Description of TRIGA Reactor

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Provided are basic technical and operational characteristics of TRIGA Mark II reactor at J. Stefan Institute. More detailed description is found in the following documents:

1. Varnostno porocilo za reaktor TRIGA Mark II v Podgorici, Revizija 3, IJS-DP-5823, junij 1992

2. I. Mele, M. Ravnik, A. Trkov, “TRIGA Mark II Benchmark Experiment, Part I: Steady-State Operation,” Nuclear Technology 105, 37-51, 1994.

3. I. Mele, M. Ravnik, A. Trkov, “TRIGA Mark II Benchmark Experiment, Part II: Pulse Operation,” Nuclear Technology 105, 52-58, 1994.

4. M. Ravnik, T. Žagar, A. Peršič, Fuel Element Burnup Determination in Mixed TRIGA Core Using Reactor Calculations", Nuclear Technology 128, 35-45, 1999.

General Description of the Reactor

The reactor is a typical 250-kW TRIGA Mark II light-water reactor with an annular graphite reflector cooled by natural convection. The side and the top views of the reactor are shown in Figures 1 and 2.

Reactor Core

The core is placed at the bottom of the 6.25-m-high open tank with 2-m diameter. The core has a cylindrical configuration (Figure 3).

In total there are 91 locations in the core, which can be filled either by fuel elements or other components like control rods, a neutron source, irradiation channels, etc. The core lattice has an annular but not periodic structure (see Figure 3).

Elements are arranged in six concentric rings: A, B, C, D, E and F, having 1, 6, 12, 18, 24 and 30 locations, respectively. Each location corresponds to a hole in the aluminum upper grid plate of the reactor. The distances between locations in a given ring are equal. The distances between the center of the core and the rings are given in Table 1 and Figure 4. Note that the ring passes through the center of the fuel elements of that ring.

Location A1 is normally filled with an empty irradiation tube made of aluminum. Fuel elements in locations D8, E10, E11 and D17, E22, E23 can be removed in groups of three. Triangular cutouts in the upper grid at these locations enable inserting big vertical irradiation tubes (approximately triangular shape with dimensions of three fuel elements). In pulse mode operation these channels are removed to avoid local power peaking.

Table 1. Number of fuel elements in rings and diameters of the rings.

Ring	Positions	Diameter [inch]
A	1	0
B	6	3.2
C	12	6.3
D	18	9.4
E	24	12.5
F	30	15.7

Core Support Grids

The core is supported by a bottom grid plate that in addition provides accurate spacing between the fuel elements. The top grid plate also provides accurate lateral positioning of the core components. They are both made of aluminum of the same thickness (0.75 inch) but of different diameters (Figure 4).

Small holes (approx. 10mm diameter) for inserting flux measuring probes are provided in the upper plate. They are positioned between the fuel elements' holes in straight lines in radial direction. There are 16 holes in three radial lines, first from B-3 to F-11, second from B-2 to F-9 and third from B-6 to F-24 (See Fig. 8, Additional material 3).

Graphite Reflector

A graphite reflector enclosed in aluminum casing surrounds the core. A 2.5-inch-wide annular groove in the upper part of the reflector body is provided to contain a special irradiation facility (rotary specimen rack). It is made of aluminum and consists of 40 holes with inner diameter of 38 mm. The dimensions of the reflector, the casing, and the rotary specimen-rack groove are provided in Figure 4 and in Table 2.

There are two horizontal irradiation channels running through the graphite reflector. The radial irradiation channel stops at the inner radius of the reflector and is positioned 2.75 inches below the horizontal mid-plane. The tangential irradiation channel is also positioned 2.75 inches below the horizontal mid-plane and passes the core 12.77 inches from the center. Radial positions of the channels can be seen in Figure 2. Both irradiation channels are filled with air and are clad with aluminum. Other horizontal channels extend only to the reflector outer edge.

Table 2. Dimensions of the reflector.

Component	Dimension [inch]	Material
Reflector		Graphite
Outer diameter	41.8	
Inner diameter	17.9	
Height	21.2	
Cladding		Aluminum
Thickness (inner, top)	0.25	
Thickness (outer, bottom)	0.50	
Rotary specimen-rack groove		Air
Outer diameter	28.9	
Inner diameter	23.8	
Height	10.2	
Specimen rack		Al
Diameter of holes	38 mm	
Irradiation channels		Al
Outer diameter	8.0	
Inner diameter	6.0	

Fuel Elements

A fuel element is a cylindrical rod with stainless steel (SS-304) cladding. Its total length is approximately 28 inches with 1.5-inch diameter. Fuel material in each element is 15 inches long. There are 2.6-inch-long and 3.7-inch-long cylindrical graphite slugs at the top and bottom ends, respectively, which act as axial reflectors. In the center of the fuel material is a 0.25-inch-diameter hole which is filled by a zirconium rod. Between the fuel meat and the bottom graphite end reflector is a 1/32-inch-thick molybdenum disc.

The fuel is a homogeneous mixture of uranium and zirconium hydride. In these experiments, only one type of fuel element will be used: standard stainless steel-clad fuel elements with 12 wt.% uranium of 20% enrichment (uranium is 20 wt.% ^{235}U). The geometry is shown in Figure 5 and dimensions are given in Table 4.

Table 4. Fuel element data

Component	Dimension [inch]	Material	Density [g/cm^3]
Fuel element			
Outer diameter	1.5		
Element length	28.4		
Fuel material		U-ZrH	6.0
Outer diameter	1.4		
Inner diameter	0.25		
Height	15.0		
Zr rod		Zr	6.5
Diameter	0.25		
Height	15.0		
Axial reflector		Graphite	1.6
Diameter	1.4		
Height upper	2.6		
Height lower	3.7		
Supporting disc		Molybdenum	10.2
Thickness	0.03125		
Cladding		SS-304	7.9
Thickness	0.02		
Top and bottom ends		SS-304	7.9
Height top	4.1		
Height bottom	3.0		

Mass of uranium [g]	278
Mass of ^{235}U [g]	55.4

U in U-ZrH [wt.%]	11.9
Enrichment [wt.%]	19.9
H/Zr atom ratio	1.6

Control Rods

Three control rods of fueled-follower type are used in the reactor: regulating (R), shim (C), and safety (S). Their locations are indicated in Figures 3 and 4. They are identical in geometry and composition. (See Table 5 and Figure 6.a.). When the control rods are in completely up position their position indicator is set to indicate 200 steps. It indicates 900 steps at completely down position.

Table 5. Description of the fuelled follower control rods.

Component	Dimension [inch]	Material
Fueled-follower control rod		
Outside diameter	1.4	
Element length	43.75	
Fuel material		U-ZrH
Outer Diameter	1.3	
Inner Diameter	0.25	
Height	15.00	
Zr rod		Zr
Diameter	0.25	
Absorber		B_4C
Diameter	1.3	
Length	15.00	
Voids		Air
Top void, length	3.75	
Bottom void, length	5.5	
Cladding		SS-304
Thickness	0.02	
Top and bottom fittings		SS-304

Mass of uranium [g]	235.7
Mass of ^{235}U [g]	46.9
U in U-ZrH [%]	11.9
Enrichment [%]	19.9
H/Zr atom ratio	1.6

Transient Rod

Similar to the fueled-follower control rods, the transient rod (T in Figures 3 and 4) consists of the absorber part and the so-called air follower, which replaces the fuel part in the fueled-follower control rods. (See Table 6 and Figure 6.b.) The purpose of the air-follower, which is in fact an empty tube, is to reduce power peaking that could appear when the transient rod is in its fully withdrawn position. The transient rod has a guide tube that is the only structural component of the reactor that extends into the active volume of the core. Vertical dimensions of the transient rod are approximately the same as of the control rods shown in Figure 6.a.

Transient rod is equipped with pneumatic system for rapid withdrawal. When the pneumatic valve is open by pressing the "Fire" signal, the air pressure pulls the rod from its completely inserted position to its preset final position defined by the transient rod drive mechanism. When the transient rod is in completely up position its position indicator is set to indicate 0 steps. It indicates 900 steps at completely inserted position.

Table 6. Dimensions of the transient rod.

Component	Dimension [inch]	Material
Transient rod		
Outside diameter	1.25	
Element length	43.75	
Air follower		Air
Diameter	1.2	
Height	21.75	
Absorber		B_4C
Diameter	1.2	
Length	15.00	
Cladding		Aluminum

Thickness	0.028	
Top and bottom ends, fittings		Aluminum
Transient-rod guide tube		Aluminum
Outside diameter	1.50	
Thickness	3 mm	

Neutron Source

The neutron-source element (Figure 7) contains a Ra-Be neutron source with activity of 10^6 neutrons/s. The outer dimensions of the source element are similar to the fuel element.

Core Configuration

Core configuration is adjusted to pulse operation. It contains 52 fuel elements in compact arrangement (no in-core irradiation channels except central one, no empty positions, approximately circular shape). Excess reactivity is approximately 3$ and slightly exceeds the transient rod worth. Shutdown margin is approx. 7$. Maximum allowed pulse reactivity is 2.5$.

Reactor instrumentation

The reactor is equipped with 5 independent nuclear channels. Their characteristics are provided in Table 7.

Table 7. Nuclear instrumentation channels

Name	**Detector type**	**Range**
Start channel	fission counter	0.05mW-50W
Linear channel	compensated ionization chamber	100mW-300kW
Logarithmic channel	compensated ionization chamber	1W-1MW
Safety channel	ionization chamber	100W-300kW
Pulse channel	ionization chamber	10MW-2GW

Signal from the safety channel is used in reactivity measurements. The ionisation chamber is compensated for this purpose.

Fuel temperature is measured in two fuel elements instrumented with thermocouples. The thermocouple tip is in the center of the fuel element where the temperature is normally the highest. Instrumented fuel elements are inserted in the locations with maximum power density (normally B ring).

Figures

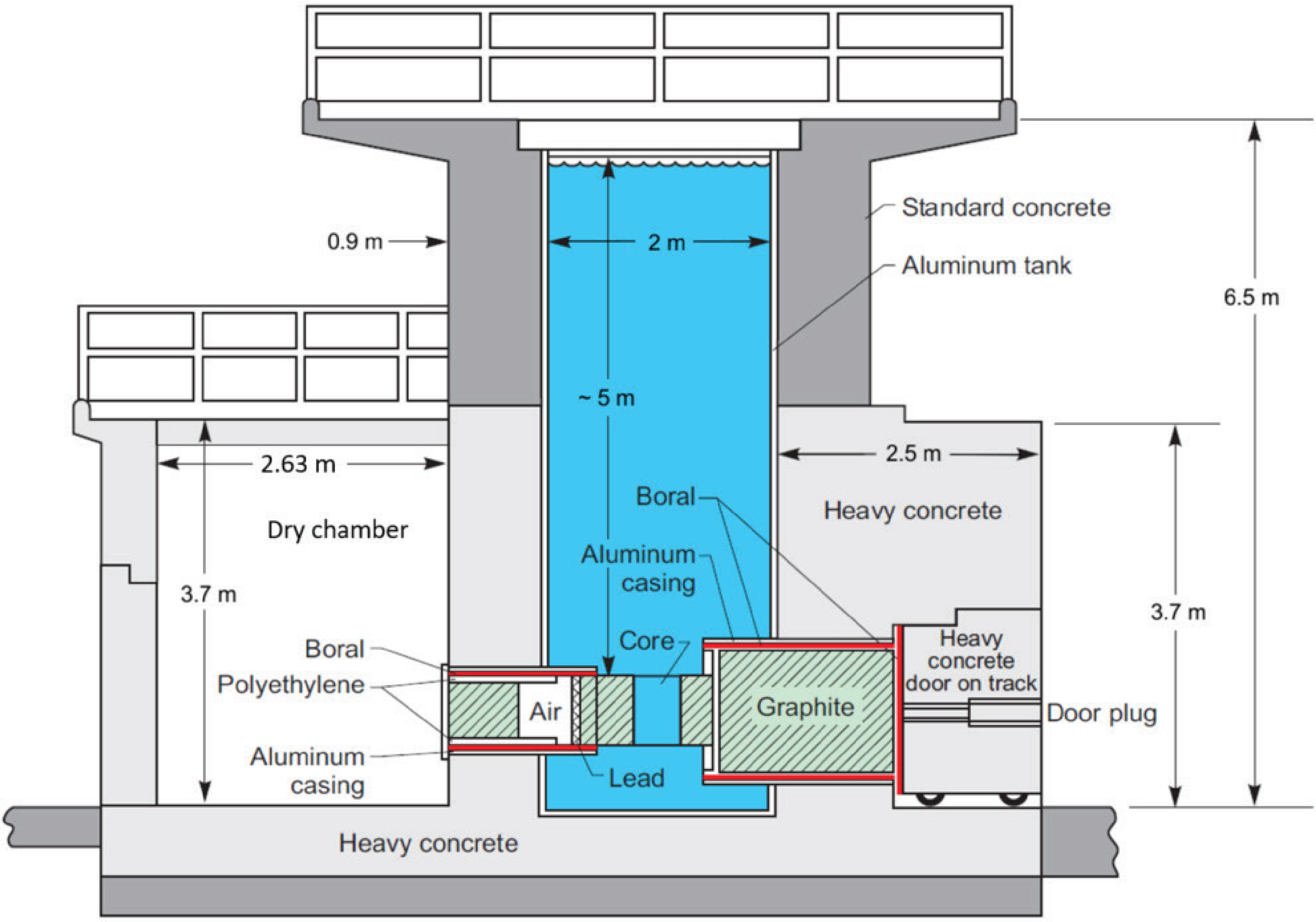

Figure 1. Side View of the TRIGA Reactor.

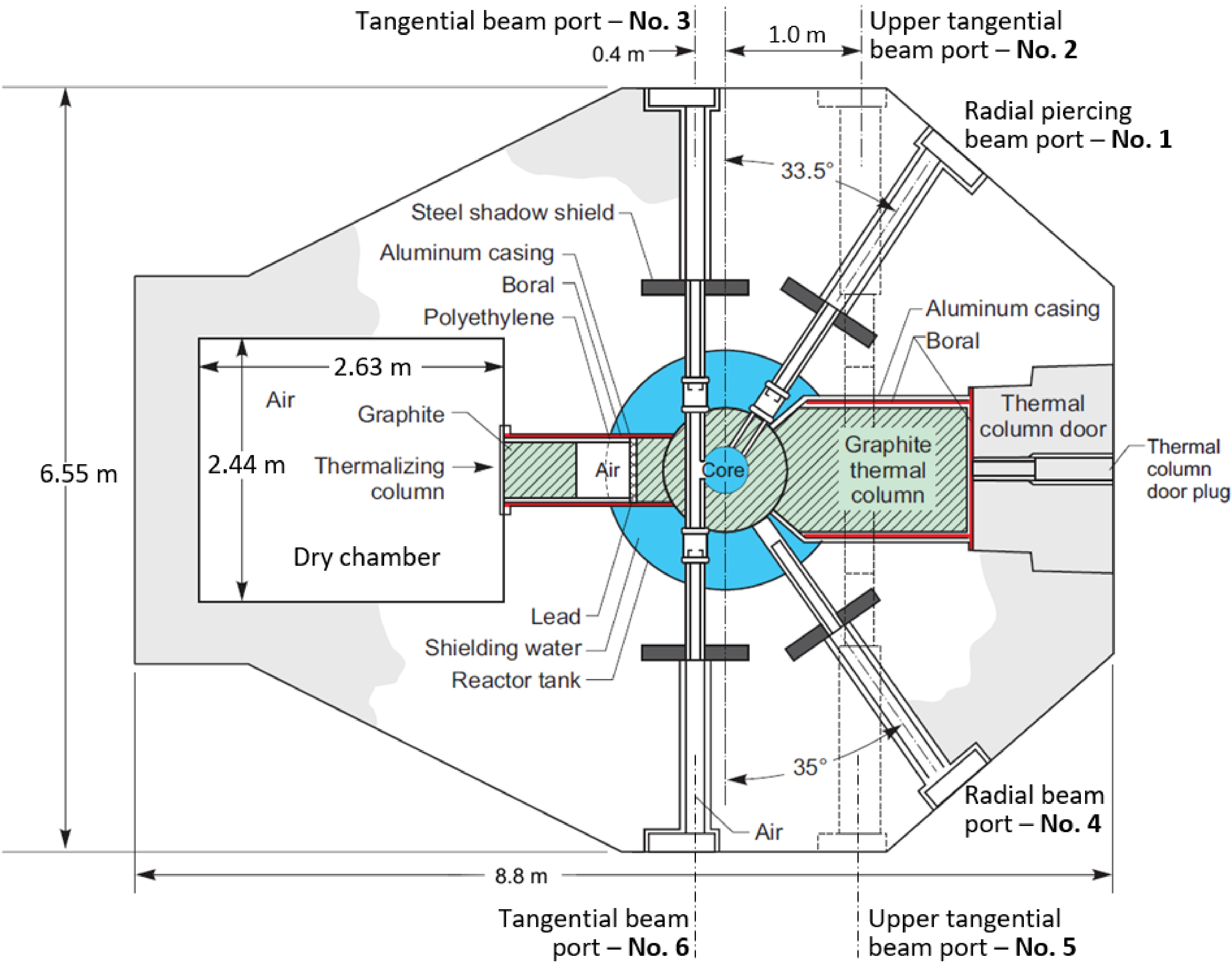

Figure 2. Top View of the TRIGA Reactor.

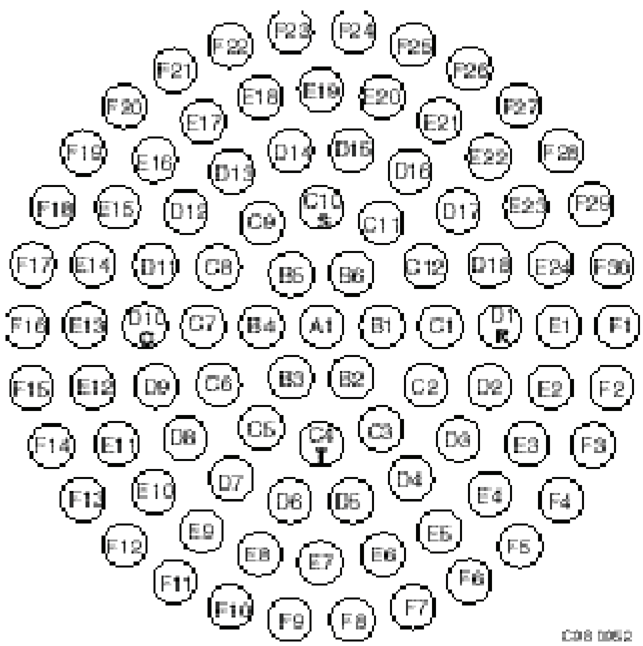

Figure 3. Core Configuration with Rod Locations Labeled.

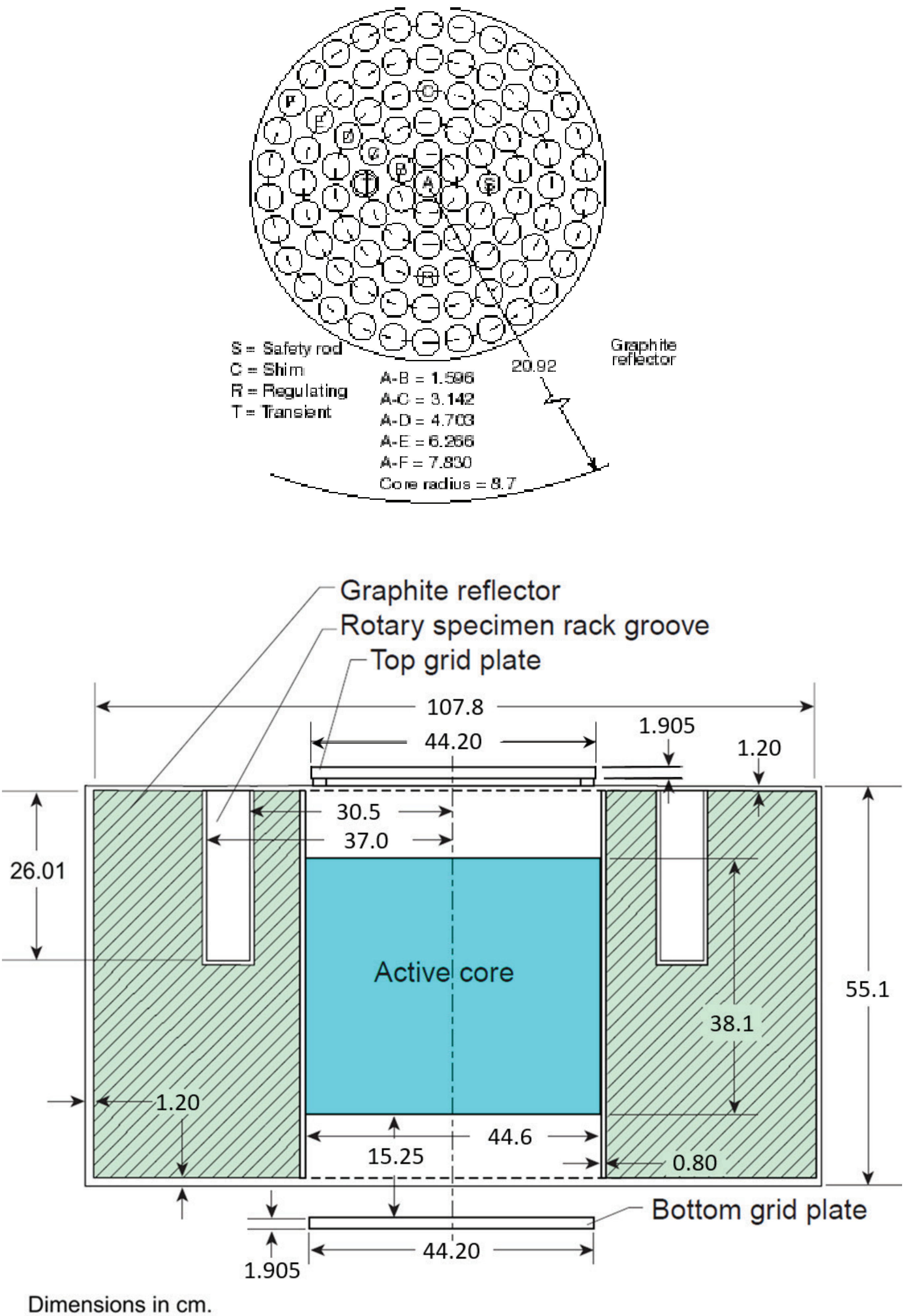

Figure 4. Schematic Top and Side Views of the Reactor Core and Graphite Reflector.

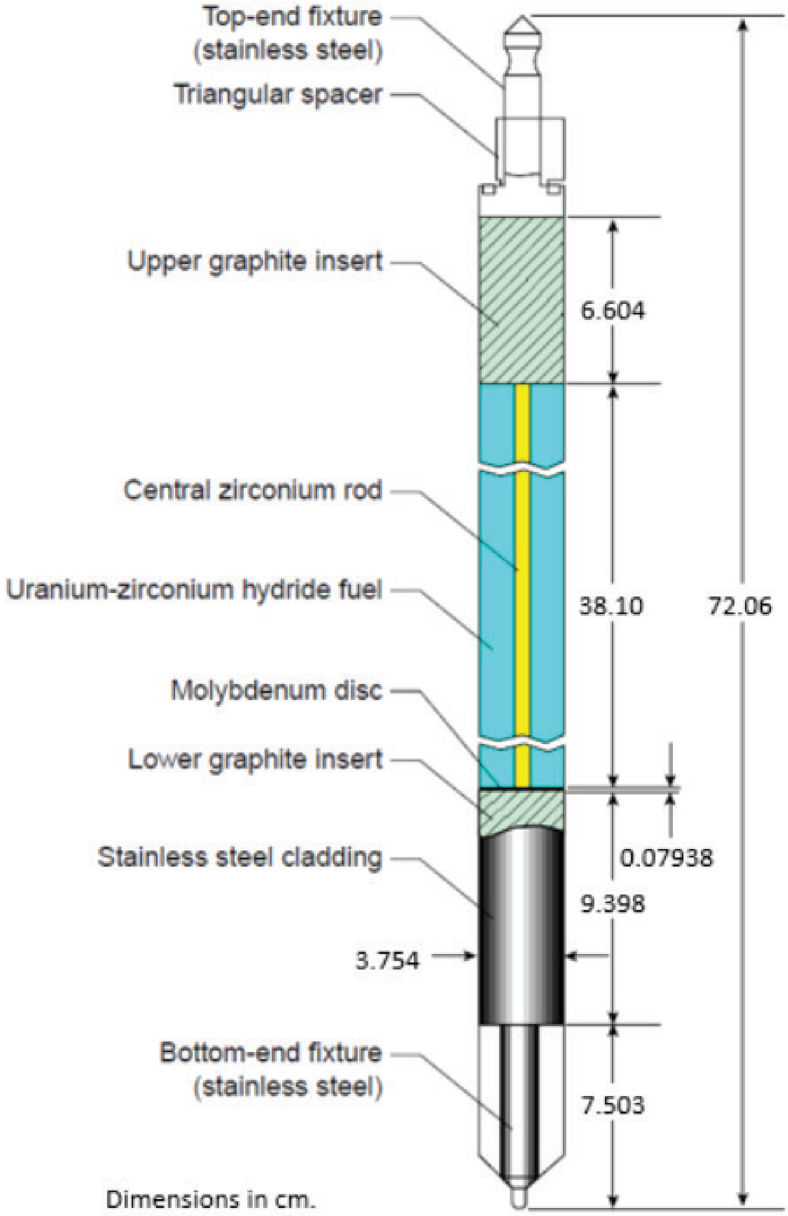

Figure 5. Fuel Element.

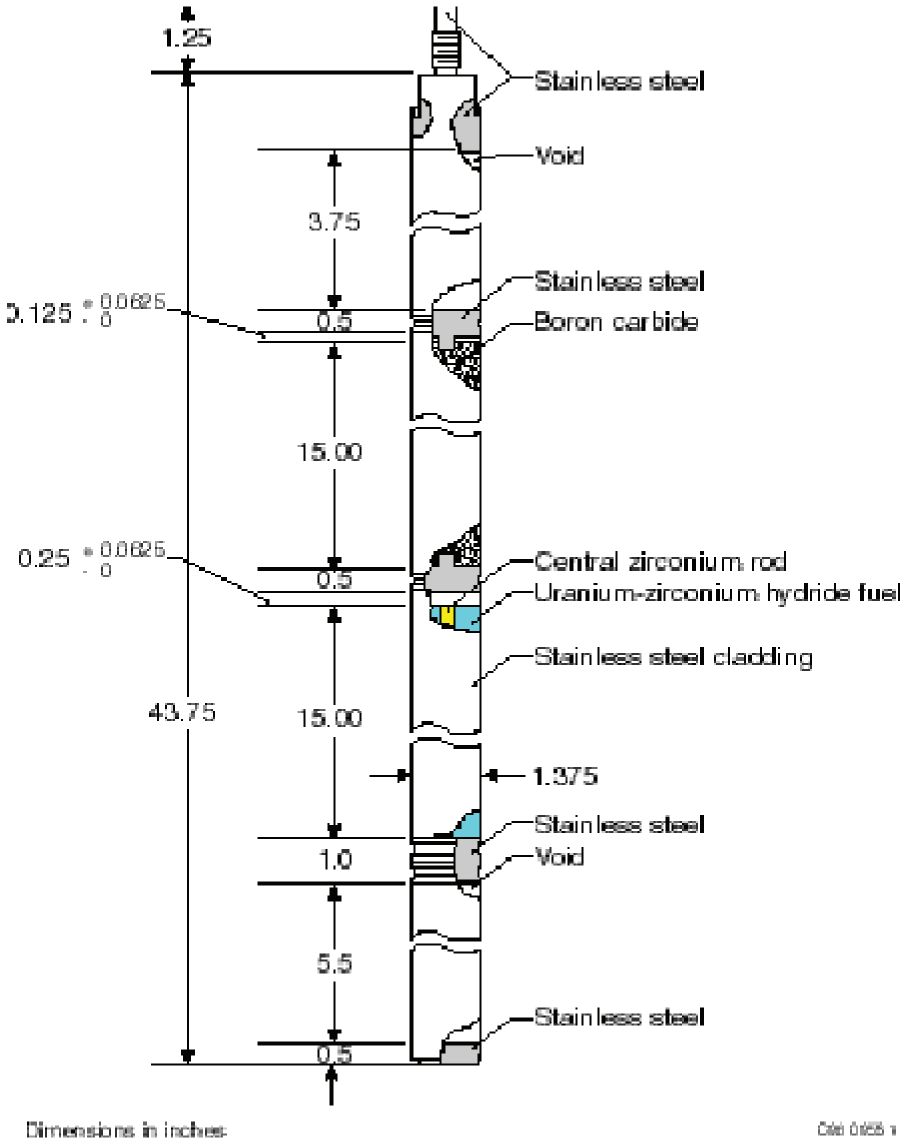

Figure 6.a. Fueled-Follower Control Rod.

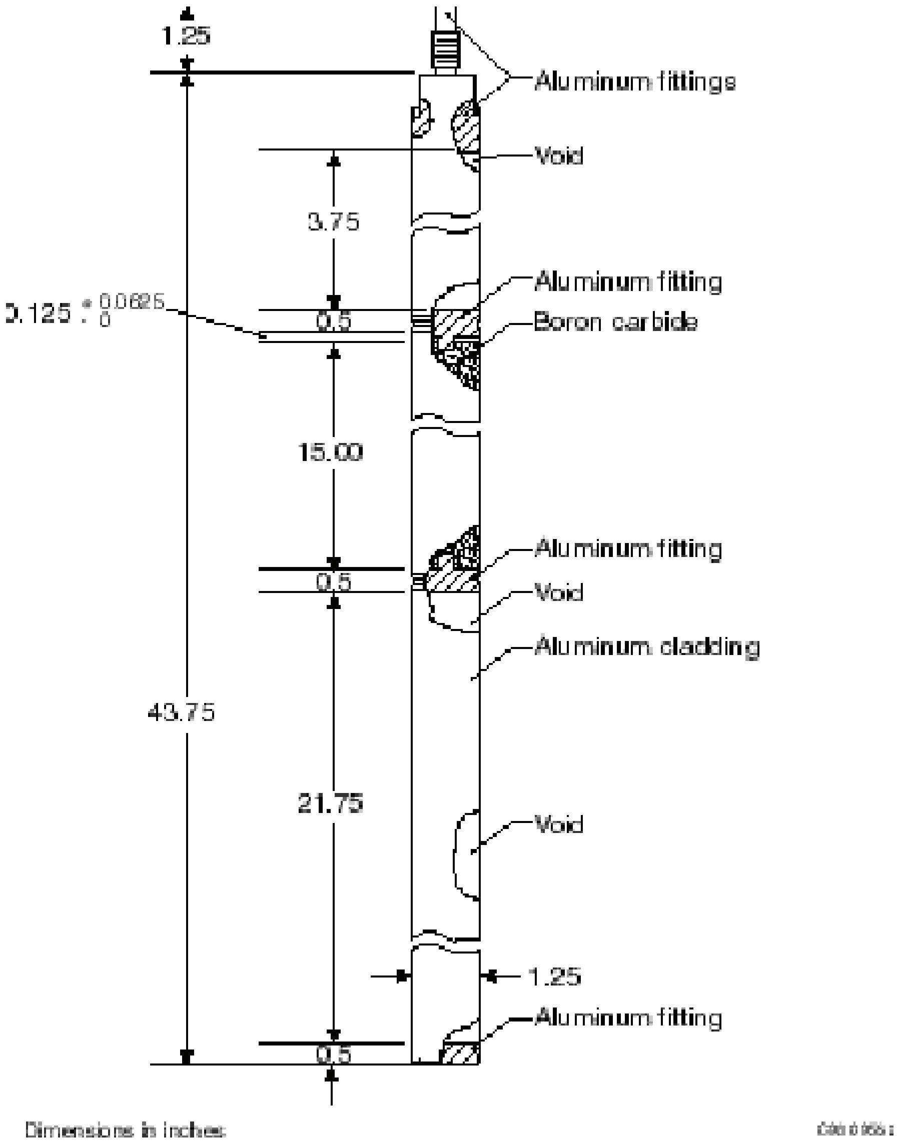

Figure 6.b. Transient Rod.

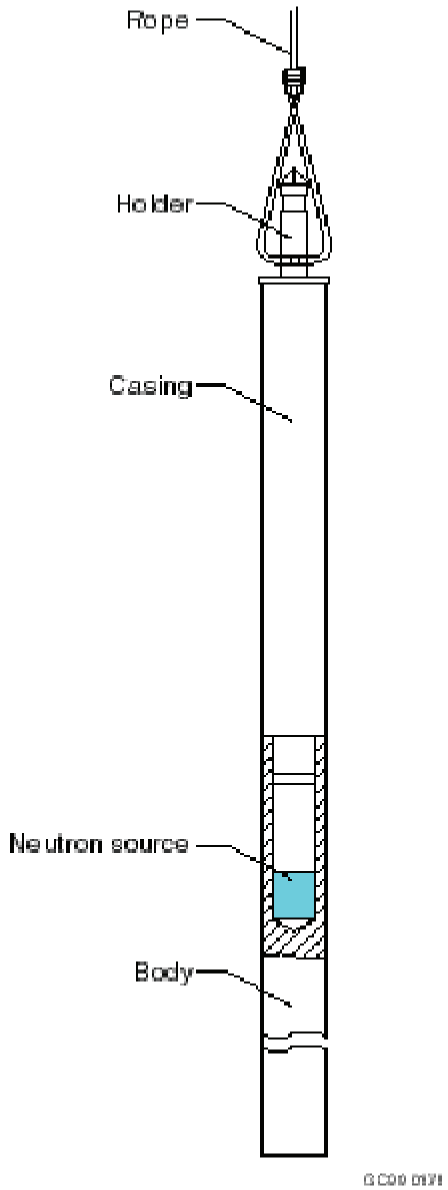

Figure 7. Neutron Source.