DOE/SF/76026--T32

-03- 824/26 8-3 Ltr. dated 9/26/78

MASTER

Rockwell International
Atomics International Division

SUPPORTING DOCUMENT

NUMBER	N254TI231005
REV LTR/CHG NO.	SEE SUMMARY OF CHG
DOCUMENT TYPE	Technical Information
KEY NOUNS	Reactor Cover, Reactor Deck, Vessel Support, Bearings, Seals
ORIGINAL ISSUE DATE	
GO NO.	09282
S/A NO.	23005
PAGE 1 OF 143 TOTAL PAGES	
REL. DATE	9-8-78 SW

PROGRAM TITLE
Liquid Metal System Development

DOCUMENT TITLE
Reactor Cover System Improvements,
Final Report FY 1978

PREPARED BY/DATE — DEPT — MAIL ADDR
J. A. McEdwards J A McEdwards 9-6-78
J. L. Matteras J L Matteras

IR&D PROGRAM? YES ☐ NO ☒ IF YES, ENTER TPA NO. ____

APPROVALS		DATE
C. Q. Torrijos	CQ Torrijos	9-6-78
C. W. Sayles	CW Sayles	9-6-78

SECURITY CLASSIFICATION

(CHECK ONE BOX ONLY)	DOE	DOD
UNCL	☒	☐
CONF.	☐	☐
SECRET	☐	☐

(CHECK ONE BOX ONLY)
RESTRICTED DATA ☐
DEFENSE INFO. ☐

AUTHORIZED CLASSIFIER — DATE

DISTRIBUTION

*	NAME	MAIL ADDR
*	E. Baumeister	
	L. Baurmash	
*	J. Brunings	
*	W. Castle	
	W. Dauterman	
*	J. Facha	
	R. Jetter	
	R. A. Johnson	
	A. F. Lillie	
*	J. L. Matteras	
	J. S. McDonald	
*	J. A. McEdwards	
*	D. B. Miller	
	L. Rico	
*	C. Sayles (11)	
	C. Q. Torrijos	
*	ASU-PLBR File E4.2	

ABSTRACT

The effort in the reactor cover study area resulted in design recommendations for the vessel support, the deck, and the bearing and seals. Sixteen configurations of bearings and seals were examined as part of this study. The selected concepts use a double inflatable seal plus a sodium dip seal. Six different deck configurations were considered as part of this study. The most attractive of these concepts is the conical deck. Five different vessel support concepts were considered. Of these, the "U" ring appears to be the most attractive.

In summary, significant findings are the following:

1) Verified that passive cooling of the deck and support lead to acceptable temperatures.
2) The assembly tolerances can be loosened for lower fabrication cost and easier operation while meeting positional and sealing requirements.
3) Determined that the conical deck is the most effective deck configuration.
4) Determined that the "U" ring is the most effective vessel support configuration.
5) Selected a bearing and seal approach that gives effective gas sealing, adequate control of sodium frost, and easy maintenance.

RESERVED FOR PROPRIETARY/LEGAL NOTICES

THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE PATENT BRANCH, ERDA

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

716-J-41/sjd

* COMPLETE DOCUMENT
NO ASTERISK, TITLE PAGE/SUMMARY OF CHANGE PAGE ONLY

AT03-76SF76026

FORM 734-C REV. 11-77

DISCLAIMER

CONTENTS

CONTENTS
(Continued)

CONTENTS
(Continued)

CONTENTS
(Continued)

CONTENTS
(Continued)

FIGURES

FIGURES
(Continued)

TABLES

1.0 SUMMARY

Components of the reactor cover system for the loop-type reactor have been improved and simplified.

The components are:

1) Seals, Bearings, and Support Structure
2) Deck Structure
3) Vessel Support Structure

The initial components are shown in Figure 1 and the improved and simplified components in the reactor cover are shown in Figure 2.

The improved components are evaluated against the following criteria:

1) Structural Performance
2) Maintainability
3) Inspectability
4) Constructability
5) Reliability
6) Installation
7) Operability
8) Cost

1.1 Seal Bearing, and Support System

The recommended seal, bearing, and support system is shown in Figures 2, 3, 4, and 5. Figure 2 shows the location of the seals, bearing, and supports on the reactor cover. Figure 3 shows an elevation of the system at the plugs' annulus. Figure 4 shows the installed relative positions of the three bearings and supports. Figure 5 shows details of the upper seal, bearing, and support.

Figure 1

FIGURE 2
REACTOR (LOOP)
COVER CONCEPT
(LARGE SYSTEM IMPROVEMENTS)

FIGURE 1
REACTOR COVER CONCEPT

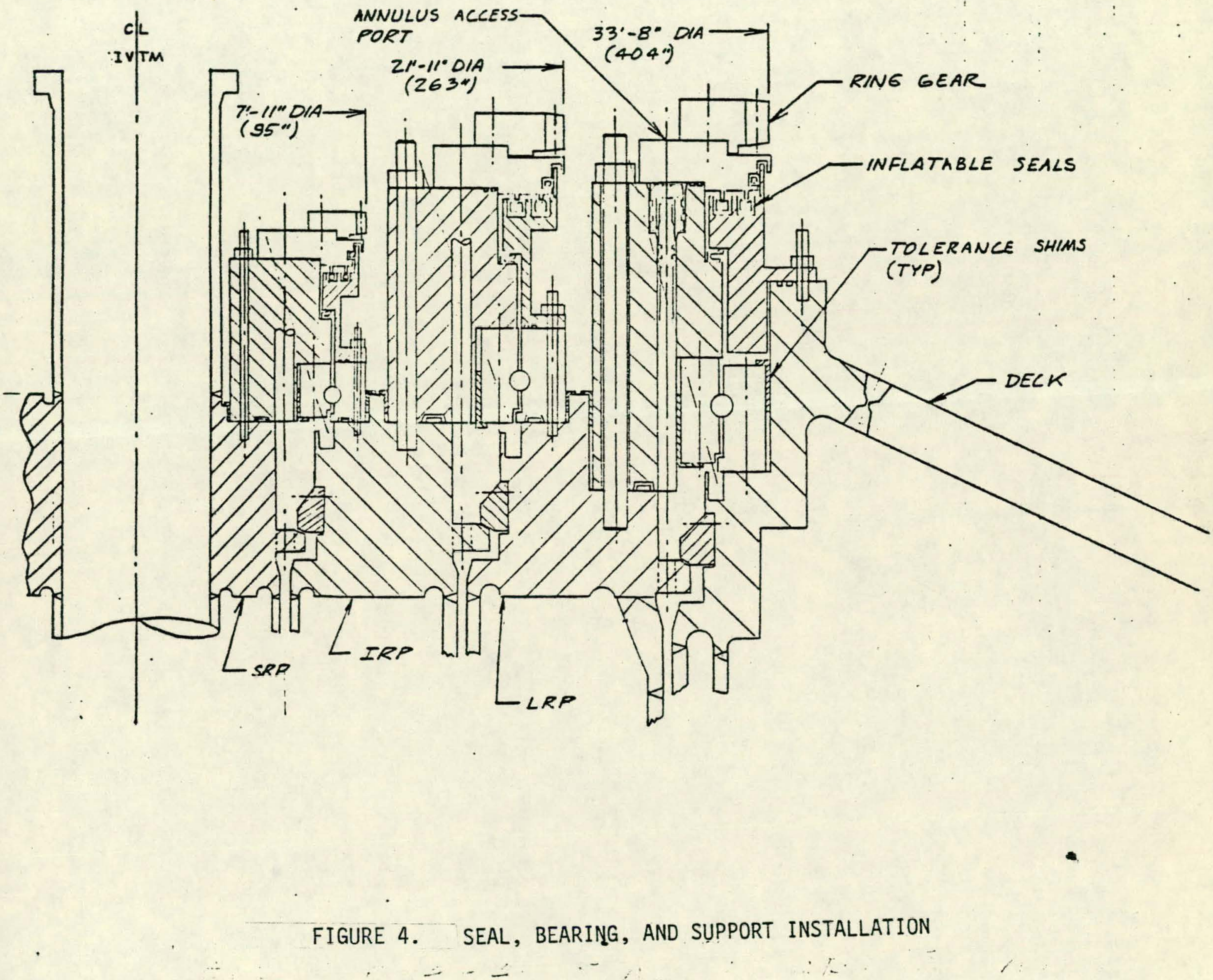


FIGURE 4. SEAL, BEARING, AND SUPPORT INSTALLATION

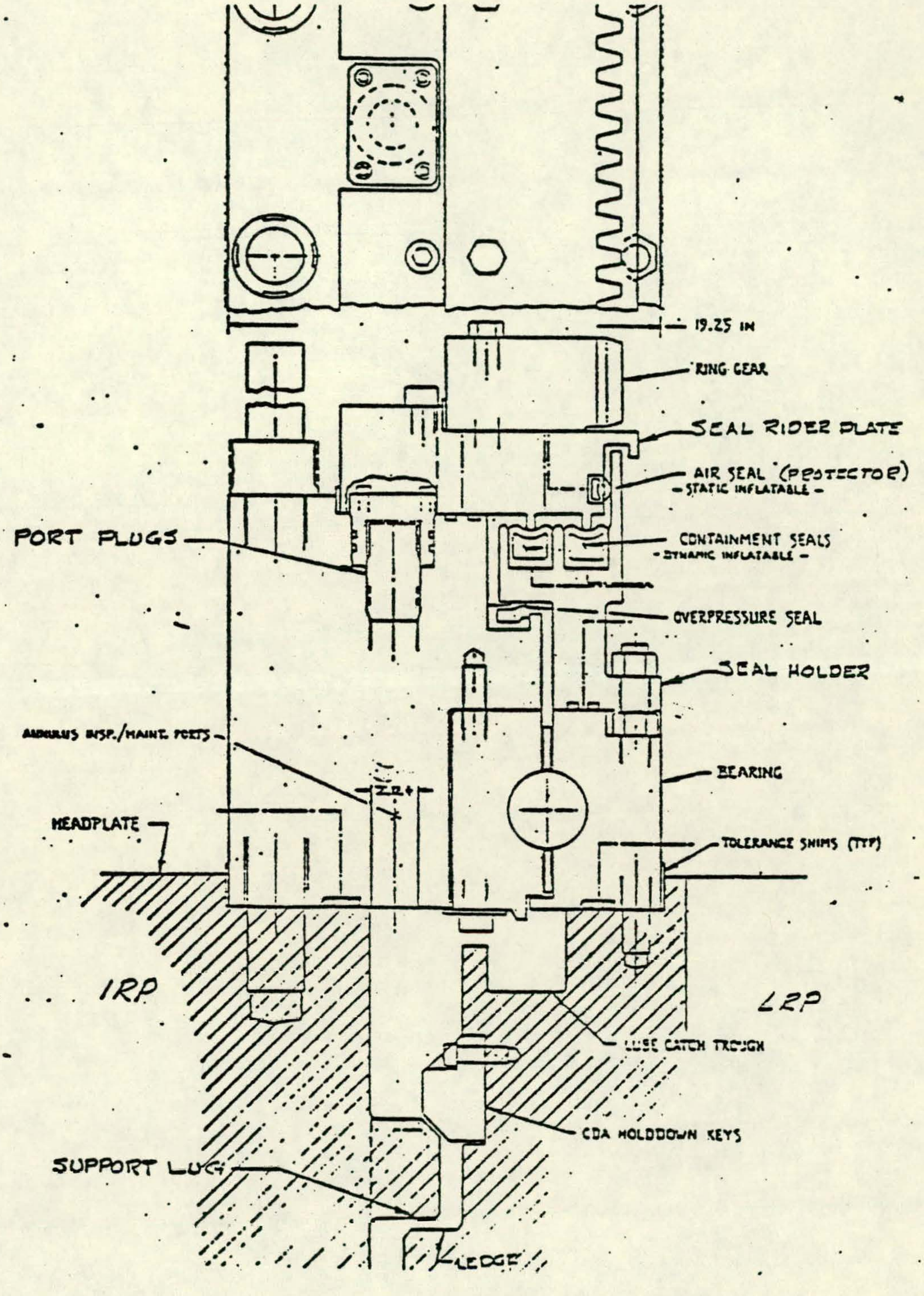


FIGURE 5. BEARING, TOP SEALS, AND SUPPORT CONFIGURATION

The sealing system for the rotating plug annuli has two parts: the bottom seal and the top seal. The bottom seal is a sodium-filled dip seal. The top seal has static and dynamic seals. The dynamic seals are two inflatable seals which accommodate rotation of the plugs for fuel handling.

Several combinations of seal systems were investigated which are:

Top Seal	Bottom Seal	Gas Purge
Inflatable	Na Dip	No
	Alloy	Yes
	Mechanical:	
	Compressible Gasket	No
	Ledge	Yes
	Na Plug (Coils)	No
	None (Annulus)	Yes
Alloy	Na Dip	No
	Mechanical:	
	Compressible Gasket	No
	Ledge	Yes
	Na Plug (Coils)	No
	None (Annulus)	Yes

1.2 Reactor Deck

Six reactor deck configurations were designed and evaluated. They are the box ring, hub-spoke-rim, flat plate, Z-cone, box ring plus Z-cone, and tangential beam.

The recommended deck configuration is the Z cone as shown in Figure 2, and the alternate recommended configuration is the tangential beam as shown in Figure 6.

1.3 Vessel Support Structure

Five vessel support structures are evaluated. They are the U-ring, box ring, integral, tangential beam, and tee configurations.

The U-ring is the recommended vessel support structure as shown in Figure 2.

The improvement and simplification of the reactor cover components is part of the Large Systems Improvement Task Work Plan, Section D., 23005 - Reactor Cover Improvements, see Reference 1.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The recommended seal system - inflatable top seal and sodium-filled dip bottom seal - was chosen because the seal system provides:

1) With 1% of the fuel pins leaking radioactive gases, there is very little contribution to the HAA/RCB airborne activity by minimizing the out-leakage of the R/A cover gas - there in 1.3×10^{-4} calculated versus 2.0×10^{-3} allowable dose rates.
2) Control of sodium vapor frost deposits on the annulus walls to prevent interference with plug rotation.
3) Capability for inspection and maintenance of the elastomer seals, bearings, annulus walls, and dip seal.
4) A passive system - does not require active systems for temperature and purge gas flow control.
5) A proven system - tested at AI for the CRBR reactor cover rotating plugs sealing system.
6) Location of the inflatable seal above the bearing to facilitate its replacement, although it is believed replacement is not necessary.
7) When designed for .1% failed fuel pins, wetted dip seal surfaces at the annulus bottom are not required.

FIGURE 6
REACTOR COVER CONCEPT (TANGENTIAL BEAM DECK)

The recommended bearing configuration of a single-row ball bearing unit was chosen as it provides:

1) Capacity for the dead weights, vertical and horizontal seismic loads.
2) Not as sensitive to mounting surfaces conditions as other configurations such as the three-row roller bearing.
3) Accommodation for the plug differential diametral growth due to temperature change.
4) A narrow width which minimizes the size of the plug diameters.
5) A unit which can be obtained from a bearing manufacturer and does not require close tolerance machining capability at the site.

The recommended plug support was chosen because it provides a structure which:

1) Can accommodate the seals and bearings.
2) Transfers the loads from one plug to the next plug and to the deck.
3) Serves as a plug lifting and lowering fixture for bearing replacement.
4) Does not require close tolerance machining.
5) Accommodates inspection and maintenance ports.
6) Has a low height and narrow width.

The three major improved components of the reactor cover can be used in the design of the reactor cover without further evaluation of alternate configurations. Sufficient analysis has been performed to indicate the components will function as required.

3.0 OBJECTIVES

The objectives of the investigation are as follows.

3.1 Seals, Bearings, and Support Structure

1) Establish the method of containment of the cover gas at the rotating plug annuli.
2) Establish the bearing support and sealing configurations.
3) Provide configurations which can accommodate loose tolerances.
4) Establish support configurations which minimized the reactor cover diameter.
5) Provide designs which facilitate inservice maintenance and inspection.
6) Provide designs which prevent air contact with sodium during inspection and maintenance.
7) Provide designs which limit sodium frost deposits in annuli.

3.2 Deck and Vessel Support Structures

1) Establish the requirements for the structures.
2) Establish applicable configurations.
3) Evaluate and choose a configuration which improves and simplifies the structure and reduces cost, increases operability, reliability, and maintainability.
4) Verify that passive cooling is feasible.
5) Provide a configuration which facilitates inservice inspection.
6) Provide a configuration which can accommodate loose tolerances.

4.0 SYSTEM REQUIREMENTS

The reactor cover system has the following system functional requirements:

1) Shall provide a system pressure-retaining boundary for the reactor cover gas and sodium vapor. The vessel support structure shall provide a containment boundary for the reactor vault atmosphere.
2) Shall provide radiation shielding between the reactor sodium pool and the head access area (HAA).
3) Shall provide a thermal barrier between the reactor sodium pool and the HAA.
4) Shall provide a support for the vessel and reactor cover by the vessel support structure and a support for the triple rotating by the deck structure.
5) Shall provide a dynamic and static seal system between the deck and the LRP and between the TRP's which limits R/A cover gas leakage to the HAA and air in-leakage to the cover gas area.
6) Shall provide accommodation for the DDHRX and fuel handling port in the deck structure.
7) Shall provide components which can be inservice inspected.
8) Shall provide components which can be passively cooled (no active temperature control systems required).
9) Deck, bearing, and its support structure to support 2.2 million lb large rotating plug and the vessel support structure to support 12.7 million lbs dead weight and during seismic conditions of the following:

Event	Horizontal		Vertical
OBE	1.8 g EW	1.6 g NS	1.3 g
SSE	2.7 g EW	2.3 g NS	2.2 g

5.0 REACTOR COVER DESCRIPTION

The reactor cover with the improved components is shown in Figure 2. The major components are the deck, bearing, support structures, and seals, the three rotating plugs, and the vessel support structure.

The outer support member for the three plugs is the Z-cone deck. The structural support member of the rotating plugs is the top flat (head) plate. Each rotating plug is supported by the next outer plug and the deck through the bearing and its support structure. Between each rotating plug and the outer rotating plug and the deck are the annuli. The sealing method chosen to contain the radioactive gas and to exclude air is shown in Figures 3, 4, and 5. Figure 3 shows the sealing system between the large rotating plug and the deck. Figure 4 shows the sealing systems for the three plugs adjacent to each other. Figure 5 shows details of the top seal, bearing, and support for the two smaller rotating plugs - intermediate (IRP) and small (SRP) plugs. These differ from the LRP design because the large diameter LRP bearing is segmented and the outer race cannot be used as part of containment.

The plugs are passively cooled by natural circulation of the head access area (HAA) air and by radiation to the air. Reflective (metal sheets) type of insulation is used in the bottom section of the plugs.

Shielding is provided by the top head plate and additional steel plates. Steps in the annulus, with the bearing support structure, provide annulus shielding.

The small rotating plug supports the in-vessel transfer machine (IVTM) and its removal cask and equipment. The intermediate rotating plug supports the control rod drive mechanisms, the instrument tree, the core hold-down structure and its drive mechanisms. The deck supports, in addition to the rotating plugs, the two decay heat removal heat exchangers, and the fuel transfer port equipment.

Should CDA energy absorbers be required, space is available for crushable inserts between the shielding plates to absorb the energy resulting from a Core Disassembly Accident (CDA) without losing the integrity of the reactor cover containment functions.

The bearing carries the loads and seismic forces from the plug to the next outer support through the bearing support structure attached to the plugs and the deck and yet provides a low friction support to allow rotation of the plugs. The inner race of the bearing is attached to the inner half of the support member and the outer race is attached to the outer plug or the deck. The bearings can withstand the dead weight, imposed vertical and horizontal seismic forces, as well as the differential temperature growth of the plugs.

The bearing has an inner and outer race capable of handling vertical thrust loads - up and down. A bearing having a top and bottom race can handle only down loads, and a separate hold-down device is required for the up loads. The width of the bearing and support structure assembly, with the inner and outer race bearing, is less than an assembly with the bearing with the upper and lower race and a separate hold-down structure. The narrower bearing and support structure assembly does not require larger diameter plugs.

The recommended annulus sealing arrangement consists of two types of series seals. The bottom seal, located in the reflective insulation section, is a sodium-filled dip seal. The top seal, located above the plugs' top plate, consists of two inflatable dynamic seals and parallel static seals.

The sodium dip seal limits the amount of radioactive gas passing from the cover gas to the annulus, and the elastomer and static seals limit the flow of the radioactive gas from the annuli to the Head Access Area (HAA), as well as limit the in-leakage of air into the annuli, thus preventing air-sodium contact.

The Z cone deck structural assembly consists of a conical shell welded to two (2) concentric cylinders. The inner cylinder has a flange at the top which is a support for the large rotating plug (LRP). It has a sodium dip seal trough at the bottom. The outer cylinder has a flange at the top. A metallic membrane seal is welded to the deck flange and the vessel flange to provide containment of the reactor cover gas.

The inner and outer cylinders are each constructed of forgings and cylindrical shells which are welded together. The cone is a welded assembly of formed plate segments. It is positioned 25 degrees from the horizontal plane and welded to the cylinders.

The 48 in. of steel shielding is located above and below the cone plate.

An additional penetration is for the fuel transfer port.

The Z cone deck is exposed at the top to the HAA and is passively cooled.

The vessel support structure supports the reactor vessel which, in turn, supports the deck and the three rotating plugs. The vessel support structure is designated as a U-ring support structure because of its shape and will be so designated in the remainder of the report.

The U-ring support is a circular girder having three sides, the inner wall, bottom plate, and outer wall. There are 30 webs, with caps equally spaced on the circumference attached to the three sides of the structure. Between each web are two gussets. The inner wall has a ledge which supports the vessel.

The structure is supported over the greater part of its bottom surface by the embedded ring girder. It is attached to the embedment by bolts. The structure is positioned on and attached to the embedment to function as a cantilever type of vessel support.

The top of the U-ring support structure is open to allow natural convection and radiation cooling as well as to provide access to its interior for inspection and maintenance.

The structure material is carbon steel.

Access for inspection of the flange-to-shell weld joint is through capped posts in the inner wall of the structure. The interior surface, weld joints, pin keys, and hold-down bolts are easily accessible for inspection and replacement or repair. The bolts attaching the vessel to the support structure are accessible for inspection by removal of the seal plate between the support structure and the vessel flange.

6.0 SEAL, BEARING, AND SUPPORT SYSTEM

6.1 Requirements

6.1.1 Seal System

1) The sodium dip seal shall attenuate the radioactive gases to no more than that equivalent to the helium leak rate of $<8 \times 10^{-6} \frac{\text{scc}}{\text{sxcmx1 atm}\,\Delta P}$ for wetted dip seal surfaces.
2) The temperature of the sodium dip seal shall be controlled to limits of about 300^{0}F to 550^{0}F with the reactor coolant sodium operating at 500^{0}F and 950^{0}F, respectively.
3) The blade depth in the dip seal sodium shall be sufficient to prevent bubbling of the cover gas into the annulus and gas out of the annulus during cover gas under and over pressures of ± 1/2 psi.
4) The inflatable elastomer seal and the bearing operating temperatures shall not exceed 150^{0}F with reactor coolant temperature of 1050^{0}F.
5) The inflatable seals shall accommodate the following blade radial runouts:

LRP	± 3/8 inch
IRP	± 3/8 inch
SRP	± 1/4 inch

6) Access ports to the sodium dip seal surfaces of not less than 3-inch diameter shall be provided for in situ insertion of equipment for rewetting of the dip seal surfaces.

7) The dip seal surfaces shall be initially tin-plated by the electro-brush method.
8) Dip seal sodium level indicators shall be provided.
9) Radiation counters shall be placed in the annulus to determine any change in radioactive gas sealing capability of the dip seal sodium.
10) Dip seal sodium temperature sensors shall be provided in the annulus.
11) All static seals shall be the double arrangement and be buffered with inert gas.
12) Permanent static seals shall be metallic seals.
13) Static seals that are disturbed when replacing the inflatable seals shall be elastomer seals.
14) Provisions to prevent gear lube contact with the inflatable seals shall be provided.
15) An inflatable protector seal shall be provided to exclude air contact from the dynamic inflatable seals.
16) "Overpressure" seals shall be provided at the annulus top. Cover gas overpressure is caused by a rapid sodium temperature increase in the reactor core area.

6.1.2 Bearings

1) The bearing shall support the loads.
2) The bearing shall accommodate the radial temperature growth of the plugs. For the LRP, the radial growth is about .025 inch.
3) The attachment bolts of the races to plugs and the deck shall hold the races solidly against the mounting surfaces.
4) The bearing shall have an integral metal grease seal on the bottom side.
5) The life goal of the bearing shall be 40 years.
6) The bearing shall be lubricated with no-drip radiation resistant grease - withstand 10^7 R gammas without impairing its ability to lubricate.

7) The bearing shall have provisions to be relubricated in service.
8) The maximum speed of the bearings is 15 ft/min (tentative).
9) The travel of the LRP bearing for 40 years is 2,000,000 ft.
10) The bearing shall be supplied as an assembled unit.
11) A grease-catch trough shall be incorporated below the bearing to catch the grease leaving the bearing.
12) The bearing shall be located below the inflatable seals and shall function in the presence of sodium frost, helium, and radioactive gases during operation and in the presence of argon and/or air during installation and maintenance.
13) The bearing shall be a single-row ball bearing with a vertical separation line between the races.
14) The width of the bearing shall be as small as practical. The height of the bearing is not limited.
15) The outer race of the bearing for the SRP and IRP shall be part of the pressure boundary and shall meet the requirements for the ASME Pressure Vessel Code, Section 3, Class 1.
16) The bearing attachment bolt holes diameter shall be oversized by 1/4 inch.
17) The bearing shall withstand the dead loads of the respective plugs in a static mode for intervals of three years without damage to the balls and raceways.

6.1.3 Plug Support Structure

The structure shall:

1) Support the loads.
2) Accommodate the inspection ports for the plugs' annulus.
3) Serve as a plug lowering and lifting fixture for bearing replacement.
4) Serve as a pressure containment bondary meeting the requirements for the ASME Pressure Vessel Code, Section 3, Class 1.
5) Interface with the plugs, bearing inflatable seals, static seals, and ring gear.

6.2 Description of Approaches Considered

The recommended seal, bearing, and plug support concept is described, followed by a description of the alternate configurations investigated for the upper seal, bearing and plug support system located at the top of the rotating plugs.

6.2.1 Sealing System

The recommended sealing system has a sodium-filled dip seal at the bottom of the annulus and double inflatable seals at the top of the annulus, Figure 3.

The dip seal consists of a sodium-filled trough and a blade immersed in the sodium. The trough is part of the outer wall of the annulus and the blade is part of the inner wall of the annulus, thus the blade, being immersed in the sodium, forms a gas seal which separates the radioactive cover gas in the lower annulus from the gas in the upper annulus. The configuration of the dip seal is shown in Figure 7. Ports for installation of ultrasonic horns are provided in the dip seal trough.

The dip seal surfaces are originally tin plated to form a sodium wetted surface at low temperatures ($<400^{0}$F) to attain low R/A cover gas leak rates across the dip seal. The ultrasonic horn ports are provided to be able to rewet the seals' surfaces in the remote event they become unwetted. The dip seal surfaces should stay wetted during the life of the plant unless exposed to oxygen.

The ultrasonic horn ports would not be required if the wetted dip seal surfaces are not required. With the present requirement of sealing for 1% failed fuel pins, a wetted dip seal surface is required to limit the HAA area dose rate to about 2.0×10^{-3} mr/hr, the design requirement.

With an unwetted dip seal surface, the leak rate of the dip seal increases by a factor of about 10, based on AI helium leak rate tests.

Therefore, about the same HAA area dose rate could be maintained with an unwetted dip seal surface if the number of failed fuel pins was lowered, a factor of 10 or more, from 1% to about 0.1%.

The dose rate with a wetted dip seal and 1% failed fuel pins is 1.3×10^{-4} mr/hr which gives a margin of about 1.5 x 10 lower than the allowable HAA dose rate of 2.0×10^{-3} mr/hr.

With an unwetted dip seal and 1% failed fuel pins, the HAA dose rate is 5.6×10^{-3} mr/hr. Reducing the 1% failed fuel pins to 0.1%, the corresponding HAA dose rate would be about 5.6×10^{-4} mr/hr which is a factor of 4 lower than the allowable dose rate.

The sodium dip seal is located in the plugs' reflective insulation section. Its elevation in the insulation section is chosen to have the dip seal sodium operate at about 300°F and 550°F when the reactor coolant temperature is at 500°F and 950°F, respectively.

Figure 8 shows the relationship between the dip seal elevation and its temperature. The upper temperature limit of 550°F was chosen to limit the amount of sodium frost deposits on the colder walls of the annulus. Figure 9 shows the sodium frost deposits for three dip seal temperatures. Reference 2 contains the calculations for the frost deposits.

The thickness of sodium frost deposits for 40 years is small and will not interfere with plug rotation. The allowable deposit thickness was kept small to provide a safety margin to account for:

1) Actual versus calculated operating temperatures of the dip seal.
2) Actual versus calculated annulus surface circumferential temperature differentials.
3) Actual versus calculated deposits.
4) Radial movement of the plug during rotation due to dimensional tolerances.

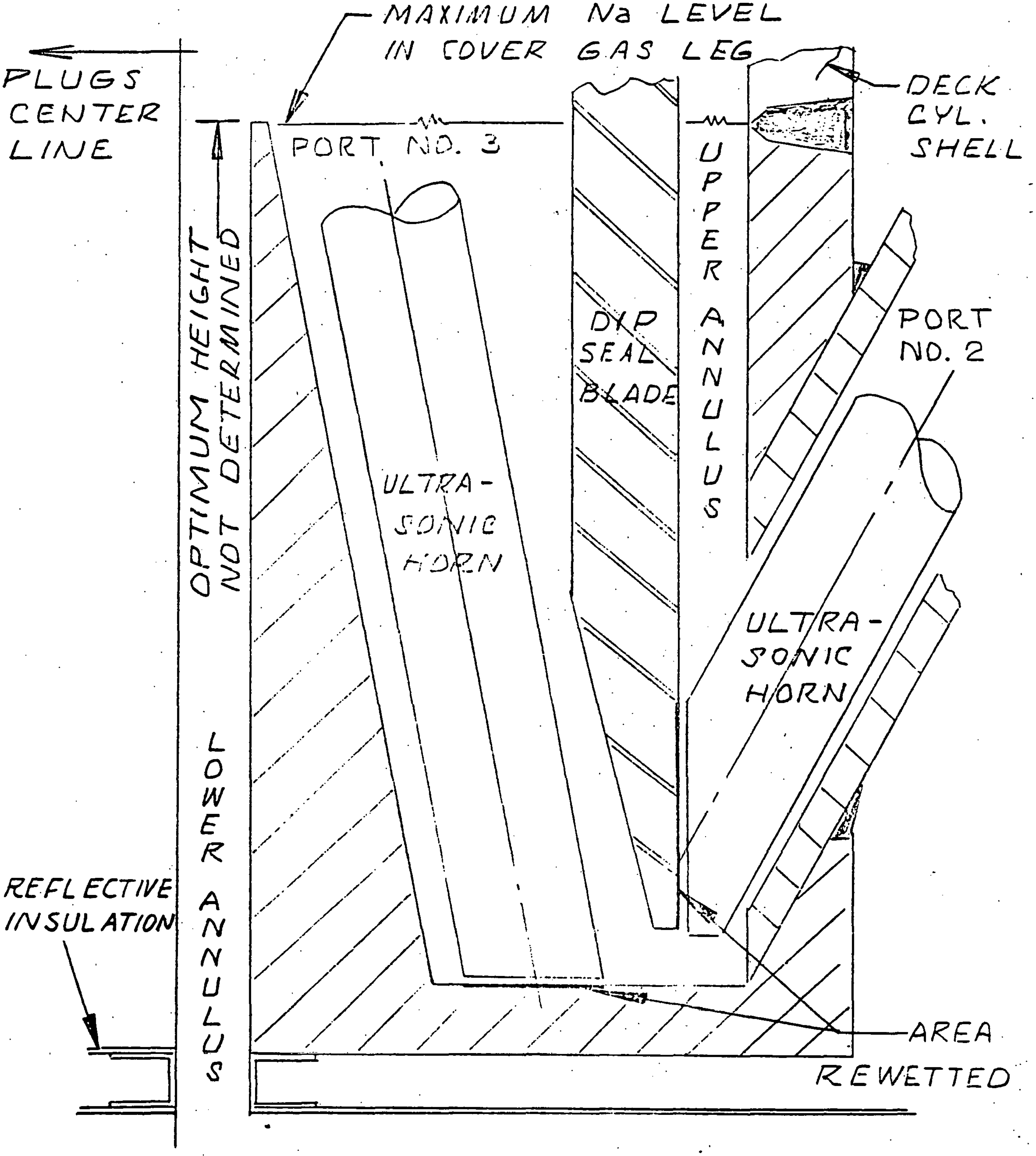


FIGURE 7. CROSS SECTION OF DIP SEAL WITH ULTRASONIC HORNS IN PLACE FOR REWETTING

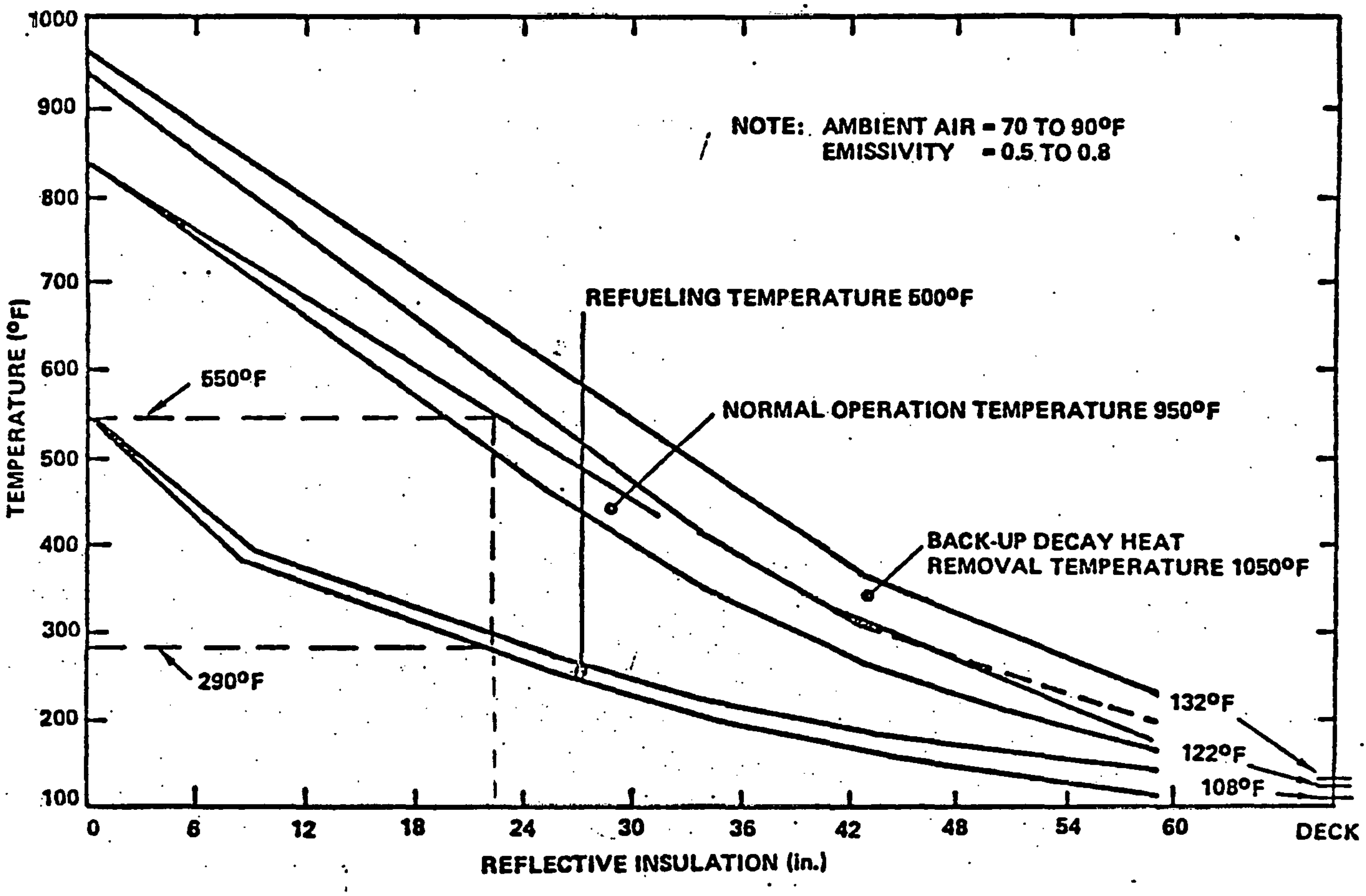


FIGURE 8. DIP SEAL TEMPERATURES (BASED ON ELEVATION) DURING 500°F, 950°F, AND 1050°F REACTOR SODIUM CONDITIONS

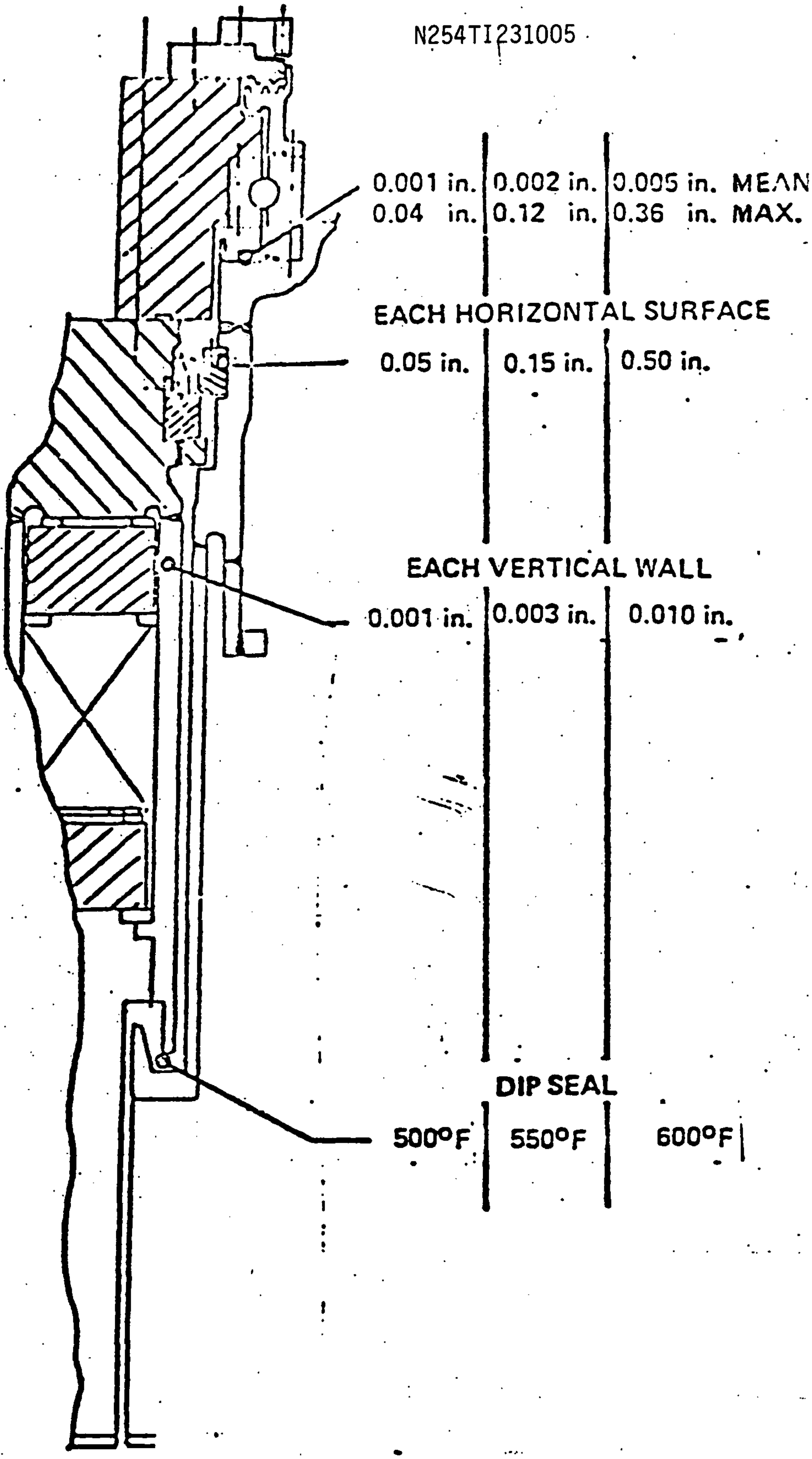


FIGURE 9. SODIUM FROST DEPOSITION

The lower dip seal temperature of about 300^{0}F was chosen to allow margin above the freezing point of Na, 208^{0}F, to account for:

1) Actual versus calculated operating temperatures.
2) Sodium oxide content in sodium due to air in-leakage through the inflatable elastomer seals.
3) An operating temperature band, above 950^{0}F and below 500^{0}F, of the reactor sodium coolant.

The gas in the annulus above the dip seal operates at the same pressure as the gas in the annulus below the dip seal during reactor steady-state operations. During transients, the lower gas annulus pressure will quickly vary and the depth of the dip seal blade into the dip seal sodium shall be sufficient to prevent bubbling of the cover gas or upper annulus gas across the dip seal blade. With the present estimated cover gas change of ±1/2 psi without a corresponding pressure change in the upper annulus, an immersed length of the dip seal blade of 6-8 inches is adequate. Figure 10 shows the relationship of the gas pressure change to depth of dip seal blade immersion.

The upper annulus seals are the two dynamic inflatable seals and the static seals. The static seals limit the leakage of the R/A upper annulus gas to the HAA between the bolted components of the support structure. The static seals are either elastomers or metallic seals. The elastomer static seals are used in locations where they will not receive high radiation doses from the R/A gases and are to be disassembled for replacement of the inflatable seals and other periodic maintenance operations. The static seals used elsewhere are metallic seals.

The inflatable seals are used to maintain sealing of the upper annulus during static and rotational modes of the plugs. The sealing function is accomplished by the blade riding on the surface of the inflatable elastomer seal which is lubricated with silicone oil, Dow

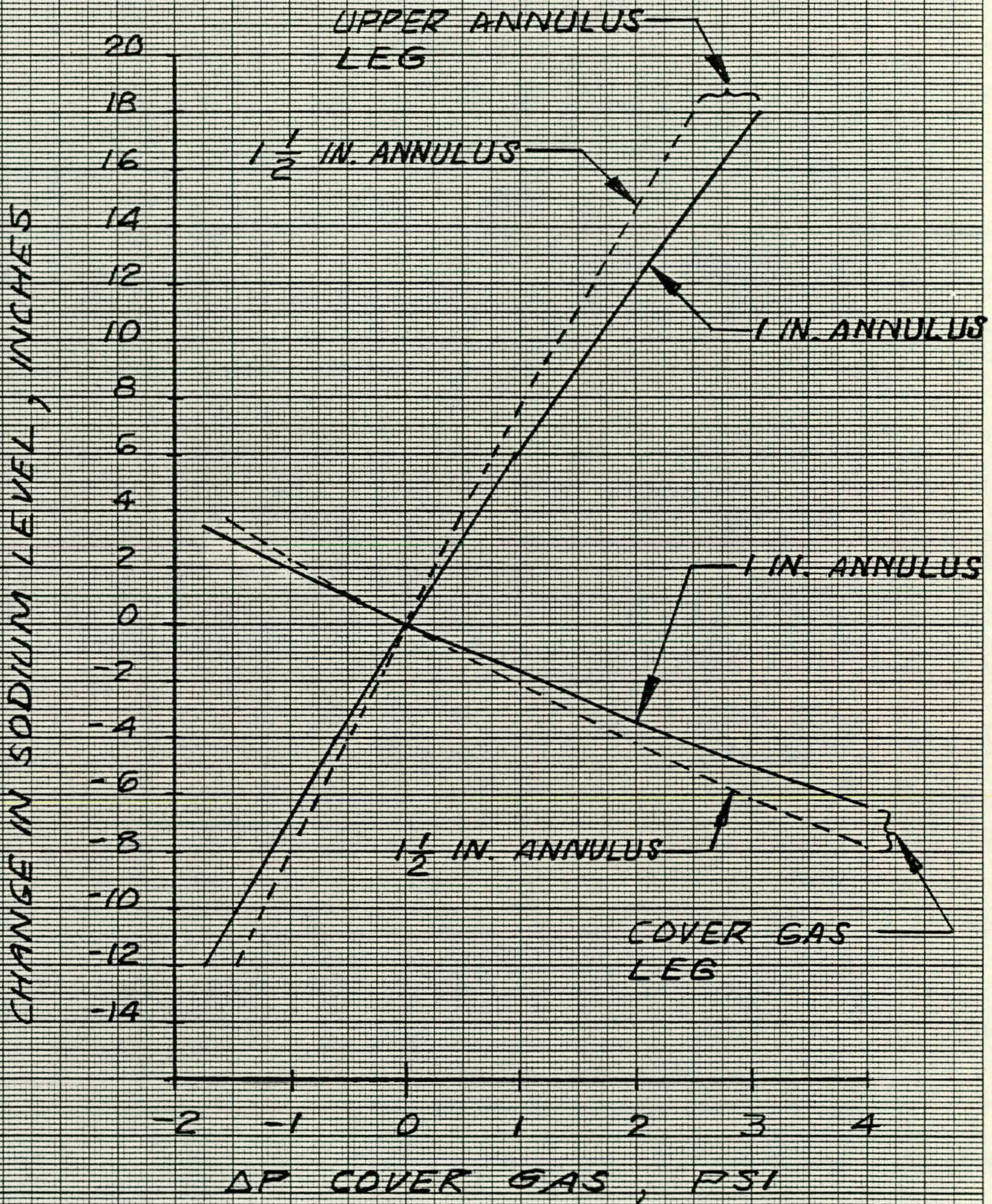


FIGURE 10 EFFECT OF CHANGE IN COVER GAS PRESSURE ON SODIUM LEVELS IN DIP SEAL

Corning 55M. The seal is inflatable to assure sealing to the blade during blade movements to allow for the variations in the vertical and horizontal path of the blade as the plug is rotated.

All seals are double and the volume between them is connected to an inert gas supply. The volume is checked for gas pressure decay at seal installation and thereafter to assure the seals are functional.

The inflatable seal and static elastomeric material is either EPDM (ethyl propylene di-monomer) or nitrile rubber. The tests of seals at AI have indicated these materials are the better of those tested, see Reference 3.

The inflatable seals are attached to a mounting plate, which allows the seals and plate to be replaced as a unit thus minimizing reactor downtime for seal replacement. A mounting plate, with seals attached and tested, is made ready prior to removal of the seals on the rotating plugs.

The blade of the member located above the inflatable seal presses into the concave surface of seal. The lubricant is placed in the concave surface to reduce the friction between the blade and seal when the blade is moved relative to the seal during rotation of the plug. Holes are provided in the blade plate for periodic relubrication of the seals.

A protector inflatable seal is placed above the two inflatable seals. Its purpose is to prevent air (ozone) contact with the inflatable seals to increase their service life. The space between the protector seal and the inflatable seals is filled with an inert gas during the stationary periods of the plugs. The protector seal is deflated during plug rotation to decrease the rotational torque required.

Degradation of elastomer seals is caused by ozone contact, radioactive gas contact, high temperature, and mechanical damage caused by blade wear and seal flexing during plug rotation.

The seals are protected from ozone by the protector seal except for periods of fuel handling. The maximum calculated radiation dose is 10^3 R on the annulus side of the seal for five years or about 10^4 R for forty-year plant life with a wetted dip seal and 1% failed fuel elements.

With an unwetted dip seal surface, the radiation dose to the inflatable elastomer seal is estimated to be about 10^5 R for a forty-year plant life with 1% fuel pin cladding failure.

Below 10^7 R, no significant elastomer damage occurs. Damage becomes progressively greater above 10^7 R, and doses above 10^8 R will cause substantial loss of properties (i.e., compression set resistance, tensile strength, and elongation). Tests at AI and at the seal manufacturer on solid cross section seals at 150°F and 10^8 R gamma have demonstrated that if the seals are undisturbed, they will retain their sealing capability. Similar tests are started on inflatable seals which are not subjected to compression set damage.

Both thermal and radiation environments cause degradation of the seals compound polymer chain, principally by cross linking, thus their effects are additive. The combined effects of the thermal and radiation degradation in the loop reactor service are well below that which would require seal replacement. No test data are available to determine specific thermal damage, however, tests are underway at AI.

The operating temperature of the seal is about 120°F as determined from the plug temperature profile. The mechanical damage to the seal during rotation is very low, see AI test data Reference 4.

Barring reactor operating incidents, the elastomer seals should last the life of the plant - 40 years.

6.2.2 Bearings

The bearings for each of the rotating plugs are located in the support structure. The bearings, through the support structure, carry the dead weight and the vertical and horizontal seismic loads of the plugs.

The outer race of the SRP and IRP bearings are part of the pressure boundary in order to minimize the diameters of the rotating plugs.

The bearings are the temperature-compensating-type which means the races are modified to allow radial growth of the plugs.

The bearings are the radial/thrust-type being designed for the vertical loads (both up and down) and the horizontal loads. The vertical movement of the races, relative one to the other, are minimized to reduce impact loads caused by the seismic events.

The bearing has a built-in non-elastomer grease seal; suggested configurations are shown in Figure 11. The seal has a dual function of retaining the grease in the bearing during normal operation and the grease-filled seal acts as a rough annulus top seal to restrict out-flow of argon gas in the upper annuli. Argon gas is used in the upper annulus to prevent oxygen contact with the sodium-filled dip seal when the inflatable elastomer seals are being replaced. There will be argon gas leakage through the rough seal but it is expected to be small. The grease seal allows passage of old grease during relubrication of the bearing.

The bearing grease used is the non-bleed-type to prevent the grease from crawling out of the catch-trough and down into the annulus where it could contact the frost deposits on the annulus wall, form gummy deposits, and either interfere with plug rotation or fall into the sodium dip seal and then find its way into the reactor coolant which is objectionable due to the hydrocarbon content of the grease. Other greases containing only silicone compounds may be applicable for bearing lubrication. Suggested types of non- or low-bleed radiation resistant greases are displayed in Table 1.

The maximum radiation dose calculated for the grease is 10^4 R for a 40-year period. The grease can withstand 10^7 R without degradation, see Table 2.

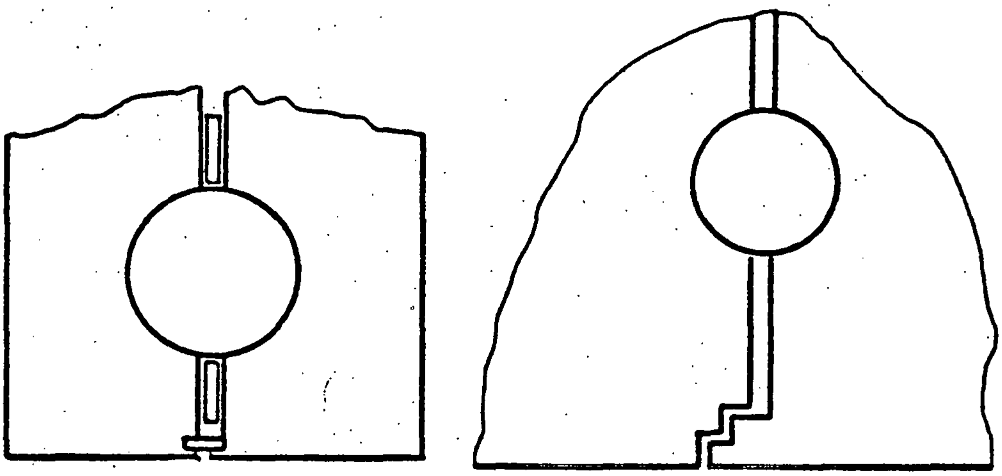
Relubrication ports are provided in the outer race side wall. The ports and valving meet the pressure boundary requirements.

The tolerance on the outside and inside diameters of the bearings are not held tight as "tolerance" shims are to be used to provide tight-fitting assembly to the adjacent components.

6.2.3 Support Structure

There are three support structures, one for each of the rotating plugs. Each support structure has two principal functions; support the dead weight and seismic loads of the plug, and serve as part of the containment boundary of the reactor cover.

The load path through the structure is from the plug top structural head plate through the bolts to the structure, from the structure through the bearing to the next outer plug or deck structure. The structure has sufficient stiffness and attachment bolt strength to accommodate the design loads. The structure is recessed in the plug head plate to securely attach the structure to the head plate during horizontal seismic loads. The bearing is placed as close to the attachment stud as possible to minimize the moment on the structure and to minimize the width of the structure. With a minimum structure width, the height is established to provide a support structure cross section which will meet the design stresses and deflections when using the support structure as a lifting and lowering fixture for bearing replacement.



LEAF SEAL

STEPPED SEAL

FIGURE 11. BEARING GREASE SEAL CONFIGURATION

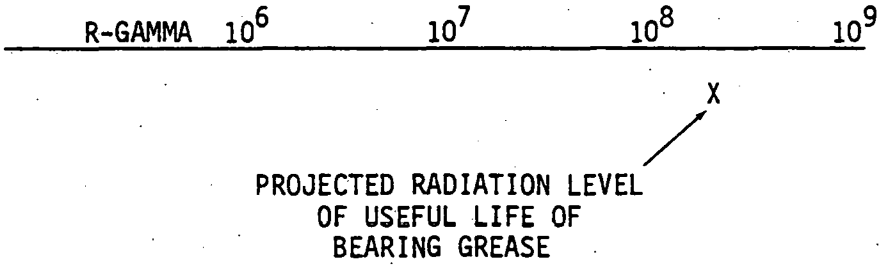
TABLE 1

SUGGESTED RADIATION RESISTANT GREASES

●	SHELL DARINA NO. 2	BLEED NIL
●	TEXACO THERMATEX EP-2	0 BLEED (50 HR AT 212°F)
●	SHELL DOLIUM R-NL61 NO. 2	.3% BLEED (30 HR AT 300°F)

TABLE 2

RELATIVE RADIATION DAMAGE TO BEARING GREASE



The dimensional tolerances on the ID and OD at the bottom of the structure can be loose as "tolerance" shims are employed to assure the parts mate snugly and the relative movement of the structure to the plug and bearing are low, less than .005 inch, under horizontal loads.

The top of the structure interfaces with the access port plugs, inflatable seal rider plate, and the overpressure seal.

The port plugs are sealed to the structure by O-rings. The upper half is sealed and attached to the structure, the lower half is positioned within and sealed to the structure. The upper section can be removed for installation of bagging equipment and still retain the cover gas with the lower part of the port plug.

The ring gear transmits the plug rotational drive torque to the structure through the seal rider plate. The seal rider plate has an overhanging lip to prevent entry of gear grease into the inflatable seals.

The inflatable seal holder is attached and sealed to the top of the bearing outside race or deck and is a pressure boundary component.

The structures and attachment bolts have been analyzed for adequacy (stress and rotation) for the seismic loads. The configurations are designed to include the results of the analysis, Reference 5. The number of jacking points around the LRP structure ring are 12 minimum, when using the jacks jack to lift and lower the plug for bearing replacement.

6.2.4 Alternate Bearing, Seal, and Support Configurations

Presented in Figures 12 through 24 are alternate bearing, seal, and support structure configurations that were considered. One of the many goals was to meet the design requirements with a minimum width of support structure using established sealing methods.

Figure 12 shows an arrangement of the seal above the bearing and the bearing above its attachment shoulder. The bearing is lowered relative to the LRP head to accommodate the horizontal seismic forces. This concept is viable for the LRP/deck bearing installation, but was not used as the support structure members' height is excessive.

Figure 13 shows the inflatable seals located above the bearing with blade-type inflatable seals and a separate wire race bearing. This configuration was not used as the blade-type seals have not been tested.

Figure 14 shows the inflatable seals against a vertical surface and with an integral bearing. This configuration was not used as the seals would not retain lubrication, has not been tested, and an inner race made of bearing-quality steel is not feasible. The configuration's width is the smallest of all the others.

Figure 15 shows the inflatable blade-type seals above the bearing and a wire race bearing. This configuration was not used as the blade-type seals have not been tested.

Figure 16 shows the inflatable seals expanding outward against a vertical surface and an integral wire race bearing. This configuration was not used due to the inability of the seals to hold lubrication.

Figure 17 is similar to Figure 15, except it has a separate seal rider plate. It was not used as the blade seals have not been tested.

Figure 18 shows an arrangement of inflatable seals on a vertical sealing surface with an integral wire race bearing. The concept was not used as it was not a tested configuration. It is believed the lubrication would not stay on the seals.

Figure 19 shows the inflatable seal below the bearing, the same as the CRBR configuration. The configuration was discarded because the seal was below the bearing which made seal replacement very difficult.

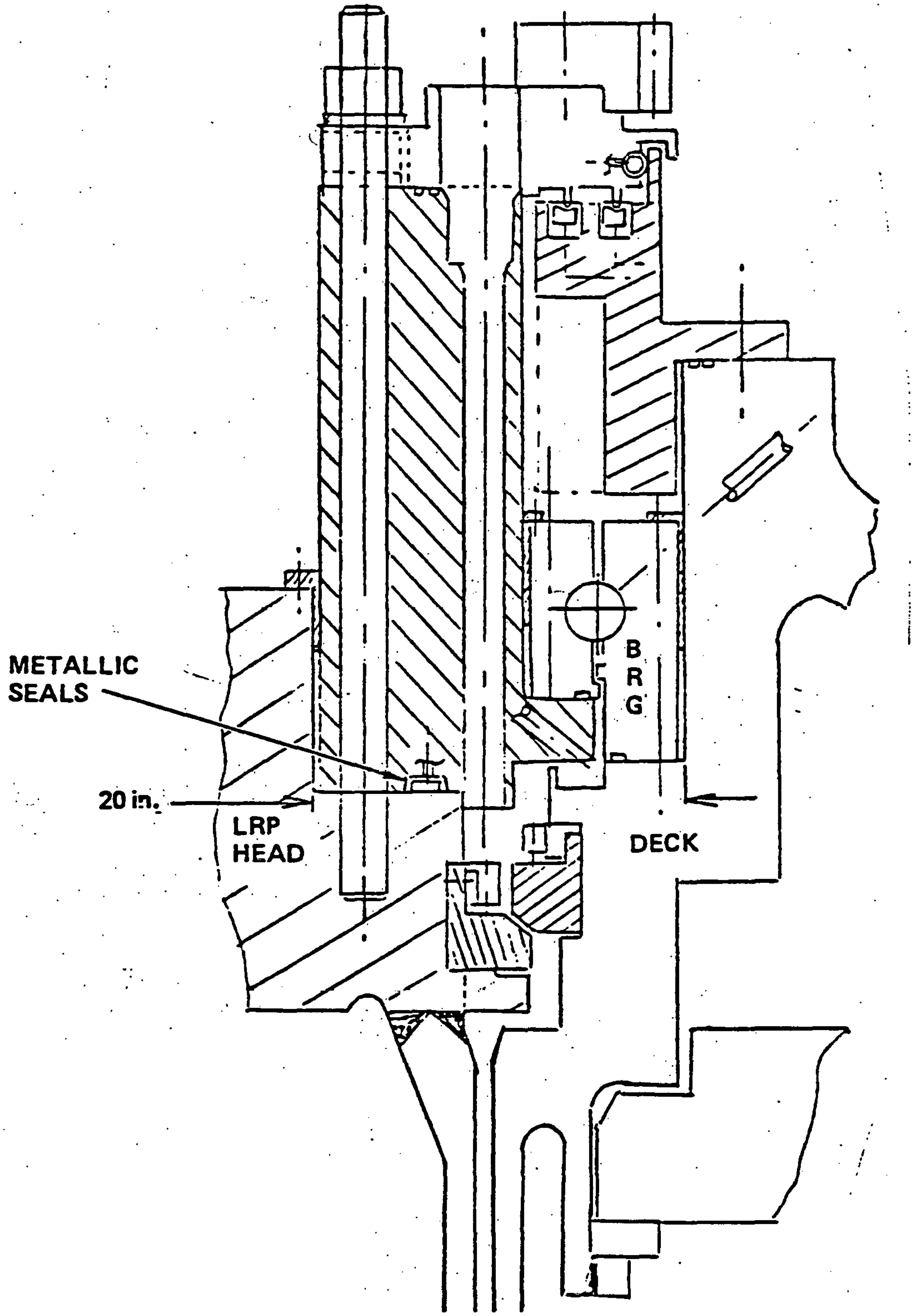


FIGURE 12. BEARING AND SEALS

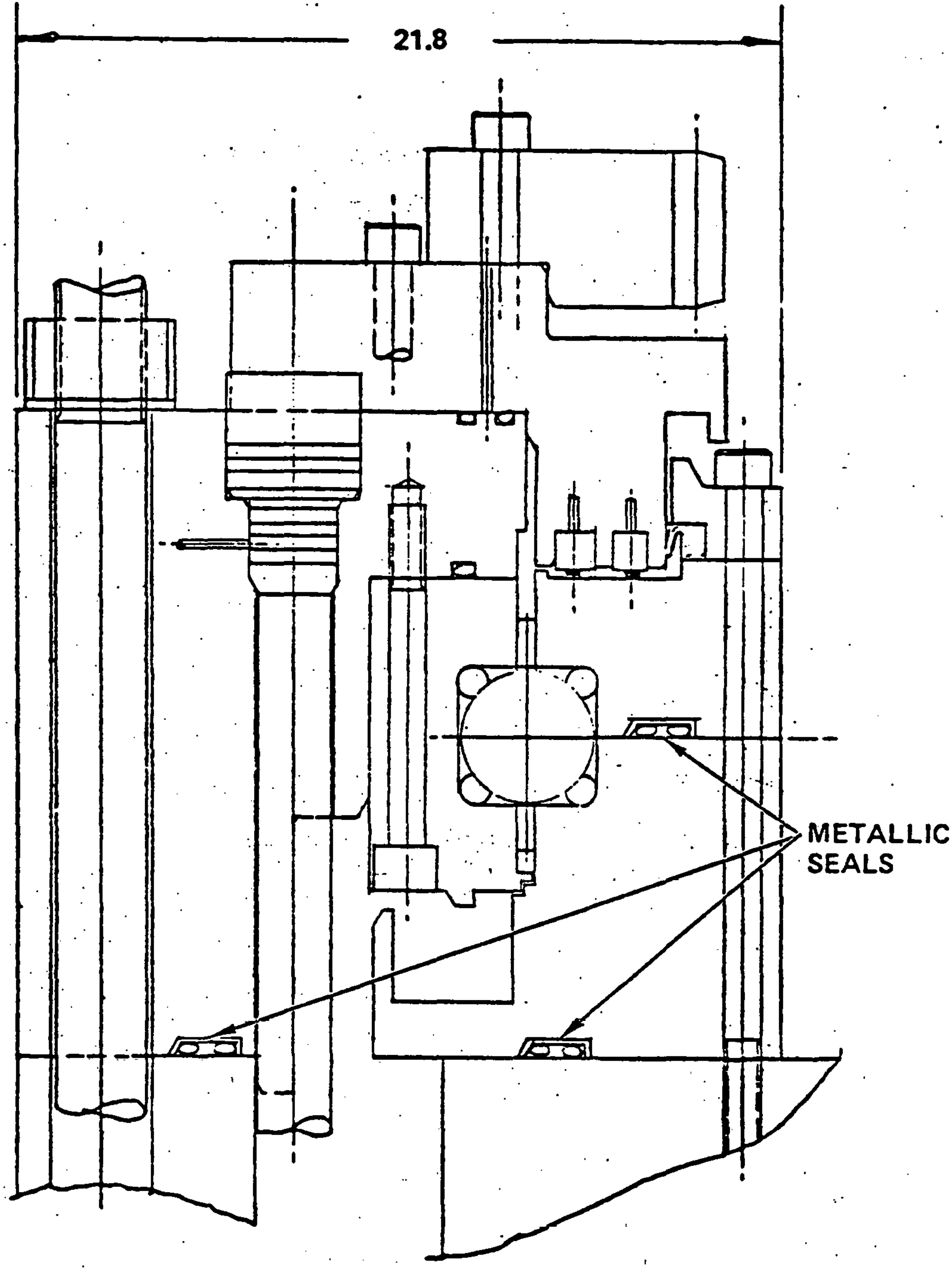


FIGURE 13. BEARING AND SEALS

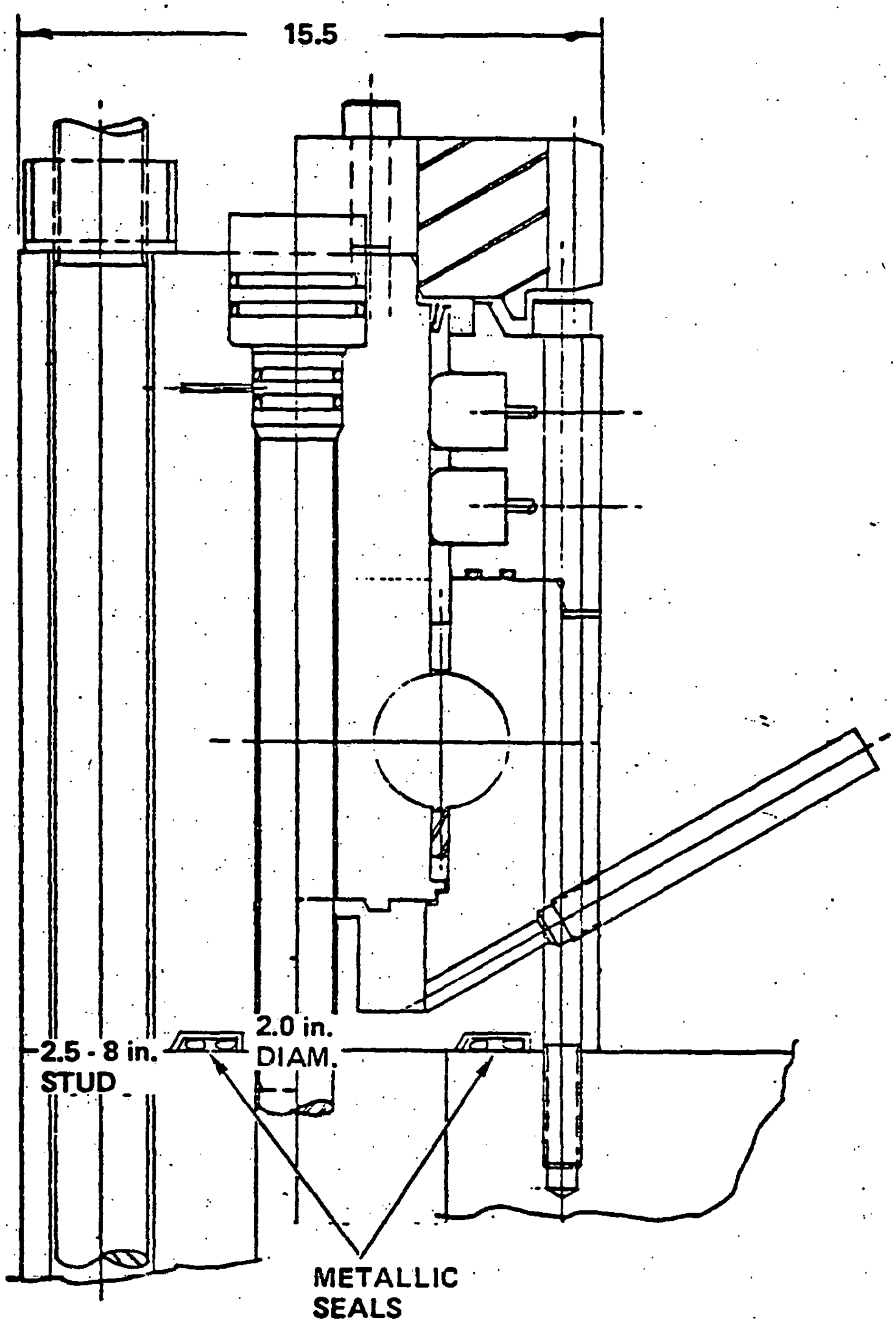


FIGURE 14. BEARING AND SEALS

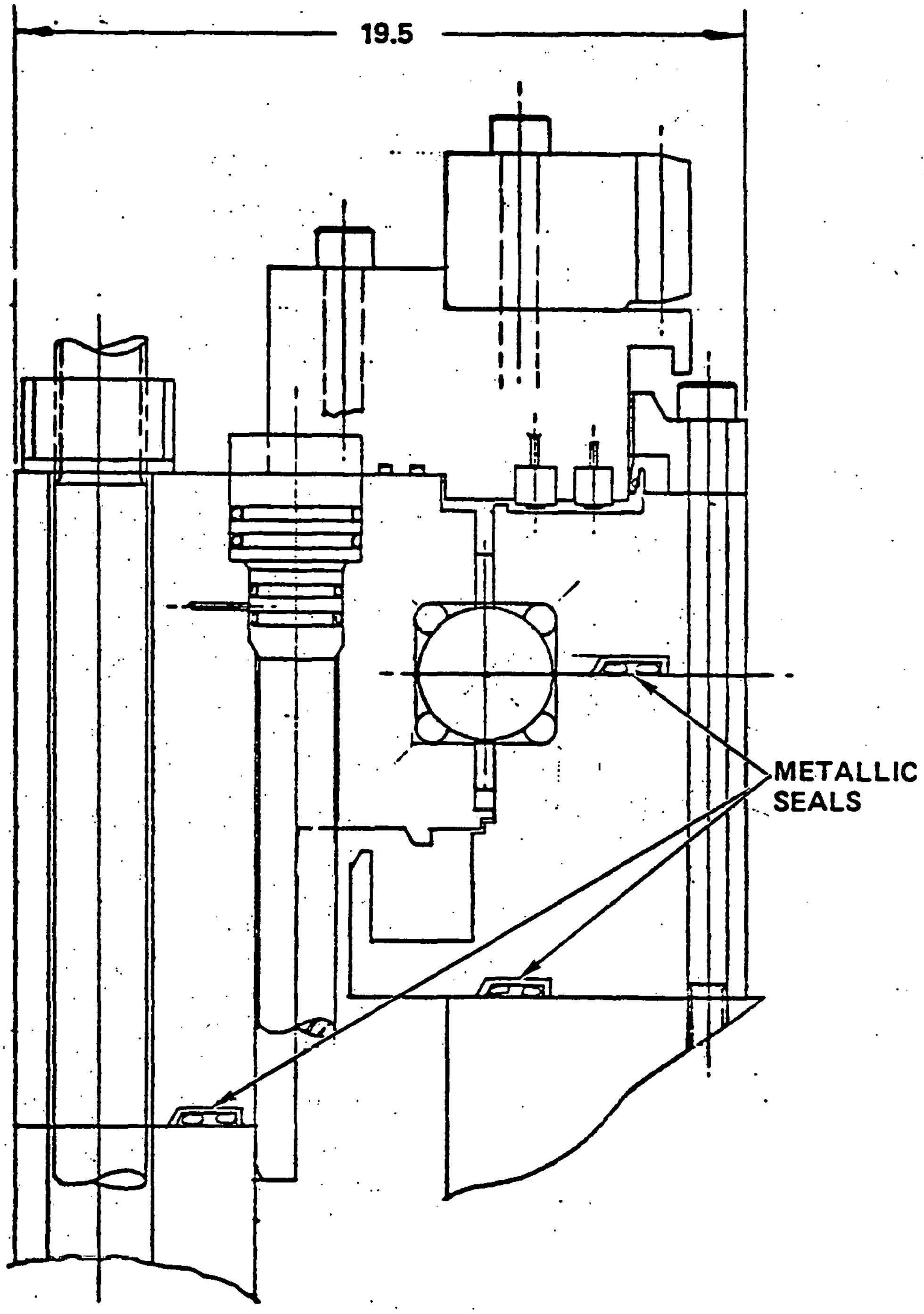


FIGURE 15. BEARING AND SEALS

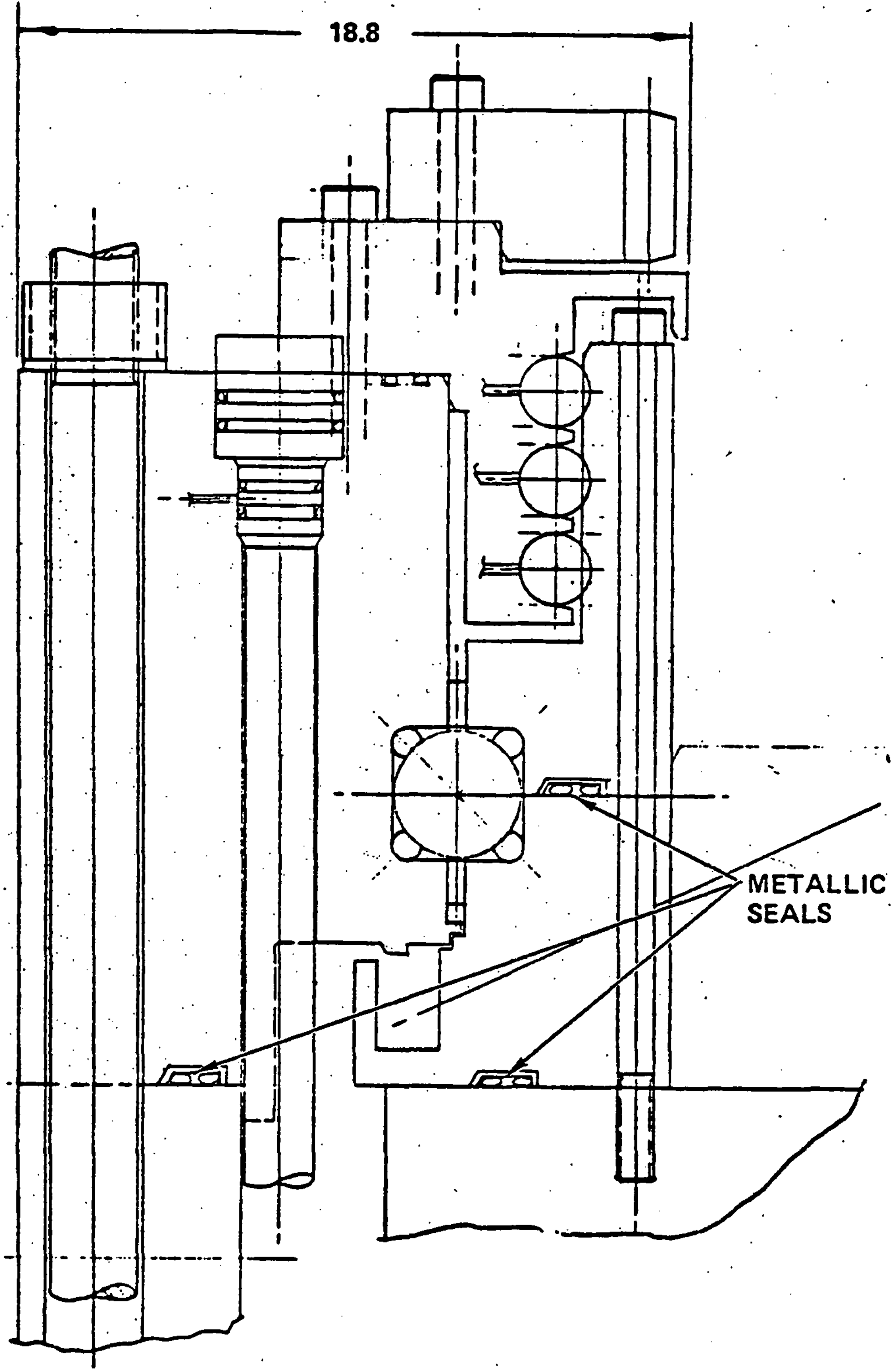
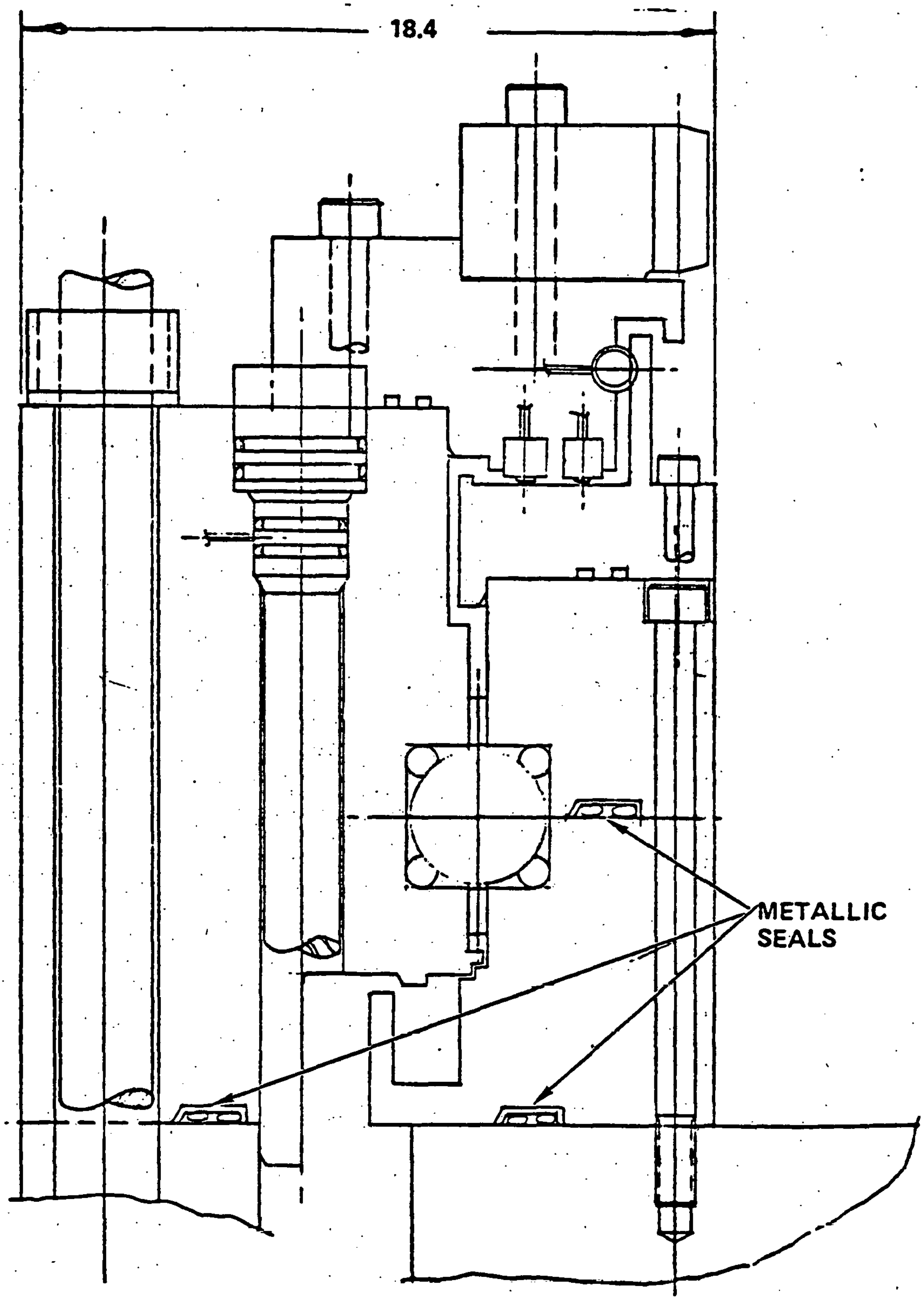
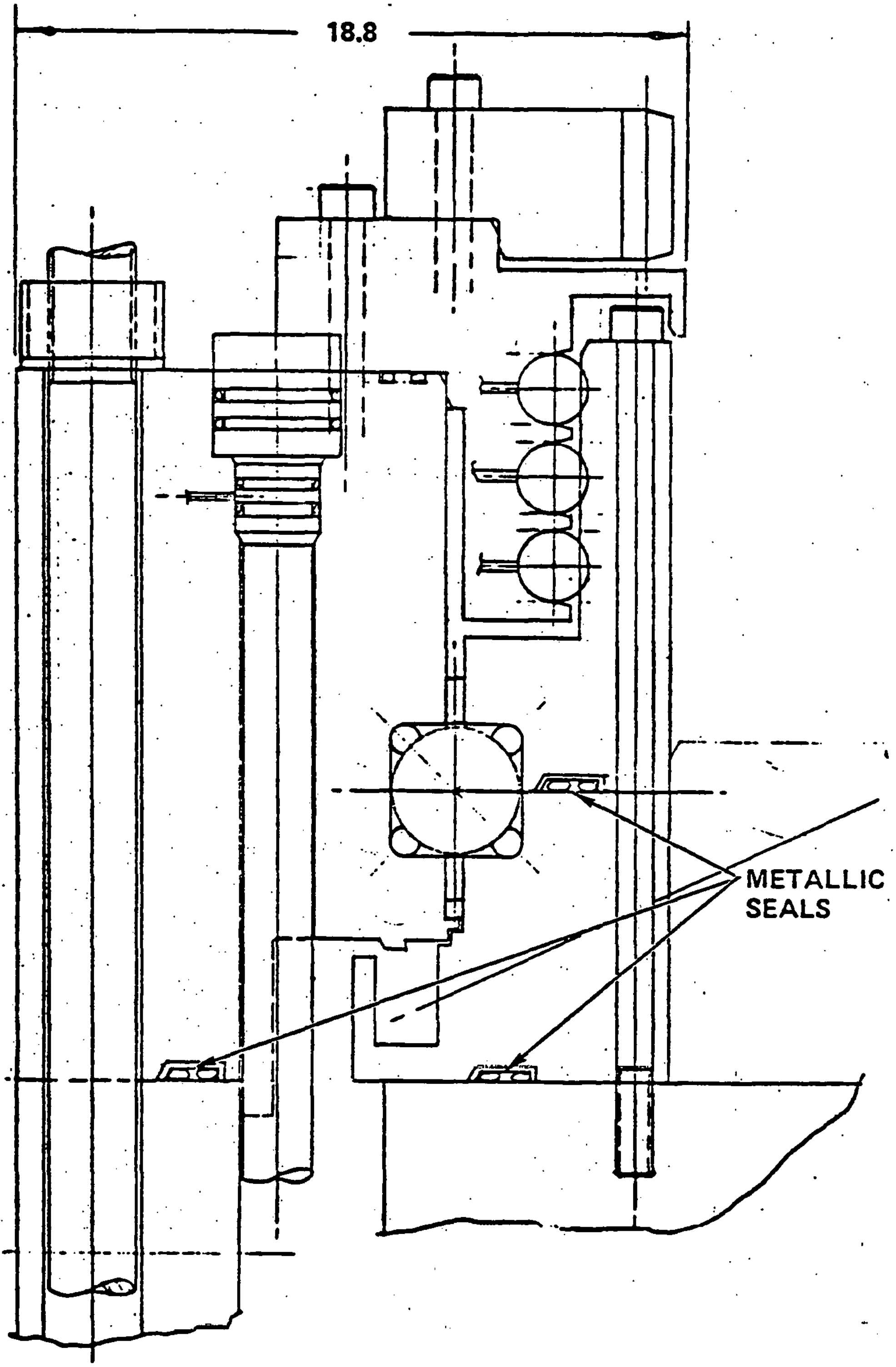


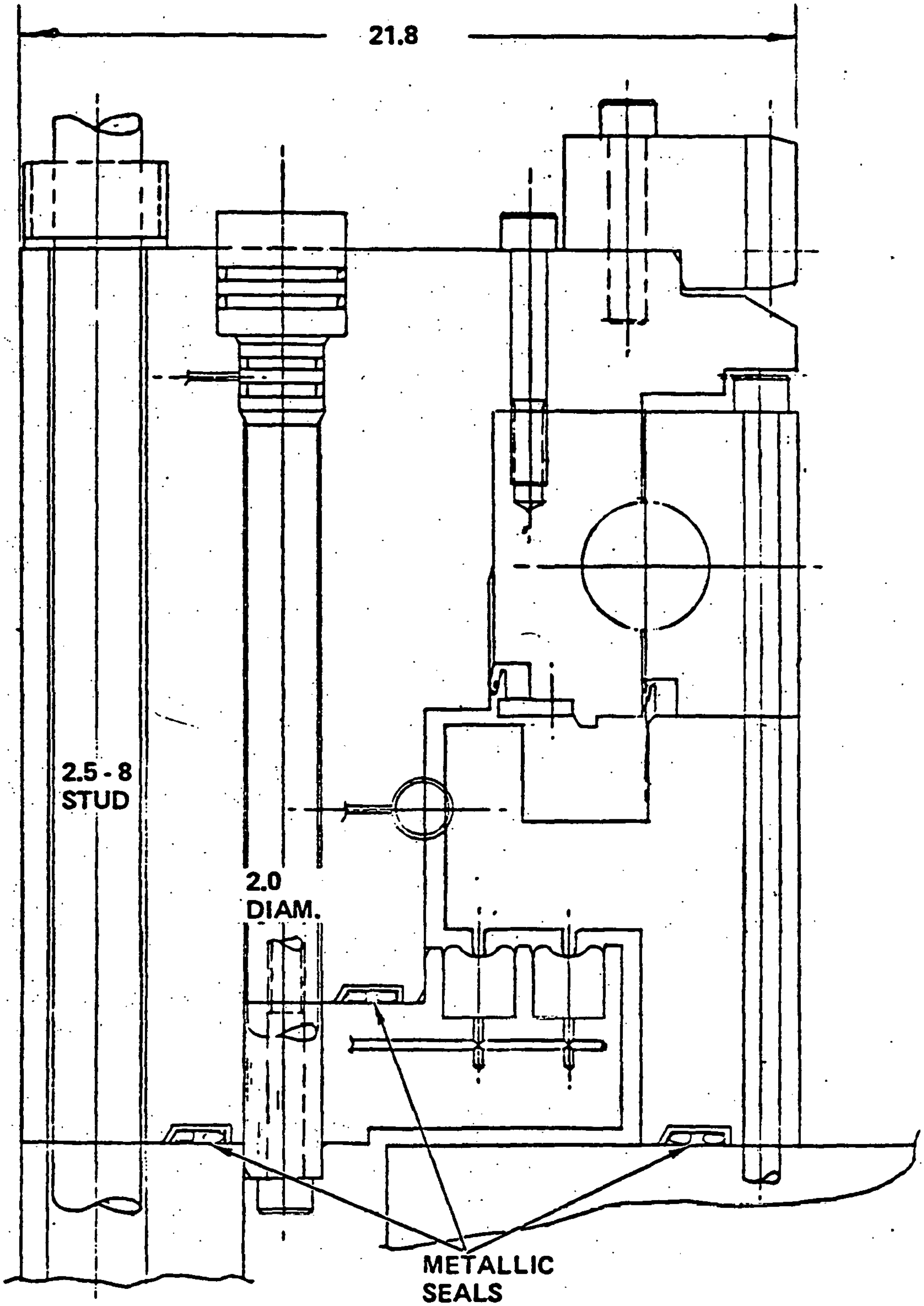
FIGURE 16. BEARING AND SEALS



17. BEARING AND SEALS



18. BEARING AND SEALS



19. BEARING AND SEALS

Figure 20 shows another LRP/deck bearing installation with a wide bearing, support structure, and no CDA keys. It was not used as the support structure is not adequate to be used as a lifting fixture, there is no room for CDA keys, and access to the lube catch-trough is difficult.

Figure 21 shows a three-row roller bearing concept which was originally developed for the tangential beam deck concept but shown with the cone deck concept. It was not used as its greater bearing width would increase the diameter of the rotating plugs.

Figure 22 shows the tin-bismuth alloy dip seal which would replace the inflatable seals for the annulus top seal. The tin-bismuth alloy top seal concept was not selected for annulus sealing.

Figure 23 shows another seal arrangement with the seal below bearing for the LRP/deck bearing installation. This concept was not used as the inflatable seal location above the bearing is preferred.

Figure 24 shows a sealing arrangement which is similar to the reference concept but without the "overpressure" seal and with a maintenance seal. This concept was not used as adding the space for the maintenance seal would increase the support structure width which would increase the diameter of the plugs.

6.3 Evaluation of Options and Selection of Preferred Approach

6.3.1 Analytical Approach

Figure 25 shows the schematic leakage flow of the radioactive gas from the cover gas space up through the seal system to the HAA area and then to the RCB area.

1) The R/A isotope gases entering the cover gas originate from the fission gas leaking through the cladding of the fuel pins. The amount is a function of the reactor power and the number of fuel pins with failed cladding.

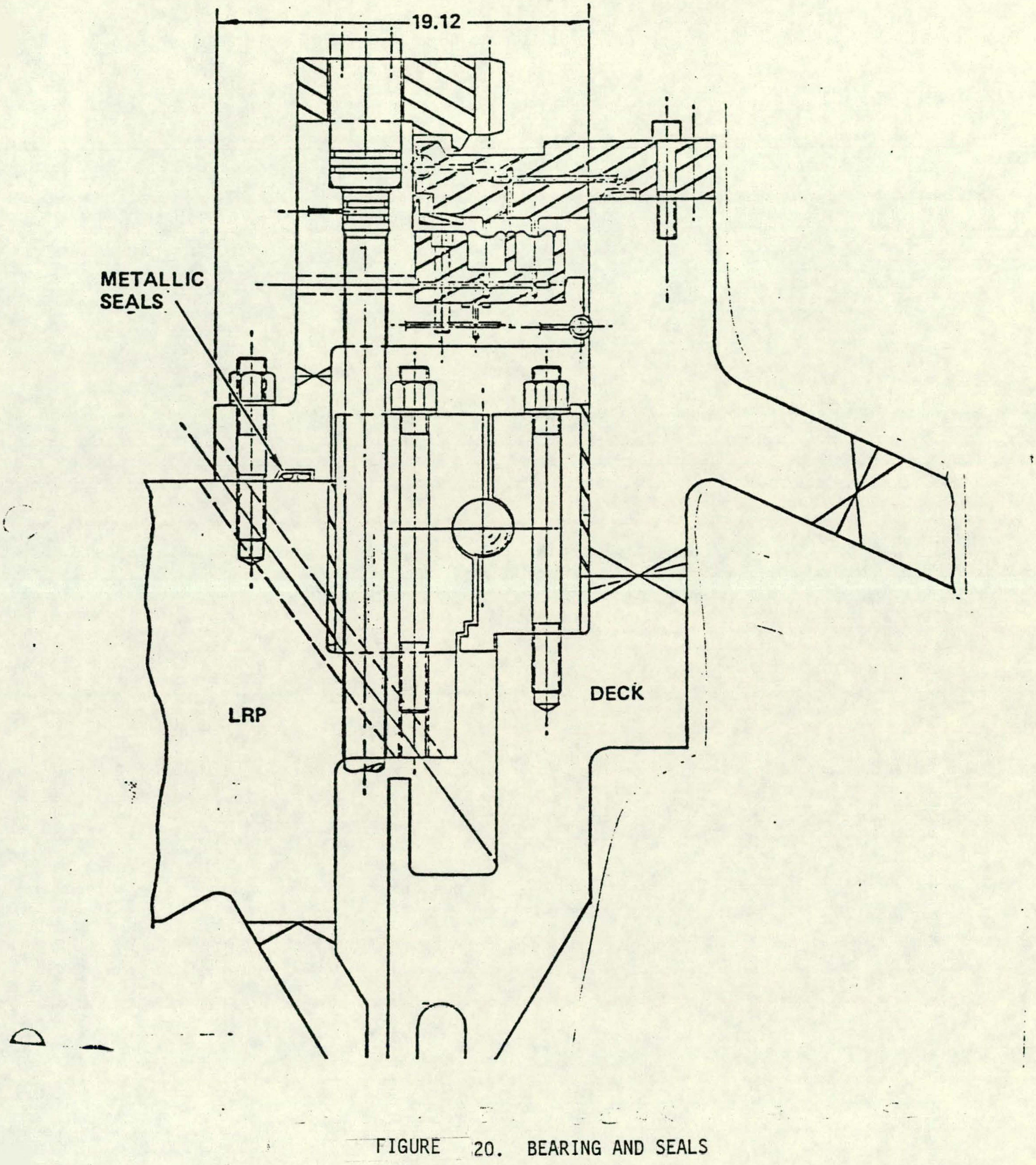


FIGURE 20. BEARING AND SEALS

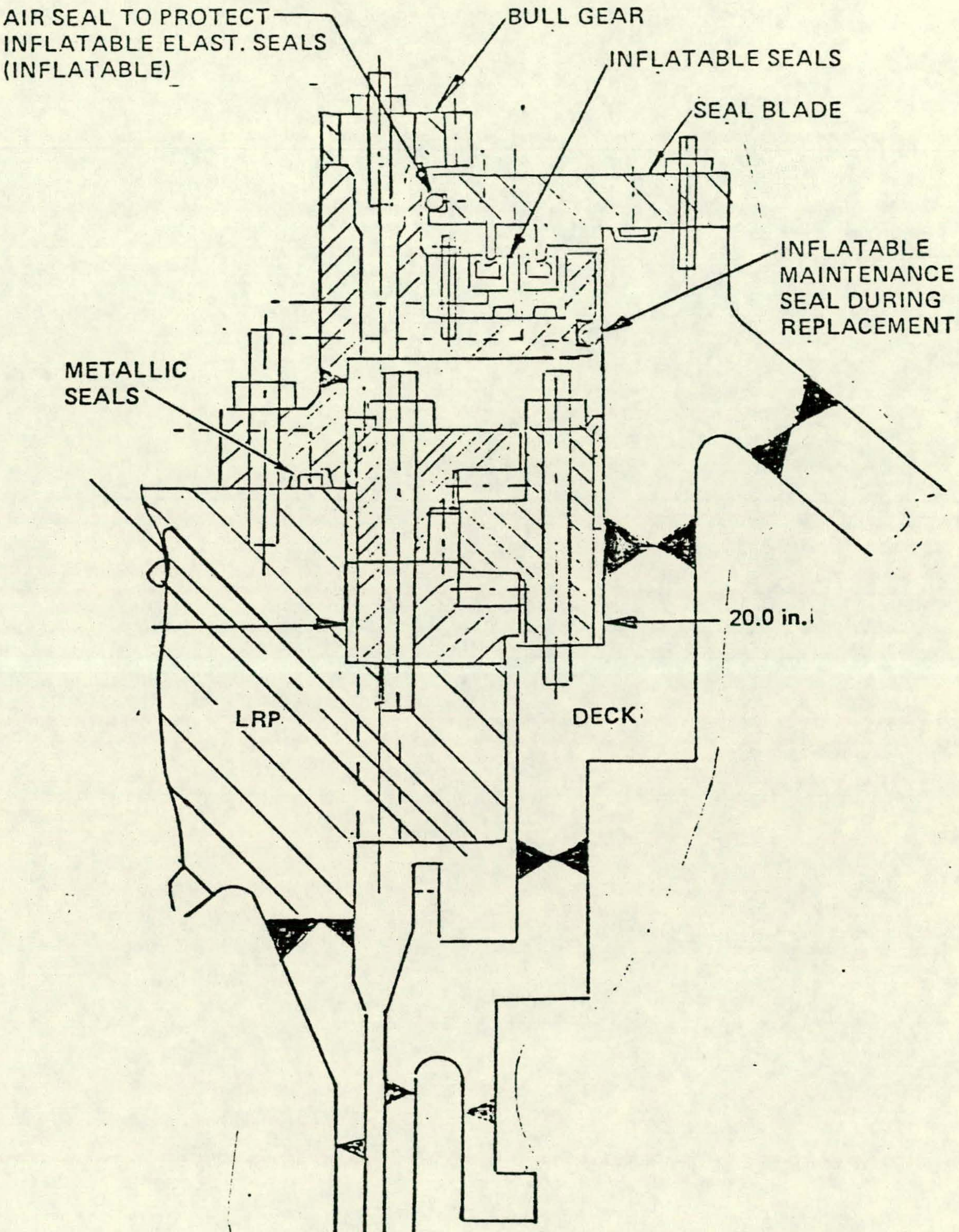


FIGURE 21. BEARING AND SEALS

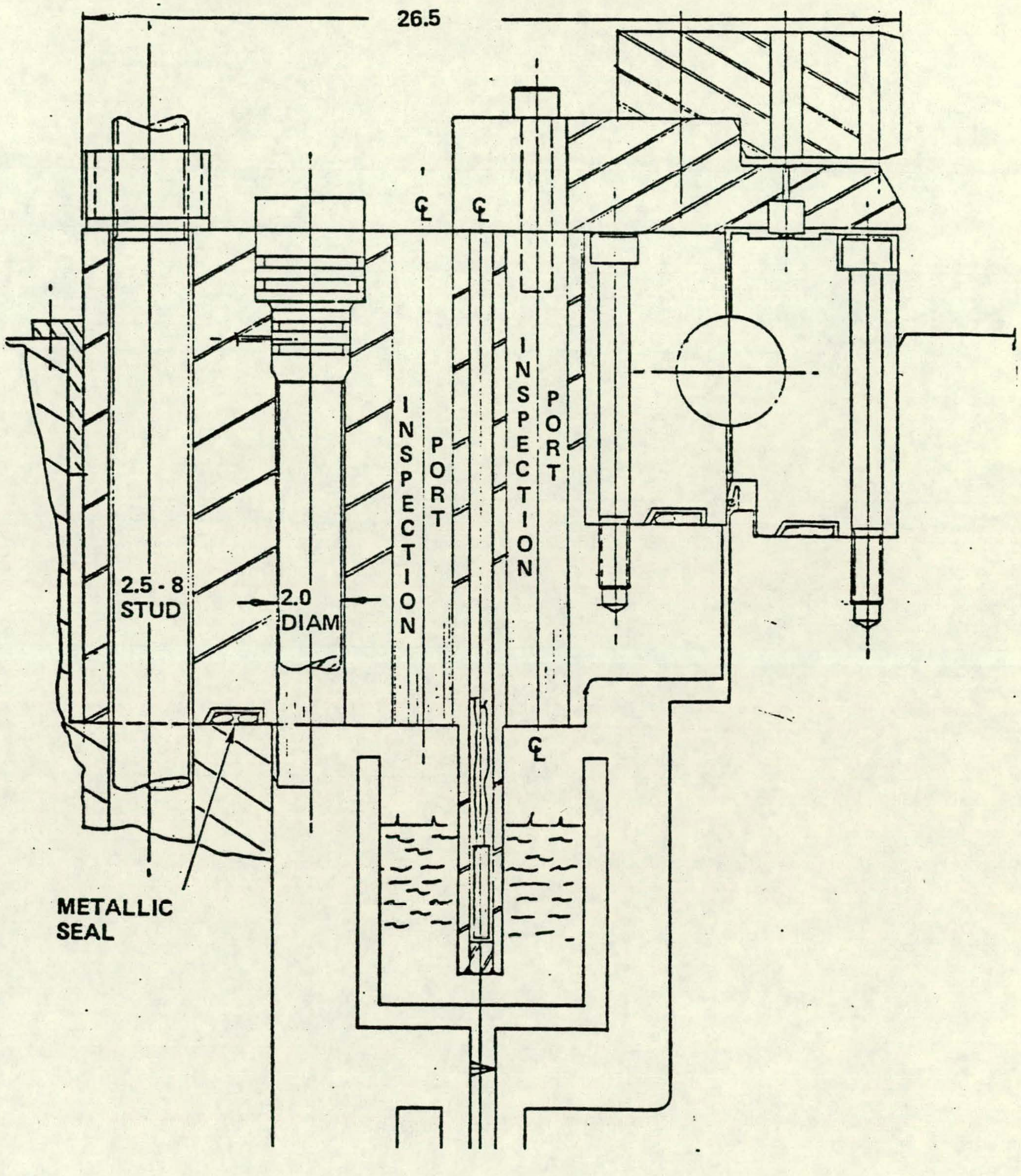


FIGURE 22. BEARING AND SEALS

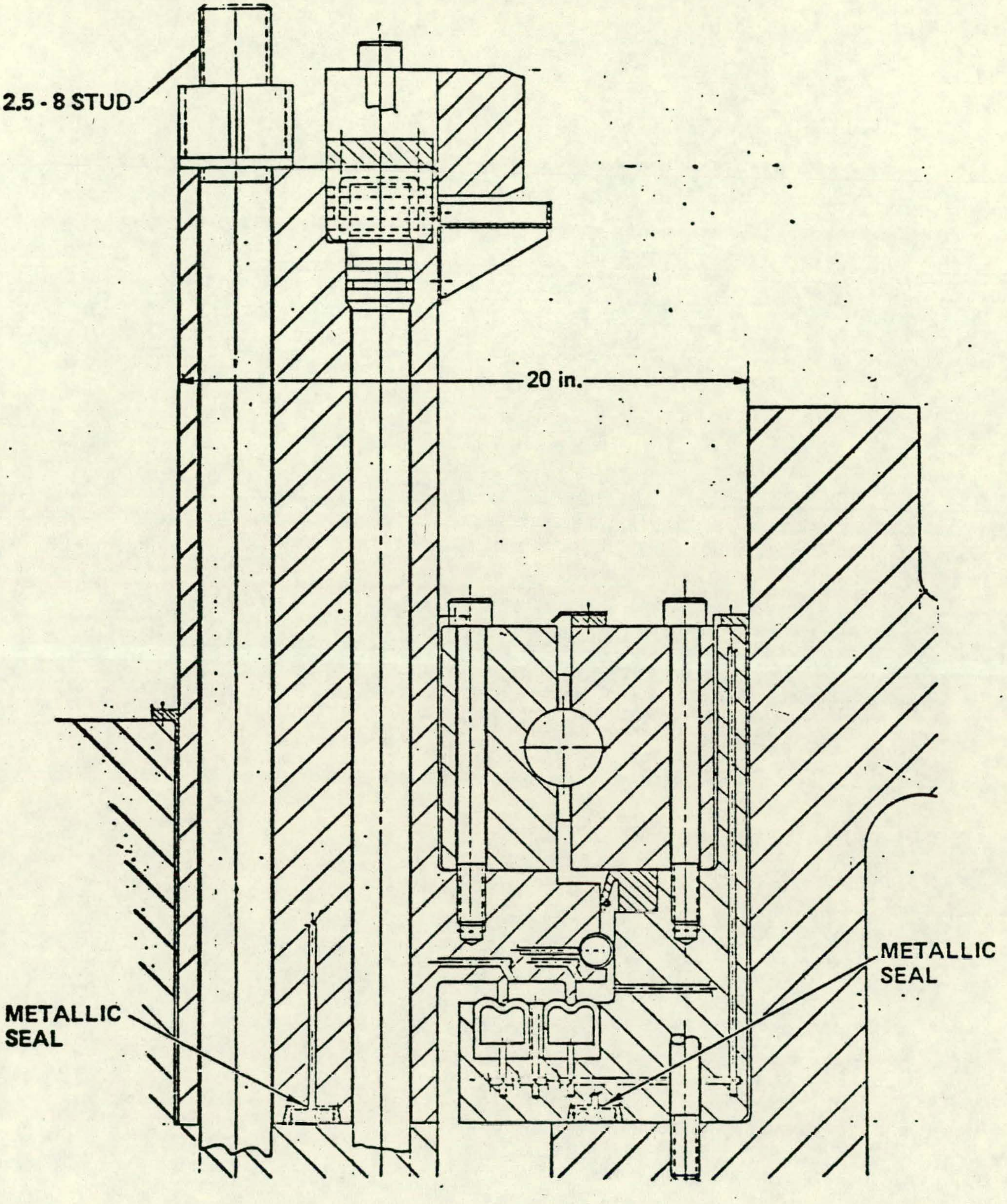


FIGURE 23. BEARING AND SEALS

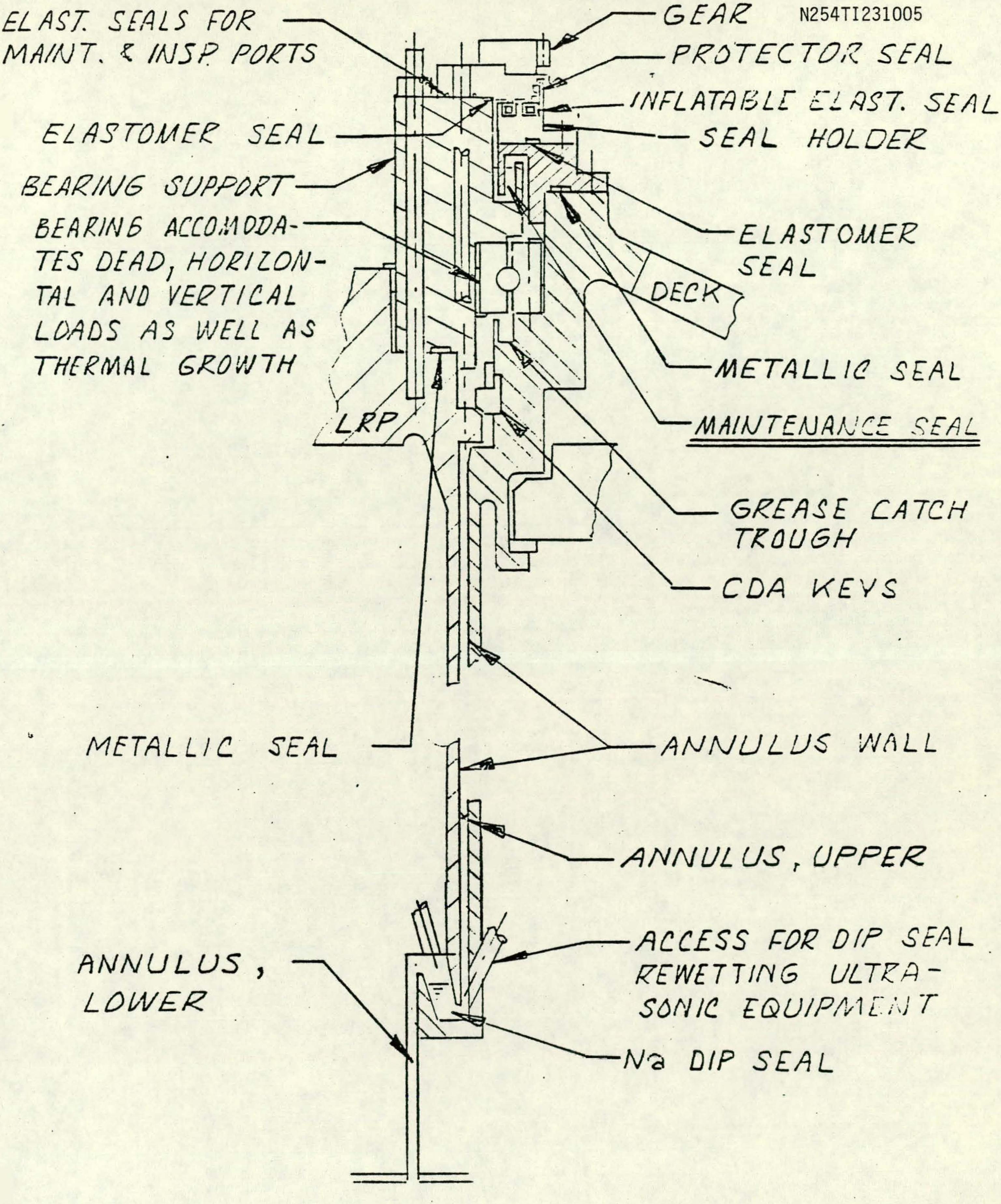


FIGURE 24. BEARING AND SEALS

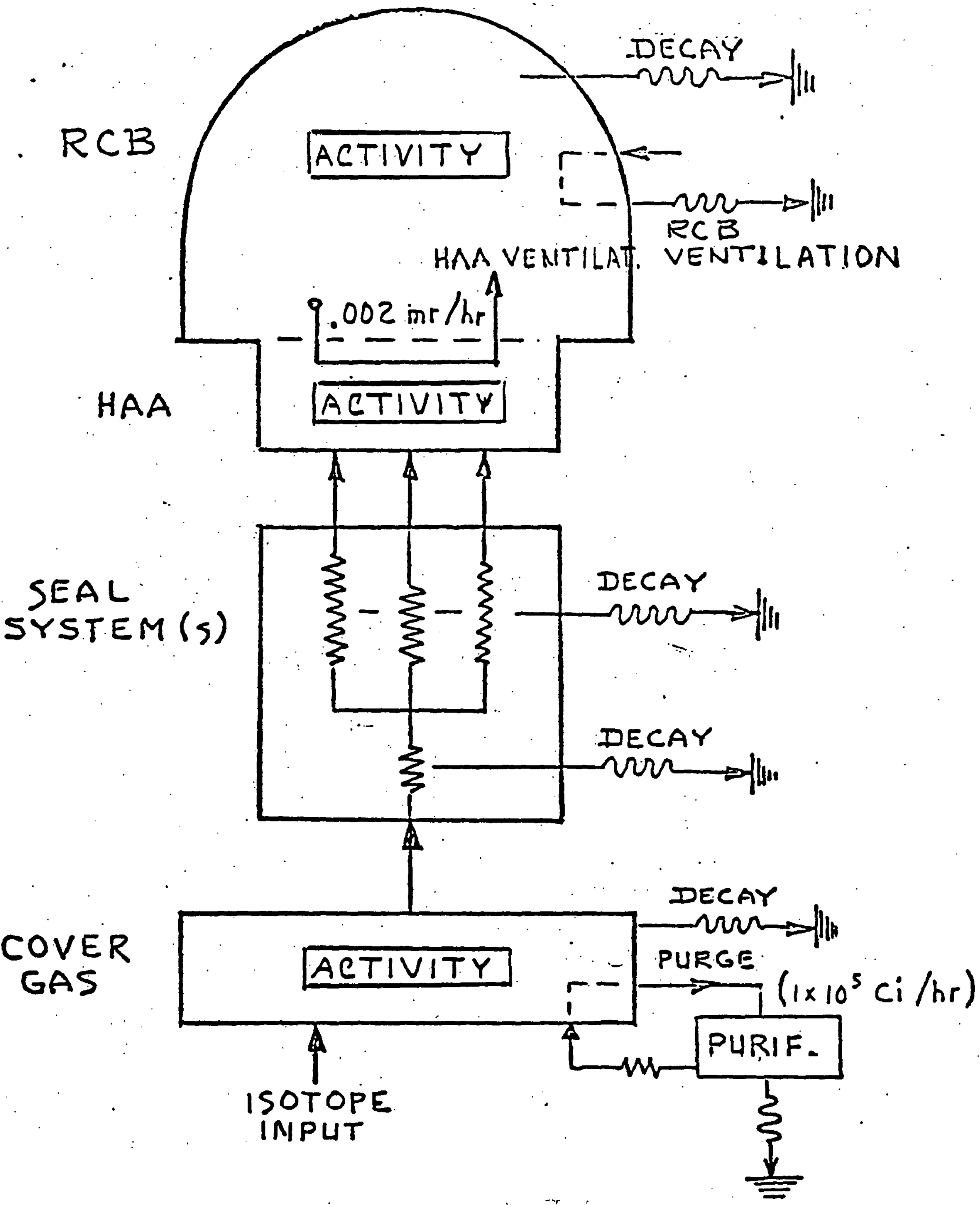


FIGURE 25. RADIOACTIVE GAS NETWORK

2) The cover gas specific activity is a function of the amount of radioactive isotopes added to the cover gas, the cover gas volume, the purge rate, and the half-lives of the radioactive isotopes.

3) The cover gas leaking through the plugs seals first leaks through the sodium filled dip seal into the upper annulus. The leakage through the liquid seal is by diffusion through the liquid and through the liquid-to-metal interface at the trough walls. The gas activity in the annulus above the liquid seal is relatively low due to the small amount of radioactive gas leaking through the seal and decay of the short-lived gaseous isotopes while in transit through the seal.

4) The R/A gas entering the HAA, from the plugs' upper annulus, leaks through the annulus top seal assembly. The activity of the gas passing through the seal system is a function of the diffusion leakage, amount of bypass leakage, and the decay of the half-lives of the gaseous radioactive isotopes.

5) The activity in the air atmosphere in the HAA and RCB is a function of the activity and rate of the R/A gas leaking through the seal system, the volume of the HAA and RCB, the rate of air circulation (ventilation) between the HAA and RCB, the rate of air circulation (ventilation) of the RCB with outside air, and the half-lives of the gaseous radioactive isotopes.

6) The amount of leakage acceptable through the seal system is limited primarily by the dose rates occurring in the HAA and RCB and the site boundary air. A secondary consideration is the dose rate in the elastomer seals in the plug annulus sealing system.

6.3.2 Basis for Calculations

Table 3, "Gaseous Radioisotopes in the Reactor Cover Gas," lists the significant isotopes, their half-lives, and their production rate in curies per day which occurs during reactor operation. The production rate for Xe and Kr is based on the continuous leakage rate of these fission products from the 1% of fuel assemblies which are assumed to have cladding failures.

The production rate of H^3 is due to the tertiary fission within the fuel and the amount which escapes from the fuel assemblies by diffusion through the cladding.

Argon 41 is formed by activation of the potassium impurity in the coolant and Ne 23 by activation of the sodium coolant. The production rates of Ar 41 and Ne 23 are therefore independent of the cladding failure rate.

Table 4, "Plug Seal Leakage and RCB Dose Rates," lists the R/A isotopes, equilibrium concentration in the cover gas, leak rates through the seal system, the seal holdup (decay) time, and the leakage contribution to the RCB containment atmosphere. The information presented assumed: 5 scfm cover gas purge rate, 1% fuel pin cladding failures, 40,000 scfm air flow between the HAA and the RCB, 14,000 scfm RCB air exchange rate with outside air, 3×10^6 ft^3. RCB volume, and the sealing system having the sodium dip bottom seal and the inflatable elastomer top seals. The total contribution to the RCB airborne activity from the R/A gas leaking through the TRP seal system is 2.8×10^{-4} mr/hr which is less than the established dose rate allocation of 2.0×10^{-3} mr/hr by a factor of about 8.

6.3.2.1 Seal Design Basis

The logic for establishing the TRP real dose rate allocation of .002 mr/hr in the RCB/HAA is given in Table 5. The allowable RCB/HAA dose rate from all sources is 2.0 mr/hr. This number was reduced by a factor of 10 to a conservative 0.2 mr/hr to provide for a design margin.

TABLE 3

GASEOUS RADIOISOTOPES IN THE REACTOR COVER GAS

Isotope	Half-Life (Hours)	Production (Curies/Day)
Xe 131 M	287	4.68×10^{2}
Xe 133 M	54.4	1.54×10^{4}
Xe 135 M	0.262	3.94×10^{5}
Xe 138	0.237	6.97×10^{5}
Kr 83 M	1.85	6.73×10^{4}
Kr 85 M	4.40	1.23×10^{5}
Kr 85	9.4×10^{4}	8.20×10^{0}
Ar 41	1.83	1.28×10^{3}
Ne 23	1.06×10^{-2}	5.83×10^{9}
H 3	1.1×10^{5}	1.39×10^{-5}

TABLE 4
PLUG SEAL LEAKAGE AND RCB DOSE RATE

Isotope	Equil. Conc. in Cover Gas uCi/scc	Seal System Leak Rate uCi/scc	Seal Hold-Up Time Hours	Rotating Plugs Seal System Leakage Contribution to RCB Atmosp.	
				µCi/scc	mr/hr
Xe 131 m	2.13	2.4×10^{-4}	9.0	5.9×10^{-13}	7.4×10^{-8}
Xe 133 m	5.36×10^{1}	6.1×10^{-3}	9.0	1.3×10^{-11}	3.3×10^{-6}
Xe 133	1.12×10^{3}	1.3×10^{-1}	9.0	3.1×10^{-10}	7.7×10^{-5}
Xe 135 m	2.25×10^{1}	2.6×10^{-3}	9.0	2.7×10^{-23}	--
Xe 135	1.98×10^{3}	2.2×10^{-1}	9.0	2.2×10^{-10}	1.4×10^{-4}
Xe 138	3.6×10^{1}	4.1×10^{-3}	9.0	3.3×10^{-24}	--
Kr 83 m	9.54×10^{1}	7.9×10^{-3}	5.0	1.3×10^{-12}	--
Kr 85 m	9.98×10^{1}	3.1×10^{-2}	5.0	2.3×10^{-11}	$9/5 \times 10^{-6}$
Kr 85	4.02×10^{-2}	1.3×10^{-5}	5.0	3.3×10^{-14}	8.2×10^{-9}
Kr 87	5.68×10^{1}	1.8×10^{-2}	5.0	1.0×10^{-12}	2.5×10^{-6}
Kr 88	1.15×10^{2}	4.5×10^{-2}	5.0	1.7×10^{-11}	4.4×10^{-5}
Ar 41	4.79×10^{-1}	2.2×10^{-4}	1.6	1.3×10^{-13}	1.6×10^{-7}
He 23	1.36×10^{4}	8	1.4	1.0×10^{-50}	--
H 3	6.83×10^{-8}	2.4×10^{-9}	0.4	6.0×10^{-18}	3.0×10^{-12}
			TOTALS	5.9×10^{-10}	2.8×10^{-4}

TABLE 5

SEAL DESIGN BASIS

● Reactor Power (MWt)	4,000
● RCB Ventilation Rate (cfm)	14,000
● RCB Volume (cu. ft)	3×10^6
● Head Access Area Dose Rate (mr/hr)	
. All Sources, Direct Radiation and R/A Gas	2.0(1)
. All Sources (Design)	0.2
. R/A Gases	0.02
. From Plug Seals	0.002(2)
● Head Access Area Ventilation Rate (cfm)	40,000
● Percent Failed Fuel Pins	1%

---

(1) Phase A Report, Appendix H, Radiation Protection Philosophy and Criteria
(2) CRBRP Design Value - 0.0002 mr/hr

The HAA gaseous activity dose rate during operating conditions was reduced to a conservative .02 mr/hr. The reduction allows for direct radiation through the shielding.

This number was also reduced by a factor of 10 to .002 m/hr which accounts only for the radioactive gas leaking through the plugs annulus sealing system. The reductions allows for contributions to the HAA dose from other sources such as the control rods, seals, the instrument tree seals, and other reactor cover penetration seals.

The reduction factors of ten are arbitrary and conservative, therefore, the allowable dose rate contribution of 2×10^{-3} mr/hr is conservative.

Note that for these dose rates, the number of failed fuel pins is assumed to be 1%. This number is believed to be high. If assumed to be lower, the contributions to the HAA dose rate would be lower.

6.3.2.2 Individual Seal Leak Rates

Data for leakage of helium and xenon gas through several types of seal configurations are shown in Table 6.

The data for helium leakage provide a basis for calculating bypass leakage and the data for xenon leakage provide a basis for calculating permeation leakages.

6.3.3 Seal Performance

6.3.3.1 Seal System Leakage

Calculated seal performances, in terms of contributions to RCB airborne dose rate in mr/hr, are given in Table 7 for the combinations of seals whose individual leak rates are given in Table 6. Seal Concepts A-1, A-2, and B-1 are the only types of seal combinations that have

TABLE 6

INDIVIDUAL SEAL LEAK RATES

SEAL TYPE	LEAK RATE BASIS	HELIUM LEAK RATE (STD. CC/SEC-CM-ATMOS.)	XENON LEAK RATE (STD. CC/SEC-CM-ATMOS.)
PLUG SEALS			
● Sodium Dip Seal			
. Wetted	AI Tests of CRBR Seal	$1 \times 10^{-8} - 1 \times 10^{-7}$	$3.2 \times 10^{-11} - 3.2 \times 10^{-10}$
. Unwetted	AI Tests of CRBR Seal	$1 \times 10^{-7} - 4.5 \times 10^{-6}$	$1.0 \times 10^{-7} - 4.5 \times 10^{-6}$
Mechanical Seal			
Compressible	Metallic O-Ring Leakage at 5% Deflection (Westinghouse)	1×10^{-4}	1.0×10^{-4}
Ledge	Navier-Stokes Equation	$30 - \infty$	$30 - \infty$
Alloy Seal			
. Wetted	None	$^{*}1 \times 10^{-8} - a.0 \times 10^{-7}$	$^{*}3.2 \times 10^{-11} - 3.2 \times 10^{-10}$
. Unwetted	None	$^{*}1 \times 10^{-7} - 4.5 \times 10^{-6}$	$^{*}1.0 \times 10^{-7} - 4.5 \times 10^{-6}$
Sodium Plug (Cooling Coils)	None	$30 - \infty$	$30 - \infty$
Inflatable (Pair)	AI Test Data of CRBR Seal	$6 \times 10^{-6} - 1.8 \times 10^{-5}$	$1.8 \times 10^{-6} - 5.3 \times 10^{-6}$
STATIC SEALS (BUFFERED)			
Metallic O-Rings (Pair)	Westinghouse Data	2.0×10^{-8}	2.0×10^{-8}
Elastomer O-Rings (Pair)	AI Test Data	$2.0 \times 10^{-6} - 6 \times 10^{-6}$	$5.9 \times 10^{-7} - 1.8 \times 10^{-6}$

---

*AI Tests of Westted and Unwetted Na Dip Seal

TABLE 7

SEAL PERFORMANCE

Concept Number	Top Seal	Bottom Seal	Gas Purge	Contribution to RCB Airborne Dose Rate (mr/hr)
A-1	Inflatable	Na Dip	No	2.8×10^{-4}
-2		Alloy	Yes (Na Control)	2.8×10^{-4}
		Mechanical		
-3		Compressible	No	1.59
-4		Ledge	Yes	0.33
-5		Na Plug	No	1.59
-6		None (Annulus)	Yes	0.33
B-1	Alloy	Na Dip	No	5.04×10^{-6}
		Mechanical		
-2		Compressible	No	5.29
-3		Ledge	Yes	1.32
-4		Na Plug	No	5.29
-5		None (Annulus)	Yes	1.32
			Allowable	2.0×10^{-3}

sufficient impedence to the leakage of R/A gas through the seals to provide a contribution to the RCB airborne activity less than the allowable dose rate of 2.0×10^{-3} mr/hr. Each of these three seals have a liquid dip bottom seal as the primary impedance to the leakage of the R/A gas through the annulus followed in series by either an inflatable elastomer or liquid dip top seal.

Seal Concepts A-3 and B-2 do not use inert gas purge across the compressible mechanical seal as the pressure required to flow gas across the very narrow seal face gap to obtain 1 cm/sec of gas flow would be very high and the inflatable seal or alloy seal at the top of the annulus could not stand the high pressure. The inflatable seal would have a tendency to compress and crawl and the alloy seal liquid would be blown out of the seal, unless made unreasonably deep.

Seal Concepts A-4 and B-3 use a gas purge across the ledge seal. The gas velocity in the annuli is 1 cm/sec to reduce the diffusion of the R/A gas across the seal. As the seal face width is narrow, 1-2 in., this width causes little impedance to the diffusion of R/A gases across the seal face against the purge gas flow.

Seal Concepts A-5 and B-4 do not use gas purge across the Na plug seal for the same reasons given for not using gas purge in Concepts A-3 and B-2 - the purge gas pressure required would be high.

Seal Concepts A-6 and B-5 use a gas purge in the open annulus below the top seal. The velocity is high, about 1 cm/sec, to reduce the diffusion rate of the R/A gas up the annulus.

The concentration of R/A gases is high under the top inflatable or alloy seal for seal Concepts A-3 through A-6 and B-2 through B-5 due to the high leakage rates through the bottom seals, these seals, the non-dip type, are not acceptable based on the allowable R/A gas contribution RCB airborne activity.

The activity of the R/A gas passing through the three referenced seal concepts is reduced by a) low leakage rate through the liquid dip seal, and b) decay of the shorter lived isotopes during the diffusion transit time through the liquid dip seal. The low leak rate and additional transit time through the upper seals also causes further reduction in the R/A gas activity.

6.3.3.2 Elastomer Seal Dose

The inflatable top seal dose rates in R/year are given in Table 8 for types of bottom seals used with the inflatable top seal. The same dose rate would be applicable to the static elastomer top seals. There is no gamma radiation damage to EPDM and butyl material seals with dose rates of 10^5 R and only incipient-to-mild damage with dose rates of 10^7 R. Therefore, the anticipated elastomer seal life is greater than the 40-year plant life for all the seal systems.

6.3.4 Seal Concepts Evaluation

6.3.4.1 Annulus Gas Sweep

The effect of gas sweep downward (purge) in the annulus to reduce the R/A gas diffusion up into the annuli of the TPP is given in Table 9 in cfm of gas flow versus annulus width in inches.

The gas velocities would be unreasonably high to control diffusion where 50 cfm provides a dose rate reduction from 1.59 to 0.33 mr/hr and the goal is 2×10^{-3} mr/hr.

The effect of the gas sweep of 50 cfm in the 1-1/2-in. wide annulus reduces the annuli R/A gas contributions to the RCB airborne dose rate by a factor of about 6. This can be seen by the difference in the dose rates of Concept A-5, Table 7, having an RCB airborne dose rate of 1.59 mr/hr, without gas purge, and Concept A-6 having a dose rate of .33 mr/hr with gas purge, see Table 7.

TABLE 8

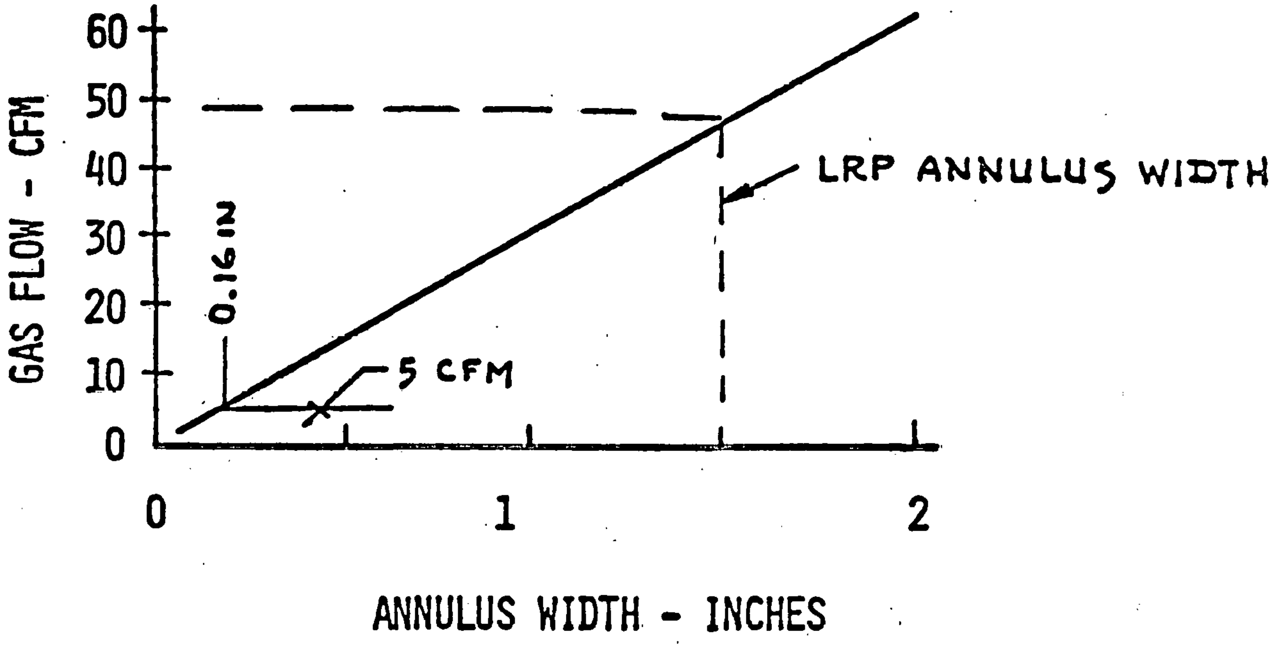
DOSE RATE AT INFLATABLE SEAL

Concept Number	Top Seal	Bottom Seal	Gas Purge	Dose Rate at Inflatable Seal (R/yr)	Seal Life
A-1	Inflatable	Na Dip	No	2 x 10^2	≫40
-2		Alloy	Yes (Na Control)	~2 x 10^2	≫40
		Mechanical			
-3		Compressible	No	1 x 109	--
-4		Ledge	Yes	2 x 105	50
-5		Na Plug	No	1 x 10^9	--
-6		None (Annulus)	Yes	2 x 10^5	50

TABLE 9
PLUG ANNULI GAS SWEEP

Flow Rate Required to Reduce Diffusion Effects

- For 190 Lin. ft of Annuli
- Gas Velocity = 1 cm/sec
- No Margin (Distribution, Eccentricities, etc.)



The helium and xenon seal leak rates are the same for both sodium and alloy dip seals with no gas purge, see Table 6.

The 1 cm/sec gas velocity was an arbitrary number chosen for the calculations to determine the relative effects of gas purge. Higher gas velocities will further reduce the HAA dose rate.

The seal concept having an open annulus gas purge is unacceptable because of the high gas purge rate required. This high purge rate requires an increase in the RAPS capacity from 5 scfm to $\gg$50 scfm which increases the RAPS cost several factors more than the estimated $10 million.

The purge gas is recirculated which requires large pipes routed to the plugs, pipe shielding, safety provisions for pipe failure, and increased in-containment space.

Summarizing, the only viable seal option using gas flow is the restricted annulus seal concept such as Concepts A-4 and B-3 having the ledge bottom seal. These particular concepts are not acceptable as the plugs have to be lifted off the ledge prior to rotation.

6.3.4.2 Initial Screening of Concepts

The results of the initial screening of the seal concepts are presented in Table 10. Listed are Seal Concepts A-1, A-2, and B-1, the seals having a liquid metal dip bottom seal. These seals meet the requirements for seal contribution to the RCB airborne dose rate of 2 x 10^{-3} mr/hr and also limit the dose rate to the elastomer top seals to allow use of the seal for the plant life.

The results of the evaluation of the alloy dip versus the sodium dip seal for the lower seal are given in Table 11. The preferred lower seal is the sodium dip seal.

TABLE 10

INITIAL SCREENING BASED ON R/A GAS LEAKAGE AND DOSE AT ELASTOMER SEAL

Concept Number	Top Seal	Bottom Seal	Gas Purge	Seal Life
A-1	Inflatable	Na Dip	No	$\gg 40$ yr
A-2		Alloy (Liquid)	Yes (Na Control)	$\gg 40$ yr
B-1	Alloy (Solid-Liquid)	Na Dip	No	N.A.

TABLE 11

LOWER SEAL EVALUATION
ALLOY (RESTRICTED ANNULUS PURGE) VS SODIUM DIP

Consideration	Preferred Alloy	 Sodium	Basis
Safety and Licensing	-	-	Both Can Meet Requirements
Maintainability		X	. Sodium Advantages - No Plug Jacking System - No Heating/Cooling System - Frost Easier to Remove . Alloy Advantages - Trough More Accessible (High) - Easier to Replace Top Seal (No Air Seal Required)
Inspectability	X		. Trough More Accessible (Higher)
Operability/Availability		X	. No Heating/Cooling Requirements . No Gas Purge Required . No Plug Jacking System

TABLE 11

LOWER SEAL EVALUATION
ALLOY (RESTRICTED ANNULUS PURGE) VS SODIUM DIP

(Continued)

	Preferred		
Consideration	Alloy	Sodium	Basis
Constructability Cost/Schedule		X	. No Isolated Trough, Insulation, Jeaters. Fins, Cooling, T/C's Sensing and Control Equipment . No Requirement for Frost Control Features
Seismic Capability		X	. Less Overhang on Plug Support Minimizes Moments . No Plug Jacks
Impact on NSSS Design		X	. Reduced Width of Seal/Bearing Support Assembly Reduces Diameter of LRP . No Services Required During Plug Rotation (Heater Power, T/C Loads)
Risk		X	. Not Dependent on Annulus Purge Performance for Frost Control . Permeation Rates Well Defined

Conclusion - Sodium Dip Lower Seal Preferred

The results of the evaluation of the alloy dip versus the inflatable elastomer for the upper dynamic seal are given in Table 12. The evaluation shows the inflatable elastomer is the preferred seal.

6.3.5 Seal Selection

6.3.5.1 Selected Seal Concept

An elevation view of the selected seal concept for the rotating plugs is shown in Figures 4 and 5. Figure 4 shows the three rotating plugs in their closed operating position, sodium filled dip seals at the bottom, and the seal arrangement at the top of each of the annuli. Figure 5, the annulus top seal arrangement, shows the locations of the inflatable (dynamic) elastomer seal, the static elastomer and metallic seals, the bearing, the access ports, the support structure, and attachment of the assembly to the head plates of the plugs.

6.3.5.2 Selected Seal Characteristics

The selected seal concept having the inflatable elastomer top seal and sodium dip lower seal has the following characteristics:

- Very low contribution to the RCB airborne activity.(1)
- Effective control of sodium frost deposits in the annulus.
- Maintenance capability for all postulated conditions and events.
- A concept characterized by analysis, experiment, and tests over the past 8 years.

(1) The allowable contribution to the RCB airborne activity is 2×10^{-3} mr/hr. The selected concept with wetted walls of the sodium dip seal contributed only 2.8×10^{-4} mr/hr and the selected concept with unwetted walls of the sodium dip seal contributed 1.32×10^{-2} mr/hr to the RCB airborne activity.

TABLE 12

UPPER SEAL EVALUATION
ALLOY DIP VS INFLATABLE ELASTOMER

Consideration	Preferred		Basis
	Alloy	Elastomer	
Safety and Licensing	-	-	Both Meet Requirements
Maintainability		X	. No Normal Maintenance Required
			. Easily Replaced
			. No Heaters or Cooling
			. No Potential Alloy Spill
			. Long Life Expectancy >10 yr
Inspectability		X	. Minimum (If Any) Inspection Required
			. Continuously Monitored by Buffer and Inflation Pressures
Operability/Availability		X	. No Active Aux. (Temp. Control)
			- Static Gas Supply Required
			. Dual Seals Provide Redundancy
			. Rapid Recovery from Sticking
			. Higher ΔP Capability

TABLE 12

UPPER SEAL EVALUATION
ALLOY DIP VS INFLATABLE ELASTOMER

(Continued)

	Preferred		
Consideration	Alloy	Elastomer	Basis
Constructability Cost/ Schedule		X	. Less Complexity - Machined Rings vs Constructed Trough, Insulation, Heaters, Fins, T/C's, Sensing and Control Equipment
Seismic Capability		X	. Less Overhang on Plug Support Flanges Minimizes Moments
Impact on NSSS Design		X	. Reduced Width of Seal/Bearing Support Assembly Reduces Diameter of LRP . No Services Required During Plug Rotation: (Heater Power, T/C Leads) - Carry Bottled Gas
Engineering/Development Risk		X	. Concept Verified by Test in U.S. (EBR-II) (Perf. Not Acceptable) . Concept Can Incorporate Advanced Materials for Increased Life, Reduced Drag

Conclusion - Elastomer Upper Seal Preferred

These rates are calculated with fuel pin failures of 1%. Assuming a fuel pin failure a factor of 10 less of 0.1%, the dip seal with unwetted walls would be acceptable.

7.0 DECK

7.1 Requirements

1) Provide a support for the TRP assembly which supports and positions fuel handling equipment to perform in-vessel fuel transfer during reactor shutdown.
2) Provide a part of the system pressure retaining boundary for the reactor cover gas and sodium vapor.
3) Provide radiation shielding between the reactor coolant and the Head Access Area (HAA).
4) Provide a thermal barrier between the reactor sodium coolant and the HAA and any temperature-limited components of or on the vessel deck.
5) Provide support for the decay heat removal heat exchangers (DDHRX).
6) Provide access for entry and exit of fuel during reactor shutdown.
7) Provide inspection and maintenance access to the sodium dip seal trough.
8) Provide hold-down and sealing to the vessel during a seismic event.
9) Provide design flexibility to demonstrate, if required, capability to withstand a core disruptive accident (CDA).
10) The outer plug (large rotating plug) shall be sealed to and supported by the stationary deck. The deck shall be sealed to and supported by the reactor vessel.

11) Sodium-filled dip seal shall be incorporated in the annulus between the deck and large plug to control the transport of sodium vapor and aerosols into the annulus and to minimize exposure of the primary (elastomer) seal to fission gas and sodium vapor.

12) The reactor deck structure and radiation shielding materials shall be carbon or low alloy steels.

13) The reactor deck thermal insulation located in the cover gas shall be layers of plates.

14) The reactor deck shall have provisions for being cooled either by active or passive means. The design goal shall be by passive cooling, i.e., dissipating the heat from the deck surface to the Reactor Containment Building (RCB) air by natural convection and radiation.

15) Hold-down devices shall be provided to limit the upward displacement of the reactor deck and LRP caused by a seismic event.

16) The main structural containment welds and attachments to the reactor deck shall be accessible for inspection.

17) The surface temperature of the reactor deck which is normally accessible to the operating and maintenance personnel shall not exceed 150°F.

18) The bulk radiation shielding of the reactor deck assembly shall shield the deck access area from reactor radiation so that the area meets the requirements of Zone II occupancy which is 2.0 mr/hr for access during reactor operation.

19) The reactor deck assembly shall contain a ledge upon which the large rotating plug can rest during bearing maintenance.

20) The reactor deck shall be designed for the mechanical loads stated below:

Deadweight (million lb)

Deck	2.6
Plugs	2.2
DHRS Heat Exchangers	.4
Fuel Transfer Port	.2
Total	5.4

Seismic Loading	Horizontal	Vertical
OBE (g)	1.8 E-W, 1.6 N-S	1.3
SSE (g)	2.7 E-W, 2.33 N-S	2.2
Deflection (in.)	-	±0.5 (tentative)

21) The reactor deck shall be constructed to the code requirements as shown on Figure 26.

7.2 Description of Concepts

Six deck configurations were investigated. They were (see Figure 27):

a) Box Ring
b) Hub-Spoke-Rim
c) Flat Plate
d) Z-Cone
e) Box Ring - Z-Cone
f) Tangential Beam

Four configurations, hub-spoke-rim, flat plate, and box ring - Z-cone, and box ring, were eliminated from further consideration since they did not meet the structural rigidity or fabricability requirements.

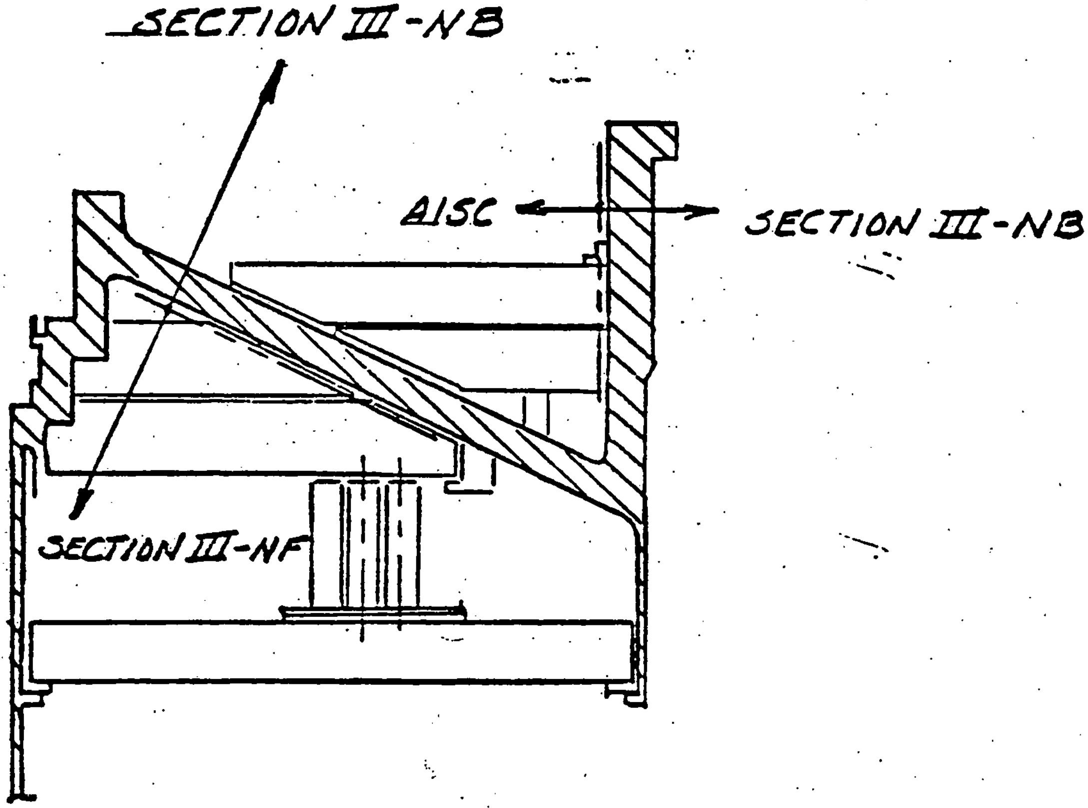
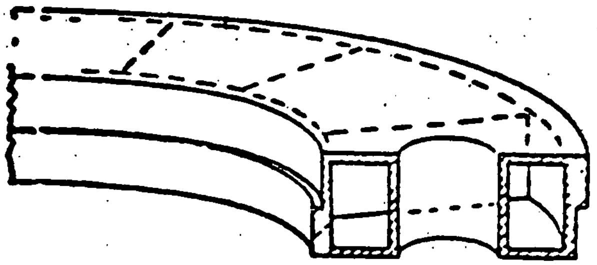
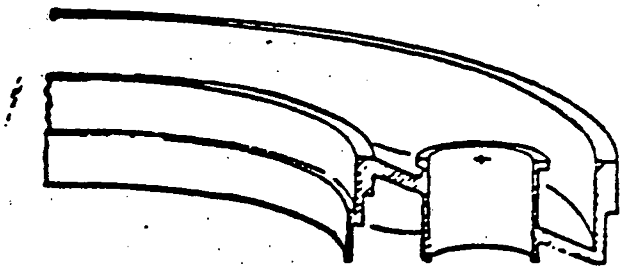


FIGURE 4-25 REACTOR DECK
CODE REQUIREMENTS

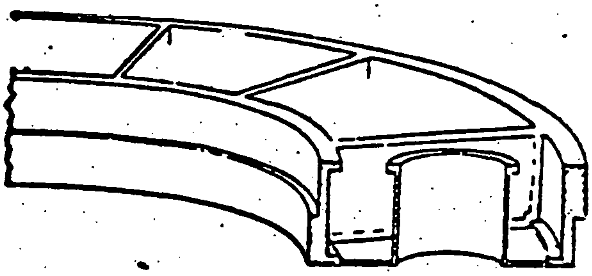
FIGURE 26. REACTOR DECK CODE REQUIREMENTS



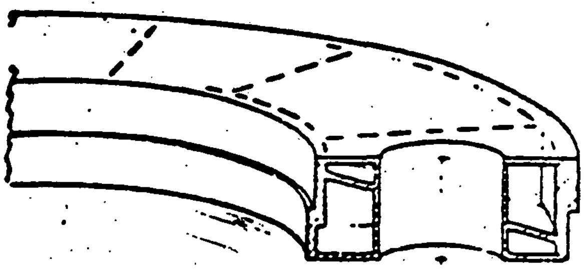
BOX RING



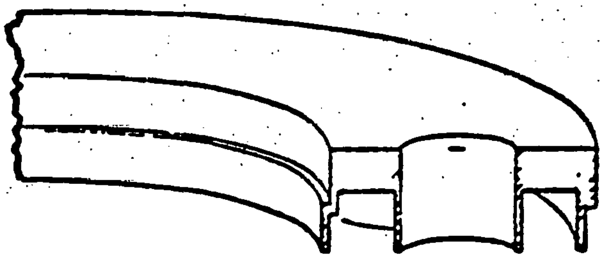
Z CONE



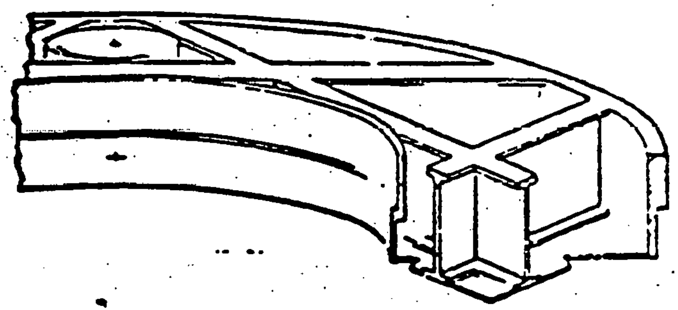
HUB – SPOKE – RIM



BOX RING + Z CONE



FLAT PLATE



TANGENTIAL BEAM

FIGURE 27. DECK CONFIGURATIONS

7.2.1 Description of Z-Cone Deck

The Z-cone deck, Figure 2, consists of a cone plate welded to two concentric cylinders. The inner cylinder has a flange at the top which is a support for the large rotating plug (LRP). It has a sodium dip seal trough at the bottom which is part of a seal system used to isolate the reactor cover gas from the HAA. The outer cylinder has a flange at the top to support the deck on the reactor vessel flange. A metallic membrane seal is welded to the deck flange and the vessel flange to provide containment of the reactor cover gas.

The inner and outer cylinders are each constructed of forgings and cylindrical shells which are welded together. The cone plate is a welded assembly of plate segments. It is positioned 25 degrees from the horizontal plane with the lower end of the cone plate welded to the outer cylinder and the upper end welded to the inner cylinder.

The neutron shielding is located above and below the cone plate. Shielding above the cone plate consists of removable steel plate segments bolted to the cone plate and the outer cylinder. Shielding below the cone plate is 15 segmented steel plate sections supported on ledges attached to the inner and outer cylinder and positioned by vertical keys. The shielding plates are also supported by tie rods attached to the cone plate. The tie rods are redundant supports to the ledge supports. The tie rods extend through the cone plate and can be removed for inspection. Total thickness of shielding is a minimum of 48 in. of carbon steel consisting of several plates of 8 to 12 in. of thickness and including the reflective insulation.

Fifteen radial sections of the reflective insulation, each consisting of 70 sheets of .10-in. thick stainless steel is chosen for its resistance to sodium buildup and better thermal emissivity consistency. The insulation is attached with tie rods and guided and centered to each radial section of shielding with a centering guide and radial keys.

A core disruption accident (CDA) energy absorbing system is incorporated into the deck.

The deck has four major penetrations. The largest is located in the center of the deck and is 33 ft and 8 in. in diameter to accommodate the LRP. Two 51-in. diameter penetrations are for mounting two DDHRX units on extension nozzles welded to the cone plate. The DDHRX is mounted to the nozzle and supported through a pair of self-aligning bushings (see Figure 2). The self-aligning feature is incorporated to allow for the necessary radial movement due to the large ($\simeq 910^0$F) temperature difference between the deck and the sodium temperature at the redan. (This large temperature differential generates a radial motion of 2.4 inches and thus could not be accommodated with a hard DDHRX support.) The self-aligning bushing joint is enclosed with a buffered double metal bellows to provide a seal for the cover gas.

The fourth penetration is the fuel transfer port. It is a rectangle of 2 ft by 4 ft located in the cone plate with the bottom end slanted towards the center of the reactor.

Smaller penetrations (about 3-in. diameter) through the deck are for rewetting of the dip seal trough. Access to the dip seal is through a pipe welded to the cone plate. A short pipe welded to the dip seal trough mates into the pipe extending through the cone plate to guide the tool to the trough. The telescoping pipe arrangement provides for thermal expansion and mechanical tolerances.

CDA-related design features are construed as concerns and not specific design requirements and are included in the Z-cone deck to demonstrate the design can accommodate the CDA requirements. Two features are provided in the deck design: a CDA energy absorber system and shear keys.

The energy absorber system consists of .060-in. thick stainless steel square cans 6 in. x 5 in. and 22 in. in height. They are located between the two shielding plates as shown in Figure 2. CDA-released energy would be absorbed by these cans in the form of strain energy. The cans are installed across the deck, except where the fuel transfer port and DDHRX penetrations occur.

The shear keys are shown in Figure 2. These keys limit the vertical motion of the LRP. There are sixty (60) keys equally spaced and located at the top of the annulus between the LRP and the inner cylinder of the deck.

Pin keys are used to attach the deck to the vessel flange as shown in Figure 2. One hundred and thirty (130) pins, 4-in. diameter on 14-in. spacing, are located around the deck outer cylinder top periphery between the deck flange and the vessel flange.

The LRP deadweight and seismic loads are transmitted to the deck through a ball bearing. The bearing is located slightly below the LRP top level, as shown in Figure 2. The radial gap between the inside diameter of the bearing and the LRP is shimmed. The gap between the outside diameter of the bearing and the deck is also shimmed. These shims ensure a tight fit and thus provide for a good horizontal seismic load path from the LRP to the deck structure.

The shielding is 48 in. of steel, which is required to maintain a 2 mr/hr dose rate above the deck during normal power operation. Of this amount, 12 in. is required to shield the radioactive cover gas caused by 1% fuel pin cladding failures.

A 24.5 in. shielding thickness is required 1 day after reactor shutdown for inservice inspection of the plates and welds of the deck. The deck has more than 25 in. of shielding located below the cone plate, therefore, access to the deck cone plate for inservice inspection is feasible.

7.2.2 Description of Tangential Beam Deck

The tangential beam deck is shown in Figure 6. The configuration has an inner and outer cylinder with six "I" beams welded to the two cylinders. The beams are arranged in a symmetrical pattern, and each is tangent to and welded to the inner cylinder. The load imposed on the inner cylinder by the LRP is transmitted to the outer cylinder by the beams. Additional short beams are located between the tangential beams and outer cylinder to add structural capability.

Welded plates installed between the inner and outer cylinder and the bottom flanges of the beams form the pressure boundary for the deck. Short beams installed between the tops of the main beams support the DDHRX.

Shielding plates are installed in two places--below the pressure boundary plate and on top of the deck. The plate thickness below the pressure boundary plate is sufficient to allow access to the interior of the deck structure for inspection when the reactor is shut down. Sections of the shielding plates on top of the deck are removed to permit entrance into the deck structure for inspection.

The tangential beam deck configuration is cooled by air forced down the stacks during normal reactor operation. Baffles in the bottom of the structure distribute the cooling air within the structure. In the event of cooling air fan failure, the cooling air is moved through the deck structure by natural convection of the air up the stack.

7.3 Analysis and Evaluation

The six deck configurations were subjected to two screening tests, see Tables 13 and 14. The first test considered deck rigidity, LRP bearing mounting surface flatness, and deck fabricability (see Table 13).

TABLE 13

DESIGN CRITERIA VS DECK CONCEPT

Deck Concept Design Criteria	Box Ring	Hub Spoke Rim	Flat Plate	Z-Cone	Box Ring & Z-Cone	Tangent Beam
Structural Rigidity, High Torsional Stiffness	Good	Poor	Poor	Good	Good	Good
LRP Bearing Mounting Surface Flatness	Good	Poor	Poor	Good	Good	Good
Fabricability and Cost	Good	Poor	Poor	Good	Poor	Good
Candidate for Second Screening Test	Good	Poor	Poor	Good	Poor	Good

TABLE 14
EVALUATION CRITERIA VS DECK CONCEPT RANKING

Item	Evaluation Criteria	Deck Concept	Box Ring	Z-Cone	Tangent Beam
1	Safety * Licensing		*	*	*
2	Structural Rigidity		3	1	2
3	Bearing Mounting Surface Flat.		2	1	3
4	Fabricability		3	1	2
5	Inspectability & Maintainability		3	1	2
6	Reliability		3	2	1
7	Weight		3	1	2
8	DHRHX Installation		2	3	1
9	Redundancy		2	3	1
10	Operability		3	1	2
11	Cooling		3	1	2
12	Risk		3	1	2
13	R&D Requirements		*	*	*
14	Cost		*	*	*
15	Cumulative Score		30	16	20
16	Rating: (1 is Best)		3	1	2

*Equal Ranking

This screening test eliminated the hub-spoke-rim and flat plate deck concepts due to high deck deflections. The box-ring - Z-cone concept was eliminated due to difficulty in fabrication.

The second screening test (see Table 14) ranked the three remaining deck configurations. The Z-cone deck has the best rating, followed by the tangential beam and the box ring. The Z-cone deck is the recommended configuration and the tangential beam is the recommended alternate configuration.

Following is a discussion of the thermal and structural performances of the two deck configurations.

7.3.1 Z-Cone Deck Thermal Characteristics

The thermal elevation profile of the Z-cone deck is shown in Figure 28. The temperature at the top of the deck is 129^{o}F with sodium pool temperature at 950^{o}F and natural convection at ambient temperature of 90^{o}F.

The dip seal sodium temperature ranges between 290^{o}F and 550^{o}F for the reactor pool temperature of 500^{o}F during maintenance and 950^{o}F during reactor normal operation (see Figure 8).

The sodium frost deposition in the upper annulus between the LRP and the Z-cone deck is shown in Figure 9. The amount of deposition is small and acceptable and represents 40 years of reactor operation. See Reference 2 for detailed analysis.

The Z-cone deck thermal deflections are shown in Figure 29 and the thermal stresses in Figure 30. Stress levels are low. Thermal deflections caused by thermal growth are acceptable and are accommodated by proper clearances and tolerances on mating parts. For complete thermal analysis, see Reference 7.

7.3.2 Tangential Beam Deck Thermal Characteristics

The thermal elevation profiles through the tangential beam deck for various reactor operating conditions are shown in Figures 31, 32, 33, and 34. The temperatures at the top of the deck are low, about 87°F. Forced cooling air is required to achieve this. The temperature at the dip seal ranges from 191°F to 422°F for the four (4) cases analyzed. Thus, the dip seal has to be positioned lower in order to increase the temperature to 250°F from 191°F. Correspondingly, the temperature will rise above 422°F during backup decay heat removal. Temperatures and temperature gradients throughout the rest of the deck appear to be acceptable.

7.3.3 Structural Characteristics

The structural characteristics comparison of the tangent beam deck and the Z-cone deck are presented in Tables 15, 16, and 17.

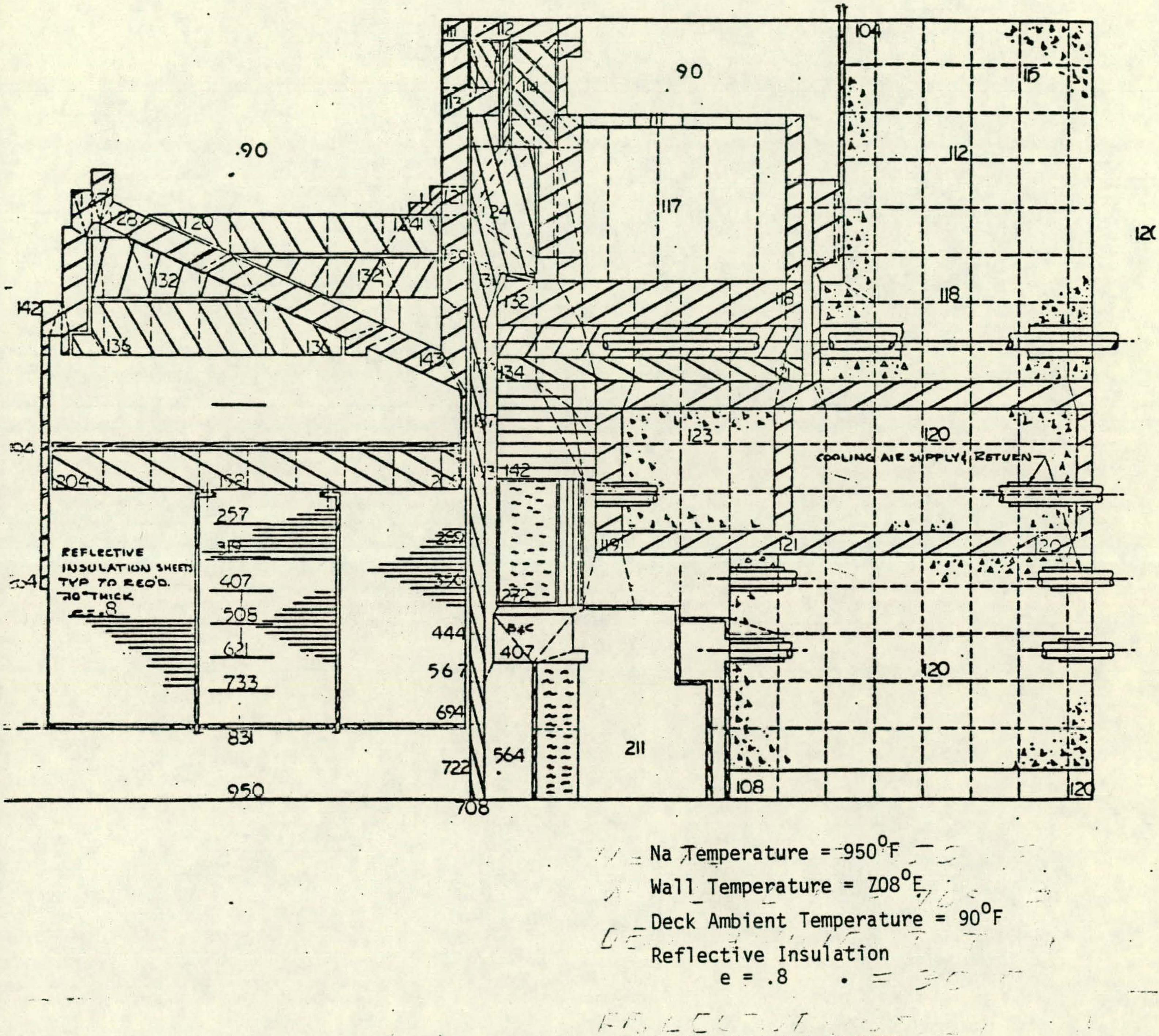
7.3.4 Overall Comparison - Deck Design

The overall comparison of the Z-cone and tangent beam deck are presented in Table 18.

7.3.5 Stress Analysis

Additional stress analyses were performed in the following areas for the Z-cone deck:

a) Large rotating plug bearing to deck mounting bolt
b) Sodium dip seal trough (thermal stresses)
c) Z-cone structure
d) DDHRX support structure
e) Deck to vessel flange shear pins



Na Temperature = 950°F

Wall Temperature = 708°F

Deck Ambient Temperature = 90°F

Reflective Insulation

e = .8

FIGURE 28. TEMPERATURE PROFILE FOR DECK AND SUPPORT

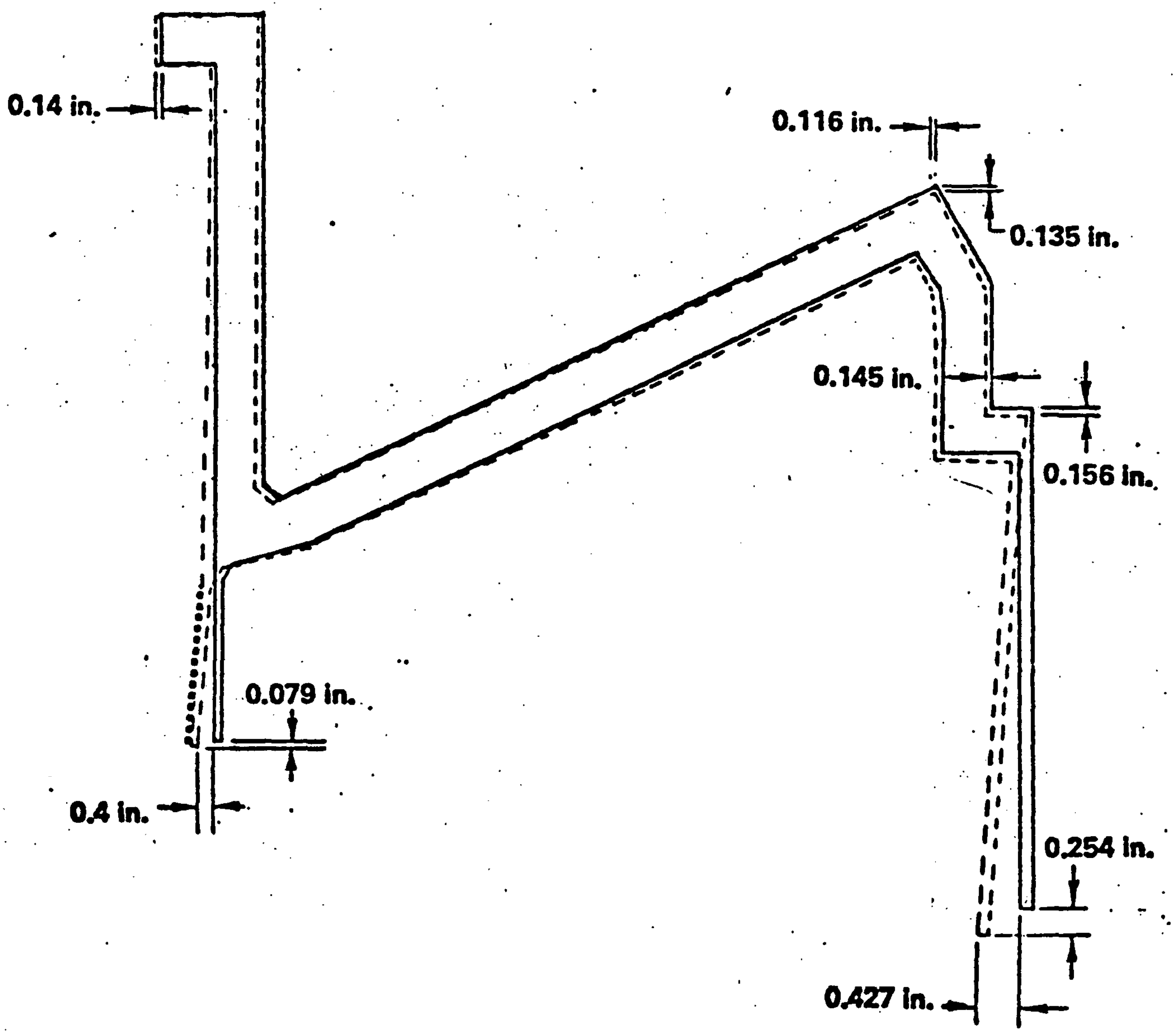


FIGURE 29. CONE DECK THERMAL DEFLECTION PROFILE
(NORMAL OPERATING CONDITION)

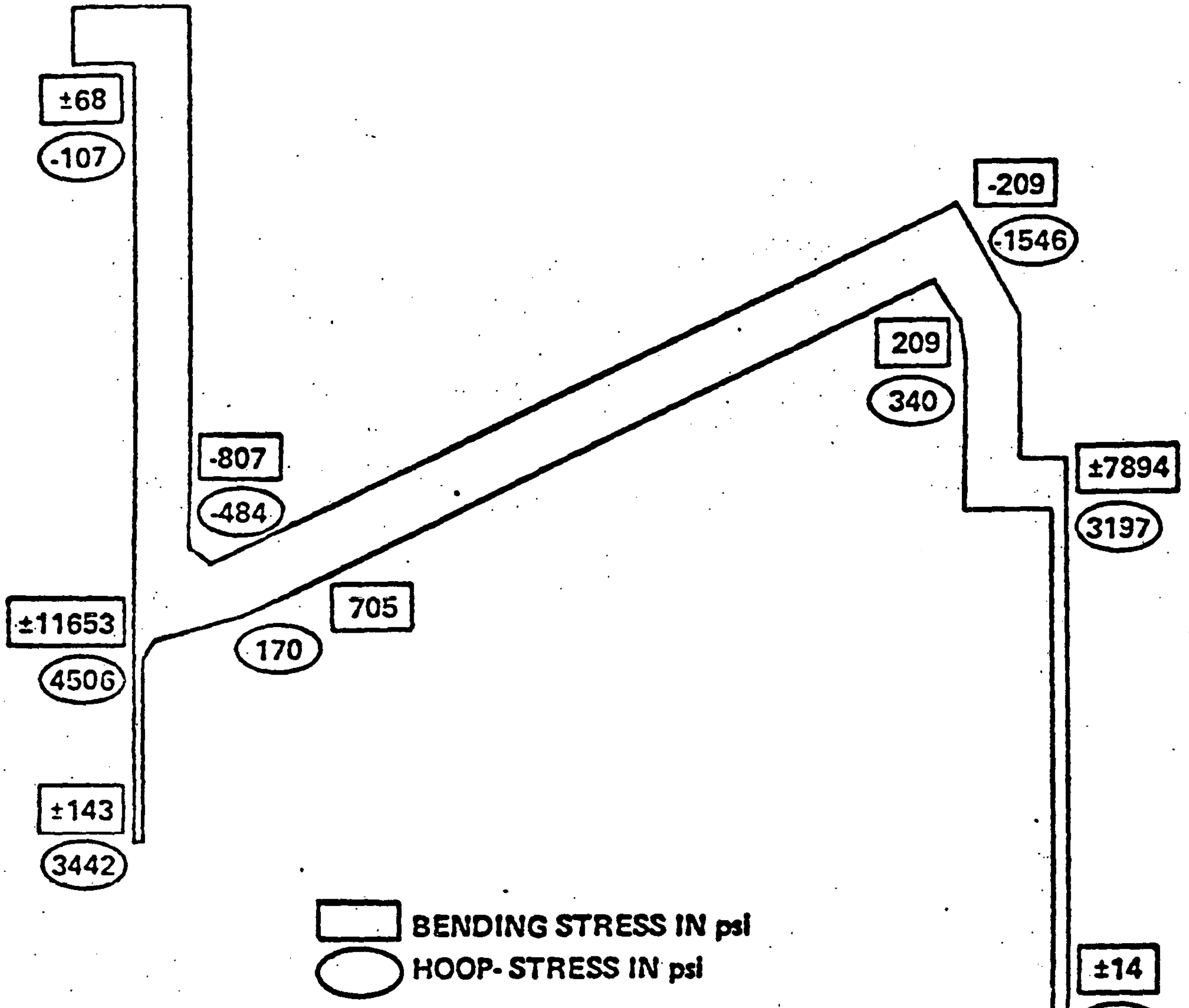


FIGURE 30. CONE DECK THERMAL STRESS PROFILE (NORMAL OPERATING CONDITION)

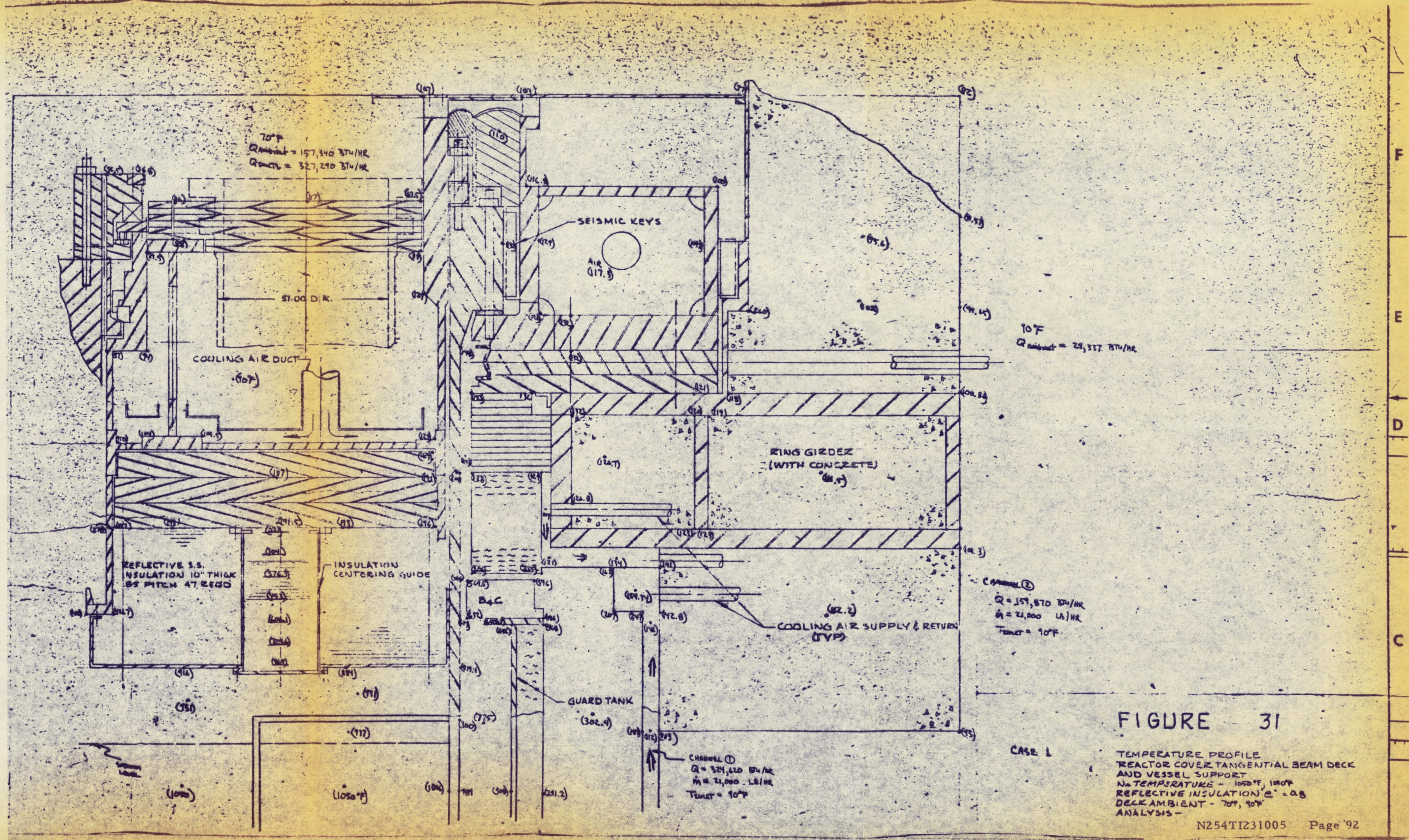


FIGURE 31

CASE 1

TEMPERATURE PROFILE
REACTOR COVER TANGENTIAL BEAM DECK
AND VESSEL SUPPORT
Na TEMPERATURE - 1050°F, 1050°F
REFLECTIVE INSULATION e' = 0.8
DECK AMBIENT - 70°F, 90°F
ANALYSIS -

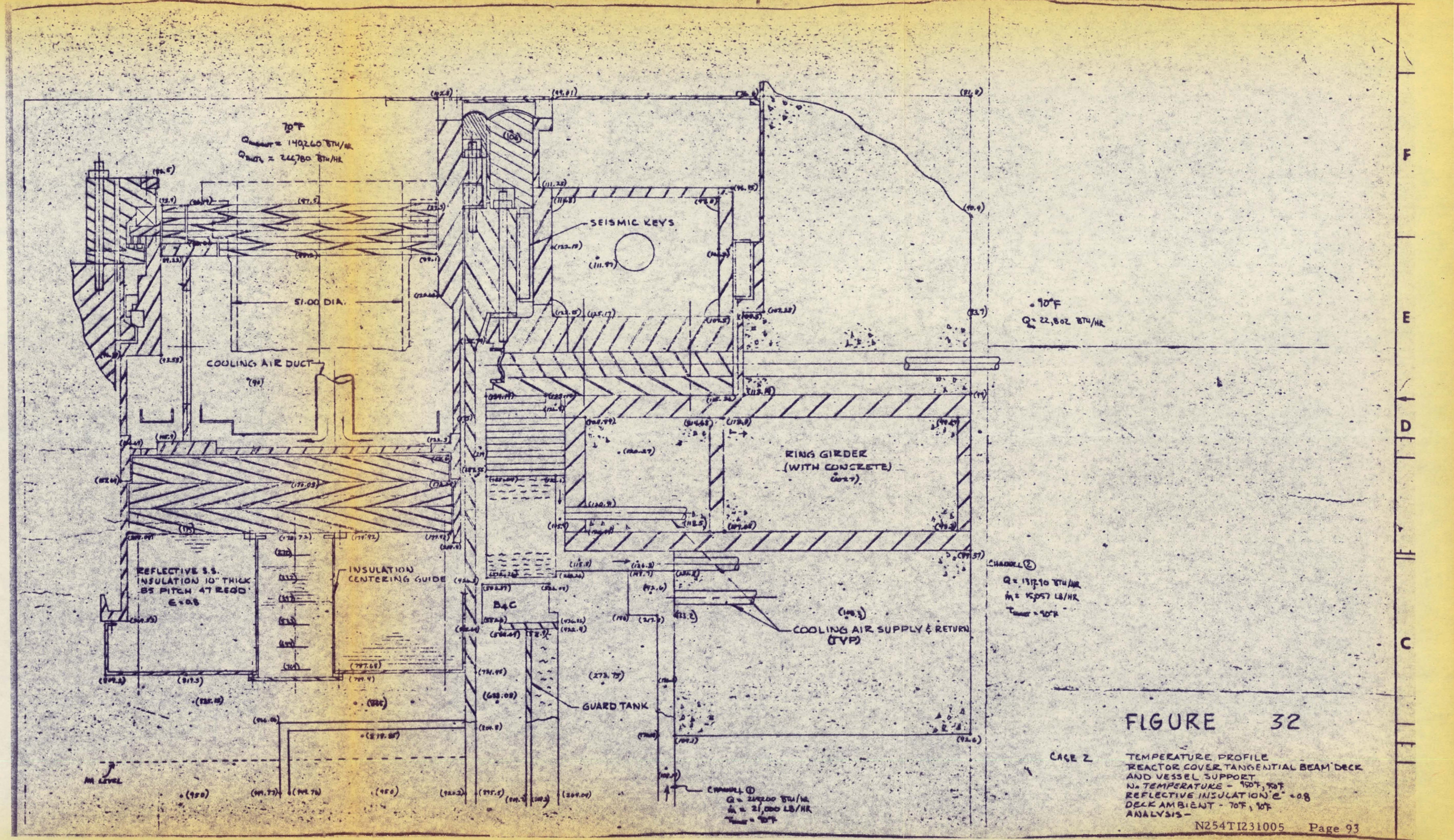


FIGURE 32

CASE 2

TEMPERATURE PROFILE
REACTOR COVER TANGENTIAL BEAM DECK
AND VESSEL SUPPORT
Na TEMPERATURE - 950°F, 900°F
REFLECTIVE INSULATION e = 0.8
DECK AMBIENT - 70°F, 90°F
ANALYSIS -

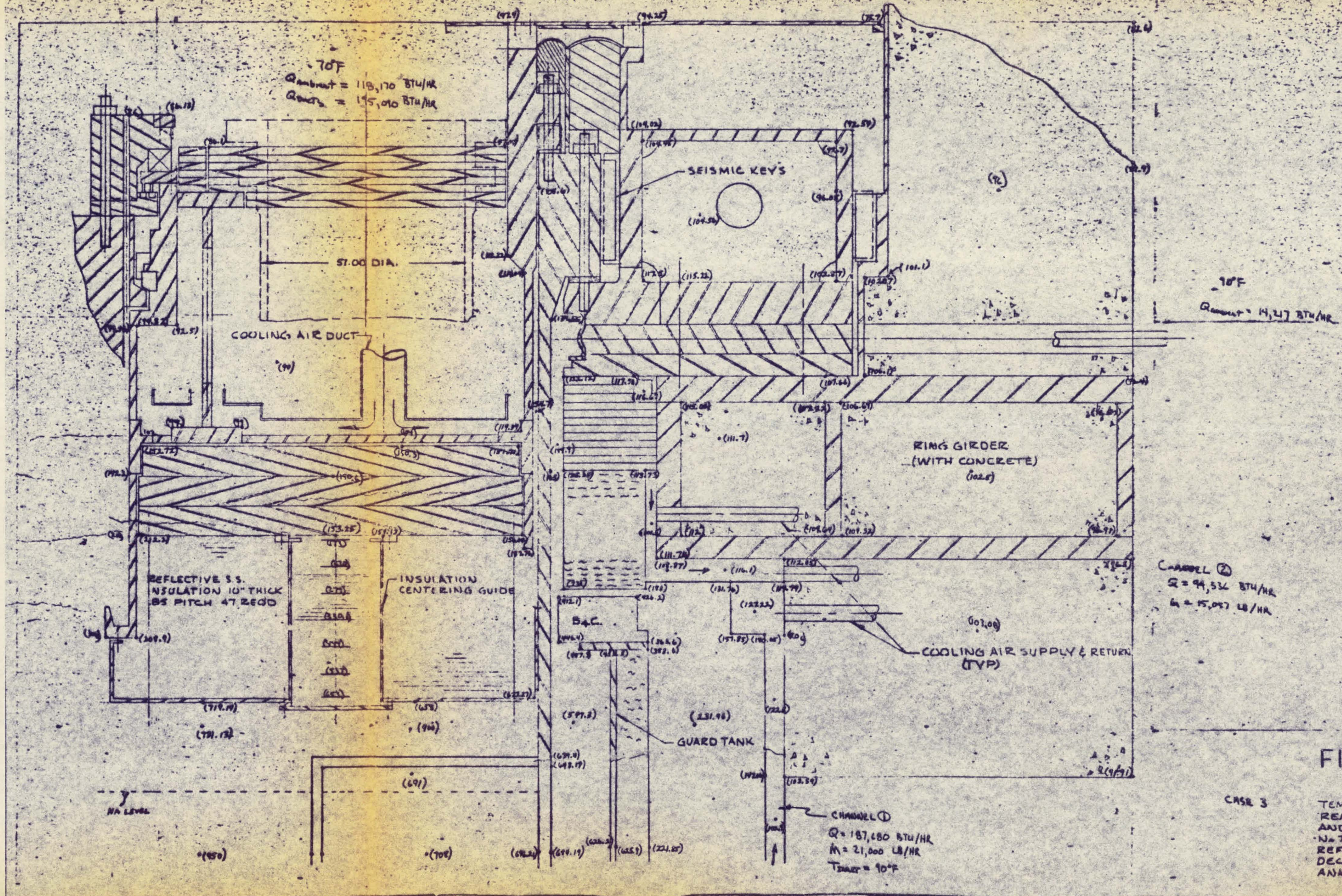


FIGURE 33

CASE 3

TEMPERATURE PROFILE
REACTOR COVER TANGENTIAL BEAM DECK
AND VESSEL SUPPORT
-Na TEMPERATURE -
REFLECTIVE INSULATION 'e' =
DECK AMBIENT -
ANALYSIS -

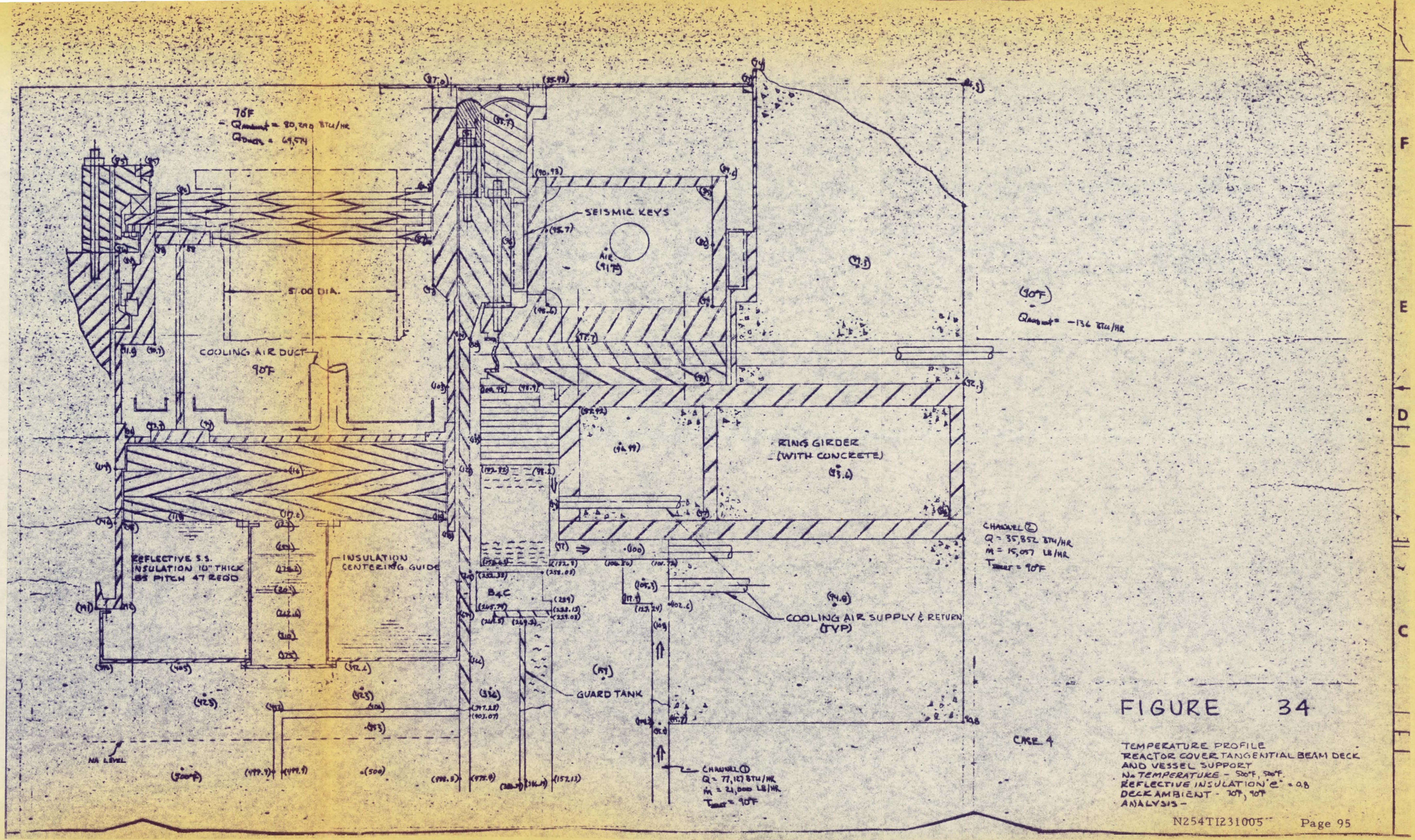


FIGURE 34

TEMPERATURE PROFILE
REACTOR COVER TANGENTIAL BEAM DECK
AND VESSEL SUPPORT
Na TEMPERATURE - 500°F, 500°F.
REFLECTIVE INSULATION 'e' = 0.8
DECK AMBIENT - 70°F, 90°F
ANALYSIS -

TABLE 15

DECK STRUCTURAL CHARACTERISTICS COMPARISON

		Tangent Beam Deck			Z-Cone Deck	
		OBE	SSE		OBE	SSE
First Horizontal First Vertical Frequency	22.0 Hz	0.7 g	1 g	19.4 Hz	1.25 g	1.75 g
	4.3 Hz	2.0 g	3 g	12.0 Hz	1.70 g	2.75 g

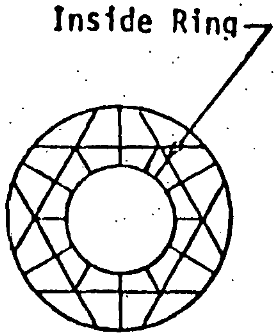
		Bearing Wall	Bearing Wall
Radial Deflection of Inside Ring Bearing Wall	Dead Load	±.0003 in.	+.0008 in.
	Dead Load + OBE	TBD - .017 Est.	±.008
	Dead Load + SSE	.025 Est.	±.013

TABLE 16

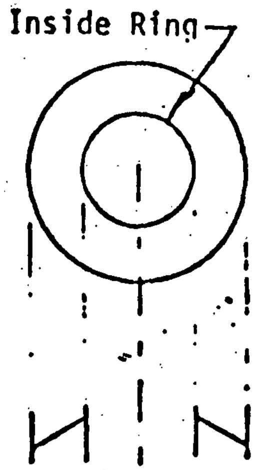
DECK STRUCTURAL CHARACTERISTICS COMPARISON

		Tangent Beam Deck	Z-Cone Deck
Vertical Deflection of Inside Ring (in.) Bearing Ledge	Dead Load	0.17 in.	0.031 in.
	Dead Load + OBE	0.40 in.	0.11 in.
	Dead Load + SSE	0.52 in.	0.14 in.

TABLE 17
DECK STRUCTURAL CHARACTERISTICS COMPARISON



Tangent Beam Deck



Cone Deck

				ALLOWABLE & MAT'L	
MAXIMUM STRESS KSI	DEAD LOAD	SA-533	7.1	SA-533	2.7
SA-533	OBE	--	15.9		7.8
	DEAD LOAD + OBE		23.0	40	10.5
	SSE		23.4		11.4
	DEAD LOAD + SSE	56	30.5	56	14.1
CYCLES TO REACH CRITICAL FLAW 4-IN. LENGTH	DEAD LOAD + OBE	EXPECTED CYCLES	2.5×10^5	EXPECTED CYCLES	2.1×10^6
	DEAD LOAD + SSE	516*	1.1×10^5	1440*	9.0×10^5

TABLE 18

OVERALL COMPARISON - DECK DESIGNS

	Z CONE	TANGENT BEAM
WEIGHT (MILLION LB)	2.3	2.6
THICKNESS		
REMOVABLE SHIELDING	DNA	1 FT - 0 IN.
DECK STRUCTURE	5 FT - 8 IN.	5 FT - 7 IN.
FIXED SHIELDING	INCLUDED ABOVE	2 FT - 0 IN.
CDA ENERGY ABSORBER	INCLUDED ABOVE	2 FT - 0 IN.*
REFLECTIVE INSULATION	5 FT - 1 IN.	3 FT - 7 IN.
TOTAL	10 FT - 9 IN.	14 FT - 2 IN.
SEISMIC (SSE) DEFLECTION (IN.)	.105	.35
FREQUENCY, Hz	TBD	4.3
COOLING	BY RADIATION & CONVECTION	BY CONVECTION USING STACKS

---

*CDA ENERGY ABSORBER NOT SHOWN ON TANGENT BEAM DRAWING

The LRP bearing outer race is attached to the deck flange with 1-in. diameter bolts on 6-in. centers. The tension load per bolt, during a seismic event, is 20,545 lb (see Reference 5). Thus, the stress developed in a bolt is 33,950 psi. The allowable stress for a SA540, Class 1, bolt is 50,000 psi. Thus, sufficient design margin is provided.

Thermal stresses exist along the inner cylinder wall of the deck due to an axial temperature gradient. The temperature at the sodium dip seal trough is 550°F and the temperature at the upper end of the cylinder, where it is welded to the deck flange, is 134°F. The resulting stress is 61,736 psi. The $3S_m$ allowable is 80,000 psi. The stresses were evaluated based on the ASME B&PV Code, Section III, Class 1, Structural Criteria, see Reference 5.

The Z-cone deck was analyzed in Reference 5 and found to be structurally adequate after increasing the cone plate thickness from 4.5 in. to 6.0 in., and the inner cylinder wall from 2.25 in. to 3.50 in. The DDHRX nozzle and adjacent deck structure was analyzed in Reference 5 for two cases: with and without nozzle to deck gussets. In both cases, the design margins were positive. The pins attaching the deck to the reactor vessel flange were analyzed (see Reference 5) and found structurally adequate.

8.0 VESSEL SUPPORT STRUCTURE

8.1 Requirements

Listed below are the requirements for the reactor support structure.

1) Provide support for the following:

Deadweight (million lb)

Support Structure	1.1
Vessel with Contents	6.2
Deck and Plugs	5.4
Total	12.7

Seismic Loading

	Horizontal	Vertical
OBE (g)	1.8 E-W, 1.6 N-S	1.3
SSE (g)	2.7 E-W, 2.33 N-S	2.2

2) Structure is to be passively cooled (goal).
3) Guard tank shall be installed prior to installation of vessel support structure.
4) Provide part of the upper boundary of cavity containment.
5) Provide inspection access to vessel flange-to-shell joint.
6) Provide access to interior of structure for inservice inspection and replacement of hold-down bolts and pin keys.
7) Provide access to the interior of the structure for inservice inspection and maintenance of the weld joints and interior surfaces.
8) Interface with the embedded ring girder support and the concrete surrounds to carry the imposed deadweight and seismic loads.
9) Contribute to the shielding above the cavity to limit the contributions to the dose rate at the head access with HAA to 2 mr/hr maximum during reactor operation.
10) Interface with the vessel flange to carry the vessel imposed deadweight and seismic loads.

11) Be fabricatable at the site.
12) The temperature of the structure shall not exceed 150°F with the reactor coolant temperature at 1050°F and the HAA at 90°F.
13) Be designed and constructed to the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, Component Supports.

8.2 Description of Concepts

The vessel support structure concepts developed are listed and briefly described.

a) U-Ring, Figure 2
b) Box Ring, Figure 35
c) Integral, Figure 36
d) Tee Ring, Figure 37
e) Tangential Beam, Figures 38 and 39

8.2.1 U-Ring Support

The U-ring support, Figure 2, is a circular girder having three sides, the inner wall, bottom plate, and outer wall. There are 30 webs, with caps equally spaced on the circumference and attached to the three sides of the structure. Between each web are two gussets. The inner wall has a ledge which supports the vessel.

The structure is supported over the greater part of its bottom surface by the embedded ring girder. It is attached to the embedment by bolts. The structure is positioned on and attached to the embedment to function as a cantilever type of vessel support.

The top of the U-ring support structure is open to allow natural convection and radiation cooling as well as to provide easy access to its interior for inspection and maintenance.

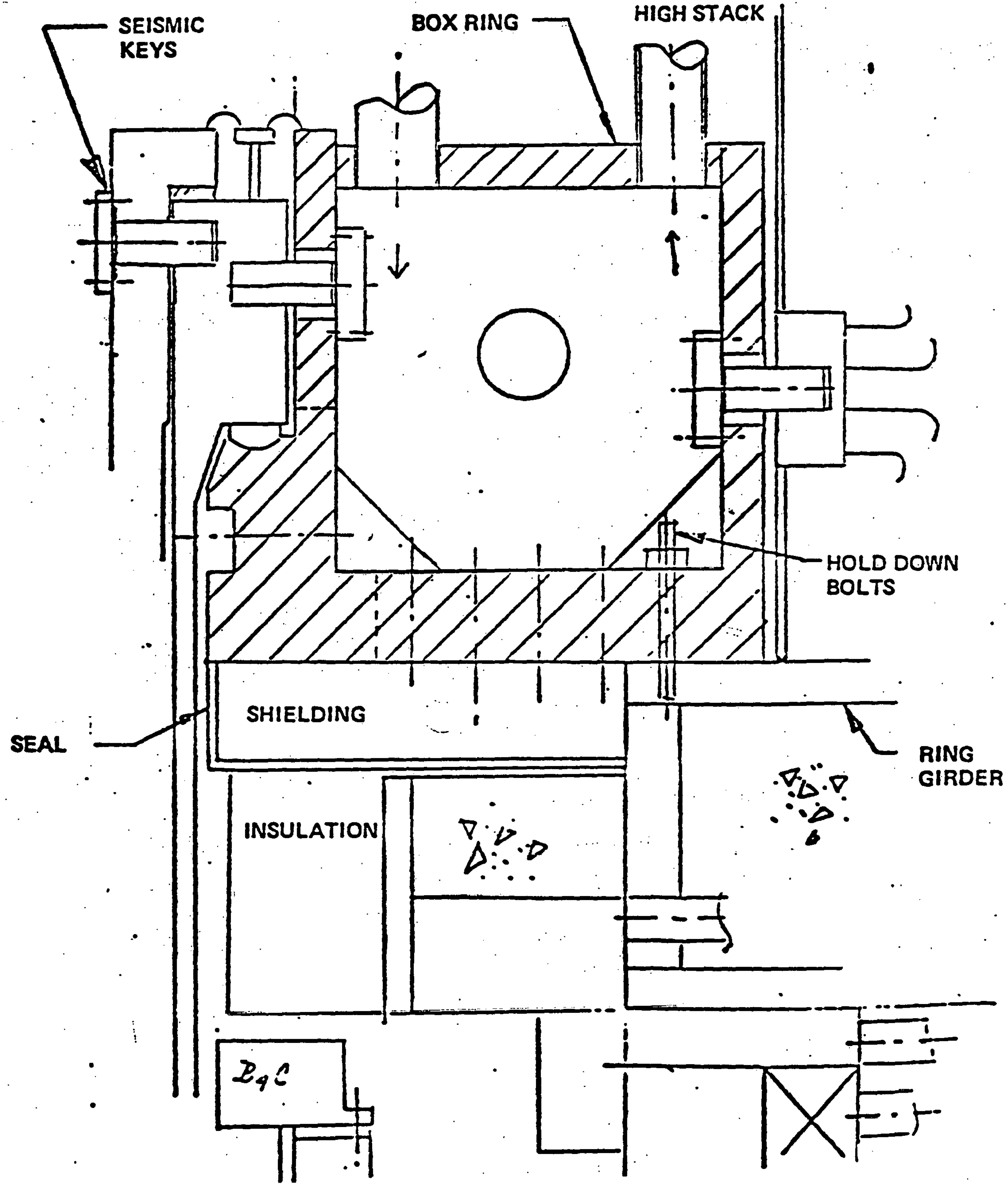


FIGURE 35.—BOX RING VESSEL SUPPORT STRUCTURE

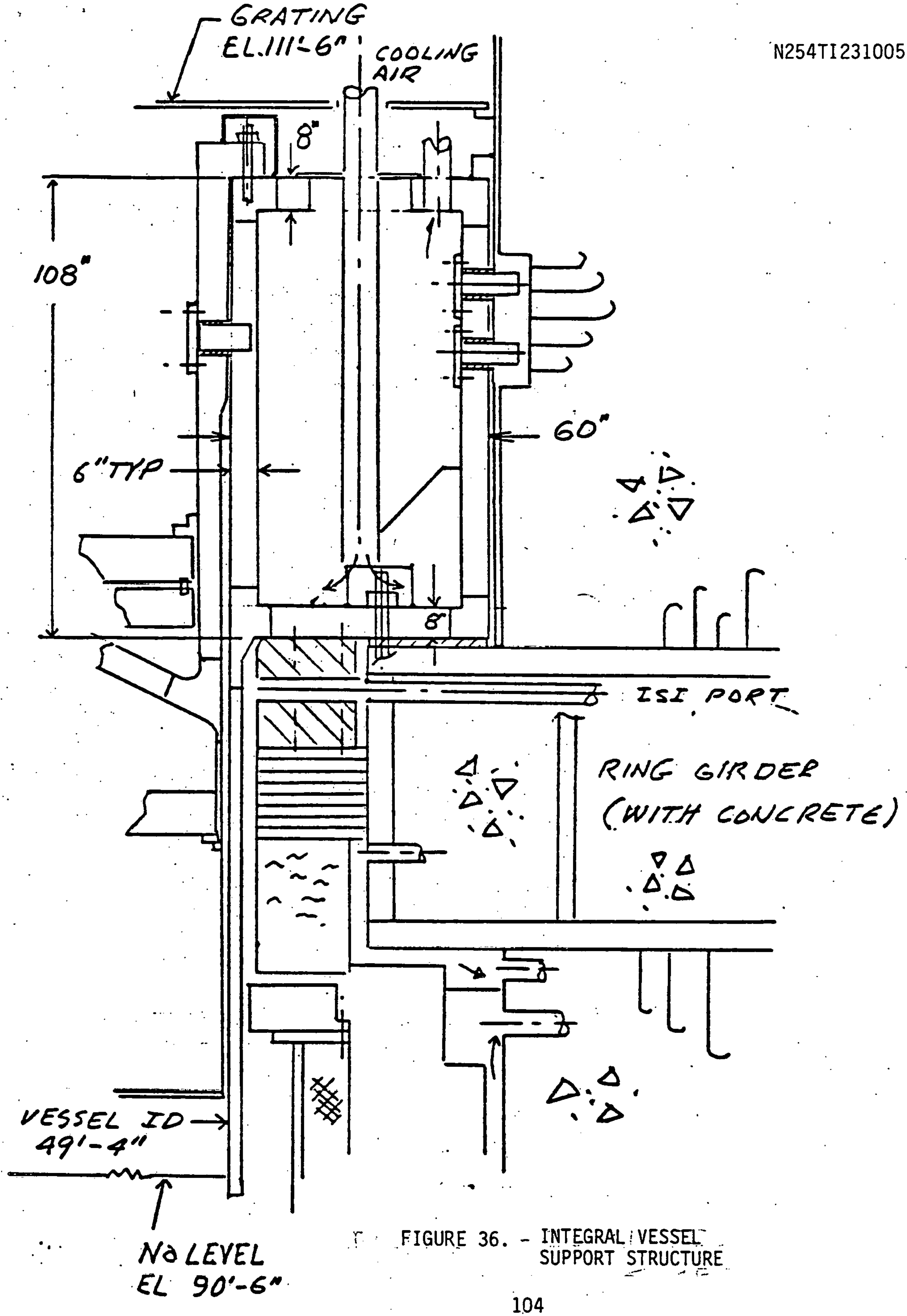


FIGURE 36. - INTEGRAL VESSEL SUPPORT STRUCTURE

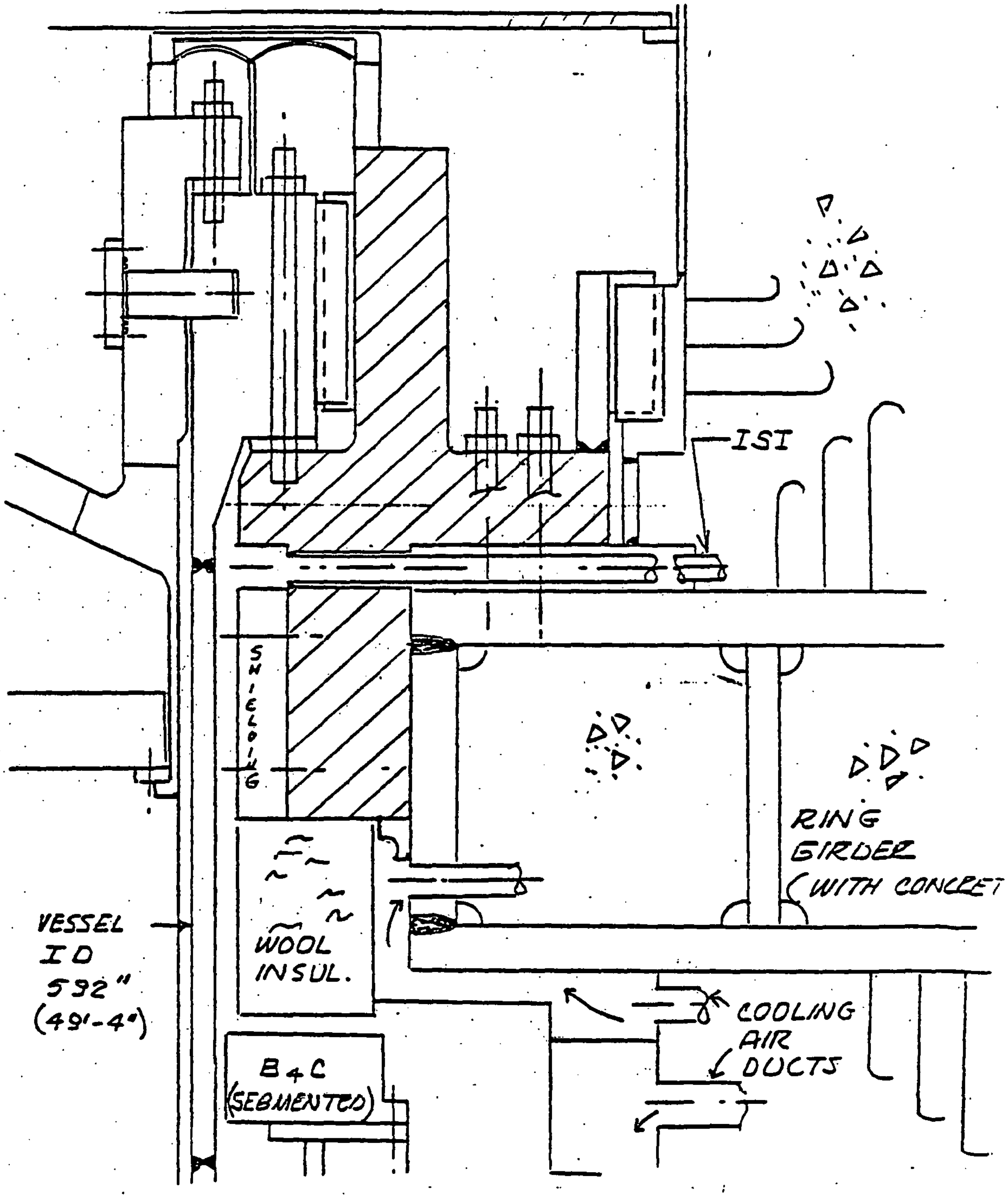


FIGURE 37. TEE RING VESSEL SUPPORT STRUCTURE

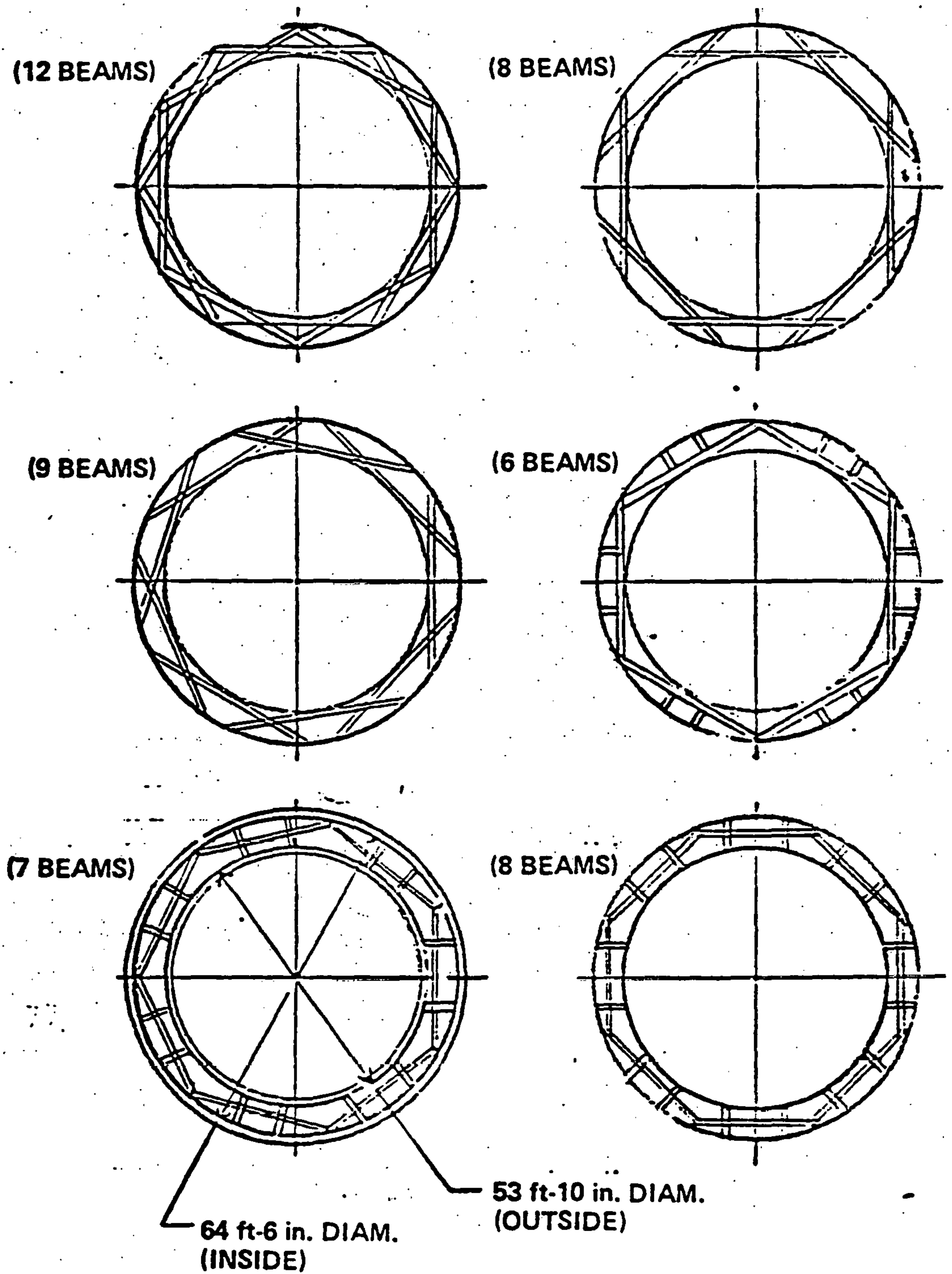


FIGURE 38. TANGENTIAL BEAM VESSEL SUPPORT STRUCTURE (PLAN VIEW)

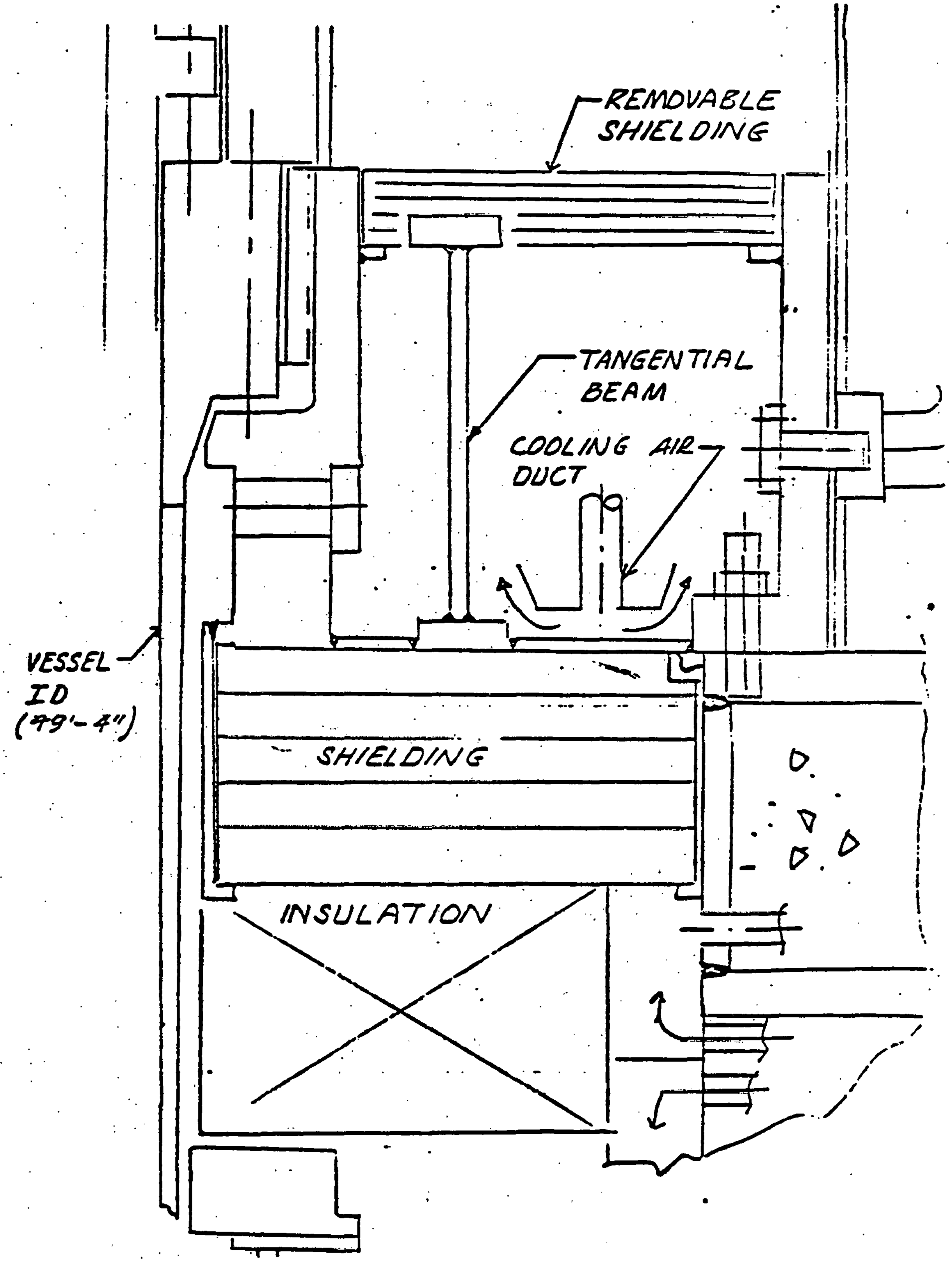


FIGURE 39. TANGENTIAL BEAM VESSEL SUPPORT STRUCTURE (ELEVATION)

The structure material is carbon steel.

Access for inspection to the flange-to-shell weld joint is through ports in the inner wall of the structure. The interior surface, weld joints, pin keys, and hold-down bolts are easily accessible for inspection and replacement or repair. The bolts attaching the vessel to the support structure are accessible for inspection by removal plugs in the seal plate between the support structure and the vessel flange.

8.2.2 Box Ring Support Structure

The box ring support structure, Figure 35, is an enclosed ring girder having four sides. There are 30 internal webs and a gusset positioned between each web. The box ring material is carbon steel. It is supported by and attached to the embedded ring girder at the structure's outer periphery. The structure functions as a torsional ring to support the vessel. As the structure is fully enclosed, enhanced convection cooling is required. Access to the interior of the structure is through manholes in the structure top plate. Access to the vessel flange-to-shell weld joint is through ports provided in the structure's inner wall.

8.2.3 The Integral Support Structure

The integral support structure, Figure 36, is a box ring structure welded to the outer surface of the vessel flange, the vessel flange becoming the inner wall of the structure. The material of the structure is stainless steel, the same material as the vessel flange to avoid dissimilar metal weld joints. The structure, therefore, is to be made to the same code requirements as the vessel. The structure is supported by and attached to the embedded ring girder at the structure's outer periphery. The structure functions as a torsional ring to support the vessel. As the structure is fully enclosed, enhanced convection cooling is required. Access to the interim is through manholes in the structure's top plate. Access to the inside of the structure flange-to-shell weld joint is through pipes located in the embedded ring girder.

8.2.4 The Tee Ring Support Structure

The tee ring support structure, Figure 37, is a weldment made of three parts - the upper ring, the horizontal plate, and the lower ring. It is supported by the embedded ring girder over a greater portion of the horizontal plate. The structure acts as a torsional ring to support the vessel. The structure is passively cooled. Access to the vessel flange-to-shell weld joint is through channels located below the horizontal plate member. The material is carbon steel. Vertical keys are shown between the support and vessel flange, however, pin type keys are acceptable.

The structure is not acceptable as sufficient structural stiffness is not available, therefore, the tee ring support structure is not included in the following evaluations and analysis.

8.2.5 Tangential Beam Support Structure

Figures 38 and 39 show six types of tangential beam support structures having 6, 7, 8, 9, or 12 tangential beams for the main structural members. Figure 39 shows the elevation of a typical tangential beam structure. This type of structure is not acceptable as the internal space for fabrication access is not sufficient, therefore, the concept was not developed and is eliminated in the following evaluations.

8.2.6 U-Ring Detailed Description

The detailed description of the U-ring vessel support structure is given below.

The U-ring support structure is an open top channel (U) type structure with stiffening webs welded to the three sides of the channel. Gussets are welded to the interior to provide additional stiffness. The interior wall of the structure has a ledge on the inside diameter on which the vessel is supported and attached by bolts. The upper half of the interior wall is 8.0-in. thick and the lower half is 11.0-in. thick. The support ledge is 9.0-in. thick. The interior wall is made of forgings and plates welded together. The bottom plate is an 8.0-in. thick and made from plate stock. The outer wall is 6.0-in. thick and is made from plate stock. The web is a 3-in. thick plate having a 4.0-in. thick by 10.0-in. wide welded cap. There are 30 webs welded to the (U) channel, located on 15° centers (approximately 5-1/2 ft). Two gussets 3.0-in. thick are located between the webs. The walls, bottom plate, webs, caps, and gussets are welded together. The space between the webs is called a bay.

The material is carbon steel and is stress relieved after welding.

Ports, with gasketed covers, are provided in the inner wall to provide access to the flange-to-shell girth weld joints.

The structure is attached to the embedded circular girder by fifteen 2.5-in. diameter bolts in each bay.

The vessel is attached to the support structure with 3-in. diameter bolts, installed throught he vessel flange.

During a seismic event, horizontal forces occur between the concrete and the support and between the support and the vessel flange. These forces are transmitted by the pin keys. There are five pins 5.0-in. diameter between the support structure and the building concrete. Between the vessel and support structure there are 4-in. diameter pins spaced on 14 in. centers. Providing the pin keys avoids shear stresses on the vessel-to-structure and structure-to-embedment attachment bolts. The pin keys in the inner wall have gasketed covers as the pin key hole penetrates the vault containment boundary.

Located in the lower inner corner of the support structure are shielding blocks which complement the shielding below the structure to provide the equivalent of 48 in. of steel shielding.

A vault seal is required between the support structure and the vessel flange. The seal is a formed thin plate welded to both the flange and support structure. Plugged access holes may be provided in the seal to allow access for periodic inspection of the vessel hold-down bolts.

Plates are required above the flange-to-support structure seal to shield the radioactive gas that may collect in the space below the seal in the event the inert vault gas becomes contaminated with radioactive gases.

8.3 Evaluation and Analysis

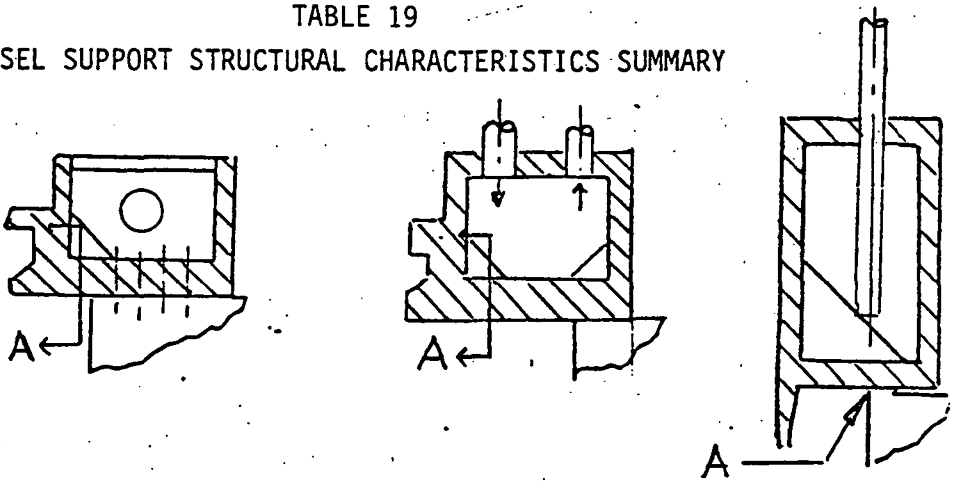
8.3.1 Evaluation

The structural characteristics of the three viable vessel support structures are given in Table 19. An overall comparison summary is given in Table 20. An evaluation of the vessel supports against given criteria is given in Table 21.

The U-ring support is the lowest stressed of the three structures at the critical Section A-A. The number of cycles to reach critical flow length is high for the bolt stresses.

The maximum deflection during OBE is low for the U support structure, much less than .10 in. The detailed structural analysis is given in Reference 5.

TABLE 19
VESSEL SUPPORT STRUCTURAL CHARACTERISTICS SUMMARY



	U Ring		Box Ring		Integral	
	Calc.	Allow	Calc.	Allow	Calc.	Allow
Bolt Stress ksi						
Dead load	$\sim$0.0	-	9.0	-	5.4	-
OBE	50.0	-	66.3	-	47.5	-
Dead Load + OBE	50.0	82.5 SA-540 GR-B21	75.3	82.5 SA-540 GR-B21	52.9	82.5 SA-540 GR-B21
Structure Stress ksi	At Section A-A		At Section A-A		At Point "A"	
Dead Load	2.0	-	4.7	-	3.0	-
OBE	14.8	-	34.9	-	19.7	-
Dead Load + Obe	16.8	40 SA-533	39.6	40 SA-533	22.7	30 SA-240
Cycle to reach Critical Flaw Length	5.7×10^5		4×10^4		NOT AVAILABLE	
Vertical deflection (OBE + deadweight) inch	<<0.10		0.291		0.10	

TABLE 20

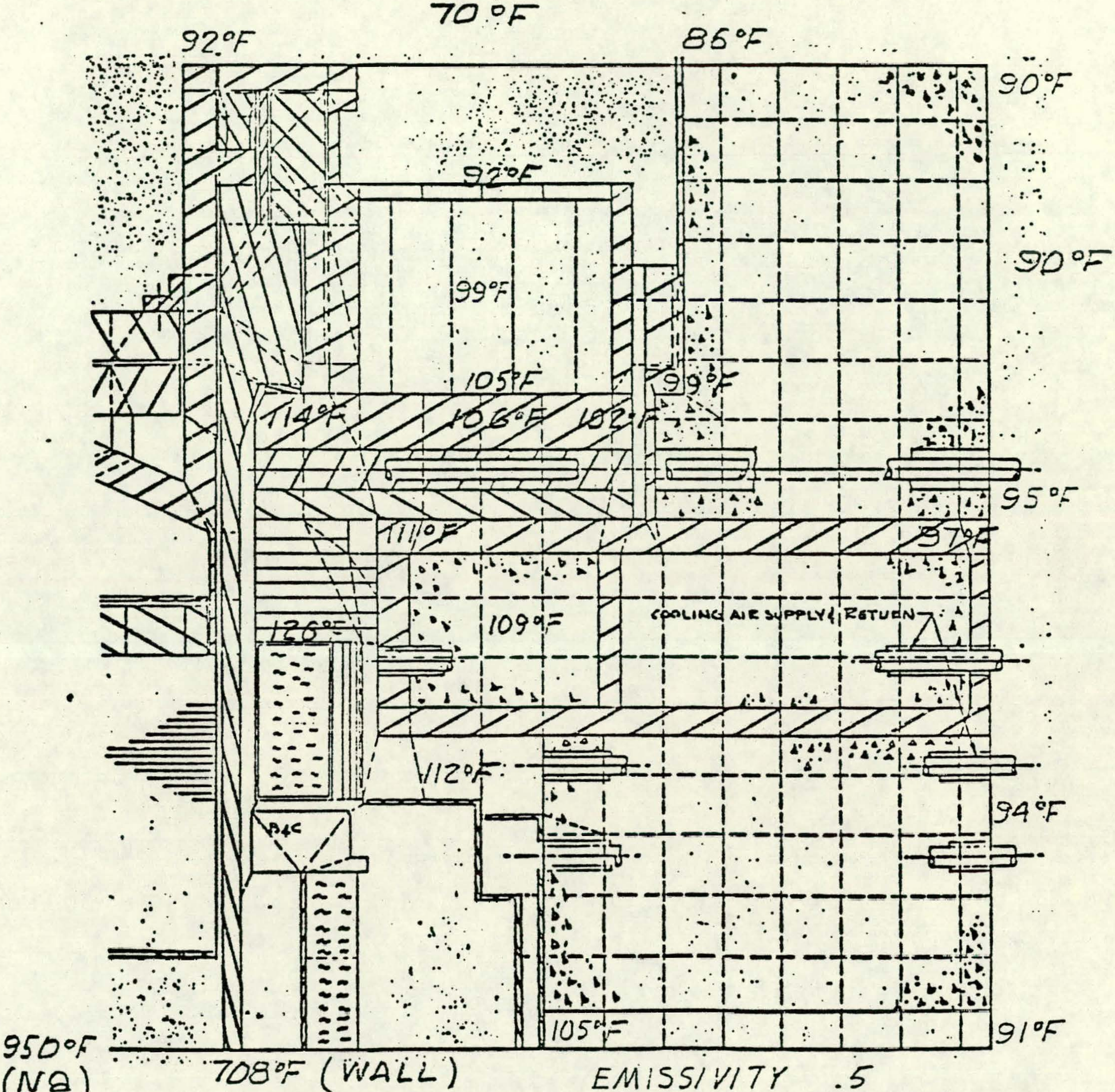
COMPARISON SUMMARY - VESSEL SUPPORT STRUCTURE

	"U" RING	BOX RING	INTEGRAL
WEIGHT (MILLION LB)	1.1	1.5	1.1
HEIGHT (IN.)	67	77	108
WIDTH (IN.)	70	87	60
COOLING	NATURAL CONVECTION	STACK CONVECTION	STACK CONVECTION
CAVITY SEALING	EASY	EASY	DIFFICULT
INSTALLATION	EASY	EASY	DIFFICULT

TABLE 21
VESSEL SUPPORT EVALUATION

	U Ring	Box Ring	Tee Ring	Tangent	Integral
Structural performance	Low deflection	Higher deflection	Deflection too great — Unacceptable	Cannot be fabricated due to lack of space — Unacceptable	Low deflection
Maintainability	Good	Same			Same
Inspectability	Good	Same			Acceptable — stainless steel limits inspection to visual
Constructibility	Relatively easy	Same			Difficult — makes support a pressure boundary as it is welded to vessel
Reliability	Extremely good	Good			Good
Installation	Relatively easy	Same			More difficult — larger diameter vessel and vault seal
Operability	Very good	Same			Same
Cost	Relatively low	Same			Higher due to use of stainless steel

N254TI231005



EMISSIVITY .5
VESSEL TEMP 708°F
AMBIENT TEMP 70°F

FIGURE 40. SUPPORT TEMPERATURE PROFILE, SODIUM TEMPERATURE 950°F

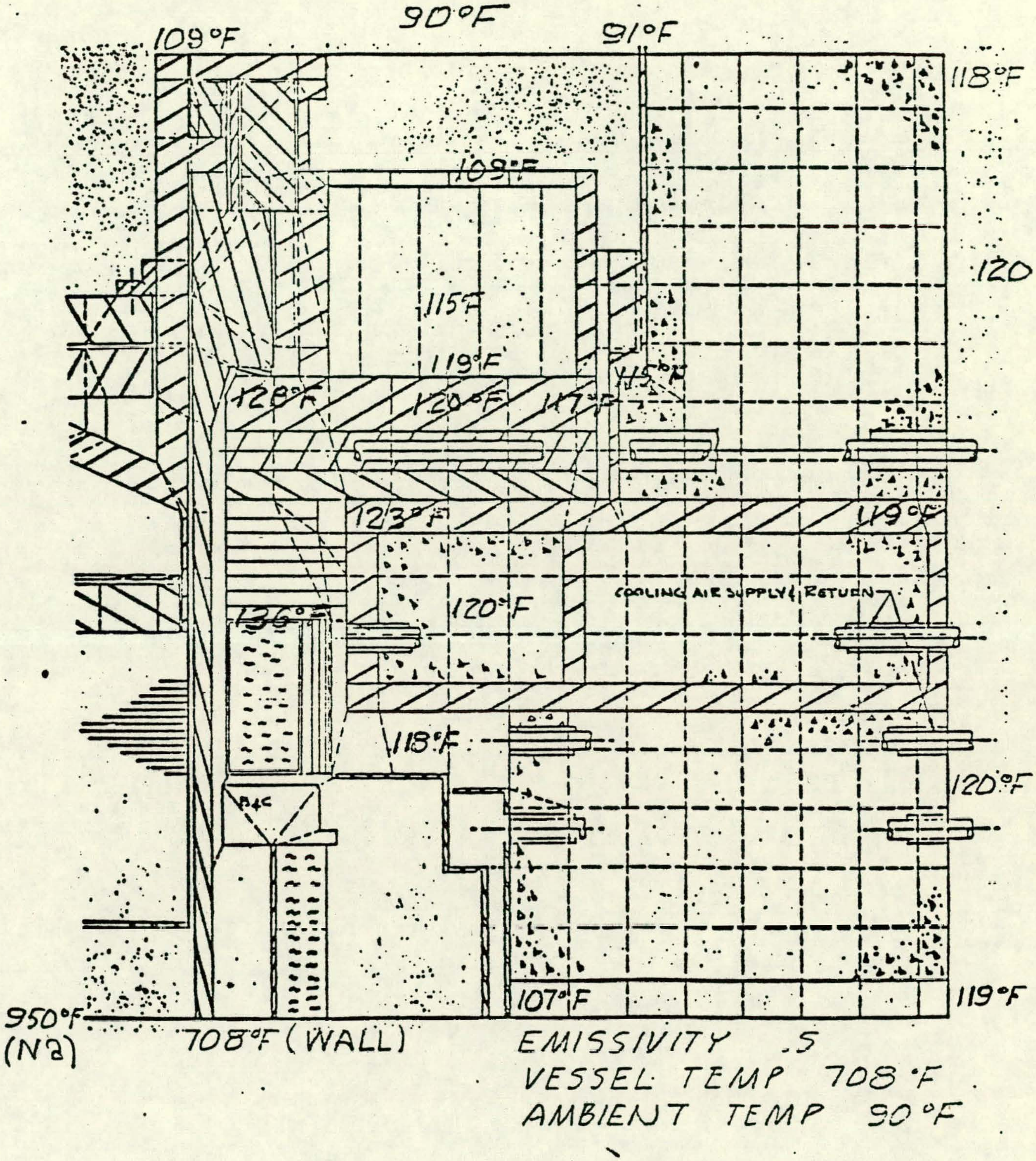
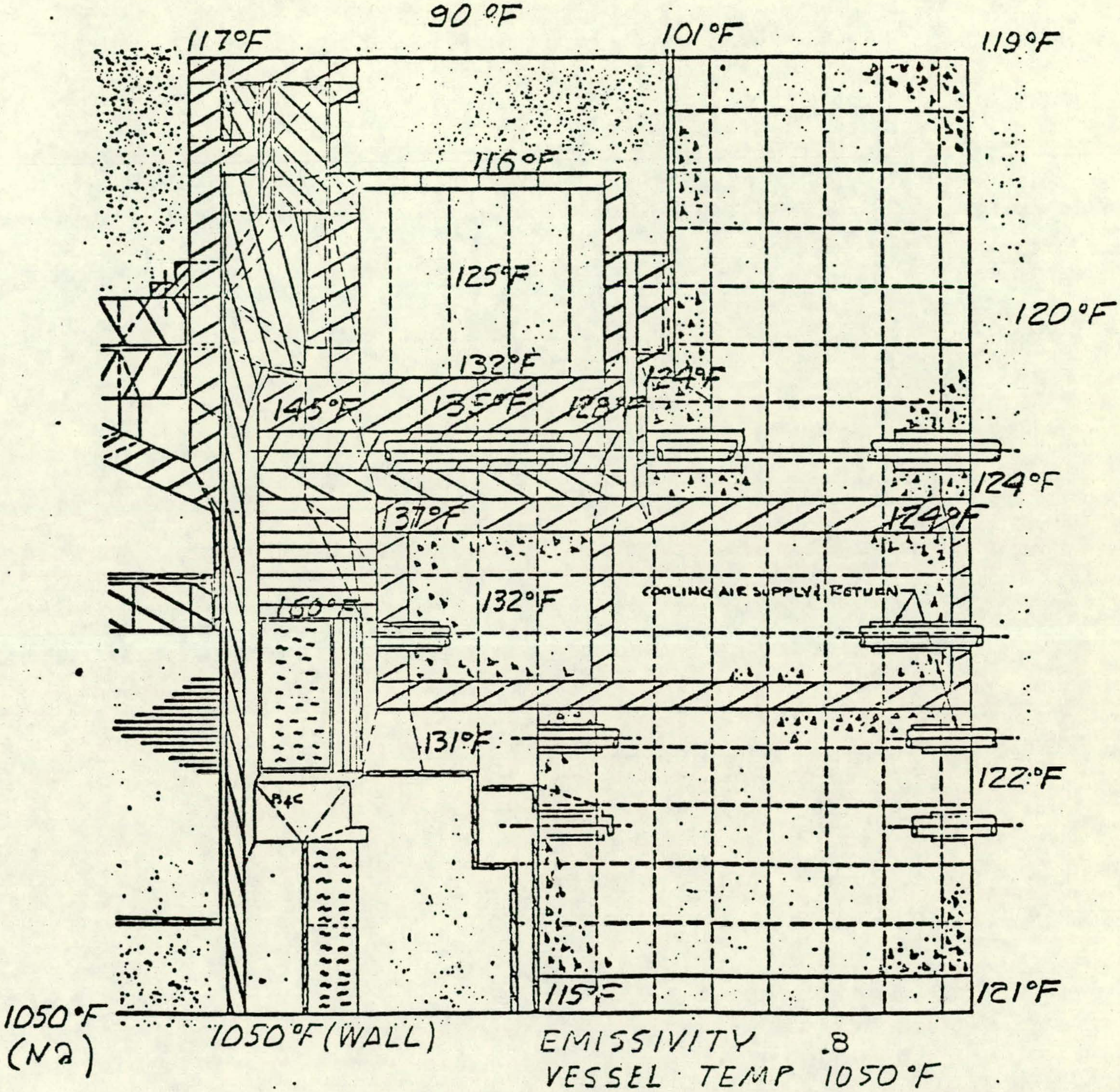
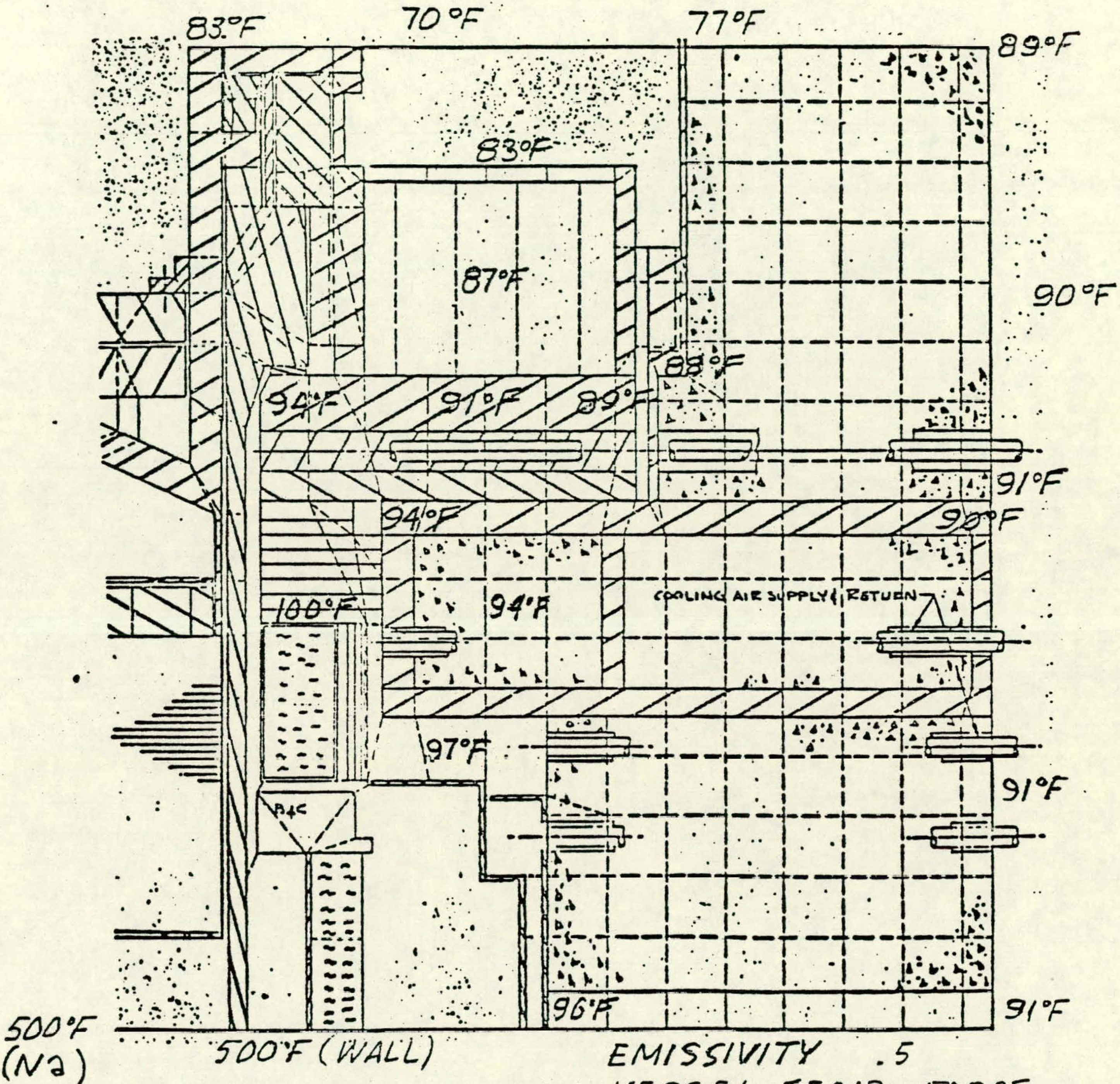


FIGURE 41. SUPPORT TEMPERATURE PROFILE, SODIUM TEMPERATURE 950°F



EMISSIVITY .8
VESSEL TEMP 1050°F
AMBIENT TEMP 90°F

FIGURE 42. SUPPORT TEMPERATURE PROFILE, SODIUM TEMPERATURE 1050°F



EMISSIVITY .5
VESSEL TEMP 500°F
AMBIENT TEMP 70°F

FIGURE 43: SUPPORT TEMPERATURE PROFILE, SODIUM TEMPERATURE 500°F

The evaluation of the vessel support configurations is summarized in Table 21. The evaluation criteria are:

- Structural Performance
- Maintainability
- Inspectability
- Constructability
- Reliability
- Installation
- Operability
- Cost

The selected configuration is the U-ring support structure (Figure 2). The reasons for the selection are:

- All carbon steel support
- Low seismic deflection and stresses
- Reliable (redundant) structure
- Passively cooled, no active cooling system required
- Good access for inservice inspection and maintenance
- Cost is low
- Site installation easy due to:
    - Support structure separate from vessel
    - One vault-to-support seal required
- Fabrication of open top structure is easy, and the time required and costs are relatively lower

8.3.2 Analysis

8.3.2.1 Thermal Analysis

The temperature profiles of the U-ring support structure for sodium temperatures of 950°F, 1050°F, and 500°F are given in Figures 40, 41, 42, and 43. The thermal analysis is given in Reference 7.

The temperature profiles are calculated with the initial support structure configuration, before the improved concept was developed. The latter configuration does not have the steel plates substructure below the support structure and the vertical keys. The temperature differences between the two types of support structures are estimated to be small - not more than 2 to 3°F, the improved structure being the warmer.

Representative thermal profiles are shown. Additional profiles are found in Reference 7.

Figure 40 shows the temperatures in the support structure for normal reactor operation with 950°F sodium, 70°F HAA, and 90°F piping vault ambient temperatures. The support structure components temperature are about 93°F in the upper section and 133°F average in the bottom plate, all being much less than the 150°F maximum allowable temperature. The temperature difference between top and bottom are small. The concrete temperature is low, being 110°F maximum.

Figure 41 has the same sodium temperature but with 90°F HAA and 120°F piping vault (high) ambient temperatures. The support structure components temperature are about 110°F in the upper section and 122°F average in the bottom plate.

Figure 42 shows the temperatures in the support structure for an upset condition whereon there is a loss of primary coolant flow and the heat is removed by the decay heat exchangers. Under this condition, the sodium and vessel wall temperatures both are 1050°F and the HAA and piping vault temperatures are 90°F and 120°F, respectively.

The temperature in the upper part of the support structure is about 115°F and about 136°F average in the bottom plate. The concrete temperatures are 136°F maximum, which is below the desired 150°F maximum temperatures.

Figure 43 shows the temperature in the support structure for refueling conditions. The sodium temperature is 500°F, and the HAA and piping vault temperatures are 70°F and 90°F, respectively. The temperature of the upper part of the structure is about 85°F and about 92°F average in the bottom plate.

The temperature profiles shown in Figures 40, 41, and 43 are shown with an emissivity of 0.5. Other figures are available in Reference 7 showing the temperature profiles for an emissivity of 0.8. The effect is minimal. The support temperature is raised about 2 to 3°F when the emissivity is changed from 0.5 to 0.8 (see Reference 7). The thermal stresses in the support structure base plate, believed to be the higher of the components, is less than 3,000 psi, see Reference 5.

8.3.2.2 Shielding

Figure 44 shows the location of shielding in the support structure and the 48-in. minimum effective shielding length for the possible paths of gammas and neutron streaming. The shield blocks in the structure are easily removed for inspection of the weld joints and for access to the flange-to-shell weld joint inspection port.

8.3.2.3 Stress

The results of the stress analyses are given in Table 19. The detailed analyses are given in Reference 5.

9.0 REACTOR COVER SYSTEM

9.1 Installation

This installation procedure covers the three reactor cover components. They are: the vessel support structure, the deck, and the TRP seal/bearing/support system. The parts and component identification is given on Figure 2. The installation starts with preparation for placement of the U-ring vessel support structure.

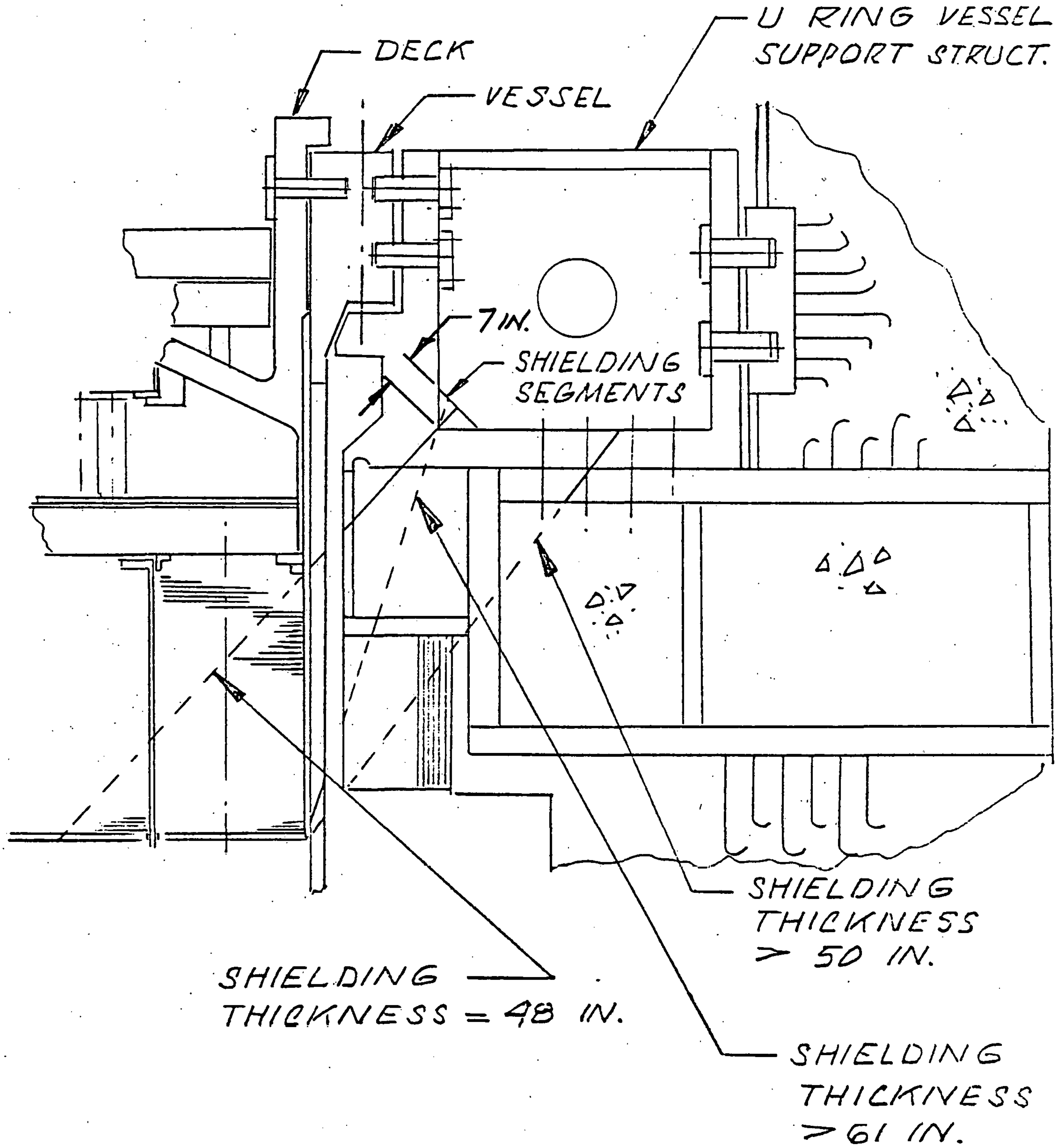


FIGURE 44. SUPPORT STRUCTURE SHIELDING

9.1.1 Installation of the Vessel Support Structure

1) Place the circular girder and cooling ducts in the proper location and place the concrete below. After the concrete hardens, the embedded circular girder is filled with concrete.
2) Complete the installation of the concrete, with its inner liner and structural embedment, above the circular girder.
3) Install guard tanks with the insulation attached. There are 3-in. of radial installation clearance between the outside of the guard tank insulation and the inner diameter of the circular girder.
4) Install the vessel support structure and bolt to the circular girder.
5) Install the vault seals between the support structure and the circular girder and test.
6) Install the shielding support below the support structure.
7) Install the shielding and the face plate.
8) Install the cooling duct header below the shielding support and test.
9) Install the insulation below the shielding support shelf.
10) Determine the vessel support ledge on the support structure is flat and level. If not, machine to meet the specified level and flatness requirements.
11) Place lubrite plates in position on the support ledge and place the vessel on lubrite plates.
12) Install the vessel hold-down bolts.
13) Install the pin keys and then cover plates in the inner and outer walls of the support structure.

The center lines of the pin keys in the vessel flange and the inner member of the support structure must align in order for the pin to fit snugly in the holes.

As it appears to be very difficult to final machine the holes in the two members in the shop so they will accurately line up when installed at the site, final machining of the holes in the vessel flange is to be done at the site after the vessel is bolted into position.

The hole in the support structure is machined to final dimension in the shop. The hole in the vessel flange is final machined in the shop to a diameter about 1/2-in. diameter less than the final diameter. These dimensions assume the holes in their respective components are located within a true position tolerance of 1/4-in. diameter, which is attainable with current shop fabrication procedures and equipment.

Boring equipment is placed in position in the support structure and the hole in the vessel flange is finish-machined to be on the same center line and is the same diameter as the hole in the support structure. An inflatable rubber dam is installed between the flange and the vessel to capture the machining chips and fluid.

The final machining of the holes in the steel ring embedment on the outside of the support structure is done in a similar manner.

14) Install the pin key cover flanges and check O-rings for absence of leaks.
15) Install the membrane vault gas seal between the support structure and the vessel flange.

9.1.2 Installation of the Deck Structure

After the internals of the vessel are installed, which require full opening of the reactor vessel, the deck structure is then installed.

The deck is assembled, except for the above-the-cone shielding plates, prior to installation in the reactor vessel. The shielding plates are not initially installed as their added weight causes the total deck weight, about 1200 tons, to exceed the crane capacity of 1000 tons. The plates are installed after the deck is placed into the vessel.

The assembly of the deck prior to installation in the reactor vessel is described below.

1) Lift each of the 15 sections of upper shielding plates, one at a time, up to the cone plate, align with the keys, left to final position, install support strips on ledges, and lower shielding plates onto support strips and ledges.
2) Assemble the CDA absorber section on the bottom shielding plate.
3) Lift the assembly into position, aligning with keys, install the support strips on the ledges, and lower the shielding plates onto the support strips and ledges.
4) Attach the insulation guide tube to the bottom shielding plate.
5) Hoist each of the 15 assembled stacks of 70 reflective insulation sheets up to the bottom shielding plate, aligning with the keys on the above guide tube, on the keys of the guide tube around the DDHRX and attach to the bottom shielding plate with the tie bolts.
6) Install the redundant shielding support bolts through the cone deck.
7) Weld on the shielding support bolts, seal caps and leak test.
8) Lift the deck assembly with the crane, move the deck over the vessel and lower into position on the vessel flange.
9) Install the pin keys between the deck and reactor vessel flange. The final machining of the pin key holes in the vessel flange, to assure alignment of the holes, is done in the same manner as previously described for the vessel support structure pin keys.

10) Install pin key cover plates and test for leakage.
11) Install the membrane seal between the deck and vessel flange.
12) Install the above-the-cone shielding plates.
13) Install the two DDHRX in their deck openings.
14) Install the fuel handling port in the deck.

9.1.3 Installation of Seal, Bearing, and Support Structure System

1) Bolt the bearing to the ring support structure with the tolerance shims properly installed.
2) Attach metallic O-rings to the ring support structure.
3) Place the large rotating plug in the deck structure supported by the ledge in the deck.
4) Center the LRP in the deck and install CDA keys.
5) Place the ring support structure with bearing and seals attached into position on the deck, install shims, and secure with the bolts to the deck.
6) Place the large studs and the tolerance shims in position and lift plug, with construction crane, up against the ring support structure.
7) Tighten nuts and check the metallic seals for leaks.
8) Install overpressure seal.
9) Install inflatable seal holders containing the inflatable and static seals. The stud nuts are tightened and the static seals are checked for leaks.
10) Install seal rider plate with its static seals and ring gear. Center the assembly with the tolerance shims and tighten bolts.
11) Install access port plugs and leak-check the seals.
12) Install seal leak-check lines, seal inflation lines, and the grease and seal lubrication lines.

13) Install access port plug to the lube catch trough and leak-check the seals.
14) Lubricate and inflate the inflatable seals.
15) Rotate plug to assure there is no binding, obtain torque values, verify that the inflatable seals were sealing, and ascertain the radial runout between the seal blade and the seals is acceptable.

The same installation method is used to attach the IRP to the LRP and the SRP to the IRP. Each plug is rotated after installation to assure correct functioning of the bearing and inflatable seals and to measure plug rotational torque.

9.2 Operation

9.2.1 Seals, Bearings, and Support Structure

Prior to operation of the reactor, the annulus is filled with helium gas, the dip seal filled with sodium, and the dip seal sodium level and temperature indicators checked.

9.2.1.1 Reactor Normal Operation

The plugs are secured by the drive units and other positive stops so that they cannot move during reactor operation.

The inflatable seal pressures are maintained to assure containment of the radioactive cover gas in the annuli. As the temperature of the plugs' top surface increases with sodium coolant temperature increase, each bearing accommodates the differential radial expansion that occurs between the plugs and between the plug and deck.

The dip seal continuously receives sodium from the sodium vapor that condenses on the insulation plates and annulus side wall and falls into the dip seal, thus continuously supplying sodium to the dip seal.

A minute quantity of the dip seal sodium vaporizes from the dip seal and is deposited as frost on the upper annulus walls.

The upper annulus and lower annulus (cover gas) gas pressures are equalized, thus maintaining the same pressure and sodium level on each side of the dip seal blade.

The dip seal sodium temperature and levels are monitored.

9.2.1.2 Refueling

Refueling operations start after the reactor coolant temperature is lowered to about 500°F and other operations are performed to allow rotation of the plugs.

The inflatable seals are relubricated and their pressures dropped, the protector seal is collapsed, and plug rotation is initiated at a very slow rate, up to 1 ft/min, to reduce starting torque. When the starting torque is too high, due to the plugs having been idle for extended periods, the torque may be reduced by alternately collapsing the seals to allow the lubricant to recover the rubbing surfaces. The inert gas on each is purged prior to and during this operation to prevent escape of contaminated gas to the head access area. Seal relubrication ports are provided between the seals.

Upon completion of refueling, the inflatable seals' pressures are increased for the plugs static mode, the protector seal is inflated, the volume between the protector seal, and the outboard inflatable seal is purged with inert gas. After leak testing, the sealing system is ready for reactor startup.

9.2.2 Deck and Support Structure

The deck and support structures are static structures, passively cooled; therefore, there are no parts, which require monitoring or supervision during reactor operation and refueling conditions.

9.3 Maintenance

Maintenance operations consist of several which are:

1) Replacement of the inflatable seals.
2) Replacement of the bearing.
3) Inspection and cleaning the annulus surfaces.
4) Rewetting the dip seal surfaces.
5) Removing oxide deposits from the dip seal.
6) Inspection of deck weldments.
7) Inspection of vessel support structure weldments.
8) Inspection of vessel flange-to-shell weld joint.
9) Inspection of pin keys, attachment bolts, tie rods, and sealing plates.
10) Crack repairs.
11) Replacement of pin keys, bolts, and tie rods.

9.3.1 Replacement of the Inflatable Seals

The bearing is lubricated in order to refill the bearing grease seal prior to seal replacement.

The reactor coolant is reduced to about 500°F, the cover gas activity is reduced by purging and the annulus gas is purged and changed to argon.

Two methods of seal replacement are possible. One is to remove the seals and the seal holder plates as a unit and replace them with a spare. The other is to remove the inflatable seals from the seal holder plate and install replacements possibly end vulcanizing the joint in situ. The latter method does not require major disassembly and removal of equipment, only lifting the upper parts sufficiently to provide access to remove the old seal and install a length of seal and vulcanize the ends.

Replacing the seal by the first method, the seals' pressures are reduced, the ring gear and seal rider plate are removed, the seal holder assembly is removed, then the new seal holder assembly is placed and bolted in position. The static O-rings are checked for leak tightness. The seal rider plate and ring gear are installed, the static O-rings are leak-checked, the inflatable seals are inflated, and the volume between the seals is pressurized to leak-check the inflatable seals.

After the inflatable and static seals are leak-checked, the annulus gas above and below the bearing is changed to helium and the sealing system is now functional.

The second method of seal replacement has the same requirements except the hardware above the seal does not need to be lifted out of the reactor cover area, lifted only high enough to allow access for removing the seals from their cavities, installing the replacement length of seal, end-vulcanizing the joint, and pressing the seal into the groove. The seal is held into the groove mechanically as adhesive is not used.

The latter method saves about two weeks of reactor downtime and many dollars for seal replacement. The mechanical method of retaining seals has not been done and requires development and testing.

9.3.2 Bearing Replacement

To gain access to the bearing, the dead weight of the plugs must be removed from the bearing by resting the plug on the ledge of the next outer plug or deck.

This is done by using the support structure as a lifting ring fixture. Hydraulic jacks (bolt tensioners) setting on top of the lifting fixture and attached to the large studs. The fixture/jack method is required on the LRP and IRP as the building crane capacity (300 ton) is not adequate to lift the plugs.

The upper annulus is purged of helium and filled with argon gas, the ID of the support structure is sealed to the plug plate with tape and plastic sheets. A minimum of 12 jacks are attached to the upper end of the studs and rest on the upper surface of the support structure. All of the nuts except the 12 are loosened by portable bolt tensioners. The jacks are activated, the nuts are backed off, and the LRP is slowly lowered by the jacks onto the support ledge of the deck. Once the weight is off the jacks, they are removed, the tape and bags are removed, the bearing outer race bolts are removed, and the support structure with bearing is removed to a maintenance area and the bearing maintenance is done.

The installation of the bearing is done in the reverse procedure of removal.

The structural analysis of the support structure used as a lifting fixture is given in Reference 6.

9.3.3 Inspection and Cleaning in the Annulus

Access to the annulus is through the ports provided in the support structure. Equipment inserted through the ports will be sealed to the support structure to prevent air in-leakage.

Inspection by boroscope for the following can be done through the port plugs; frost build-up on the annulus walls, sodium oxide formation on the dip seal surface, and visual inspection of the skirt-to-plate weld joints.

Removal of frost deposits in the annuli can be done by inserting a scraping tool with a fold-out foot through the access ports, extending the foot and pushing the frost deposits down into the dip seal sodium. The deposits will melt in the dip seal sodium. The plug support lug is not continuous which allows tool insertion by the lug.

Inspection of the frost and grease deposits in the lube catch-trough is done through ports installed in the bearing support structure. The port through the support structure permits removal of deposits in the lube catch-trough as the plug can be rotated, thus providing 360° access to the trough.

9.3.4 Rewetting the Dip Seal Surfaces

Ultrasonic horns are used to rewet the surfaces of the dip seal. The horns are positioned in place through ports provided in the plugs' top plate. The area under the horns are wetted and then the plug is rotated so the horns will wet an adjacent surface. Several ports are provided around the periphery of the dip seal to allow use of several horns at one time thus reducing reactor downtime. Rewetting of the dip seal is not required should the rate of fuel cladding failure be reduced from 1% to 0.1%, thus the horn access ports would not be required.

9.3.5 Removal of Dip Seal Oxide Deposits

Minute quantities of oxygen can reach the dip seal sodium by several ways; in-leakage through the seals, in-leakage through the access ports during inspection and maintenance, and back diffusion through the argon purge during elastomer seal or bearing replacement. In-leakage of oxygen through the seals and the amount of sodium oxide produced in the dip seal has been previously discussed (see 6.3.3).

The in-leakage of oxygen during inspection and maintenance has not been calculated, but it is expected to be small.

The sodium oxide in the dip seal is removed by the refluxed sodium dripping into the dip seal from the adjacent structures which will cause overflowing of the dip seal trough, thus continuously diluting the sodium oxide in the trough. This is possible as long as the oxide does not bridge the trough and prevent plug rotation. Rotating the plug will stir the oxide into the sodium.

The sodium/oxide mixture can also be replaced by introducing sodium into the trough through heated lances inserted through the top access ports or through the ultrasonic horn ports.

9.3.6 Inspection of Deck Weldment

The surface of the plates and forgings, and the welds of the deck which are accessible from the HAA area, can be easily ultrasonic and dye penetrant inspected. The shielding plates above the cone plate are removed to provide access to the welds located below the shielding plates.

9.3.7 Inspection of Vessel Support Structure Weldment

The surfaces of the plates and forgings and the welds of the support structure weldment can be ultrasonic and dye penetrant inspected from the interior of the U-ring vessel support structure. The top is open which provides easy access to the interior.

9.3.8 Inspection of Vessel Flange-to-Shell Weld Joint

The inspection of the vessel flange-to-shell weld joint is done by either visual or dye penetrant inspection methods. The results of UT inspection of stainless steel is not meaningful. Access to the weld joint is provided through the inspection ports provided in the inner wall of the vessel support structure.

The vault volume is normally filled with an inert gas, therefore, the inspection operations require bagging equipment to confine the inert gas.

9.3.9 Inspection of Pin Keys, Attachment Bolts, Tie Rods, and Sealing Plate

The pin keys attaching the deck to the vessel and the vessel to the support sturcture can be UT inspected in situ after removing the cover plates. The covers for the pin keys have metallic O-rings to contain the cover gas and the vault gas. Bagging equipment is used during inspection of the pin keys to contain the cover gas and inert vault gas. The installed cover plate O-rings are leak checked.

The attachment bolts of the support structure can be UT in situ. If indications are found, they can be removed, without breaking containment, for further inspection.

The redundant shielding support tie rods can be in situ UT inspected. The seal caps are removed and bagging equipment is employed.

The vessel attachment bolts are UT inspected in situ. Access to the bolts is through sealed ports in the vault gas seal plate between the vessel and the support structure.

The two seal plate welds are either UT or dye penetrant inspected.

9.3.10 Crack Repairs

Although not anticipated, cracks that may develop in the plates, forgings, and welds of the deck and support structure weldments are repairable. There is adequate space and access to the interiors of both structures to allow operation of the necessary machining and welding equipment.

The equipment and procedures are not discussed in this report.

9.3.11 Replacement of Pin Keys, Bolts, and Tie Rod

The pin keys, bolts, and redundant shielding support tie rod can be replaced if found faulty during inspection. Square shanks, threaded holes, etc., are provided in each to provide attachment for removal equipment. Bagging equipment is used where access to the items penetrate the cover gas and vault gas boundaries.

10.0 SUMMARY OF FEATURES AND IMPROVEMENTS

10.1 Features

The following are key features and characteristics of the Reactor Cover System components.

10.1.1 Seal, Bearing, and Support Structure

- Limits cover gas leakage to acceptable levels.
- Limits air in-leakage to cover gas.
- Support and bearing structurally adequate.
- Limits deposits in annuli.
- Provides acceptable inflatable seal environment.
- Accommodates large radial runouts.
- Accommodates thermal expansion.
- Accommodates reactor sodium coolant temperatures.
- Inflatable seal easily replaceable.
- Seal and housing replaceable as a unit.
- Facilitates bearing removal.
- Permits in-place lubrication and inspection of bearing and inflatable seal.
- Prevents entry of lubricant into annuli.
- Accommodates loose tolerances of mating parts.
- Facilitates removal of dip seal and annulus wall deposits.
- Bearing lubrication not degraded by frost.

- Width of support is small which holds down diameters of plugs.
- There are no active control systems.
- Each bearing support is structurally adequate to use as a lifting fixture with hydraulic "biach" jacks to lower and raise the plugs for bearing removal.
- Dip seal operating temperature will limit amount of vapor from dip seal which deposits on annulus walls.
- Access is provided to rewet the dip seal surfaces - if required.
- All static seals are double and buffered.
- The method of controlling gas leakage during static and dynamic modes have been proven.
- The amount of radioactive gas leakage into the HAA with a dip seal is predictable and acceptable.
- Access ports are provided at the top of the annulus and at the dip seal for removal of sodium oxide deposits.
- Plugs stay centered to each other and to the deck during sodium coolant temperature changes.

10.1.2 Deck Structure

- Passively cooled structure.
- Redundant shielding supports provided.
- Accommodates two DDHRX and one fuel transfer port.
- Provides for angular movement of DDHRS.
- Contains cover gas at DDHRX mounting by metallic membrane seal.
- Top accessible surfaces are below 150^{o}F at all reactor operating conditions.
- Provides easy access for inservice inspection of the plates, welds, shielding support bolts and pin keys.
- Simple shaped structure which is easily fabricated and installed.
- Reflective type plate insulation used is a proven concept.
- CDA energy absorbers can be incorporated if required.

- The shielding plates and reflective insulation are easily attached.
- Pin keys are used to attach deck to vessel.
- The stresses and deflections are low.
- Adequate "shutdown" shielding is provided for inservice inspection operations.
- The thermal stresses are low.

10.1.3 Support Structure

- The support is a cantilever type of structure which provides redundancy.
- The stresses and deflections are low.
- The structure can be passively cooled. All accessible surfaces are below 150°F for all reactor operating conditions.
- Provides easy access for inservice inspection of plates, forgings, welds, bolts, and pin keys.
- Provides access for inspection of vessel flange-to-shell joint.
- Majority of structure is not part of vault containment boundary.
- Attachment bolts to embedment are outside of vault containment boundary.
- The structure is easily fabricated and installed.
- The structure requires minimal space.
- Construction of concrete shield surrounds is not dependent on delivery of the support structure.

10.2 Improvements

The following are the improvements developed by this study.

10.2.1 Seal, Bearing, and Support Structure

- Relocated seal above bearing to provide easy access.
- Reduced width of support structure and bearing assembly to hold-down diameter of the cover.
- Support structure strengthened so it can be used as a lifting fixture to lower the plug for bearing removal.
- Catch trough and no-drip grease provided to prevent entry of bearing lubricant into the annulus.
- Inspection ports provided for inservice inspection of the bearing and inflatable seals.
- Loose tolerances of parts accommodated by use of tolerance shims.
- An overpressure seal added to retain cover gas in the event the pressure becomes too great to be retained by the inflatable seals.
- A protector seal is provided to prevent air (ozone) contact with the inflatable seals to increase their longevity.
- The CDA keys are relocated below the bearing which provides structurally adequate members having small space requirements.
- The inflatable seals are wider to allow large radial runout of the seal rider blade.
- Access ports are provided for rewetting the sodium dip-seal trough surfaces.

10.2.2 Deck Structure

- Redundant shielding plate supports are provided.
- The DDHRX support and seal were defined.
- The deck-to-vessel attachment is modified by replacing the keys and keyways with pin keys.
- The shielding above the cone plate can be easily removed for inservice inspection.

- The thicknesses of the cone plate and the cylinders at each end of the cone plate are increased to reduce stresses and deflections.
- The horizontal load capability of the LRP bearing is increased by providing a backup member.
- The reflective insulation stack height is increased, thus reducing the top surface temperature of the deck and the thermal stresses in the weldment.
- The inner and outer cylinder forgings are simplified by modifying their shape.
- The DDHRX support is modified to provide radial angular motion capability.

10.2.3 Vessel Support Structure

- The vessel-to-structure attachment is modified by replacing the keys and keyways with pin keys.
- The substructure below the vessel support is eliminated.
- The height and width is reduced.
- The access to the flange-to-shell joint are improved.
- The thicknesses of the forgings are reduced.
- The structure-to-concrete attachment is modified by replacing the keys and keyways with pin keys.

11.0 RECOMMENDED ENGINEERING AND DEVELOPMENT EFFORT

The following are recommended areas for follow-on engineering and development of the reactor cover.

11.1 Engineering

1) Perform detail design and analysis of the bearing, DDHRX mounting, and fuel transfer port installation.

2) Determine methods to decrease the undesirable temperature gradients in the vessel wall. Revisions to the lower part of the deck may be necessary.

3) Conduct thermal transient analysis to determine thermal stresses and movements of plugs, deck, and support.

4) Conduct detailed thermal and stress analysis for the:

   a) LRP dip seal region
   b) Heat exchanger penetration and mounting area
   c) Fuel transfer port penetration and mounting area

5) Improve the design of the deck, vessel support, and vessel flange to reduce costs.

6) Design and analyze the vessel support substructure.

7) Review design to eliminate vessel hold-down bolts.

8) Continue with reflective insulation thermal and mechanical design and assembly procedure in the plugs and deck.

9) Prepare outline specifications for:

   Plugs
   Deck
   Vessel Support
   Bearing
   Seals

10) Identify and prepare sketches of the major maintenance and inspection equipment.

11) Investigate alternate methods to attach the shielding plates in the deck structure and the rotating plugs.

12) Perform a study to determine if the fuel pin cladding failure rate can be reduced from 1.0% to 0.1%. The effect simplifies the reactor cover by eliminating the need for the capability to rewet the sodium wetted dip seal surfaces, which, in turn, eliminates the access ports for insertion of the rewetting tools.

13) Develop system computer model with support structure, DDHRX, etc.
14) Develop a detailed structural model of the conical deck.
15) Develop computer code for modeling and estimating gas volume purge systems.

11.2 Development

1) Conduct additional test of sodium dip seals with high O_2 content and lower operating temperatures to determine their effects on plug rotational torque and sealing capabilities.
2) Test the wide inflatable seal configuration.
3) Test the overpressure seal.
4) Perform a mockup test, which includes the vessel support structure interface, to determine the equipment and procedures required for inservice inspection of the vessel flange-to-shell weld joint. This would be done after considerable design work had been accomplished.
5) Conduct tests to reduce breakaway drag for inflatable seals.

12.0 REFERENCES

1. N254WPL110001, Revision A, dated April 4, 1978, "Large Systems Improvements (Liquid Metal Systems Development) Work Plan"

2. IL 650-78-055 dated February 7, 1978, T. Shimazaki, "Sodium Frost Deposition in PLBR Plug Annuli"

3. AI Document AI-BD-DOE-77-34, Status Report: December 1, 1977, by staff, issued January 9, 1978, "Cover Gas Seal Components, SA026"

4. AI Document AI-BD-DOE-78-5, A Technical Review by F. H. Welch dated February 8, 1978, "Cover Gas Seals"

5. N254SR231001, W. Castle, "Large System Improvement (LSI) Reactor Cover Structural Analysis"

6. N254TI231002 dated June 30, 1978, J. A. McEdwards, "Report: Reactor Cover - Seals, Bearing, and Support System Investigation and Recommendation"

7. N254TI30004 dated June 17, 1978, D. M. Harrison, "Thermal Analysis of Cone Deck/Support Concept"

716-J.41/sjd