PHYSICS DESIGN OF 30 MW MULTI PURPOSE RESEARCH REACTOR

Archana Sharma

Research Reactor Services Division

BHABHA ATOMIC RESEARCH CENTRE, INDIA

Objective

- **To meet the increasing needs of radio-isotopes for application in the field of medicine, agriculture and industry**

- **To provide enhanced facilities for basic research in frontier areas of science and for applied research related to development and testing of new and novel materials.**

- **In order to meet the large requirement of high specific activity radioisotopes like Co^{60} for teletherapy, Ir^{192} for brachytherapy, Sm^{153}, Y^{90}, W^{188} and P^{32} (requiring high fast neutron flux levels), a research reactor providing high irradiation volume at a neutron flux level greater than 3×10^{14} n/cm^2/s is essential.**

Design Philosophy

- **Plate Type, LEU fuel in the form of U_3Si_2 dispersed in Aluminum Matrix with 19.75 Wt% ^{235}U Enrichment**

- **Small, Compact and Under Moderated Core**

- **DM Water Moderated & Cooled**

- **Large Radial Heavy Water Reflector Tank to provide large Irradiation Volume and large excess reactivity**

- **To achieve high thermal and fast neutron flux levels in irradiation/ experimental positions**

Cont…

- **Core operable for about 25 full power days without the need for core reconstitution**

- **Minimum achievable Discharge fuel burn-up more than atom 35% of the initial fissile material**

- **From safety considerations, all reactivity coefficients to be maintained negative at all power levels**

- **Sufficient shut down margin**

Salient Design Features

Reactor type	**Tank in pool type reactor with fixed core**
Thermal Power	**30 MW**
Max. Neutron Flux (in core)	
Thermal flux	**6.7×10^{14} n/cm^2/sec**
Fast flux	**1.7×10^{14} n/cm^2/sec**
Max. Thermal Neutron Flux (in Reflector region)	**3.2×10^{14} n/cm^2/sec**
Core height (active)	**60 cm**
Core Radius	**27.5 cm**
Fuel loading	**36 Kg of U (LEU)**

Cont…

Primary Coolant	**Demineralised water**
Moderator	**Demineralised water**
Reflector	**Heavy Water in an annular tank surrounding the core (80 cm thick)**
Shutdown device Material	**Hafnium**
Beam tubes	**6 tangential beam tubes**
In core irradiation positions	**1 central, 3 peripheral**
Irradiation / Experimental positions in reflector region	**Radioisotope production : 12 Pneumatic carrier facility (NAA): 2 Neutron Transmutation Doping: 2 Material irradiation studies: 3**

Core & Reflector

- **Core is constituted by 24 lattice positions laid in a square pitch of 85.6 mm and 8 positions in filler region. Equilibrium core consists of**

19 Standard Fuel Assemblies

4 Control Fuel Assemblies

1 In-core irradiation position

3 Irradiation positions in filler

2 Adjuster rods in filler

2 Safety rods in filler

1 Fine control rod in filler

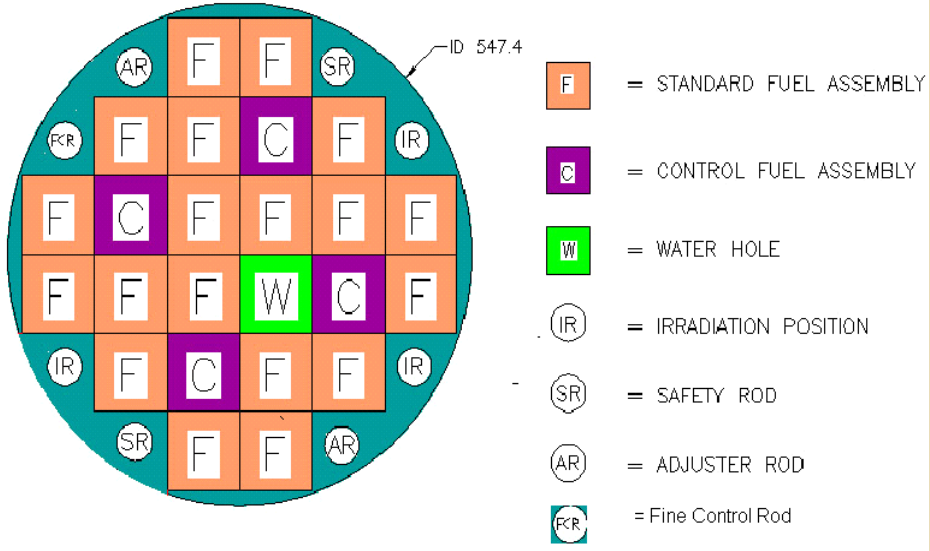


FIG.- 1 : CORE CONFIGURATION
(PITCH = 85.6 MM)

CORE CONFIGURATION

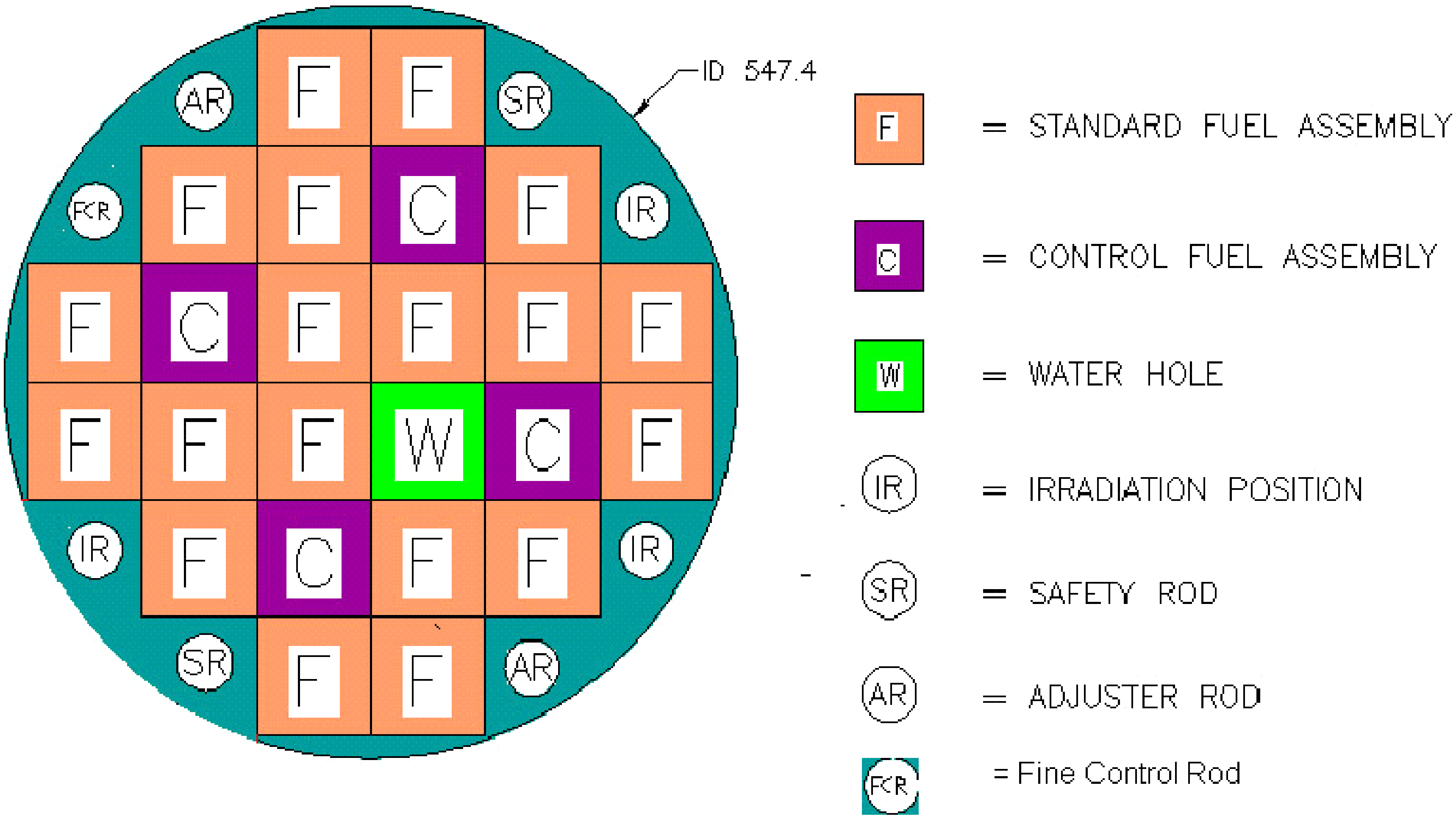
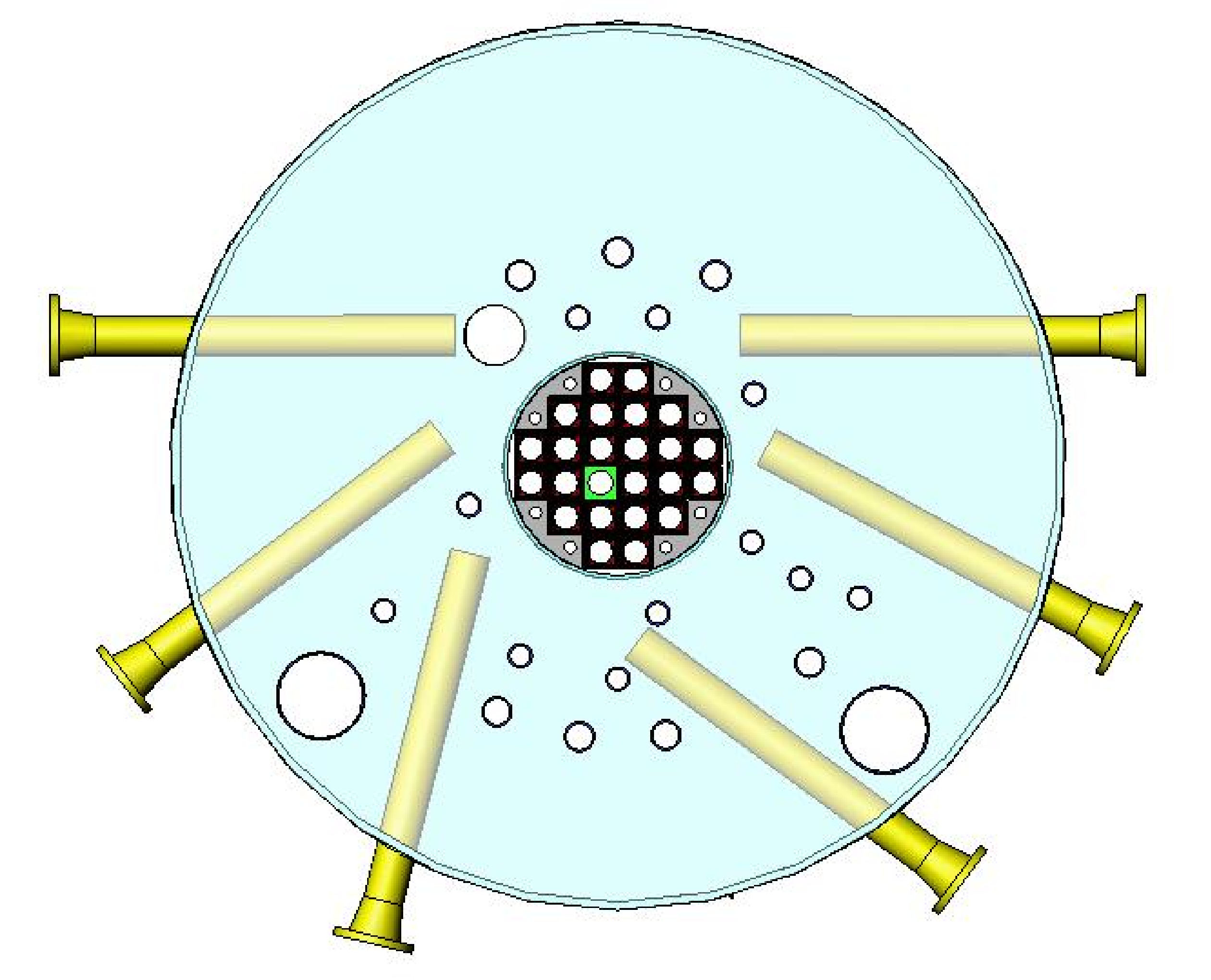


FIG.- 1 : CORE CONFIGURATION

(PITCH = 85.6 MM)

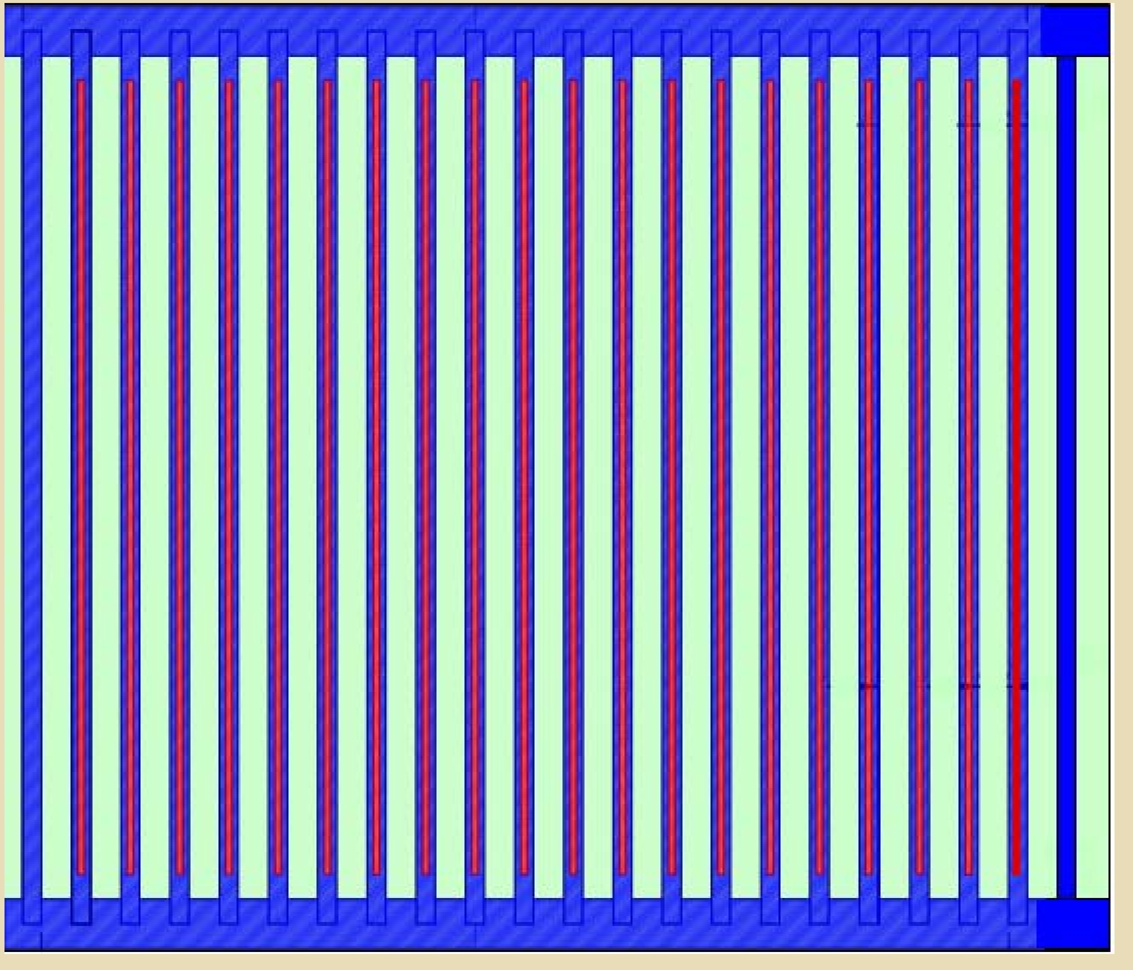
Core with Reflector Tank



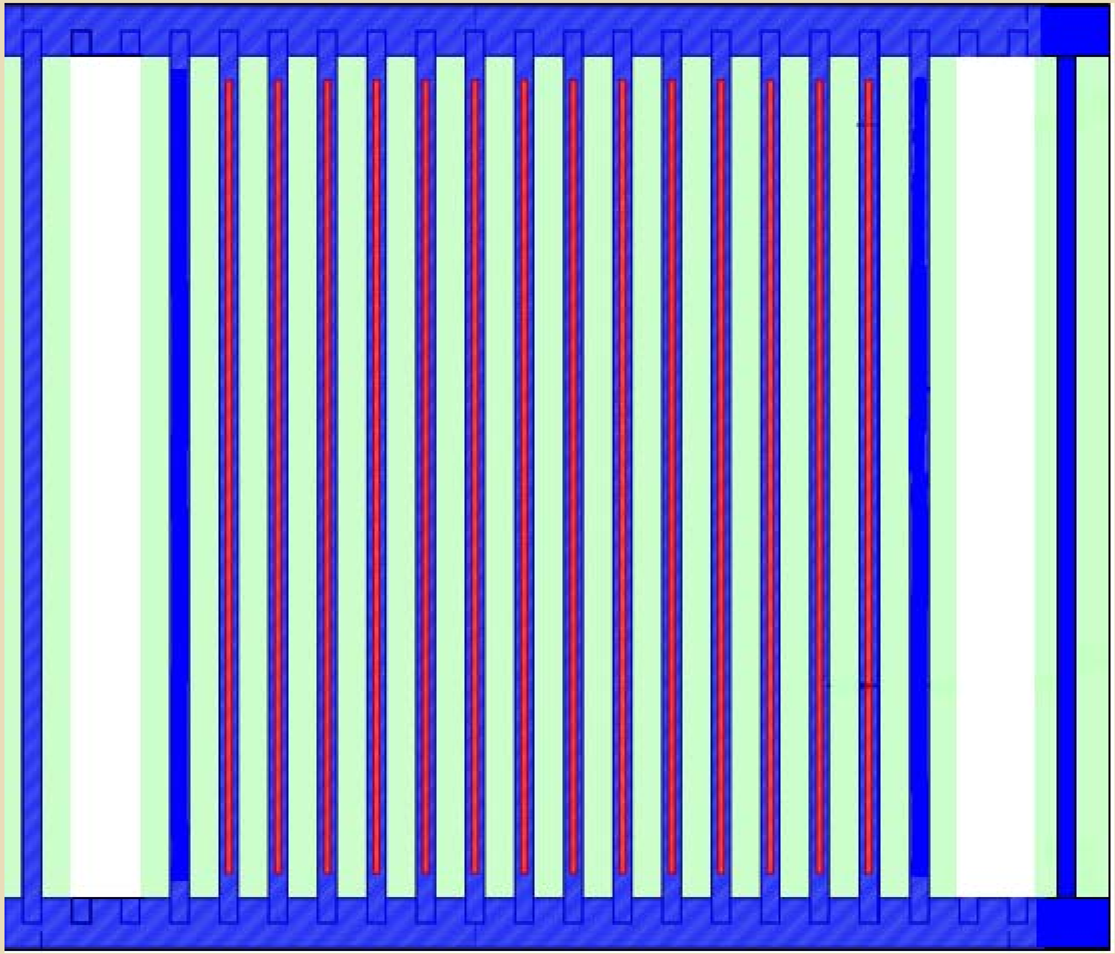
STANDARD & CONTROL FUEL ASSEMBLY DATA

Parameters	Standard Fuel Assembly	Control Fuel Assembly
Fuel material	**U_3Si_2 - Al**	**U_3Si_2 - Al**
Enrichment (U-235)	**19.75%**	**19.75%**
Number of fuel assemblies	**19**	**4**
Number of fuel bearing plates per fuel assembly	**20**	**14**
Active height (mm)	**600**	**600**
Fuel plate thickness (mm)	**1.4**	**1.4**
Meat thickness (mm)	**0.6**	**0.6**
Meat width (mm)	**68.9**	**68.9**
Clad thickness (mm)	**0.4**	**0.4**
Water gap between plates (mm)	**2.3**	**2.3**
Hf blade Thickness (mm)		**6**

Standard Fuel Assembly



Control Fuel Assembly



Fuel Properties

U_3Si_2 dispersion fuel in Al matrix

- Quite high uranium density in fuel meat
- Good compatibility with aluminum
- High thermal conductivity
- Excellent blister resistance threshold (~ 515 ^oC)
- Stable swelling behaviours under irradiation
- High fission products retaining capacity
- Low release of volatile fission products and
- Better fabricability

Reactivity Devices

- 4 Control cum Shutoff rods
- 2 Safety rods
- 2 Adjuster Rods
- Partial dumping of heavy water reflector

Physics Design Calculations

The reactor physics calculations performed in two steps

- **Generation of a few group homogenized nuclear cell data using multigroup transport theory (Lattice level) & multi group cross section libaray**

- **Global reactor calculations using few group diffusion theory (Core Level or Global calculations)**

(i) Lattice calculation by WIMS.

(ii) 3-D diffusion theory code FINSQR based on finite difference and nodal methods used to determine the core parameters which include:

- **Core excess reactivity, Shut down margin, worth of control rods, reactivity coefficients**
- **Neutron flux distribution in and around the core region**
- **Power distribution, peaking factors at various core control rods position**

Benchmark Problem

- A benchmark problem [IAEA-TECDOC-233, 1980] on pool type research reactor for LEU core was analyzed
- 10 MW , 6x5 elements core (lattice pitch = 81 x 77 mm) reflected by a graphite row on two opposite sides, and surrounded by water
- The standard and control fuel elements contain 23 and 17 fuel plates
- The three group homogenized cross sections of multiplying assemblies were obtained from WIMSD computer codes using 69 neutron energy group cross section libraries ENDFB6, IAEA, and JENDL3
- The core excess reactivities for fresh core, at BOC and at EOC were calculated using FINSQR.

Values of k-eff from 3-D diffusion theory code

Description	ANL	JAERI	CEA	BARC ENDBF6	BARC IAEA	BARC JENDL3
Fresh fuel	1.168	1.183	1.187	1.175	1.174	1.180
BOC	1.021	1.057	1.039	1.030	1.029	1.035
EOC	1.001	1.041	1.019	1.012	1.011	1.017

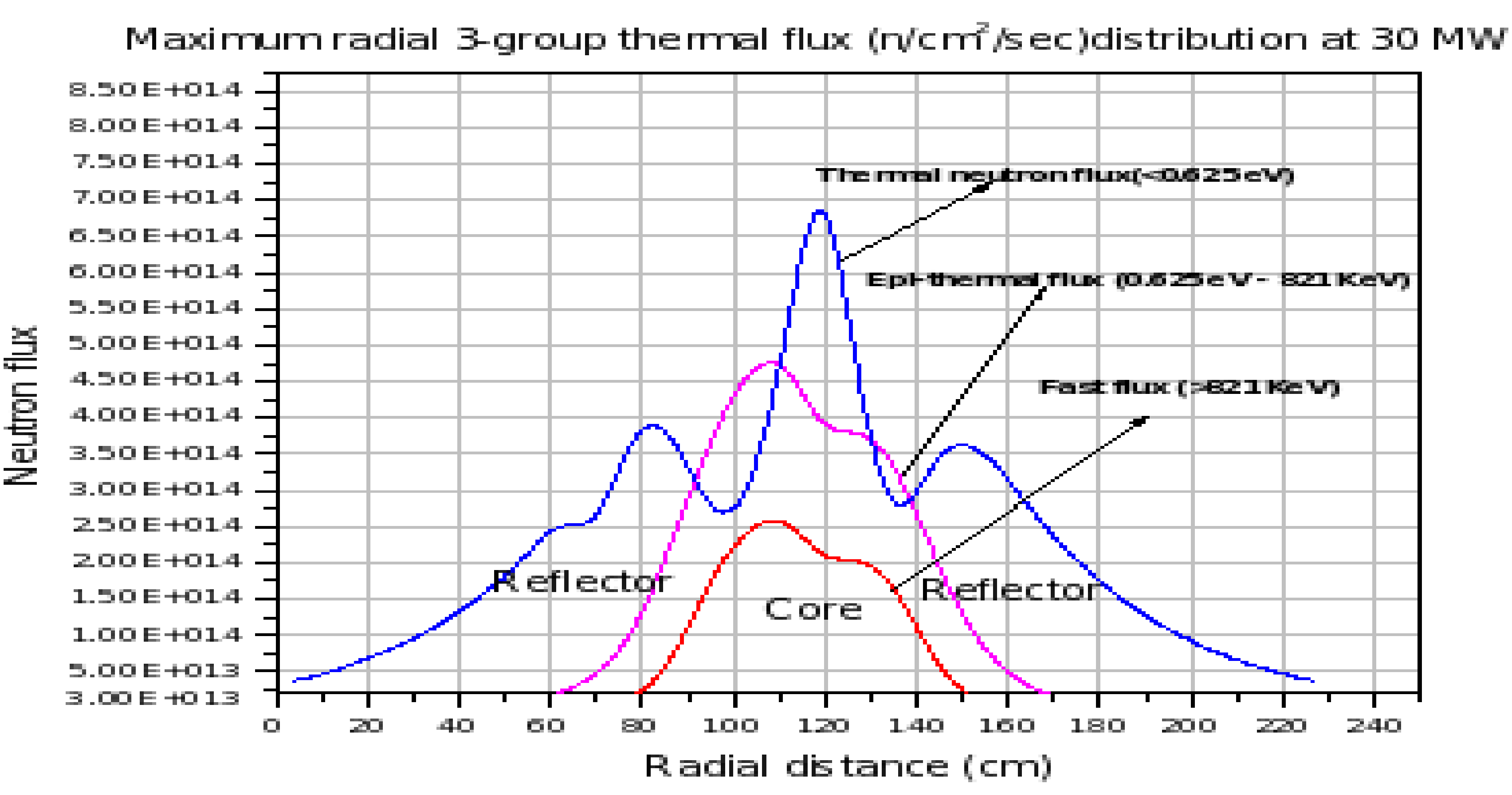
Reactivity Requirement in Equilibrium MPRR Core

PARAMETER	Reactivity load (mk)
Xenon, Sm and other FPs	40
Power & Temperature	3
Xenon over-ride	15
Experiments / Irradiations	15
Core burn up (25 days operating cycle)	37
Total	110

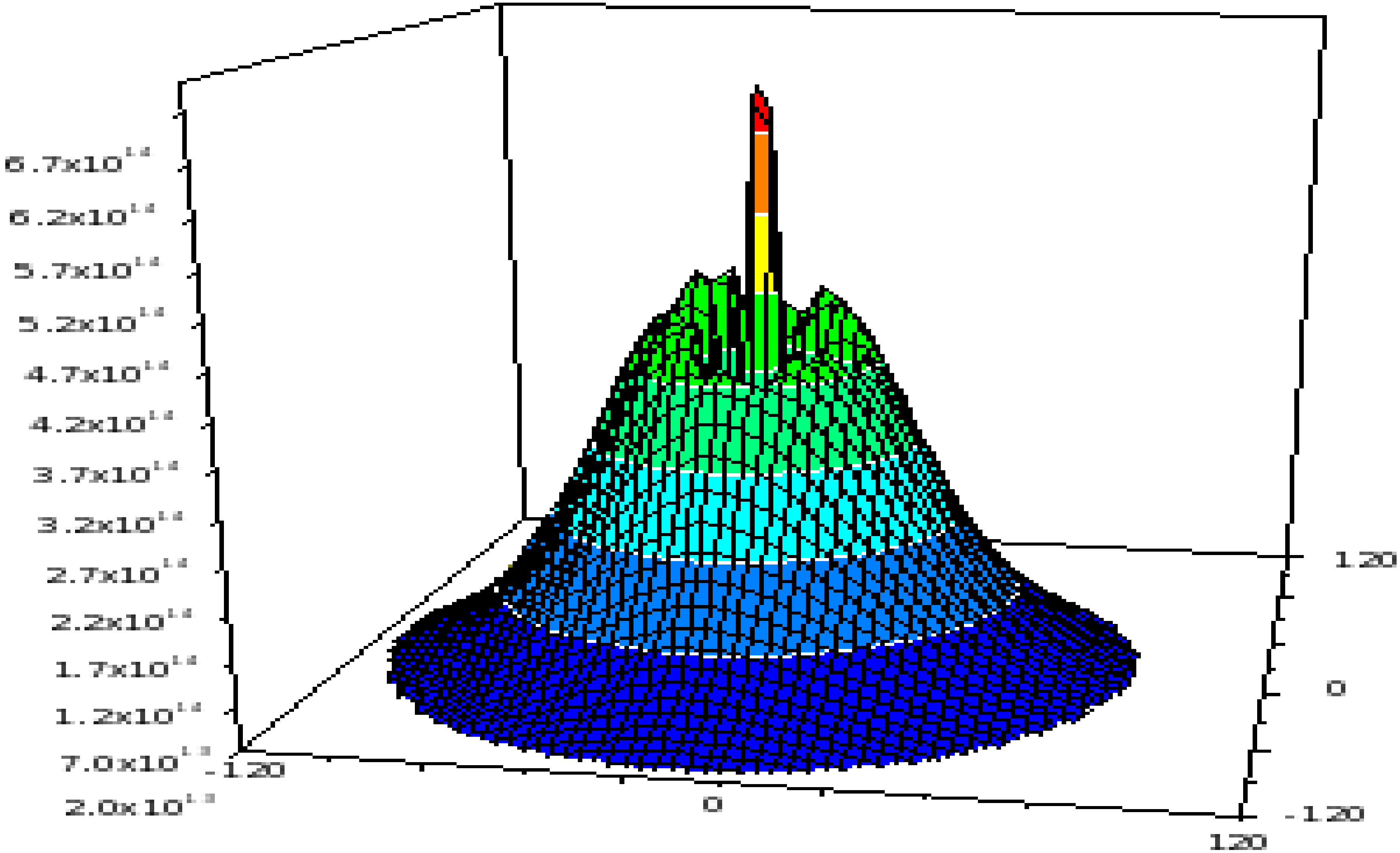
Neutron Flux

Max. Flux in In Core Water Hole **Thermal ($n/cm^2/sec$)** **Epithermal** **Fast**	**FINSQR** **6.7 E+14** **3.0 E+14** **1.8 E+14**
Max. Flux in Peripheral Water Hole **Thermal** **Epithermal** **Fast**	**4.2E+14** **2.5E+14** **8.5E+13**
Max. Flux in Reflector ($n/cm^2/sec$) **Thermal** **Epithermal** **Fast**	**3.2E+14** **7.0E+13** **6.3E+12**

Three Group Neutron Flux Profile



Thermal Flux Mapping in the Core and Heavy Water Reflector



Power Distribution

Max Assembly Power

- **SFA 1566 KW (CRs Fully Out)**

  1536 KW (CRs 50% In)

  Local peaking Factor = 1.18

  Axial Peaking Factor = 1.53 (CRs 50% In)

- **CFA 1053 KW (CRs Fully Out)**

  942KW (CRs 50% In)

  Local peaking Factor = 1.22

  Axial Peaking Factor = 1.68 (CRs 50% In)

Core Neutronics Characteristics
(Equilibrium Core)

Core excess reactivity at BOC	110 mk
Core average burn up	BOC 20 % of U^{235} EOC 37 % of U^{235}
Operating cycle length	25 days
Reactivity coefficients	Fuel temp. coeff. = -0.012 mk/ ^{o}C Coolant temp. coeff. = -0.04 mk/ ^{o}C Coolant void coeff. = -0.7 mk/ % void Burn up coeff. = -0.056 mk /MWD
Reactivity worth of control system	188 mk
Shutdown margin	50 mk

Concluding Remark

The MPRR with its high neutron flux and large irradiation volume will provide a versatile facility to meet the future requirements for basic and applied research , material irradiation and production of radioisotopes for application in the fields of medicine, agriculture & industry.

Thank You

- **6.1 kg of U235 mass in equilibrium core (36 kg U)**
- **Annual requirement of LEU ~115 kg**
- **Core reflected by heavy water**
- **Core mounted on an aluminium gridv**