	4.58	5.48	0.9	.1642	8.3814	1.2531	10.5026	58.872
3-BEG	4.27	9.78	5.51	.5634	4.6963	1.2531	5.8849	9.670
-MID	5.54	10.52	4.98	.4734	4.3660	1.2531	5.4709	10.444
-END	4.39	8.16	3.77	.4620	5.6287	1.2531	7.0532	14.102
4-BEG	4.45	8.95	4.50	.5028	5.1318	1.2531	6.4306	11.801
-MID	5.58	16.49	10.91	.6616	2.7853	1.2531	3.4902	4.764
-END	4.25	13.13	8.88	.6763	3.4981	1.2531	4.3834	6.003
5-BEG	4.80	12.52	7.72	.6166	3.6685	1.2531	4.5970	6.834
-MID	6.93	16.94	10.01	.5909	2.7113	1.2531	3.3975	5.057
-END	4.23	9.19	4.96	.5397	4.9978	1.2531	6.2627	10.751
6-BEG	4.22	8.98	4.76	.5301	5.1147	1.2531	6.4091	11.204
-MID	4.29	13.84	9.55	.6900	3.3186	1.2531	4.1585	5.578
-END	4.44	11.79	7.35	.6234	3.8957	1.2531	4.8816	7.226

Material: SS316
Temperature = 1015°F
S_U = 57.554 ksi
$S_A = 3 \times S_m$ = 45.93 ksi

1-See Figure 3-2 for elbow locations.

TABLE 3-4. PHTS 24" COLD LEG

LOCATION[1]	σ_{cn} (CYCLE 11-U)	σ_c (CYCLE 15-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	3.42	14.44	11.02	.7632	3.2202	1.2361	3.9806	4.905
-MID	4.07	18.20	14.13	.7764	2.5549	1.2361	3.1582	3.780
-END	3.55	7.25	3.7	.5103	6.4138	1.2361	7.9283	14.577
2-BEG	3.72	9.77	6.05	.6192	4.7595	1.2361	5.8833	8.886
-MID	3.56	13.97	10.41	.7452	3.3286	1.2361	4.1145	5.179
-END	3.39	11.71	8.32	.7105	3.9710	1.2361	4.9086	6.501
3-BEG	3.44	15.49	12.05	.778	3.0019	1.2361	3.7108	4.484
-MID	3.53	18.54	15.01	.8096	2.5081	1.2361	3.1003	3.594
-END	3.58	11.26	7.68	.6821	4.1297	1.2361	5.1048	7.018
4-BEG	3.79	12.44	8.65	.6953	3.7379	1.2361	4.6206	6.207
-MID	5.89	17.78	11.89	.6687	2.6153	1.2361	3.2328	4.339
-END	3.82	8.59	4.77	.5553	5.4133	1.2361	6.6915	11.249
5-BEG	3.25	10.3	7.05	.6845	4.5146	1.2361	5.5806	7.692
-MID	3.24	12.74	9.5	.7457	3.6499	1.2361	4.5118	5.709
-END	3.71	10.03	6.32	.6301	4.6361	1.2361	5.7308	8.508
6-BEG	4.04	10.60	6.56	.6189	4.3868	1.2361	5.4226	8.146
-MID	4.75	16.03	11.28	.7037	2.9008	1.2361	3.5858	4.675
-END	3.70	11.45	7.75	.6769	4.0611	1.2361	5.0201	6.939
7-BEG	4.37	12.90	8.53	.6612	3.6047	1.2361	4.4558	6.227
-MID	4.94	19.97	15.03	.7526	2.3285	1.2361	2.8783	3.496
-END	4.63	14.02	9.39	.6698	3.3167	1.2361	4.0999	5.628
8-BEG	3.22	14.47	11.25	.7775	3.2135	1.2361	3.9724	4.823
-MID	3.24	23.28	20.04	.8608	1.9974	1.2361	2.4691	2.707
-END	4.26	17.89	13.63	.7619	2.5992	1.2361	3.2130	3.905
9-BEG	4.50	13.52	9.02	.6672	3.4393	1.2361	4.2515	5.873
-MID	6.78	15.73	8.95	.5690	2.9561	1.2361	3.6542	5.665
-END	5.77	18.85	13.08	.6939	2.4668	1.2361	3.0493	3.953

Material: SS304
Temperature = 750°F
S_U = 57.48 ksi
$S_A = 3 \times S_m$ = 46.50 ksi

1-See Figure 3-3 for elbow locations.

TABLE 3-5. IHTS 24" HOT LEG

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 19-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	6.88	13.35	6.47	.4846	3.4764	1.2868	4.4736	8.168
-MID	10.47	16.85	6.38	.3786	2.7543	1.2868	3.5443	7.720
-END	6.13	11.47	5.34	.4656	4.0462	1.2868	5.2068	10.035
2-BEG	6.21	10.70	4.49	.4196	4.3374	1.2868	5.5815	11.919
-MID	7.89	12.53	4.64	.3703	3.7039	1.2868	4.7663	11.171
-END	6.09	8.99	2.90	.3226	5.1624	1.2868	6.6432	18.493
3-BEG	6.15	8.28	2.13	.2572	5.6051	1.2868	7.2128	25.156
-MID	8.35	11.50	3.15	.2739	4.0357	1.2868	5.1932	16.309
-END	6.01	9.23	3.22	.3489	5.0282	1.2868	6.4704	16.679
4-BEG	5.98	8.82	2.84	.322	5.2619	1.2868	6.7712	18.923
-MID	6.66	9.87	3.21	.3252	4.7021	1.2868	6.0509	16.532
-END	6.66	10.28	3.62	.3521	4.5146	1.2868	5.8095	14.660
5-BEG	5.73	8.94	3.21	.3591	5.1913	1.2868	6.6803	16.818
-MID	5.87	9.72	3.85	.3961	4.7747	1.2868	6.1442	13.987
-END	6.18	10.05	3.87	.3851	4.6179	1.2868	5.9425	13.834

Material: 316SS
Temperature = 965°F
S_U = 59.22 ksi
$S_A = 3 \times S_m$ = 46.41 ksi

1-See Figure 3-4 for elbow locations.

TABLE 3-6. IHTS 24" COLD LEG

LOCATION[1]	σ_{cn} (CYCLE 1-U)	σ_c (CYCLE 18-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	6.24	11.42	5.18	.4536	4.1874	1.2091	5.0629	9.957
-MID	6.44	14.39	7.95	.5525	3.3231	1.2091	4.0179	6.462
-END	6.60	11.51	4.91	.4266	4.1546	1.2091	5.0233	10.431
2-BEG	7.14	13.33	6.19	.4644	3.5874	1.2091	4.3374	8.187
-MID	9.64	15.69	6.05	.3856	3.0478	1.2091	3.6850	7.963
-END	6.70	10.58	3.88	.3667	4.5198	1.2091	5.4648	13.176
3-BEG	6.76	10.52	3.76	.3574	4.5456	1.2091	5.4960	13.580
-MID	7.39	13.84	6.45	.4660	3.4552	1.2091	4.1776	7.819
-END	6.99	12.81	5.82	.4543	3.7330	1.2091	4.5135	8.734
4-BEG	6.45	11.31	4.86	.4297	4.2281	1.2091	5.1121	10.570
-MID	6.72	14.94	8.22	.5502	3.2008	1.2091	3.8700	6.216
-END	6.85	11.82	4.97	.4205	4.0457	1.2091	4.8915	10.254
5-BEG	6.31	12.27	5.96	.4857	3.8973	1.2091	4.7121	8.643
-MID	6.41	16.09	9.68	.6016	2.9729	1.2091	3.5934	5.311
-END	6.54	11.85	5.31	.4481	4.0354	1.2091	4.8792	9.657
6-BEG	6.39	11.33	4.94	.4360	4.2207	1.2091	5.1031	10.411
-MID	6.86	15.42	8.56	.5551	3.1012	1.2091	3.7495	5.953
-END	6.50	12.14	5.64	.4646	3.9390	1.2091	4.7626	9.099

Material: SS304
Temperature = 690°F
S_U = 57.818 ksi
$S_A = 3 \times S_m$ = 47.82 ksi

1-See Figure 3-5 for elbow locations.

TABLE 3-7. IHX VENT RETURN LINE

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} ($\sigma_c - \sigma_{cn}$)	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-MID	3.03	26.33	23.30	0.8849	1.744	1.2531	2.186	2.340
2-MID	2.96	24.65	21.69	0.8799	1.863	1.2531	2.335	2.517
3-MID	3.32	24.55	21.23	0.8648	1.871	1.2531	2.344	2.555
4-MID	3.30	17.43	14.13	0.8107	2.635	1.2531	3.302	3.840
5-MID	3.11	13.45	10.34	0.7688	3.415	1.2531	4.279	5.265
6-MID	2.38	8.14	5.76	0.7076	5.643	1.2531	7.071	9.579
7-MID	2.99	6.58	3.59	0.5456	6.980	1.2531	8.747	15.199
-END	1.98	4.14	2.16	0.5217	11.094	1.2531	13.902	25.729
8-MID	4.10	13.07	8.97	0.6863	3.514	1.2531	4.404	5.959
9-MID	5.89	14.82	8.93	0.6026	3.099	1.2531	3.884	5.785
10-MID	2.04	25.65	23.61	0.9205	1.791	1.2531	2.244	2.351
11-MID	6.13	15.73	9.60	0.6103	2.920	1.2531	3.659	5.357
12-MID	4.12	13.59	9.47	0.6968	3.330	1.2531	4.235	5.642
13-MID	4.59	17.17	12.58	0.7327	2.675	1.2531	3.352	4.210
14-MID	2.03	16.17	14.14	0.8745	2.840	1.2531	3.559	3.927
15-MID	2.09	15.98	13.89	0.8692	2.874	1.2531	3.602	3.993
16-MID	3.16	15.79	12.63	0.7999	2.909	1.2531	3.645	4.307
17-MID	2.56	20.04	17.48	0.8723	2.292	1.2531	2.872	3.146
18-MID	4.48	20.32	15.84	0.7795	2.260	1.2531	2.832	3.351
19-MID	3.06	20.49	17.43	0.8507	2.242	1.2531	2.809	3.126
20-MID	3.74	12.02	8.28	0.6889	3.821	1.2531	4.788	6.499
21-MID	3.16	26.27	23.11	0.8797	1.748	1.2531	2.191	2.354
22-MID	6.40	33.72	27.32	0.8102	1.362	1.2531	1.707	1.872
23-MID	1.47	35.15	33.68	0.9582	1.307	1.2531	1.637	1.665
24-MID	1.39	19.69	18.30	0.9294	2.333	1.2531	2.923	3.069
25-MID	1.58	16.83	15.25	0.9061	2.729	1.2531	3.420	3.670
26-MID	1.56	22.47	20.91	0.9306	2.044	1.2531	2.561	2.678
27-MID	1.66	20.30	18.64	0.9182	2.263	1.2531	2.835	2.999
28-MID	1.82	24.05	22.23	0.9243	1.910	1.2531	2.393	2.507

Material: SA-403, Type WP316
Temperature: 1015°F
$3 \times S_m = 45.93$ ksi
$S_u = 57.554$ ksi

1-See Figure 3-6 for elbow locations.

TABLE 3-8. 6" BUBBLER LINE

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} ($\sigma_c - \sigma_{cn}$)	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	1.14	21.51	20.37	0.9470	2.135	1.2531	2.676	2.769
-MID	2.69	31.62	28.93	0.9149	1.453	1.2531	1.820	1.896
-END	0.41	21.97	21.56	0.9813	2.091	1.2531	2.620	2.650
2-BEG	0.43	21.69	21.26	0.9802	2.118	1.2531	2.654	2.687
-MID	0.86	33.04	32.18	0.9740	1.390	1.2531	1.742	1.762
-END	0.47	21.74	21.27	0.9784	2.113	1.2531	2.647	2.684
3-BEG	0.97	10.02	9.05	0.9032	4.584	1.2531	5.744	6.252
-MID	1.68	13.05	11.37	0.8713	3.520	1.2531	4.410	4.914
-END	0.66	8.52	7.86	0.9225	5.391	1.2531	6.755	7.238
4-BEG	0.58	20.14	19.56	0.9712	2.281	1.2531	2.858	2.913
-MID	0.75	27.27	26.52	0.9725	1.684	1.2531	2.111	2.142
-END	0.86	19.01	18.15	0.9548	2.416	1.2531	3.028	3.124
5-BEG	0.76	15.29	14.53	0.9503	3.004	1.2531	3.764	3.909
-MID	2.37	19.63	17.26	0.8793	2.340	1.2531	2.932	3.197
-END	0.61	12.14	11.53	0.9498	3.783	1.2531	4.741	4.939
6-BEG	0.47	10.28	9.81	0.9543	4.468	1.2531	5.599	5.819
-MID	0.98	15.30	14.32	0.9359	3.002	1.2531	3.762	3.951
-END	0.61	9.93	9.32	0.9386	4.625	1.2531	5.796	6.110
7-BEG	0.23	6.19	5.96	0.9628	7.420	1.2531	9.298	9.618
-MID	0.30	11.72	11.42	0.9744	3.919	1.2531	4.911	5.013
-END	0.45	7.01	6.56	0.9358	6.552	1.2531	8.210	8.705
8-BEG	0.42	7.17	6.75	0.9414	6.406	1.2531	8.027	8.464
-MID	1.21	6.67	5.46	0.8186	6.886	1.2531	8.629	10.319
-END	0.43	4.79	4.36	0.9102	9.589	1.2531	12.016	13.102
9-BEG	0.41	6.31	5.90	0.9350	7.279	1.2531	9.121	9.685
-MID	1.17	11.54	10.37	0.8986	3.980	1.2531	4.987	5.437
-END	0.21	3.13	2.92	0.9329	14.674	1.2531	18.388	19.638

Material: SA-403, Type WP316
Temperature = 1015°F
3 x S_m = 45.93 ksi
S_u = 57.554 ksi

1-See Figure 3-7 for elbow locations.

TABLE 3-9. 2" PUMP DRAIN LINE

ELBOW #[1]	NODE	σ_c ksi	σ_{cn} ksi	σ_{cs} ksi	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1	2	9.441	1.319	8.122	0.8603	4.865	1.2531	6.096	6.924
	3	21.111	1.034	20.077	0.9510	2.176	1.2531	2.726	2.815
2	6	3.376	0.437	2.939	0.8706	13.605	1.2531	17.048	19.434
	7	11.298	0.683	10.615	0.9395	4.065	1.2531	5.094	5.358
3	13	8.880	1.766	7.114	0.8011	5.172	1.2531	6.481	7.842
	14	15.081	0.487	14.594	0.9677	3.046	1.2531	3.816	3.910
4	16	8.649	1.798	6.851	0.7921	5.310	1.2531	6.655	8.138
	17	29.647	1.128	28.519	0.9620	1.549	1.2531	1.941	1.979

Material of Elbows: SA-403, Type WP316

1-See Figure 3-8 for elbow locations.

Temperature - 1015°F

$3 \times S_m = 45.93$ ksi

$S_u = 57.554$ ksi

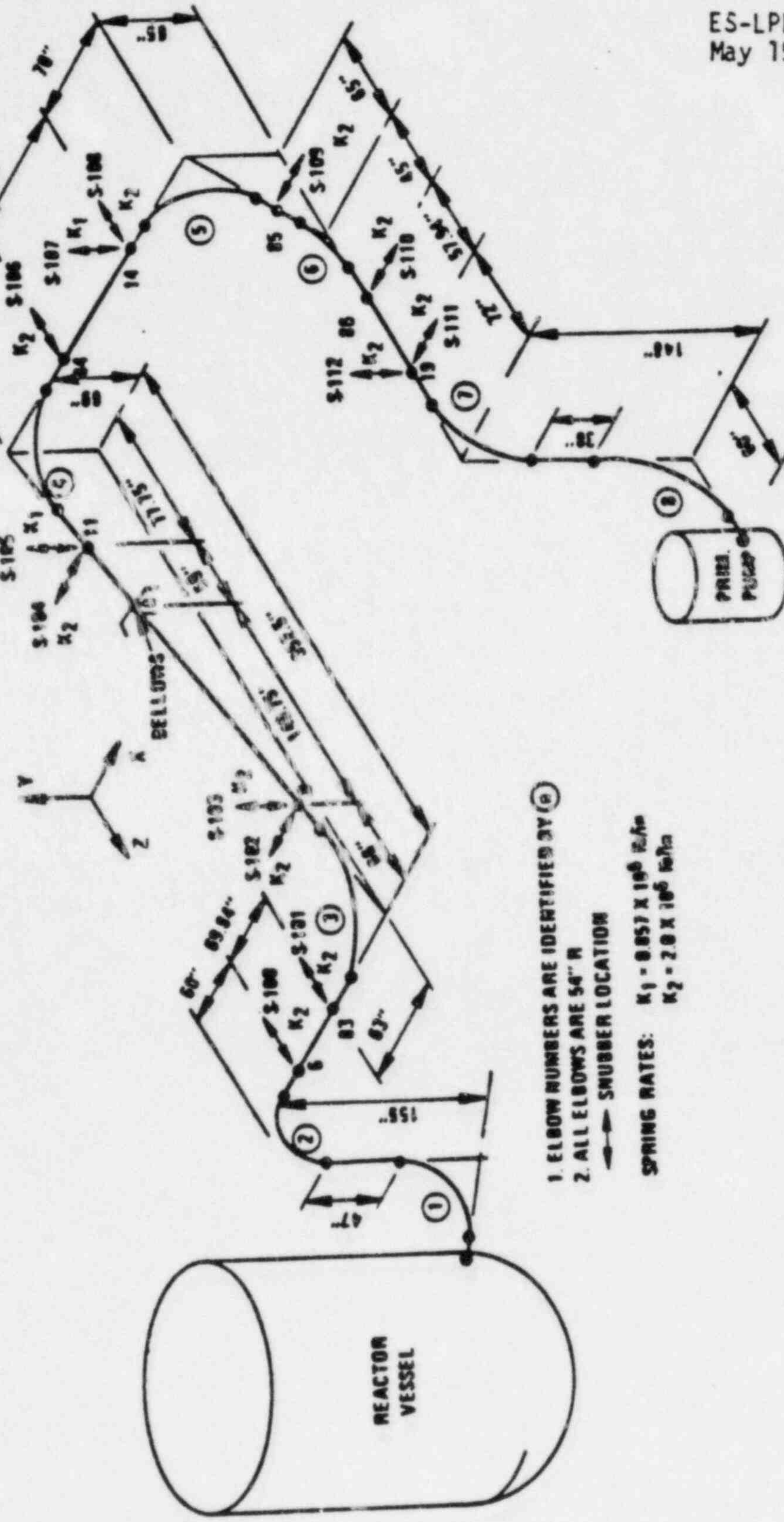


Figure 3-1 36" Primary Hot Leg Loop 1 Seismic Model

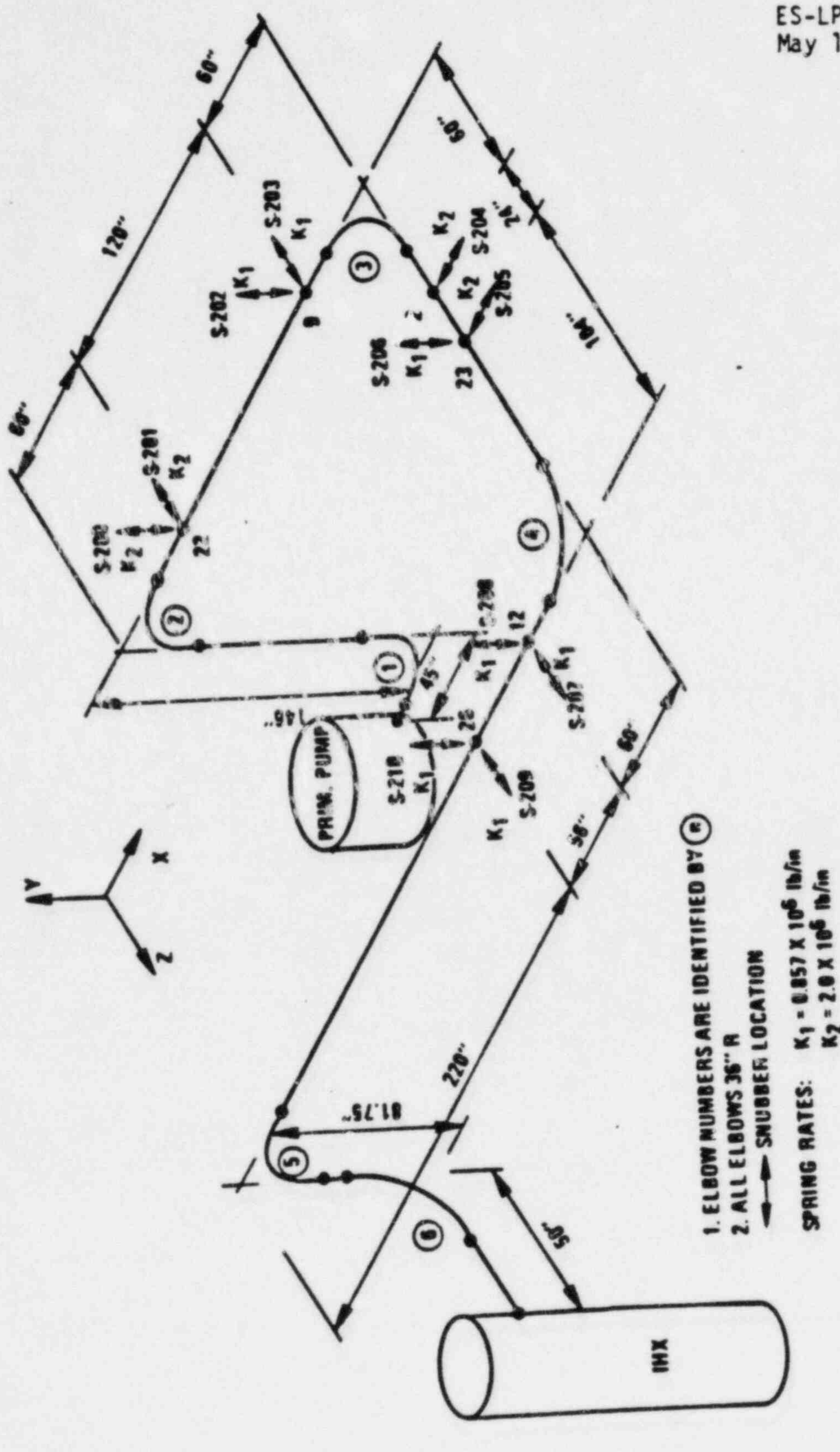


Figure 3-2 24" Primary Hot Leg Loops 1, 2 & 3 Seismic Model

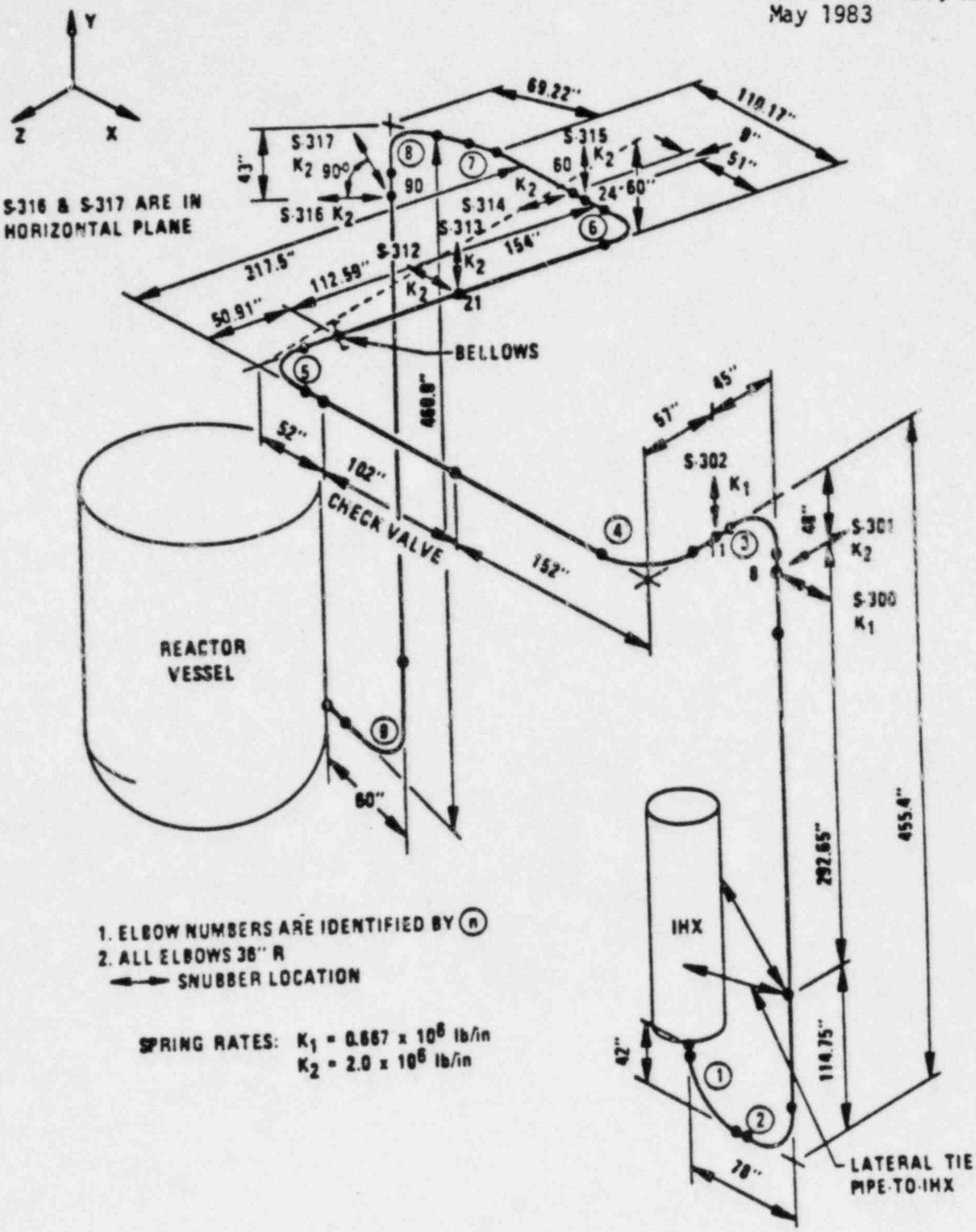


Figure 3-3 24" Primary Cold Leg Loop 1 Seismic Model

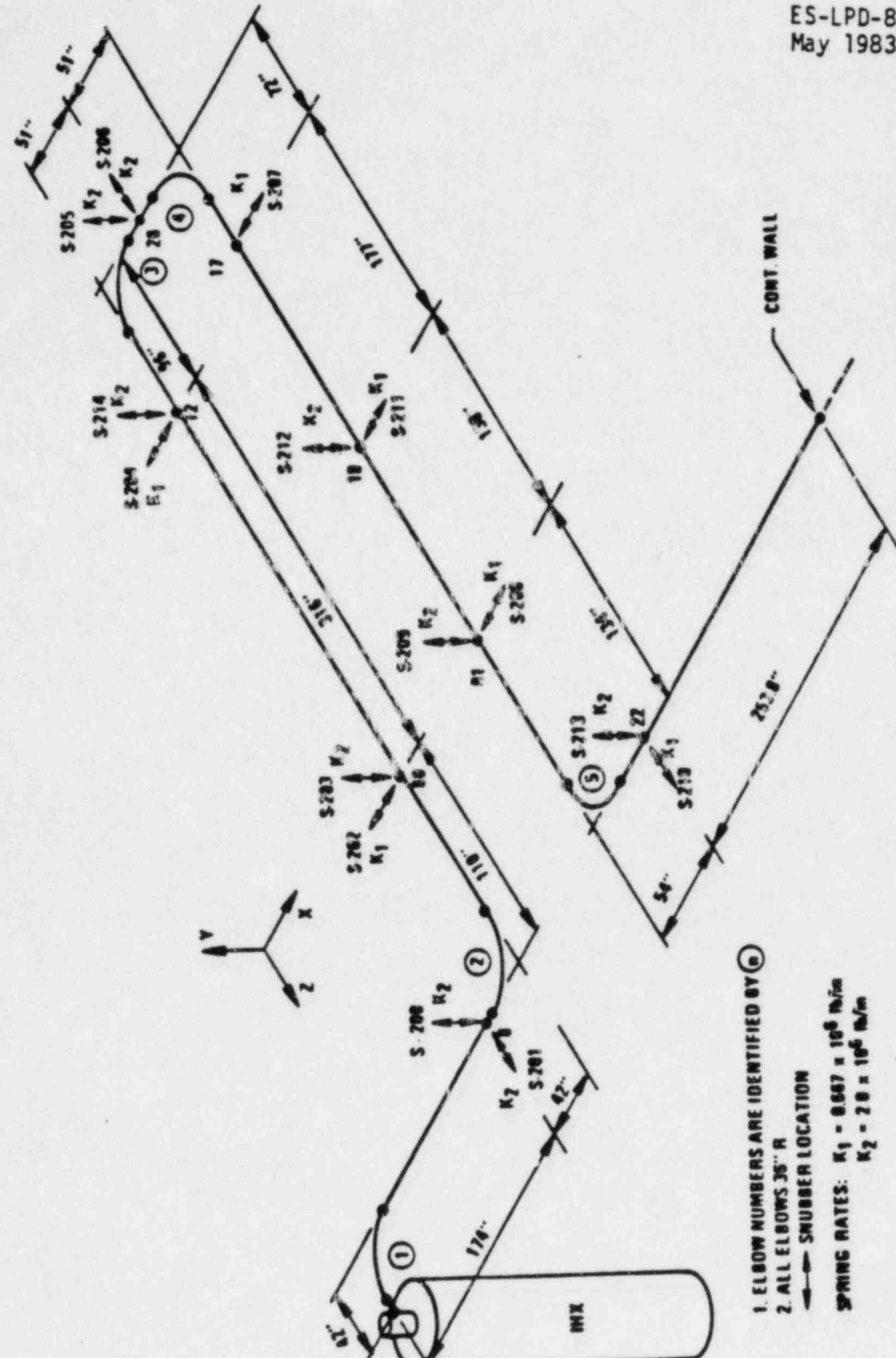


Figure 3-4 24" Intermediate Hot Leg Loop 1 Seismic Model

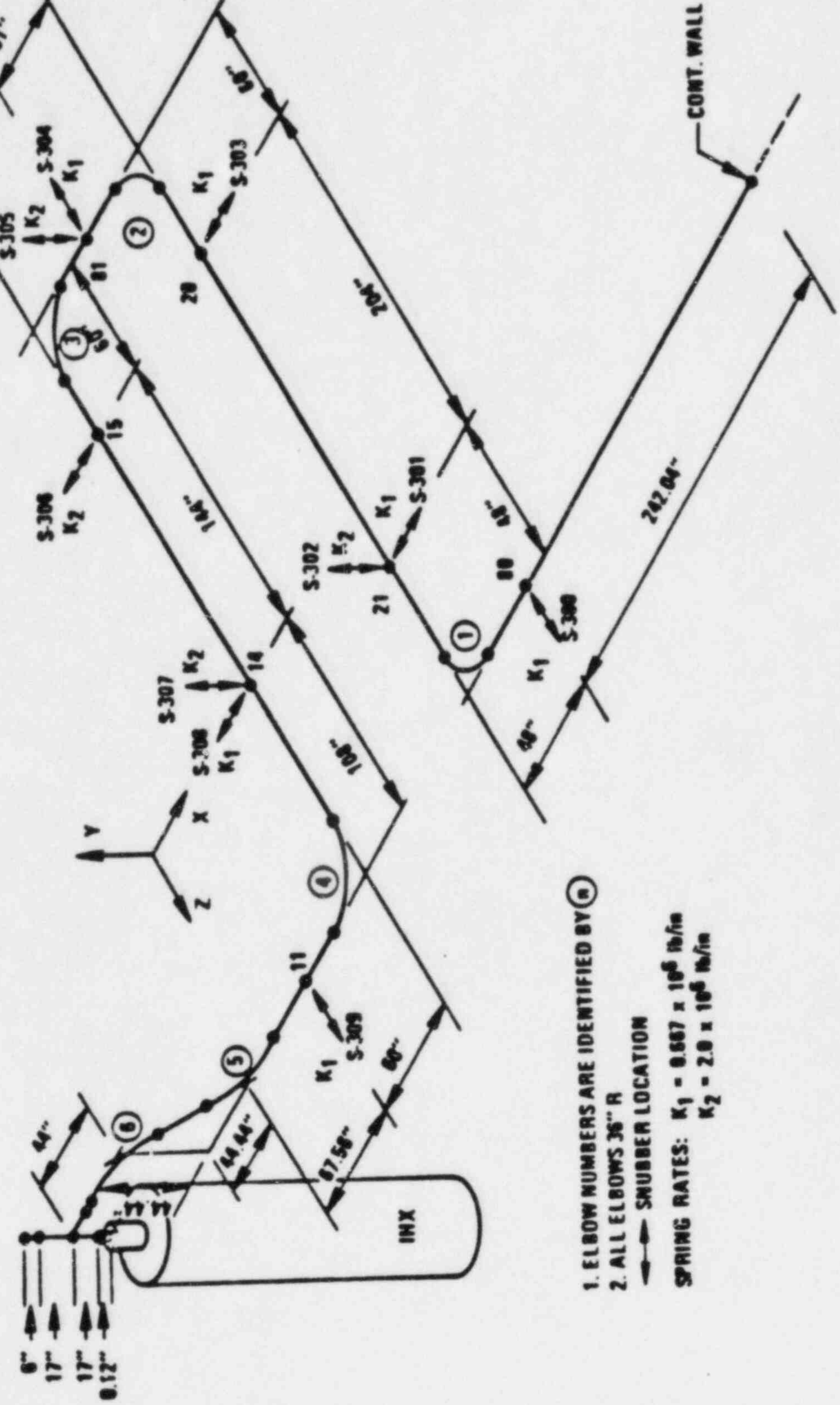


Figure 3-5 24" Intermediate Cold Leg Loop 1 Seismic Model

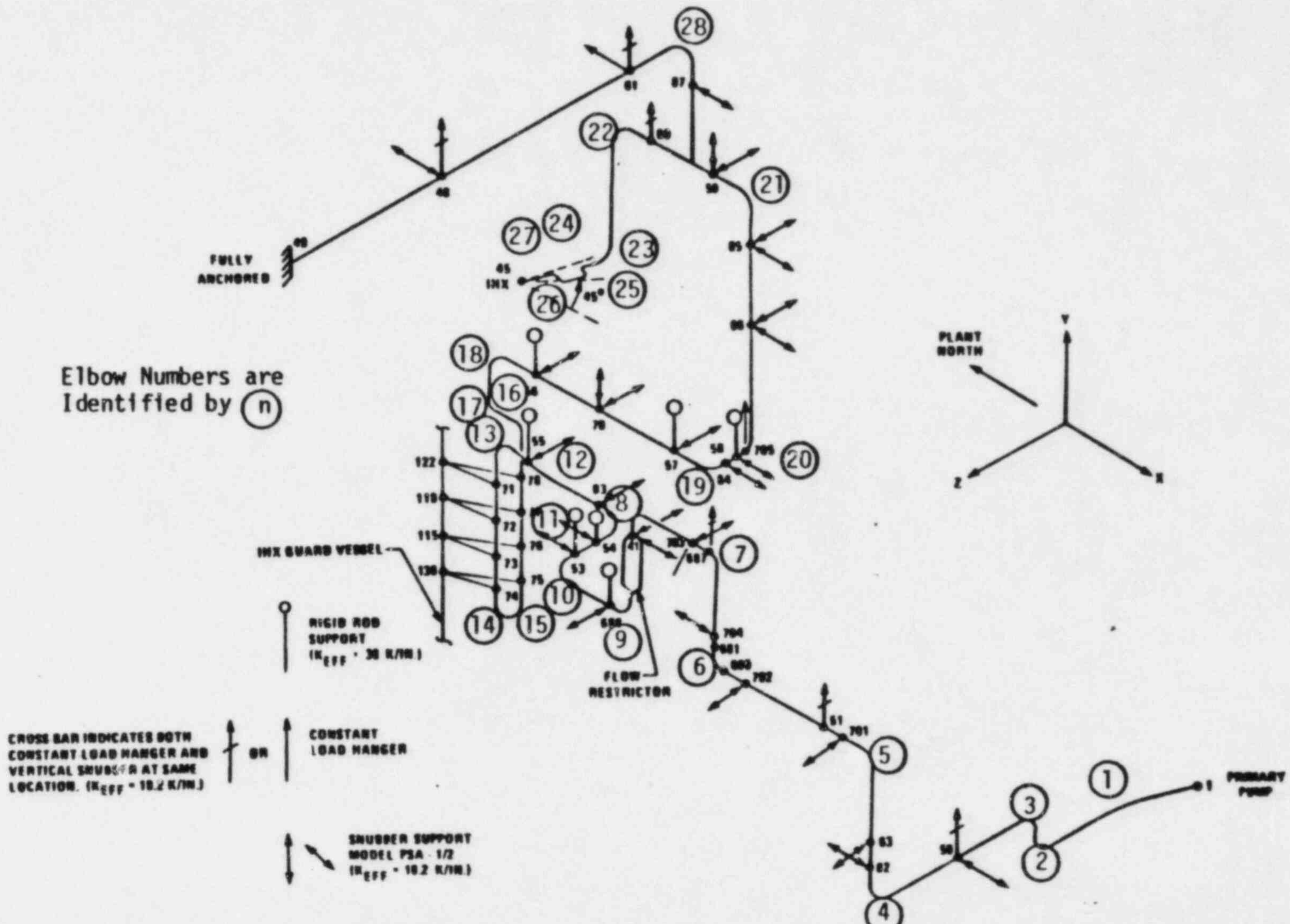


FIGURE 3-6. IHX Vent Return Line PRP(D) & PRP(E) Loop 1 Seismic Model

Elbow numbers are identified by (n)

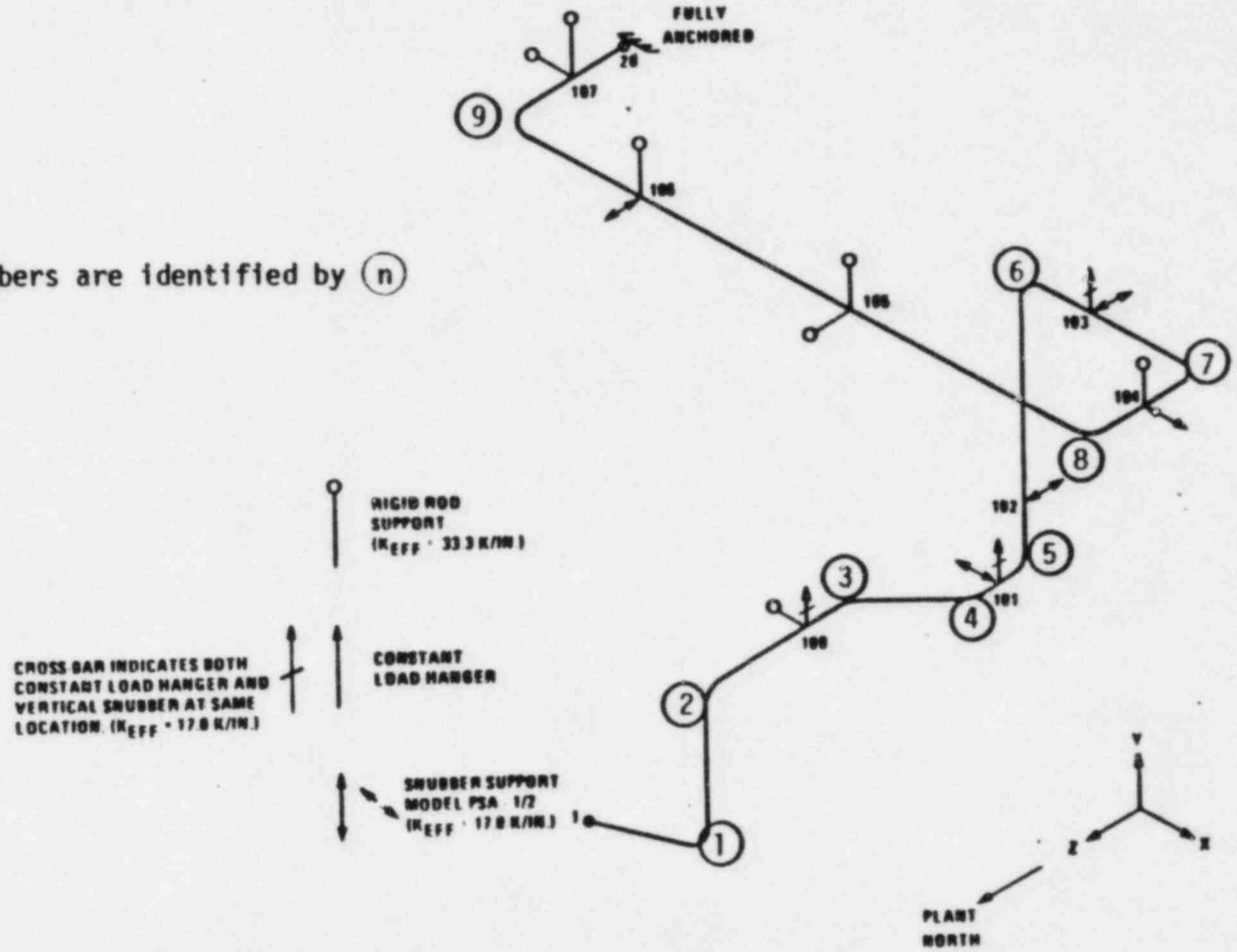


FIGURE 3-7. Primary Sodium Pump Bubbler Line Loop 1 Seismic Model

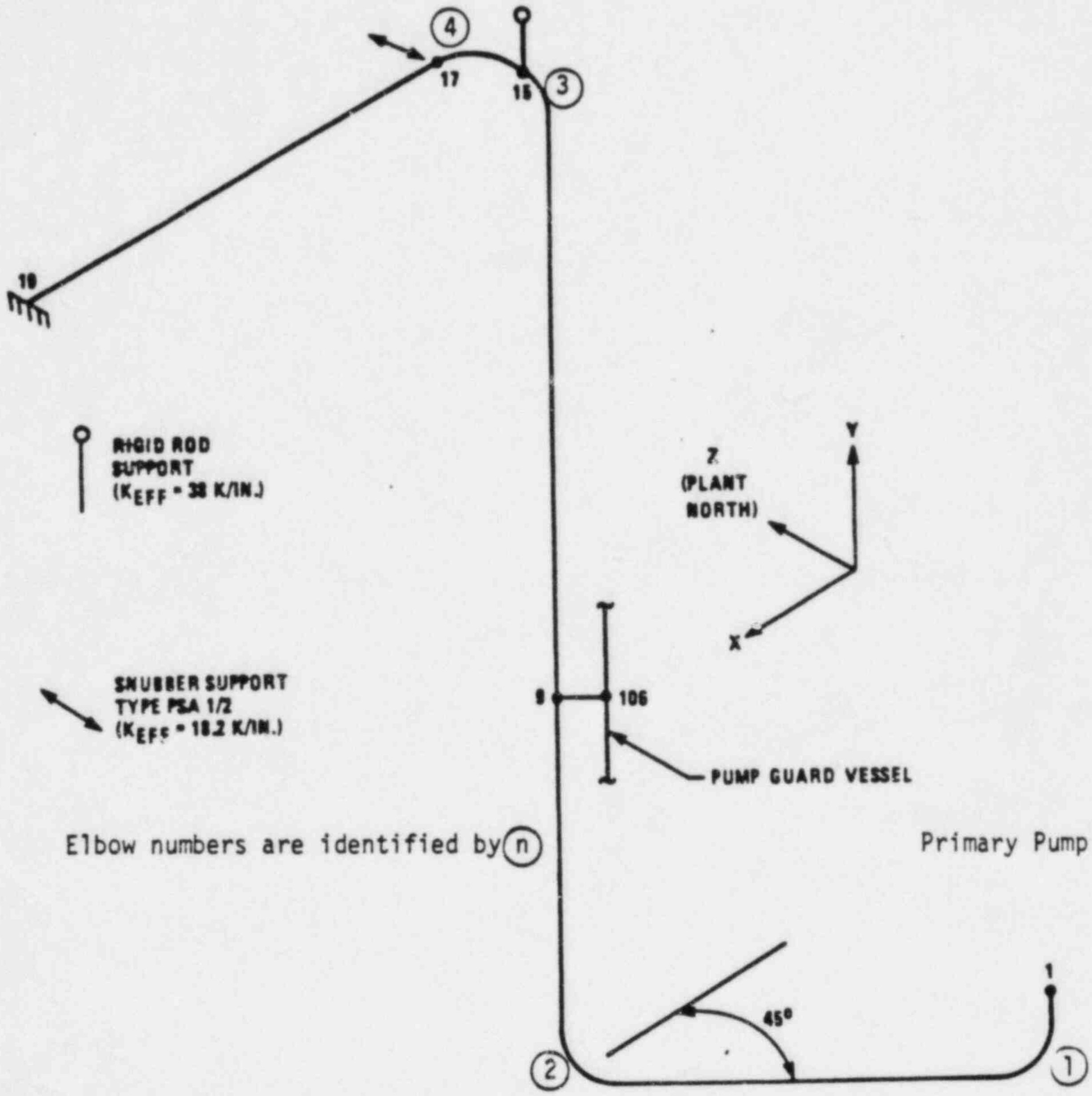


FIGURE 3-8. Primary Sodium Pump Drain Line
Loop 1 Seismic Model

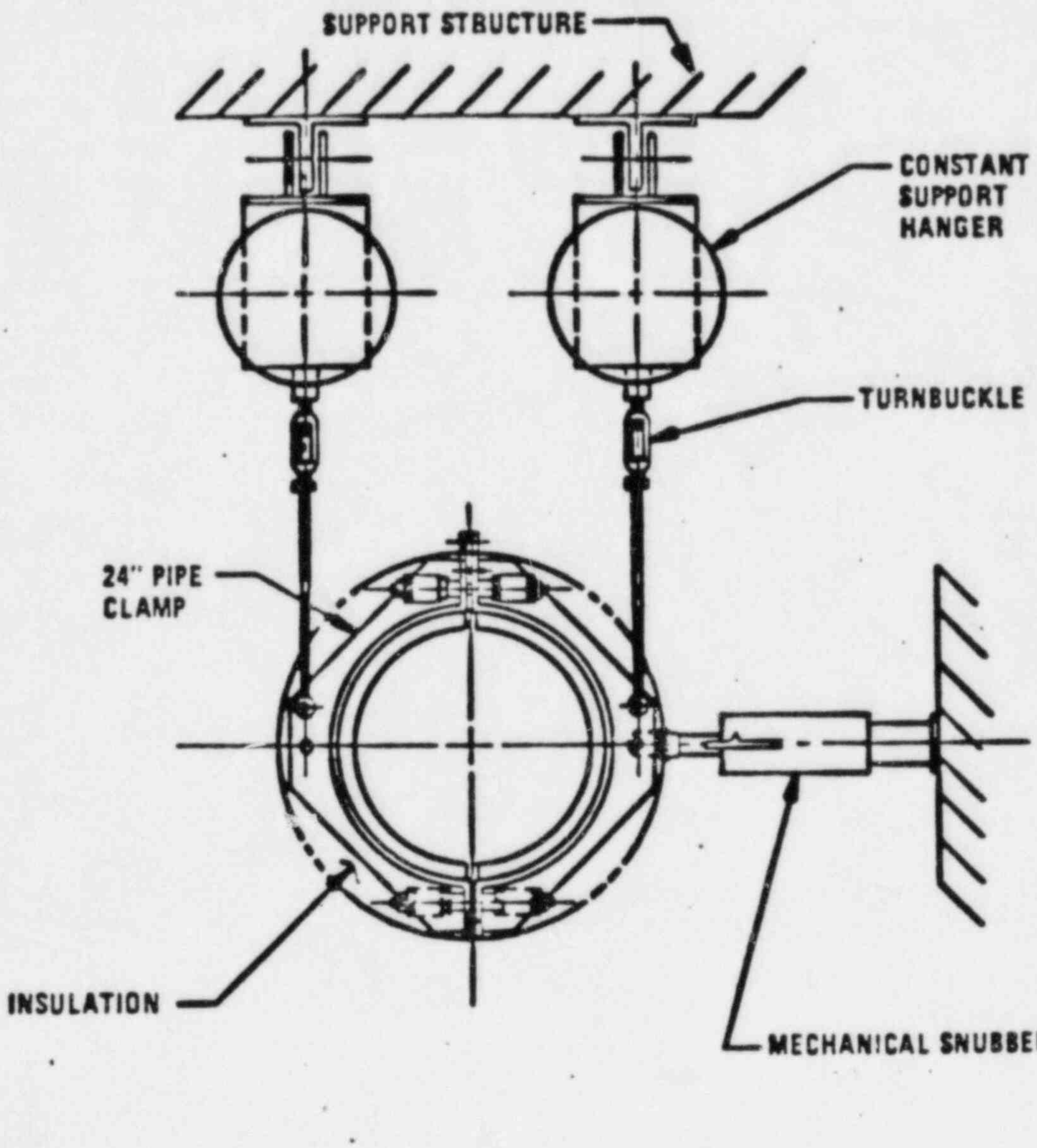


Figure 3-9. Typical 24" Pipe Restraint Assembly for CRBRP

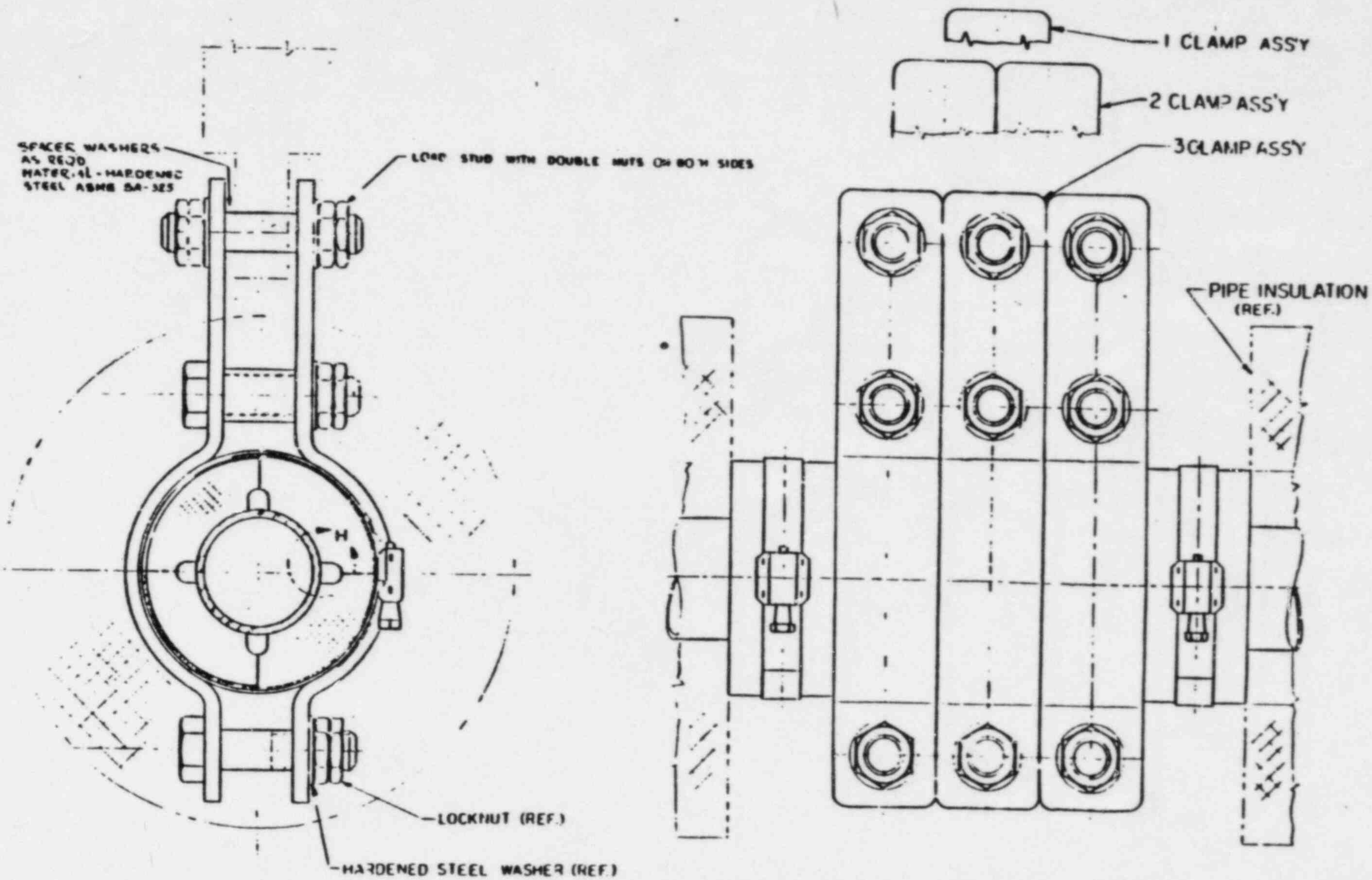


FIGURE 3-10. Typical Small-Diameter Pipe Clamp

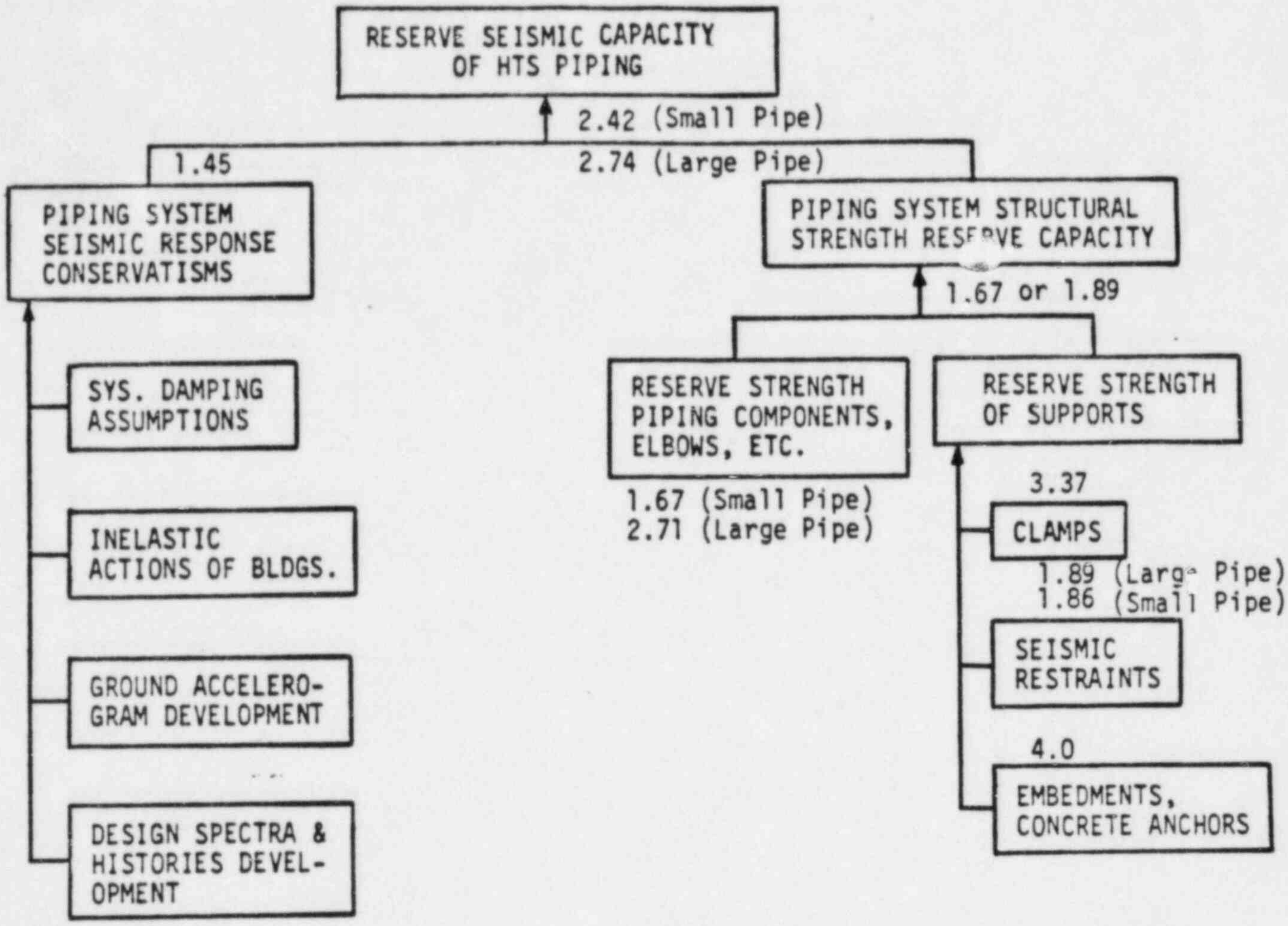


FIGURE 3-11

CRBRP HTS PIPING SYSTEM MINIMUM RESERVE SEISMIC CAPACITY RESULTS

4.0 SUMMARY AND CONCLUSIONS

The inherent reserve capacity of the CRBRP heat transport system incontainment piping has been determined using the approach developed by Rodabaugh and Desai in NUREG/CR-2137. The sources of reserve seismic capacity were divided into the following three broad categories:

(a) Conservative predictions of the piping seismic response,

(b) Conservative definitions of structural and functional performance limits, and

(c) Reserve seismic capacity incorporated by means of designer/analyst conservatisms.

Reserve seismic capacities from Items (a) and (b) were considered in arriving at seismic margins for the piping system. Reserve seismic capacities from Item (c) are listed and discussed, but not quantified.

The reserve seismic margin was determined by combining the design margin for the SSE event and the nominal margin (margin between ASME Code allowable and ultimate failure). The various margins were defined as follows:

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress}}{\text{Calculated Stress}} = \frac{S_A}{\sigma_c}$$

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress}}{\text{Allowable Stress}} = \frac{S_u}{S_A}$$

The actual or combined margin was determined from the product of the above two margins, or:

$$\text{Actual Margin (AM)} = \text{DM} \times \text{NM} = \frac{S_u}{\sigma_c}$$

If k is defined as the ratio of seismic-only stress or load to the total calculated stress (σ_c), the seismic only margin (SOM) was determined as follows:

$$\text{SOM} = \frac{(\text{NM} \times \text{DM} - 1)}{k} + 1.0$$

This margin was used directly to determine the reserve seismic capacity of the HTS piping system.

The reserve strength capacity for the HTS piping system was dependent on seismic-only margins (SOMs) for the piping components (elbows, tees, etc.) and the piping restraints system. The reserve margin calculations for the piping restraints system accounted for the behavior of the pipe clamps, restraints (or snubbers), and the embedments (concrete anchor bolts). The minimum reserve strength capacities obtained for these components are listed below:

(a) Piping Components = 1.67

(b) Clamp = 3.37

(c) Snubbers = 1.86

(d) Embedments = 4.0

In addition to the strength reserves, conservatism was introduced into the piping seismic response predictions. These result from such items as (a) system damping assumptions, (b) development of ground acceleration, (c) reduction of floor response spectra (or time histories) due to inelastic action of the buildings and (d) development of design response spectra (or time histories). The net effects of these items are responsible for a 1.45 factor on predicted seismic responses.

Combining the results for the reserve strengths and the response predictions conservatisms, gives an overall reserve seismic capacity of 2.42 which translates into a reserve margin earthquake of 0.605 g's.

5.0 REFERENCES

1. NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping", E. C. Rodabaugh and K. D. Desai, June 1981.

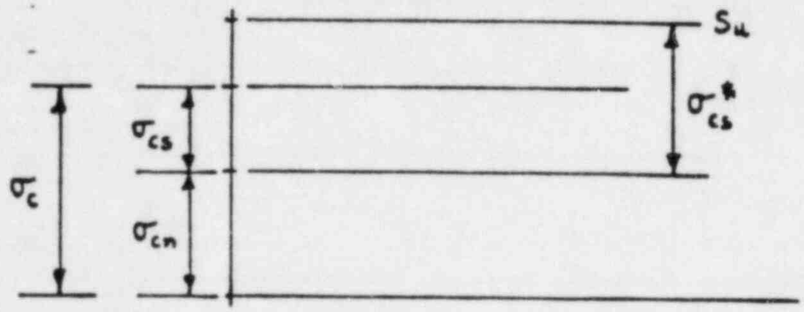
2. "CRBRP Reserve Seismic Margins", ACRS Presentation on February 11, 1983, A. Morrone.

3. ASME Boiler and Pressure Vessel Code, 1974, Section III, Nuclear Power Plant Components, with Addenda through Summer 1975.

4. TID-26666, Nuclear Systems Material Handbook.

APPENDIX A

DERIVATION OF SEISMIC-ONLY MARGIN (SOM)



$$\text{Thus, SOM} = \frac{\sigma_{cs}^*}{\sigma_{cs}} = \frac{S_u - \sigma_{cn}}{\sigma_{cs}}$$

$$= \frac{S_u - (\sigma_c - \sigma_{cs})}{\sigma_{cs}}$$

$$= \frac{\frac{S_u}{\sigma_c} - (1 - \frac{\sigma_{cs}}{\sigma_c})}{\sigma_{cs}/\sigma_c} \quad \text{if } k = \sigma_{cs}/\sigma_c$$

$$= \frac{AM - (1-k)}{k}$$

$$= \frac{(AM-1)}{k} + 1$$

$$\text{or, SOM} = \frac{(NM \cdot DM - 1)}{k} + 1$$

APPENDIX B

SMALL-DIAMETER PIPING INTEGRITY CONSIDERATIONS

B.1 INTRODUCTION AND SUMMARY

It was shown in the body of this report that the predicted reserve seismic margins for the CRBRP large diameter piping and small diameter piping are comparable. On the face of it, this may seem to contradict experience with LWRs which indicates a higher rate of failure for small-diameter piping (Reference 1). This apparent contradiction is addressed in the following paragraphs. It is concluded that comparable reserve seismic margins for the CRBRP large and small-diameter piping are realistic.

Firstly, it is important to understand that reserve seismic margin and observed failure rates are very different measures of integrity. Observed failure rates for small pipe tend to derive from high cycle vibration, environmental effects and detailed design features. Failures associated with a seismic event are overload type failures rather than fatigue type failures. Therefore, it is reasonable for large and small-diameter piping to have comparable reserve seismic margins in spite of the higher failure rate observed for small piping in LWR experience.

There is also a reason why overload failures in piping tend to arise as failures in connected small diameter piping. Evaluations of extreme loads beyond the design base on piping systems are usually very conservatively performed in that failure is predicted without fully accounting for load redistribution away from peak load locations. Extensive load shedding occurs in very ductile redundant piping typical of both LWR and LMFBR systems. Very large displacements of main piping can occur under extreme loads without failure of the main piping. The failures from such extreme loads tend to occur in the attached small diameter piping because it is restrained against the large ductile motions of the large pipe and is the weaker of the two items. Therefore, a more refined analysis of reserve seismic margin would tend to increase the reserve seismic margin predicted for large piping rather than reduce the reserve seismic margin predicted for small piping.

There are important additional reasons why the reserve seismic margin for the CRBRP small-diameter piping is judged to be comparable to the large diameter piping. The diameter of the small diameter HTS piping is larger than the diameters of the lines with the highest failure rates. The HTS small diameter piping is as fully engineered as the main piping; no field run lines, no socket fittings, etc. Design codes are equivalent. The leak-before-break characteristic is established and inspection and leak detection are equivalent to ensure that the piping is not weakened significantely prior to a seismic event. These considerations are discussed in the following subsections.

Overall, it is concluded that the reserve seismic margin predicted for the HTS small-diameter piping is realistic.

B.2 DESCRIPTION OF SMALL-DIAMETER PIPING AND INSTRUMENTATION

A description of the small-diameter piping and reactor heat transport system instrumentation that attach to the Primary and Intermediate Heat Transport System piping and components within containment is provided. Emphasis is placed on those design features which enhance the integrity of the piping and components or limit the consequences in the unlikely event of a failure of the pressure boundary.

The arrangement of heat transport system and the locations of the major components relative to the reactor vessel are shown in Figure B-1. The primary system small-diameter piping includes three identical loops made up of a 2" nominal vent return line between the IHX and primary pump and from the vent line itself to the argon receiving system, a 6" nominal bubbler line between the pump and argon gas receiving system, and a 2" nominal drain line attached to the bottom of the pump and extending to the auxiliary liquid metal fill system.

The 2-inch IHX vent line is routed from the IHX to the primary pump tank to prevent gas accumulation in the IHX. The line connects to the IHX at an elevation near the highpoint of the shell side and runs to a point on the pump tank which is below the specified minimum safe level of the pump. The elevational location for the vent line at the pump prevents flow of gas from the pump cover gas space into the IHX and consequent loss of syphon in the event of a leak.

The portions of the small-diameter PHTS piping below the reactor minimum safe level are located in guard vessels to provide protection against loss of coolant in the event of a leak.

In addition to the small-diameter piping attached to the primary system, there are special branch connection nozzles provided in the PHTS system for attaching (1) the high point vent to 36-inch hot leg, (2) the high point vent to the cold leg check valve, and (3) the fill/drain connection at the primary cold leg piping near the primary outlet from the IHX. Instrumentation (including temperature and pressure sensors) is attached to the primary system large-diameter piping using these special branch connections also.

The special branch connection nozzle fittings are contoured and integrally reinforced to minimize pressure and thermal discontinuity stresses (see Figure B-2). The basic method of lap type reinforcements and joints for attaching branch piping to vessels or large piping create geometries that produce areas of high stress concentrations. The contoured branch fittings used for CRBRP fully integrate the branch and run pipes and are attached with full penetration welds. They are contoured both in shape and thickness for low stresses with the insert and branch welds far away from critically stressed areas.

Temperature sensors in the PHTS piping are installed in dry thermowells (see Figure B-3 for configuration). A special branch connection is used as a transition from the pipe to the thermowell assembly to avoid abrupt discontinuities (see Figure B-1 for locations). This installation is designed to withstand the normal environment including pressure and temperature transients defined in the piping design specification. The use of this thermowell maintains the integrity of the primary pressure boundary while permitting replacement of the sensor. A secondary seal is provided by the connection head enclosure and the cable entrance fitting.

Branch connection nozzle fittings are also provided for attaching pressure sensors (see Figure B-1 for locations). The actual pressure sensor is not in the primary sodium but primary sodium pressure is transmitted to the sensor through a bellows which has primary sodium on one side and NaK on the other side (see Figure B-4). The primary side installation is designed to meet the requirements of the piping design specification. The use of a bellows to separate the primary sodium from the pressure sensor permits replacing the pressure sensor while maintaining the primary pressure boundary.

The intermediate heat transport system within containment has small-diameter piping between the IHX intermediate side and the main IHTS piping loops (see Figure B-5) which serves to vent the IHX. The IHTS vent system includes (1) a 2" nominal hot leg between the IHX intermediate side outlet high point vent and the IHTS main loop hot leg piping, (2) a 2" nominal interconnecting line, with a manual valve between the running vent line and IHTS cold leg main loop piping, and (3) a 2" argon gas/rupture disc piping assembly connected to both the continuous hot leg vent line and IHTS cold leg main loop piping.

The IHTS small diameter piping is attached to the main IHTS piping and IHX with integrally contoured nozzles or branch connections.

The primary small diameter piping and the intermediate piping within containment are contained in separate, shielded and inerted cells. Concrete shielding between cells minimizes neutron activation of piping, supports and components and prevents propagation of postulated structural failures. The cells are steel-lined to restrict leakage of the nitrogen gas used for inerting and to avoid a sodium-concrete reaction in the event of a sodium spill. The inert environment (with a maximum oxygen concentration of 2% by volume and moisture content of about 1000 vppm) minimizes corrosion and retards flaw growth. Also, the inert environment limits cell pressure transients for any postulated leaks. A lower bound of 0.5% on the oxygen concentration is imposed to prevent nitridation of coolant boundary materials. The average temperature in the cells is maintained at or below 120°F by cooling the nitrogen atmosphere. This feature assures that the pipe snubbers and hangers will not experience the elevated temperatures seen by the piping.

Special consideration has been given to the design of pipe supports to assure their integrity and to minimize the impact of postulated support failures on piping integrity. Pipe clamps for attachment of pipe supports are of the non-integral type. These clamps are located away from elbows and girth welds to permit access for inservice inspection of the welds without having to dismantle the clamps. The design of the piping insulation is such that there is no mechanical interference with the pipe clamps. Mechanical snubbers are used exclusively for the piping within containment. No axial snubbers are used so as to eliminate the possibility of a pair of seized axial snubbers interfering with free axial thermal expansion of the piping. Redundant constant load and rigid type pipe hangers are used to support the weight of the insulated piping filled with sodium. Pipe supports are welded to steel plates embedded in the concrete walls.

Removable, replaceable insulation is used where equipment or piping within containment requires removal of insulation for access, inservice inspection and maintenance. The requirements for insulation provide for a minimum of chlorides and other corrosive materials. The insulation material is jacketed to protect it from mechanical damage and deterioration in service. Additionally, the insulation is designed with a gap surrounding the piping or component with small openings arranged to assure adequate purging of this area with inert cell gas and to provide for leak detection.

B.3 DESIGN/ANALYSIS CONSIDERATIONS

The piping design specification provides a complete basis for the construction of the HTS small-diameter piping within containment. Both the primary and intermediate piping (including the large and small diameter) will be constructed to ASME Code Class 1 and supplemental requirements.

The pressure containing components and instrumentation attachments will be designed and built to meet the requirements of the ASME Code and those RDT Standards which have been designated applicable to the CRBRP piping. ASME requirements will also be met for structural members such as piping supports and seismic restraints.

The ASME Code includes basic requirements governing materials, design, fabrication, examination, testing and installation. Requirements unique to the RDT Standards and/or based on FFTF experience are added as deemed necessary.

The installed HTS small-diameter piping must satisfy the CRBRP piping design specification and be designed and constructed in accordance with ASME Code, supplemented by several RDT Standards mandated for the CRBRP Project; most notably RDT E15-2NB-T. The design specification defines features needed in the piping to assure system performance. The ASME Code and RDT Standards insure quality and safety through all phases of the Project from inception through operation.

B.4 QUALITY ASSURANCE CONSIDERATIONS

CRBRP Specifications provide explicit requirements derived from the source Codes, standards and experience described above.

Prior to issue and use of CRBRP Specifications, the quality requirements come under intensive scrutiny by qualified experts in all allied activities: design; analysis; material application; manufacturing; quality assurance; construction; safety; and licensing. All revisions or deviations receive comparable review.

Since the finished piping must meet ASME Code requirements for Class 1 piping, the Authorized Inspector will conduct an independent review of quality and safety aspects, as defined in the Code, and certify that these have been satisfied. This certification with the inspections by manufacturer, fabricator and purchaser provide confidence that all specified requirements will be met.

In accordance with approved project procedures, all of the activities at supplier's facilities are periodically monitored by knowledgeable individuals both from the Project and the ASME Code Authorized Inspection Agency (where applicable). Permanent records of these examinations and tests are kept so that quality verification is maintained in a fashion that permits re-verification if required.

B.5 FAILURE EXPERIENCE

There are two sources of piping failure experience on which to predicate reliability estimates for CRBRP large and small diameter HTS piping; (1) piping failures in existing sodium cooled nuclear reactors and various liquid sodium test facilities and (2) those in commercial water-cooled nuclear reactor (LWR) plants. The failure history for liquid sodium piping is of limited extent and it should be recognized that the CRBRP piping differs from previously constructed sodium piping in some significant respects (Reference 2).

Sodium test facility piping is often not a fully engineered design. Such piping is typically installed using "off-the-shelf" components and with non-nuclear construction techniques. The CRBRP HTS piping is a Class 1 component designed, analyzed, and constructed in accordance with the stringent, conservative requirements of the ASME B&PV Code. Comparisons to existing liquid metal-cooled nuclear reactors are complicated by the various differences in reactor design and by the fact that the old designs do not embody the many advances in design, analysis and metallurgy which have been made in the intervening period (Reference 3).

The history of piping failures in commercial water-cooled nuclear reactor (LWR) plants is in some respects superior to the history of failures in sodium piping as a base on which to evaluate reliability of CRBRP HTS large and small diameter piping. The LWR history is significantly larger than the liquid metal piping sample, and the LWR history reflects the behavior of nuclear-quality piping, which should more closely resemble the quality level of the CRBRP piping than does existing liquid metal piping. The data base for the LWR piping failure categorization is a collection of summaries of more than 800 Licensee Event Reports (LERs) filed with the NRC by holders of operating licenses for those nuclear facilities under NRC jurisdiction.

An evaluation of piping failures based on the review of abnormal operation reports or LERs was conducted in Reference 1, and the incidents were grouped by reactor type, pipe size, location of failure and cause of failure. The significant aspect of data is the large number of cases of failure in lines 1-inch or less in diameter (more than 60% of the failures). These failures occurred predominantly at welds (usually socket) and in most instances were at the attachment point of small lines to a much larger line. In most cases failures of the small pipe were in welds due either to fatigue or to construction because of weld porosity or fit-up usually in socket welds.

The higher rate of failure for the LWR 1-inch or smaller piping can be attributed to many reasons. Firstly, the ASME Code waives many design, analysis, fabrication and inspection requirements for pipe of this size. Secondly, piping of this size is in many cases field run. Field run piping is usually arranged based on engineering judgement with limited analysis backup. Lastly, this piping is usually attached to vessels or large pipe with socket joints. Socket joints use fillet welds that are difficult to inspect, they introduce stress concentrations, and their fabrication correctness is difficult to confirm.

For CRBRP HTS small-diameter piping within containment, the same rigid ASME Code requirements being used for the large-diameter piping will be applied. Detailed analysis will be used to establish the design and the same quality assurance program during fabrication and installation will be used. In addition, the use of socket joints to attach small-diameter liquid metal piping and instrumentation will be prohibited. Special contoured branch connections will be used. Full penetrations welds will be used to attach the branch connection or nozzle fitting to the large pipe or vessel, and to attach the branch piping to the branch connections. The smallest branch connection size for CRBRP incontainment small piping is 1.5-inch nominal diameter. These extra design and fabrication precautions should insure that the CRBRP small diameter piping will be as reliable as the large sodium piping.

B.6 LEAK-BEFORE-BREAK CONSIDERATIONS

In Reference 4, an evaluation of the large-diameter HTS piping was performed to demonstrate that a leak-before-break characteristic is applicable to the HTS piping. This is an experimental assessment of margin in which extreme conditions are imposed such that extensive crack growth is forced to occur. First, a critical crack length is established by model elbow burst tests. This is the crack length at which a crack begins to bulge open and thereby permit gross leakage. Secondly, model elbows with intentional surface defects are tested under cyclic loading to demonstrate that substantial crack growth results in development of a through-wall (leakage) crack at relatively short crack lengths.

Extensive experimental data which are available for stainless steel straight pipe and elbows, show that, for the HTS large and small diameter piping, the critical crack is a very long through-wall crack. For the 2-inch nominal IHX vent return line (the most highly loaded small-diameter pipe) at normal operating pressure, the critical crack length is predicted to be 8.6 inches.

The extensive experimentation of scale models (4-inch) of the large-diameter HTS piping elbows show that crack growth proceeds through the pipe wall before substantial crack growth extension occurs. It is reasonable to expect that these test results apply to elbows with 2-inch nominal diameter also. Therefore a growing crack would develop a leak long before the critical crack size could be reached. Studies of the IHX vent return line show that the PHTS design basis leak (DBL) will be reached by a through-wall crack before the critical crack size of the 2-inch nominal pipe has been obtained. Having established the leak-before-break characteristic for the HTS large and small diameter piping, it remains only to consider leakage and leak detection to preclude gross failure of the pipe.

The CRBRP leak detection system design is the same for large and small diameter piping. It was shown in Reference 4, that the system can detect leaked sodium in times much less than the time required for a leaking crack to grow to a critical length. This ensures that the small diameter piping will not be weakened significantly prior to occurrence of a seismic event.

B.7 REFERENCES

1. S. H. Bush, "Reliability of Piping in Light-Water Reactors", Nuclear Safety, Vol. 17, No. 5, 568 - 579 (September-October 1976).

2. "Failure Data Handbook for Nuclear Power Facilities: Volume I, Failure Data and Applications Technology", LMEC-Memo-69-7, Volume I, LMEC, Canoga Park, California, August 15, 1969.

3. R. C. Bertucio, "Effect of Repair Times on Relative SHRS Reliability", WARD-SR-3045-6, Westinghouse Electric Corp., Advanced Energy Systems Division, Madison, PA, November 1978.

4. R. H. Mallett and B. R. Nair, "Clinch River Breeder Reactor Plant: Integrity of Primary and Intermediate Heat Transport System Piping in Containment", CRBRP-ARD-0185, Westinghouse Electric Corp., Advanced Energy Systems Division, Madison, PA, October 1977.

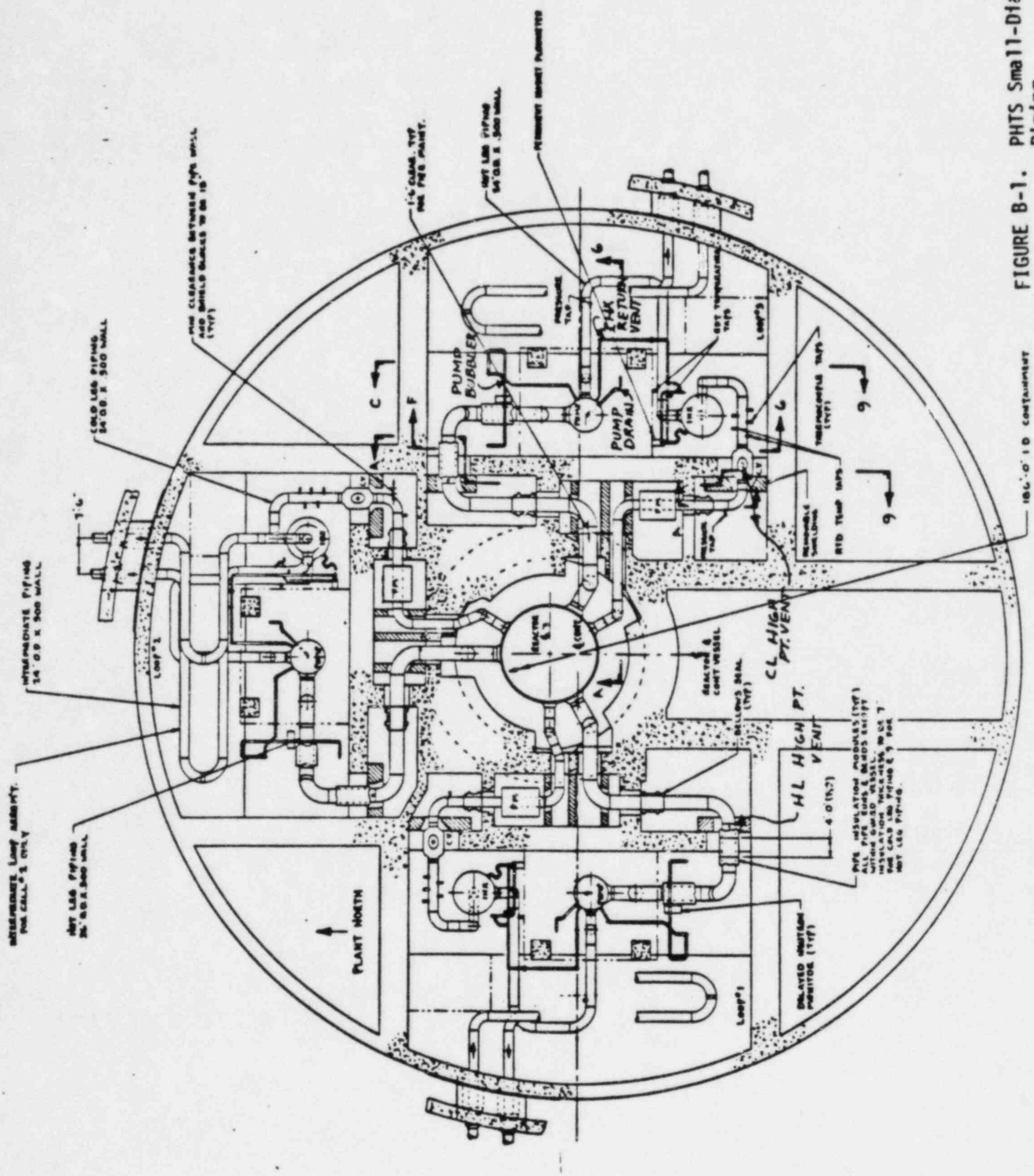
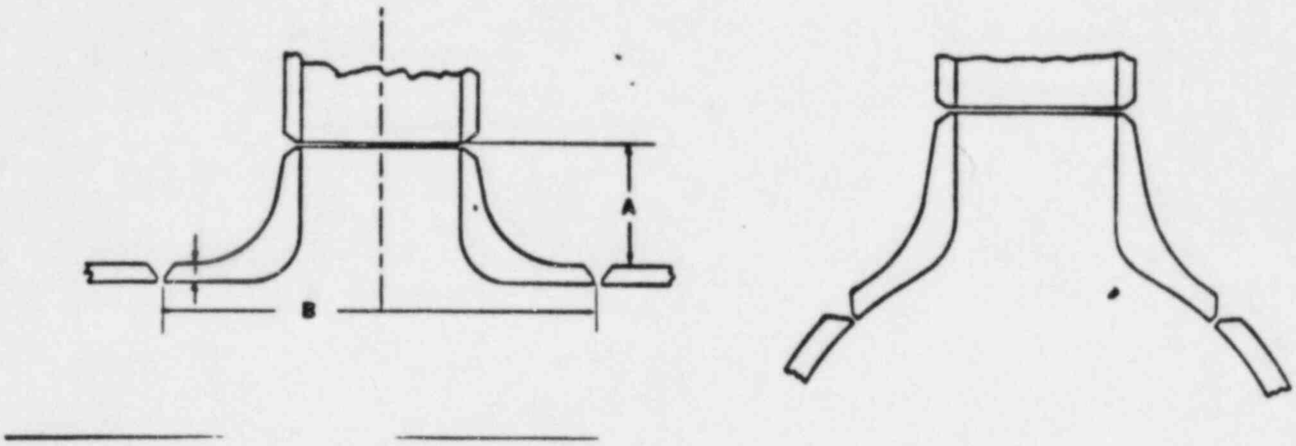


FIGURE B-1. PHTS Small-Diameter Piping



CONTOURED AND INTEGRALLY REINFORCED

BRANCH CONNECTIONS

FIGURE B-2

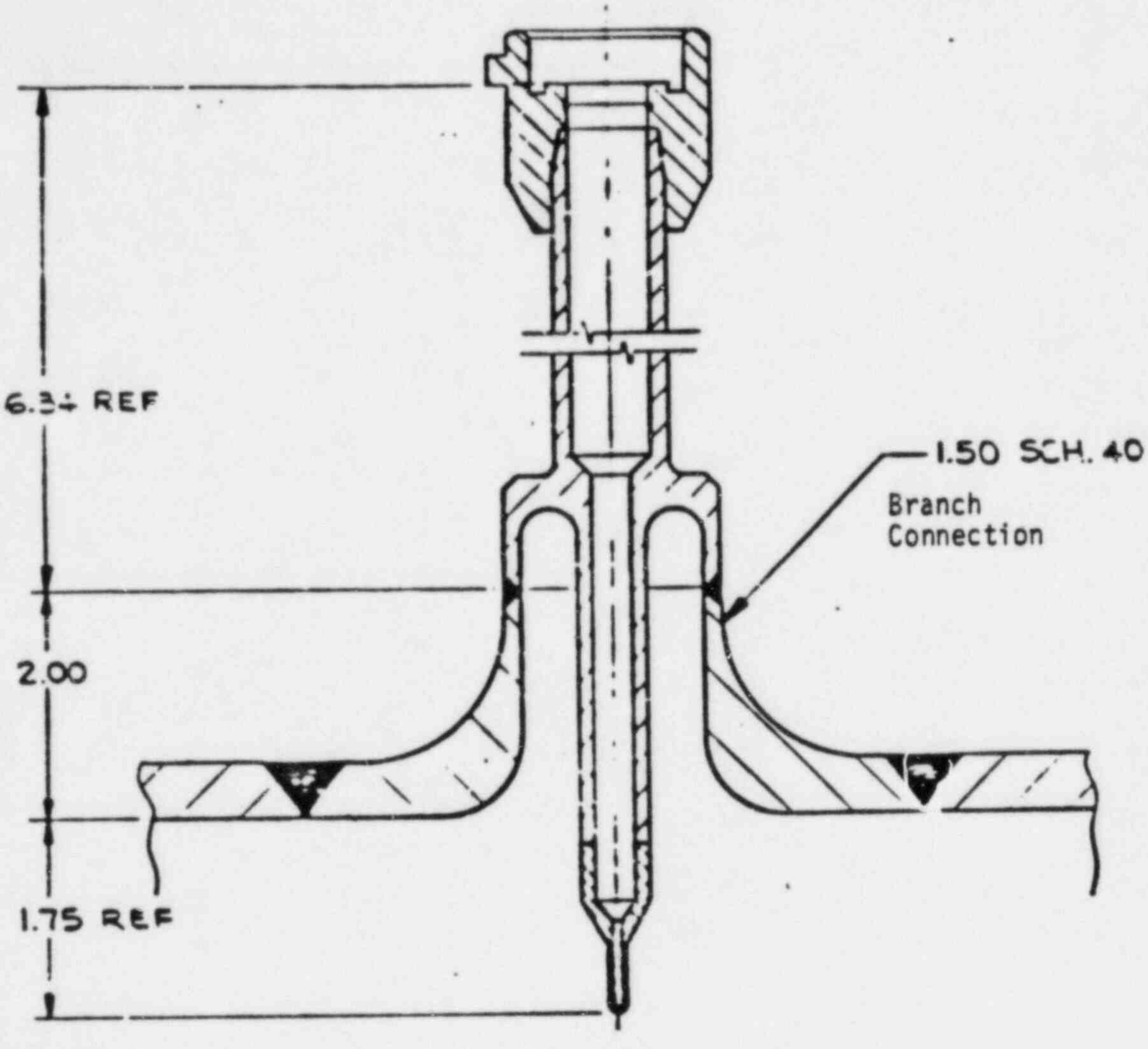


FIGURE B-3. Temperature Sensor Installed in a Branch Connection

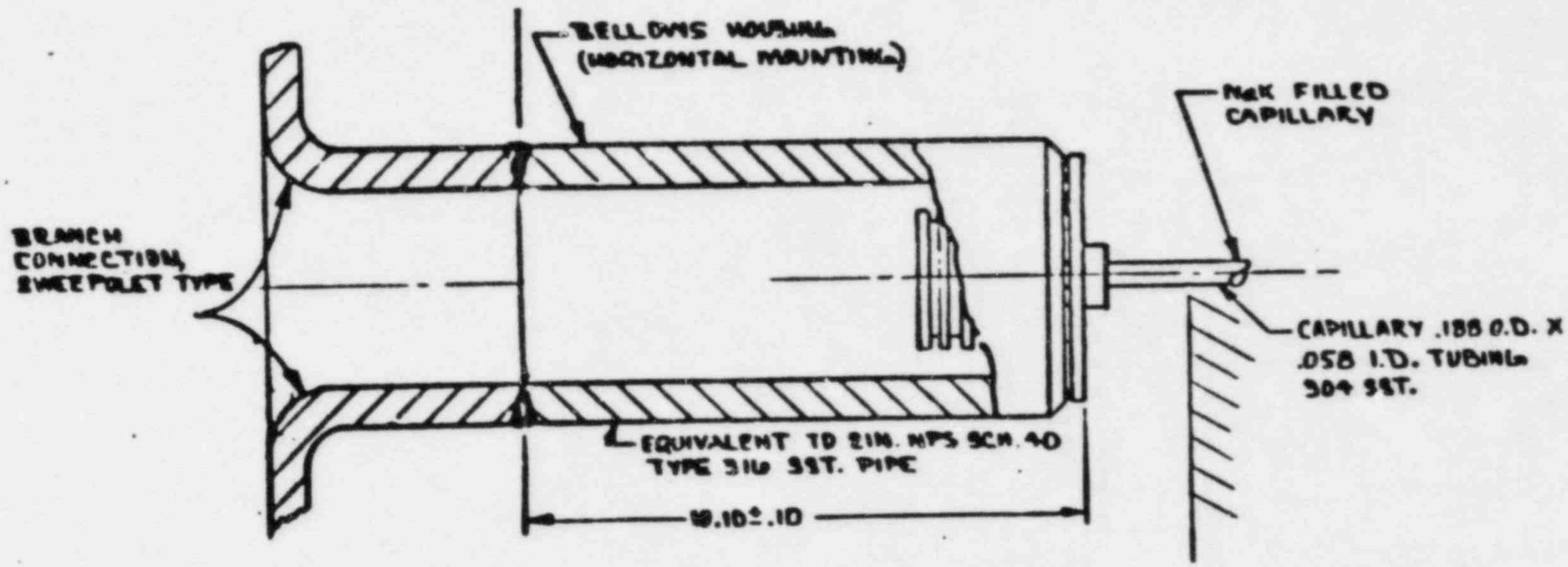


FIGURE B-4. Pressure Sensor Insta'led in Branch Connection

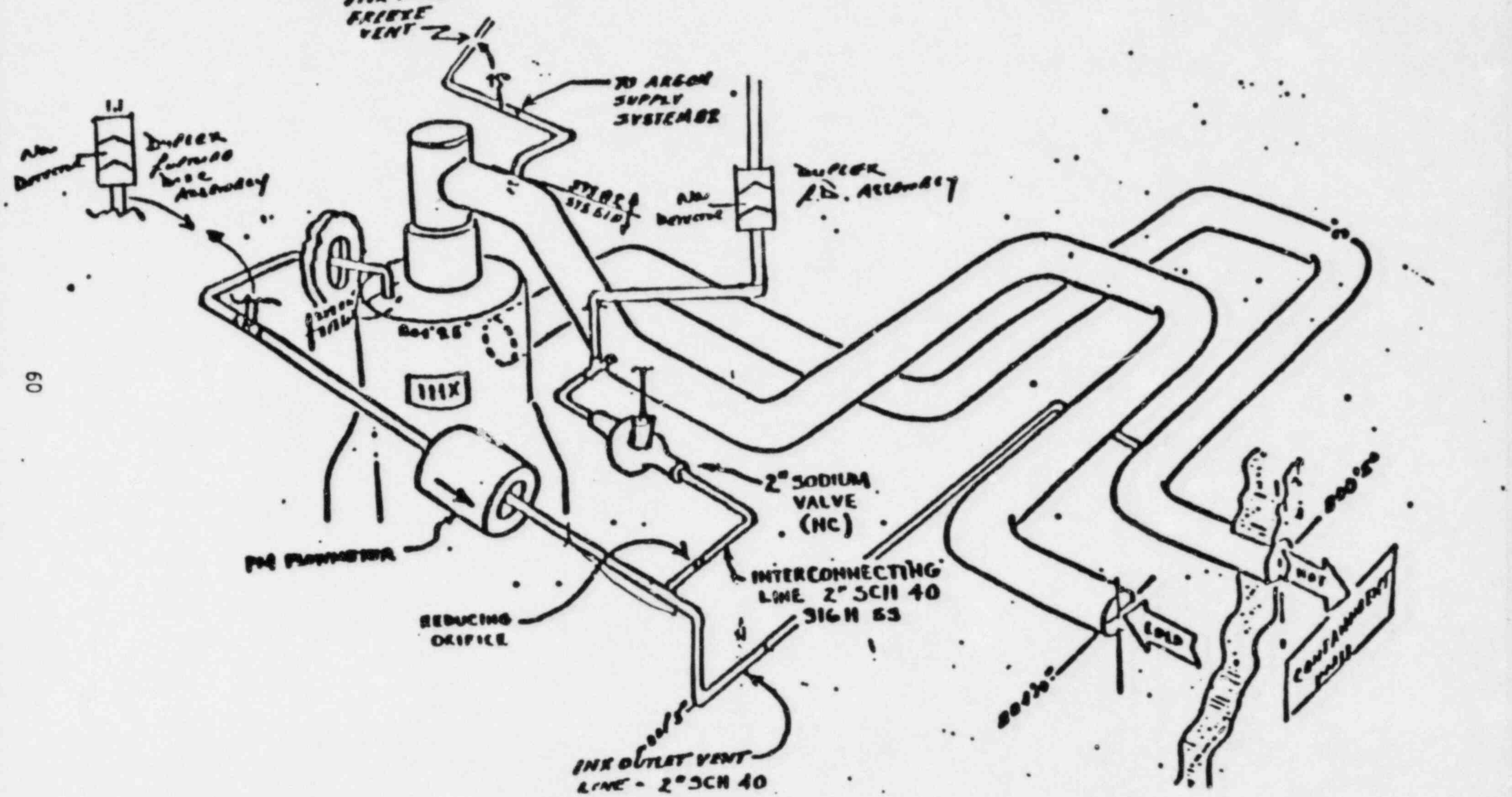


FIGURE B-5. IHTS Incontainment Small-Diameter Piping

ENCLOSURE 2

EFFECTS OF POSTULATED SMALL-DIAMETER PHTS PIPING LEAKS ON SHRS AVAILABILITY

The guard vessel-elevated piping approach used in CRBRP assures adequate primary coolant inventory for decay heat removal after any postulated primary coolant boundary leak, including a leak from any branch line. Figure 1 shows the normal sodium level in the reactor vessel (794'9"). The argon cover gas over the sodium is maintained at a pressure of approximately one atmosphere.

The level of sodium in the reactor vessel depends on the operating state of the heat transport system (HTS). Under full power, full flow operation the normal sodium level (NSL) in the reactor vessel is 794'-9" (See Figure 1). When the reactor is shut down and decay heat is being removed by forced convection with pony motors (nominally 7-1/2 - 10% flow) the reactor vessel sodium level will rise nearly two inches due to a redistribution of flow betwen the reactor vessel annulus and plenum due to a decrease in core pressure drop. (See Figure 2.) The reactor vessel sodium level in this case can be referred to as the "shutdown sodium level" (SSL). To place the Direct Heat Removal Service (DHRS) into operation the flow rate through the reactor overflow nozzle is increased from 150 gpm to 600 gpm by increasing make-up to the reactor vessel. The increase makeup flow for DHRS operation causes the reactor vessel sodium level to rise to a steady state level of 795' 7.6". This level, which corresponds to the DHRS operating with a single active failure (loss of an EM pump), can be referred to as the DHRS sodium level (DSL). The Minimum Safe Level (MSL, 782' 4") is 12 feet 5 inches below the Normal Sodium Level (NSL). This is the elevation at which it is conservatively assured that sodium can be drawn out of the PHTS outlet nozzle as necessary for heat removal through the heat transport loops. This level is 2'-5" above the top of the reactor vessel outlet nozzles. Figure 3 is a PHTS hydraulic profile which illustrates the guard vessel-elevated piping approach.

The consequences of a leak from small-diameter PHTS piping at the numbered locations (illustrated in Figure 3 as locations 1 through 14) are summarized in Table 1. The size of the postulated small-diameter pipe leak is not significant with regard to the long term impact on decay heat removal capability because the long term coolant level is essentially independent of the leak rate. However, because of make-up capability and excess PHTS sodium inventory (see Figure 4), many of the system funtional "failures" discussed herein would not occur until long after the leak is initiated, especially if the leak is small.

For illustrative purposes, the consequences of leaks in small diameter PHTS piping can be classified into five general categories based on leak location. These categories are shown as end states in Figure 5. The end states are based on a combination of

answers to the nodal questions (criteria) of Figure 5 regarding the location of the leak.

The first category of leaks is one where the leak occurs in piping inside a guard vessel and at elevations lower than the reactor shutdown sodium level. Since all piping inside a guard vessel is below shutdown sodium level, the "above SSL" node was bypassed. An example would be Location 1, where a leak is postulated to occur in the 2" IHX vent line between the PHTS pump and the IHX, but within the IHX guard vessel. Following such a leak, the reactor vessel sodium level would fall until the sodium level difference between the reactor vessel and the IHX guard vessel is equal to the pump head at the leak location*. The elevation of each guard vessel lip is more than five feet above the MSL. Therefore, the reactor vessel sodium level would remain above the MSL. This concept is illustrated in Figure 6 for a PHTS cold leg leak inside the IHX guard vessel. Because the reactor vessel sodium level would remain above MSL (and syphon would not be broken in the leaking loop), heat removal through all three heat transport loops would be possible. For this reason the "main flow unaffected" node in Figure 5 was not applicable to this leak category and therefore, bypassed. However, because the reactor vessel sodium level would fall below the DSL level, DHRS operation would not be possible.

The second category of leaks is those that are above the reactor vessel shutdown sodium level and do not disable DHRS. If a leak above the shutdown sodium level is (1) in a location that is upstream of the pump or (2) downstream of the pump but at an elevation that is high enough above shutdown sodium level to compensate for the pump head, then the reactor vessel sodium level could rise to the DSL and DHRS operation would be possible. Sodium level would remain above MSL and syphon would not be broken in the leaking loop; heat removal through all three HTS loops would be possible. Small diameter piping in Locations 6, 13 and 14 fall into this category.

Category three corresponds to small-diameter piping leaks that are above shutdown sodium level and impact the main PHTS flow path (i.e., a sweepolet leak) by breaking syphon and thereby precluding decay heat removal through the affected loop. If the leak location falls into this third category, as it does in Location 11, the reactor vessel sodium level could rise to the DSL and DHRS operation would be possible even though the affected heat transport loop is disabled.

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*It is conservatively assumed throughout this assessment, that the pony motors were running continuously without any operator intervention to turn them off. When operating with pony motors the pump shut off head is 4.2 ft Na at pump discharge.

Pipe leaks that are postulated to occur outside of a guard vessel and at elevations below the reactor vessel shutdown sodium level constitute the fourth and fifth categories of leaks. All large and small-diameter PHTS piping outside of the guard vessel is sufficiently above the MSL such that the reactor vessel sodium level could never fall below the MSL in the event of a pipe leak. An example that falls within the fourth category is a pipe leak in the IHX vent return line as shown in Location 3 of Figure 3. The main PHTS flow path is not connected to the IHX vent return line and is, therefore, not affected by a leak in that line. Following the leak, the reactor vessel sodium level will fall until the pump and static head is insufficient to drive sodium up the elevated piping and out of the leak location. The reactor vessel sodium level would remain above the MSL and, because a leak at this leak location would not break syphon in the main PHTS flow path, decay heat removal through all three heat transport loops would be possible. However, this category of leaks, like the first category, would prevent DHRS operation.

Location 7 and Location 9 on Figure 3 correspond to locations where a 2" sweepolet joins the main PHTS hot leg piping. These locations would fall into a fifth category of leaks. The characteristics of a leak in either of these locations would be similar to the characteristics of the fourth category of leaks discussed above, except in this case the sodium would drain until siphon is broken in the hot leg piping, and the reactor vessel sodium level would fall until the combined reactor vessel sodium head and pump head is insufficient to drive sodium up the elevated piping and out of the leak location. Since this leak location and siphon break is in the main PHTS flow path, decay heat removal through the affected PHTS loop is precluded. As before, the reactor vessel sodium level will remain above MSL allowing decay heat to be removed through the two remaining heat transport loops. This concept is illustrated for a PHTS cold leg leak outside a guard vessel in Figure 7.

In summary, the guard vessel-elevated piping approach assures that an adequate primary coolant inventory exists for any postulated primary coolant boundary leak, including a leak from any branch line. There is only one category of leaks in the small-diameter PHTS piping that could result in the loss of a heat transport loop <u>and</u> DHRS. This category applies only to those pipe leaks that are outside guard vessels, below shutdown sodium level and have the potential to affect the main PHTS flow path. All large and small-diameter PHTS piping outside the guard vessel is sufficiently above the MSL such that the reactor vessel sodium level could never fall below the MSL in the event of a pipe leak. At a very minimum, two heat transport loops will be available to provide decay heat removal following this, or any postulated primary coolant boundary leak.

TABLE 1

Line	Location On Hydraulic Profile	Location of Postulated Leak	Impact on HTS Loop***	Impact on DHRS ***	Shutdown Heat Removal Paths Available
IHX 2" Vent	1	In Guard Vessel	None	Fails	3
IHX 2" Vent	2	Between IHX and Guard Vessel (at connect to IHX)	None	Fails*	3 - 4*
IHX 2" Vent	3	Beyond Guard Vessel	None	Fails	3
Drain 2" (Both Pump and IHX)	4	Inside or Outside Guard Vessel	None	Fails	3
6" Pump Stand Pipe Bubbler	5	In Guard Vessel	None	Fails	3
	6	Outside Guard Vessel	None	Depends on Exact Location**	3 - 4**
2" Sweepolet for Pressure Detector	7	1) Elevated Section Hot Leg	Fails	Fails	2
	8	1) Elevated Section Cold Leg	Fails	Fails	2
Temperature 2" Sweepolet	9	2) Elevated Section Hot Leg	Fails	Fails	2
	10	5) Elevated Section Cold Leg	Fails	Fails	2
2" High Point Vent	11	Elevated Section Hot Leg	Fails	None	3
	12	Elevated Section Cold Leg (Check Valve)	Fails	Fails*	2 - 3*
	13	Top of IHX	None	None	4
	14	Top of IHX Na Vent	None	None	4

* No failure of DHRS if operator shuts down the pony motor within 1 hour of leak initiation.

** No loss of DHRS for leak locations above 795' 7.6" (DSL)

*** The impact on the HTS loop or DHRS would not occur until long after the leak is initiated, especially if the leak is small.

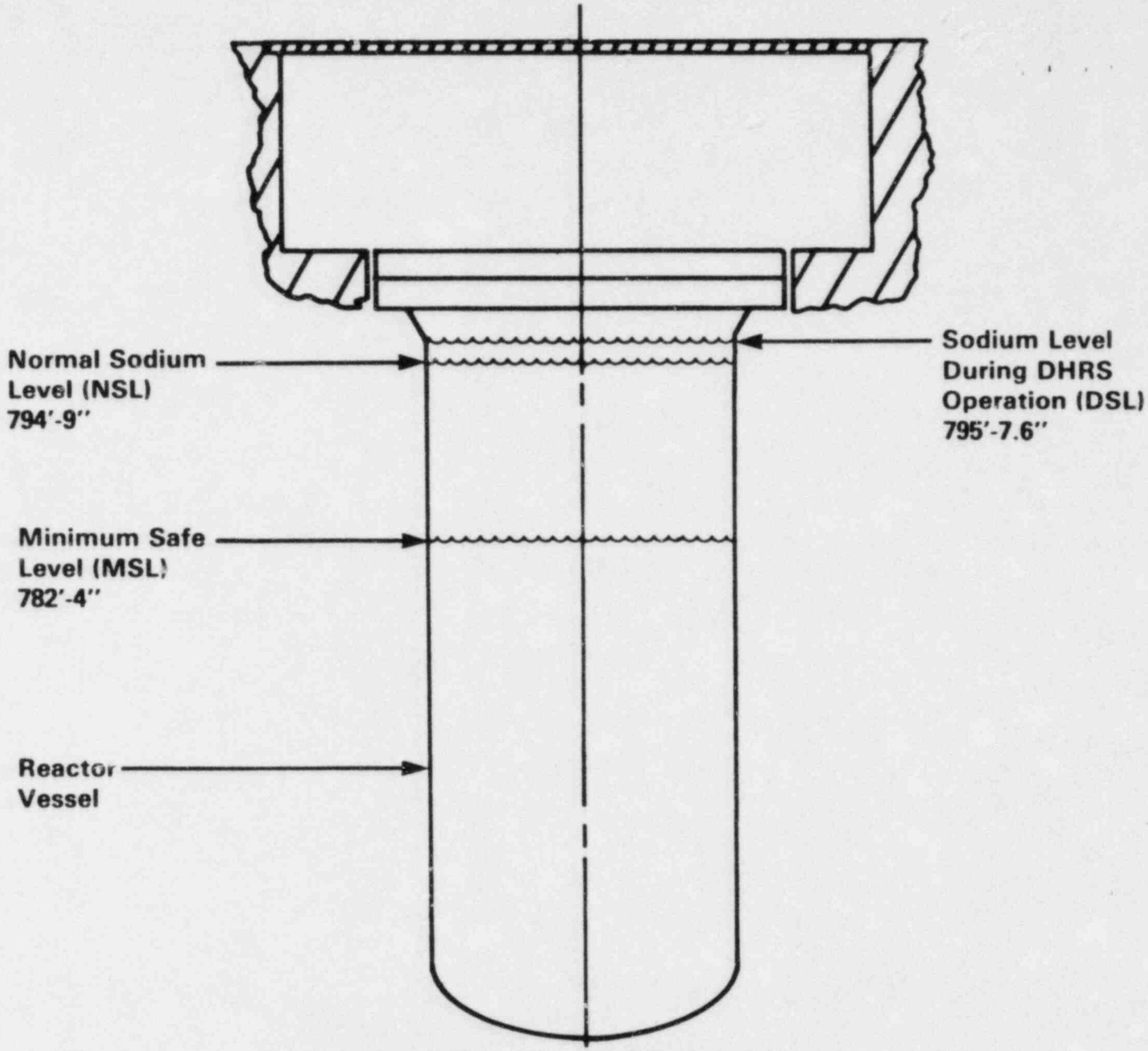

Figure 1. Reactor Vessel Na Levels

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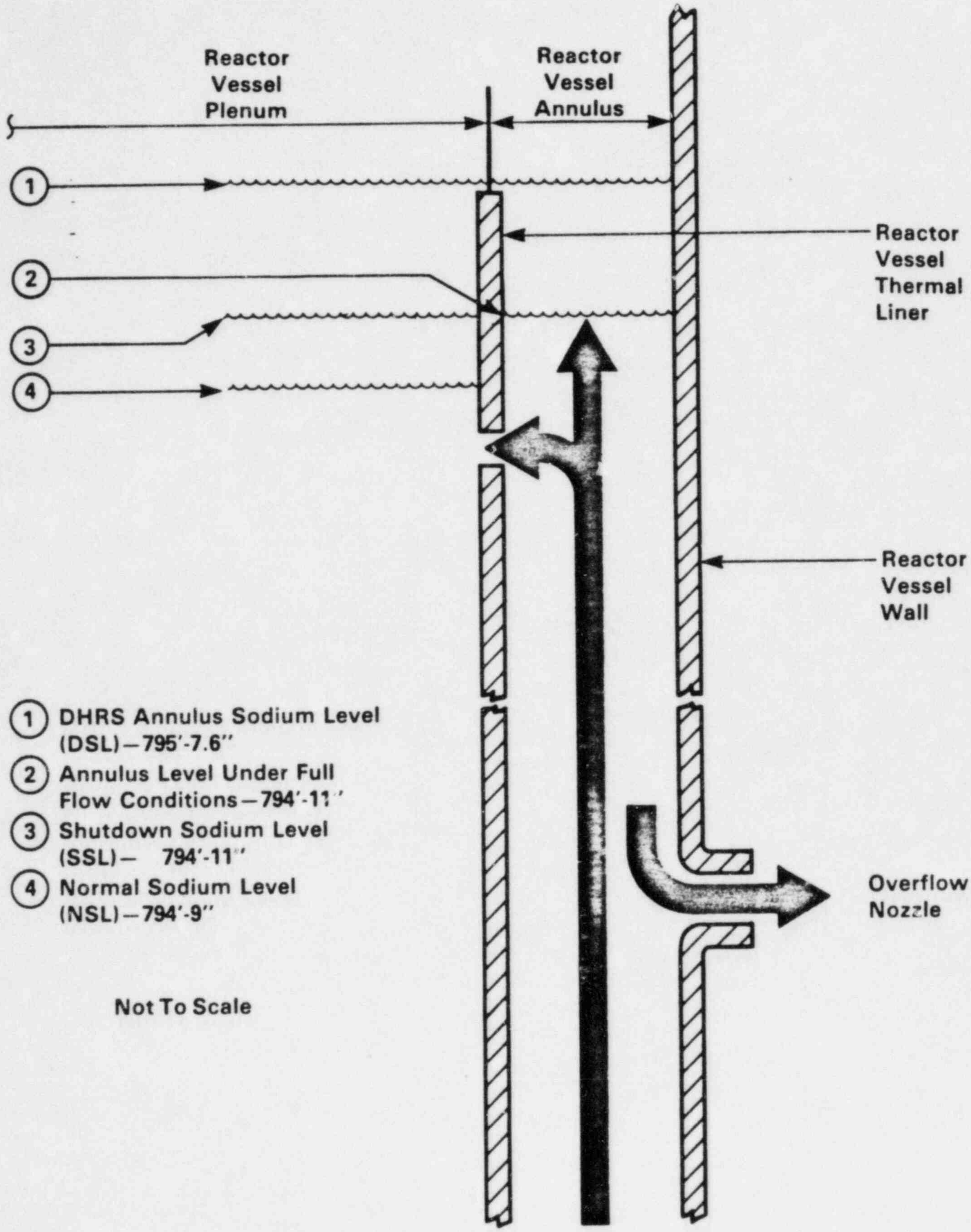


Figure 2. Reactor Vessel Sodium Level Between Annulus and Plenum

5 83 3377 1

FIGURE 3

PHTS HYDRAULIC PROFILE

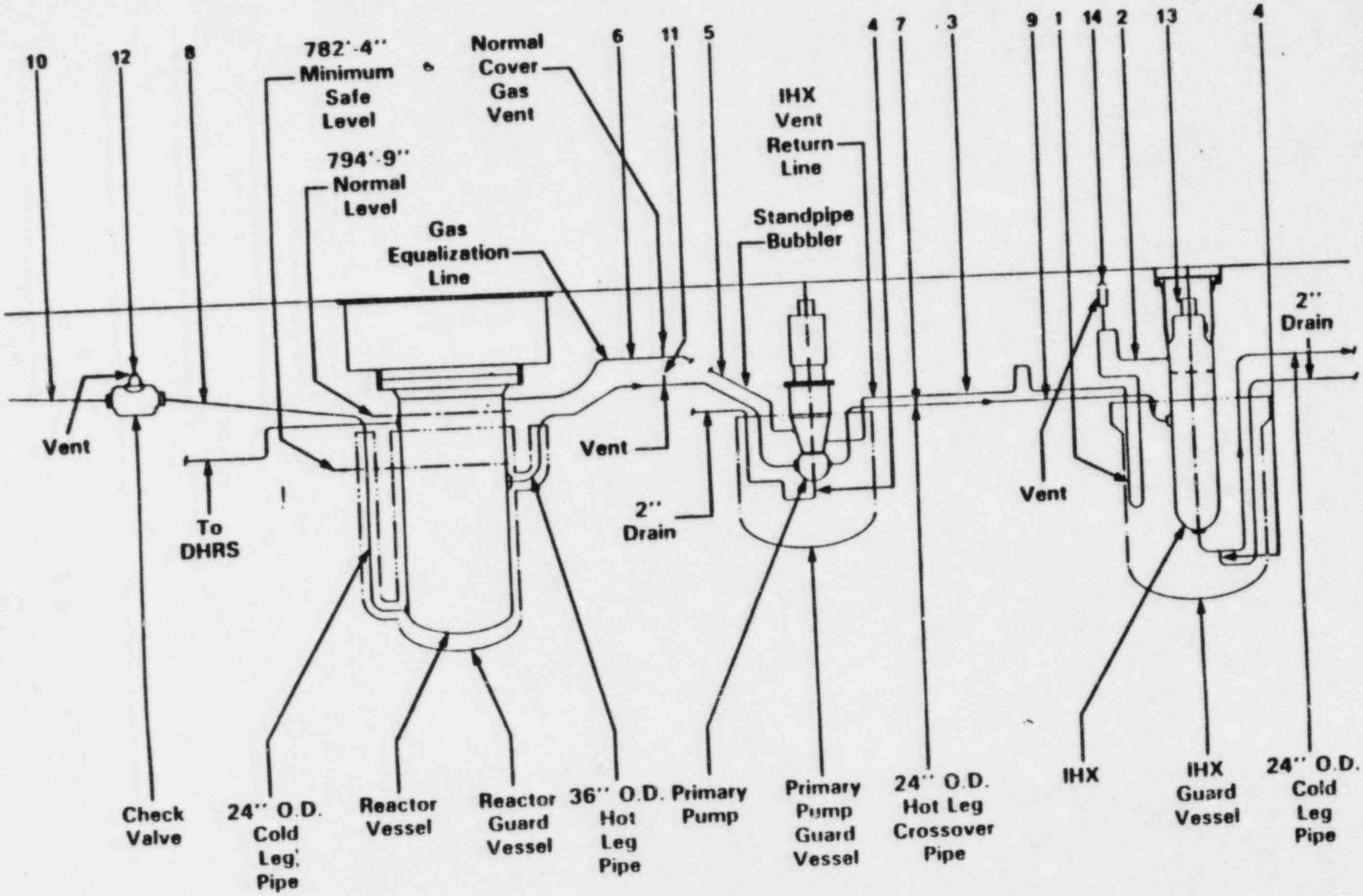
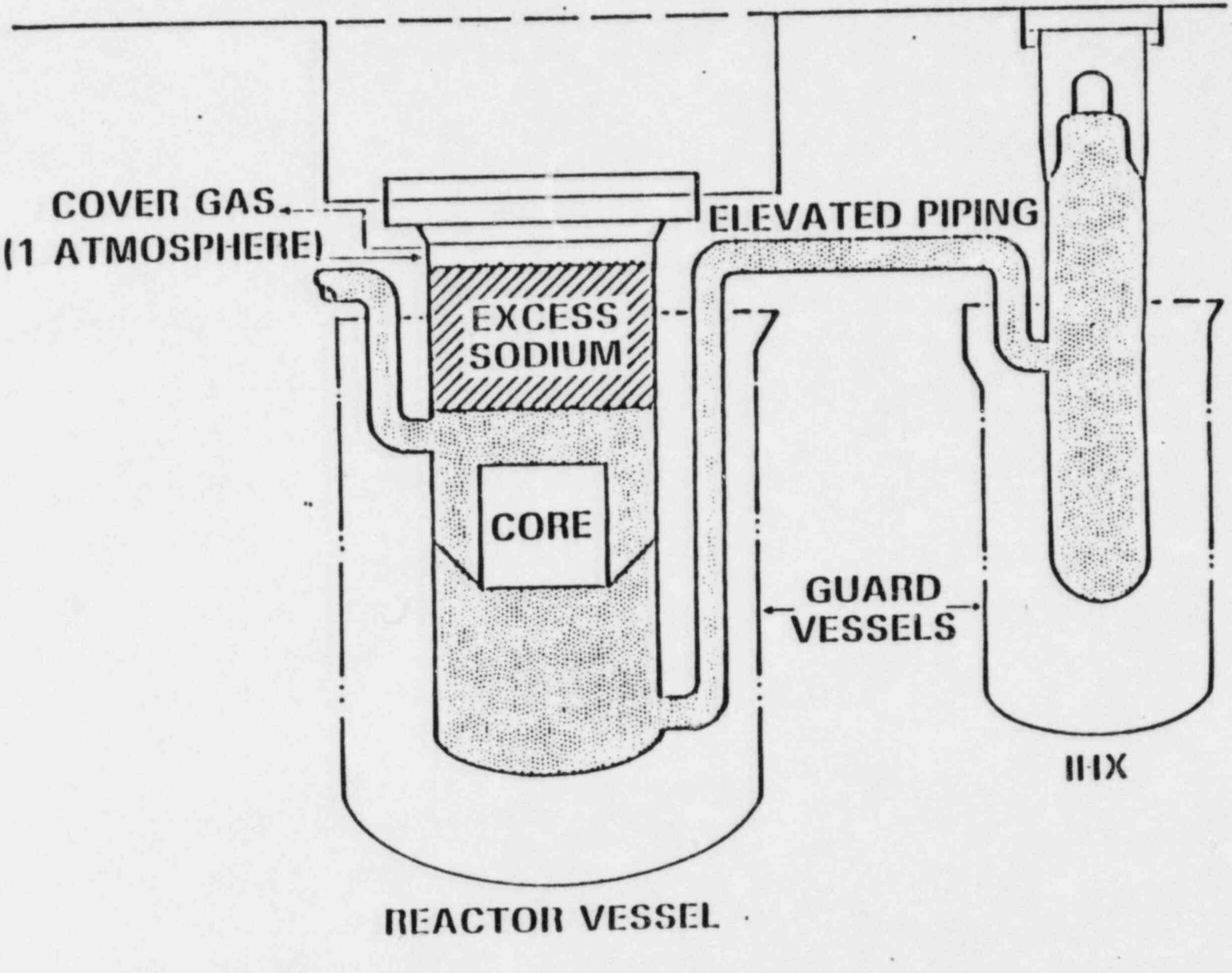


Figure 4


COVER GAS
(1 ATMOSPHERE)
ELEVATED PIPING
EXCESS
SODIUM
CORE
GUARD
VESSELS
IHX
REACTOR VESSEL

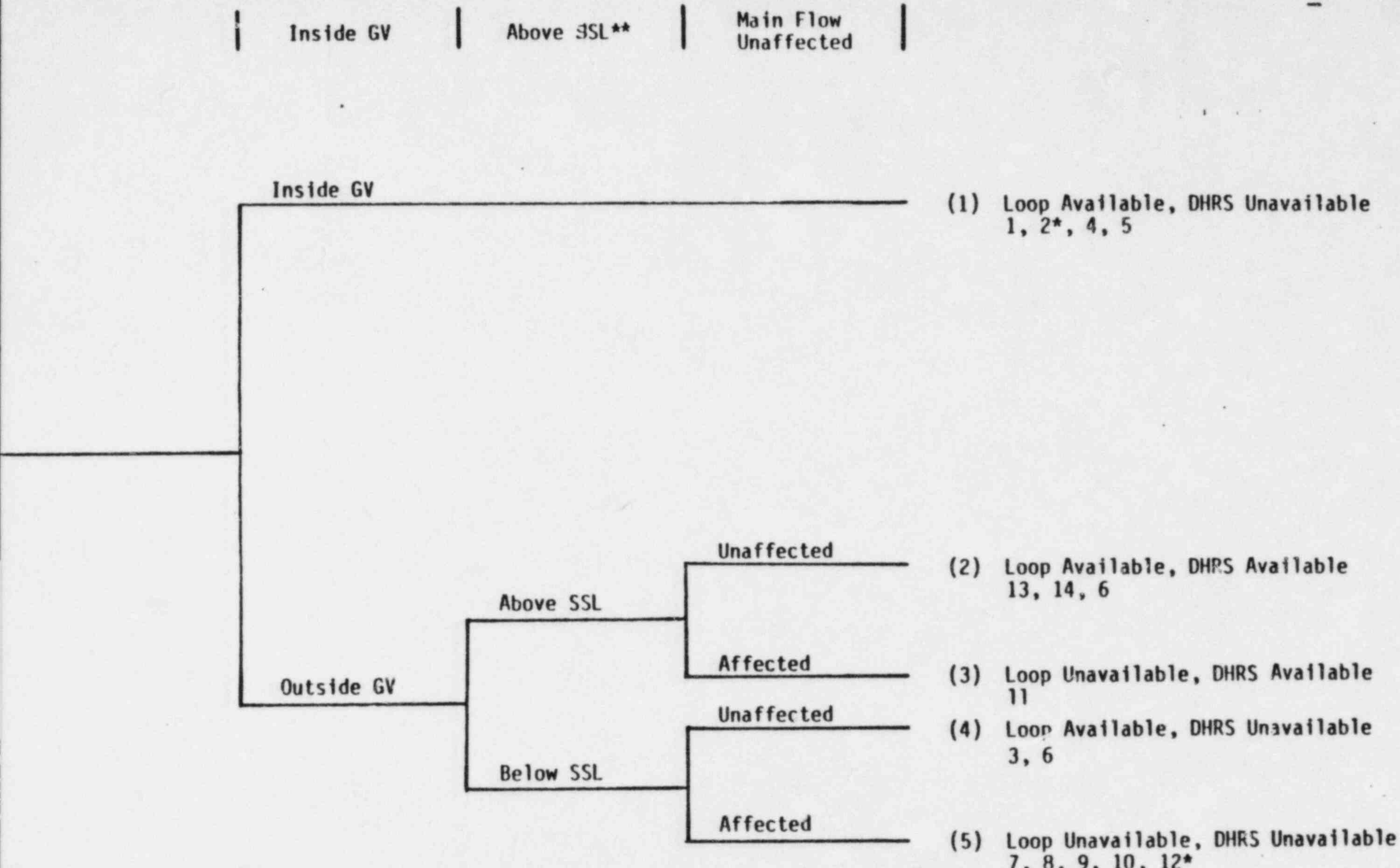


FIGURE 5

*No failure of DHRS if operator shuts down the pony motor within one hour of leak initiation.

**This node acknowledges the fact that a leak downstream of the pump must be about 4' higher than the NSL to prevent the reactor vessel sodium level from falling below the NSL.

NOTE: If the criterion of each node is met, the logic branches upward and if the criterion is not met, the logic branches downward.

Figure 6

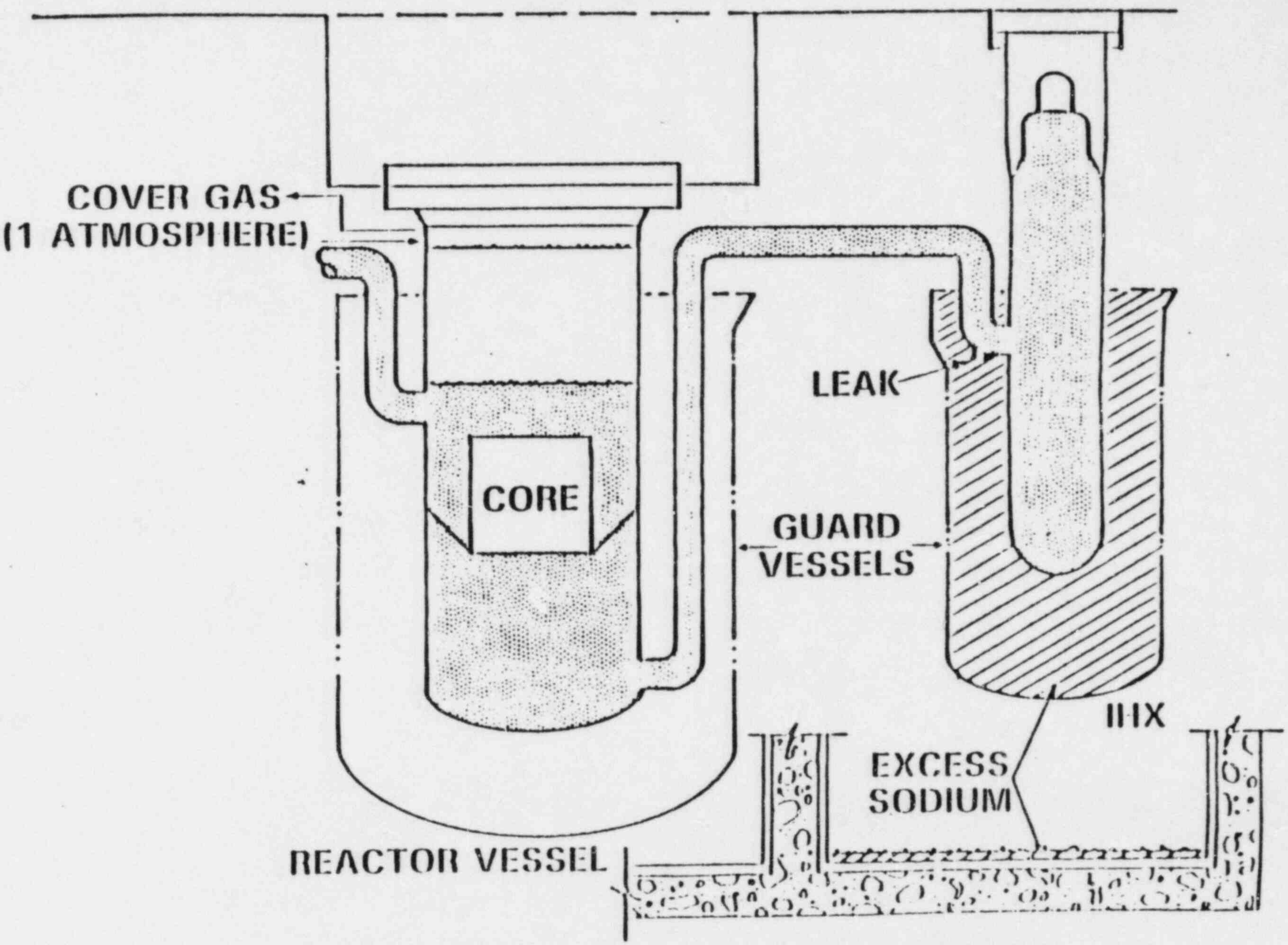
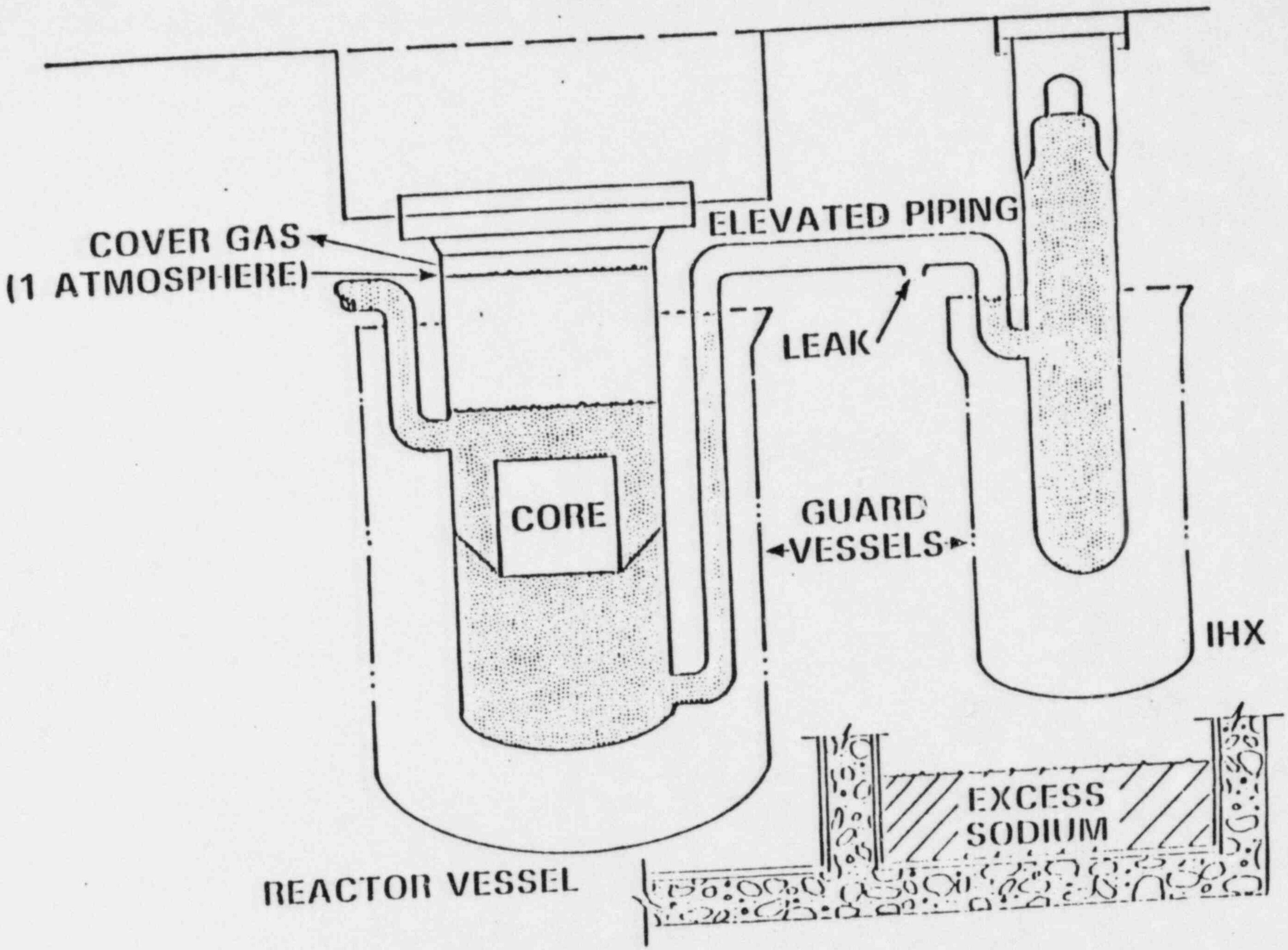

COVER GAS
(1 ATMOSPHERE)
CORE
LEAK
GUARD
VESSELS
IHX
EXCESS
SODIUM
REACTOR VESSEL

Figure 7



COVER GAS
(1 ATMOSPHERE)
ELEVATED PIPING
LEAK
CORE
GUARD
VESSELS
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