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FFTF REACTOR VESSEL
CONCEPT EVALUATION SUMMARY

July 1969

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FFTF REACTOR VESSEL
CONCEPT EVALUATION SUMMARY*

Compiled By

D. J. Oakley

Engineering Department
FFTF Project

July 1969

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ABSTRACT

Two concepts embodying proposed design of the FFTF reactor pressure were comparatively evaluated for the purpose of selecting the configuration demonstrating the greater overall advantage. The two concepts, the Annular Inlet and Piped Bottom Inlet, differ primarily in location of inlet nozzles, method of vessel wall cooling, and containment of system inlet pressure. Principal areas of the study involved methods of fabrication, ease of inspection, thermal balance, individual design features, accident containment capabilities, shock and vibration responses, heat transport and emergency cooling factors, and cost. Results of the detailed evaluations were concluded, from the standpoint of overall advantages, to favor the Piped Bottom Inlet concept.

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FFTF REACTOR VESSEL CONCEPT EVALUATION SUMMARY

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to evaluate two reactor vessel concepts proposed for use as the FTR vessel and, based upon this evaluation, to recommend one as the reference vessel concept. The important features of each concept are compared and evaluated on a relative basis, and the concept most advantageous for FTR use is indicated.

1.2 BACKGROUND

In a meeting between Battelle-Northwest (BNW), Westinghouse (W), and Babcock & Wilcox (B&W)⁽¹⁾ at Waltz Mill, Pennsylvania, in August 1968, a reactor vessel concept was discussed. During a subsequent meeting,⁽²⁾ a reactor vessel concept based upon that of a pressurized water reactor was proposed (SK-345592J, Appendix D). Continued meetings^(3,4) failed to produce a reference vessel concept selection between the proposed Piped Bottom Inlet concept (SK-3-14540, Appendix D) and the proposed Annular Inlet concept (SK-3-45592J, Appendix D). As a result of the December 10, 1968 meeting at Richland,⁽⁴⁾ a list of work tasks was formulated to be used in selection of the FFTF Reactor Vessel Configuration. The results of these tasks, utilized as the basic measures for comparing each of the vessel concepts, are described herein. They are presented in the section "Principal Areas of Evaluation."

2.0 SUMMARY

This report evaluates two reactor vessel concepts proposed for the FTR. These concepts are the Annular Inlet and the Piped Bottom Inlet. The concepts differ mainly in the location of the inlet nozzles, the method of vessel wall cooling, and the containment of system inlet pressure. The Annular Inlet concept locates the inlet nozzles above the core, cools the vessel by use of the main coolant stream in series with the core, and contains the inlet pressure within the entire vessel. The Piped Bottom Inlet concept places the inlet nozzles below the core leading into a relatively small inlet pressure plenum (high pressure), while the majority of the cylindrical vessel is at outlet plenum pressure (low pressure) and cools the vessel walls in parallel with the core. Results of the detailed evaluation accord an overall advantage to the Piped Bottom Inlet concept.

3.0 REQUIREMENTS

3.1 INTRODUCTION

The reactor vessel functions and requirements are fulfilled by both vessel concepts. The functions and requirements place restraints on the vessel concept and are given for reference in Appendix A. The vessel function relating to protection from the effects of a Design Basis Accident (DBA) is included as a basis for comparison of the concepts considered in this report.

Three of the basic design requirements are also utilized as a basis for comparison of the two concepts considered. These are as follows:

- 1) Reactor System vibration and seismic analysis for piped bottom inlet.
- 2) Vessel wall vacuum collapse analysis (500 °F at full vacuum).
- 3) Relative inspectability of alternative concepts.

3.2 REACTOR VESSEL DESIGN TEMPERATURE

Another basic design requirement included inherently in both concepts is that the reactor vessel shall be designed for 1200 °F. This requirement refers to sustained reactor operation at a core coolant bulk temperature of 1200 °F rather than to the operating metal temperature of the reactor vessel wall. During the meeting of December 10, 1968, BNW/W/B&W⁽⁵⁾ agreed that "a metal design temperature of 1200 °F is not feasible for the FTR vessel pressure boundary. However, it is considered feasible to design and operate the FTR vessel with a 1200 °F mixed mean outlet temperature." A metal operating temperature of 1200 °F is above temperatures specified in the ASME Code for Nuclear Vessels, Section III.

3.2.1 Application of Design Criteria

Design criteria are affected by the operating conditions of the vessel which is being designed. For FFTF vessel application, design criteria must include the effect of a high temperature and a high fluence environment.

3.2.1.1 High Temperature Environment

A high temperature environment reduces the allowable fatigue stress S_a and the allowable design stress S_m . For 304 stainless steel, the effect of temperature is shown on S_a and S_m in Figure 3.1. The reduction of S_m above 1000 °F is to be noted. Values of S_a are strongly temperature dependent.

3.2.1.2 High Fluence Environment

The fluence limit allowable for 10% residual ductility is shown in Figure 3.2 for both minimum design limit and an average residual ductility. Note that the fluence limit is a maximum near 1000 °F.

Instead of the equal treatment originally accorded, the design criteria for total fluence are being modified to weight the damage factors of different energy groups.

Vessel wall cooling is required to alleviate the magnitude, rate, and duration of transient temperature time differences imposed upon the pressure boundary by the coolant and their effects upon austenitic stainless steel, rather than for reducing the specific temperature of 1200 °F. The use of these alloys under "state-of-the-art" knowledge of their mechanical properties involves unwarranted risk, particularly in the area of fatigue behavior at long hold times and elevated temperature. The reactor vessel must reliably sustain the predicted transients for 20 years under existing code rules. The discharge nozzles are particularly affected by these considerations. Analysis of a variety of candidate nozzle configurations and thermal baffles

FIGURE 3.1. Allowable Stress for Type 304 SS

FIGURE 3.2. Fluence Limit for FTR Vessel and Core Barrel as a Function of Temperature

has shown that the allowable code stress limits are exceeded if the nozzles are subjected directly to the predicted transients.

Both concepts under consideration utilize vessel wall cooling (although in a different fashion) in order to ensure vessel wall isolation from transient temperatures and within "state-of-the-art" design criteria.

3.2.2 Allowable Stresses for 304 Stainless Steel

As previously noted, the allowable design stresses (S_m) and the allowable fatigue stresses (S_a) are a function of temperature (Figure 3.1). The ASME Boiler Code presently does not exceed 800 °F, as shown by the points for Case 1331 in Figure 3.1.

3.2.2.1 S_m Values and Temperatures in Excess of 800 °F

As shown in Figure 3.1, the value of S_m between 800 and 1200 °F is reduced by approximately one half, but is not covered by Code cases. For temperatures up to approximately 1000 °F, little reduction in the value of S_m occurs.

3.2.2.2 S_a Values for Temperatures in Excess of 800 °F

The allowable fatigue stress, S_a , is sharply reduced at temperatures above 800 °F, and also by increases of allowable fatigue cycles from $n = 100$ to $n = 1000$.

3.2.3 Thermal Mechanical Design

Thermal mechanical design considers the effect of thermal stress on the structural stresses of the component. Thermal stresses are caused by differential thermal expansion produced by a changing temperature on the metal surface or surfaces, or by temperature differences between surface and bulk mean temperature.

3.2.3.1 Thermal Transients Upon Interior Vessel Surfaces

The most severe temperature transients occur in the reactor outlet plenum when the reactor is operating at steady-state at full power and then is suddenly shut down by a scram. The coolant temperature drops rapidly while the vessel walls and outlet nozzles temperatures remain at the initial levels.

3.2.3.1.1 Type 1 Transient (No Pump Scram). This coolant temperature transient occurs when the reactor is scrammed while the primary coolant pump continues to run. The time-temperature history of the coolant shown in Figure 3.3 represents the most severe operational transient which can occur.

3.2.3.1.2 Type 2 Transient (Pump Scram). This type, the normal coolant temperature transient, occurs whenever both the reactor and the primary coolant pumps are scrammed. The time-temperature history of the coolant is shown in Figure 3.4.

3.2.3.2 Thermal Stresses Developed in Reactor Vessel Wall of Various Thickness

The temperature time transients (Figures 3.3 and 3.4) were imposed on the bare vessel wall shown in Figure 3.5 for various wall thicknesses. Figures 3.6 and 3.7 show the resulting temperature-time distributions as a function of wall thickness for the transients shown on Figures 3.3 and 3.4, respectively. Note the greater initial slope and temperature differences between front and rear surfaces in the more rapid transient (Transient 1, Figure 3.6).

The maximum temperature difference between the mean temperature of the section (the average temperature between front and rear surface) and the wall surface washed by coolant is determined from the transient. The resulting temperature differences are plotted in Figures 3.8 and 3.9 as a function of wall thickness for the transients shown on Figures 3.3 and 3.4,

FIGURE 3.3. Primary System Hot Leg Transient No. 1

FIGURE 3.4. Primary System Hot Leg Transient No. 2

FIGURE 3.5. Vessel Wall Configuration

FIGURE 3.6. Temperature Profiles Transient No. 1

FIGURE 3.7. Temperature Profiles Transient No. 2

FIGURE 3.8. ΔT_{Max} Versus Thickness Transient No. 1

FIGURE 3.9. ΔT_{MAX} Versus Thickness Transient No. 2

respectively. The resulting thermal stresses for Transient 1 and 2 (Figures 3.3 and 3.4) are shown also as a function of vessel wall thickness in Figures 3.10 and 3.11, respectively. Note the resulting high stresses, particularly from Transient 1 (Figure 3.8).

Values of the stress, σ , from Figures 3.10 and 3.11, can now be plotted in Figure 3.1 (for the mean metal temperature of about 1100 °F). The resulting points indicate that, for the thicker vessel walls, the fatigue life will be very limited when compared to S_a .

3.2.3.3 Temperature Profiles and Thermal Stresses

Developed in Cooled Reactor Vessel Walls

Temperature distributions resulting from the temperature transients shown in Figures 3.3 and 3.4 may be ameliorated by flowing coolant between a thermal liner and the vessel wall. Figures 3.12 and 3.13 show such an arrangement and the temperature distributions in the vessel wall resulting from the transients shown in Figures 3.3 and 3.4. The vessel wall is observed to be virtually unaffected by the temperature transients. Thus, vessel wall cooling essentially removes the effect of the specified temperature transients from the vessel wall.

FIGURE 3.10. σ Versus Thickness Transient No. 1

FIGURE 3.11. σ Versus Thickness Transient No. 2

FIGURE 3.12. Bypass Sodium Cooling Effectiveness

FIGURE 3.13. Bypass Sodium Cooling Effectiveness Transient No. 2

4.0 DISCUSSION OF VESSEL CONCEPT

4.1 DESCRIPTION OF CONCEPTS

This comparison of reactor vessel concepts is based upon the parameters of the Piped Bottom Inlet Vessel and the Annular Inlet Vessel.

4.1.1 Piped Bottom Inlet

4.1.1.1 Vessel Arrangement (See SK-3-14540, Appendix D)

The Piped Bottom Inlet Vessel uses piping to discharge reactor coolant into an inlet plenum at the bottom of the vessel. The inlet pipes, from each of the three loops of the Heat Transport System, enter the inlet plenum at the bottom of the vessel. It is to be noted that this reactor vessel concept does not depend upon the number of inlets, but simply that the inlet pipes connect directly to the inlet plenum of the pressure vessel. The fluid pressure in the inlet plenum comprises the highest pressure in the reactor vessel, and this pressure is contained within a structurally reinforced portion of the vessel. The main portion of the reactor vessel is cylindrical and contains reactor coolant at the core outlet pressure level, plus static head pressure. Thus, the main portion of the reactor pressure vessel contains fluid at a relatively low pressure.

The reactor vessel head (closure head) closes the top of the reactor vessel, thereby containing a low-pressure cover gas above the liquid level of the reactor coolant. Reactor coolant does not wash the bottom of the vessel head.

The three reactor outlet nozzles are attached directly to the vessel at a level just above the top of the core.

The entire structure is top supported from a ring girder which rests on a foundation. The hold-down head bolts are fastened to this ring. The entire vessel is contained in a guard vessel.

4.1.1.2 Proposed Downcomer Concept Flow Path (Bottom Inlet)

The coolant enters the vessel at the inlet plenum from piped downcomers from each heat transport loop. The number of inlet nozzles does not affect the concept except for guard vessel size. From the inlet plenum, the coolant flows into an inner plenum through a flow straightener, and then into the core with some flow directed for vessel wall cooling.

The coolant exits from the driver ducts into the outlet plenum and leaves the reactor vessel through the outlet nozzles, one for each heat transport loop. A flow balance diagram for the piped bottom inlet is shown in Figure 4.1.

4.1.2 Annular Inlet (See SK-345592J, Appendix D)

4.1.2.1 Vessel Arrangement

The annular inlet vessel concept is basically a conventional pressurized water reactor design. Inlet nozzles (the number of which does not affect the concept) from the heat transport loop penetrate the reactor vessel at a high elevation (near the top of the vessel), and are distributed circumferentially around the vessel. Outlet nozzles at the same elevation also penetrate the vessel and are also distributed circumferentially.

A second vessel, the core barrel, internal and concentric to the reactor vessel, supports the core structure and forms a flow path for coolant from the inlet pipe to the core.

The entire structure is top-supported on a ring which rests on a foundation. The hold-down head bolts are fastened to this ring. A skirt at the lower end provides restraint against lateral movement. The reactor vessel is contained in a guard vessel.

NOTE: Flow amounts assumed per analysis (Appendices B & C).

FIGURE 4.1. Piped Bottom Inlet Concept

4.1.2.2 Annular Concept Flow Path (Annular Inlet)

Coolant enters near the top of the reactor vessel from the inlet nozzles, and flows downward through an annulus between vessel and core barrel to the inlet plenum. From the inlet plenum, coolant flows through the core and exits into a plenum region above the fuel ducts. It leaves this plenum by flowing to the outlet nozzles through "jumpers" connecting the core barrel to the outlet nozzles of the vessel. There is one outlet nozzle for each heat transport loop. A flow balance diagram for the annular inlet is shown in Figure 4.2.

4.2 SIMILARITY BETWEEN CONCEPTS

Since the concepts considered are reactor vessel designs, the components contained within the vessels are generally similar. Both concepts are analogous in that both reactor vessels perform the same functions and requirements (stated in Appendix A).

- The core components in both concepts, except for core structure, are identical. Figure 4.3 shows the core cross section.
- The hydraulic balance concept in both vessel concepts is identical. However, the hydraulic hold-down receptable and its arrangement are different between the concepts, as described below. The hold-down force and hydraulic leakage for hold-down is similar between the concepts.
- Locations of outlet nozzles are similar. Both are above the core and are distributed circumferentially. The location of the outlet nozzles can be made identical between concepts.
- Closure head is held down by bolts in both concepts. The bolts are long (~10 ft) to allow stretching for DBA energy absorption without failure.

NOTE: Flow amounts assumed per analysis (Appendices B & C).

FIGURE 4.2. Annular Inlet Concept

FIGURE 4.3. Core Map Concept 5-A

- The closure head covers the vessel opening and allows passage of exactly the same number of components (i.e., control rods, closed loops, instrumentation, fuel handling machine, etc.) and have exactly the same configuration of openings.
- The reactor vessel wall is cooled in order to protect it from rapid coolant transient temperatures. The cooling is required in order to ensure a vessel lifetime equal to that of the reactor (20 years).

4.3 DIFFERENCES BETWEEN CONCEPTS

The basic differences between concepts exist primarily in nozzle location and secondarily in the method of vessel cooling. Figure 4.4 presents a comparative side-by-side view of the two designs.

4.3.1 Inlet Nozzle Location

The inlet nozzles in the Annular Inlet concept enter the vessel above the core and are distributed circumferentially around the vessel. Coolant is discharged into an annulus between vessel and core barrel. The incoming coolant exerts a high internal pressure on the reactor vessel and an external pressure on the core barrel.

The Bottom Inlet concept places the inlet nozzles at the bottom of the reactor, distributing them circumferentially around a high pressure inlet plenum.

Thus, the main difference between concepts is that the inlet annulus vessel must contain a relatively high pressure while the cylindrical portion of the bottom inlet vessel contains a low pressure. However, a significant criterion for vessel wall thickness is the vacuum collapse analysis (see Section 6.4.4) which indicates a required wall thickness of approximately 2 in. for both the system pressure containment vessel and the low pressure fluid container.

FIGURE 4.4. Reactor Vessel Design Features

4.3.2 Reactor Vessel Cooling

Both concepts provide for cooling the reactor vessel as protection against transient temperatures of the core effluent. However, the Annular Inlet concept specifies cooling the vessel with 95% of the total reactor flow while by-passing only 5% of the flow. Thus, the vessel cooling path is placed in series with the core.

The Bottom Inlet concept also utilizes vessel wall cooling, but places the wall cooling path in parallel with the core. This path utilizes 10% of the flow.

The liners used to form the inner boundary of the by-pass coolant are radically different in concept. The inner boundary in the Annular Inlet concept is formed by the core barrel lines. The core barrel is a structural component supporting both the core and containing the external pressure of the incoming fluid. It is a heavy structural component requiring thermal baffles and internal cooling. In addition, a number of leakage paths in the core barrel allow fluid to by-pass the core and escape to the outlet plenum.

The annulus between core barrel and pressure vessel of the Annular Inlet concept, containing high-pressure inlet coolant, poses a difficult problem in conducting the hot coolant from the outlet plenum to the outlet nozzles across this annulus. A sleeve, termed a "jumper," conceived to perform this function will require solution of numerous problems to assure its success. Among the problems are:

- External pressure loading
- Alignment
- Accommodation of thermal expansion
- Prevention of by-pass leakage
- Thermal stresses induced by temperature transients
- Retention
- Tolerances and fits in fabrication.

The Bottom Inlet concept utilizes a thermal liner to form the inner boundary of the flow path for the vessel coolant. This liner is not a structural member as it supports only its own weight and in the coolant channel, is provided with vertical ribs to form coolant channels for preventing formation of natural convection loops and consequent thermal striping. No additional leakage paths exist in this thin shell.

4.3.3 Reactor Hydraulics

The reactor hydraulics, except for the exits of the pressure vessel cooling paths, differ mainly in the inlet regions.

4.3.3.1 Inlet Plenum

In the Annular Inlet concept, both the annulus and the inlet plenum region are at high inlet pressure. Flow entering from the nozzles impinges on the core barrel and flows circumferentially around the core barrel in opposite directions from the nozzle. Each stream meets an oncoming stream from the neighboring nozzle to produce a stagnation zone where the kinetic energy of the fluid velocity is converted to static pressure. The maximum downward flow exists from these regions. Below the nozzles, reverse flow from the plenum to the nozzles usually occurs. Large rotating vortices, oscillating flow regions, and some stagnant regions exist between the downward and upward flow regimes.

The flow pattern in the annulus causes numerous vortices in the inlet plenum which can detrimentally affect the core flow distribution, as shown by hydraulic tests on a FFTF Annular Inlet flow model.⁽⁶⁾ Uniform flow characteristics can be achieved by a slowly rotating flow in the annulus created by flow baffles at the inlet nozzles.

In the Bottom Inlet concept, the inlet nozzles enter the inlet plenum directly and discharge high velocity streams directly into the plenum. Tests now being conducted (on a

toroidal shaped inlet plenum) show that an angular displacement of the inlet nozzles creates a slowly rotating flow which also provides uniform flow characteristics. Similar tests will be conducted on an elliptically shaped inlet plenum in April 1969.

It is not clear which of the two concepts, top or bottom, has an advantage in terms of the conceptual design plenum factor. Inlet coolant flow distribution is recognized as a serious problem for both vessel concepts and must be solved by careful and experimental development testing.

4.3.3.2 Mixing

In both concepts, utilizing slowly rotating flow in the plenums and annulus promotes good mixing. Mixing will prevent thermal striping, i.e. a region of hotter or colder fluid than the surrounding fluid will cause an abrupt temperature change on the boundaries except during very low flow where laminar flow exists. Thermal striping causes additional thermal stresses in the vessels containing the fluid. Thus, both concepts could be affected by thermal striping without use of proper hydraulic design to promote mixing.

5.0 SAFETY EVALUATION

Evaluation of the conceptual configurations of the two alternative vessel designs, based upon the capability of each to mitigate or prevent potential accident conditions, has not indicated any major preference for one over the other. Two design concept areas of difference concerning safety have been identified as follows:

- Location of the inlet coolant nozzles
- Response to core disruptive conditions.

The safety considerations for each of these areas are described briefly in the following section. Specific design details shown on the particular drawings for these two concepts, but not considered relevant to concept selection and outside the scope of the assessment at this time, were not evaluated.

5.1 LOCATIONS OF INLET COOLANT NOZZLES

As shown in the configuration drawings, the Piped Bottom Inlet concept shows the inlet coolant pipes penetrating the reactor vessel below the core elevation in the high-pressure plenum region, whereas the annular concept shows all penetrations well above the core.

In many reactor systems, including the FTR, core submergence in the primary coolant is one essential requirement for adequate heat removal to prevent ultimate core meltdown. Since the probability of vessel failure is sometimes greater in regions of discontinuities such as pipe nozzles, emphasis is usually placed on locating all nozzles at the higher elevations to reduce the probability of complete loss of cooling to the core.

In early concept evaluations for the FTR, all vessel penetrations were located above the top plane of the active core. However, this location was recognized as but one means

of implementing the basic requirement for maintaining continuity of cooling, stated in Criterion 1.3 of the Design Safety Criteria for the Reactor Vessel and Shield Component⁽⁷⁾ as follows:

The vessel design will be coordinated with the emergency core cooling system and guard vessel design to maintain reactor core cooling for the intact core even in the unlikely event of a 'Major Fault.'

Incorporation of the guard vessel as an engineered safeguard effectively limits the quantity of coolant which may be lost from the primary coolant system even with complete failure of one of the inlet coolant pipes. Therefore, a reliable guard vessel will ensure that protection is provided for maintaining emergency core cooling upon the occurrence of a major pipe failure independent of the nozzle elevations. However, reliance upon the guard vessel to protect against loss of cooling, particularly in the Piped Bottom Inlet concept, emphasizes that any failure originating with the reactor vessel must be adequately alleviated to prevent progressive failure of the guard vessel. Therefore, design precautions must be taken to ensure against pipe whiplash or missile generation as a result of the pipe or nozzle failure.

In the Piped Bottom Inlet concept, the probability of violation of the guard vessel in the event of a pipe rupture is higher with the bottom inlet than with the Annular Vessel concept.

5.2 RESPONSE TO CORE DISRUPTIVE CONDITIONS

The responses of the vessel and the head to the forces generated in a core disruptive accident are somewhat dependent upon the rigidity of the vessel wall. The current methods of analysis indicate that the dominant lifting force on the top

head following core disruption results from impact of the sodium slug accelerated upward by the expanding vapor products within the core region. Thus, any relief of this pressure by timely radial deformation of the vessel wall will reduce the magnitude of the subsequent slug impact upon the top head.

The Piped Bottom Inlet concept for the reactor vessel permits a reduced effective wall thickness (including vessel wall and core barrel) because of its lower design pressure as compared to the Annular Inlet concept. Therefore, the Piped Bottom Inlet concept is expected to radially deform more than the Annular Inlet concept under given DBA conditions. However, the uncertainties of the analysis and the complicating effects of the internal structures make it difficult to quantify the amount of credit which can be taken for increased radial deformation of one concept over the other.

Other design considerations are relevant to the wall thickness of the vessels. For example, each concept must be capable of withstanding less severe accident conditions without an effect upon its capability to operate throughout the facility lifetime.

The specific response of either concept as a mitigating factor during core disruptive conditions is not expected to be significant considering the uncertainties involved.

6.0 PRINCIPAL AREAS OF EVALUATION

Each vessel configuration is evaluated to determine its effects on the FFTF Project and upon the overall plant design, including detailed regions.

The effects on the FFTF Project are felt primarily in the relative cost of each configuration, the relative fabricability and its effect on the overall schedule, and in the relative inspectability. These effects, of course, are closely related.

Overall plant design is affected by the relative thermal balance, design considerations of each configuration, the impact of each configuration upon the Heat Transport System, the DBA analysis, the vibration and seismic analysis, and the vacuum collapse analysis.

6.1 MANUFACTURABILITY

A comparative evaluation of the fabricability of both vessel concepts was performed. This study was confined primarily to the reactor vessel and head, since these are the most unique components. The required forgings were assumed to be procurable in one piece and the design for both concepts to provide for final adjustment of the grid plate to obtain necessary head-grid plate alignment.

6.1.1 Bottom Inlet Concept

The bottom-inlet vessel has the advantages of:

- Requiring relatively few forgings, thus shortening the fabrication span time from both a procurement and fabrication standpoint.
- Simplicity of overall design. There are relatively few areas where separate components must fit closely at final assembly.

The bottom-inlet vessel, primarily of thin wall construction with a large diameter and length, requires special procedures to maintain alignment. Fabrication and shipping considerations related to the thin wall, large diameter construction result in the following disadvantages:

1. The circularity of the vessel must be held to reasonable limits by using closely-spaced strut rings during fabrication. Strut rings would also be required during machining operations where the vessel centerline is horizontal. The rings would also be required for any other operations where the vessel is horizontal, including shipping.
2. The thermal liner must also be controlled for circularity in a manner similar to that used for the vessel to maintain a reasonably uniform cooling annulus and to ensure proper alignment with the outlet nozzles. However, assembly and shipment then becomes more difficult because two concentric cylinders instead of one must be controlled.
3. The bottom-inlet plenum is another region requiring special fabrication procedures. The lower head must be fabricated in sections in a manner designed to prevent misalignment problems. The upper portion of the plenum will be the most difficult section of the high pressure plenum to fabricate, since it involves nozzles, a vessel shell, plate, and core support forgings.

6.1.2 Annular Inlet Concept

The vessel shell of this concept, approximately the same thickness as the bottom inlet vessel but somewhat larger in diameter will provide the same relatively thin shell, and will retain many of the same circularity problems identified in the Bottom Inlet concept. The Annular Inlet concept has the following advantages:

- Several forgings required in the reactor vessel shell and lend additional stiffness to the assembly and ease the machining problems.
- The lower head of the reactor vessel provides additional stiffness to the reactor vessel shell, and may thus be easier to fabricate.

The annular inlet vessel, also a thin walled vessel with a large diameter and length, presents alignment problems similar to those of the piped bottom inlet vessel. Disadvantages are as follows:

- More pieces are involved than with the bottom inlet vessel.
- The upper extension of the shell will require greater thickness than presently depicted in order to machine the radial seal surface.
- The core barrels in the top-inlet vessel have an outer shell of 4-in. thickness requiring a tightly controlled ovality. Full machining of these pieces, both outside and inside, will be required to achieve the required circularity and uniformity of wall thickness. Even though cylinder thickness is adequate, the operation will be quite difficult.
- The core support ring on the lower core barrel, a forging most likely procurable in four sections, would be assembled by welding. These forgings may be difficult to procure.
- The four layers of thermal shielding inside the core barrels and the supports for the shields present a high degree of fabrication difficulty. The outer ring and the core barrel form an annulus for cooling flow and, therefore, this space must be sealed from the inner, low-pressure fluid.

- The precise, time-consuming, and expensive techniques required in maintaining a uniform annulus are further complicated by the extremely small clearances between each of the shields. These clearances will require that each of the 52 thermal shield rings of 1.5-in. thickness be machined inside and out to achieve the required circularity and wall thickness.
- The support bars for the shielding and the core barrel must be of equivalent circularity and able to accept, hold, and seal the thermal shielding rings. The assembly of these pieces is a major task which becomes even more difficult in practice than in theory. Tightly controlled weld shrinkage and exacting alignment techniques will be required for the assembly.
- The outlet nozzles of the top-inlet vessel represent the connecting points between the core barrel and the vessel shell. The jumper traversing the coolant inlet annulus will require precise tolerances and is, in itself, a complex shape to fabricate. The most difficult task, however, will be aligning the openings in the core barrel with those of the vessel shell and maintaining the required clearances between the jumper and the two shells.
- The openings in the core barrel may require machining with the core barrel installed in the vessel to provide true alignment with the vessel nozzles. The jumper must then be fabricated to suit the resulting openings. Clearances are a problem here because of the high differential pressure across the jumper and core barrel and the resulting leakage that could occur with large clearances in this area.
- This vessel is larger in diameter and, consequently, has larger forgings. Since the procurement of large steel

forgings has historically been a problem, more uncertainty exists in this area with the top inlet vessel.

6.1.3 Conclusions

Considering the advantages and disadvantages of the fabricability study, the piped bottom inlet vessel is concluded to be significantly easier to fabricate because of core barrel problems associated with the top inlet vessel. This conclusion considers the complexity of the individual manufacturing operations involved with each design, as well as potential pitfalls during the entire fabrication process.

Additional difficulties common to both vessels are presented by shipping and heat treatment. Shipping will be difficult because shell thickness requires the vessel be supported to maintain circular as well as axial stability. Heat treatment of the vessel, to achieve dimensional stability in operation, will require annealing which is probably not feasible for the entire vessel. The temperature producing the desired effect without introducing other problems must be determined in lieu of complete annealing.

Since both vessels require adjustment of the core grid plate in the field, no significant advantage arises from fitting several smaller pieces together rather than one large and one small component, i.e. top-inlet and bottom inlet, respectively.

6.1.4 Feasibility Evaluation of FFTF Closure Head

The closure head is a vessel concept dependent only upon the equivalent DBA derived static pressure that it must withstand (see Section 6.5) and the approximately 1.5-ft increase in diameter required by the Annular Inlet concept with respect to the Bottom Inlet concept. This size effect is summarized in Table 6.1.

TABLE 6.1. *Closure Head Size Summary*

Condition	Annular Inlet Concept	Bottom Inlet Concept
6-Hole Cover, Dwg. No. SK-3-14541 Appendix D	Vessel Diam, 19 1/2 ft Closure Head OD, 23 1/2 ft	Vessel Diam, 18 ft Closure Head OD, 22 ft
3-Hole Cover, Dwg. No. SK-3-12897 Appendix D	Vessel Diam, 18 1/2 ft Closure Head OD, 22 1/2 ft	Vessel Diam, 17 ft Closure Head OD, 21 ft

Investigation into the feasibility of the closure head was directed toward both design and fabrication aspects. Its major goal was to determine the feasibility of a large closure head under near term state-of-the-art conditions. The question of feasibility was prompted by the requirements of diameter and thickness, penetration pattern, behavior under DBA conditions, and early delivery date. To make the determination, three heads were considered. These are described in a following section. However, no attempt was made to extrapolate the designs for the purpose of determining parameters such as maximum thickness, or the effect of increases or decreases in diameter.

The FFTF reactor vessel head must fulfill two criteria under the DBA condition. First, the head or any portion of it must not shear off and become a projectile during the initial sodium impact and, secondly, the head must withstand the pressure remaining after the sodium impulse.

In this study, the feasibility of three head configuration concepts have been investigated. The three concepts investigated include a flat head built from sections and welded into one solid piece, a flat head comprised of an inner disc and an outer ring bolted together, and an ellipsoidal head. The study of these concepts has been directed towards feasibility rather than design.

6.1.4.1 Criteria

This study has assumed the head loading to be at an initial sodium impact of 446 ft/sec, a mass of 2328 slugs (75,000 lb), and an after-pressure of 1200 psi.⁽⁸⁾ The head has also been assumed to be isothermal at 400 °F. The hole pattern considered is shown in Drawing SK-3-14541, Appendix D. The head diameter considered is for an 18.5-ft ID vessel. A larger vessel diameter would require a correspondingly thicker head and add fabrication difficulty.

6.1.4.2 Evaluation

The solid flat head requires a thickness of about 3 ft, thus presenting several fabrication problems in welding and meeting all the nondestructive testing requirements of Section III of the ASME Code. Procurement of the large forgings is also expected to be difficult. Heating the head uniformly and maintaining an isothermal condition will be more difficult than the solution of problems caused by a thinner head because of the 3-ft thickness. Of the three concepts, the solid flat head appears the most difficult to fabricate and the one requiring the longest fabrication schedule.

The second concept investigated was the segmented (disc and ring) design. In this design, the head is comprised of an inner disc bolted to an outer ring. The size of this head is the same as that in the solid flat-head concept. Therefore, most of the problems associated with the solid head also apply to this concept. The basic advantage of this concept is that much of the welding required by the solid flat head can be eliminated and possibly shorten the time required for fabrication. However, sealing of the disc-ring interface may be equally difficult, and the problem is complicated by the outer large penetrations passing through the subject interface. Additional investigation is required before the true magnitude of this problem can be determined.

The final concept considered was a 10-in. thick ellipsoidal head requiring 30 plates of 1-in. thickness beneath it to act as gamma shields and thermal barriers. Some of these plates are required by any concept for temperature control (see Drawing SK-3-14541, Appendix D). This concept should meet the design and fabrication requirements of Section III of the ASME Code. The ellipsoidal head is by far the least difficult to fabricate and indicates the shortest schedule. However, a major design penalty requiring evaluation by the system designer, and therefore not treated herein, is the additional system height required.

6.1.4.3 Conclusions

The increased equivalent DBA-derived static design pressure at the annular inlet, indicated by preliminary calculations as approximately three times that at the bottom inlet (see Section 6.5) is a factor contributing to greater design and manufacturing difficulties. For this reason, the Bottom Inlet concept is preferred on a Closure Head Manufacturability Basis.

It is felt that experimental stress analysis is necessary in order to evaluate accurately the effect of the irregular hole pattern shown in Drawing SK-3-14541, Appendix D. This effort will require approximately six months of work. In this study the hole pattern has been evaluated on the basis of engineering judgement, and should be a realistic approximation.

6.2 RELATIVE INSPECTABILITY AND SURVEILLANCE

This evaluation was based upon the piped bottom inlet (Drawing SK-3-14540, modified by Drawing SK-3-12899, Appendix D) so that the outlet nozzle was lowered to an elevation near the top of the core, the thermal sleeve was assumed to be the same as that in the Annular Inlet concept, and the siphon breaker was removed from inside the vessel. The guard vessel indicated in Drawing SK-3-14540, Appendix D was assumed

to open at the top and allow access to the external surface of the vessel. The major components of each concept are rated on a scale of potential necessity for inspection and surveillance, and availability of access and space.

6.2.1 Bases for Evaluation

The inspection requirements are based on input from the Westinghouse Task 12 study,⁽⁹⁾ review of the intent of the USASI N-45 Code for In-service Inspection,⁽¹⁰⁾ and on requirements under review and evaluation by Southwest Research Institute as the initial phase of their conceptual design contract.⁽¹¹⁾

The access and space provisions for inspection include a capability for visual inspections, and measurements of motion or vibration, displacement or movement, dimensional changes, and volume of the material by such means as ultrasonic transducers. Unless specified in the ratings, "surface" refers to the capability for several or all of these inspections. All inspections inside the vessel require draining the sodium below the component of interest. Should these inspections require lowering the sodium below the core level, the removal of all fuel and an extensive shutdown period would be compelled. Inspections in this drained sodium environment would not include volumetric inspections of components in place.

The placement of metallurgical and/or corrosion coupons adjacent to the component to determine the behavior of the material in the radiation and/or liquid sodium environment, as well as the capability for making neutron flux, fluence, and/or spectra measurements in conjunction with the coupons would require evaluation.

6.2.2 Inspection Criteria

Access and space shall be available to permit visual, dimensional, vibration, displacement, and/or volumetric

in-service inspections of the following areas, from the direction specified, and for the reasons indicated:

Component	Direction	Reason
Reactor vessel		
Surface	Externally	Primary coolant boundary
Surface (visual)	Internally	Effect of sodium
Vertical wall to bottom head weld	Externally	Primary coolant boundary
Top flange		
Flange material	Top Surface	Vessel support
Vessel weld	Internally	Critical flange area
Inlet nozzles		
Nozzle material	Externally	Primary coolant boundary
Vessel weld	Externally	Critical nozzle area
Pipe weld	Externally	Critical nozzle area
Outlet nozzles		
Nozzle material	Externally	Primary coolant boundary
Vessel weld	Externally	Critical nozzle area
Pipe weld	Externally	Critical nozzle area
Thermal sleeve	Internally	Primary flow outlet (Drawing SK-345592J)
Vessel liner (core barrel of Drawing SK-3-14540) surface	Internally	Vessel coolant flow (Drawing SK-3-14540) Primary coolant channel (Drawing SK-345592J)
Vessel contact surface-bottom	Internally	Positions liner
Vessel contact surface, mid-elevation	Internally	Supports core (Drawing SK-345592J)
Top flange to barrel weld	Internally	Sodium liquid-gas interface
Mid-elevation flange weld	Internally	Critical area of flange supporting core (Drawing SK-345592J)

<u>Component</u>	<u>Direction</u>	<u>Reason</u>
Bottom flange weld	Internally	Supports core (Drawing SK-345592J)
Bottom support structure shear ledge welds	Internally	Core support and primary coolant boundary
Support collar contact	Internally	Core support
Structure	Internally	Core support
Inlet plenum surface (visual)	Internally	Flow entrance to the core
Grid plate		
Surface in fuel area	Upper side	Core support
Surface in reflector and shield area	Upper side	Core support
Lower high pressure zone surface (visual)	Internally	Flow to core
External vessel supports	Externally	Vessel lateral motion

6.2.3 Surveillance Criteria

Access and space shall be available for placement of surveillance coupons and neutron monitors adjacent to the following components for the reasons indicated:

<u>Component</u>	<u>Location</u>	<u>Reason</u>
Reactor vessel	Inside wall	Primary coolant boundary
Vessel liner (core barrel of Drawing SK-345592J)	Inside wall	Primary coolant channel
Outlet nozzles	Inside edge	High temperature and erosion
Grid plates	In fuel nose piece	Core support
Reflector	In reflector can	Predict material service life
Shield	In shield can	Predict material service life

6.2.4 Evaluation Method and Ratings

The respective requirements for inspection and for surveillance of each component of each concept were evaluated on the following relative bases:

- (3) Most probable
- (2) Possible
- (1) General interest only

Each component of each concept was evaluated for accessibility and for space adequacy on the following relative bases:

	<u>Accessibility</u>	<u>Space</u>
(3)	Easy	Adequate
(2)	Difficult	Limited
(1)	Extremely difficult	Very limited

The rating under each component was found by multiplying the ratings for requirements, accessibility, and space since all are interrelated and both space and access are required to conduct inspections or surveillance. The total rating for each concept is the percentage of the sum of the component totals for that concept to the sum of the maximum totals for the components applicable to that concept. The maximum totals were found by multiplying the actual requirement rating for the component by the maximum of $3 \times 3 = 9$ rating for access and space.

6.2.5 Results

The evaluations are tabulated in Tables E-1 and E-2 of Appendix E. The total evaluation gave these results:

<u>Total Rating</u>	<u>Concept</u>	
	<u>Piped (Drawing SK-3-14540)</u>	<u>Annular (Drawing SK-345592J)</u>
Inspection	65%	59%
Surveillance	55%	36%
Grand total	63%	54%

Based upon this evaluation, the Piped Bottom Inlet concept is favored. For inspection, the Piped Bottom Inlet concept has a low relative rating in the inlet nozzle area, while the Annular Inlet concept has a low rating in the critical core barrel area in relation to the Piped Bottom Inlet concept support structure area. For surveillance, the Annular Inlet concept provides inadequate access and space in the reactor vessel and core barrel areas.

6.3 EVALUATION OF THERMAL BALANCE

Both concepts depend upon cooling the pressure vessel wall. However, the methods utilized are different and produce different results with respect to the amount of flow supplied to the core. The maximum difference in these bypass flows is 5% of total reactor flow.

The Piped Bottom Inlet concept entails cooling the pressure vessel wall by utilizing the entire wall coolant requirements (10%) in parallel with the core flow (see Appendix B).

The Annular Inlet concept cools the pressure vessel wall by utilizing 95% of vessel wall coolant flow in series with the core. To cool the pressure vessel wall above the nozzles and the core barrel, 5% of the core flow is allowed to bypass the core, while the remaining 95% cools the pressure vessel before entering the core (see Appendix C).

Two cases of providing the vessel coolant flow have been investigated. Case 1 provides additional total flow while

maintaining present core flow and Case 2 maintains present total flow while allowing lower core flow. Case 1 requires additional flow from the pumps, and reduces the temperature rise over the reactor. Case 2 increases the temperature rise over the core (increasing cladding temperatures) while maintaining the temperature rise over the reactor.

A thermal balance study has been performed to evaluate both concepts under the conditions given in the preceding cases. This information, tabulated as follows, denotes with an "S" the most important parameters common to both concepts.

	<u>Total Flow</u>	<u>Core Flow</u>	<u>Core ΔT</u>	<u>Total Heat</u>
Case 1	-	5	-	5
Case 2	5	-	-	5

The values of the parameters upon which this study were based are as follows:

Temperature Rise Bypass (maximum metal temperature of 1000 °F)	$\Delta T_b = 100 \text{ } ^\circ\text{F}$
Piped Inlet Concept-Flow in Bypass Annulus	$M_{b1} = 10\% \text{ of Core Flow}$
Annular Inlet Concept-Flow in Bypass Annulus	$M_{b2} = 5\% \text{ of Core Flow}$
Annular Inlet Concept- Temperature Rise in Annulus- Inlet Nozzles to Core	$\Delta T_2 = 3 \text{ } ^\circ\text{F}$

6.3.1 Results

Results of the study (see Appendix B for calculation details) are as follows:

CASE 1

<u>Concept</u>	<u>Nozzle to Nozzle ΔT, °F</u>	<u>Core Temperature Rise ΔT, °F</u>
Piped Bottom Inlet	286	305
Annular Inlet	300	307

It is noted that, in the Annular Inlet concept, the temperature rise from the incoming coolant temperature to the core outlet temperature is 310 °F, including the 3 °F temperature rise in the annulus.

CASE 2

<u>Concept</u>	<u>Nozzle to Nozzle ΔT, °F</u>	<u>Core Temperature Rise ΔT, °F</u>
Piped Bottom Inlet	300	320
Annular Inlet	300	307

NOTE: *For annular inlet, the temperature rise from inlet temperature is 310 °F.*

In Appendix C, "Analysis of By-Pass Cooling," the basis for 10% bypass cooling of the Piped Bottom Inlet concept shows the temperature rise in the bypass coolant as a function of the amount of bypass coolant.

6.3.2 Conclusions

It may be concluded that, for equal core flows and equal total heat (Case 1), the most important difference is the 14 °F lower nozzle outlet temperature for the Piped Bottom Inlet concept. For an overall temperature rise of 300 °F, the corresponding nozzle-to-nozzle temperature rise of 286 °F for the bottom inlet would require an additional 10% flow from the pumps for the Piped Bottom Inlet concept, and an additional 5% flow for the Annular Inlet concept.

The core outlet temperature for the Annular Inlet concept would be about 5 °F higher than the Piped Bottom Inlet concept.

For the equal total flow rates of Case 2, the core flow for the Bottom Inlet concept is 5% less and the temperature correspondingly higher at the core outlet (10 °F) than for the Annular Inlet concept. This performance is reflected in possibly higher cladding temperatures for the Piped Bottom Inlet concept.

From the preceding discussion, it may be concluded that the Piped Bottom Inlet concept is at a slight disadvantage when compared to the Annular Inlet concept.

6.4 DESIGN CONSIDERATIONS

A number of considerations for specific regions of each concept must be made during design development of the pressure vessel and associated components. This section evaluates some of the major design items for each concept, none of which are infeasible although involving different considerations and varying degrees of difficulty.

6.4.1 Design of Core Support Barrel and Thermal Liner for Piped Bottom Inlet Concept

6.4.1.1 Core Support Barrel

The core support barrel in the Piped Bottom Inlet concept is primarily utilized for applying radial restraint against core expansion. It must fulfill the following functions:

- Provide radial restraint against core expansion
- Provide additional stiffness to reduce core vibration and increase the core natural frequency
- Prevent core movement induced by flow forces
- Support core alignment
- Consider allowable radiation damage (fluence) effect.

6.4.1.2 Thermal Liner

The thermal liner in the Piped Bottom Inlet concept is utilized to channel the vessel cooling flow. It must fulfill the following functions:

- Channel vessel wall cooling flow to provide uniform velocity to the top of the outlet plenum
- Provide flow into the thermal sleeves of the outlet nozzles
- Suppress natural connection flow loops between liner and vessel wall in order to prevent "thermal striping"
- Prevent additional leakage paths enabling primary coolant to by-pass the reactor core.

6.4.1.3 Evaluation

A considerable design effort will be required to assure a suitable core support barrel designed to satisfactorily fulfill its intended functions.

Although the thermal liner is a relatively simple component with no structural requirements, design verification of its thermal/hydraulic functions will be required. However, no unusually difficult design problems appear in this region.

6.4.2 Design of Core Barrel for Annular Inlet Concept

The core barrel in the Annular Inlet concept is a complex structure. It must fulfill the following functions:

- Sustain full line pressure externally (approximately 200 psi). An analysis of radial buckling in a core barrel approximately 18 ft in diam is shown in the following tabulation.

Thickness, in.	Core Barrel Length 20 ft ASME Allowable Pressure	Core Barrel Infinite Length ASME Allowable Pressure	Actual Buckling Pressure from "Platude" Com- puter Program with 2-in. Ovality and Infinite Length
5	200	---	---
6.5	---	200	---
7	---	---	190-200

- Provide thermal baffling and internal coolant to relieve thermal stress gradients and severe outlet coolant temperature transients.
- Sustain a dead load of the bottom grid plate, in-core fuel storage equipment, radial core restraint devices, and the core itself during low flow and reactor shutdown periods, and its own weight.
- Sustain an axial buckling load equivalent to the force developed from the pressure difference inlet to outlet plenum applied over the large diameter of the core barrel (approximately 15 to 18 ft). This force, approximately 5.5×10^6 lb, develops a compression stress of approximately 4500 psi partially negated by the dead load.
- Prevent flow-induced vibration of the core barrel and adjacent structures by positive means or show it to be incredible by detailed and complete flow testing.
- Maintain alignment of the core components with the closure head. During normal 3-loop operations, any mismatch of temperatures in the primary coolant loops will cause a thermal striping of the exterior of the core barrel and result in thermal movement with consequential displacement and misalignment. Poor mixing characteristics can be expected between the coolant from the primary coolant loops. Partial loop operation will further aggravate the problem.

- Consider creep-collapse possibilities⁽¹²⁾ of this configuration, including the effects of the dimensional tolerances.
- Consider effect of allowable radiation damage (fluence) to the beltline of the core barrel.

6.4.2.1 Evaluation

The core barrel is a complex structure and will require a considerable design effort to assure satisfactory performance.

6.4.3 Development Problems Associated with Outlet Jumper for Annular Inlet Concept

The Annular Inlet concept requires a jumper between the high-temperature, low-pressure fluid and the outlet nozzle on the top inlet configuration. Such a jumper must withstand high pressure and temperature differential, seal the two fluids from each other, and accommodate differential expansion between vessel components. The significant amount of development work needed to ensure the proper operation of the jumper and predict its theoretical behavior in-service appears to require a detailed test and analytical program. The problems of achieving the required dimensional accuracy in the vicinity of the jumper were discussed earlier in this section.

Most of the design problems associated with the outlet jumper for the top inlet concept are caused by the presence of the high-pressure inlet annulus. In contrast to the Piped Bottom Inlet concept, cavitation erosion and flow distribution problems are foreseen in the coolant flow area around the jumper.

One method to resolve the cavitation and corrosion problems would be to ensure that no leakage paths exist in the jumper and that any holes carrying coolant are designed to reduce erosion and cavitation. Because flow distribution

analysis is extremely difficult, the desirable approach would be a model testing program consisting of:

- Coolant flow distribution in the immediate vicinity of the jumper. In conjunction with heat transfer analysis, this problem requires calculation of the possible distortion of the jumper barrel and core barrel.
- Coolant flow distribution in the annulus between the core barrel holddown cylinder and its thermal shield. The objective here is to assess the variation in the annulus temperature to flow maldistribution.

These tests would be run in parallel. An initial estimate indicates an approximate cost of \$50,000 over a time span on the order of six months. Indications are that this time span should not significantly affect the vessel delivery schedule because the programs would run concurrently with other efforts.

6.4.3.1 Evaluation

The design and development problems presented by the outlet jumper, although difficult, can be resolved.

6.4.4 Vessel Wall Vacuum Collapse Analysis

An analysis will be needed to investigate the vacuum collapse characteristics of both vessel concepts during vacuum hot fill (500 °F at full vacuum). It appears that the initial vacuum hot fill of the reactor vessel will establish the required vessel wall thickness, which will be the same for both concepts. The results of the analysis are tabulated in Table 6.2.

6.4.4.1 Evaluation

Results of the vessel wall vacuum collapse analysis indicate no difference between concepts, and will establish the required vessel wall thickness.

TABLE 6.2. *Results of Vessel Wall Vacuum Collapse Analysis*

Thickness, in.	Allowable External Pressure from ASME Section III with 38-ft Long Vessel, psi		Allowable External Pressure from ASME Section III with Infinitely Long Vessel, psi		Actual Buckling Pressure from "Platude" Computer Program with Ovality and Infinitely Long Vessel, psi	
	Annular Inlet Vessel Diam 19 1/2 ft	Bottom Inlet Vessel Diam 18 ft	Annular Inlet Vessel Diam 19 1/2 ft	Bottom Inlet Vessel Diam 18 ft	Annular Inlet Vessel Diam 19 1/2 ft	Bottom Inlet Vessel Diam 18 ft
1	12.8	13.0	--	--	--	--
1 1/8	15.8	16.7	--	--	--	--
2	59.8	67.9	11.4	13.6	27-28	30-35

6.4.5 Thermal Striping Considerations

Thermal striping is defined as a region of hotter or colder fluid than that of surrounding fluid flowing in another region. It is of particular concern in the following specific regions:

Annular Inlet

- Annulus between pressure vessel and core barrel
- Inlet plenum region
- Inner surface of core barrel
- Grid plate
- Outlet nozzle jumper
- Outlet nozzle

Piped Bottom Inlet

- Inlet plenum
- Bottom grid plate
- Inner surface of pressure vessel - under thermal liner.
- Outlet nozzle

The effect of thermal striping is to introduce a thermal stress in the region of concern because of the temperature discontinuity between the thermal stripe and the surrounding fluid. Two methods available for combatting the effects of

thermal striping are: (1) isolate the thermal stripe from the component of concern by use of thermal baffles, and (2) eliminate the thermal stripe by means of fluid mixing.

Means for controlling the thermal striping effect, as listed in the foregoing, are separately treated for each of the concepts in the following discussions.

6.4.5.1 Annular Inlet Concept

- Annulus between Pressure Vessel and Core Barrel - the effect can be partially nullified by mixing the coolant entering from the inlet nozzles by rotation of the fluid in the annulus. The method and results were obtained in model tests.⁽⁹⁾ The term "partially nullified" was used, since the mixing did not completely occur until some distance down the annulus. The temperature discontinuity in this case must be generated by a temperature mismatch between the coolant loops.
- Inlet Plenum Region - Mixing removes the thermal stripe in the manner described for the annulus except, in the case of very low flow (laminar), it can also affect the annulus above.
- Inner Surface of Core Barrel - The effects of thermal striping caused by mismatched core outlets and/or natural convection in the outlet plenum, must be removed by thermal baffles on interior surface of barrel as shown by Drawing SK-345592J in Appendix D.
- Grid Plate - Mixing removes the effect except that, for laminar flow, thermal baffling would be required.
- Outlet Nozzle Jumper - Cooling flow and baffling is required to prevent thermal striping mismatches and leakage flow from inlet annulus.

- Outlet Nozzle - The effects, caused by the same conditions previously described, must be removed by cooling flow and thermal baffles.

6.4.5.2 Piped Bottom Inlet Concept

- Inlet Plenum - Thermal striping can be removed (except for laminar flow rates) by mixing of fluid in the plenum. The mixing can be accomplished by creating a slow rotation of the fluid in the plenum. This method has been experimentally verified on the toroidal shaped inlet plenum of the FFTF feature flow model, and will be studied on other tests to be conducted on the feature flow model.
- Bottom Grid Plate - The effect is similar to that for the inlet plenum.
- Inner Surface of Pressure Vessel - The thermal liner will remove thermal striping from the outlet plenum. The design of the liner must be such that natural convection is suppressed in the annulus between the pressure vessel and liner by metering flow uniformly into an annulus equipped with such flow restrictors as vertical ribs to restrict natural convection and to channel the cooling flow. The design will be verified by flow model tests for uniformity of flow (Hydraulic Core Mock-up - 1/2 scale model). Partial loop operation will also be verified to ensure uniformity of flow. The orificing and flow amount will require optimizing between partial and full loop operation.
- Outlet Nozzle - Cooling and thermal baffling will be required to prevent thermal striping from affecting the outlet nozzle - pressure vessel joint. The coolant flow in the annulus between the thermal liner and pressure vessel will be utilized for the outlet nozzle cooling.

6.4.5.3 Evaluation

Both concepts will require design and testing effort to ensure that protection from thermal striping is provided. Neither concept is seen to have an advantage over the other in this region.

6.4.6 Conclusion

Neither concept, based on evaluations described in the foregoing, can be regarded as infeasible from a design standpoint. However, in weighing the design and development effort required for the bottom inlet core support barrel and thermal liner against that required for the annular inlet core barrel and "outlet jumper," an advantage favoring the Bottom Inlet concept is concluded.

6.5 ANALYSIS OF TWO ALTERNATIVE CONCEPTS RELATIVE TO CAPABILITY TO ACCOMMODATE THE DBA

The purpose of analyzing the response of the reactor vessel (and particularly the closure head) to a calculated 1500 MW-sec propellant-type work energy release is to establish conservatism in design sufficient to ensure retention of the products of the DBA. This amount and type of energy release accelerates the coolant above the core and, acting as a slug, it impacts upon the cover. The problem is retention of the cover. Retention is defined as allowing an unseating of the cover to take place with gross ductile deformation allowable but without catastrophic failure occurring as disintegration, shear, or release of component parts.

Analysis assumes a rigid cover with cover displacement energy transmitted directly to the hold-down bolts. The displacement of the cover results in the elongation of the bolts and absorption of the cover energy. The bolts reduce the cover velocity to zero, during which time the bolts apply deceleration forces to the cover. At this time, these forces can be equated

approximately to the same force generated by a static pressure acting on the cover. In this mode, an equivalent static pressure derived from a DBA can be obtained for the closure head design.

6.5.1 Assumptions

The cover should be able to withstand from a DBA any rapid buildup of pressure not sufficient to rupture the vessel. This capability would prevent a DBA from introducing quasi-steady loads (occurring over fractions of seconds rather than milliseconds) capable of damaging the vessel cover but of insufficient magnitude to rupture the vessel. In other words, the cover is at least as strong as the vessel walls. An additional restriction is that vessel walls should not absorb more energy than available from a DBA assuming the cover bolting can provide sufficient restraint to prevent the cover from becoming a missile.

The primary distortion-producing forces on the cover during and following coolant slug impact is from hold-down bolts. Coolant slug impact will transfer kinetic energy to the cover, which then is decelerated by the hold-down bolts. At this time, the deceleration forces have been considered approximately equivalent to an effective pressure.

A summary of the elements of the analytical model is shown in Figure 6.1, and the analytical model in Figure 6.2. The results of the analysis in pressure time history are shown in Figure 6.3, and slug and cover energy in Figure 6.4 for the bottom inlet model.

6.5.2 Initial Conditions

Pressure-time histories establishing cover integrity are determined for quasi-steady loadings during a DBA. The initial conditions utilized for the reactor vessels under consideration are:

I. MODEL ANALYSES FOR EACH VESSEL PART:

COMPLETE PRESSURE AND DEFORMATION HISTORY
COMPLETE VELOCITY AND STRAIN RATE HISTORY
RUPTURE STRAINS FOR VESSEL AND BOLTS

II. MODEL CHARACTERIZES:

DBA WORK ENERGY PARTITIONING
IMPACT PRESSURE DEFINITION
PRESSURE FUNCTION WHICH ACCELERATES COOLANT SLUG BEFORE WALLS
VESSEL WALL INERTIA AND STRENGTH
COOLANT SLUG MOTION
RADIAL VESSEL WALL MOTION
DOWNWARD VESSEL MOTION
VESSEL COVER MOTION
STRETCH BOLTS (FASTENED TO COVER) DEFORMATION

III. ASSUMPTIONS:

NEWTONIAN ACCELERATION OF ALL MOTIONS
FLUID WAVE MOTION MAY BE NEGLECTED
VESSEL COVER DOES NOT DEFLECT

FIGURE 6.1. Elements of Analytical Model for Reactor Vessel Response to DBA

FIGURE 6.2. Response of Reactor Vessel to DBA Analytical Model (Asprin)

FIGURE 6.3. Vessel Cover Pressure Time History

FIGURE 6.4. Slug and Cover Energy

Run No.	Concept	Vessel Diameter, ft	Cover OD, ft	Thickness, ft (including 3 ft of shield)
1	Bottom Inlet	18	6 Hole Cover 22	7
2	Annular Inlet	19 1/2	6 Hole Cover 23 1/2	7
3	Bottom Inlet	17	3 Hole Cover 21	7
4	Annular Inlet	18 1/2	3 Hole Cover 22 1/2	7

Effective wall thicknesses established for the annular and bottom inlet were 7 in. and 2 in., respectively.

Masses established for the 18-ft diam vessel (others will use scaled masses) were 600,000 lb for the cover and 170,000 lb for the coolant. No cover gas volume was included in the analysis, while hold-down bolts 700 in.² in area and 10 ft long were used. It should be noted that driving pressure goes to zero when vessel radial strain exceeds 10%, while DBA energy is 1,500 MW-sec when expanded to 1 atm with a maximum pressure of 616 atm.

6.5.3 Results

The results obtained from the DBA analysis, assuming in Assumption A "that the cover should be able to withstand pressures which build up rapidly from a DBA and yet are not sufficient to rupture the vessel," are as follows:

Concept	Maximum Cover Pressure
• Bottom Inlet (2 in. wall, 18 ft diam)	1150 psi
• Annular Inlet (7 in. effective wall) (19 1/2 ft diam)	3150 psi*

* Reduced because of 1500 MW-sec energy limitation in vessel wall.

The deceleration forces applied by the hold-down bolts, susceptible to deformation but not to rupture under Assumption A, would yield comparably effective cover pressures under Assumption B. The bolt length, determined by energy absorption requirements, would be approximately 10 ft.

6.5.4 Conclusion

The Bottom Inlet concept has a decided advantage in that its closure head must be designed to withstand an equivalent internal static pressure approximately one-third that of the Annular Inlet concept.

6.6 REACTOR SYSTEM VIBRATION AND SEISMIC ANALYSIS

The alternative concepts were analyzed for shock and vibration to ensure that vibrations will not damage the reactor system or interfere with its operation, and that earthquake shocks will not damage it significantly. The basic design features of each concept are compared on the basis of these considerations.

6.6.1 Methods of Analysis

The analysis consists of determining natural frequencies and modes, and of estimating the excitation. The consequences (stresses, flow disturbance, etc.) can then be computed. The analysis was begun for lateral vibrations with earthquake excitation.

One traditional computational method requires the representation of the problem as a model with lumped masses. The point masses are numbered, and the deflection at any point determined for a unit force at any point in order to generate the matrix of influence coefficients. From this matrix and the masses, the eigen-values (frequencies) and mode shapes can be found by standard computer methods. To find the fundamental frequency, only the diagonal values in the influence-

coefficient matrix are required for Dunkerley's method. This approach has been used for a number of hand calculations.

Another method, used extensively on the PWR's, permits the use of models involving both beams and point masses, and works with transfer matrices. It is particularly well adapted to series-connected beams. The program used here (MDM) is restricted to collinear beams, but permits a number of particular parallel connections. Trial frequencies are introduced until the desired natural frequencies are found, and thus become characterized when the end conditions are met. Mode shapes can then be determined.

For preliminary survey and identification of problem areas, the first criterion of adequate rigidity is a sufficiently high lowest natural frequency (preferably over 25 Hz). The final test of a design, however, will be the acceptability of the stresses and deflections in numbers which cannot readily be reinforced, particularly by the fuel assemblies.

6.6.2 Models

The pertinent beam and mass models are shown in Figures 6.5 and 6.6, respectively. The concepts compared by lumped-mass methods are shown for the piped bottom inlet in Figure 6.7 and for the annular top inlet in Figure 6.8. Five point masses were used to represent the core.

6.6.3 Initial Results

First, computations were carried out parallel to design development. Hence, the early results are reflected in the current design. On the other hand, numerical results are based on dimensions subsequently changed and therefore no longer applicable. These results are reported only because they indicate the trends and help in comparing design alternatives.

MODEL D7

MODEL D81

MODEL D82

MODEL D83

FIGURE 6.5. Beam-Type Annular Top Inlet Models

INTERIALS MODEL

FOR ANNULAR TOP INLET

INTERNAL MODEL

FOR PIPED BOTTOM INLET

FIGURE 6.6. *Lumped Mass Models for Both Annular Top Inlet and Piped Bottom Inlet Concepts*

FIGURE 6.7. *Piped Bottom Inlet Concept*

FIGURE 6.8. *Annular Top Inlet Concept*

A number of simple structural elements first were looked at independently by means of well-known analytical solutions computable by hand. Specifically, the individual fuel elements were found to have a fundamental mode (supported near the ends) at about 2.5 Hz. A loose bundle of fuel elements would have increased damping with a similar fundamental frequency. This result, identifying the fuel elements as a problem area with respect to lateral shock and vibrations, demands further analysis.

At the same time, the computer program MDM was used to investigate a series of annular top inlet models representing parts of the FTR. The first one representing vessel, core barrel, internals, core, and supports (D-7) yielded a fundamental frequency of 2.52 Hz. The fundamental mode was dominated by the core elements, which sustained the largest deflections.

A core restraint mechanism of possible use for bundling the fuel assemblies on possibly five intermediate planes was considered. This mechanism would place extensive damping on the motion of the fuel elements and presumably would also tie them to a surrounding cylinder.

This simulation employed the next model (D-8-1) to represent the core and its surrounding barrel as a single beam (up to its fifth mode) with appropriate beam properties. This additional restraint raised the fundamental to 4.5 Hz, a significant improvement. The participation of this beam in the overall oscillations also was smaller.

The first conclusion, therefore, was that restraint of the fuel elements, as indicated, would be highly desirable to reduce the bending deflections likely to be induced in them through lateral excitations.

Another design feature presently under discussion is a relatively closely fitted seismic tie. Whether it might help to brace the assembly or reduce beneficial isolation of the core from seismic shock has not yet been determined.

The addition of such a tie to the model (D-8-2) led to typical values around 13 Hz, and a very stiff tie (D-8-3) induced 21 Hz. This result indicated significant stiffening in the system as a whole, with smaller deflections and lower base velocity inputs from the seismic spectrum. As a second conclusion, therefore, the subsequent design concepts should incorporate seismic ties.

Also sought was information concerning responses of a core supported from the bottom (associated with piped bottom inlet) and a core braced from the side (associated with an annular top inlet). To describe some of the essential differences, each was modeled by lumped masses, and Dunkerley's method applied.

Disregarding the vessel, the frequency of the internals in case of the standing core was 29.3 Hz for the fundamental mode. Inclusion of the vessel would lead to lower values. Flexure in this mode was roughly distributed equally between the supporting bottom ring girder and the core cylinder. Hence, making either one perfectly rigid would improve the frequency up over 40 Hz. However, girders added laterally around the core cylinder improved the rigidity only enough to attain 32 Hz, which was not significant. Reinforcing the bottom ring girder might bring greater gains.

Including core barrel deflections, the laterally supported core still achieved a frequency of 84 Hz for the fundamental mode of the core internals. This design is therefore more rigid.

The difference between the two concepts is not important with respect to seismic effects. The given seismic input spectrum is such that, while the base velocity input decreases for

the higher frequencies from 0.37 in./sec at 24.5 Hz to 0.06 in./sec at 84 Hz, the base acceleration inputs (g-loadings) are almost constant at about 0.17 g, so that different frequencies in this range are presumed to be about equally favorable.

Nevertheless, a more rigid design is preferred since the stiffer system would better resist the same seismic accelerations. While these results did not exclude either concept from consideration, a number of contributions towards improving internals-support design have been derived.

6.6.4 Summary

The initial analysis presented herein has provided information about the proper lateral support of the reactor internals. The use of a braced core restraint and a seismic tie on the lower part of the vessel are recommended. Both the annular inlet concept and the bottom inlet concept are feasible, although the former is capable of providing more radial rigidity.

6.7 IMPACT OF VESSEL SELECTION ON HEAT TRANSPORT SYSTEM INCLUDING THE EMERGENCY CORE COOLING SYSTEM

The impact of the pressure vessel concept selection was reviewed from the information shown in Drawing SK-3-14540 and SK-345592J, Appendix D, in order to assess the impact of these concepts on the Heat Transport System and the Emergency Core Cooling System.

6.7.1 Heat Transport System

The largest effect of vessel concept selection on the Heat Transport System is the amount of bypass coolant required for vessel wall cooling, assuming the core temperature rise to remain constant. This aspect is discussed in detail in Section 6.3.

No increase in flow capability to compensate for vessel wall cooling will be required for either concept. However, the additional bypass flow required, while resulting in a slightly higher core ΔT , will not affect the nozzle-to-nozzle temperature rise. This is Case 2, Section 6.3 and, therefore, does not affect the Heat Transport System.

6.7.2 Emergency Core Cooling System

Comparison of the Piped Bottom Inlet concept and the Annular Inlet concept with respect to emergency core cooling indicated that, given an external pipe failure, the two concepts are similar with regard to the design of the ECCS. The failure of the "jumper" in the top inlet concept presents a major design problem unique to the Annular Inlet concept.

At the outlet nozzles, the annular inlet requires a "jumper" to conduct the hot coolant from the outlet plenum at low pressure across the inlet annulus containing inlet fluid at a cooler temperature and higher pressure. The "jumpers" extend from the core barrel to the outlet nozzles and are subjected externally to the full reactor pressure drop and maximum thermal stress, and to distortion or displacement caused by differential thermal expansion between core barrel and vessel.

A failure of the "jumper" induced by fracture, collapse, distortion, or loss of its retention in position would create a large bypass flow around the core and reduce the cooling flow through the core. Since the "jumpers" are larger in diameter than the inlet nozzles, the resulting bypass flow rate would be much greater than from a comparable inlet nozzle break and thus produce a more severe loss of coolant accident. The Emergency Core Cooling System, as presently conceived, would be unable to provide adequate core cooling should a jumper fail, since the reactor core is still bypassed during emergency cooling.

The Piped Bottom Inlet concept provides outlet nozzles opening directly to the outlet plenum. These nozzles have thermal sleeves with bypass cooling to protect the nozzle and vessel from temperature transients. This coolant is at a pressure only slightly higher than the outlet plenum. Thus, loss of the thermal sleeve would subject an outlet nozzle to temperature transients, but not to a loss of coolant accident.

6.7.3 Natural Convection of the ECCS

The Annular Inlet concept, with its heating effect on the cold leg sodium, would tend to oppose natural convection and, therefore, would adversely affect the capability of the Emergency Core Cooling System for natural convection.

The Bottom Inlet concept, since it has piped downcomers, would not adversely affect natural convection of the Emergency Core Cooling System.

6.7.4 Conclusions

The preceding discussions indicate that neither concept would greatly affect the Heat Transport System. Their effects upon the Emergency Core Cooling System would be similar in event of an external pipe break. However, failure of the "jumper" employed in the Annular Inlet concept would have a significant adverse impact upon the ECCS and its capability to cool the core during accident conditions. Therefore, the Piped Bottom Inlet concept is to be preferred for the ECCS.

6.8 COST

An approximate cost analysis was performed to provide a relative cost comparison between the two vessel configurations. This comparison is based upon Babcock & Wilcox Drawings 29371F and 29370F, Appendix D. The results of the comparison show the reactor vessel of the Annular Inlet concept to be slightly less costly than the reactor vessel of the Bottom Inlet concept.

However, the cost of the Annular Inlet concept core barrel is not duplicated in the Bottom Inlet concept and results, therefore, in a significantly higher total cost for the Annular Inlet concept. The bottom inlet vessel will cost approximately 4.5 million, while the total cost of vessel and core barrel for the Annular Inlet will approximate twice this amount, or about 9.0 million. It is to be noted that these estimates, intended to show relative costs only, are not absolute values since equivalent factors have been omitted (e.g., engineering costs, guard tank, etc.). Additional design work will somewhat alter the magnitude of the difference, but not in the basic relative cost.

6.9 SCHEDULE

Assuming a June contract date, fabrication could not begin until the period of April to June 1970. Although more prompt delivery can be expected for the Annular Inlet vessel than for the correspondingly equipped Bottom Inlet vessel, inclusion of the core barrel would result in a longer overall delivery cycle for equipment required by the Annular Inlet concept. Thus, delivery of the piped Bottom Inlet concept components would require the shortest overall time span (approximately 27 months), and promise a higher probability of meeting the target delivery date of April 1972.

7.0 RESULTS OF EVALUATION

Results of the preceding discussions are tabulated as follows:

<u>Area of Evaluation</u>	<u>Concept "A" Annular Inlet</u>	<u>Concept "B" Bottom Inlet</u>	<u>Remarks</u>	<u>Advantage</u>
Manufacturability	More regions of difficulty	Fewer components and regions of difficulty	"Thin" vessel of both concepts require special procedures	B
Relative Inspectability	Approximately 60%	Approximately 65%	Better overall inspectability for B, although A has better inspectability in some regions	Standoff
Relative Surveillance	Approximately 36%	Approximately 55%	Better overall surveillance for B	Standoff
Thermal Balance	Approximately 5% bypass-95% series flow	Approximately 10% bypass-90% parallel flow	A requires less bypass flow, more complex core barrel, B requires more bypass, less complex thermal liner	A
Design Considerations:				
Core Support Barrel and Thermal Liner	Supported off core barrel	Supported off ring girder	Performs function of core restraint	B
Core Barrel	Complex structure, thick-walled supporting core	Thermal liner-thin nonstructural wall	Thick walled structure of A, requires internal cooling	B
Outlet Jumper Development	Requires development	Only thermal liner	A is external pressure bearing with alignment problems	B
Vacuum collapse Vessel Wall	Requires approximately 2-in. wall	Requires approximately 2-in. wall	Both are the same	Standoff
Thermal Stripping	Requires thermal baffles and careful hydraulic design	Requires thermal baffles and careful hydraulic design	Both require hydraulic model testing	Standoff
Heat Transport System & ECCS	Outlet jumpers handicap ECCS on loss-of-cooling accident	Thermal liners no handicap	Most important difference is jumper failure	B
Ability to Accommodate DBA	Thick wall sections	Thin wall sections	A must have head designed to withstand pressure approximately 3 times B design pressure	B

Area of Evaluation	Concept "A" Annular Inlet	Concept "B" Bottom Inlet	Remarks	Advantage
Vibrations and Seismic Considerations	Lateral vibrations, core and internals restrained by formers to thick core barrel	Lateral vibrations core and internals restrained by inner core support barrel	A is more rigid than B but seismic base acceleration is approximately the same. A will be better able to resist seismic loads since it is more rigid	A
Cost	Greater than 4.5 million dollars	4.5 million dollars	A is substantially more costly than B by 2.0 times	B
Schedule	Requires longer time		A more complex than B, and has more parts	B
Pressure	Vessel walls at inlet pressure	Vessel walls at outlet pressure	For higher pressure, A would require a somewhat thicker vessel wall, and the operating membrane stress in A would be higher	B
	Core barrel external pressure	No significant pressure on core structural barrel	A requires a much thicker core barrel than B. With an approximately equivalent thickness of 7 in., core barrel on A becomes main support for the Core and Internals. Its design temperature will be beyond ASME Section III unless four extra thermal baffles are used. B requires a relatively thin (approximately 2 in. thick) core barrel and thermal baffles	B
Diameter	Approximately 18 1/2 ft to allow space for thicker core barrel, thermal baffles, and annular downcomer	Approximately 17 ft	Larger diameter for A requires larger and thicker head	B

The results of the evaluation summarized in this tabulation clearly indicate an overall advantage favoring the Piped Bottom Inlet concept over the Annular Inlet concept.

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APPENDIX A

FUNCTIONS AND REQUIREMENTS

APPENDIX A
FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

- A. The reactor vessel and cover constitute a pressure boundary which envelopes the FTR core nuclear reactor, the core coolant, the coolant cover gas, and the core components.
- B. The reactor vessel is the central component in the primary heat removal system and, as such, distributes coolant flow to remove heat generated in the core, reflector, shield, and other vessel internals including structural elements.
- C. The reactor vessel provides a reservoir of excess coolant above the core to:
 - 1. Regulate differences in channel discharge temperatures.
 - 2. Mitigate coolant temperature transients.
 - 3. Maintain core submergence, in conjunction with an external guard vessel, for all predictable conditions exclusive of the design basis accident.
 - 4. Attenuate radiation from the core.
- D. The reactor vessel component includes an external shield to:
 - 1. Reduce radiation penetrating the vessel to tenable intensities in the surroundings.
 - 2. Absorb blast energy in the event of postulated accident conditions.
- E. The reactor vessel contains a meltdown section to disperse and hold core fuel in a noncritical geometry in the event of a partial core meltdown.
- F. The reactor vessel and cover provide positioning and support for all core components and vessel internals.

- G. The reactor vessel cover is the main process interface through which all driver fuel, tests, and accompanying instrumentation must pass, as well as the control mechanisms for the core. Other functions performed by the vessel cover are:
1. Attenuation of gamma radiation emanating from the coolant.
 2. Absorption of blast energy without fragmentation in the event of a core-disruptive accident.
 3. Thermal insulation of the structural and process regions of the cover from the coolant.
 4. Prevention of sodium transport, by vapor deposition or other mechanisms, through the pressure boundary.

1.2 NON-CONCEPT RELATED REQUIREMENTS

- A. Design and fabrication of the reactor vessel and cover shall conform, as a minimum baseline requirement, to applicable (as established by BNW) portions of the following:
1. Section III, Nuclear Vessels, of the ASME Boiler and Pressure Vessel Code and associated sections: Section II, Material Specifications, and Section IX, Welding Specifications; Code Cases; Addenda to the Code; and Addenda to the Code Cases (latest).
 2. AEC Tentative Regulatory Supplementary Criteria for ASME Code - Constructed Nuclear Pressure Vessels.
 3. AEC Division of Reactor Development and Technology Material; Plant; and Equipment Standards.
 4. General Design Criteria for Nuclear Power Plant Construction Permits, Appendix A to 10CRF50, and
 5. Design Safety Criteria for the Reactor Vessel.
- B. The basic configuration of the reactor vessel shall comprise a top-supported, right circular, cylindrical barrel with a bottom inlet plenum.

- C. The reactor vessel and cover shall be designed for maximum steady-state operating conditions of 1200 °F bulk outlet sodium coolant temperature and 900 °F bulk inlet sodium coolant temperature.
- D. The reactor vessel and cover shall be designed to accommodate a maximum steady-state temperature difference of 400 °F between the bulk inlet and bulk outlet coolant temperatures.
- E. Reactor vessel and cover design pressures shall include allowances for the most severe combinations of temperatures and pressures occurring during normal operation or a "single-fault" condition obtainable in any region of the component, and the frequency and severity of the expected temperature and pressure transients over the design life including full system vacuum at 500 °F.
- F. The vessel and cover shall be designed for a service life of 20 years, including all predictable operating cycles. Component parts, for which a 20-year life expectancy cannot be ensured, shall be designed to permit replacement without structural cutting and welding. Vessel internal shielding shall be installed as necessary to reduce the total neutron fluence at the vessel wall (and nonreplaceable structural internals) to a limit which ensures not less than 10% residual total elongation at the end of the 20-year life at 75% availability.
- G. The reactor vessel, cover, and internal structural components wetted by the sodium coolant and/or vapors shall be of Type 304 stainless steel.
- H. The reactor vessel shall be single-walled and surrounded by a guard vessel. The guard vessel shall be designed to the applicable portions of the same codes, criteria, and standards as in 1.2.A.1 above, for a vessel of its class.

The purpose of the guard vessel is to maintain core submergence in sodium in case of leakage in the reactor vessel or connecting primary piping. Failure of the reactor vessel, nozzles, or connecting piping (exclusive of failures caused by core disruptive accidents) shall not compromise the integrity of the guard vessel.

- I. The guard vessel shall have no penetrations nor openings below the sodium coolant elevation required for core emergency heat removal. The effective diameter of the guard vessel shall ensure this minimum coolant level.
- J. The reactor vessel shall be designed to permit draining, by means of appropriate connections and without entrapment of coolant, to a residuum of determinable amount. The guard vessel also shall be equipped with similar drainage capability. Drainage of either vessel shall be accomplished without bottom penetrations.
- K. The guard vessel shall be surrounded by an external shield. The degree of radiation attenuation to be provided by the external shield shall be sufficient to ensure the continued radiation tolerance by structure and external equipment. In addition, the external shield shall provide the space and support for the reactor flux monitoring instrumentation, and absorption of DBA blast energy.
- L. The internal and external shields, and penetrations thereof, shall be designed to preclude neutron streaming or other adverse effects which would prevent attainment of the shielding functional requirements.
- M. The average velocity of the coolant in the reactor vessel or adjacent piping, and exclusive of the core, shall not exceed 20 ft/sec in any coolant passage.
- N. The component design shall include provisions to accommodate periodic surveillance, and in-service inspection and

monitoring of the vessel and guard vessel. Capability to inspect 100% of the volume of pressure boundary welds shall be ensured.

- O. Establishment of the limiting values for design stress intensity shall include allowances for any known or predictable degradation of mechanical properties that may occur as a result of irradiation and stress at service temperature over the design life (i.e., 20 years at 75% availability for the vessel and internal structural components).
- P. A meltdown protection section shall be located below the core in the reactor vessel to ensure a subcritical accumulation of molten fuel, assuming a meltdown of a portion of the core. Sufficient thermal conductance and structural thickness will be provided by this protective subassembly to ensure reactor vessel pressure boundary integrity as long as the subcritical accumulation is surrounded by the sodium coolant.
- Q. The component shall have the following instrumentation as a minimum. Redundancy and replaceability of the associated sensors, and treatment and usage of the signals are discussed elsewhere. Data from these sensors shall be stored subject to recall for analysis.
 - 1. Coolant level
 - 2. Cover-gas pressure and temperature
 - 3. Cover inner and outer temperature
 - 4. Vessel wall temperatures at each inlet and outlet nozzle; and at selected beltline locations
 - 5. External shield inner and outer temperatures and at selected locations
 - 6. Guard vessel sodium accumulation
 - 7. Reactor vessel and guard vessel relative motion

8. Inlet plenum pressures
 9. Neutron fluence at the vessel wall (beltline), and grid plates regions.
- R. The reactor vessel, exclusive of the core support structure and cover, shall be designed to accept future cores without structural modifications.
- S. The detail design shall include an analysis of the dynamic response of the component to seismic forces which have been quantified by qualified experts.
- T. The Quality Assurance program necessary to establish component reliability shall be separately documented and will define the procedures and responsibilities for the following:
1. Design competency and adequacy
 2. Manufacturing and erection feasibility
 3. Fabrication and construction quality
 4. Operational capability
- U. The selection of allowable stresses shall incorporate allowances for "faulted" conditions.
- V. The vessel and shield component shall be designed to provide a reliability and maintainability consistent with achieving an FFTF overall plant availability goal of 75%, including effects on interfacing systems.
- W. The maximum allowable primary piping end-forces and moments, counter-acted at the vessel by reaction forces at the inlet and outlet nozzles, shall be established prior to the start of the detail of the primary piping system.
- X. The cover shall be cooled to maintain the top of the structural portion at a temperature less than 400 °F and to minimize radial and axial thermal gradients across the head.

- Y. The elevation of the outlet nozzles above the core and the normal operating elevation of the free surface of the vessel coolant above the outlet nozzles shall satisfy the requirements of the HTS system.

1.3 SAFETY REQUIREMENTS

The following are safety-related requirements which correspond directly to the italicized items in the Design Safety Criteria for the Reactor Vessel and Shield Component.

- A. The reactor vessel and top cover will be designed and constructed to the applicable requirements of the ASME Boiler and Pressure Vessel Code, Section III - Nuclear Vessels, including applicable code cases, with allowance for cumulative neutron doses over the specified lifetime of the facility. The design requirements corresponding to the accident severity are defined in the Criteria for Accident Severity Levels - FFTF Reactor Systems.
- B. The reactor vessel and top cover will be designed to mitigate the effects of the containment design basis accident as follows:
 - 1. The vessel and top cover will withstand the effects of any generated shock and/or pressure waves without fragmentation to prevent generation of missiles which could compromise the containment or other engineered safeguards.
 - 2. The top cover will be designed to remain intact even under the sodium hammer effect to prevent missile damage per (1), but may deform to the extent that leak tightness to the exterior regions is not maintained.
- C. The vessel design will be coordinated with the emergency core cooling system and guard vessel design to maintain reactor core cooling for the intact core even in the unlikely event of a "Major Fault."

- D. The reactor vessel bottom head and internal structure will contain deflection devices to disperse any molten fuel and prevent assembly of a critical mass below the core within the vessel in the event of a partial core meltdown or disruption.
- E. Core reactivity changes under normal operational or accident conditions resulting from thermally, hydraulically, and mechanically induced deflections of the reactor vessel, top head, and/or internal support structure will be limited to ensure conformance to the design safety criteria for reactivity coefficients.
- F. The reactor vessel, top cover, and internal core support structure will be designed to withstand the effects of the design basis earthquake without damage - no loss of the containment integrity of the vessel or loss of positioning control of the core and related components which may affect the reactivity status of the core.
- G. Materials used in the reactor vessel and top cover will be selected to ensure compatibility with adjoining materials and the environmental conditions over the range of design conditions and lifetime requirements.
- H. The reactor vessel, top head, and internal support structure will be designed to established allowable stresses which are based upon specified time and temperature dependent mechanical properties of structural materials.
- I. The design of the reactor vessel, top head, and internal support structure will accommodate an integrated program for surveillance and in-service inspection to ensure continued integrity of the components and detection of possible failures prior to the occurrence.
- J. Instrumentation will be provided to monitor the thermal and mechanical load conditions of the reactor vessel, top

head, and internal support structure to ensure continued operation within the design ranges.

- K. The design of the top head in conjunction with shielding will ensure that exposure to personnel during normal maintenance and refueling operations is within the limits of AECM-0523 with RL Supplement.
- L. Materials used in the internal structural components will be chosen to ensure compatibility with the environmental conditions and to maintain satisfactory end-of-life properties to fulfill their intended function over the range of design conditions and lifetime requirements.
- M. The core internal support structure will be designed to sustain no damage under "Minor Accident" (Ref. 11) conditions and to limit core movement under "Major Accident" conditions to prevent reactivity additions by fuel movement which will lead to potentially significant additional fuel damage.
- N. Instrumentation support structures will be designed to support and possibly protect instrumentation under normal and accident conditions to ensure that the instrument fulfills its designed function under the various conditions.
- O. The reactor vessel will be surrounded by a guard vessel capable of limiting loss of sodium, to the extent that emergency core cooling for the intact core is maintained even in the event of failure of a high-pressure inlet nozzle or lead in the reactor vessel (magnitude not greater than the nozzle failure).
- P. The guard vessel will be designed and constructed to the applicable requirements of the ASME Boiler and Pressure Vessel Code, Section III - Nuclear Vessels, with allowance for cumulative neutron doses over the specified lifetime of the facility.

- Q. The design of the guard vessel will accommodate an integrated program for surveillance and in-service inspection to verify continued integrity of the guard vessel.
- R. Criterion 1.3 (H) for the reactor vessel and upper head also applies to the design criteria for the guard vessel.
- S. The guard vessel will be designed to withstand the effects of the design basis earthquake without damage - no loss of containment integrity to ensure emergency core cooling.
- T. Design features will be provided to accommodate sensors to detect sodium leakage from the reactor vessel to the guard vessel.
- U. The neutron shield outside the reactor vessel will be designed to:
 - 1. Limit radiation activation of cooling systems (e.g., the secondary sodium within the primary heat exchanger) such that accidental fires or other failures outside containment of those activated systems will not result in release of radioactive material beyond the guidelines of 10 CFR 100.
 - 2. Limit radiation to operating personnel to ensure that exposures are within the limits of AECM-0524 with RL Supplement for normal maintenance and refueling operations.
 - 3. Limit radiation damage to the walls of the reactor cell to maintain their structural integrity, and
 - 4. Protect instrumentation systems to ensure their performance in fulfilling their design objectives.
- V. Protection of the reactor cavity walls from the effects of any shock and blast energies generated by the Design Basis Accident will be provided to ensure maintenance of any engineered safeguards features provided by the cavity walls.

- W. Shielding materials, including shield cladding, will be selected to ensure compatibility with the environmental conditions under both normal and postaccident conditions.
- X. Shielding structures which function as engineered safeguards for mitigating the effects of the containment DBA will be designed to withstand the effects of the design basis earthquake without loss of its capability to mitigate the consequences of the DBA in fulfilling its design function.
- Y. Criterion 1.3(H) also applies to the design of the shield structural material.
- Z. Instrumentation will be provided to monitor and control shielding temperatures within the defined operational ranges.

APPENDIX B

GENERAL CALCULATIONS

APPENDIX B
GENERAL CALCULATIONS

Bottom Inlet

M_c - Flow Through Core
 M_b - Flow in Bypass Annulus
 ΔT_c - Temperature Rise in Core
 ΔT_b - Temperature Rise in Bypass
 ΔT_T - Nozzle-to-Nozzle Temperature Rise

Top Inlet

1 - Bottom Inlet
 2 - Top Inlet
 Q_T - Total Heat, Nozzle-to-Nozzle
 K - Bypass Flow/Core Flow Ratio
 C_p - Specific Heat (Assumed Constant)

Basic Equations:

$$Q_{T1}/C_p = (M_{b1} + M_{c1}) \Delta T_{T1} = M_{b1} \Delta T_{b1} + M_{c1} \Delta T_{c1} \quad (1)$$

$$Q_{T2}/C_p = (M_{b2} + M_{c2}) \Delta T_{T2} = M_{c2} \Delta T_{c2} + M_{b2} \Delta T_{b2} \quad (2)$$

Case 1

$$Q_{T1} = Q_{T2} \quad (\text{Total Power Same})$$

$$M_{c1} = M_{c2} = M_c \quad (\text{Core Flows Equal})$$

$$\Delta T_{b1} = \Delta T_{b2} = \Delta T_b$$

From (1) and (2)

$$(M_{b1} + M_c) \Delta T_{T1} = (M_{b2} + M_c) \Delta T_{T2}$$

$$\frac{\Delta T_{T1}}{\Delta T_{T2}} = \frac{M_{b2} + M_c}{M_{b1} + M_c}$$

$$\frac{\Delta T_{T1}}{\Delta T_{T2}} = \frac{1 + K_2}{1 + K_1} \quad (3)$$

$$\text{If } K_1 = 0.1, K_2 = 0.05$$

$$\frac{\Delta T_{T1}}{\Delta T_{T2}} = \frac{1.05}{1.10} = 0.954$$

$$\text{If } \Delta T_{T2} = 300^\circ \text{F} \quad \Delta T_{T1} = \underline{286.3^\circ \text{F}}$$

From (1)

$$M_{b_1} \Delta T_b + M_c \Delta T_{c_1} = (M_{b_1} + M_c) \Delta T_{T_1}$$

$$\therefore K_1 M_c \Delta T_b + M_c \Delta T_{c_1} = M_c (1 + K_1) \Delta T_{T_1}$$

$$\Delta T_{c_1} = (1 + K_1) \Delta T_{T_1} - K_1 \Delta T_b \quad (4)$$

If

$$K_1 = 0.1$$

$$\Delta T_b = 100 \text{ } ^\circ\text{F}$$

$$\Delta T_{T_1} = 286.3 \text{ } ^\circ\text{F}$$

$$\Delta T_{c_1} = 304.9$$

From (1) and (2)

$$M_{b_1} \Delta T_b + M_c \Delta T_{c_1} = M_c \Delta T_2 + M_c \Delta T_{c_2} + M_{b_2} \Delta T_b$$

$$\Delta T_{c_2} - \Delta T_{c_1} = \Delta T_b (K_1 - K_2) - \Delta T_2$$

It can be shown that $\Delta T_2 = 3 \text{ } ^\circ\text{F}$

$$\Delta T_{c_2} - \Delta T_{c_1} = 2 \text{ } ^\circ\text{F}$$

$$\Delta T_{c_2} = 306.9$$

Case 2

$$Q_{T_1} = Q_{T_2}$$

$$M_{c_1} + M_{b_1} = M_{c_2} + M_{b_2}$$

$$\Delta T_{b_1} = \Delta T_{b_2} = \Delta T_b$$

From (1) and (2)

$$(M_{b_1} + M_{c_1}) \Delta T_{T_1} = (M_{b_2} + M_{c_2}) \Delta T_{T_2}$$

$$\Delta T_{T_1} = \Delta T_{T_2}$$

From given conditions

$$M_{c_1} = M_{c_2} - (M_{b_1} - M_{b_2})$$

$$M_{c_1} = M_{c_2} - (K_1 M_{c_1} - K_2 M_{c_2})$$

$$M_{c_1} \approx M_{c_2} (1 - K_1 + K_2)$$

With

$$K_1 = 0.1$$

$$K_2 = 0.05$$

$$M_{c_1} = 0.95 M_{c_2} \quad (\text{obvious})$$

From 1

$$M_{b_1} \Delta T_b + M_{c_1} \Delta T_{c_1} = (M_{b_1} + M_{c_1}) \Delta T_{T_1}$$

$$\Delta T_{c_1} = \left[(M_{b_1} + M_{c_1}) \Delta T_{T_1} - M_{b_1} \Delta T_b \right] \frac{1}{M_{c_1}}$$

$$\Delta T_{c_1} = (K_1 + 1) \Delta T_{T_1} - K_1 \Delta T_b$$

$$\Delta T_{c_1} = K_1 (\Delta T_T - \Delta T_b) + \Delta T_T$$

Similarly

$$\Delta T_{c_2} = K_2 (\Delta T_T - \Delta T_b) + \Delta T_T - \Delta T_2$$

Using typical values

$$\Delta T_{c_1} = 0.1 \times 200 + 300 = \underline{320} \text{ } ^\circ\text{F}$$

$$\Delta T_{c_2} = 0.05 \times 200 + 300 - 3 = 307 \text{ } ^\circ\text{F}$$

Core Outlet Temperatures

$$T_{c_1} = 900 + 320 = \underline{1220} \text{ } ^\circ\text{F}$$

$$T_{c_2} = 900 + 3 + 307 = \underline{1210} \text{ } ^\circ\text{F}$$

APPENDIX C

ANALYSIS OF BYPASS COOLING

APPENDIX C

ANALYSIS OF BYPASS COOLING

A method of achieving lower thermal gradients is to bypass cooler fluid along the wall. This may be accomplished by orificing flow from the high-pressure inlet plenum at the expense of higher temperatures in the core region.

The bypass coolant temperature distribution was evaluated by performing a heat balance for a differential length of wall assuming no heat losses from the wall to the environment surrounding the vessel,

$$\text{Thus} \quad m C_p \Delta t = \frac{(t - t_{\infty}) \Delta X}{R_n} ,$$

where:

m = bypass mass flow rate,

C_p = specific heat of sodium,

t_{∞} = sodium pool temperature,

R_n = overall resistance between stagnant sodium pool and bypass flow,

$\Delta t, \Delta x$ = incremental values of temperature and axial distance.

If t_{∞} is assumed to be constant, the closed form solution to the expression given above is

$$\frac{t_{\ell} - t_{\infty}}{t_o - t_{\infty}} = e^{-\ell/m C_p R_n} ,$$

where:

ℓ = length over which heat transfer is occurring,

o, ℓ = subscripts designating condition of inlet (o) and at position ℓ , respectively.

For different quantities of bypass flow, the axial temperature distribution of the coolant was determined for a length of 20 ft, which is the assumed distance to the outlet nozzle. These results are presented in Figure C.1.

At the outlet nozzle, a portion of the bypass flow is used to cool the nozzles while the remainder continues to cool the upper section of the vessel wall. For a total bypass flow of 10%, the nozzle and vessel wall temperature characteristics are shown in Figure C.2 as a function of the % bypass passing each region. To operate both regions at the same maximum temperature would require 10% bypass flow with 8% along the vessel wall and 2% for the three nozzles. The resulting temperature would be 1006 °F. Similarly, for a total bypass of 15%, 12% would be required along the vessel wall and 3% for the three nozzles. In this case, the temperature is reduced by 31°. These results are shown in Figure C.3.

FIGURE C.1. Bypass Flow Required to Cool Vessel Wall for Piped Bottom Inlet Concept

FIGURE C.2. Bypass Flow Required to Cool Upper Vessel Wall and Nozzles
 for Piped Bottom Inlet Concept

FIGURE C.3. Bypass Flow Required to Cool Upper Vessel Wall and Nozzles
 for Piped Bottom Inlet Concept

APPENDIX D

DRAWINGS

SK-3-12897

SK-3-12898

SK-3-12899

SK-3-14540

SK-3-14541

SK-345592J

B&W-29370F

B&W-29371F

IDENTIFICATION LEGEND OF REACTOR HEAD PENETRATIONS

- ① DUAL PURPOSE REFUELING POSITION
(3) PLACES
- ② FEED TUBE ASSEMBLY (3) PLACES
- ③ EXTERNAL VESSEL HANDLING MACHINE
PORT (3) PLACES
- ④ RADIAL RESTRAINT MECHANISM
(6) PLACES
- ⑤ CONTROL ROD POSITIONS (9) IN-CORE &
(15) PERIPHERAL
- ⑥ OPEN & CLOSED LOOP POSITIONS
9 PLACES
- ⑦ FLUX MONITOR POSITIONS
(2) PLACES
- ⑧ COMBINATION STIF AND FLUX MONITOR
- ⑨ REACTOR HEAD STRETCH BOLT HOLES
(100) PLACES
- ⑩ INSTRUMENT POSITIONS (3) LIQUID LEVEL
(3) PRESSURE-TEMPERATURE MONITOR

THIS DRAWING COMPLIES
WITH THE DECEMBER 1968
CONCEPT GUIDE LINES

3RD ISSUE 3.21.69
2ND ISSUE 2.20.69
1ST ISSUE 1.23.69

CONCEPTUAL			
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#2			
#3			
#4			
#5			
#6			
APPROVED		REACTOR HEAD PLAN FAST FLUX TEST FACILITY 300 GEN. SK-3-12897	
ENGR.	<i>[Signature]</i>		
CITIZEN ARMO	<i>[Signature]</i>		
DIRECTOR			
TERRA	<i>[Signature]</i>		
REV NO.	<i>[Signature]</i>		
REVISION	<i>[Signature]</i>		
NONE		DATE REC'D 1500-01 RECD BY 1500-01 FILE NO.

ALTERNATE ARRANGEMENT
FLAT RING GIRDER PRESSURE BARRIER

OPERATING FLOOR EL 0'-0"

EL +15'-9"

EL +11'-9"

EL +12'-6"

12" INLET TYP FOR (6)
EQUALLY SPACED

EL +21'-0"

"CLAMSHELL" ENCASEMENT
AROUND INLET PIPES
WITHIN GUARD VESSEL TO
MINIMIZE SODIUM LEAKAGE
IN THE EVENT OF A
DOUBLE-ENDED BREAK

EL +33'-0"

GUARD VESSEL
21'-6" O.D.

REACTOR VESSEL
17'-0" O.D.

THERMAL LINERS
18'-0" O.D.
(3-1" THK PLATES
W/1/2" ANNULAR SPACES)

TOP OF GRID PLATE
EL +46'-0"

EL +55'-9"

NORMAL SODIUM LEVEL

EL +39'-0"

INLET PLENUM

CORE BARREL

RING GIRDER
SUPPORT

EL +18'-6"

26" OUTLET TYP FOR (3)
EQUALLY SPACED

EL +29'-0"

INTERRUPTED
SHEAR RING

THIS DRAWING COMPLIES WITH
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CONCEPTUAL

2700 ISSUE 3-15-69

U. S. ATOMIC ENERGY COMMISSION
PACIFIC NORTHWEST LABORATORY
OPERATED BY BATTELLE MEMORIAL INSTITUTE

REACTOR VESSEL
ELEVATION

FAST FLUX TEST FACILITY

300 GEN. 1500.01

NONE

SK-3-12899

• •

DRAWING TITLE AND NUMBER			
REV	DATE	BY	CHK
1	1/3/69	J. L. C.	J. L. C.
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SK-345592J
FFTF Concept 5-A Annular Top Inlet Vessel Concept

- NOTES:
1. VESSEL TO BE FABRICATED IN ACCORDANCE WITH ASME BOILER & PRESS. RE. VESSEL CODE SECTION III.
 2. MATERIAL TYPE 304 STAINLESS STEEL.
 3. CONCEPT FROM PNL DWG. SK-3-14540.

PRELIMINARY

CONTRACT NO. 596-3561-51

OWN BY: BENNINGTON	THE BABCOCK & WILCOX COMPANY
CHD BY:	NEW YORK, NEW YORK
EXAM BY:	
APD BY:	FFTR REACTOR VESSEL
DATE: 1-6-69	CONCEPT 'A'
APPROVED BY:	BOILING INLET VESSEL
	CODE: 92439 F 29370F
	SCALE: 1/2"=1'-0"

RECEIVED BY: 1/11/69

TABLE E.1. Relative Inspectability Evaluation of Vessel Concepts

Component	Evaluation Rating								Remarks
	Inspection		Accessibility		Space		Total		
	A	B	A	B	A	B	A	B	
Reactor Vessel									
Surface - externally	3	3	3	3	3	3	27	27	
Surface - internally	2	2	1	1	1	1	2	2	
Vessel Vertical Wall to Bottom Head Weld	3	2	2	3	3	3	18	18	
Top Flange									
Flange material	2	2	2	1	3	3	12	6	A. Must pull cover B. Must pull core barrel
Vessel weld	3	3	2	1	3	3	18	9	
Inlet Nozzles									
Nozzle material	1	1	2	3	2	3	4	9	
Vessel weld	3	3	2	3	2	3	12	27	
Pipe weld	2	2	2	3	3	3	12	18	
Outlet Nozzles									
Nozzle material	2	2	3	3	3	3	18	18	
Vessel weld	3	3	3	3	3	3	27	27	
Pipe weld	3	3	3	3	3	3	27	27	
Thermal sleeve	2	3	1	1	3	3	6	9	
Vessel Liner (Core barrel of Ref. B)									
Surface	2	3	1	1	3	1	6	3	
Vessel contact (Mid-elevation)	NA*	3	-	1	-	1	NA*	3	
Vessel contact (bottom)	2	3	2	1	3	3	12	9	
Flange to barrel weld (top)	1	2	3	2	3	3	9	12	
Flange to barrel weld (mid-elevation)	NA*	3	-	1	-	3	NA*	9	
Flange to barrel weld (bottom)	NA*	2	-	1	-	3	NA*	6	
Bottom Support Structure									
Shear Ledge Welds	3	NA*	3	-	3	-	27	NA*	
Support Collar Contact	3	NA*	1	-	3	-	9	NA*	
Structure	2	NA*	1	-	3	-	6	NA*	
Inlet Plenum									
Surface	2	2	2	2	2	2	8	8	By removal of fuel ducts and grid plate

TABLE E.1. (contd)

Component	Evaluation Rating								Remarks
	Inspection		Accessibility		Space		Total		
	A	B	A	B	A	B	A	B	
Grid Plate									
Surface in fuel area	3	3	2	2	2	2	12	12	
Surface in reflector and shield area	2	2	2	2	2	2	8	8	
Lower High Pressure Zone									
Surface	2	2	2	1	2	3	8	6	
External Vessel Support									
Surface	3	3	3	3	3	3	27	27	
							315	300	
							486	513	
							65	59	
Reactor Vessel	3	3	2	1	3	1	18	3	A. Must extrapolate temp. ~300 °F.
Vessel Liner (Core barrel Ref. B)	NA*	3	3	1	3	1	NA*	3	
Outlet Nozzles	3	3	2	2	3	3	18	18	A. Must extrapolate temp. ~300 °F.
Grid Plate	3	3	2	2	2	2	12	12	
Reflector	2	2	2	2	2	2	8	8	
Shield	2	2	2	2	2	2	8	8	
							64	52	
							117	144	
							55	36	
							63	54	

*NA - Not applicable

Key

A. Piped Downcomer

B. Annular Downcomer

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