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Title: FFTF and CRBRP Reactor Vessels

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The Fast Flux Test Facility (FFTF) reactor vessel and the Clinch River Breeder Reactor Plant (CRBRP) reactor vessel each serve to enclose a fast spectrum reactor core, contain the sodium coolant, and provide support and positioning for the closure head and internal structure. The overall CRBRP reactor arrangement is shown in Figure 1. The FFTF reactor arrangement is shown in Figure 2. Each vessel is located in its reactor cavity and is protected by a guard vessel which would ensure continued decay heat removal capability should a major system leak develop.

Although the two plants have significantly different thermal power ratings, 400 megawatts for FFTF and 975 megawatts for CRBRP, the two reactor vessels are comparable in size as illustrated in Figure 3, with the CRBRP vessel being approximately 28 percent longer than the FFTF vessel.

The FFTF vessel diameter was controlled by the space required for the three individual In-Vessel Handling Machines and Instrument Trees. Utilization of the triple rotating plug scheme for CRBRP refueling enables packaging the larger CRBRP core in a vessel the same diameter as the FFTF vessel.

Some comparative statistics are shown in Table 1.

Table 1

FFTF and CRBRP Reactor Vessel Statistics

Characteristic	FFTF Reactor Vessel	CRBRP Reactor Vessel
Inside Diameter	20 feet 3 inches (6.17 meters)	20 feet 3 inches (6.17 meters)
Outside Diameter at Support	28 feet (8.53 meters)	26 feet 10 inches (8.18 meters)
Overall Length	44 feet 11 inches (13.69 meters)	58 feet 3 inches (17.88 meters)
Weight Including Support	770,000 pounds (350 tonnes)	940,000 pounds (427 tonnes)
Outlet Plenum Wall Thickness	2 - 3/8 inches (60 millimeters)	2 - 3/8 inches (60 millimeters)

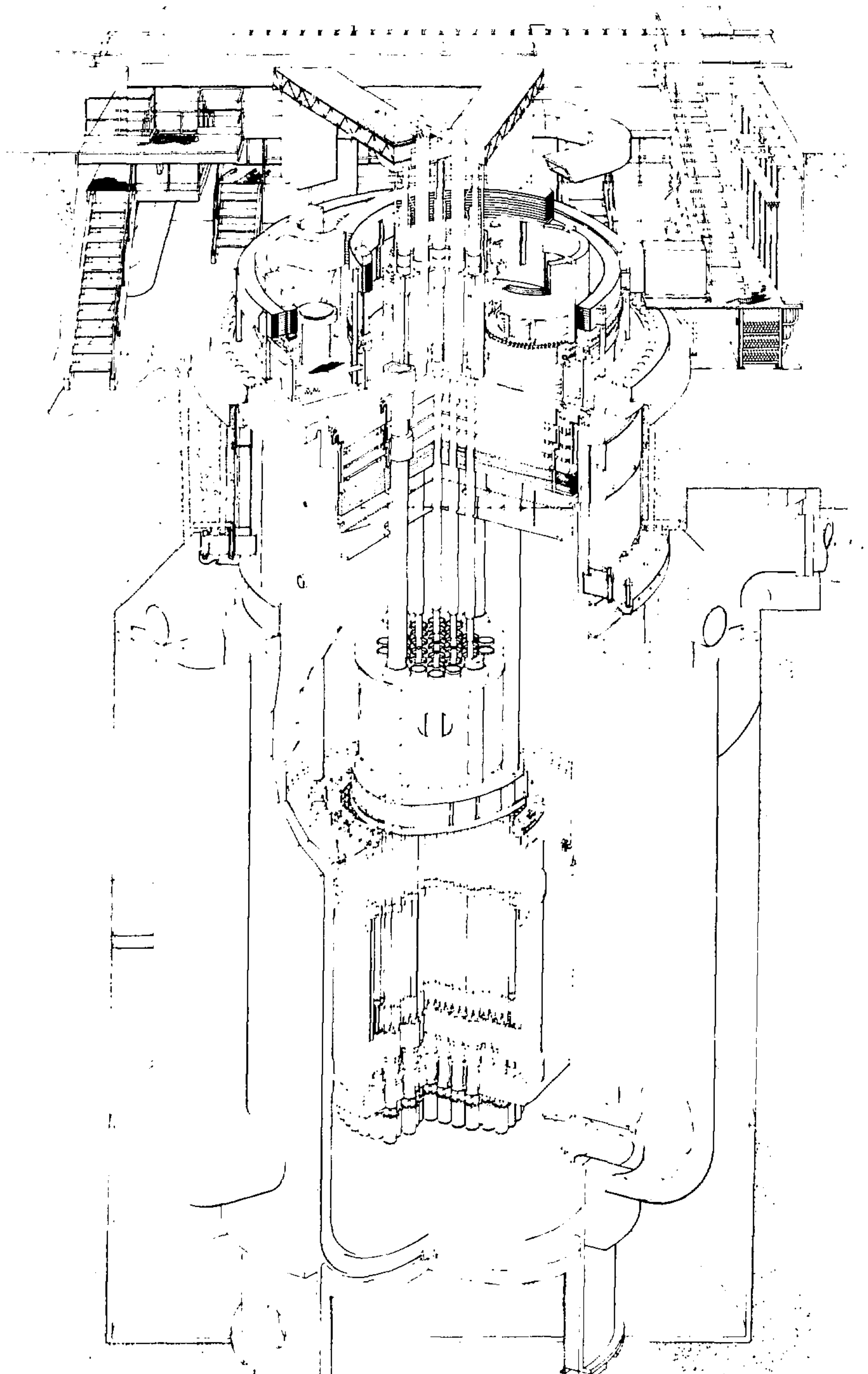

Figure 1. CRBRP

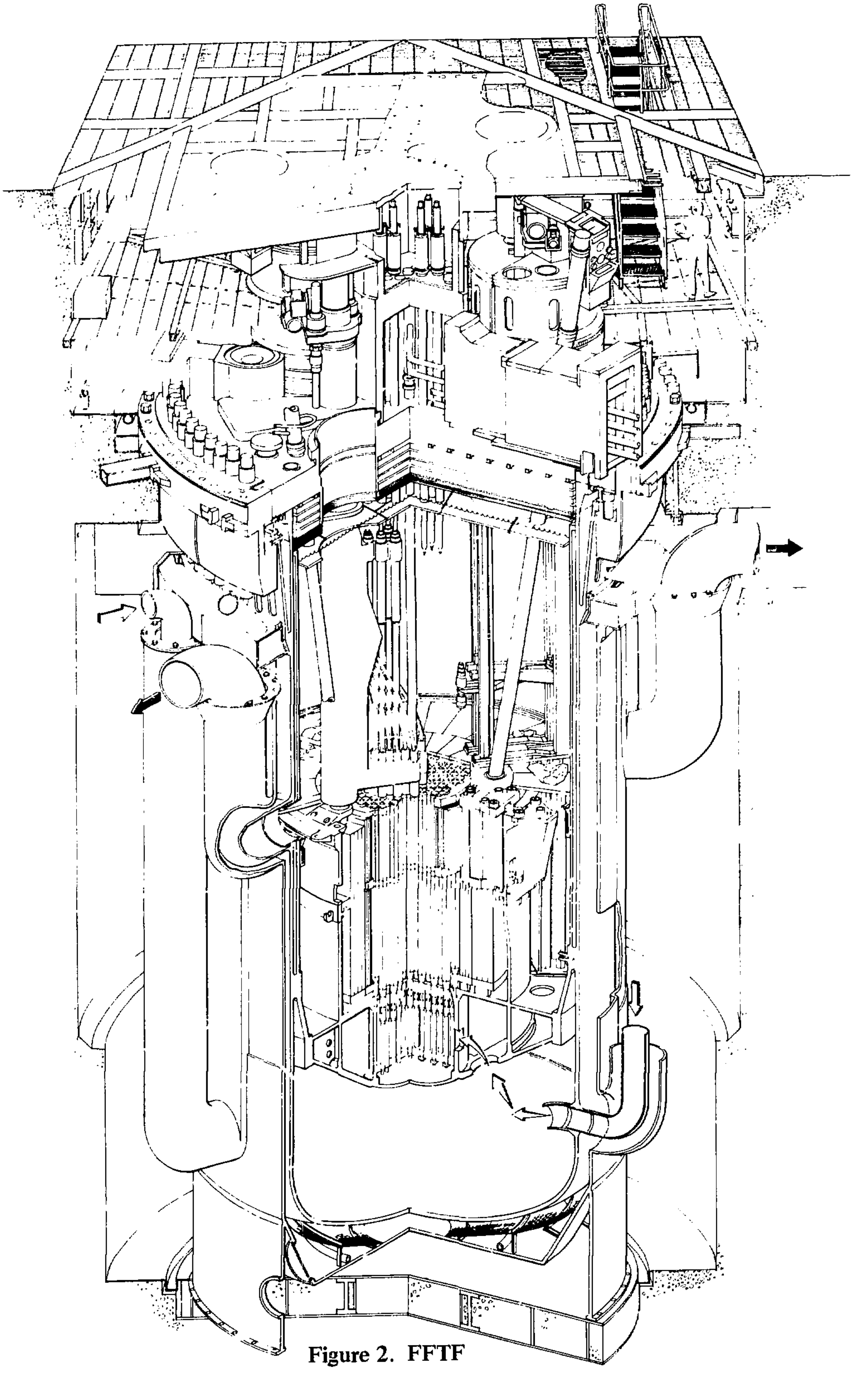

Figure 2. FFTF

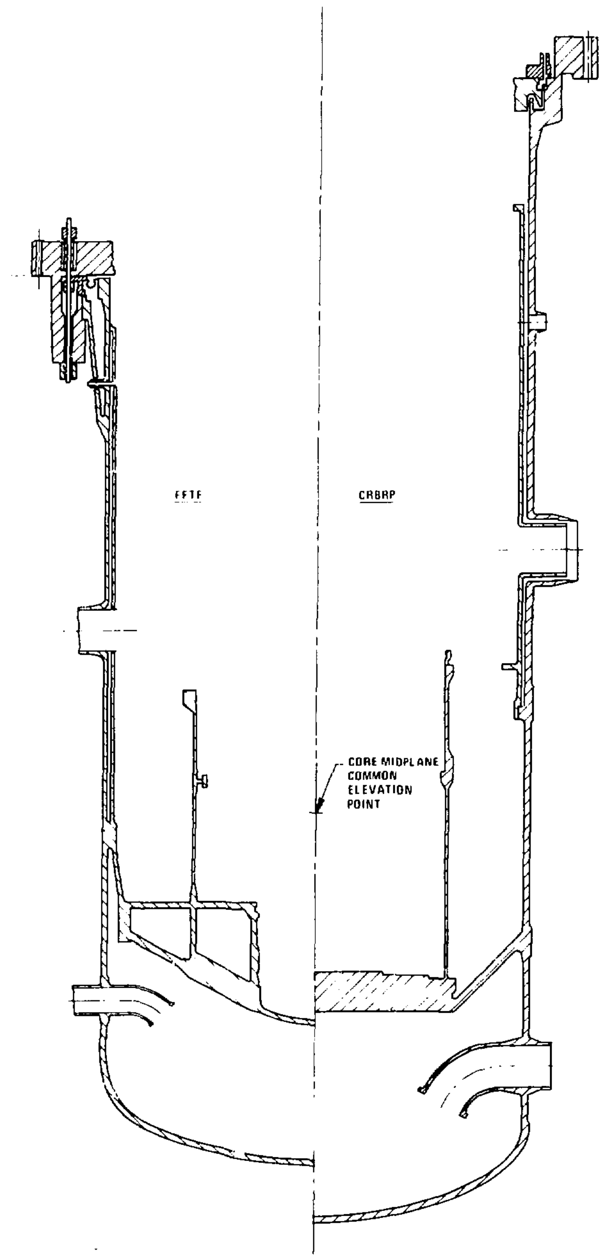

Figure 3. FFTF and CRBRP Reactor Vessel Cross Sections

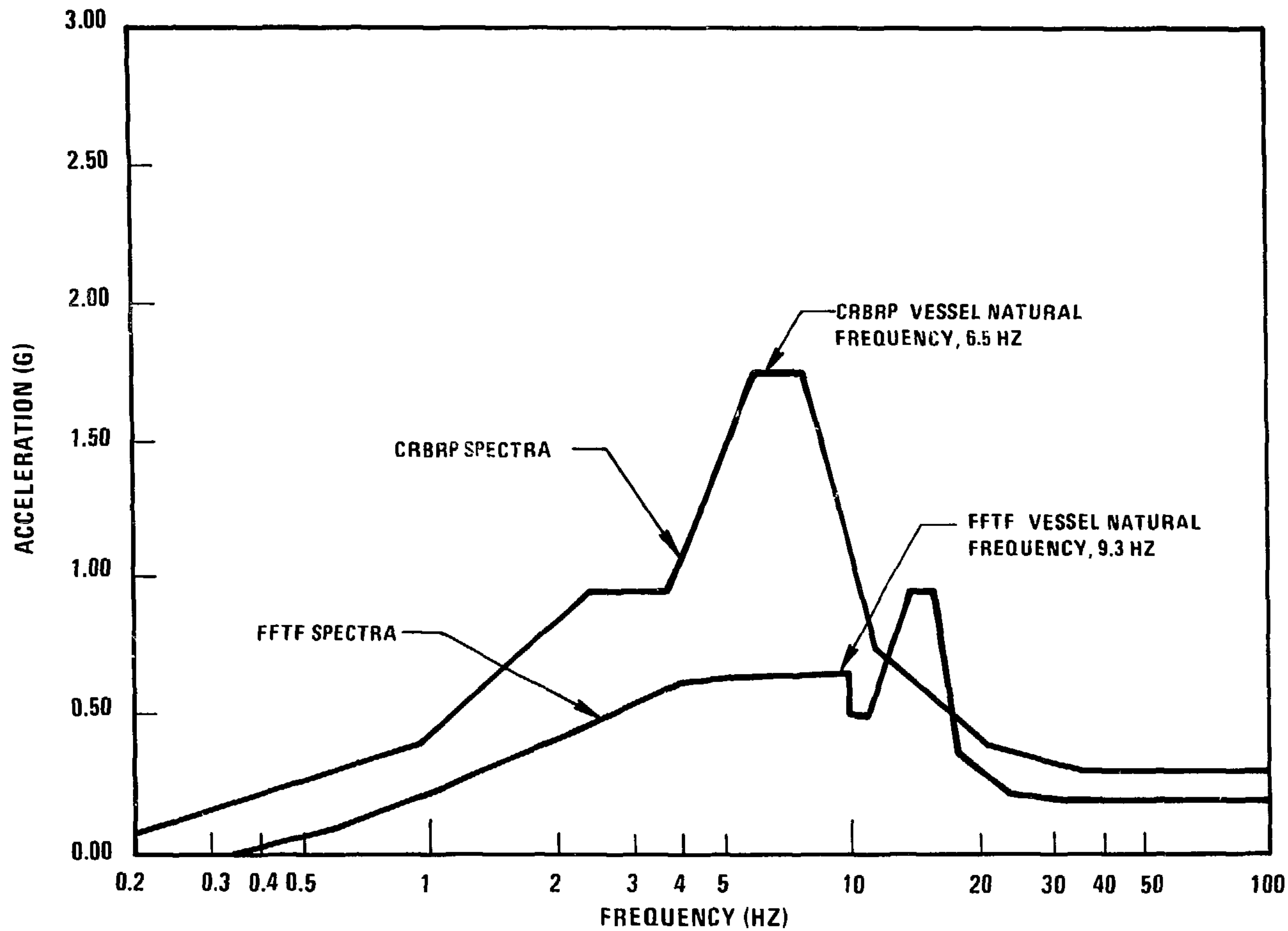

Figure 4 FFTF and CRBRP Operating Basis Earthquake Horizontal Floor Response Spectra at Reactor Vessel Supports

The longer length of the CRBRP vessel accommodates the 2 foot longer fuel assemblies and provides larger mixing volumes which aids in mitigating the effects of thermal transients. The CRBRP total reactor flow of 41 million pounds per hour (19,000 tonnes per hour) is 2.4 times larger than the 17 million pounds per hour (7900 tonnes per hour) FFTF flow rate. The coolant mixing which occurs in the outlet plenum of each vessel is important in mitigating the thermal shock experienced by the hot leg piping and primary pumps due to reactor trip transients.

Design of the CRBRP vessel evolved from the FFTF vessel design, taking advantage of the technology developed for FFTF to the extent possible. Hence both vessels contain many common features. The principal factors influencing design of both vessels include seismic loading and thermal loadings due to steady state and transient temperature distributions.

A comparison of the Operating Basis Earthquake horizontal floor response spectras at the reactor vessel support elevations for the two plants is shown in Figure 4. This figure shows the CRBRP seismic loading to be significantly more severe than the FFTF seismic loading, particularly at the vessel natural frequencies, 9.3 hertz for FFTF and 6.5 hertz for CRBRP, where the CRBRP seismic loading is a factor of 2.7 higher than the FFTF seismic loading. The seismic loading for each plant is based upon a 0.125g horizontal ground acceleration for the Operating Basis Earthquake. The differences in site soil characteristics is a significant factor in the different level of seismic response for the two plants.

The design pressures and temperatures for the two plants are similar as shown in Table 2.

Table 2

FFTF and CRBRP Reactor Vessel Design

Temperatures and Pressures

Parameter	FFTF Reactor Vessel	CRBRP Reactor Vessel
Inlet Plenum Design Pressure	225 psig (15.3 atmospheres)	200 psig (13.6 atmospheres)
Inlet Plenum Design Temperature	830°F (443°C)	775°F (413°C)
Outlet Plenum Design Pressure	15 psig (1 atmosphere)	15 psig (1 atmosphere)
Outlet Plenum Design Temperature	1100°F (593°C)	1100°F (593°C)
Reactor Vessel Outlet Nozzle Temperature	1050°F (566°C)	1015°F (546°C)

The transient severity of the two plants is also similar as indicated by Figure 5. This figure shows the outlet plenum coolant temperature transient near the top of the thermal liner during normal scram. Figure 5 also illustrates that the CRBRP vessel outlet plenum operating temperatures will run about 25°F below the conditions for which FFTF is designed.

In addition to the design basis mechanical and thermal loadings, the design of each reactor enclosure system has been evaluated for its capability to withstand a hypothesized accident loading, termed Hypothetical Core Disruptive Accident (HCDA) for FFTF, and recently renamed Structural Margin Beyond Design Basis (SMBDB) for CRBRP. The FFTF vessel was shown to be structurally capable of withstanding a 150 megajoule event loading while the CRBRP vessel has been shown capable of withstanding a 661 megajoule event loading without structural failure.

Each vessel is designed, analyzed, fabricated, tested, and inspected in accordance with Section III of the ASME Boiler and Pressure Vessel Code, the 1968 Edition for FFTF and the 1974 Edition for CRBRP. The FFTF reactor vessel high temperature service conditions necessitated the development of time-dependent structural criteria for application to the FFTF vessel, which led to the development of todays high temperature Code Case 1592. This criteria developed for use on the FFTF project considered stress rupture, creep-fatigue interaction, ratchetting, and strain limits, as well as recognizing the utilization of inelastic analysis, much in the same way as does Code Case 1592.

Each vessel is top end supported, contains a thermal liner in the outlet plenum region, and an integrally attached core support structure. The outlet plenum thermal liners permit the use of a cooler bypass flow to maintain the vessel primary boundary walls below the temperature regime in which significant creep effects would occur. The FFTF vessel wall temperature is maintained below 960°F, while the CRBRP vessel wall temperature is maintained below 900°F. In addition to maintaining cooler primary boundary temperatures, the vessel thermal liners mitigate the transient thermal effects experienced by the primary boundary.

While protecting the primary boundary, each vessel thermal liner becomes critical relative to creep damage because of the high steady state strains imposed by the radial temperature gradient. Type 316 stainless steel was selected for the CRBRP vessel thermal liner because of its superior resistance to creep damage over Type 304 stainless steel, whereas, the FFTF vessel thermal liner is fabricated of Type 304 stainless steel.

Special, controlled residual element electrodes were developed for welding the high temperature regions of the FFTF reactor vessel. Through control of residual elements in the deposited weld metal, a weld with enhanced stress rupture properties is produced, which is at least as strong as the plate and forging materials being joined. Similarly, the use of 16-8-2 weld wire was selected for fabrication of the CRBRP

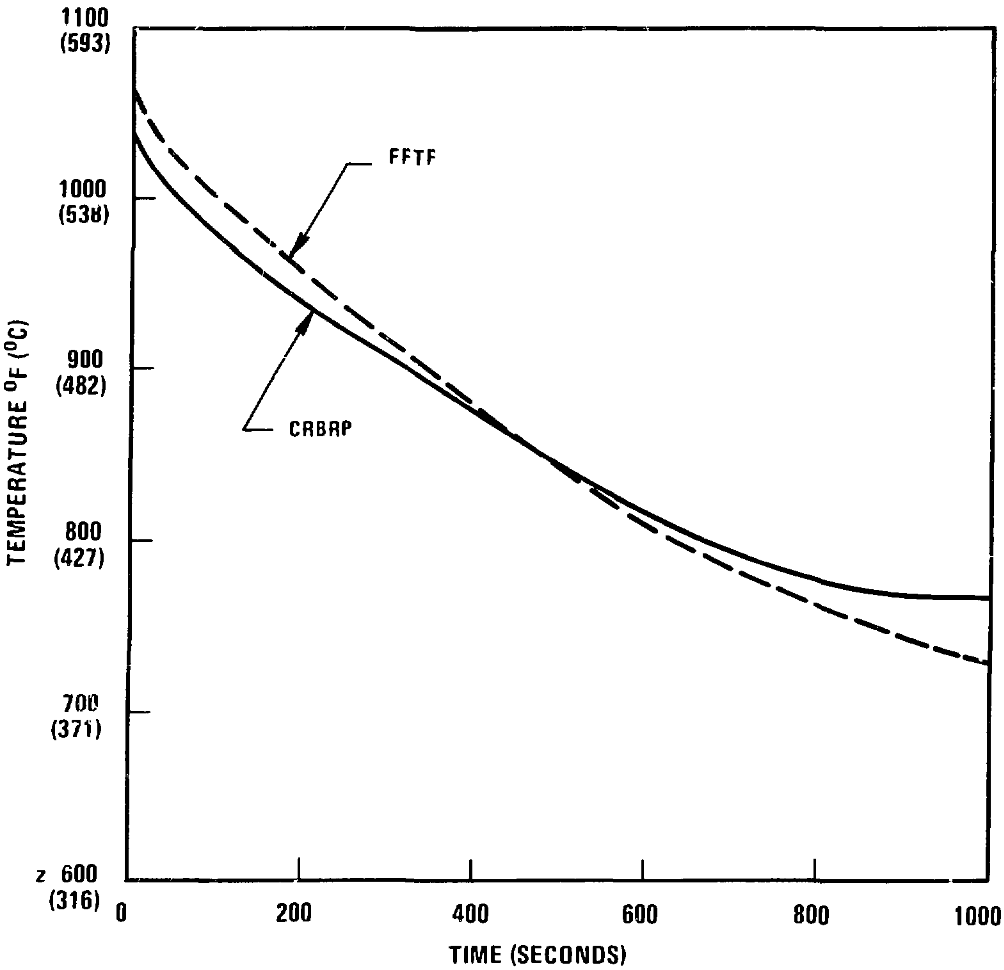

Figure 5 FFTF and CRBRP Reactor Vessel Outlet Plenum Coolant Transient During Normal Scram

vessel thermal liner because of its enhanced high temperature properties in comparison to conventional Type 316 stainless steel weld material. A testing program by Oak Ridge National Laboratory confirmed the suitability of the 16-8-2 weld material for the CRBRP vessel liner use.

The FFTF vessel contains 3 inlet nozzles, 3 outlet nozzles, and 3 auxiliary nozzles, with the auxiliary nozzles being one each for overflow, makeup, and sodium sampling, as shown in Table 3. Similarly, the CRBRP vessel has 3 inlet and 3 outlet nozzles plus 4 auxiliary nozzles, one overflow, one makeup, and two cover gas. It was necessary to move the cover gas nozzles from the closure head in the FFTF design to the vessel in the CRBRP design due to the use of closure head rotation for CRBRP refueling. In FFTF, the closure head remains stationary during refueling. Where nozzles penetrate the thermal liner, such as the outlet nozzles in both vessels, the makeup and overflow nozzles in the FFTF, and the makeup nozzle in CRBRP, bridge liners are required to bridge the bypass flow annulus between the vessel wall and thermal liner.

Table 3

FFTF and CRBRP Reactor Vessel Nozzles

	FFTF Reactor Vessel		CRBRP Reactor Vessel	
	Quantity	Nominal Size	Quantity	Nominal Size
Inlet	3	16 inches (0.41 meters)	3	24 inches (0.61 meters)
Outlet	3	28 inches (0.71 meters)	3	36 inches (0.91 meters)
Makeup	1	3 inches (0.076 meters)	1	4 inches (0.10 meters)
Overflow	1	6 inches (0.15 meters)	1	8 inches (0.20 meters)
Sodium Sampling	1	2 inches (0.051 meters)	None	
Cover Gas	None		2	3 inches (0.076 meters)

Installation of the core support structure by the reactor vessel supplier permits pressure testing of the inlet plenum without pressurizing the entire vessel. Each vessel has gas vents located at the high point beneath the core support cone to avoid buildup of cover gas in this region. The inlet nozzles of each vessel include flow deflectors inside the inlet plenum to ensure mixing of the inlet flow streams.

Principal differences in the design features occur in the vessel upper regions in the areas of vessel support and closure head interfaces as illustrated in Figure 6. The FFTF support region consists of a separate main support structure which is bolted to the reactor cavity ledge, to which the vessel is attached through support arms. In contrast, the CRBRP has an integral top end support ring which is bolted to the reactor cavity ledge. The FFTF support arms provide thermal isolation, flex to accommodate differential thermal expansion between carbon steel support structure and the stainless steel vessel, and through yielding under HCDA loading, limit the downward load transmitted to the reactor cavity ledge. In the CRBRP vessel, an Inconel transition shell is utilized between the carbon steel reactor vessel flange and the stainless steel shells. This Inconel shell mitigates the differential expansion effects caused by differing thermal expansion coefficients, and permits stress relief of the carbon steel weldment prior to attachment of a stainless steel shell, thereby avoiding sensitization. Yielding of the stainless steel shell under SMBDB loading limits the downward load transmitted to the CRBRP reactor cavity ledge.

While yielding of the FFTF vessel support arms protects the reactor cavity ledge from overload due to HCDA loading, the support arms are critical in the buckling failure mode when loaded by a lateral seismic overturning moment. Similarly, while yielding of the CRBRP vessel upper shell under SMBDB loading protects the reactor cavity ledge from overload, this shell is critical in the buckling failure mode under lateral seismic loading.

The FFTF closure head seals to the reactor vessel through a separate sealing ring structure which in turn is attached to the vessel flange by a flexible welded Omega seal. In this fashion the closure head is structurally attached to the main support structure independent of the reactor vessel. Yielding of the FFTF closure head bolts under HCDA loading limits the upward load transmitted to the reactor cavity ledge.

The CRBRP closure head assembly attaches to the reactor vessel flange through the large riser assembly. A shear ring is provided between the large plug and the vessel flange for transmission of SMBDB loading independent of the risers. Hence, the entire mass of the reactor vessel acts to mitigate the upward SMBDB loading transmitted to the CRBRP reactor cavity ledge.

The FFTF vessel was designed and built in the 1969 to 1973 period by Combustion Engineering at Chattanooga, Tennessee. The main support structure was fabricated from two large carbon steel ring forgings joined

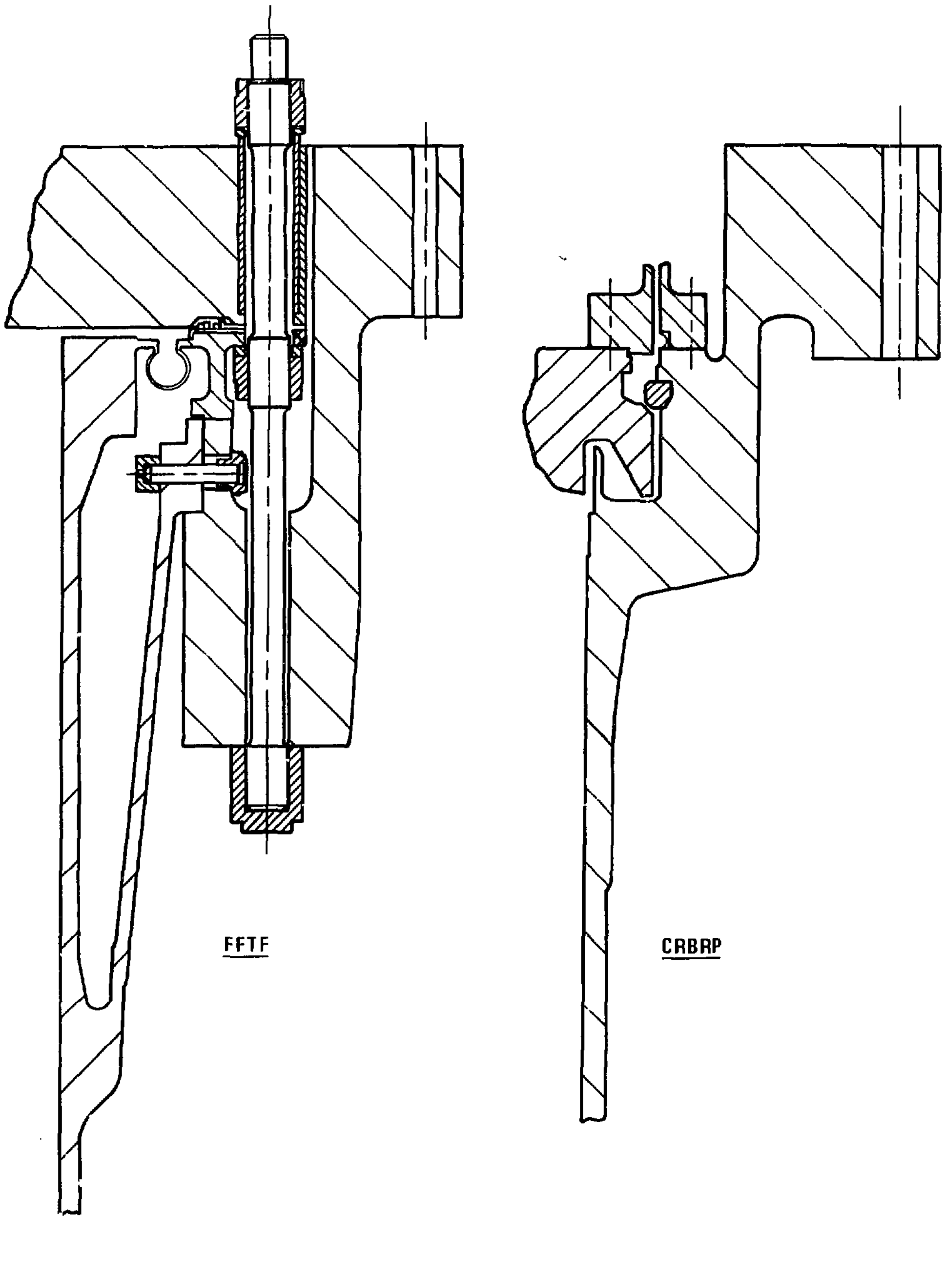

Figure 6. FFTF and CRBRP Reactor Vessel Support Regions

by a girth weld. The FFTF vessel contains three heavy section rings at the top flange, where the support arms connect and at the core support cone attachment. Each of these rings was fabricated from Type 304 stainless steel bar forgings which were formed into a hoop and butt welded. The shell courses between the rings are made from Type 304 stainless steel plate, rolled, and long seam welded. Each of the nozzles is a forging welded into a shell course. The FFTF core support structure was welded to the cone prior to welding the bottom head to the vessel. The support arms are individual forgings welded to the vessel.

The FFTF vessel was fitted to the main support structure in the shop for pressure testing with a dummy I-bar and Omega seal and a pressure test closure head. The inlet plenum was hydrostatically pressure tested at 282 psig (19 atomspheres). The entire vessel was pneumatically pressure tested at 32 psig (2.2 atmospheres).

Since the Omega seal is part of the primary pressure boundary, the FFTF vessel could not be Code stamped until the Omega seal was installed, welded to the vessel, and the weld inspected at the plant site. FFTF vessel installation was initiated in 1973 and culminated with N Stamping the vessel in March 1976.

The CRBRP vessel design and fabrication were initiated in 1975 by Babcock and Wilcox with fabrication at the B&W Mt. Vernon, Indiana facility. The support ring and flange are separate carbon steel ring forgings joined by a girth weld. An Inconel 600 shell course is welded to the bottom of the flange. This subassembly has been completely welded, stress relieved, and final machined. The two heavy section rings at the thermal liner support and at the core support cone were fabricated from Type 304 stainless steel bar forgings, pressed into hoops and butt welded. The shell courses made from Type 304 stainless steel plate are all rolled and welded. Several of the shell courses have been joined by girth welds into larger subassemblies, with the total vessel being about two-thirds complete.

The CRBRP core support structure will be welded to the cone prior to installation of the bottom head. The inlet plenum will be hydrostatically pressure tested at 250 psig (17 atmospheres). The entire vessel will be pressure tested at 19 psig (1.3 atmospheres).

The CRBRP vessel and closure head each will be shipped to the site as NPT stamped parts. The vessel N stamp will be applied after the closure head is installed on the vessel and the entire component is pressure tested.