FFTF AND CRBRP INTERMEDIATE HEAT EXCHANGER DESIGN, TESTING AND FABRICATION

by

R. W. DEVLIN, Manager
Mechanical Equipment and Piping Design

J. D. BRESNAHAN, Senior Engineer
Mechanical Equipment

Westinghouse Electric
Advanced Reactors Division
Waltz Mill Site
P. O. Box 158
Madison, Pennsylvania 15663
United States

ABSTRACT

The Heat Transport Systems of the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor Plant (CRBRP) include Intermediate Heat Exchangers (IHXs) to form barriers between the primary radioactive and secondary non-radioactive sodium coolant loops. The design, development and fabrication of the IHX for the FFTF has been completed and the units installed in the facility. The design and development of the IHX for the CRBRP has progressed through the performance sizing stage and flow testing of critical areas into early fabrication. The design evolution of these two heat exchangers may be considered a continuous development because the design and fabrication organizations have been the same for both units. Structural considerations to meet ASME Code requirements, support testing experience and manufacturing experience from the FFTF program has been factored into the CRBRP program. This paper outlines the similarities and differences between the FFTF and CRBRP designs. Special attention has been given to utilization of flow distribution devices and associated hydraulic testing, tube bundle and tube-to-tubesheet joint configurations, and fabrication differences.

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Introduction

The United States liquid metal fast breeder program includes a Fast Flux Test Facility (FFTF) under construction at Hanford, Washington and a demonstration plant to be located on the Clinch River in Tennessee (CRBRP). The intermediate heat exchangers for these applications have been or are being designed and fabricated by Foster Wheeler Energy Corporation under contract to Westinghouse Advanced Reactors Division. A continuity of technical development has been occasioned by the design and fabrication of these units under the same supplier. The similarities and differences between the units is discussed in this paper.

A. Plant Arrangement

Both the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor Plant (CRBRP) use three parallel heat transport circuits. The three primary loops have common flow paths through the reactor vessel but are otherwise not connected. One primary heat transport loop for each plant, shown in plan view in Figure 1, contains a hot leg primary pump, an intermediate heat exchanger, a cold leg check valve and associated piping to a reactor vessel. In addition the FFTF plant has two motor operated isolation valves in the primary sodium loop which permits the isolation of a primary loop.

The primary sodium is heated by the reactor. The prime function of the IHX is to provide for heat transfer from the primary to the intermediate sodium. The other major function of an IHX is to provide a confinement for the radioactive primary sodium. The FFTF plant has an air-cooled heat exchanger for the final dissipation of the heat to the atmosphere. The CRBRP plant has steam generators, steam piping and associated components e.g. steam turbines, feedwater heaters and condensors for production of electrical power. When operated with three cooling circuits the nominal thermal rating for FFTF is 400 MWt and for CRBRP is 975 MWt.

B. Intermediate Heat Exchanger (IHX)

Figure 2 is a graphical comparison of the IHX's for FFTF and CRBRP. The IHX for FFTF is shown in phantom. A tabular comparison of the physical characteristics is also presented on Figure 2. The major difference derives from the thermal ratings of 133 mw per IHX for FFTF and 325 mw per IHX for CRBRP.

C. Design Features

1. Similarities

Both IHX's are vertical shell-tube heat exchangers using essentially counterflow arrangement of heated and cooled sodium as shown on Figure 3. The radioactive primary sodium is on the shell side while the non-radioactive intermediate sodium is on the tube side. The primary sodium enters the shell side of the heat exchanger through a nozzle located in the side of the shell at an elevation near the upper tubesheet of the tube bundle. The primary sodium flows into an annular plenum section around the tube bundle. The IHX's have a primary bypass seal device which prevents the primary sodium from bypassing the tube bundle. The sodium exits this plenum, through a distribution device, into the tube bundle where it flows around the tubes down through the bundle and exits the shell through a nozzle in the hemispherical head of the shell. The intermediate sodium enters the tube side through a nozzle at the top of the unit attached to the central downcomer. The sodium flows down the downcomer into the lower hemispherical plenum where the flow of sodium is redirected up through the tubes. The flow of sodium exiting the tubes at the upper tubesheet is collected in a cylindrical plenum chamber. The sodium exits the plenum through a nozzle in the side of plenum at the top of the unit.

The material of construction is predominantly 304SS in both units. In CRBRP, the upper shell courses including the primary inlet nozzle are constructed from 316SS.

The IHX's have a running vent located in the upper region of the primary inlet plenum. If any gas comes out of solution from the primary sodium, this vent stream carries it to the primary pump where it returns to the cover gas system. Thus, gas is prevented from accumulating in the IHX. This precludes the possibility of gas expansion during pressure reduction operations and the potential for gas transport to the core.

The IHX's have a flow distribution ring located in the intermediate hemispherical plenum at the bottom of the tube bundle. The purpose of this ring is to provide an even flow distribution of sodium up through the tubes. The elevation and width of the ring was determined by flow model testing using water.

The IHX's are hung from a flange which is attached to a building support ledge located in the operating floor. The opening in the floor is covered over with a radiological shield plug. All piping connections are made below the operating floor in a cell containing an inert atmosphere during normal operating periods.

The lower portion of the IHX is suspended inside of a stainless steel guard vessel. The purpose of the guard vessel is to collect the sodium, in the unlikely event there is a leak in the shell or at the weld joints between the nozzles and primary piping, so the level of sodium in the reactor vessel will be maintained above the reactor vessel outlet nozzles to preserve continuity of flow paths in the unaffected loops.

The IHX's are also provided with external electric heater elements which are used to heat the component up to 400°F prior to sodium fill and to maintain the component at this temperature at hot standby. The heaters are attached on the outside of the guard vessel. For those portions of the IHX above the guard vessel the heaters are supported off the insulation supports adjacent to the surface of the IHX. The support cylinders are not insulated to allow the temperature at the support flange to be maintained below the 150°F limit.

During power operation, the intermediate system pressure is maintained higher than the primary system pressure to ensure that in the unlikely event of a tube leak in the bundle the flow will be from the non-radioactive intermediate side into the primary side. This ensures the radioactive sodium will remain inside containment.

2. Differences

The major difference between the FFTF IHX and CRBRP is that the FFTF is made up of those distinct major parts; Hanging Support Cylinder, Shell, and Tube Bundle, while the CRBRP unit is an integral unit with a non-removable bundle. Initially the CRBRP IHX was to be a scaled-up version of the FFTF IHX. However, after a cost effectiveness study the CRBRP design was changed from the removable bundle with bent tubes to an integral unit with straight tubes. The difference concerning the change from bent tubes to straight tubes will be covered separately.

The three piece FFTF design utilizes three large ring forgings at the bundle to shell to hanging support junction: bundle support flange; shell shear key flange and the hanger lower support flange as shown on Figure 4. Two of these forgings require extensive intricate machining to provide the close tolerance fit of the mating shear keys which is required to react to the loads imposed on the shell by the piping expansion and seismic events. Also there is precise machining required on the bundle support flange and the shell shear key flange to accommodate the omega seal and the shear keys.

On CRBRP these three ring forgings were replaced with one machined ring forging, also shown on Figure 4. This has been called the "Z" forging due to its cross sectional geometry. The Z forging provides the welded transition joining the shell, bundle, and hanging support. Using the "Z" forging allowed the reductions in diameter of the hanging support top flange, which also resulted in a cost savings.

There are some other saving features associated with the integral IHX design which influenced its acceptance. The first being the elimination of the need for an omega seal between the shell and bundle flanges. Secondly, there is no need to design a special closure head for the shell and a special vessel for the bundle in order to perform the testing of the component in accordance with Section III Article NB6000 of the ASME Boiler and Pressure Vessel Code. Thirdly, there is no need to provide three different sets of shipping and handling equipment. Lastly, there is no need for field assembly which was required by the FFTF unit. This also eliminates the need for special fixturing and procedures to perform the field assembly. The elimination of field assembly also drastically reduces the possibility of having dirt and other contaminants gettings into the bundle and the associated expense of a rigidly controlled storage area for the bundle.

Another major difference, as mentioned earlier, is the straight tube design of CRBRP and the bent tube design of FFTF which was brought about by a cost effectiveness study. The FFTF IHX has a rigid downcomer joining the two tubesheets together and since the downcomer and tube will not be at the same temperature some means had to be provided to accommodate the differential thermal expansion. This was accomplished by providing an expansion bend in each of the tubes. All tubes have the same offset which is in a single plane as shown in the side view of the tube (Figure 5). Then, the tube is bent out of plane on a radius to match the location of the row into which the tube will be installed. The final effect is to have the tubes in each concentric row rest within other tubes in the same row. There is an open annular space between adjacent rows of tubes. The tube bends were made on a specially designed tubing bender which produced the compound bend at one time. The primary flow exits the tube bundle above the tube bend area to avoid the potential for flow induced vibration in this geometrically complex region. As a result the extra tube length is not active in heat transfer performance.

With an expansion bend in each tube it became necessary to assemble the bundle a row of tubes at a time starting with the innermost tube circumferential row. The tubes are welded to a machined nozzle on the backface of each tubesheet using an internal bore welding procedure. Also, the five of the eight tube support plates in the bundle consisted of a series of concentric arc segments supported by and attached to radial support bars by plug welds as indicated on Figure 7.

The CRBRP IHX does not have a rigid member tieing the two tubesheets together. Instead a flexible bellows unit is provided between the rigid downcomer attached to the lower tubesheet and the inner channel-inner attached to the upper tubesheet (Figure 2). The bellows are located at the top of the unit to allow for maintenance and to insure it is located in a region below 800°F during normal operation. All the tubes can then be inserted through both tubesheets and all the support plates in the normal routine assembly sequence. The tube to tubesheet joint is the standard front face fillet weld with the tube kinetically expanded into the tubesheets. The elimination of a tube bend area allows the use of shorter tubes by avoiding the stagnant primary sodium region experienced in FFTF. By taking advantage of a floating lower tubesheet, a toridal upper tubesheet feature i.e. supported at the inner and outer edges by the channel, and the shorter tube i.e. less thermal expansion load, it was possible to reduce the thicknesses of the upper and lower tubesheets from 16 and 14 inches for FFTF to 6 and 11 inches respectively, for CRBRP.

Another difference between the two IHX designs is related to the approach path of the primary heat transport system inlet piping.

The entrance of the primary sodium into the FFTF IHX is through a 90° elbow oriented in a horizontal plane which causes the entrance flow to favor one side of the IHX. The entrance of the primary sodium into the CRBRP IHX is through a 90° elbow oriented in a vertical plane which intersects the shell and passes through the centerline. The sodium entering this elbow passes through another 90° elbow oriented in a vertical plane perpendicular to the plane containing the elbow attached to the shell. This arrangement does not favor one side of the IHX as strongly as does the FFTF entrance arrangement but it does not provide a uniform flow of sodium into the bundle around its periphery. The flow out of the nozzle passes tangentially along the plenum wall and turns upward at a higher rate in the plenum section opposite the nozzle.

On the FFTF IHX a conical flow distribution shroud and vertical plates to segment the entrance radially as shown on Figure 6 were used to establish uniform flow into the primary side of the bundle. The flow hole pattern was determined by performing a flow model test. The test results indicated the flow distribution into the bundle would be balanced within ± 2% for flows down to 60% of full flow. Maldistributions increases somewhat for flows down to 40% where it becomes +19% and -6%.

On the CRBRP IHX a cylindrical flow distribution cylinder and an eccentric horizontal baffle ring at the entrance to the primary side of the bundle as shown on Figure 6 were used primarily as a cost savings due to ease of manufacturing as compared with a conical design. The flow test results indicated a flow distribution of +3%/-5% would be obtained at 100% flow. The distribution would be ± 7% at the lowest flow rate measured.

The tube support structure in both units was tailored to produce the desired, although different shell side flow distributions. The objective in FFTF was to establish axial flow through the bundle because the tube geometry can readily accommodate tube to tube differential expansion. The objective on CRBRP was to establish an adequate cross flow to control the tube to tube temperature difference becuase the tube to tube differential expansion is less readily accepted. This is particularly significant in the region of a plugged tube should such a condition be encountered.

For FFTF it was determined by bundle flow tests that the tube support flow paths be varied radially as shown on Figure 7. The spacing parameter is of course different in the solid tube support plates (flow holes) than in the segmented tube support plates (annular spacings).

For CRBRP, it was determined by the flow tests that the use of a combination of full and partial support plates as shown on Figure 8 would provide the desired degree of cross flow. The partial plates overlap with each covering 2/3's of the flow area. All plates have a uniform hole spacing between tubes.

There were other benefits derived from the straight tube designs. The tube spacing was changed from a circular pitch to a standard triangular pitch pattern providing a more efficient use of the space available. The number of tubes could be increased for a given shell size thereby saving on the overall length. The combination parallel and cross flow provided more efficient utilization of heat transfer area.

The CRBRP IHX does not have the need to provide an intermediate bypass seal as in the case of the FFTF IHX since there is no possible bypass flow path with the integral bundle design.

The use of thermal liners in the primary sodium entrance area was also eliminated on the CRBRP IHX by utilizing higher stress allowable material, type 316 stainless steel rather than type 304, in this region of the shell. This eliminated several machined parts and eliminated the associated assembly sequences.

D. Thermal Hydraulic and Structural Design

1. Thermal Hydraulic Design

The IHX's have been designed to meet the thermal hydraulic requirements in terms of thermal rating and pressure drop limitations on both the primary and intermediate sides. In addition, assurance of flow stability must be established to preclude damage accruing from flow induced mechanical vibrations. Special attention has been directed to the analyses of the uncertainties in the thermal hydraulic parameters and their affects on the heat transfer surface requirements. Special affects which could influence thermal performance of the unit such as the existance of plugged tubes, sodium side fouling, and flow bypasses in either the primary or intermediate sides have been included in the design.

The heat transfer tube length of the units has been established as the sum of tube length requirements necessary to satisfy the following:

a. The heat transfer area for nominal correlations and average tube wall thickness.

b. Uncertainties in the tube or shell side heat transfer coefficients and deviations in the tube wall thickness.

c. Allowance for flow bypass, tube fouling or tube plugging.

The thermal performance calculations of the FFTF IHX at full load for an effective tube length of 161 inches and a uniform 3/32 inch gap between the tube supports and the shroud showed an excess heat transfer area of 8.5%. Inclusion of the flow distribution results from the 72° flow model, to be discussed later show that the shell side flow maldistribution reduced the excess flow area by 0.2%. This result portrays the fact that the flow model and orificing of the shell side flow distribution was very effective in providing uniform shell side flow. The primary flow has a bypass path through the primary seal which separates the inlet plenum from the outlet plenum. The bypass flow has been estimated in the FFTF design to be less than 0.67%. The effect of this bypass flow on the full load performance is a reduction of the excess heat transfer area. At full load less than .1% reduction of excess surface was found due to the bypass flow and since this amount is very small the bypass flow is found not to be an important consideration. The 8.5% excess heat transfer area is based upon the maximum tube wall thickness and minimum heat transfer coefficients and therefore is an allowance for fouling and tube plugging in the FFTF design.

The approach used to establish the active heat transfer area in the CRBRP IHX differed only in detail, not in approach. In this instance the heat transfer tube length requirements were broken down into specific values to account for the basic design, the uncertainties, and the allowances. The results of this breakdown are shown on Table 1. (Reference 1). The values, when converted to percentages equivalent to the FFTF results, show a 14% excess heat transfer area to account for fouling, tube plugging allowance, and design margin.

The pressure drop calculations on both the primary and intermediate sides of the IHX units have followed the standard procedures of adding up the pressure drops in various sections due to friction, contraction and expansion, abrupt turning of the flow and other effects such as mixing and splitting of fluid streams. For either unit the bulk of the pressure drop on the primary side takes place in the tube bundle, particularly through the tube support plates. On the intermediate side more than 1/3 of the total pressure drop occurs in the bottom header. For both units the pressure drops allocated to the IHX have been satisfied by the designs.

The element of the IHX most susceptible to flow induced vibration are the heat transfer tubes. The approach to establishing that no tube vibration will occur, especially in view of the element of cross flow deliberately built into the CRBRP units, has been addressed by a full scale bundle flow test described later in this paper.

Table 1

Breakdown of CRBRP Heat Transfer Tube Length Requirements

Parameter	Value
Basic Design*	217 in.
Uncertainties:	
1. 15% reduction in tube side "h_i", ΔL_{hi} = 0.25	"
2. 20% reduction in shell side "h_o", ΔL_{ho} = 0.33	"
3. Maximum tube wall thickness, nominal value of thermal conductivity, ΔL_e = 0.20	"
Cumulative length for all uncertainties, ΔL	18 in.
Allowances:	
- Flow bypass (2.825% of primary flow)	15 in.
- Fouling 9% of (Total design tube length minus tube plugging allowance)	25 in.
- Tube plugging 3% of design tube length	9 in.
- Design margin	6 in.
Total	290 in.

*Heat transfer surface area is based on 0.875 in. outside tube diameter, and 2850 tubes in the unit.

The thermal hydraulic design of large size nuclear heat exchangers requires detailed investigation of the flow and temperature fields to insure that the unit will attain its thermal rating and preserve its structural integrity. These detailed investigations have been brought to bear on both the FFTF and CRBRP intermediate heat exchangers.

2. Structural Design

The structural design of the FFTF IHX was conducted in accordance with Section III, Class A, of the ASME and as supplemented by RDT E4-6 all ASME Code Cases througn Summer, 1970. This meant that the design of the unit above 800°F was guided and controlled by the Code Case 1331.4. In addition to this code case, the high temperature design was further subjected to the specifications given in a design document known as FRA-152. This document was a forerunner to the Code Case 1331.5 and its subsequent revisions.

The design of the CRBRP IHX was conducted in accordance with Section III, Class 1 of the ASME Code and with Summer 1974 addenda as supplemented by RDT-E15-2NB all ASME Code Cases through Winter, 1975. The design of the unit above 800°F was guided and controlled by the Code Case 1592-1. This code case incorporated and reflected many of the experiences derived in FFTF design.

The design documents permit elastic analysis to be used even for limited inelastic behavior. However, when elastically computed stresses and strains in components exceed the specified design limits, inelastic analyses may be used to validate the design. The use of inelastic methods on the FFTF and CRBRP IHX's was generally of the same scope. The nozzle regions, the tubesheet regions and major flanges or forgings in the support all involved inelastic analyses. Just two regions of these units are notably different with respect to the structural evaluations. First, there is in the CRBRP unit a bellows element which did not exist in the FFTF design. This unit, although operating below 800°, at normal power conditions is an element subjected to cyclic strains and is of concern with respect to fatigue failure. That element of the design has been subjected to extensive testing and was the subject of a code inquiry pertaining to analytical methods and criteria because an applicable code section, although in preparation, is not issued. Second, there is a difference in the tube configuration. The FFTF tubes being of the curved design are built to accommodate differential thermal expansion due to tube to tube temperature differences. The CRBRP unit, on the other hand, is of a straight tube design so that tube-to-tube differential temperature must be limited to a value acceptable for tubes constrained to essentially the same length between tubesheets. Analyses of these tubes and tube support length as existing in CRBRP has resulted in a limiting temperature differential of 35°F. Our analyses have indicated that the existing maximum temperature difference is about 24°F due to flow maldistribution and proximity to a plugged tube. Our conclusion is that this unit is not susceptible to a tube buckling phenomena.

E. Testing

A considerable amount of testing was conducted to prove out the various design features of the FFTF IHX. Some of this testing was found to be applicable to the CRBRP IHX design and therefore was not repeated. The flow model testing, although similar, had to be repeated due to the differences in flow parameters. A discussion of the various test programs follows:

FFTF IHX

1. Tube to tubesheet joint.

To demonstrate the ability of the tube-tubesheet butt welds to withstand imposed thermal shocks a seven-tube, double tubesheet, autoclave-type vessel using liquid sodium as the heat transfer medium was used. The tube-tubesheet joints were subjected to a total of 252 thermal shocks, using the most severe temperature changes the welds will experience. The tests were performed by heating the tubesheets and sodium to the temperatures required to produce the desired differential temperature and then rotating the autoclave 180 degrees allowing the sodium to run through the tubes and tubesheets to the opposite end. Following the test runs the tube-tubesheet welds were subjected to examinations. There was no evidence of cracking in the weld zone or spigot nozzle area or separation of the cladding material from the base material joint, are indicative of the integrity of the front face fillet joint used on the CRBRP IHX.

2. Tube to tube support fretting.

In order to determine the tube fretting wear to be expected on the IHX tubing a flow induced vibration test was conducted. The test utilized a three tube three span mock-up a tube bundle where flow induced vibrations were simulated in a 1050°F sodium environment. After 200 million cycles the fretting wear was found to be too small to express in quantitative terms. As a result of this test a fretting wear test was not proposed for CRBRP IHX since the particular parameters were identical to the test performed for FFTF.

3. Tube support hydraulics.

In order to determine the pressure loss characteristics of flow through the flow holes in the support plates and to ascertain flow induced vibrations at different flow combination a water test was performed on a seven-tube model. The tests indicated the expected flow pressure drops and demonstrated there were no vibrational problems even well beyond the expected flow ranges. Since the CRBRP IHX is essentially a scale up of the FFTF IHX additional testing was not considered necessary.

4. Tube bend area support study.

The FFTF IHX contains a rather long stagnant tube area section and the need for a center support mechanism to damp out any flow induces vibrations either from the flow of sodium through the tube or the flow of sodium past the tube adjacent to the stagnant region of the tube bundle was tested. The flow test performed in a heated water medium indicated there was no need for a tube support in the bend area. Since the CRBRP has no expansions bend area testing was not considered necessary.

5. Primary inlet flow distribution.

A flow model test was performed to determine the optimum flow hole pattern to be employed in the conical flow distribution device. The tests were performed to achieve a flow area hole plan which would provide the most uniform flow distribution. As indicated earlier a flow balance of $\pm$ 2.5% was obtained for a flow of 60 to 100%. For flows down to 40% the balance swings to +19% and -6%. A separate flow test program was performed on the CRBRP IHX since a different flow distribution scheme was used.

6. Intermediate flow distribution.

A flow test was deemed necessary to demonstrate that a uniform flow of sodium could be obtained up through the bundle from the lower hemispherical plenum section. A test was performed first with no device to determine the degree of maldistribution. Flow testing indicated satisfactory flow distribution could be attained by using an annular ring attached to the inside surface of the hemispherical head. The results of this test program were not directly applicable to CRBRP IHX due to the differences in hydraulic parameters. However, the results were indicative that the same type of design could be utilized but would have to be substantiated by flow testing.

7. Primary bundle flow characteristics.

In order to determine the flow distribution on the primary side of the IHX between support plates from the center of the bundle to the outside a full scale model test covering the active tube heat transfer area was proposed. The model was a 72° segment of the bundle, since this segment is repeated five times in the actual unit. The model test also demonstrated the pressure drop across the support plates. The test was performed over the 25% to 100% flow range. The results indicated some change was required in the flow hole pattern in some of the flow baffles which was incorporated into the final design in order to meet the Equipment Specification requirements. A decision was made after successful completion of this test to ascertain what would occur if the primary flow were increased by 50%. To achieve the desired test data with the available equipment at the least amount of cost the model was reduced to a 48% segment. The testing showed that no resonance occurred from the flow induced vibrations. Although these test results are not directly applicable to CRBRP they are indicative that no problem would be experienced.

CRBRP

The FFTF tests were evaluated for applicability to CRBRP in establishing the CRBRP testing. The conclusions are presented below.

1. Tube to tubesheet joint.

Since the tube-tubesheet joint is a standard type which has been demonstrated over the years further testing was not considered warranted.

2. Tube to tube support fretting.

As indicated above, further tube fretting tests were not deemed necessary.

3. Tube support hydraulics.

The CRBRP IHX support plate flow hole configurations similar to the non-segmented plates used in part of the FFTF bundle and further testing was not considered necessary.

4. Tube bend area support study.

The CRBRP IHX does not employ a tube bend or stagnant area so this test is not applicable.

5. Primary inlet flow distribution.

Due to the fabrication experience on FFTF it was determined the conical distribution sections should be replaced with a cylindrical distribution device. A scaled down flow model test, as on FFTF, was performed including the inlet piping. The test results dictated the desired inlet flow baffle ring and distribution cylinder flow hole pattern to be used in order to provide the most uniform flow distribution over the entire operating range.

6. Intermediate flow distribution.

A flow test similar to that performed on FFTF was performed and it was determined that a similar type flow distribution ring in the lower hemispherical plenum section could be utilized to provide the desired flow distribution through the tubes.

7. Primary bundle flow characteristics.

Since the CRBRP IHX uses a different tube configuration, triangular vs. circular pitch and it was necessary to achieve uniform tube temperatures, a full scale flow test using a 30° segment was performed to determine the optimum flow baffle configuration to be used. The test results indicated the use of overlapping flow baffles equal to 2/3's of the flow area would provide the proper cross flow distribution within the bundle.

8. Bellows test.

The CRBRP IHX required one additional development program over FFTF and that was associated with the bellows used to accommodate the thermal expansion between the tubesheets. At the present time the bellows design is not covered by the ASME Boiler and Pressure Vessel Code for Class 1 Nuclear applications, and a code inquiry was resolved to establish the applicable design methods and criteria. The bellows was designed to the stress limits of the code and was cyclic tested well beyond the expected design life (by a factor of 4). These tests indicate the bellows will be adequate for the application intended.

F. Fabrication

At the present time the FFTF IHX units have been completed and the three plant units have been installed at the FFTF Site. Fabrication releases have been granted for the three CRBRP IHX units and they are scheduled for completion in the first quarter of 1980.

As indicated earlier the FFTF IHX is composed of three parts i.e. hanger, shell (including the thermal liner) and tube bundle. The hanger support and shell sections were completed and where shipped to the FFTF Site and installed before the tube bundles. This necessitated the need for three different shipping and handling devices for each IHX. Whenever possible a device was utilized for more than one unit. Due to the need to control the fitup of the mating keys and slots of the lower flange on the hanging support and the shear key flange on the shell it became necessary to match machine the two parts. Figure 4 shows how these three flanges are assembled in the completed unit. This meant a particular shell had to be used with a particular hanger support. This same match machining problem arose with the machining of the bundle support flange in order to assure proper fit-up of the primary seal ring.

During the field assembly of the bundle subassemblies i.e. thermal liner, primary bypass seal, etc. it was discovered the outer shroud sections had experienced considerable weld shrinkage and distortion which resulted in the shrouds being shrunk on the support bars. The bundles had to be returned to the suppliers plant for extensive rework. It was discovered during the rework of the shrouds that the design used for the integral weld backup strip was inadequate to prevent weld burn-through.

As a result of the FFTF experience the outer shroud for the CRBRP IHX was designed to provide stiffener rings at each support plate with the remaining shroud sections being 360° cylinders formed with a single longitudinal butt weld instead of two 180° half cylinders as in FFTF. The shroud is assembled into two major sections and the stiffener ring inside diameters line bored to obtain the minimum out-of-roundness, thereby accurately controlling the critical gap dimensions between the tube support plates and the outer shroud. The two shroud sections will be slipped over the tube support cage and welded to the distribution cylinder which has been welded to the upper tubesheet and welded to each other. The two final circumferential welds use an integral weld backup ring design which has been verified by a weld mock-up.

The most significant differences in fabrication between the FFTF and CRBRP units are related to tube bundle assembly and final unit assembly. On the FFTF IHX the individual parts (shell, bundle, hanger support) were carried to completion independently and shipped to the site. On CRBRP IHX, the component parts are completed to a certain stage where they are integrated with the other parts for shop assembly. The fabrication sequence will be described in terms of bundle assembly, shell assembly, hanger assembly and unit assembly in that order.

Tube Bundle Assembly

The FFTF tube bundle assembly sequence is shown in Figure 9. The major steps are: 1) weld upper tubesheet to downcomer, 2) install solid tube supports on downcomer 3) weld lower tubesheet to downcomer 4) install tubes and segmented tube supports 5) weld upper channel assembly to upper tubesheet 6) install outer shroud and stiffeners and 7) weld lower plenum assembly to lower tubesheet. The resultant assembly is shipped to the site.

The CRBRP tube bundle assembly sequence is shown in Figure 10. The major steps are 1) weld strongback and flow distribution cylinder to upper tubesheet 2) install tube supports on strongback 3) install tubes 4) install outer shroud over tube support 5) insert downcover into strongback and pull tubes through lower tubesheet and weld tubes to tubesheets and kinetically expand tubes into the tubesheets and 6) weld lower plenum assembly to lower tubesheet. The resultant assembly is advanced to final assembly in the shop.

Shell Assembly

The FFTF shell assembly sequence is shown on Figure 11 and the CRBRP shell assembly sequence is shown on Figure 12. The assembly sequences are very similar in that the main shell course is assembled from 3 shell sections and a lateral support ring. Also the lower head and primary nozzles are handled in an analogous fashion. The FFTF shell assembly includes an upper support ring which does not exist on the CRBRP shell. Finally, the lower shell head and primary outlet nozzle assembly are attached to the FFTF shell for shipment to the site. For CRBRP the lower shell head and primary outlet nozzle assembly are held for connection to the shell at a later point in the shop fabrication sequence.

Hanger Support

The FFTF hanger support assembly sequence is shown on Figure 13. There are just three subassemblies involved. These are the lower support ring, the upper cylinder ring and the upper support flange. Welding of these three units into a single piece as shown on Figure 13 results in a support assembly with a flange on the upper end from which the unit weight is carried and a flange on the lower end for mating with the shell subassembly during field construction. The hanger support assembly is shipped to the site.

The CRBRP hanger support assembly sequence is shown on Figure 14. It is comprised of four elements, the hanging support flange, and three cylindrical cone sections. The final assembly, as in FFTF, has a flange at the upper end from which the unit will be supported, but has a weld preparation on the lower end for attachment to the bundle assembly during final assembly.

Final Assembly

The FFTF unit is field assembled as shown on Figure 15. The hanging support is bound into place on the support ledge in the operating floor. The hanging support extends down into the inerted cell. Next the shell is lowered into the hanging support. The shell is lowered off center until the primary inlet nozzle clears the lower flange of the hanging support. The shell is then moved to the center of the assembly and the shell lowered to where the shell flange and the lower flange of the hanging support are interlocked. The shell and hanging support are locked together by means of the hold down ring shown earlier on Figure 4.

The various subassemblies i.e. inlet plenum, thermal liner and primary bypass seal are attached to the bundle as shown on Figure 15. The completed bundle is then lowered into the shell. The seal ring which had been welded to the bundle flange previously is then welded to the shell flange. The shear blocks are then installed into the groove in the shell flange. These blocks eliminate the shear load on the seal ring. The blocks are kept in position by means of a locking ring. This completes the field assembly.

The CRBRP unit is shop assembled as shown on Figure 16. The final assembly proceeds with the unit in the horizontal orientation as shown. The upper downcomer, inner channel, inlet nozzle and bellow seal and outer channel subassemblies are attached to the bundle assembly. Note that the upper support forging (Z forging) is part of the outer channel subassembly. The hanging support subassembly is then attached to the outer channel subassembly in preparation for addition of the shell assembly. After installation of the shell assembly and lower head assembly the unit is ready for shipment to the site. At this point the unit is complete and no further field assembly is required.

It is felt that the completion of the CRBRP unit in the shop will represent a significant advantage in construction difficulty compared to the FFTF.

Reference

1. M. M. Aburomia, et al., "Thermal/Hydraulic Design Considerations for Clinch River Breeder Reactor Plant Intermediate Heat Exchangers", ASME Paper No. 75-WA/HT-101, August, 1975.

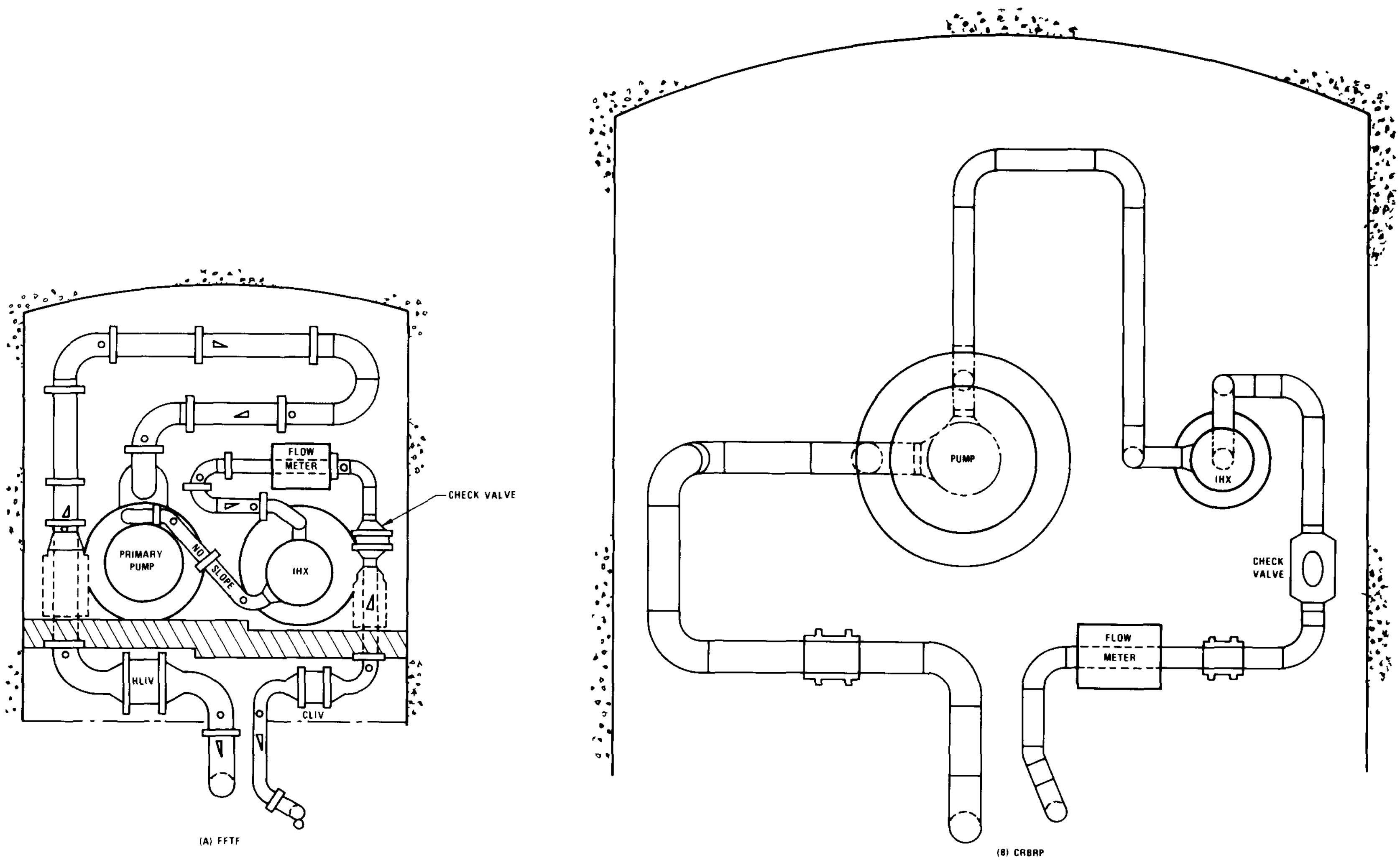


Figure 1. FFTF and CRBRP Primary Heat Transport System Arrangement Plan

FFTF (DOTTED LINE)

LENGTH	39.5 FT
SHELL DIAMETER	6.5 FT
WEIGHT (DRY)	174,100 LB
(OPERATING)	217,000 LB
THERMAL DUTY	133 MWt
TUBE LENGTH	19.6 FT
ACTIVE TUBE LENGTH	67 PERCENT
NUMBER OF TUBES	1,540
SURFACE	4,733 FT^2
LOG MEAN TEMPERATURE DIFFERENCE	85^oF
OVERALL HEAT TRANSFER COEFFICIENT	1,226 $BTU/HR\text{-}^oF\text{-}FT^2$
PRIMARY FLOW	5.76×10^6 LB/HR
INTERMEDIATE FLOW	5.71×10^6 LB/HR

CRBRP (SOLID LINE)

LENGTH	52.1 FT
SHELL DIAMETER	8.8 FT
WEIGHT (DRY)	230,000 LB
(OPERATING)	340,000 LB
THERMAL DUTY	325 MWt
TUBE LENGTH	25.8 FT
ACTIVE TUBE LENGTH	94 PERCENT
NUMBER OF TUBES	2,850
SURFACE	11,810 FT^2
LOG MEAN TEMPERATURE DIFFERENCE	68.5^oF
OVERALL HEAT TRANSFER COEFFICIENT	1,374 $BTU/HR\text{-}^oF\text{-}FT^2$
PRIMARY FLOW	13.82×10^6 LB/HR
INTERMEDIATE FLOW	12.78×10^6 LB/HR

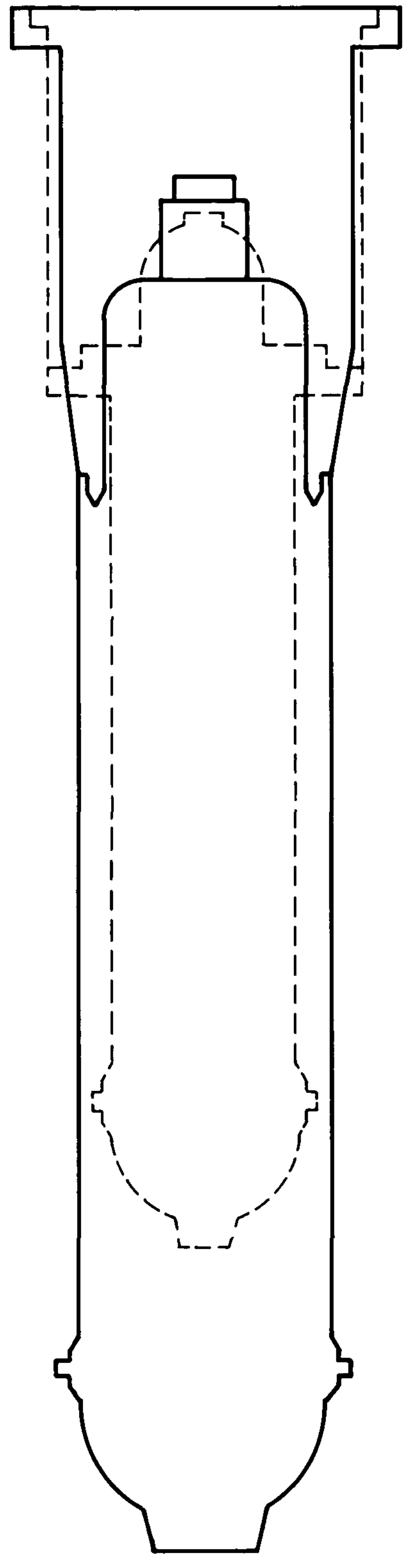


Figure 2. Comparison Between FFTF and CRBRP IHX Design Parameters

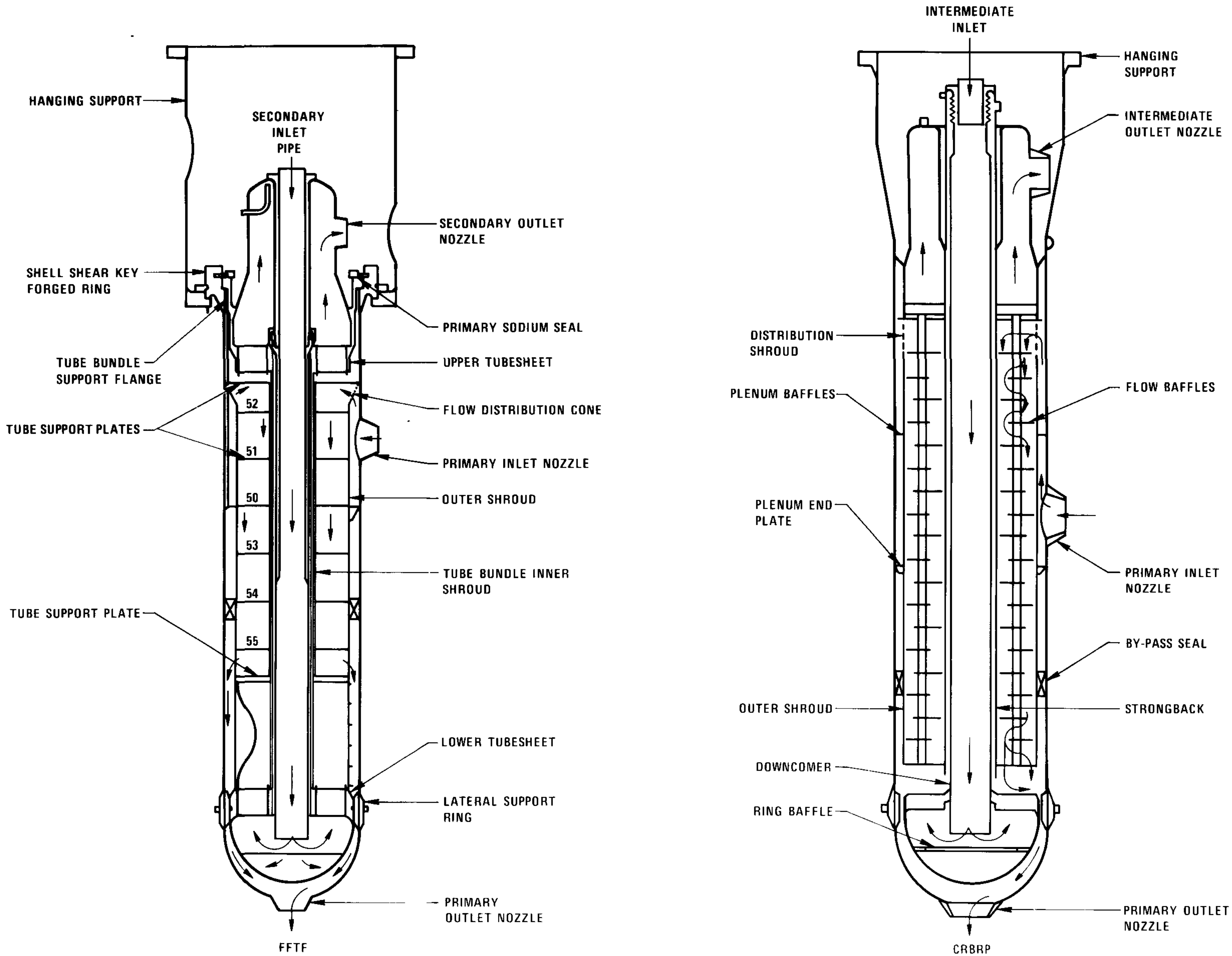


Figure 3. General Arrangement of FFTF & CRBRP Intermediate Heat Exchangers

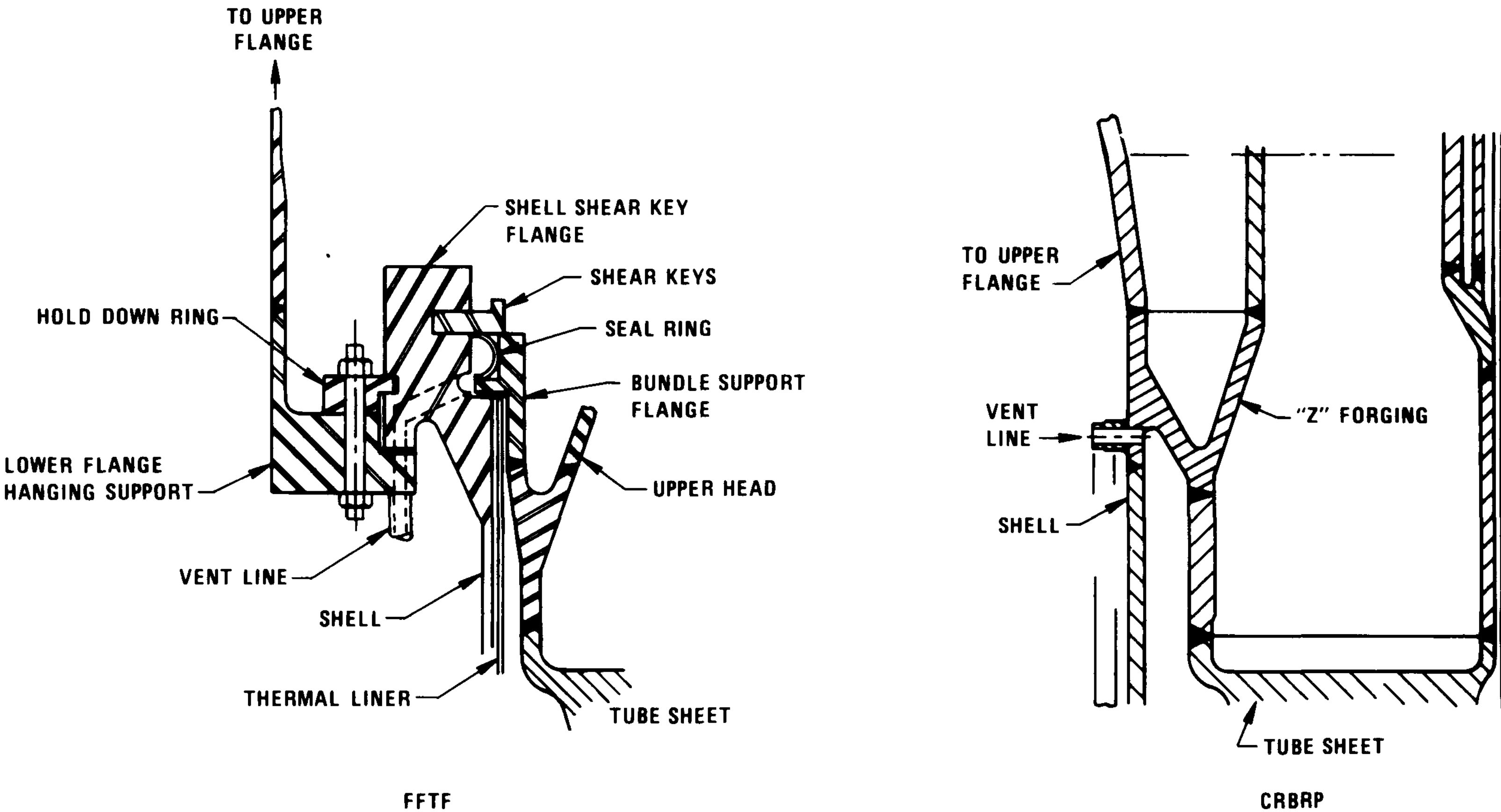


Figure 4. FFTF and CRBRP Support Cone to Shell and Bundle Joints

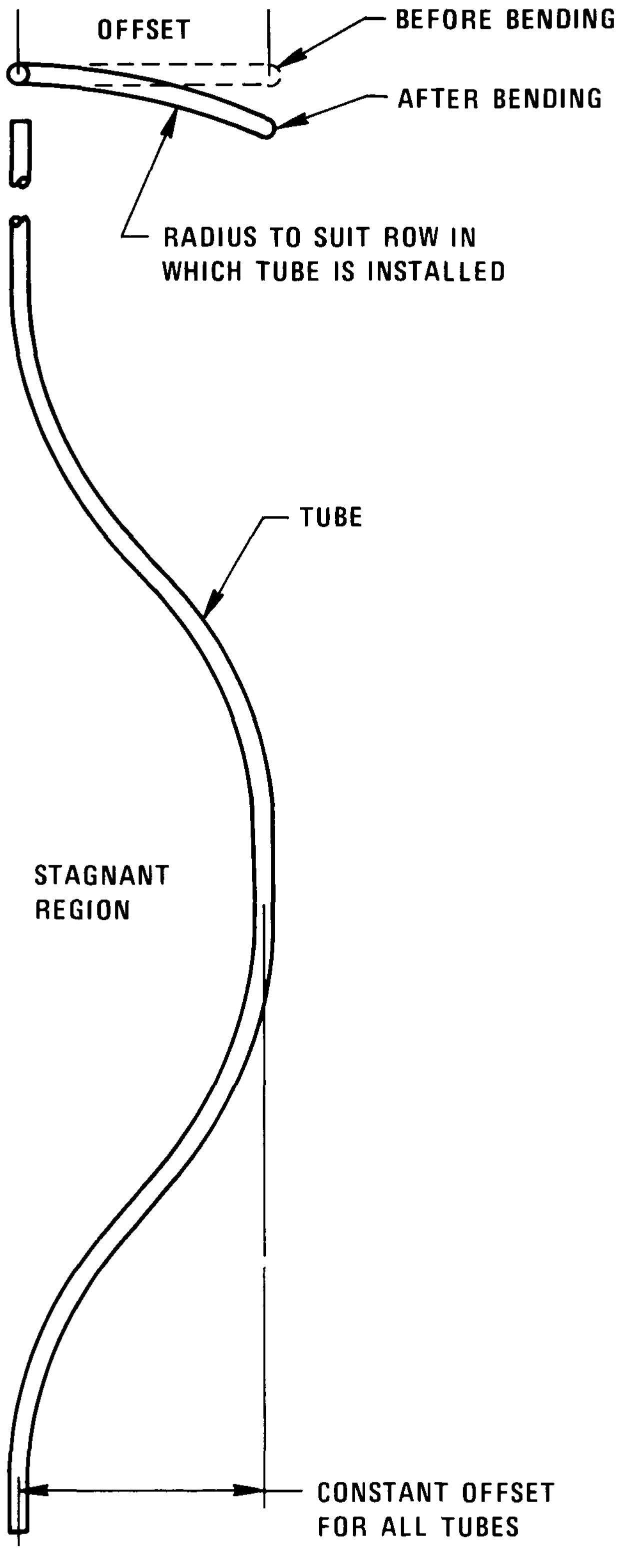


Figure 5. Configuration of FFTF Heat Transfer Tubes

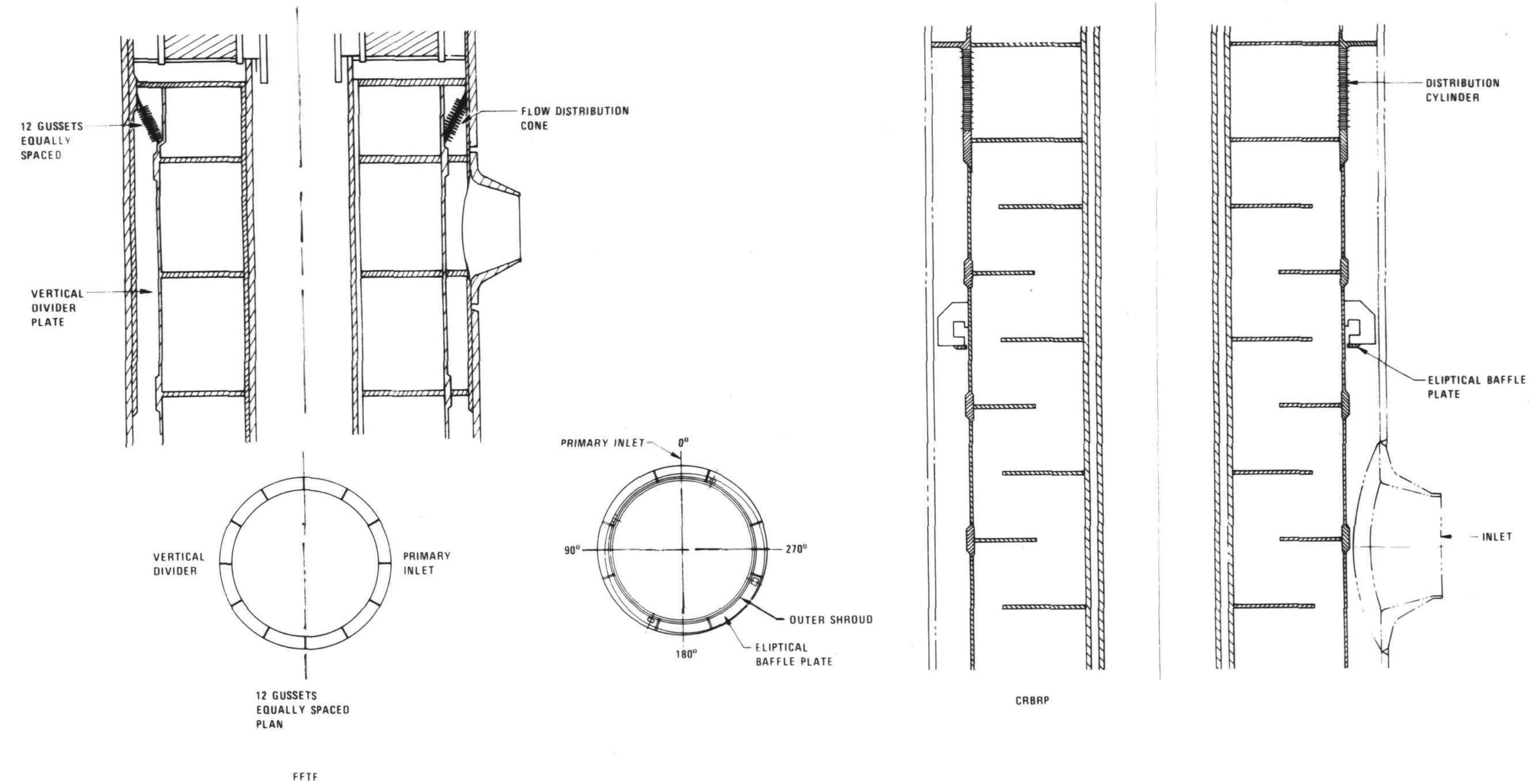
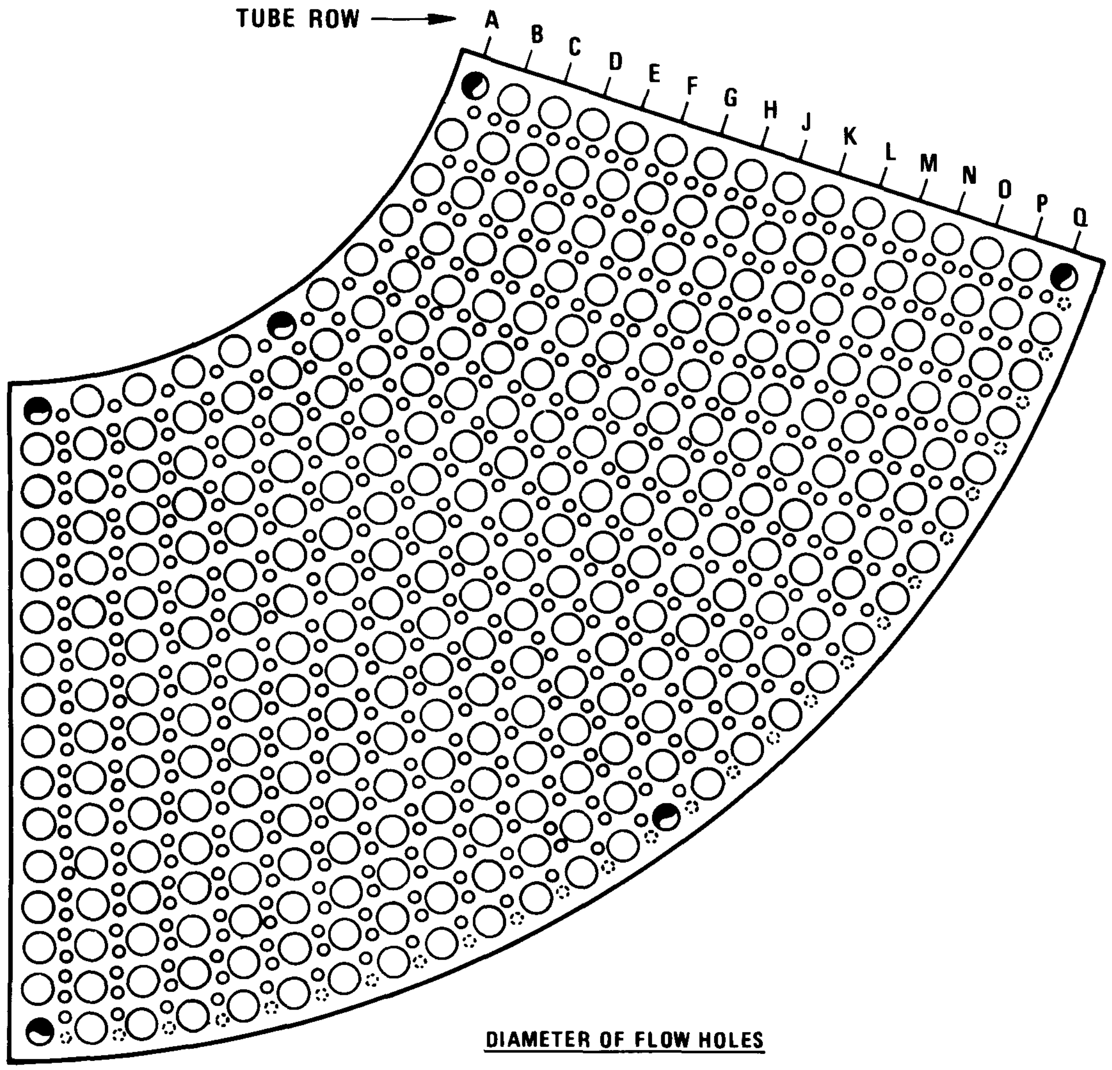


Figure 6. FFTF and CRBRP Primary Inlet Flow Distribution Devices

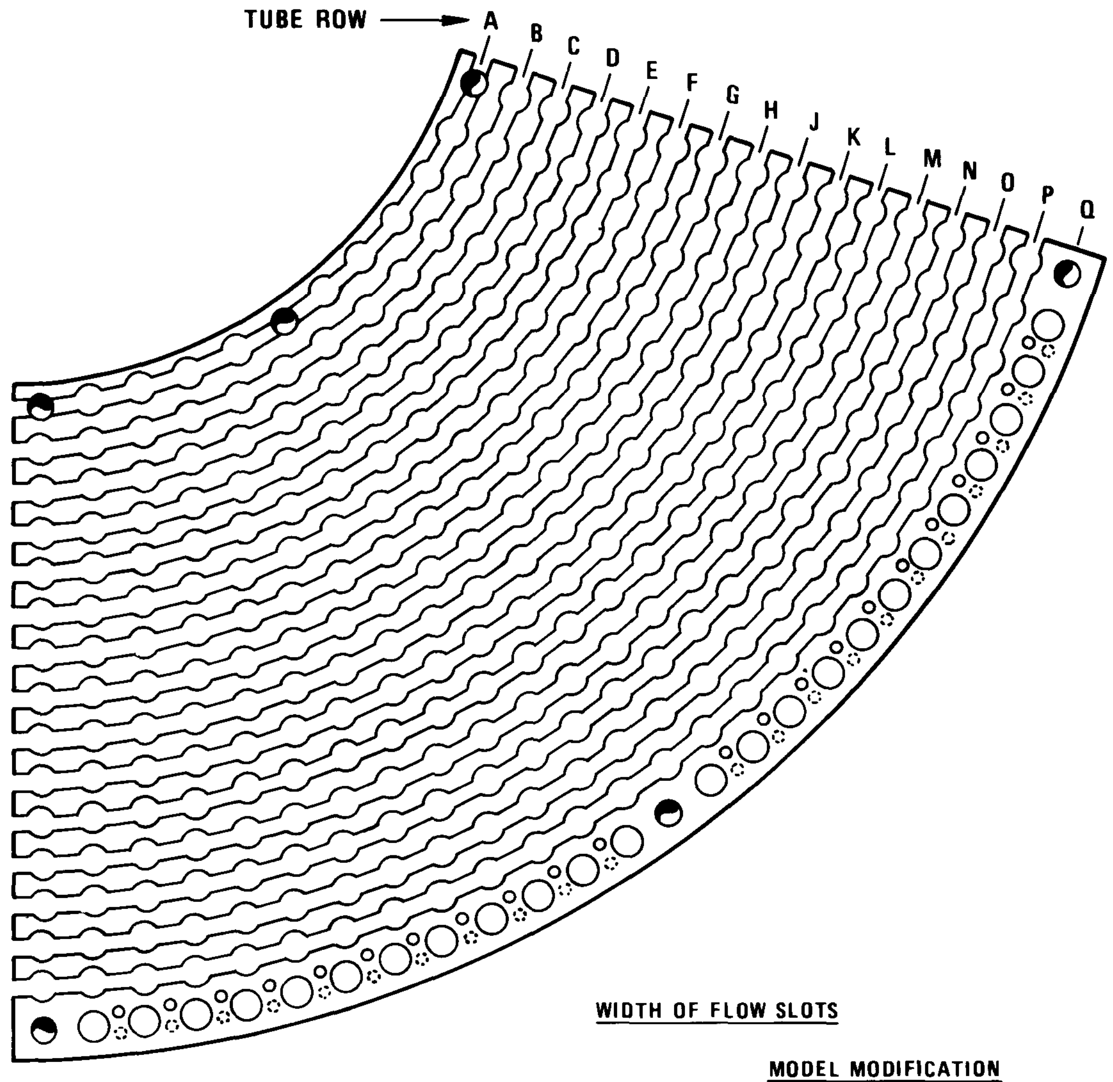


DIAMETER OF FLOW HOLES

SUPPORT** PLATE NO.	TUBE ROWS	MODEL MODIFICATION ORIGINAL	FIRST	SECOND
52	A	0.437	0.437	0.437
	B – H	0.437	0.437	0.397
	J – M	0.397	0.397	0.397
	N – Q	0.344	0.397*	0.437*
50, 51	A – Q	0.437	0.437*	0.437*

NOTES: *DENOTES 0.437 DIA. HOLES ADDED BETWEEN ROW Q AND OUTER SHROUD.
**SUPPORT PLATE NUMBERS LOCATED AS SHOWN ON FIG. 3.

SOLID TUBE SUPPORT PLATES



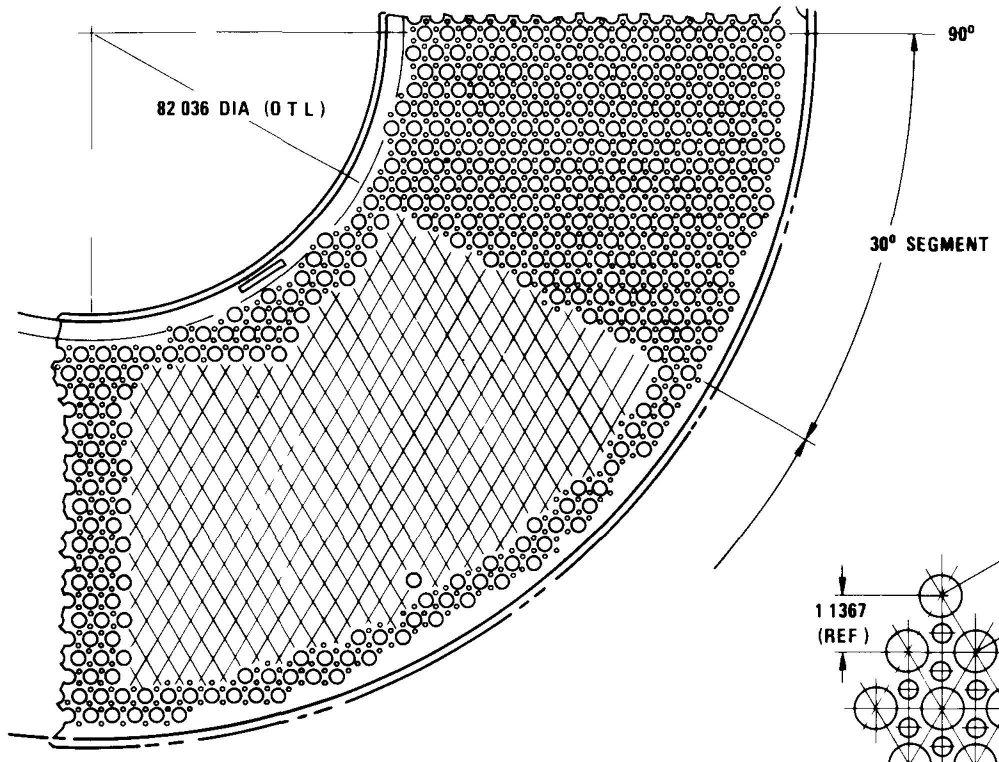
WIDTH OF FLOW SLOTS

SUPPORT** PLATE NO.	TUBE ROWS	MODEL MODIFICATION ORIGINAL	FIRST	SECOND
53, 54	A	0.300	0.300	0.300
	B – P	0.500	0.500	0.500
	Q	0.437 HOLES ONE SIDE	0.437 HOLES BOTH SIDES	0.437 HOLES BOTH SIDES
55	A	0.300	0.300	0.300
	B – H	0.582	0.582	0.582
	J – M	0.500	0.500	0.500
	N – P	0.392	0.392	0.392
	Q	0.344 HOLES ONE SIDE	0.344 HOLES ONE SIDE	0.344 HOLES ONE SIDE

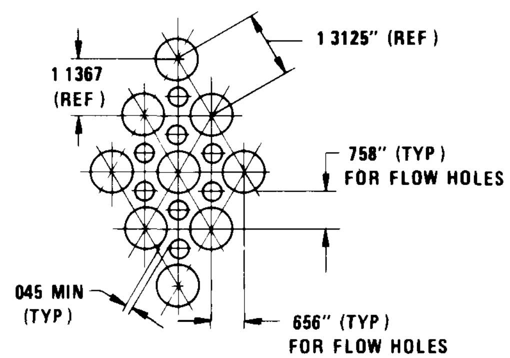
NOTE **SUPPORT PLATE NUMBERS LOCATED AS SHOWN ON FIG. 3.

SEGMENTED TUBE SUPPORT PLATES

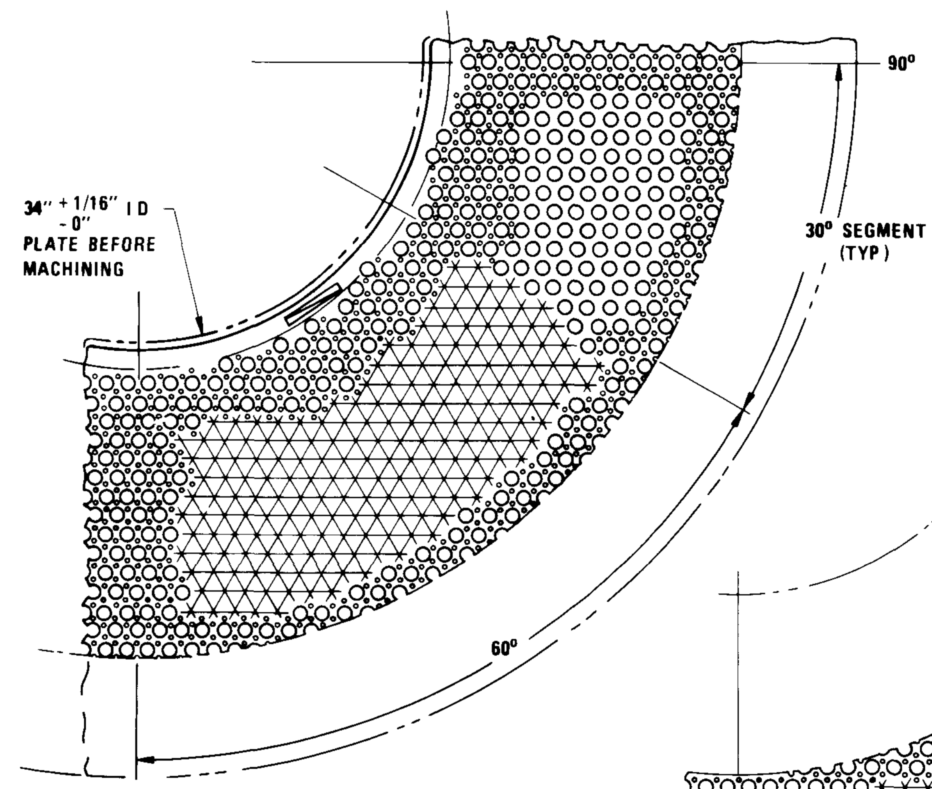
Figure 7. FFTF Bundle Tube Support Configurations



FULL SUPPORT PLATE*

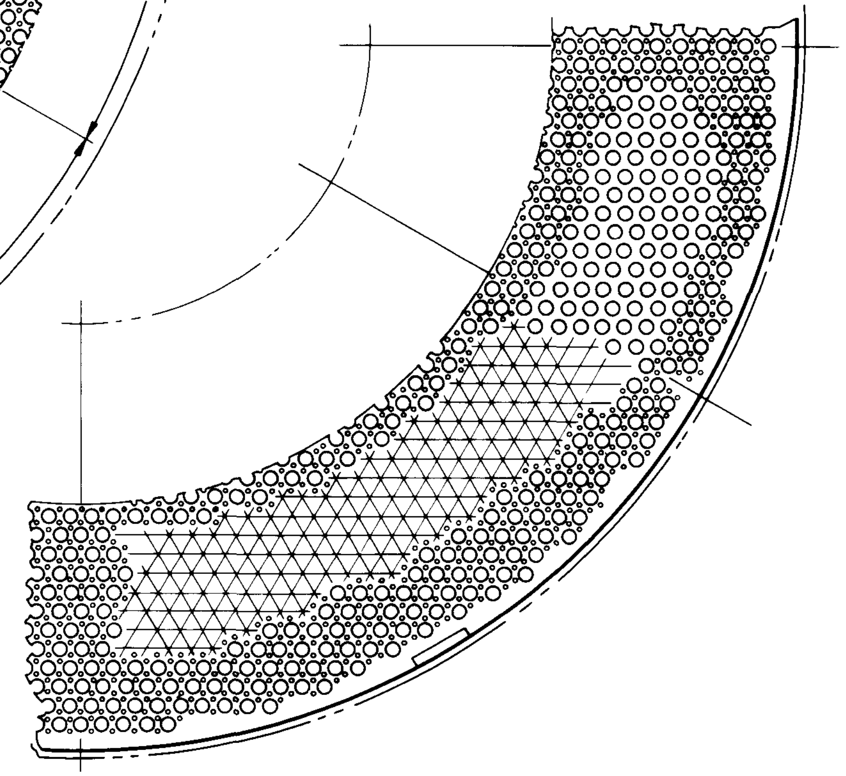


*LOCATION OF FULL, INNER AND OUTER SUPPORT PLATES LOCATED AS SHOWN ON FIG 2



SUPPORT PLATE AS VIEWED FROM TOP OF UNIT ~ DRILL ENTRY SIDE

INNER SUPPORT PLATE*



OUTER SUPPORT PLATE*

Figure 8. CRBRP Bundle Tube Support Configurations

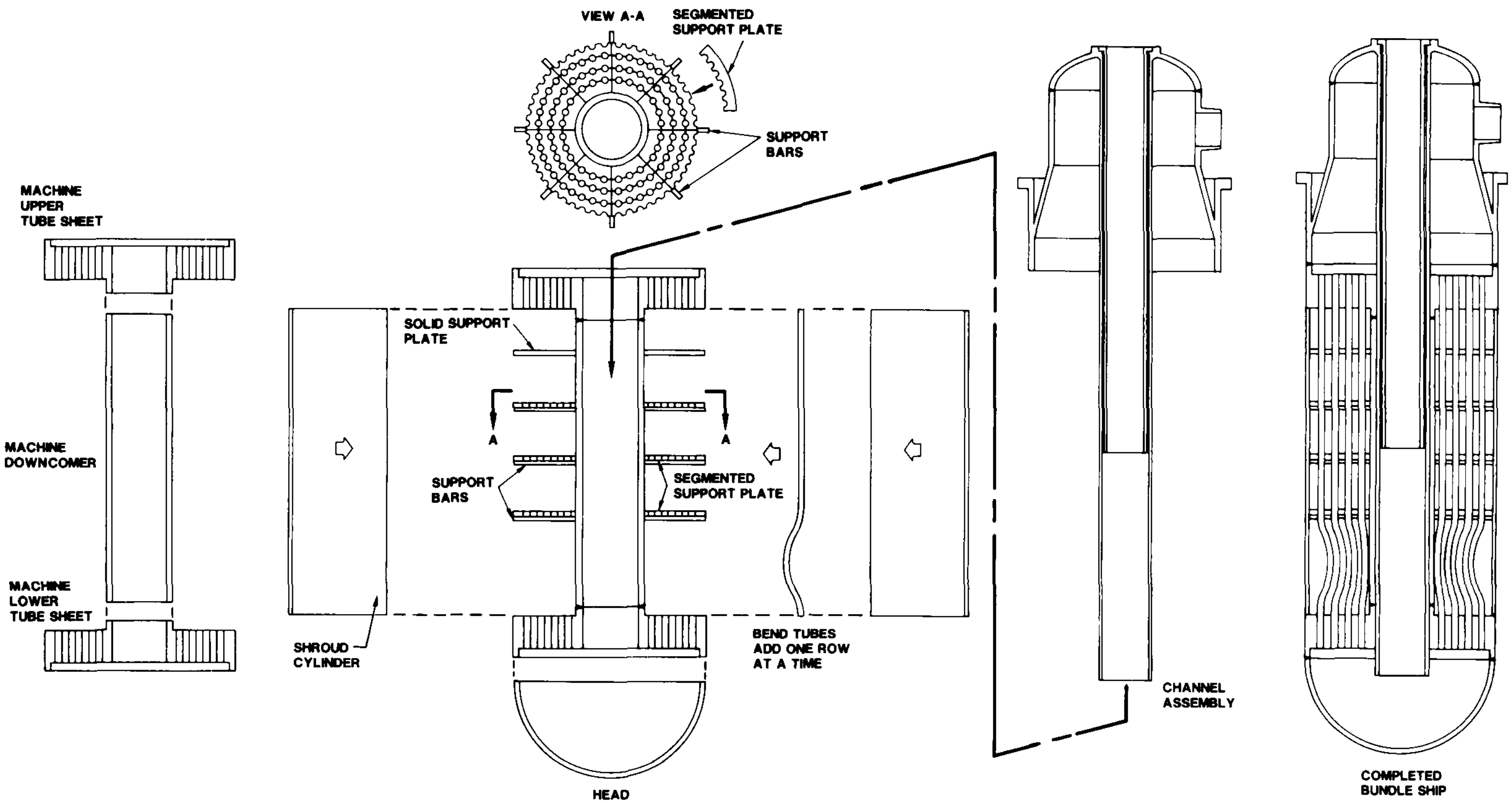


Figure 9. FFTF Bundle Assembly

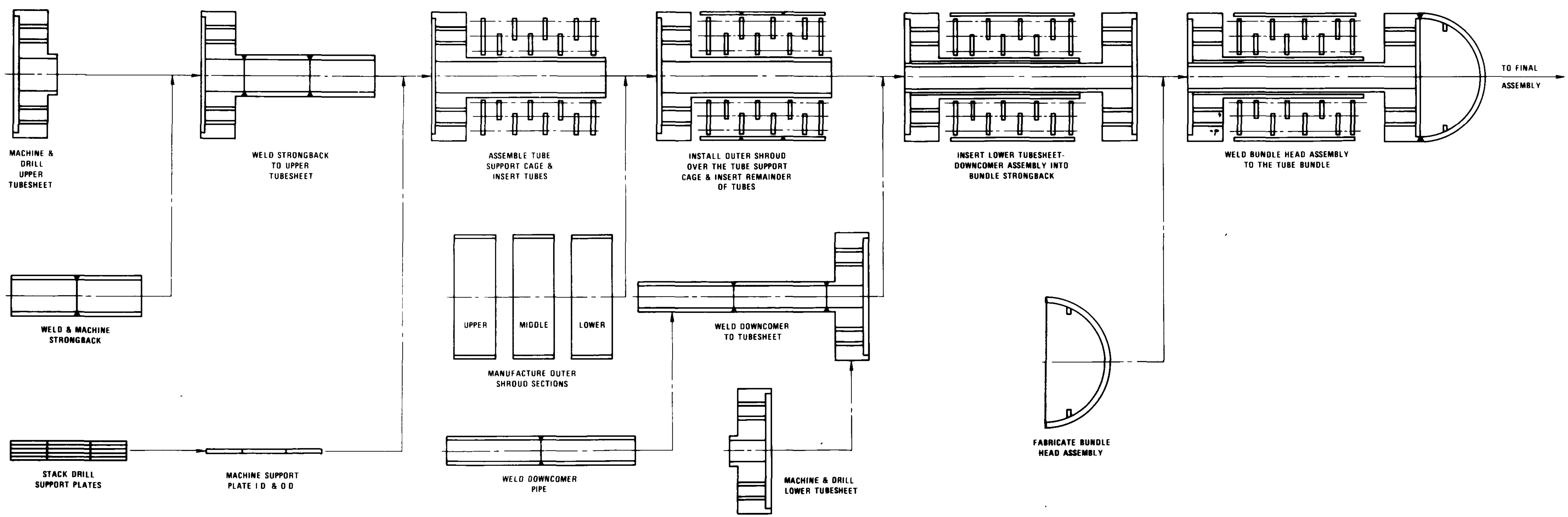


Figure 10. CRBRP Bundle Assembly

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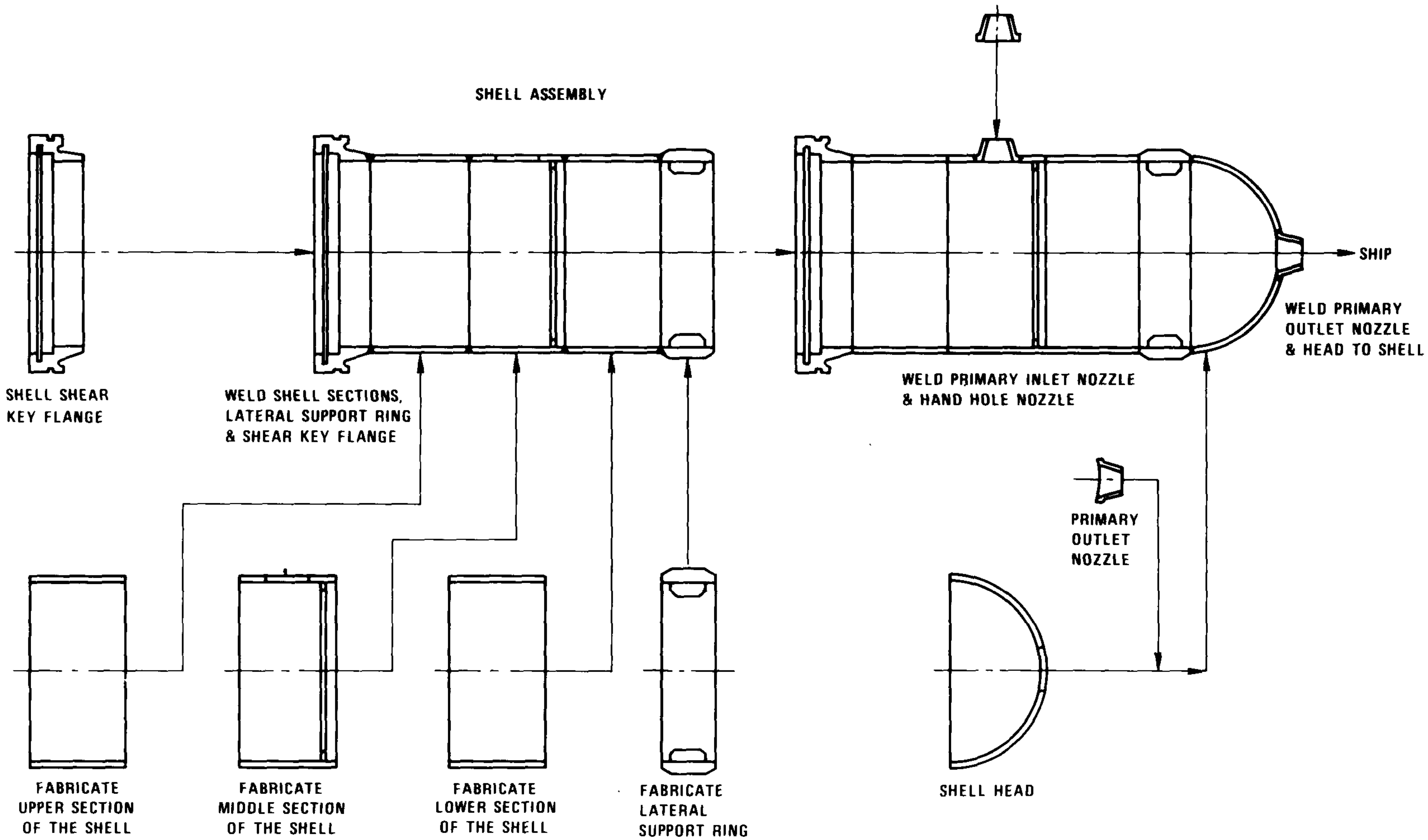

Figure 11. FFTF Shell Assembly

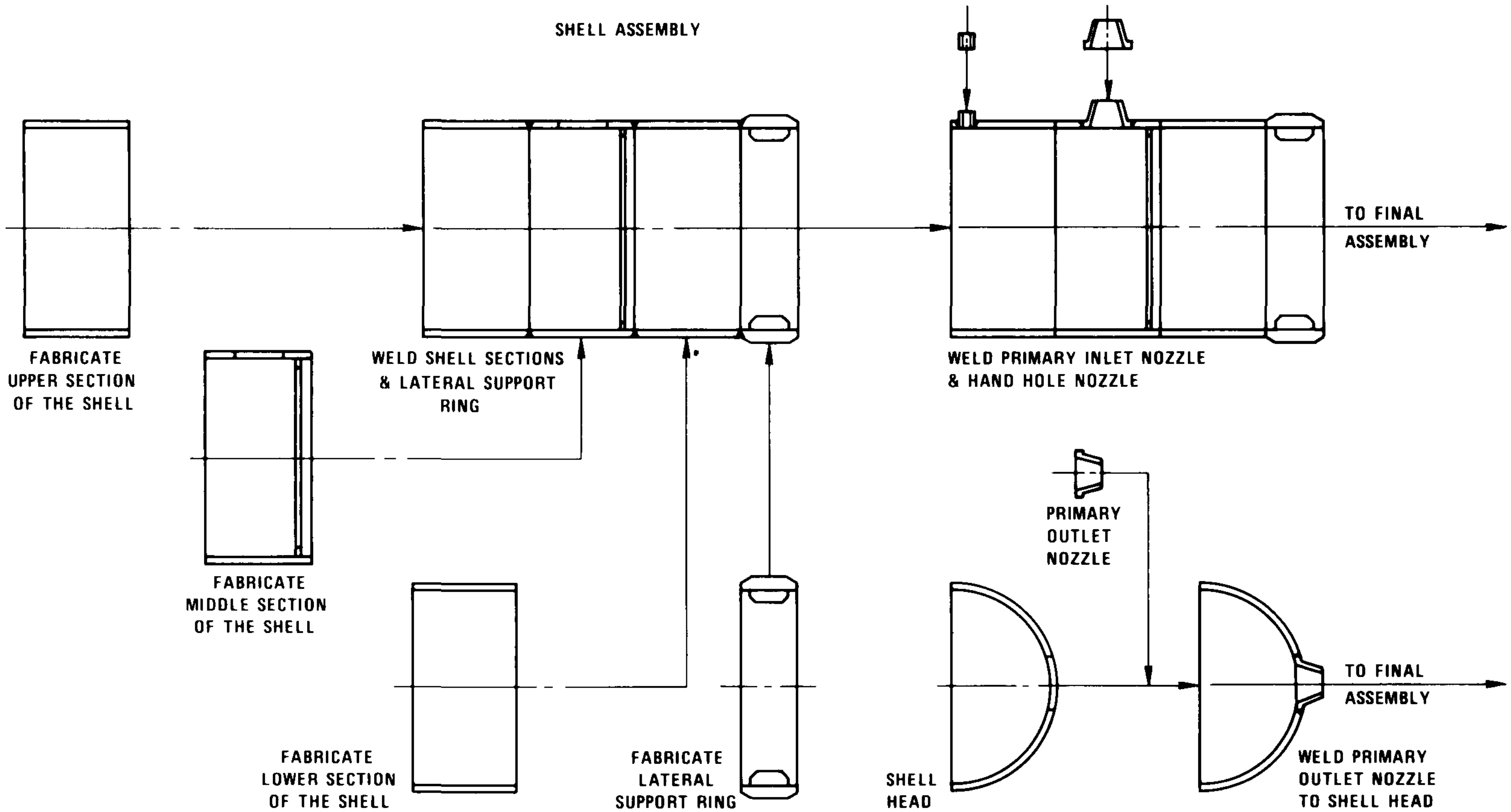

Figure 12. CRBRP Shell Ass'y.

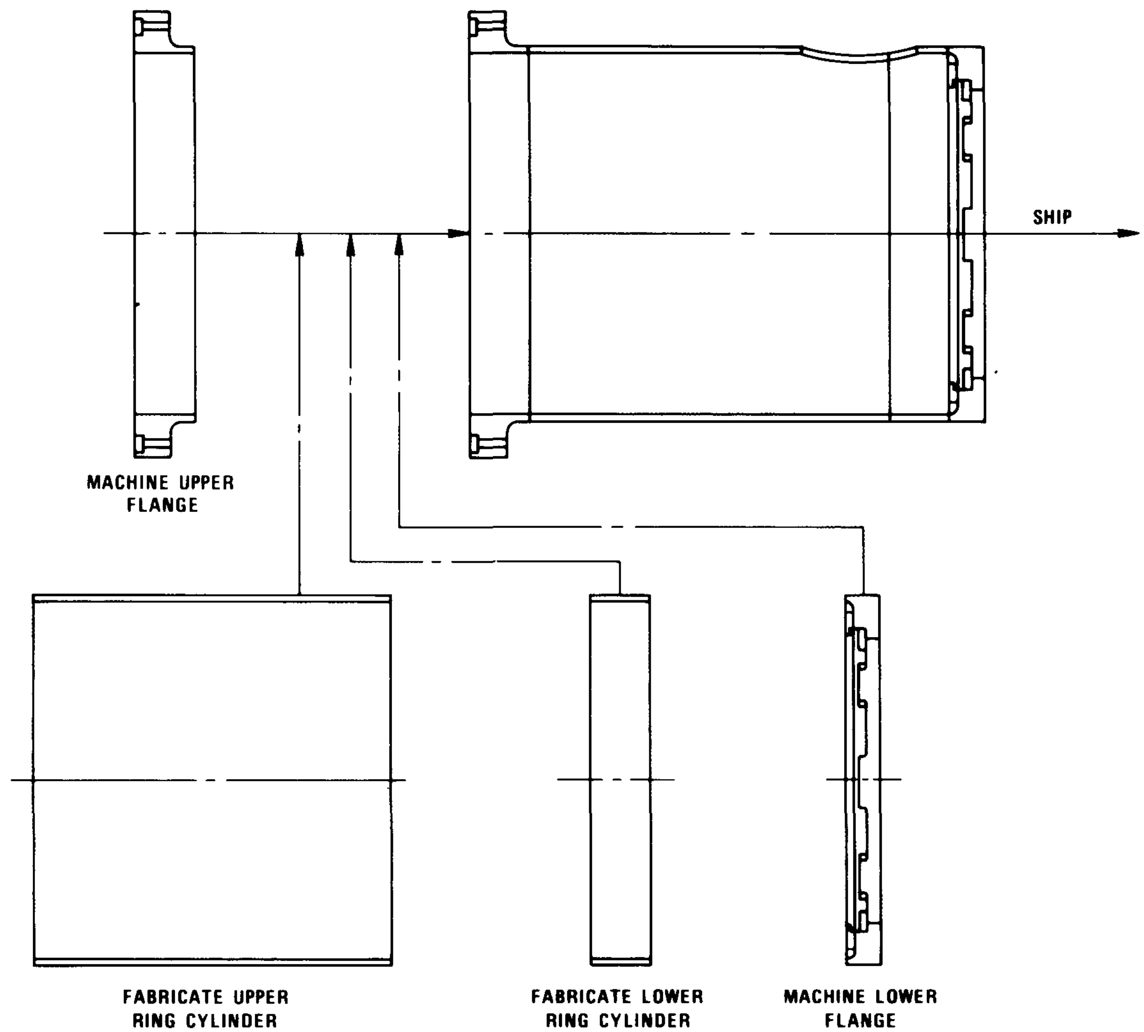

Figure 13. FFTF Hanger Support Assembly

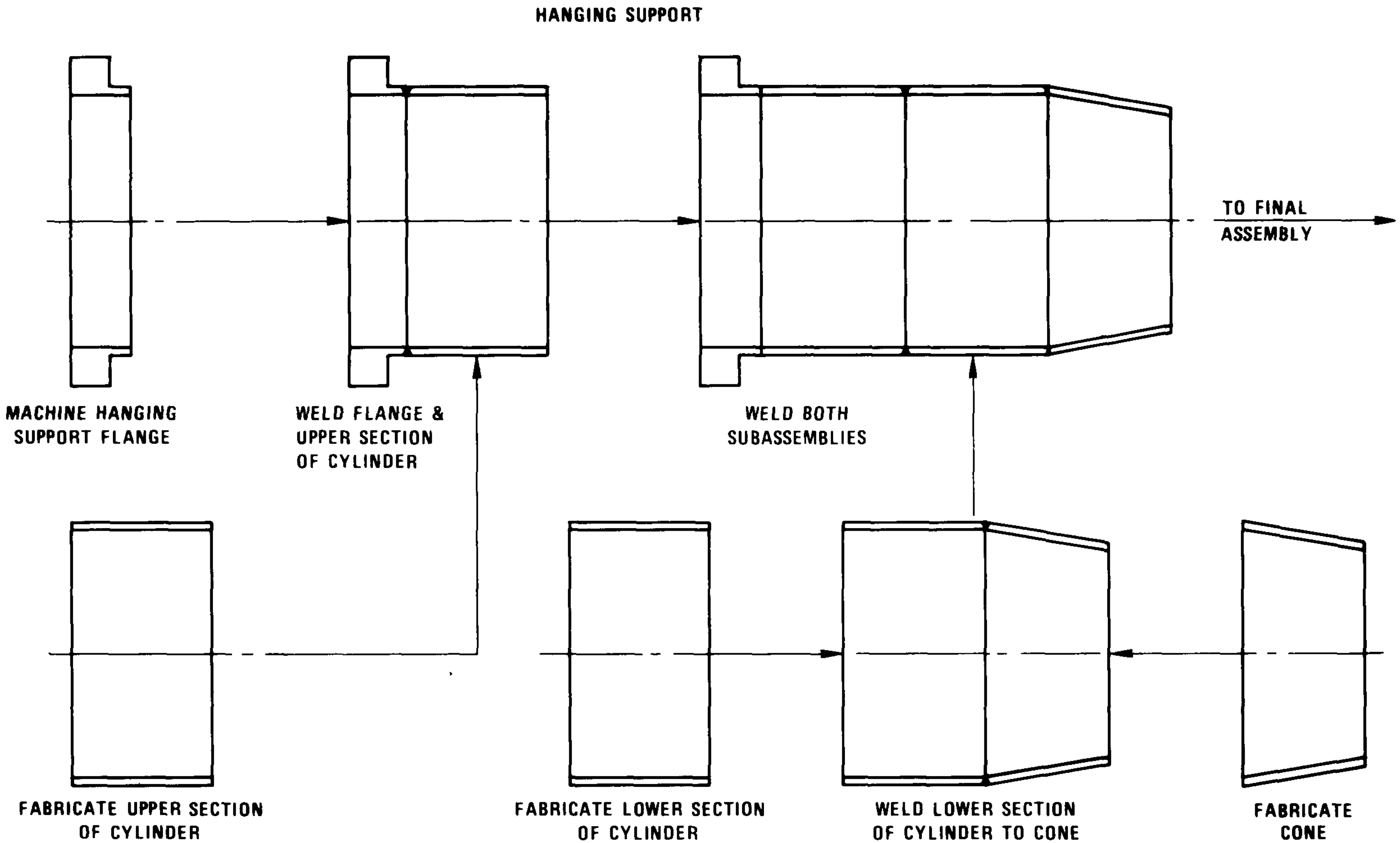

Figure 14. CRBRP Hanger Support Assembly

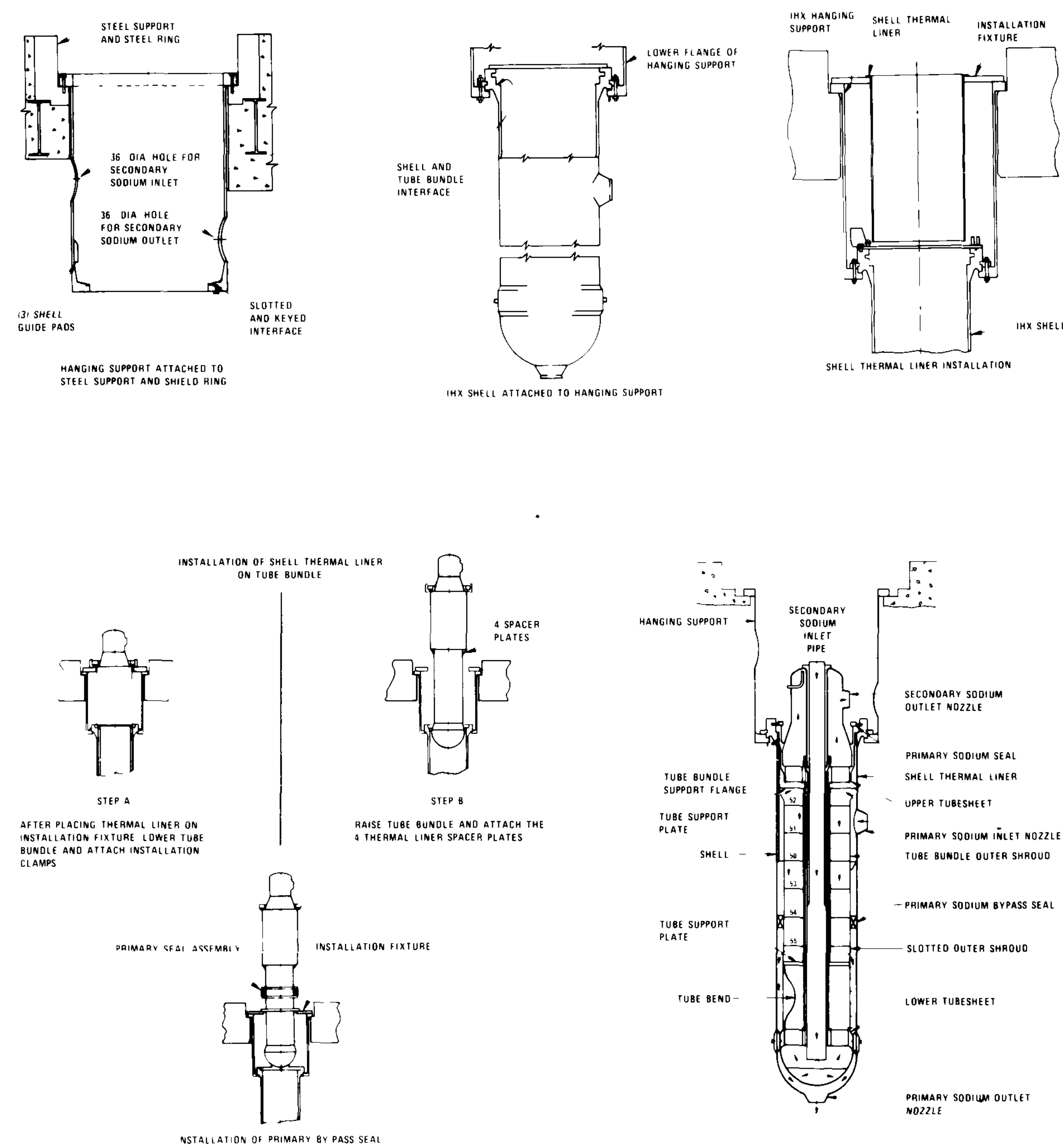

Figure 15. FFTF Field Assembly

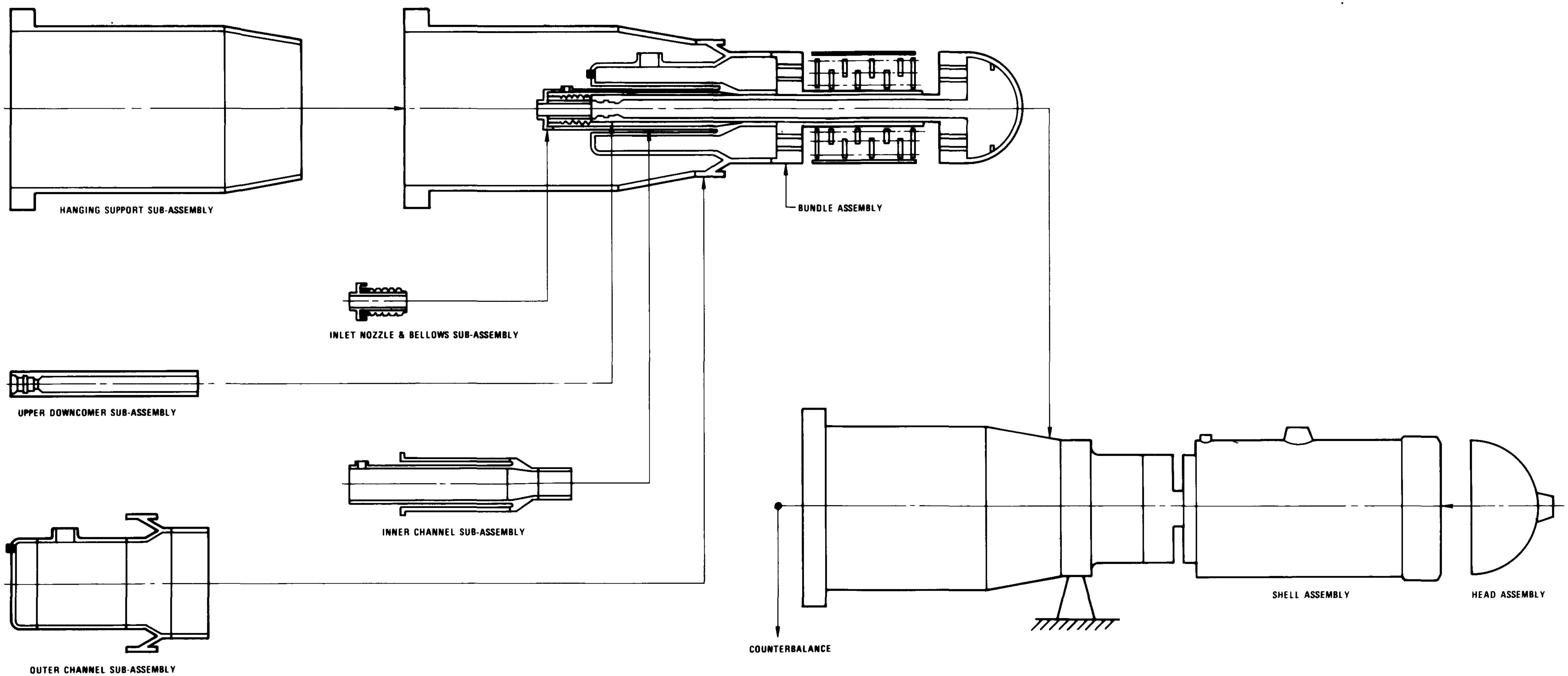

Figure 16. CRBRP Final Shop Assembly

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