OPAL NUCLEAR REACTOR: REACTOR SPECIFICATION

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Abstract

The report provides technical details on the Open Pool Australian Light Water (OPAL) nuclear reactor core and immediate structure for analysis purposes. The goal of the report is to provide sufficient geometric and material data to build a computational neutronic model of the facility.

1. GENERAL DESCRIPTION

The Open Pool Australian Light Water (OPAL) Reactor is a 20 MW, open pool type research reactor. It is composed of a compact core surrounded by a heavy water reflector. The reactor includes several irradiation facilities, beam tubes and a cold neutron source (CNS). The irradiation facilities are used for the production of radioisotopes, neutron activation analysis and silicon transmutation doping. There are also five beam tube facilities: two for thermal neutron studies; two for cold neutron studies; and one for hot neutron source studies, which is currently a thermal neutron beam. Table 1 presents the main general data.

2. CORE CHIMNEY

The reactor core contains 16 (4 × 4) fuel assemblies and four control plates and one regulating plate (CRPs). The CRPs comprise four control flat plates, referred to as lateral plates, and one cross shaped central plate which is the regulating plate. The CRPs are located inside a cross shaped control rod guide box (CRGB). The CRGB divides the core into four quadrants, each comprising four fuel assemblies. Each fuel assembly contains 21 parallel fuel plates held between 2 aluminium side plates, and the core is arranged so that 8 fuel assemblies have their fuel plates oriented in a north–south direction and the other 8 in an east–west direction. The fuel assemblies and CRGB are located within a zircaloy chimney with a square cross-section. Outside the chimney is the heavy water reflector.

3. REACTOR GEOMETRY

The arrangement of the fuel assemblies and CRPs is shown schematically in Fig. 1. Labels such as A1 and B2 are used to designate fuel positions in the core. Figure 1 also shows the CRP numbering scheme with labels CR1–CR5.

Three different types of fuel assembly with different uranium densities were used for the first operating cycle. They are designated as type 1 fuel, type 2 fuel and standard fuel, with low, medium and high uranium density, respectively. The fuel configuration for the first operating cycle is shown in Fig. 1. Note that type 1, type 2 and standard fuel assemblies have nominally 212 g, 383 g and 484 g of 235U per fuel assembly, respectively. Type 1 and type 2 fuel assemblies were used in place of partly burnt fuel. They have lower uranium density than standard fuel to compensate for the fact that all the fuel is fresh in a reactor which has not previously been in operation.

TABLE 1. GENERAL DESCRIPTION OF THE OPAL FACILITY

Type of reactor	Open pool
Nominal power	20 MW thermal
Max. neutron flux	
Thermal, in core	2×10^{14} $cm^{-2} \cdot s^{-1}$
Thermal, irradiation position in reflector	3×10^{14} $cm^{-2} \cdot s^{-1}$
Fast, in core	2×10^{14} $cm^{-2} \cdot s^{-1}$
Fast, irradiation position in reflector	8×10^{12} $cm^{-2} \cdot s^{-1}$
Fuel type	Flat plate U_3Si_2-Al dispersion Al clad parallel plates
Enrichment	19.8wt%
Reference pressure of the facility	Pool open to atmosphere
Coolant (type and flow direction)	Light water, upward flow
Moderator	Light water
Reflector	Heavy water
Max. heat flux (for 20 MW operation)	Max. (nominal) 173 W/cm^2 Avg. 72 W/cm^2
Nominal flow rate	
Total	2000 m^3/h
Flow rate through core	1972 m^3/h
Flow rate with natural circulation	Depends on power
Experimental facilities	5 tangential beam tubes
Irradiation positions	Out of core only

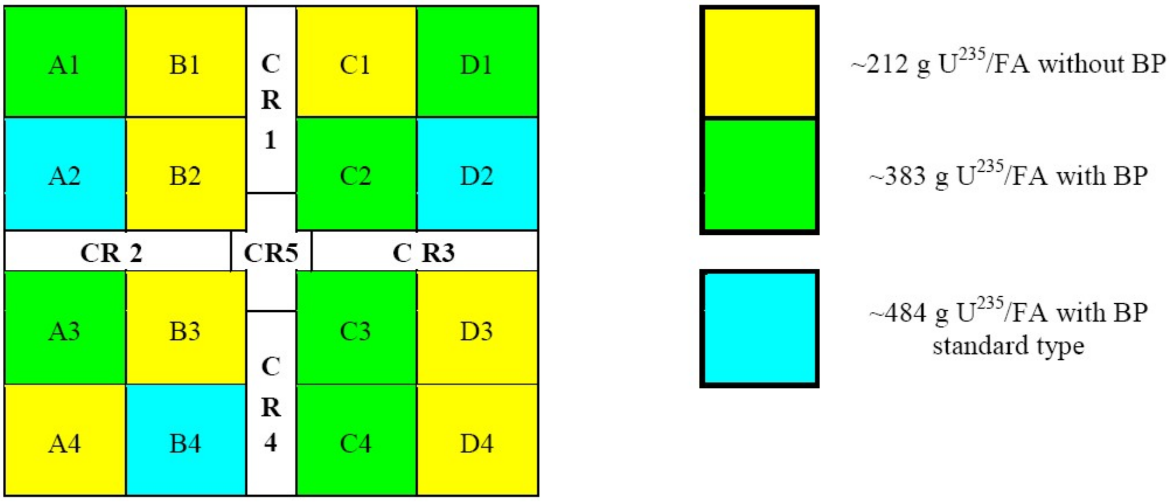


FIG. 1. Fuel assembly locations, control plate labels and arrangement of fuel types for the first operating cycle. BP — burnable poison; CR — control rod; FA — fuel assembly. The position of the cold neutron source is above B1 and C1. The image is not to scale.

4. FUEL COMPONENT

Each fuel assembly has 2 aluminium side plates, each with 21 slots to hold the 21 fuel plates. The slots are slightly deeper than required to accommodate the fuel plates, leaving a narrow gap, which is filled with water. The external fuel plates (plates 1 and 21) are longer (in the axial direction) and have thicker cladding than the internal plates. The active region is centred around the internal fuel plates but offset for the external fuel plates. The relative positions are given in Tables 2–3.

TABLE 2. MAIN PARAMETERS OF OPAL

No. of fuel assemblies		16
Arrangement of fuel assemblies		4 × 4
Layout		0º and 90º rotated
Fuel assembly x × y lattice dimensions		81.5 mm × 81.5 mm
No. of control and safety absorbers		5
Core coolant and moderator material		Light water
Core coolant and moderator density		
Operation	(42°C)	Pumps on: 0.99160 g/cm^3
Shut down	(20°C)	Pumps off: 0.99837 g/cm^3
Pool coolant material		Light water
Pool coolant density		
Operation	(41.4°C)	Pumps on: 0.99180 g/cm^3
Shut down	(20°C)	Pumps off: 0.99837 g/cm^3
Composition of pool and core coolant (wt%)		H: 11.191 O: 88.809

TABLE 3. FUEL ASSEMBLY SPECIFICATIONS

Parameter	Value
Assembly geometry	21 parallel plates, with 2 burnable poison wires alongside every second plate (total 20 wires) in standard and type 2 fuel
Enrichment	19.8wt%
U density	
Type 1 fuel	2.1 g/cm^3
Type 2 fuel	3.8 g/cm^3
Standard fuel	4.8 g/cm^3
Plate geometry	Flat rectangular
No. of plates per assembly	21
Assembly x dimension	80.5 mm
Assembly y dimension	80.5 mm
Fuel assembly type	U_3Si_2-Al dispersion
Axial assembly dimension (height)	1045 mm
Axial plate dimension, external fuel plates (plates 1 and 21 in each fuel assembly)	825 mm
Axial plate dimension, internal fuel plates (plates 2–20)	655 mm
Active height (meat height), all fuel plates	615 mm
Location of active region relative to bottom of external fuel plate	148 mm
Location of active region relative to bottom of internal fuel plate	20 mm
Plate width	75 mm
Meat width	65 mm
Meat thickness [a]	0.61 mm
Clad thickness, external fuel plates (plates 1 and 21 in each fuel assembly) [a]	0.445 mm
Clad thickness, internal fuel plates (plates 2–20) [a]	0.37 mm
External fuel plate thickness, measured [a]	Mean 1.484 mm (SD[b] 0.005 mm)
Internal fuel plate thickness, measured [a]	Mean 1.322 mm (SD[b] 0.007 mm)
Coolant gap size	2.45 mm
Clad fuel gap	None
Burnable absorber type	Cd cylindrical wires (standard and type 2 fuel)

TABLE 3. FUEL ASSEMBLY SPECIFICATIONS (cont.)

Parameter	Value
Burnable absorber diameter, nominal	0.50 ± 0.025 mm
Burnable absorber diameter, measured [c]	0.493 mm
Burnable absorber length	308 ± 2 mm
Burnable absorber position	Lower end of the Cd wire is 123 mm above the bottom of the meat
Side plate dimensions (thickness × width × height)	5.0 × 80.5 × 890 mm
Side plate slots for external fuel plates (width × depth)	1.6 × 2.5 mm
Side plate slots for internal fuel plates (width × depth)	1.45 × 2.5 mm
Grooves for cadmium wires in side plates (width × depth) (not for type 1 fuel)	0.5 × 0.6 mm

[a] The meat thickness and clad thickness are nominal values. The fuel plate thickness values are measured values for the total thickness, which is the sum of twice the clad thickness plus the meat thickness. These results are based on measurements of fuel plates in several standard fuel assemblies. Both the mean and standard deviation are given. The nominal fuel plate thickness and coolant gaps are not consistent with the overall fuel assembly dimensions. This is because the values are nominal and the differences are within the manufacturing tolerances. The analyst will need to adopt a consistent numerical model.

[b] SD: standard deviation.

[c] The measured value of the burnable absorber diameter is the mean of a sample of three cadmium wires.

Burnable poison is present only in standard and type 2 fuel. In these fuel assemblies, two cadmium wires are provided for every second fuel plate. Every second slot in each side plate has a groove in which the cadmium wire is inserted. The groove runs for the full length of the slot, but the cadmium wire is only 308 mm long, whereas the active height of the fuel is 615 mm. The bottom of the cadmium wire is 123 mm above the bottom of the meat. The groove is filled with water surrounding the cadmium wire. Type 1 fuel assemblies, which lack burnable poison, do not have grooves. The various axial components and dimensions of a fuel assembly and cross-section of the end box are indicated in Fig. 2.

The fuel plates consist of U_3Si_2-Al dispersion fuel meat with aluminium cladding. The nominal thicknesses of meat and cladding for internal and external fuel plates are given in Table 3. The uranium densities in Table 3 are nominal. Actual data are given in Tables 4 to 6.

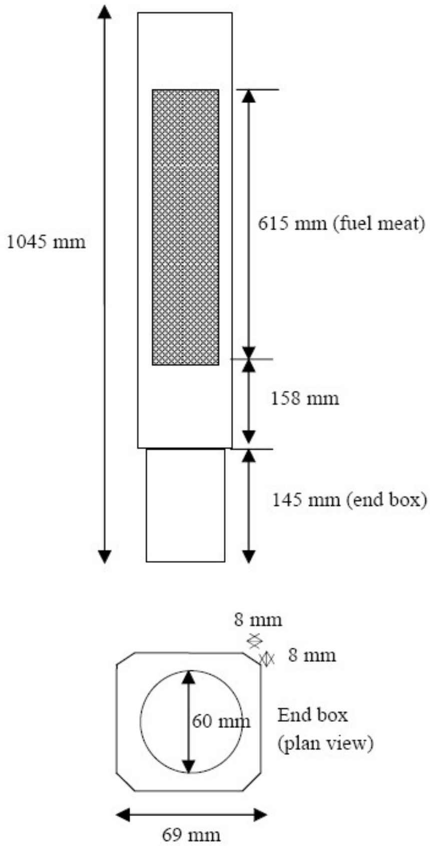


FIG. 2. Fuel assembly showing the various axial sections and plan view of the end box.

TABLE 4. MEAT SPECIFICATIONS: TYPE 1 FUEL

U-235 mass per fuel assembly	211.68 g
U total mass per fuel assembly	1 076.03 g
Total mass of meat per fuel assembly	2 229.10 g
Density assuming meat thickness 0.61 mm	4.353 0 g/cm^3
Element	Concentration (wt%)
Al	47.697
Si	3.9322
U-234	0.0737
U-235	9.4962
U-236	0.0997
U-238	38.602
Impurities: EBC [a]	0.000671

[a] EBC: equivalent boron content.

TABLE 5. MEAT SPECIFICATIONS: TYPE 2 FUEL

U-235 mass per fuel assembly	383.19 g
U total mass per fuel assembly	1 940.15 g
Total mass of meat per fuel assembly	2 928.46 g
Density assuming meat thickness 0.61 mm	5.7187 g/cm^3
Element	Concentration (wt%)
Al	28.281
Si	5.3968
U-234	0.1012
U-235	13.085
U-236	0.1368
U-238	52.928
Impurities: EBC [a]	0.000548

[a] EBC: equivalent boron content.

TABLE 6. MEAT SPECIFICATIONS: STANDARD FUEL

U-235 mass per fuel assembly	484.23 g
U total mass per fuel assembly	2 443.63 g
Total mass of meat per fuel assembly	3 319.29 g
Density assuming meat thickness 0.61 mm	6.482 0 g/cm^3
Element	Concentration (wt%)
Al	20.325
Si	5.9969
U-234	0.1124
U-235	14.588
U-236	0.1520
U-238	58.766
Impurities: EBC [a]	0.000498

[a] EBC: equivalent boron content.

Table 7 summarizes the aluminium 6061 fuel cladding, side plates and end box. Table 8 describes the cadmium burnable absorber.

TABLE 7. ALUMINIUM 6061: FUEL CLADDING, SIDE PLATES AND END BOX

Density	2.71 g/cm^3	
Concentration (wt%)	Fuel cladding	Side plates
Al	97.51	97.36
Cr	0.07	0.11
Cu	0.22	0.21
Fe	0.58	0.70
Mg	0.85	0.86
Mn	0.04	0.02
Si	0.63	0.60
Ti	0.05	0.07
Zn	0.04	0.06
Impurities: EBC [a]	0.0012	0.0009

[a] EBC: equivalent boron content.

TABLE 8. CADMIUM: BURNABLE ABSORBER

Density	8.64 g/cm^3
Concentration (wt%)	Min. 99.95

5. CONTROL COMPONENT

CRPs comprise a hafnium plate (or two intersecting hafnium plates in the case of the central plate CR5) held in a Zircadyne frame. The hafnium plate has sections of different thickness. A cylindrical, zircaloy-4 follower is attached to the bottom of the plate. The structure which connects the plate to the follower is referred to as the lower cap. The CRPs are located inside a cross shaped CRGB made of zircaloy-4. The CRPs (including followers) are surrounded by water within the CRGB. Table 9 summarizes the control assembly specifications and Figs 3 to 7 illustrate the complex geometry. Control plate positions are given in the experimental data in terms of percentage extraction: 0% indicates that the top of the absorber plate is 317.5 mm above the core centreline; 100% indicates that the top of the absorber plate is 942.5 mm above the core centreline.

TABLE 9. CONTROL ASSEMBLY SPECIFICATIONS

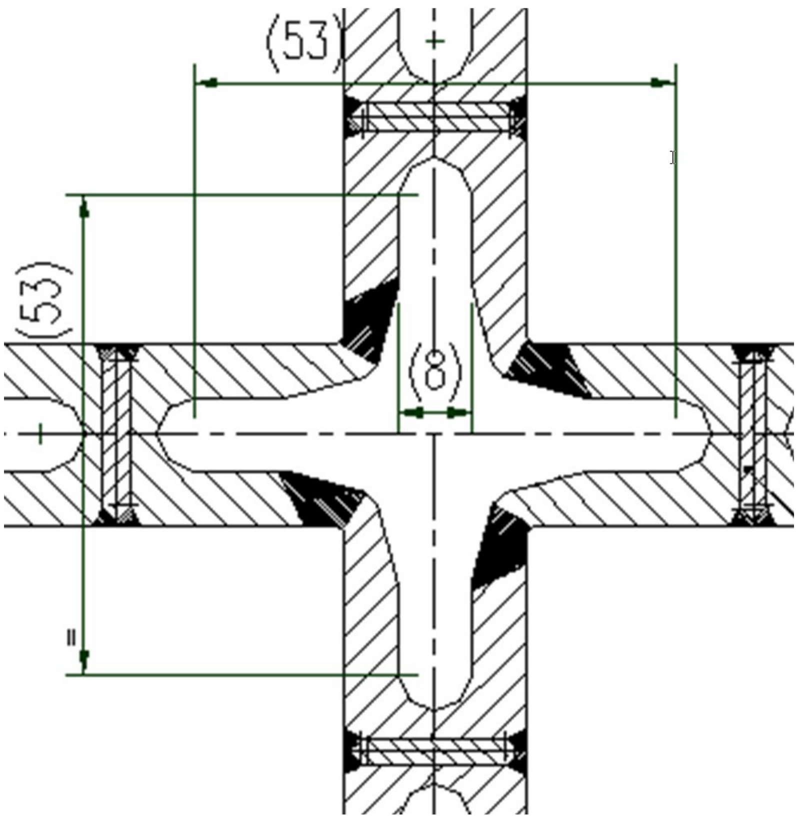
Parameter	Value
Control type	Hf plate with zircaloy-4 follower
Full travel distance (control rod	625 mm
Direction of travel	Down
No. of CRPs	5
Width of control plates CR1 to CR4	126 mm
Width of regulating plate CR5	57 mm

TABLE 9. CONTROL ASSEMBLY SPECIFICATIONS (cont.)

Parameter	Value
Height of plates CR1 to CR5	635 mm
Thickness of plates CR1 to CR5	6.0 mm
Follower diameter	16.2 mm
Location of control plate CR1	x = 0 mm, y = +104.5 mm
Location of control plate CR2	x = −104.5 mm, y = 0 mm
Location of control plate CR3	x = +104.5 mm, y = 0 mm
Location of control plate CR4	x = 0 mm, y = −104.5 mm
Location of regulating plate CR5	x = 0 mm, y = 0 mm
Position when fully inserted for all plates	z = −317.5 mm to 317.5 mm (from core centreline)
Assembly x dimension	n.a. [a]
Assembly y dimension	n.a. [a]
Axial assembly dimension (including follower)	5134 mm

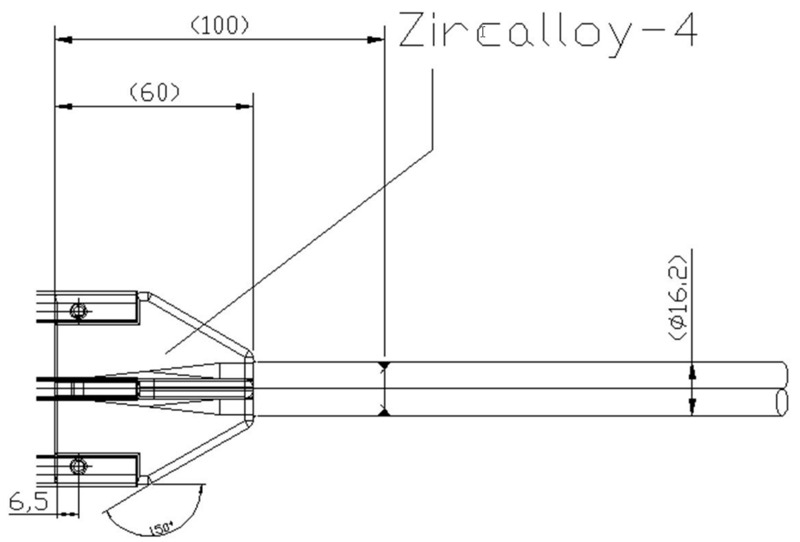
Note: CR: control rod; CRPs: control and regulating plates.

[a] n.a.: not applicable.



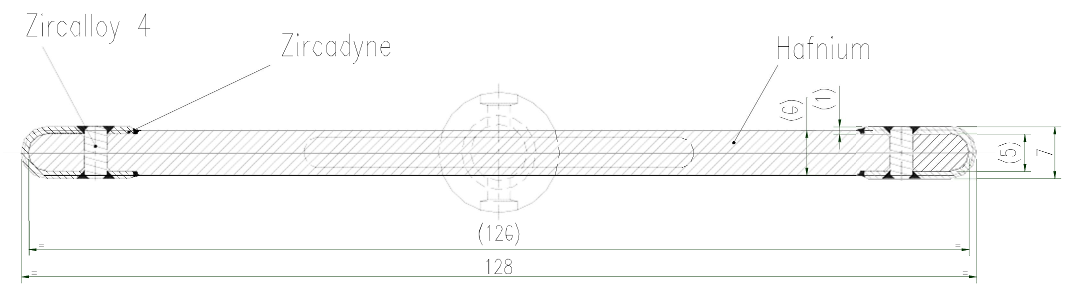
Dimensions in mm.

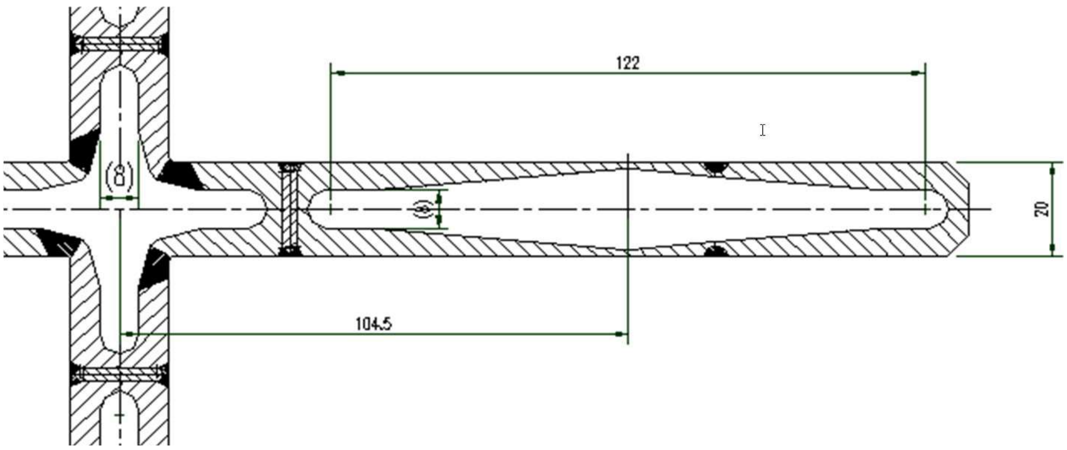
FIG. 4. Regulating plate CR5 (central CRP).



Dimensions in mm.

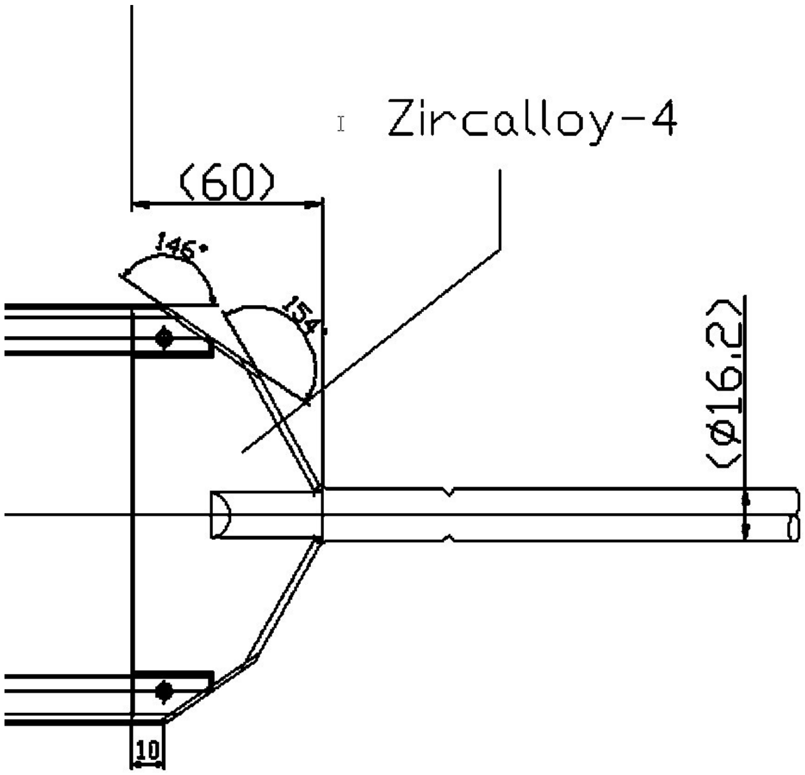
FIG. 5. Lower cap and follower for the regulating plate CR5.





Dimensions in mm.

FIG. 6. Control plates CR1, CR2, CR3 and CR4.



Dimensions in mm.

FIG. 7. Lower cap and follower for control plates CR1, CR2, CR3 and CR4.

Table 10 summarizes the CRGB specification.

TABLE 10. CONTROL ROD GUIDE BOX SPECIFICATIONS

Parameter	Value
Material of guide box	Zircaloy-4
Inner coolant	Light water
Width of guide box	20 mm
Wall thickness (nominal) surrounding plates CR1 to CR4	Min. 1.5 mm Max. 6.0 mm
Wall thickness (nominal) surrounding plate CR5	Min. 4.4 mm Max. 6.0 mm
Water gap (nominal) between guide box and absorber plates CR1 to CR4	Non-uniform: min. 0.5 mm
Water gap (nominal) between guide box and absorber plate CR5	Non-uniform: min. 0.5 mm
Water gap (nominal) between guide box and follower for CR1 to CR4	Non-uniform: min. 0.4 mm
Water gap (nominal) between guide box and follower for CR5	Non-uniform: min. 1.7 mm

Tables 11 to 13 describe zircaloy-4 composition, Zircadyne composition and the hafnium control plate absorbers.

TABLE 11. ZIRCALOY-4 (ZRY-4)

Specification	ASTM B 352 grade R60804
Density	6.55 g/cm^3
Concentration (wt%)	
Cr	0.115
Fe	0.225
O	0.12
Sn	1.29
Zr	98.1895
Impurities: EBC [a]	0.000144

[a] EBC: equivalent boron content.

TABLE 12. ZIRCADYNE 702

Specification	ASTM/UNS R60702
Density	6.51 g/cm^3
Concentration (wt%)	
C	0.02
Hf	0.6
N	0.005
O	0.13
Zr	99.165
Fe + Cr	0.08

TABLE 13. HAFNIUM: CONTROL PLATE ABSORBER

Specification	ASTM B 776-91 grade R1
Density	12.9 g/cm^3
Concentration (wt%)	
Hf	97.86
Zr	2.14

6. CORE GRID

The core grid is a structure located below the fuel assemblies and provides location and support for the fuel assemblies, fuel clamps, CRGB and control rod stems. There are two components separated by a 13 mm gap — the upper grid made from Al 6061 and the lower grid made from stainless steel 316L. The fuel assembly end box sits inside the upper grid. The core grid dimensions are provided in Table 14. The axial locations of the fuel assembly and core grid relative to the reflector vessel and inlet plenum are shown in Fig. 8.

TABLE 14. CORE GRID SPECIFICATION

Upper grid	
Material	Al 6061
Array x–y dimensions	350 × 350 mm
Lattice	x spacing = 81.5 mm y spacing = 81.5 mm
Thickness	150 mm
Passing holes dimensions	70 mm × 70 mm (slightly rounded corners)
Lower grid	
Material	Stainless steel 316L
Array x–y dimensions	350 × 350 mm
Lattice	x spacing = 81.5 mm y spacing = 81.5 mm
Thickness	35 mm
Passing holes dimensions	58.4 mm diameter

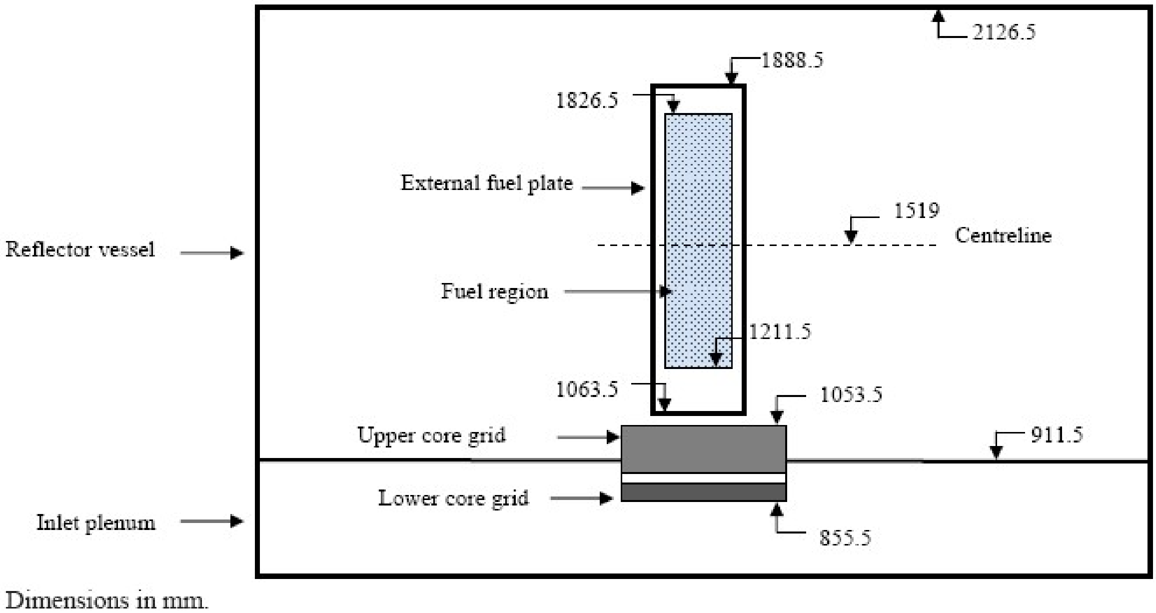


FIG. 8. Axial position of key components relative to reactor pool bottom.

7. REFLECTOR

The core chimney is surrounded by the reflector vessel (see Fig. 9). Both are made of zircaloy-4 (see Table 11 for the composition). The specifications for the chimney and reflector vessel are given in Tables 15 and 16. The reflector heavy water composition at the beginning of the first operating cycle is given in Table 17.

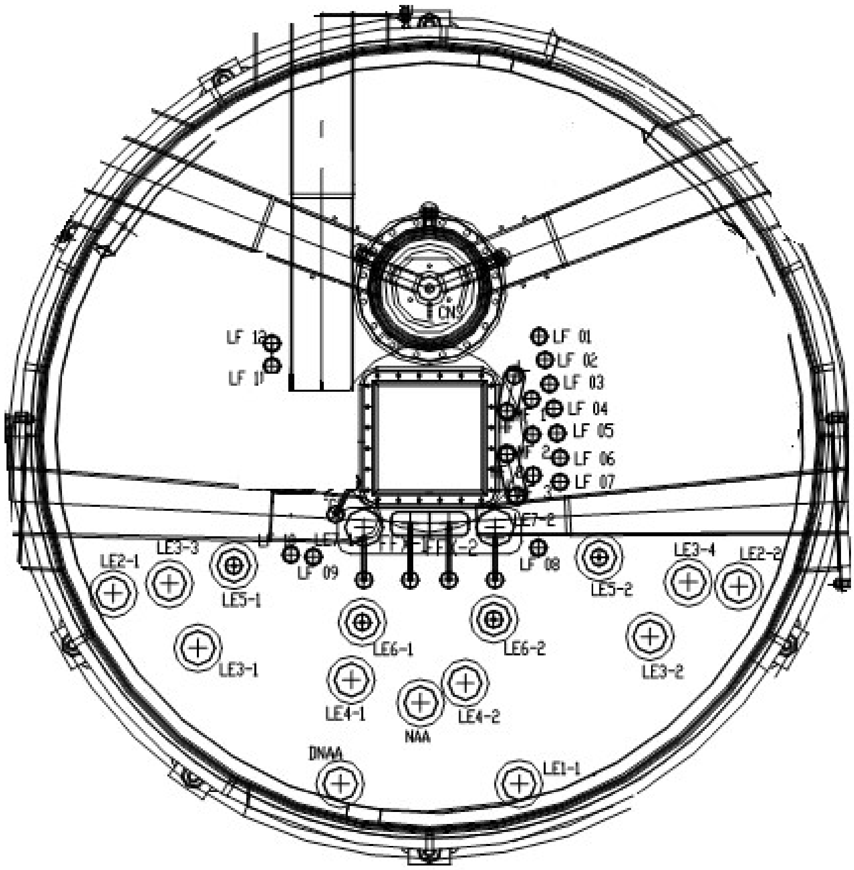


FIG. 9. Plan view of the reflector vessel showing the core, cold neutron source, neutron beams and irradiation facilities.

TABLE 15. CHIMNEY SPECIFICATIONS

Parameter	Value
Material	Zircaloy-4
Shape	Square
Height in reflector vessel	1265 mm
Panel thickness	4.89 mm
Gap between fuel assemblies and chimney	1.5 mm
Gap between fuel assemblies and control rod guide box	1.5 mm

TABLE 16. REFLECTOR VESSEL SPECIFICATIONS

Parameter	Value
Material	Zircaloy-4
Shape	Cylindrical
Diameter (internal)	2600 mm
Height (internal)	1215 mm
Thickness	
Side	9 mm
Top and bottom	25 mm

TABLE 17. HEAVY WATER: REFLECTOR

Parameter	Value
Density at 43.4°C	1.094 92 g/cm^3
Density at 20.0°C	1.103 08 g/cm^3
D_2O fraction	99.92% molar
Concentration (wt%)	
D	20.09888
H	0.008052
O	79.89307

8. COLD NEUTRON SOURCE

The CNS consists of a moderator vessel filled with liquid deuterium when the CNS is in normal operation mode (or gaseous deuterium when in standby operation mode). The moderator vessel is encased by a jacket, which itself is located inside a containment vessel. Between the moderator vessel and jacket, there is cryogenic helium. Between the jacket and containment vessel is vacuum. The geometry of the moderator and jacket is depicted in Fig. 10. Above the jacket is a heavy water plug. A general diagram of the CNS is given in Fig. 11. Details of the dimensions and materials are given in Tables 18 to 20.

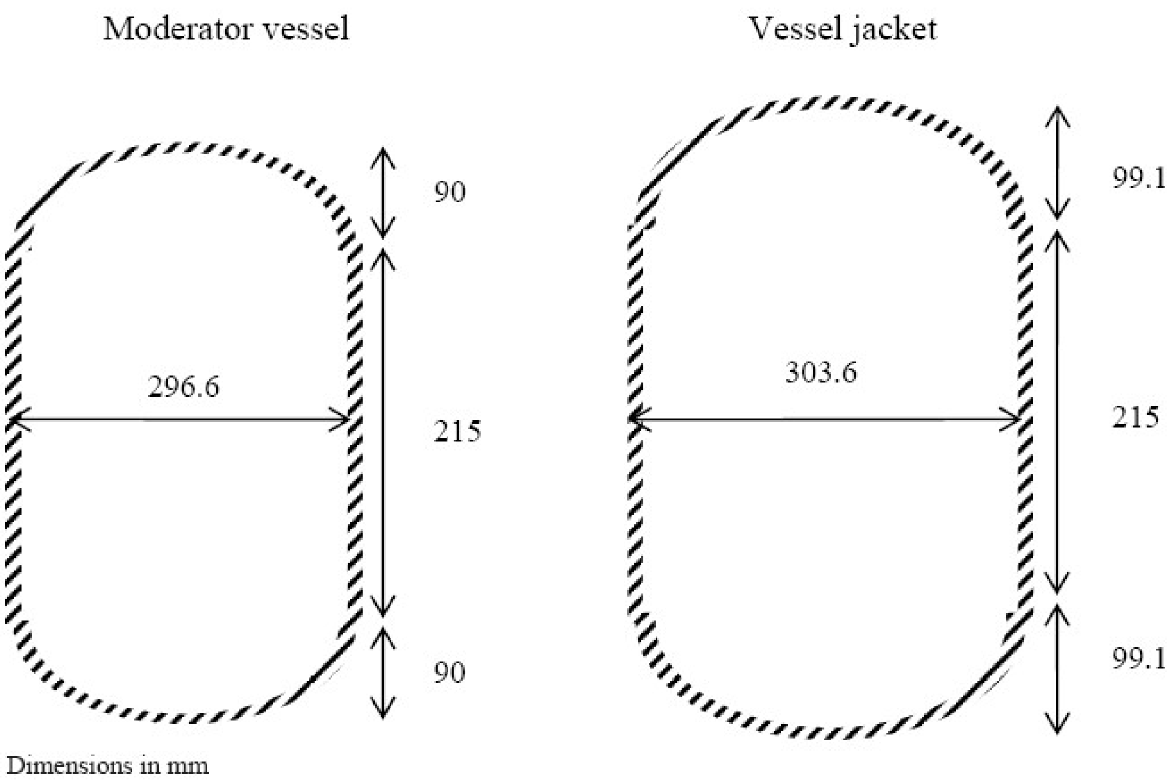


FIG. 10. CNS moderator vessel and jacket.

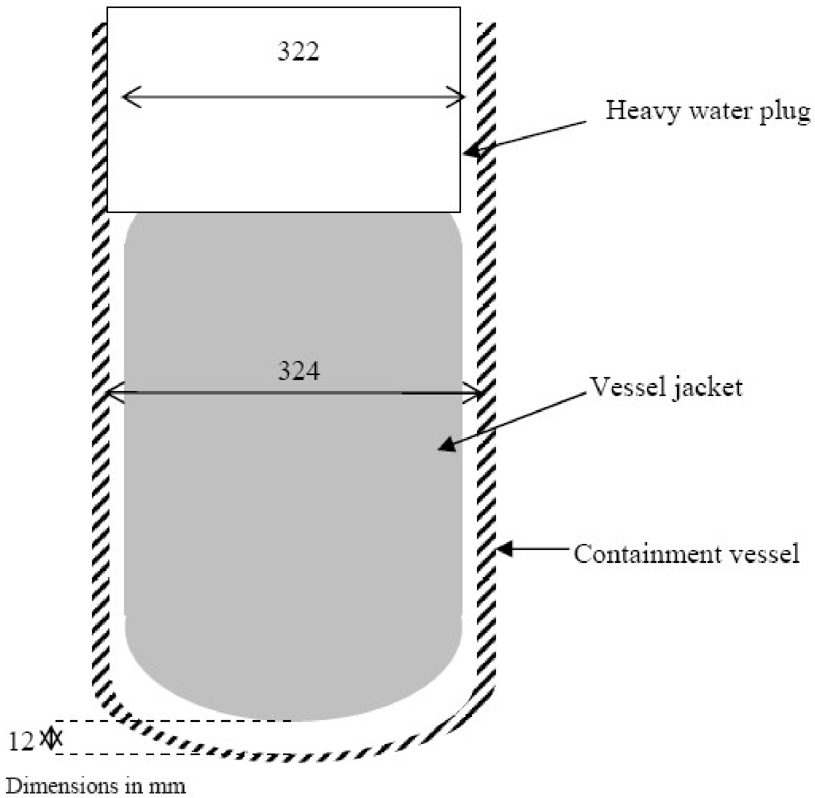


FIG. 11. CNS general geometry.

TABLE 18. COLD NEUTRON SOURCE SPECIFICATIONS

Parameter	Value
Moderator vessel	
Inner radius	146.7 mm
Outer radius	148.3 mm
Material	$AlMg_5$
Vessel jacket	
Inner radius	150.3 mm
Outer radius	151.8 mm
Material	$AlMg_5$
Shape (vessel, jacket and containment)	Cylindrical body with torispherical caps
Moderator (normal operation mode)	
Material	Liquid D
Temp.	23 K
Density	0.144 g/cm^3
Moderator (standby operation mode)	
Material	Gaseous D_2
Temp.	300 K
Density	0.000 8 g/cm^3
Containment vessel	
Inner radius	162 mm
Outer radius	165.15 mm
Material	Zr-2.5%Nb
Coolant	
Material	He
Temp.	22 K
Density	1.785×10^{-4} g/cm^3
Reflector plug	
Material chamber	$AlMg_5$
Material reflector	Heavy water
Inner radius	158 mm
Outer radius	161 mm
Height total	366 mm
Height above jacket	330 mm
Position (relative to fuel centreline)	
x	0 mm
y	500 mm
z [a]	120 mm

[a] Axial distance to moderator vessel mid-plane.

TABLE 19. ALMG5: COLD NEUTRON SOURCE VESSEL, JACKET, DISPLACER AND REFLECTOR PLUG

Specification	GOST 4784-74
Density	2.64 g/cm^3
Concentration (wt%)	
Al	93.88
Cu	0.1
Fe	0.32
Mg	5.0
Mn	0.4
Si	0.18
Ti	0.04
Zn	0.08

TABLE 20. ZR-2.5%NB: COLD NEUTRON SOURCE CONTAINMENT VESSEL

Specification	Zr 3125 (Zr-2.5%Nb)
Density	6.6 g/cm^3
Concentration (wt%)	
Nb	2.5
Zr	97.33
Impurities (ppm)	
Al	<30
B	<0.4
Be	<10
C	100
Ca	<100
Cd	<0.3
Cl	<10
Cr	<100
Cu	<100
F	<30
Fe	100
H	1.9
Hf	400
K	<30
Li	<7
Mn	<10
Mo	<30
N	30

TABLE 20. ZR-2.5%NB: COLD NEUTRON SOURCE CONTAINMENT VESSEL (cont.)

Specification	Zr 3125 (Zr-2.5%Nb)
Ni	<100
O	300
Pb	<30
Si	<100
Sn	<100
Ti	<30
Impurities: EBC [a]	6.0 ppm as from ASTM C 1233

[a] EBC — equivalent boron content.

9. BEAMS

There are five beam tubes in total — the main data for the beam tubes is presented in Table 21. The beam tubes may have a thinner wall thickness in the sections closer to the source and then a thicker section further out. This is indicated in the various side, top and bottom wall thickness values. The distance from the inner most part of the beam tube to the transition point (change in thickness) is also indicated.

TABLE 21. BEAM TUBE SPECIFICATIONS

Parameter	Cold neutron source		Thermal neutron source		Hot neutron source
No.	2		2		1
Material	Zry-4		Zry-4		Zry-4
Inner gas	He		He		He
Name	Assembly C	Assembly	Assembly	Assembly B	Assembly E
Side wall thickness (mm)	8/8 [a]	8/8	6/8	6/8	4/6
Top wall thickness (mm)	6/8	6/8	6/8	6/8	4/6
Bottom wall thickness	4/8	4/8	6/8	4/8	4/6
Transition distance from inner end (mm)	304.65	451.23	300.0	371.67	692.0
Inner end face thickness (mm)	2.7	2.5 (corner zone 3.0)	3.0	2.11	3.0
Inner end face width (inside) (mm)	162	162	90	140	200
Inner height (mm)	335.97	300.20	340.18	240.38	200
Wall front shape	Concave cylindrical	Concave cylindrical	Flat	Convex cylindrical	Concave cylindrical
Radius of curvature (mm)	166.1	166.1	n.a. [b]	70	151
Divergence	~1.2°	~1.2°	2.73°	1.67°	0°
Angle from x axis	21°	159°	3°	177°	90°

TABLE 21. BEAM TUBE SPECIFICATIONS (cont.)

Parameter	Cold neutron source		Thermal neutron source		Hot neutron source
x [c] (mm)	155	−155	157	−158	−361.5
y [c] (mm)	560	560	−277	−279	151
z [c] (mm)	120	130	−60	−60	−136

[a] 8/8 indicates 8 mm at the closer section and 8 mm further out.

[b] n.a.: not applicable.

[c] Central point coordinates of inner end face.

10. BULK PRODUCTION IRRADIATION FACILITIES

The specifications for the bulk production facilities are provided in Table 22. The facilities are simply light water cooled volumes within the reflector for loading of rigs and targets. They can be assumed to extend the full height of the reflector vessel. The surveillance probe facility specifications are provided in Table 23.

TABLE 22. BULK PRODUCTION FACILITIES SPECIFICATIONS

Tube diameter	60 mm	
Tube thickness	3.2 mm	
Length of facility within the reflector vessel (full height)	1215 mm (nominal)	
Tube material	Zry-4	
Coolant material within tube	Light water	
Facility label	x (mm)	y (mm)
HF 1	260	90
HF 2	260	−55
MF 1	342	130
MF 2	345	10
MF 3	347	−125
LF 01	368	340
LF 02	388	261
LF 03	403	180
LF 04	418	98
LF 05	428	16
LF 06	438	−66
LF 07	438	−148
LF 08	365	−368
LF 09	−390	−398
LF 10	−466	−390
LF 11	−530	240
LF 12	−530	316

Note: HF: high flux; LF: low flux; MF: medium flux.

TABLE 23. SURVEILLANCE PROBE FACILITIES SPECIFICATIONS

Tube diameter	60 mm
Tube thickness	3.2 mm
Length of facility within the reflector vessel (from top of reflector to fuel centreline)	607 mm (nominal)
Tube material	Zry-4
Coolant material within tube	Light water
Cooling tube	
Tube dimension	13.7 mm
Tube thickness	1.7 mm
Length of facility within the reflector vessel (from fuel centreline to bottom of reflector)	607 mm (nominal)
Tube material	Zry-4
Coolant material within tube	Light water
Location	
x (mm)	−260
y (mm)	−150

11. PNEUMATIC IRRADIATION FACILITIES

There are many pneumatic facilities at various distances from the core to accommodate a range of flux and spectrum requirements. The detailed description of these facilities is complex due to the many components and multiple irradiation positions within each facility. Rather than providing a detailed engineering specification, a neutronic specification will be provided suitable for whole reactor calculations. Details will be given only for those facilities close to the core. The remaining facilities are judged to have little neutronic influence.

There are two facilities designated LE6 (LE6-1 and LE6-2), which in the neutronic model are divided into four axial zones as shown in Fig 12. The total height is equal to the reflector vessel height (i.e. the upper and bottom zones extend to the limits of the reflector height). The axial location relative to the core centreline is also provided. Each zone has different compositions in the neutronic model, which are indicated in Table 24. The geometry adopted is cylindrical with concentric cylinders of different material.

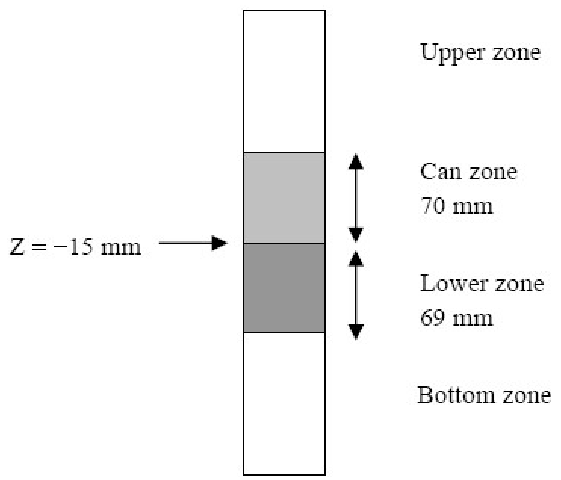


FIG. 12. Axial details for LE6 pneumatic facilities.

TABLE 24. LE6 FACILITIES SPECIFICATIONS

Location	Dimension (mm)
LE6-1	
x	−226
y	−617
LE6-2	
x	216
y	−607
	Diameter (mm)
Composition: upper zone	
Material	
N	<53.56058
Al-6061	<60.89903
Light water	<97.8
Al-6061	<103.8
Light water	<110.28
Zry-4	<114.5
Heavy water (reflector)	>114.5
Composition: can zone	
N	<39.20242
Al-6061	<60.89903
N	<97.8
Al-6061	<103.8
Light water	<110.28
Zry-4	<114.5
Heavy water (reflector)	>114.5
Composition: lower zone	
Al-6061	<86.6
N	<102.4
Light water	<110.28
Zry-4	<114.5
Heavy water (reflector)	>114.5
Composition: bottom zone	
Light water	<35.6
Zry-4	<38.1
Heavy water (reflector)	>38.1

There are two facilities designated LE7 (LE7-1 and LE7-2), which in the neutronic model are divided into three axial zones as shown in Fig. 13. The upper zone extends to the upper limit of the reflector height. The axial location of the bottom of the can zone in indicated in Fig. 13 and the value provided in Table 25. Each zone has a different composition in the neutronic model and is indicated in Table 25. The geometry adopted is cylindrical with concentric cylinders of different material.

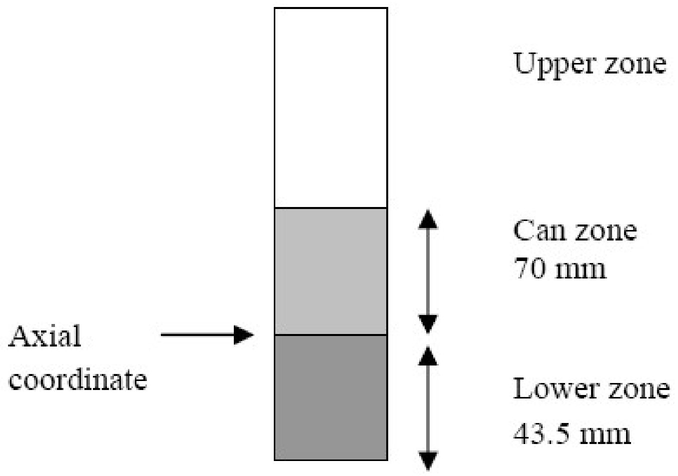


FIG. 13. Axial details for LE7 and FFX pneumatic facilities.

TABLE 25. LE7 FACILITIES SPECIFICATIONS

Location	Dimension (mm)
LE7-1	
x	−220
y	−300
z	225
LE7-2	
x	220
y	−300
z	225
	Diameter (mm)
Composition: upper zone	
N	<69.326 94
Al-6061	<79.429 40
Light water	<114.0
Al-6061	<120.0
H2O (pool)	<128.47
Zry-4	<131.55
Heavy water (reflector)	>131.55
Composition: can zone	
N	<50.854 74

TABLE 25. LE7 FACILITIES SPECIFICATIONS (cont.)

Location	Dimension (mm)
Al-6061	<79.429 40
N	<114.0
Al-6061	<120.0
Light water	<128.47
Zry-4	<131.55
Heavy water (reflector)	>131.55
Composition : lower zone	
Al-6061	<100.4
N	<120.0
Light water	<128.47
Zry-4	<131.55
Heavy water (reflector)	>131.55

There are two facilities designated FFX (FFX-1 and FFX-2), which in the neutronic model are divided into three axial zones as shown in Fig. 13. The upper zone extends to the upper limit of the reflector height. The axial location of the bottom of the can zone is indicated in Fig. 13, and the dimensions are provided in Table 26. Each zone has different compositions in the neutronic model and these are indicated in Figs 14 and 15. The geometry adopted is a combination of rectangular and cylindrical of different material.

TABLE 26. FFX FACILITIES SPECIFICATIONS

Location	Dimension (mm)
FFX-1	
x	−65
y	−288
z	205
FFX-2	
x	65
y	−288
z	205

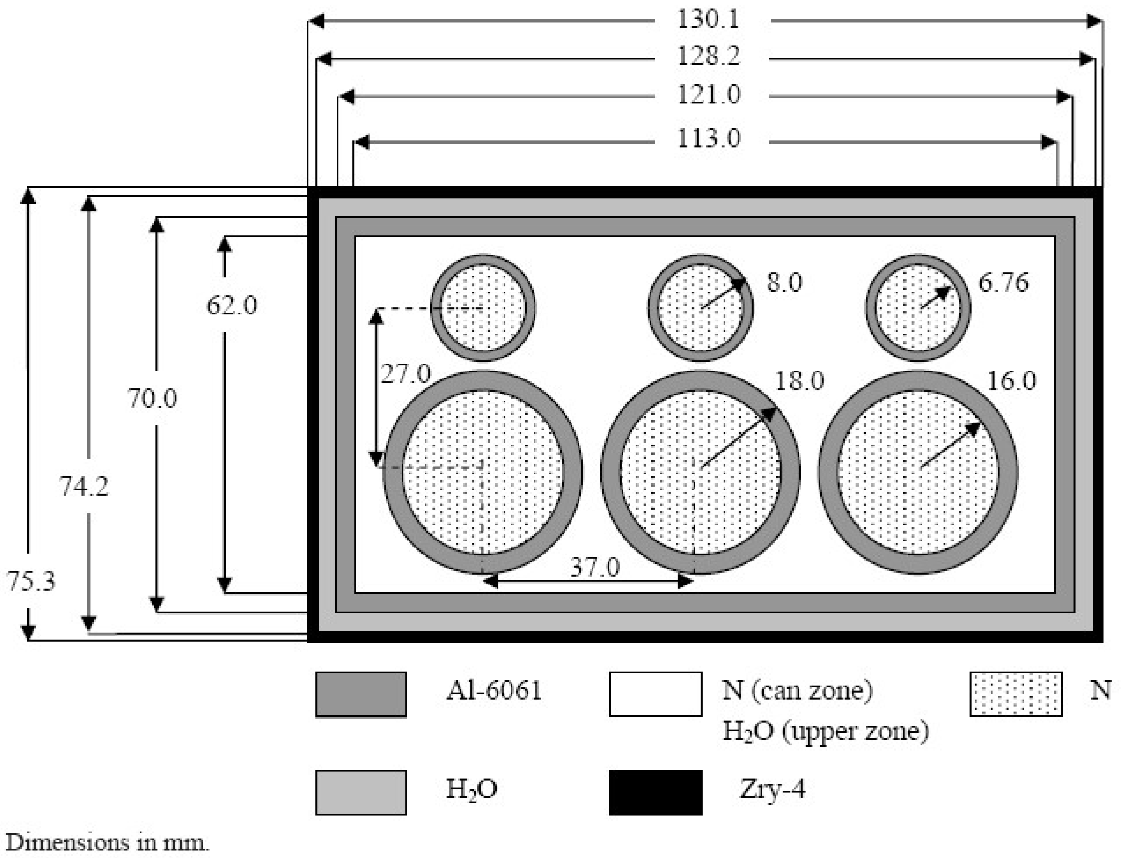


FIG. 14. FFX details for the upper and can zones.

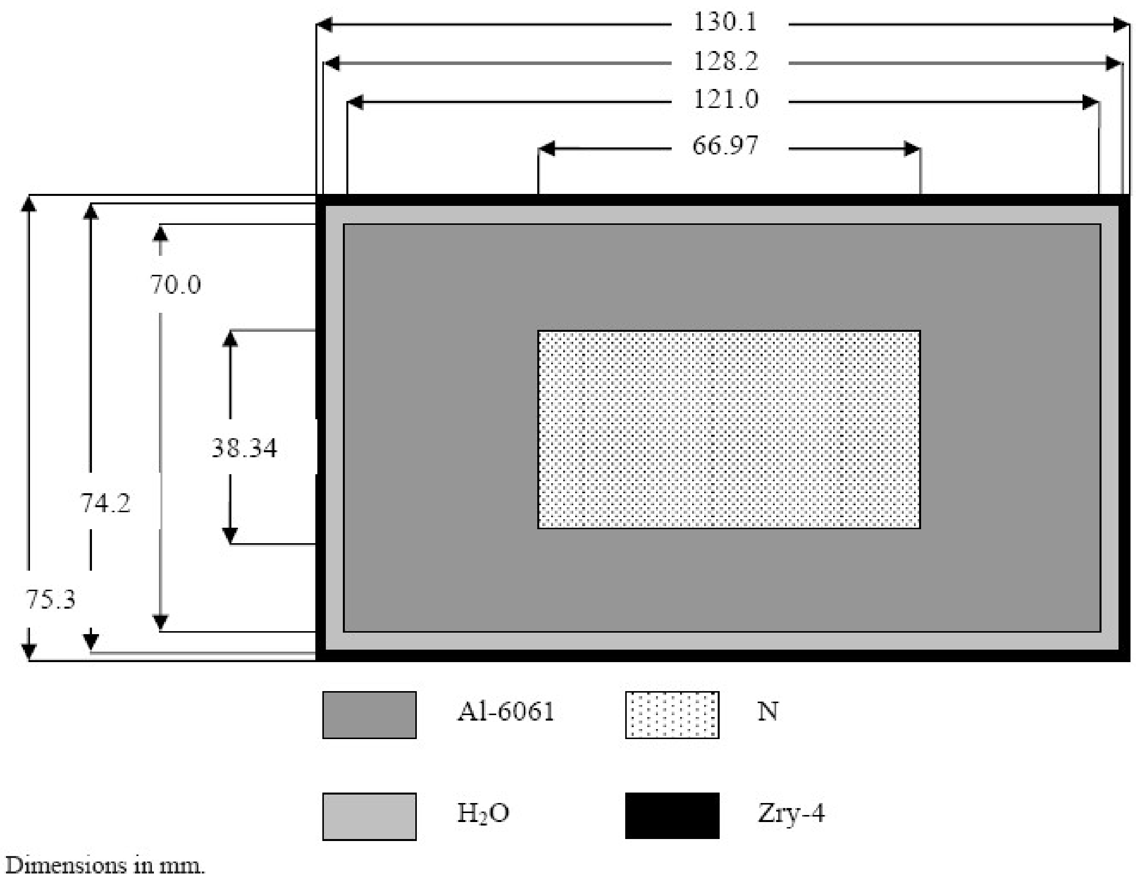


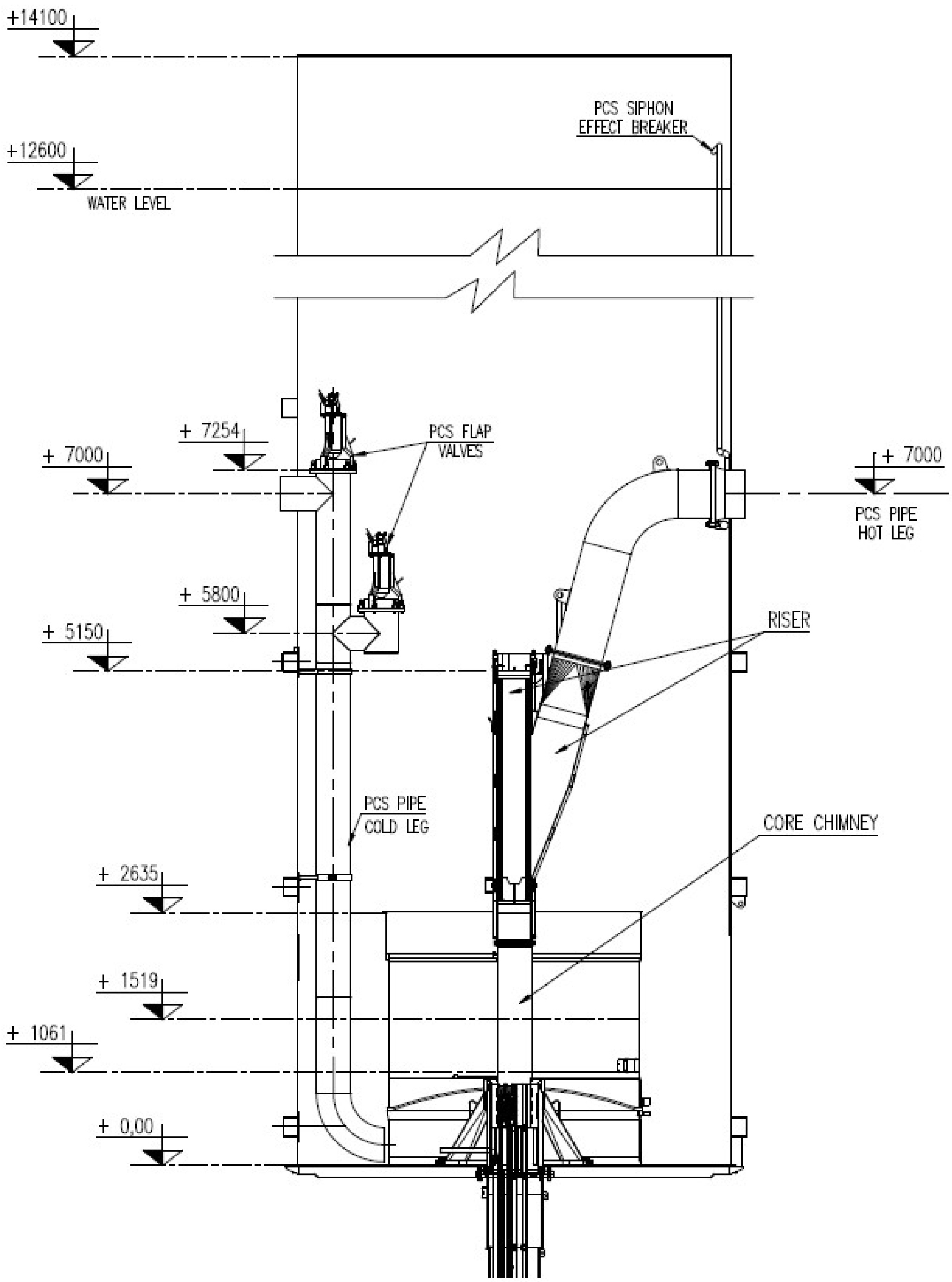
FIG. 15. FFX details for the lower zone.

12. REACTOR POOL

The reflector vessel is located at the bottom of an open pool (see Fig. 16). The pool is cylindrical, and it extends from level 0 mm to +140 00 mm at the top. Coolant enters through two inlet pipes that penetrate the pool at a height of +7000 mm and then extend to the bottom of the pool, where they enter the inlet diffuser. This conical device mixes the coolant to achieve a homogeneous flow through the core. After flowing upwards through the core, the coolant exits through a single outlet pipe that also penetrates the pool wall at a height of +7000 mm. There are two sets of two redundant flap valves that not only serve to transition from forced circulation to natural circulation but also serve as siphon breakers. The valves are located at +7000 mm and at +5800 mm. Dimensions of the pool and various internal components are provided in Table 27.

TABLE 27. POOL AND INTERNAL COMPONENTS SPECIFICATIONS

Diameter	4 500 mm
Total height	14 000 mm
Water depth	12 600 mm
Effective water volume	186 m^3
Core elevation above the pool bottom	1 519 mm (centreline)
Inlet pipe	
Quantity	2
Internal diameter	350 mm
Outlet pipe	
Quantity	1
Internal diameter	500 mm
Inlet plenum	
Diameter	2 600 mm
Height	565.5 mm
Outlet chimney	
Cross-section	380 mm × 380 mm
Height (above reflector vessel)	2 734 mm
Natural circulation device	
Type	Flap valves
Quantity	4
Elevation from pool bottom	7 000 (2), 5 800 (2)
Opening condition	0.2–0.6 kPa



Dimensions in mm.

FIG. 16. Reactor pool and internal components

13. PRIMARY COOLING SYSTEM

The reactor can be operated in two cooling regimes, forced flow or natural convection. In the forced flow regime, the cooling is provided by the primary cooling system (PCS). This system provides coolant (demineralized light water) upwards through the core. All the components of the PCS located within the reactor pool are described in Section 12. Only those components of the PCS outside the reactor pool are described in Section 13.

The coolant leaves the reactor pool and enters a delay tank to allow the 16N to decay. The residence time is 120 s. The coolant then flows through one of two branches to a PCS pump and then a heat exchanger. In total, there are three such branches, but only two operate at a time. After each heat exchanger, the branches merge to a common pipe that splits into two just before entering the reactor pool again. Details of the out of pool components are provided in Tables 28 and 29.

TABLE 28. PUMP SPECIFICATIONS

No.	3 (2 in service)
Power	124 kW
Nominal flow rate	1150 m^3/h
Efficiency	83%
Rotation speed	1450 rpm
Elevation height (from pool bottom)	−5.0 m
Moment of inertia	70 $kg \cdot m^2$ (including flywheel)

TABLE 29. HEAT EXCHANGER SPECIFICATIONS

No.	3 (2 in service)
Pressure drop (primary side)	65 kPa
Heat transfer area	392 m^2
Heat transfer coefficient	3970 $W \cdot m^{-2} \cdot C^{-1}$

14. REACTOR MATERIAL/INVENTORY DISTRIBUTION

The facility relevant experiments were carried out with the core loaded entirely with fresh fuel. The reactor had been operated only at low power, so burnup was negligible. Consequently, it is not necessary to provide estimated isotopic data for the fuel for each axial layer.

15. REACTOR STATE DEFINITIONS

All experiments were carried out at low power with essentially zero xenon concentration and with natural circulation rather than forced coolant flow. The nominal moderator temperature is 20ºC and the moderator density is 0.998 37 g/cm3. The nominal fuel temperature is 20ºC.

For analysis of operational data provided for the purpose of burnup and reactivity calculations, it can be assumed that the reactor was at full power.