ORNL Zero-Power Reactor Experiment (ZPRE) Design

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1 Introduction

The reactor described herein (ZPRE) was built under the auspices of the US Atomic Energy Commission (AEC) as part of the Aircraft Nuclear Propulsion (ANP) program and the circulating-fuel reactor program at the Pratt and Whitney Aircraft Company (PWAC). It was to serve as a full-scale mockup of the core and reflector of the Pratt and Whitney Aircraft Reactor No. 1 (PWAR-1). This document is meant to be a comprehensive overview of the design, dimensions and material specifications outlined in ORNL-2536 for the purpose of creating an accurate CAD model of the reactor to be used as the geometry for neutronics simulations in OpenMC.

Care is taken to give proper references to the original data, figures, tables, etc. Likewise, any quantity or feature lacking documentation or reference not yet found will be estimated or extrapolated from available information.

2 Reactor Assembly

Core

The primary components of the ZPRE core assembly are shown in Figure 1. ORNL-2536 page iii states ‘‘The mockup consisted of a 8.1-in.-dia cylindrical beryllium central region surrounded by a fuel annulus contained between two Hastelloy X core shells. The inner shell was 8.5 in. in diameter and 0.125 in. thick. The outer one varied from 21.4 in. diameter and 0.156 in. in thickness at the midplane to 14.8 in. in diameter and 0.25 in. in thickness at the ends. This core shell assembly was covered by a 13-in.-thick beryllium reflector. Coolant passages, but not the coolant, were mocked up in both beryllium regions." Further detail regarding core configuration is outlined on page 4: "The fuel was contained in the annulus formed by the inner and outer Hastelloy X core shells ... The central moderator column, or the island, consisted of beryllium through which longitudinal holes 0.250 in. in diameter were drilled to mock up coolant passages... An annular void 0.125 in, in average thickness was located between the inner core shell and the island beryllium to mock up a coolant passage. Because of engineering and operational complications, none of the coolant passages contained sodium as they would in the power reactor itself. ...

The reflector was built up around the core shell assembly, ... , with 4-in.-thick beryllium rings ... Holes 0.250 in. in diameter were drilled through these slabs to approximate the probable distribution of coolant passages in the reflector of the power reactor... Again no sodium was contained within these coolant passages; however, a helium atmosphere was maintained in the reactor tank ... to protect the Beryllium"

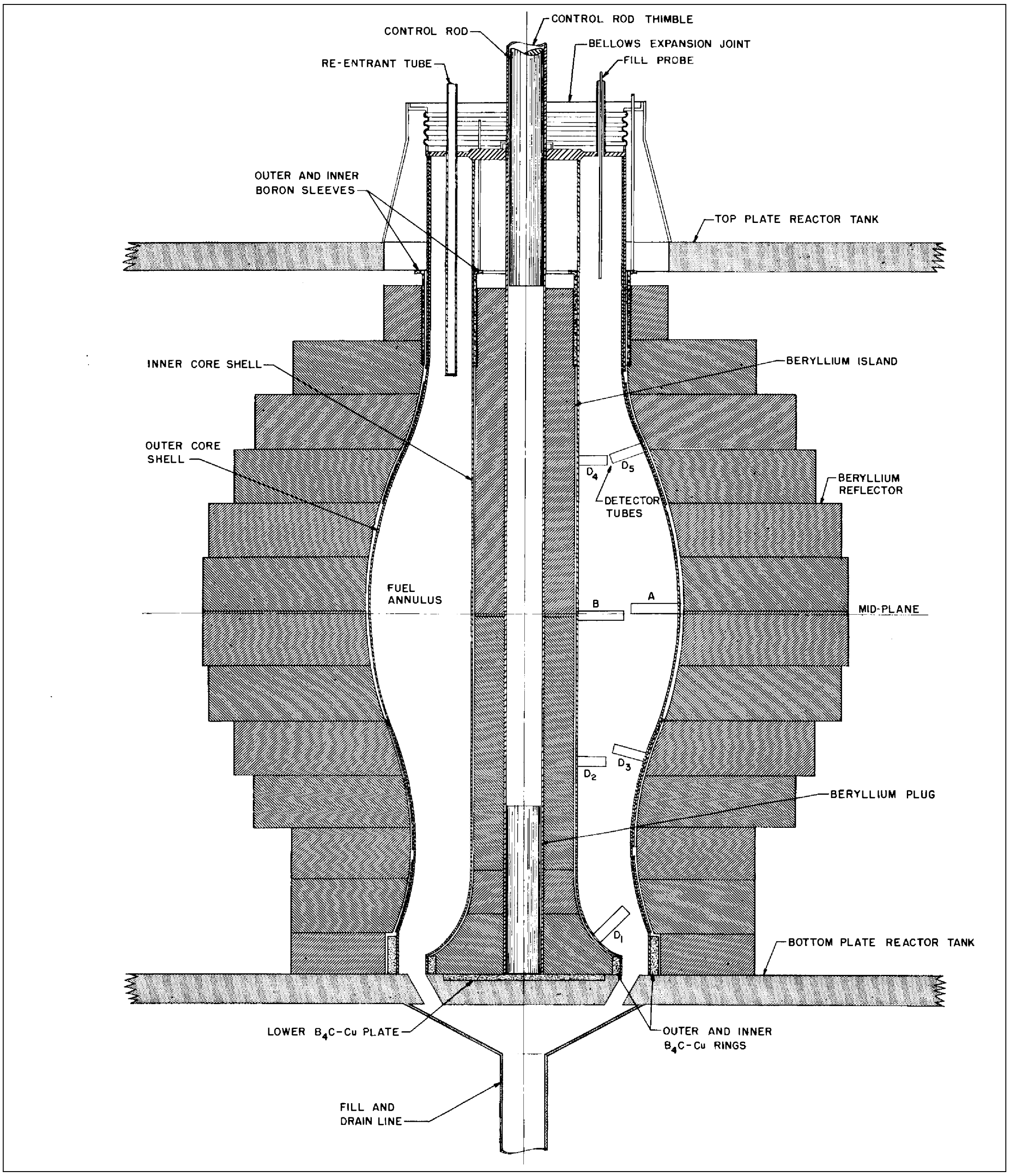


figure 1: zpre assembly (Scott et al. 1958, Figure 1)

Figure 2 shows the primary dimensions of the core assembly, with values given in Table 1.

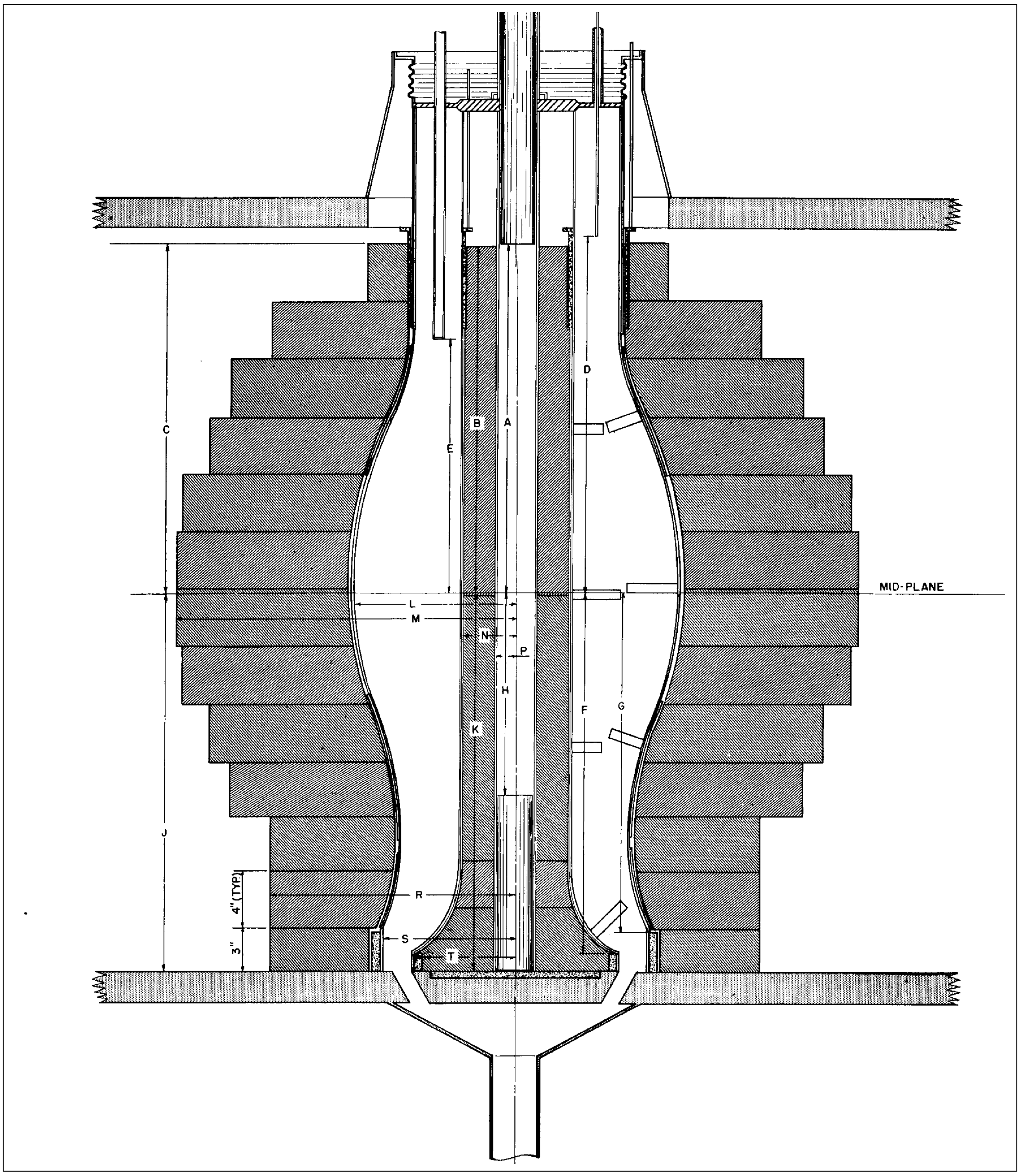


figure 2: zpre assembly dimensions (Scott et al. 1958, Figure 8).

Designation[a]	Cold (in.)	Hot (in.)	Description
A	23.906	24.155	Control rod zero
B	23.855	24.155	Midplane to top of island beryllium
C	24.250	24.553	Midplane to top of reflector beryllium
D	-	25.527	Midplane to top of fuel, fill probe on
E	17.737	17.924	Midplane to lower limit of longitudinal power traverse
F	25.649	25.927	Midplane to top of inner B_4C-Cu ring inside lower end duct
G	23.750	24.028	Midplane to top of outer B_4C-Cu ring around lower end duct
H	14.812	14.949	Midplane to top of beryllium plug in lower portion of control rod thimble
J	26.750	27.028	Midplane to base of reflector beryllium
K	27.149	27.427	Midplane to base of island beryllium
L[b]	10.529	10.639	Maximum inside radius of the outer core shell
M	24.000	24.274	Radius of reflector (slab G)
N	4.000	4.046	Radius of island beryllium
P	1.318	1.332	Radius of control rod thimble
R	16.000	16.182	Radius of reflector (slab B)
S	8.920	9.013	Radius of outer core shell in lower end duct
T	7.250	7.325	Radius of inner core shell in lower end duct

table 1: zpre assembly dimensions (Scott et al. 1958, Table 4).

The partial reflector assembly in Figure 3 shows the aforementioned coolant channels, the distributions of which are given in Table 2.

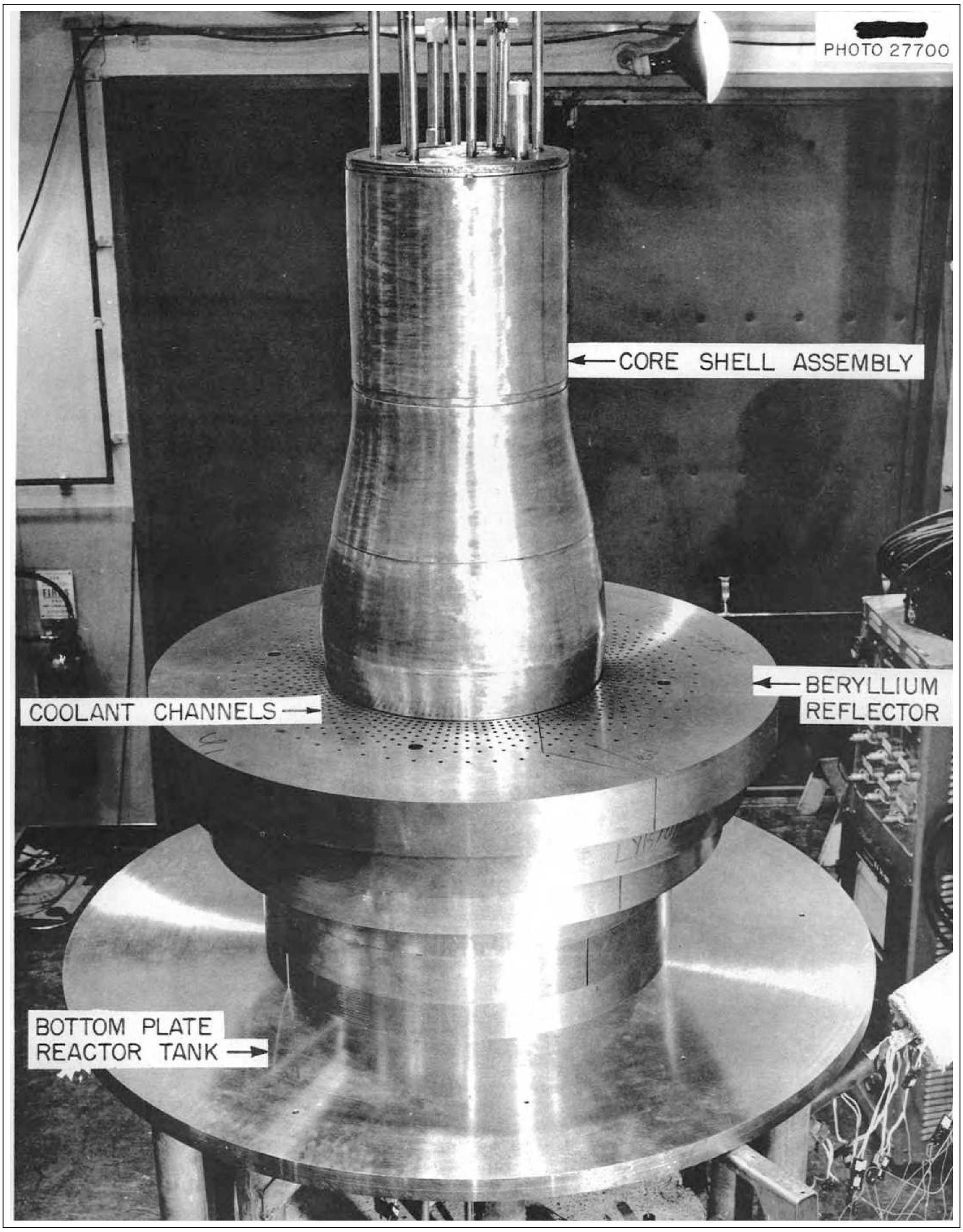


figure 3: partial reflector assembly (Scott et al. 1958, Figure 3).

Table 3. Distribution of Holes[a] in the Reflector and Moderator

In Reflector						In Island	
16 in. Above and Below Midplane		8 in. Above and Below Midplane		At Midplane		at All Elevations	
Radius, (in.)[b]	No. of Holes	Radius, (in.)[b]	No. of Holes	Radius, (in.)[b]	No. of Holes	Radius, (in.)[b]	No. of Holes
8.123	120	9.897	120	11.134	120	1.787	16
8.626	60	10.400	60	11.637	60	2.137	16
8.710	60	10.484	60	11.721	60	2.687	32
9.162	60	10.900	60	12.137	60	3.287	32
9.234	60	11.067	60	12.304	60	3.687	32
9.793	60	11.567	60	12.804	60		
10.126	60	11.900	60	13.137	60		
10.626	60	12.400	60	13.637	60		
11.126	60	12.900	60	14.137	60		
11.626	60	13.400	60	14.637	60		
12.293	60	14.067	60	15.304	60		
12.960	60	14.734	60	15.971	60		
14.626	60	16.400	60	17.637	60		

a. All holes were 0.250 in. in diameter and were distributed equally around 360 deg at the given radius.
b. The radii given apply only at the indicated elevations since these are continuous holes which roughly follow the outer core shell contour. Straight lines between corresponding

table 2: coolant channel distribution (Scott et al. 1958, Table 3).

Table 3 gives the composition and weights of the Beryllium reflector and island parts (refer to Figure 5).

Piece[a]	P and W Dwg. No.	Composition[b]										Density (g/cc)	Weight[d] (kg)
		wt%				ppm							
		Be	BeO	Fe	Al	Mn	Li	Co	Ni	Cd	B		
Reflector													
A	T 291496	98.29	1.72	0.15	0.025	90	< 0.3	5	190	< 0.2	1.1	1.843	47.2
B	T 291497	99.20	1.18	0.12	0.041	80	< 0.3	5-10	150	< 0.2	0.8	1.840	64.8
C	T 291498	98.85	1.38	0.15	0.038	80	< 0.3	3	190	< 0.2	0.1	1.840	68.2
D	T 291499	98.90	1.54	0.16	0.057	70	< 0.3	20	400	< 0.2	0.8	1.846	118.4
E	T 291500	98.50	1.62	0.15	0.019	120	< 0.3	3	260	< 0.2	0.2	1.853	139.2
F	T 291501	98.90	1.46	0.10	0.025	120	< 0.3	4	160	< 0.2	1.3	1.852	167.8
G	T 291502	98.90	1.50	0.14	0.020	130	< 0.3	4	200	< 0.2	1.3	1.850	175.8
H	T 291503	98.60	1.81	0.12	0.026	130	< 0.3	4	160	< 0.2	1.8	1.849	172.5
I	T 291504	98.60	1.78	0.14	0.013	130	< 0.3	4	180	< 0.2	0.6	1.849	168.6
J	T 291505	98.60	1.61	0.15	0.019	120	< 0.3	3	260	< 0.2	2.0	1.853	140.6
K	T 291506	98.90	1.39	0.14	0.041	80	< 0.3	6	230	< 0.2	1.1	1.856	118.8
L	T 291507	98.67	1.46	0.15	0.028	100	< 0.3	4	210	< 0.2	c	1.845	69.3
M	T 291508	98.40	1.48	0.14	0.046	80	< 0.3	1	160	< 0.2	1.1	1.847	66.9
												TOTAL	1518.1
Island													
1	T 291509	98.38	1.70	0.12	0.041	80	< 0.3	1	90	< 0.2	0.6	1.860	13.46
2	T 291510	98.30	1.81	0.15	0.035	90	< 0.3	2	240	< 0.2	c	1.854	5.83
3	T 291511	98.80	1.40	0.15	0.025	90	< 0.3	5	270	< 0.2	1.4	1.860	26.83
4	T 291512	98.40	1.64	0.13	0.031	80	< 0.3	2	150	< 0.2	c	1.857	20.33
												TOTAL	66.45

table 3: Beryllium Reflector Composition (Scott et al. 1958, Table 24).

For the sake of simplicity, each reflector part was assumed to have uniform composition defined as the weighted average of those listed above.

Reactor Tank & Sump Tank

ORNL-2536 page 3 describes the tank assembly: "The reactor assembly was mounted within the reactor tank in a helium, atmosphere. The sump tank, located under the reactor tank, contained the fuel when it was not in the reactor core. Helium pressure was used to transfer the fuel from the sump tank through a fill and drain line to the reactor core." Material detail is given in Appendix A on page 53: "The reactor tank was constructed of Inconel and served to contain the entire reactor assembly ...

The exterior of the reactor tank was insulated with 4-in.-thick blocks of calcined diatomaceous silica, and the tank assembly was mounted about 5ft above floor level on a stainless steel stand."

Details on the sump tank are also given in Appendix A starting on page 53: "The sump tank, also constructed of Inconel, had a capacity of 287 liters at operating temperature. It was suspended from a tripod stand located below the reactor tank ... and connected to the core region of the reactor through a vertical 3.5-in.-OD Inconel fill and drain line (0.216-in.-thick wall)."

Figure 4 shows a photo labelling major components of the reactor assembly.

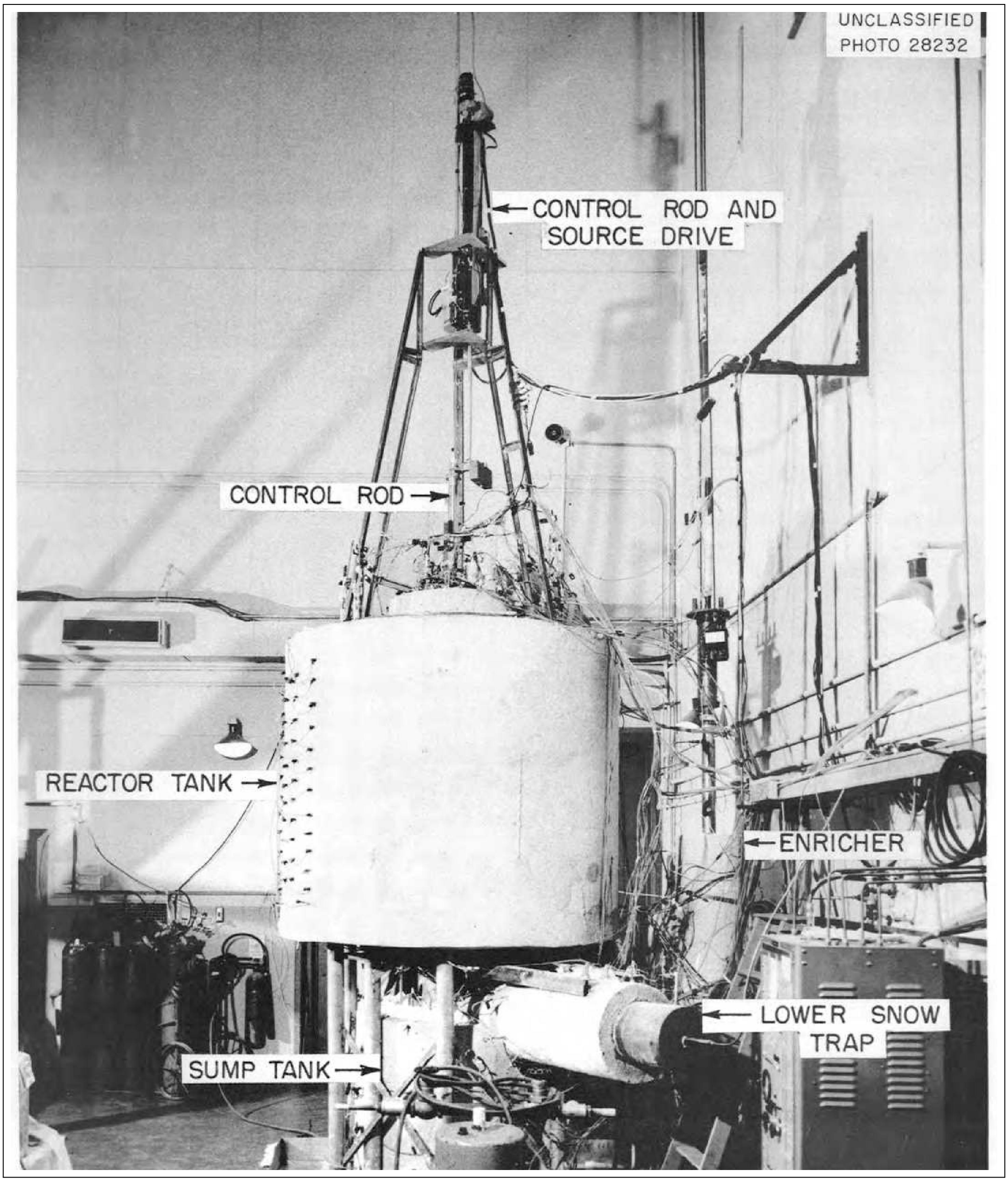


figure 4: full assembly photo(Scott et al. 1958, Figure 6).

A schematic of this assembly with dimensions is shown in Figure 5

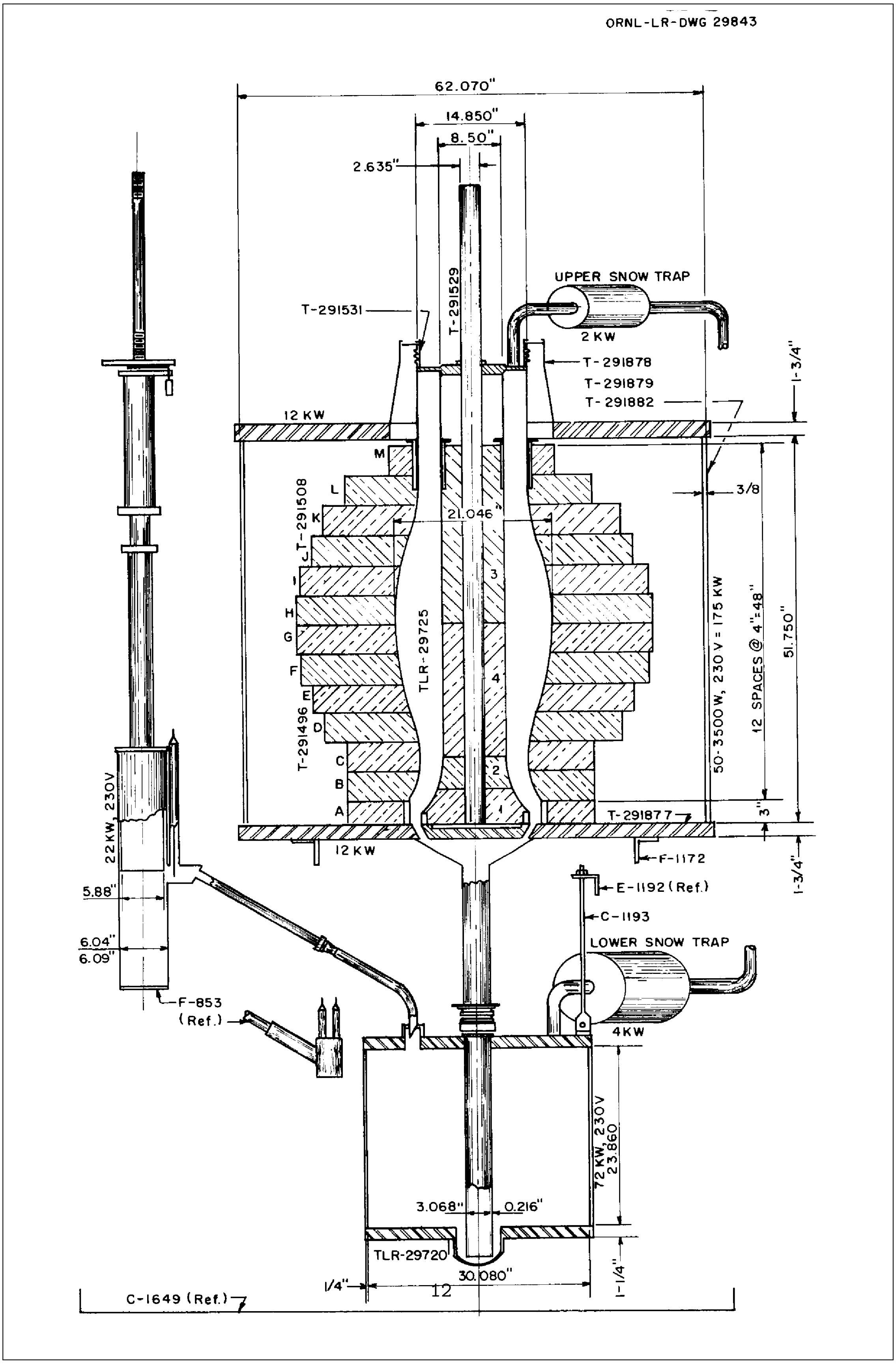
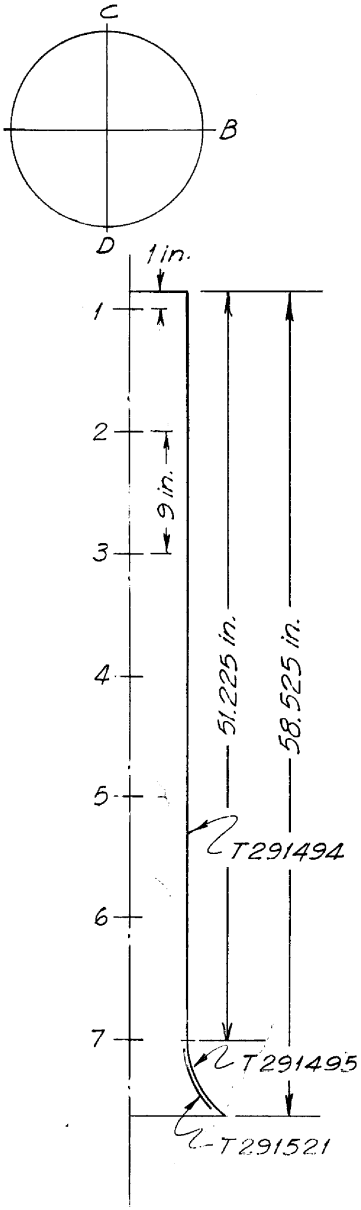


figure 5: full assembly (Scott et al. 1958, Figure 23).

3 Core Shells

ORNL-2536 page 4 states "The fuel was contained in the annulus formed by the inner and outer Hastelloy X core shells ... The outer shell was 0.156 in. thick in the region of the midplane (cross section at maximum core diameter) and 0.250 in. thick in regions further than $7\frac{3}{4}$ in. above and below midplane. The inner core shell was uniformly 0.125 in. thick except in the lower end duct where its thickness increased to 0.250 in. Due to difficulties encountered in the fabrication of these shells, variations in the wall thickness of $\pm$ 0.025 in., as well as out-of-roundness and departures from designed contour, occurred." Tables 4 and 5 detail respectively the final shapes and thickness of the inner and outer core shells.



A. Liner Section T 291494

Station	Outside Diameter (in.) A B	C D
1	8.554	8.473
2	8.542	8.485
3	8.533	8.478
4	8.545	8.430
5	8.543	8.435
6	8.537	8.486
7	8.523	8.508

B. Liner Section T 291495

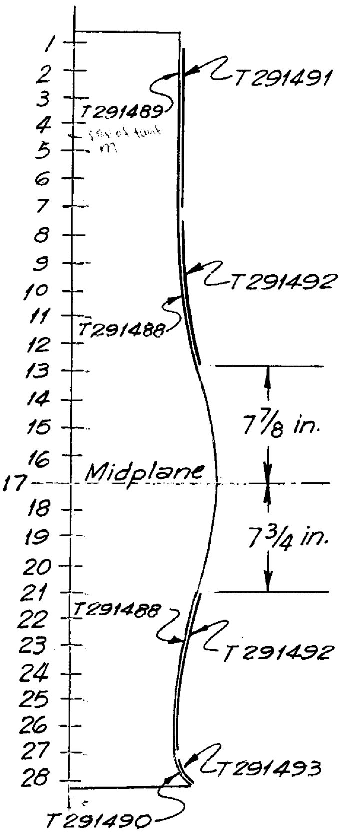
Distance from Small End (in.)	Inside Radii (in.) Design	Actual
0	4.125	4.125
1	4.170	4.170
2	4.280	4.300
3	4.520	4.550
4	4.840	4.910
5	5.280	5.340
6	5.875	5.935
6.5	6.260	6.320
7	6.700	6.730
7.3	7.050	7.050

a. T numbers are Pratt and Whitney drawing numbers corresponding to the sections being described.

b. The wall thickness for each of the three sections of the inner core shell (liners T 291494 and T 291495 and stiffener T 291521) was 0.125 in. ± 0.005 in.

c. All dimensions are for room temperature.

table 4: inner core shell dimensions (Scott et al. 1958, Table 19).



Station (2 in. Apart)	Inside Diameter (in.) Mean Design	Inside Diameter (in.) Measured	Measured Deviation in Inside Diameter[b] (in.)	Measured Average Wall Thickness (in.)	Maximum Deviatic in Wall Thicknes (in.)
1	14.850	14.765	0.121	0.156	0.010
2	14.850	14.775		0.156	0.010
3	14.850	14.779		0.156	0.010
4	14.850	14.795		0.156	0.010
5	14.850	14.805		0.156	0.010
6	14.850	14.815		0.156	0.010
7	14.850	14.815		0.156	0.010
8	14.850	14.912	0.012	0.156	0.010
9	15.038	15.106	0.020	0.166	0.020
10	15.576	15.646	0.014	0.165	0.016
11	16.400	16.470	0.022	0.160	0.017
12	17.414	17.485	0.136	0.157	0.010
13	18.482	18.481	0.064	0.164	0.004
14	19.494	19.464	0.016	0.150	0.013
15	20.320	20.270	0.016	0.151	0.008
16	20.858	20.829	0.020	0.154	0.005
17	21.046	21.058	0.010	0.148	0.007
18	20.858	20.840	0.026	0.145	0.013
19	20.320	20.288	0.038	0.147	0.012
20	19.994	19.478	0.240	0.153	0.012
21	18.482	18.494	0.034	0.154	0.012
22	17.414	17.488	0.036	0.149	0.011
23	16.400	16.466	0.010	0.152	0.011
24	15.576	15.632	0.024	0.153	0.011
25	15.038	15.112	0.010	0.158	0.016
26	14.850	14.932		0.156	0.010
27		15.042		0.156	0.010
28		15.713		0.156	0.010

B. Average Wall Thickness for Each Section

Section[c]	Average Wall Thickness (in.)
Liners[d]	
T 291489	0.156 + 0.005
T 291488 (upper)	0.158 ∓ 0.005
T 291488 (lower)	0.151 ∓ 0.005
T 291490	0.156 ∓ 0.005
Stiffeners[d]	
T 291491	0.094 + 0.005
T 291492 (upper)	0.094 ∓ 0.005
T 291492 (lower)	0.094 ∓ 0.005
T 291493	0.094 ∓ 0.005

a. All dimensions are for room temperature.
b. I.e., the difference between two perpendicular diameters.
c. T numbers are Pratt and Whitney drawing numbers corresponding to the sections being described.
d. Gaps between stiffeners and liners = 0 to 0.020 in.

table 5: outer core shell dimensions (Scott et al. 1958, Table 20).

Table 6 gives the material composition of the core shells (refer to Tables 4 and 5)

Piece[a]	P and W Dwg. No.	Composition: wt% Mo	Fe	Cr	Co	Mn	W	Ni	ppm[b] In	B	Dy	Cd	Eu	Sm	Gd	Weight (kg)
Outer Core Shell																
Top liner	T291489	9.41	17.2	23.36	1.45	0.70	-	bal.	c	0.001-0.0001		c				15.12
Middle liner[d]	T291488															
Upper, A		8.52	20.8	22.9	1.71	0.71	-	bal.	-	-	5	-	5	5	5	22.53
Upper, B		7.4	17.6	23.0	1.69	0.96	-	bal.	-	-	5	-	5	5	5	
Lower, C		8.5	19.5	18.4	1.27	0.58	-	bal.	-	-	5	-	5	5	5	21.95
Lower, D		8.5	17.3	22.5	1.55	0.48	-	bal.	-	-	5	-	5	5	5	
Top stiffener	T291491	7.91	17.0	21.7	1.74	0.67	-	bal.	c	0.001-0.0001		c				9.13
Middle stiffener	T291492															
Upper		8.55	17.8	20.1	-	0.92	-	bal.	-	-	5	-	5	5	5	7.44
Lower		6.76	16.8	21.6	1.42	0.61	-	bal.	-	-	5	-	5	5	5	7.42
Bottom liner	T291490	10.2	17.1	22.5	1.19	0.56	-	bal.	c	0.001-0.0001		c				10.81
Bottom stiffener	T291493	8.69	17.2	22.9	1.21	0.56	-	bal.	c	0.001-0.0001		c				
															Total	94.40
Inner Core Shell																
Top liner	T291494	7.50	17.3	24.5	1.61	0.72	-	bal.	-	-	5	-	5	5	5	23.04
Bottom liner	T291495	7.66	16.9	23.3	1.12	1.21	-	bal.	-	-	5	-	5	5	5	5.84
Bottom stiffener	T291521	7.50	15.0	24.5	2.14	0.62	-	bal.	c	0.001-0.0001		c				
															Total	28.88

table 6: Core Shell Composition (Scott et al. 1958, Table 25).

For the sake of simplicity, the core shells were assumed to have uniform composition defined as the weighted average of those listed above.

4 Upper & Lower End Ducts

ORNL-2536 page 13 states "Natural boron carbide-copper plates, which simulated boron-containing regions on the PWAR-1 design, surrounded the lower end duct. A boron carbide-copper plate was also placed at the bottom of the island to limit fissioning to the core region. The areal density of boron carbide in these plates was 0.35 g/cm^2.

Sleeves containing elemental B^{10} power packed to a density of 1.5 g/cc in an annulus 0.060 in. thick surrounded the upper end duct. These sleeves, which acted as neutron shields, could be moved from a position of complete retraction to their fully inserted position about 6 in. below the top of the beryllium by actuating rods protruding from the top of the reactor through gastight fittings. Longitudinally through the end duct annulus, in the neighborhood of these shields, a re-entrant tube was provided in which fission rate measurements were made for various positions of the boron shields." Figure 6 shows the design of the boron sleeves.

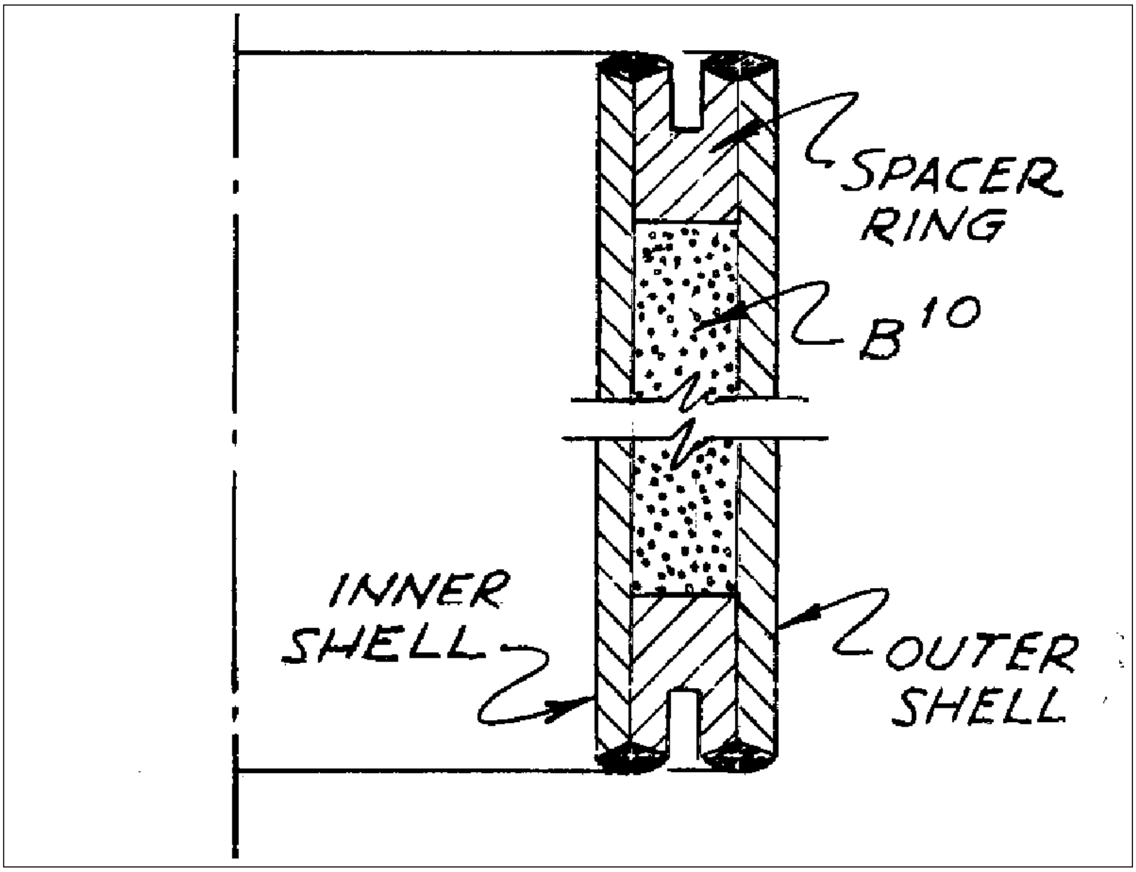


figure 6: full assembly (Scott et al. 1958).

ORNL-2536 page 72 details some design adjustments to the boron plates in the lower end duct; "Boron-containing neutron shields in the lower hemisphere of the reactor were designed to be a B_4C-Cu cement clad in stainless steel.* Unfortunately, efforts to fabricate one of these shields, the largest piece, failed. Because of this difficulty the shields were redesigned as Inconel cans containing boron carbide powder."

There were also minor modifications to the design of the boron sleeves described above. Page 72 details "It was extremely difficult to maintain the continuity of the plated surfaces due to scratching during the boron packing process. The following design changes were therefore made. Type 410 stainless steel, which contains no nickel, was substituted for the Hastelloy X ... The boron annulus thickness was accordingly decreased to 0.062 in. ... "

Table 7 gives the composition of the B^{10} pieces

Table 21. Composition of B^{10} Pieces

Material	wt%
Total Boron	94
B^{10}	92
Iron	0.23
Oxygen	~6

table 7: B^{10} Component Composition (Scott et al. 1958, Table 21).

5 Control Rod & Po-Be Source

Page 4 of ORNL-2536 states "The control rod, which also served as a safety rod, consisted of a 2.430-in.-OD x 2.000-in.-ID annulus of 70% Ni, 30% Lindsay Mix* cement 36 in. long (see Appendix A). This annulus was physically contained in a 0.035-in.-thick Inconel jacket ...

A 4.3 x 10^6 neutrons/sec (Jan. 31, 1957) Po-Be source rode longitudinally down through the center of the annular control rod into the control rod thimble to its normal position which, during multiplication measurements and startups, was a little below the reactor midplane."

The footnote on page 4 gives the composition of Lindsay Mix: "Lindsay mix is a rare earth oxide mixture consisting of 63.8 wt% Sm, 26.3 wt% Gd, 4.8 wt%

Dy, and 0.9 wt% Nd."

Table 8 gives the composition of the cement in the control rod

Material	wt%
Nickel	70
Lindsay Mix[a] (Rare Earth Oxides)	30
Sm (b)	63.8
Cd (b)	26.3
Dy (b)	4.8
Nd (b)	0.9
Misc. (b)	4.2

table 8: Control Rod Cement Composition (Scott et al. 1958, Table 22).

Figure 7 shows the control rod design and dimensions

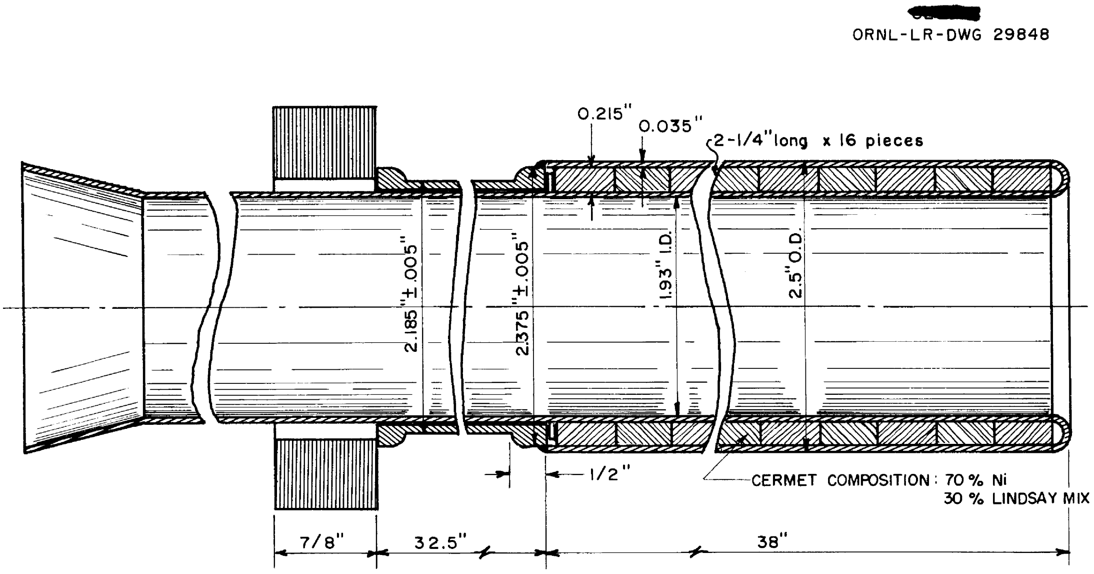


figure 7: Control Rod (Scott et al. 1958, Figure 28).

6 Fuel

The summary on ORNL-2536 page iii states "The fuel was a mixture of the fused fluoride salts of sodium, zirconium, and uranium. The critical concentration of the clean reactor was 10.22 wt% U^{235} at 1258°F." Table 9 details the initial critical concentration

Uranium (wt%)		UF_4 (wt%)		NaF (wt%)		ZrF_4 (wt%)	
By Analysis	By Inventory	By Analysis	By Inventory	By Analysis	By Inventory	By Analysis	By Inventory
10.97	10.963	14.514	14.501	20.082	20.152	65.416	65.343

table 9: Critical Fuel Composition (Scott et al. 1958, Table 1).

As described on page 4, "The clean critical uranium concentration is defined as that concentration of uranium in weight percent of a specified fuel for which, at a specified temperature, the experiment was critical with the control rod and B^{10} sleeves completely withdrawn."

7 Scintillation Counter

The scintillation counter setup is described on ORNL-2536 page 35: "The relative effectiveness of each of several arrangements of the B^{10} sleeves in the upper end duct in the reduction of the leakage of fast neutrons from that region of the reactor was measured. A fast-neutron scintillation counter sensitive only to neutrons with energies above 1 Mev, and similar to the one developed by Hornyak,[3] was secured to the top of the reactor tank for this purpose. The scintillator, a 2-in.-dia, 1/4-in.-thick ZnS-Lucite disk, was viewed by a DuMont 6292 photomultiplier tube, and both were mounted in a water-cooled brass can. A water flow rate of about 1 liter/min was sufficient to hold the photomultiplier temperature near 68°F when the ambient temperature outside the can was 110°F." Figure 8 shows the location of the detector with respect to the reactor assembly.

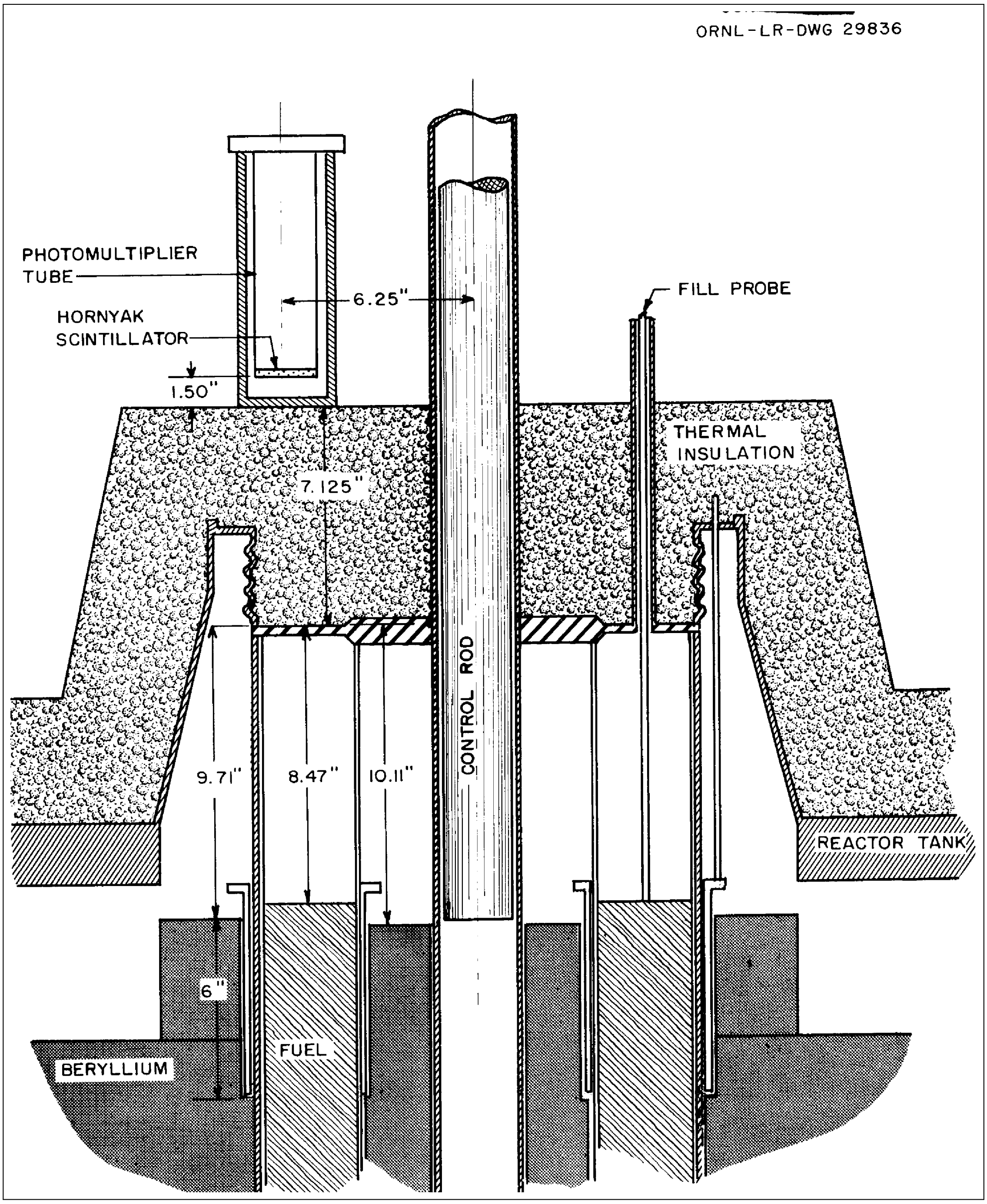


figure 8: Neutron Leakage Detector (Scott et al. 1958, Figure 16).

8 Detector Tubes

The summary on ORNL-2536 page iii states "The power distribution through the fuel region was measured by counting the fission fragment gamma-ray activity in small uranium disks positioned in the fuel annulus throughout the experiment."

Inconel tubes containing uranium foils - "detector tubes" - were welded to the inside of the core shells to measure radial fission rate distribution in the core. ORNL-2536 page 39 describes "Sixty-one foils were arranged in each of six detector tubes. A representative number of these foils were within a narrow weight range for counting purposes and the others were selected to give the correct average density. The detector tubes consisted of 7/8-in.-OD Inconel tubing with a 0.035-in.-thick wall and 0.076-in.-thick end caps. The calcium fluoride spacers were made cup-like to isolate the uranium from the Inconel, thereby preventing intermetallic diffusion at operating temperature. In addition, aluminum oxide spacers were placed at the ends of the tubes where welds were made since the stability of calcium fluoride at the welding temperature was in doubt." Continuing on page 43, it is described "The detector tubes were welded to the core shells and remained in the reactor during the entire period of operation. The detector tubes consisted of 7/8-in.-OD Inconel tubing with a 0.035-in.-thick wall and 0.035-in.-thick end caps. The tube lengths varied with their positions in the assembly. The uranium foils inside the tubes were separated with calcium fluoride spacers ... ". The physical arrangement of material in the detector tubes is shown (for tube D_1) in Figure 9.

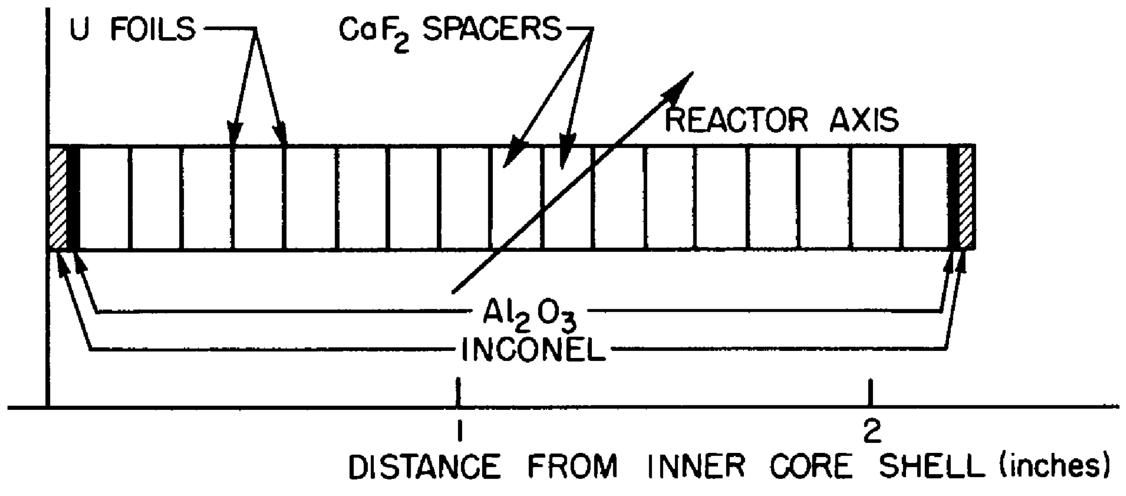


figure 9: Detector Tube (Scott et al. 1958, Figure 21).

Table 10 lists their positions.

Tube Designation	Distance from Reactor Midplane at Point of Attachment (in.) In Cold Assembly	In Hot Assembly	Core Shell to Which Attached	Angle of Tube Axis to Reactor Axis (deg)
Above Midplane				
D_5	11.00	11.11	Outer	76
D_4	10.06	10.17	Inner	90
At Midplane				
A	0	0	Outer	90
B	0.07	0.07	Inner	90
Below Midplane				
D_3	11.00	11.11	Outer	104
D_2	11.44	11.56	Inner	90
D_1*	24.32	24.57	Inner	41

* In lower end duct.

table 10: Detector Tube Positions (Scott et al. 1958, Table 15).

One detector tube, when drawn in CAD as described above, can be over 20 parts even after a boolean operation on the calcium fluoride. With all seven detector tubes drawn as described, the model becomes cumbersome. Additionally, the fact that the uranium foils are enclosed, together with their very small size with respect to other reactor dimensions, creates meshing challenges. It was therefore decided to approximate the contents of the detector tubes as single volumes with material composition defined as the weighted average of their constituent parts.

9 Gold Foils

As described on ORNL-2536 page 50, "Gold foils were used to measure the neutron flux distribution in the beryllium reflector at three nominal elevations: the midplane, 8 in. below the midplane, and 16 in. below the midplane." Table 11 gives the heights of the gold foil placement.

	Distance from Midplane (in.)	
Nominal Position	In Cold Assembly	In Hot Assembly
At midplane	0.03 (below)	0.03 (below)
8 in. below midplane	8.03	8.09
16 in. below midplane	16.03	16.16

table 11: Gold Foil Positions (Scott et al. 1958, Table 17).

Page 50 continues "The gold foils 5/16 in. in diameter and 2 mils thick. They were held in covered beryllium oxide cups and placed in slots on the beryllium slabs which were then placed in the reflector. The foils remained in the reflector throughout the period of operation." The beryllium oxide "cups" were assumed to be of the same composition as the reflector, and thus were not modelled separately. Table 12 gives the radial positions of the foils at each height along with their activity relative to the foil used for normalization.

Distance from Inner Surface of Beryllium Reflector (in.)	Relative Activity		
	At Midplane	8 in. Below Midplane	16 in. Below Midplane
0.190	0.473	0.478	0.217
1.125	0.687	0.826	0.414
2.125	0.866	0.998	0.412
2.875			0.600
3.125	1.000[a]	1.008	
3.625			0.613
3.875	0.998	0.951	
4.375			0.559
4.625	0.947	0.841	
5.375	0.855	0.847	
6.375	0.739	0.711	
6.500			0.350
7.375	0.595	0.610	
7.935			0.122
8.875	0.450	0.420	
10.375	0.269	0.257	
11.710		0.095	
13.010	0.063		

a. This foil used for normalization.

table 12: Gold Foil Radial Positions (Scott et al. 1958, Table 18).

Bibliography

Scott, D. et al. (1958). ‘‘A Zero Power Reflector-Moderated Reactor Experiment at Elevated Temperature’’. In: oak ridge national laboratory ornl-2536.