

INNOVATION PROJECT FOR TRIGA2000 RESEARCH REACTOR BANDUNG

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BATAN



OUTLINE PRESENTATION

- **INTRODUCTION**
- **METHODOLOGY**
- **DESCRIPTION OF TRIGA2000 CORE**
- **NEUTRONIC CALCULATION FOR TRIGA2000 CORE**
- **RESULTS and DISCUSSION**
- **CONCLUSION**

INTRODUCTION

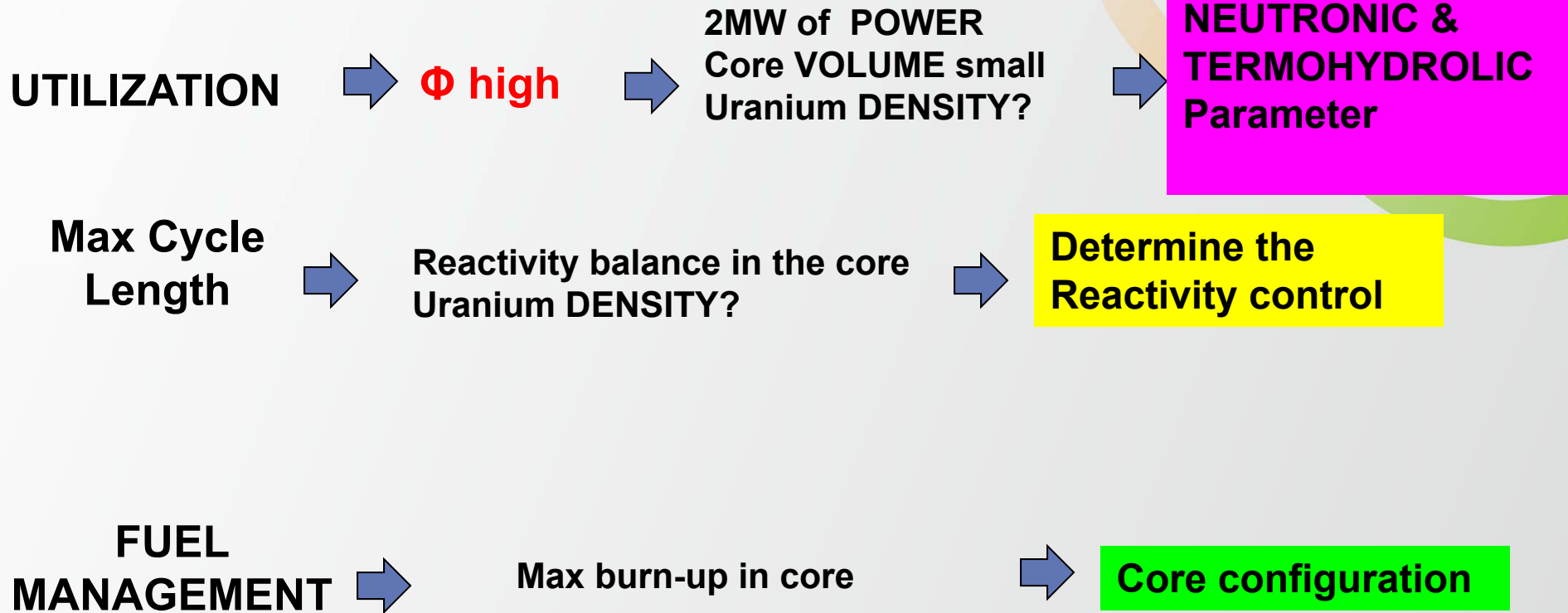
- o TRIGA2000 reactor is 2 MW in Bandung
- o First the TRIGA MARK II is operated with 250 KW since 1965. up-grade to 1 MW in 1975 . Up-grade to 2 MW in 2000.
- The Fuel (rod type) is not produced anymore by *General Atomic (GA)*
- o We plan to exchange the fuel to plate type using U_3Si_2-Al , enrichment of $U = 19.75\%$.
- o The TRIGA MARK II Reactor is used as Radioisotope production.
- o to have an experience about core design in research reactor

Introduction ...cont..

- ❖ **FUEL is plate type (MTR Type)**
- ❖ **The material of fuel is U_3Si_2-Al (250, 300 and 450 g = density of 2.96; 3.55 and 4.8 gU/cc). Control rods material is AgInCd (80%,15%,5%)**
- ❖ **Reflector is graphite**
- ❖ **Neutronic parameter calculation using WIMSD/5B (ENDF-VII) and Batan-FUEL SRAC2006, MCNP5, MTRDYN, NODAL**

METHODOLOGY

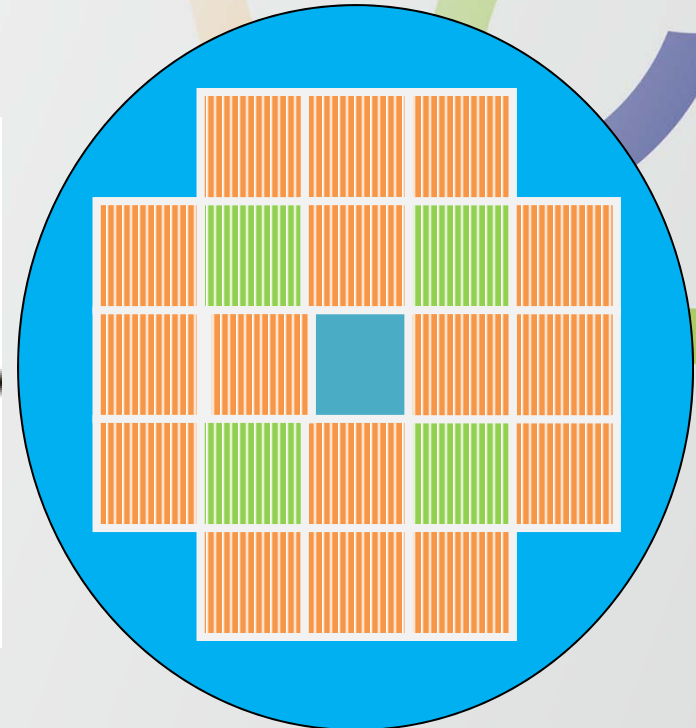
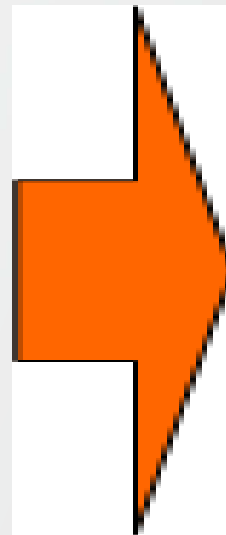
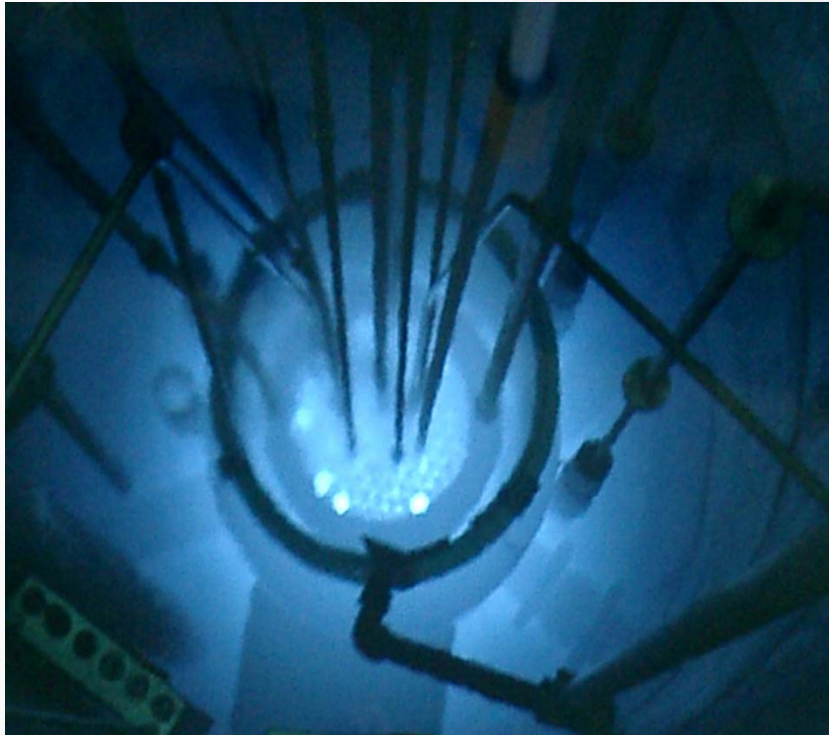
$$\Phi = P / (v\Sigma_f \times \text{core volume})$$



Validation code (Batan-FUEL)

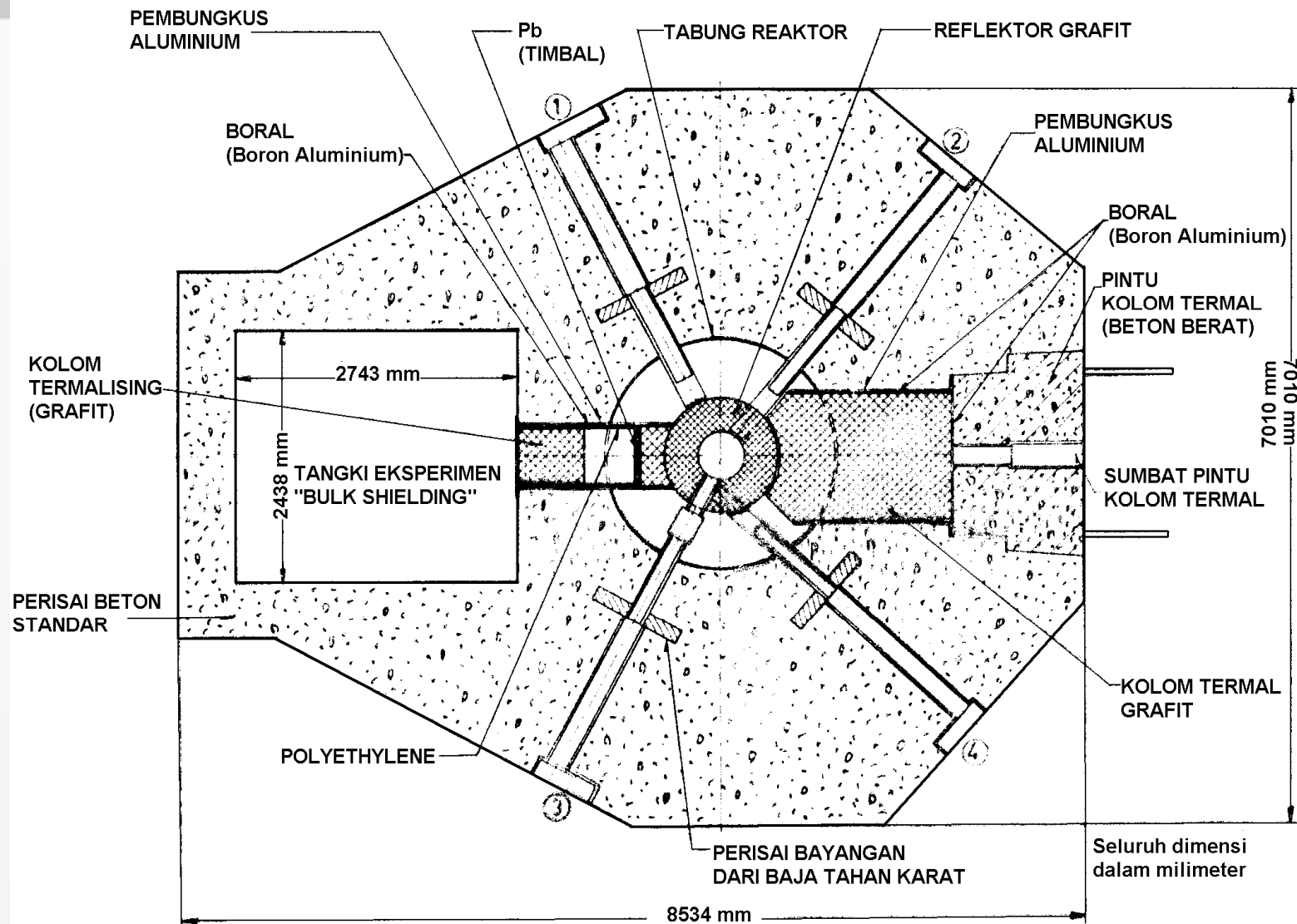
Core Configuration	Experiment Data	Batan-FUEL
9 standard fuel elements (FE) and 6 control fuel element (CE), (First Criticality), k_{eff}	1.0	1.00207 (0.21% $\Delta k/k$)
12 and 6 CEs (Full core and control rods are fully up)	8.46%	9.68% (1.22% $\Delta k/k$)
Control rods worth (%)	-17.80% $\Delta k/k$	-17.50% $\Delta k/k$ (1.69%) ²

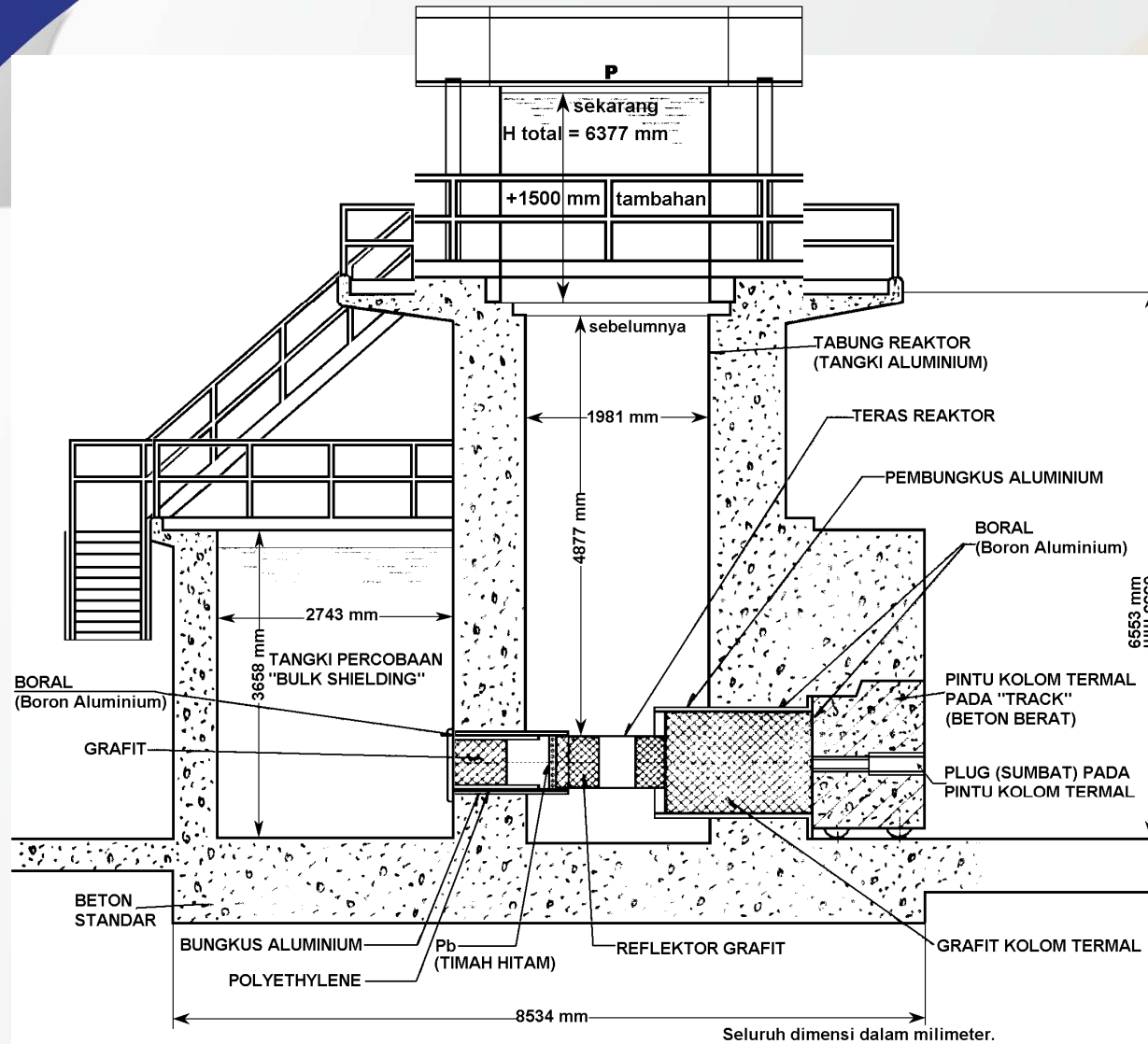
Description of TRIGA2000 core



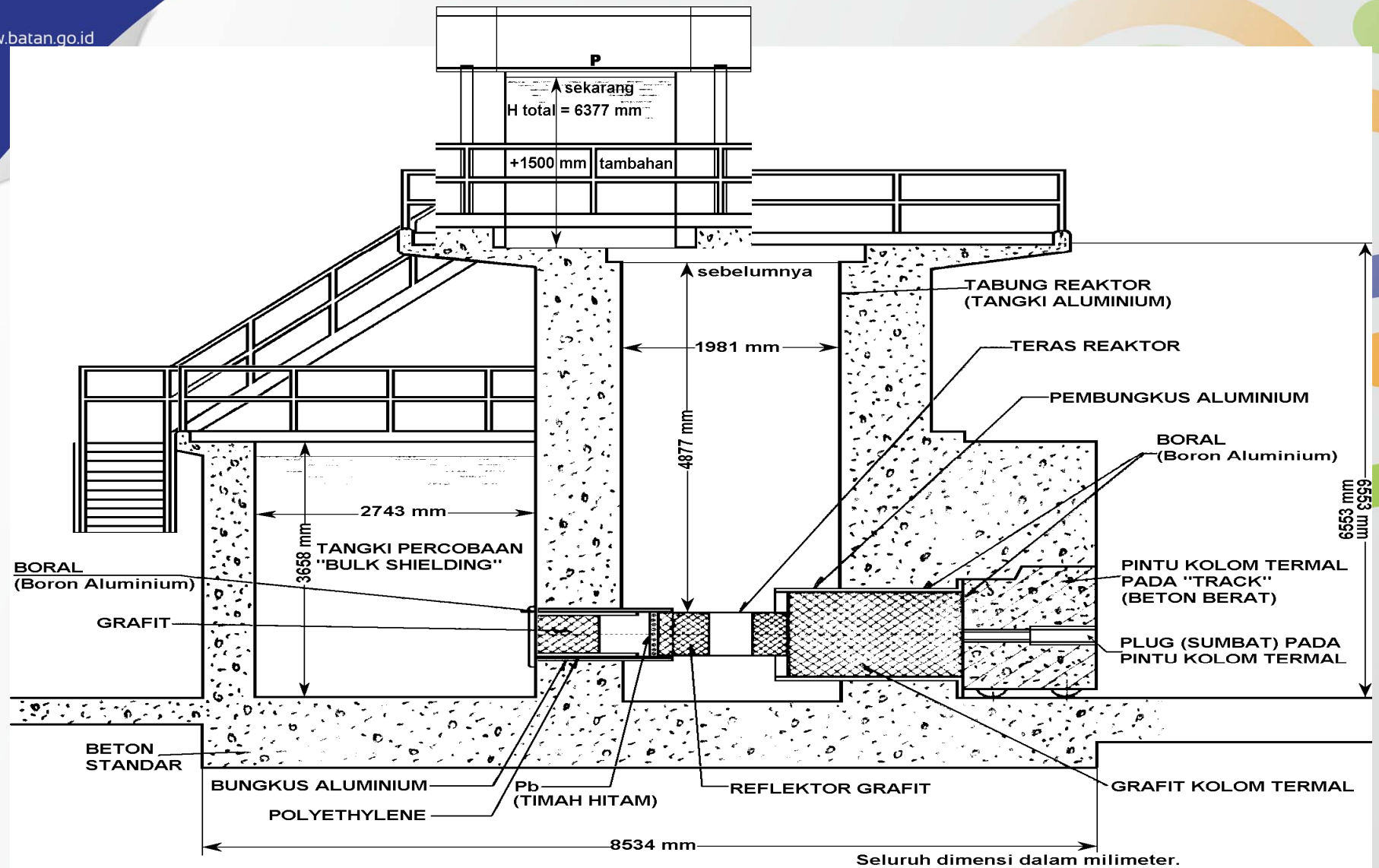
Core diameter 0.61 m and the fuel size is 8.10 x 7.71 cm

Horizontal View of Triga2000



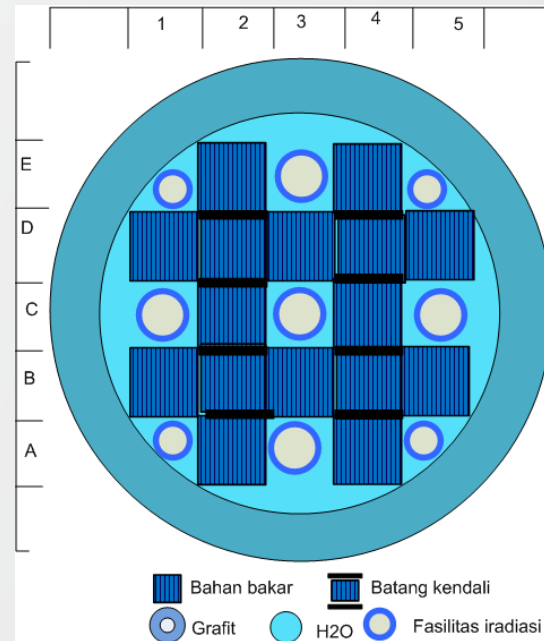
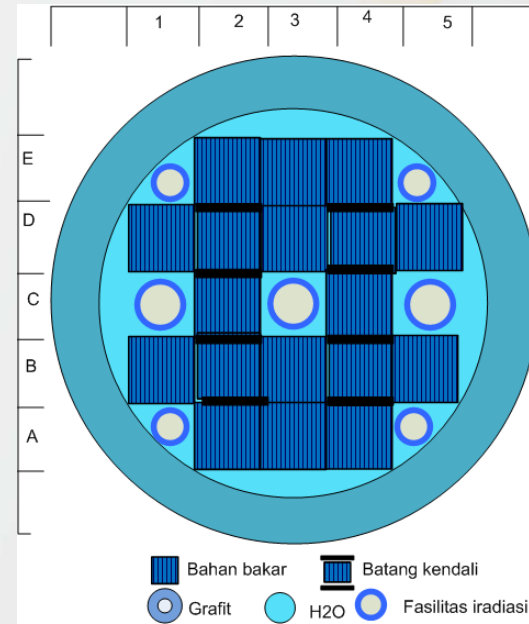
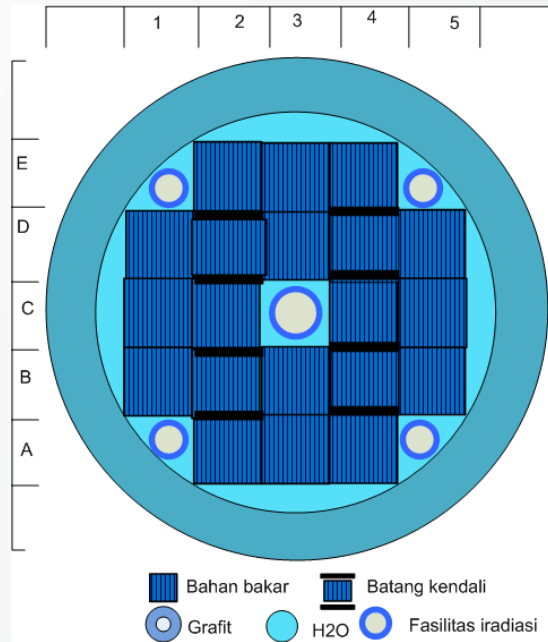


Tampang irisan bujur tegak (vertikal) reaktor riset Triga Mark-II (TRIGA-2000) **setelah** ketinggian kolom airnya ditambah 150 cm

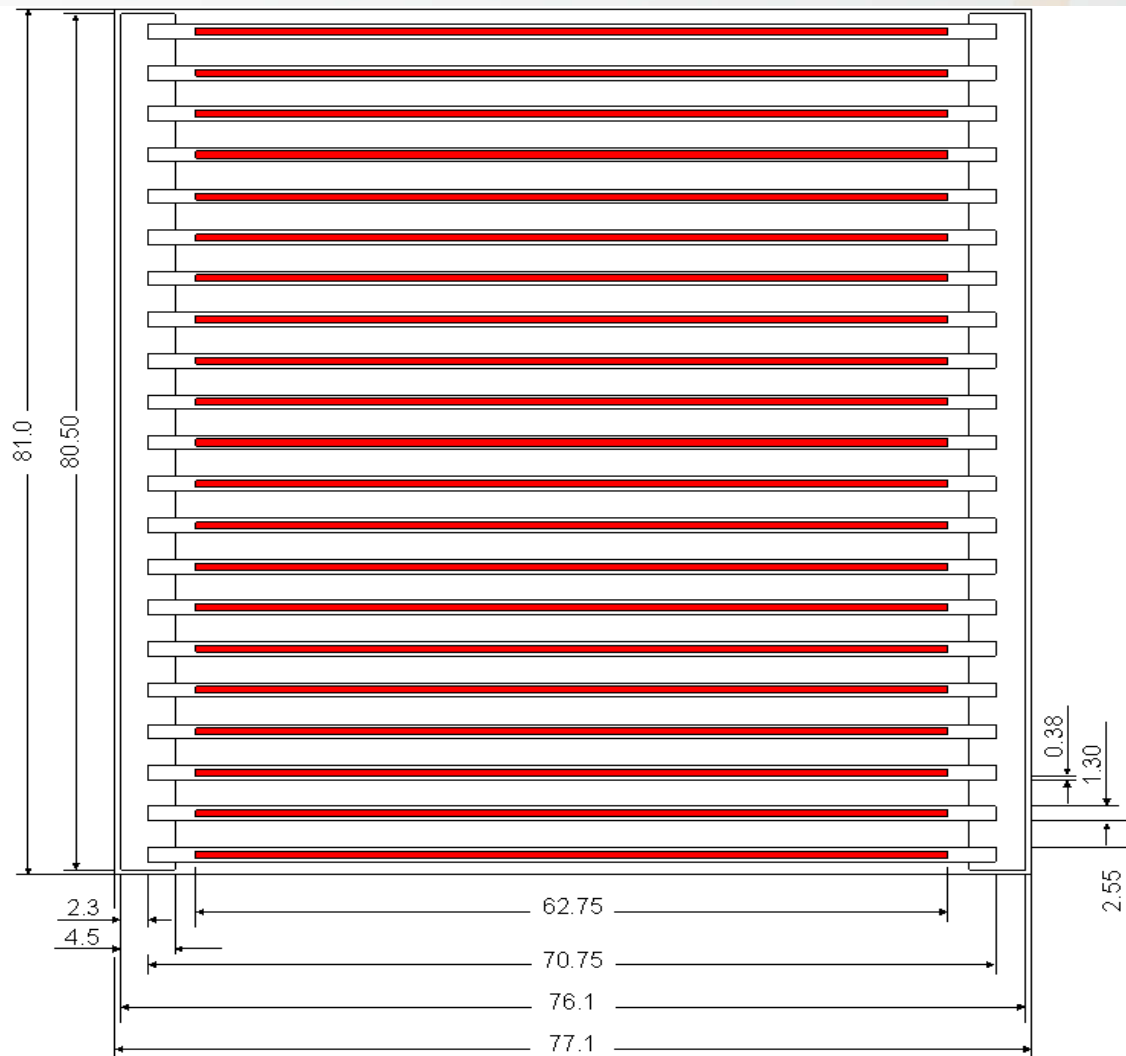


Vertical view of TRIGA-2000 Bandung

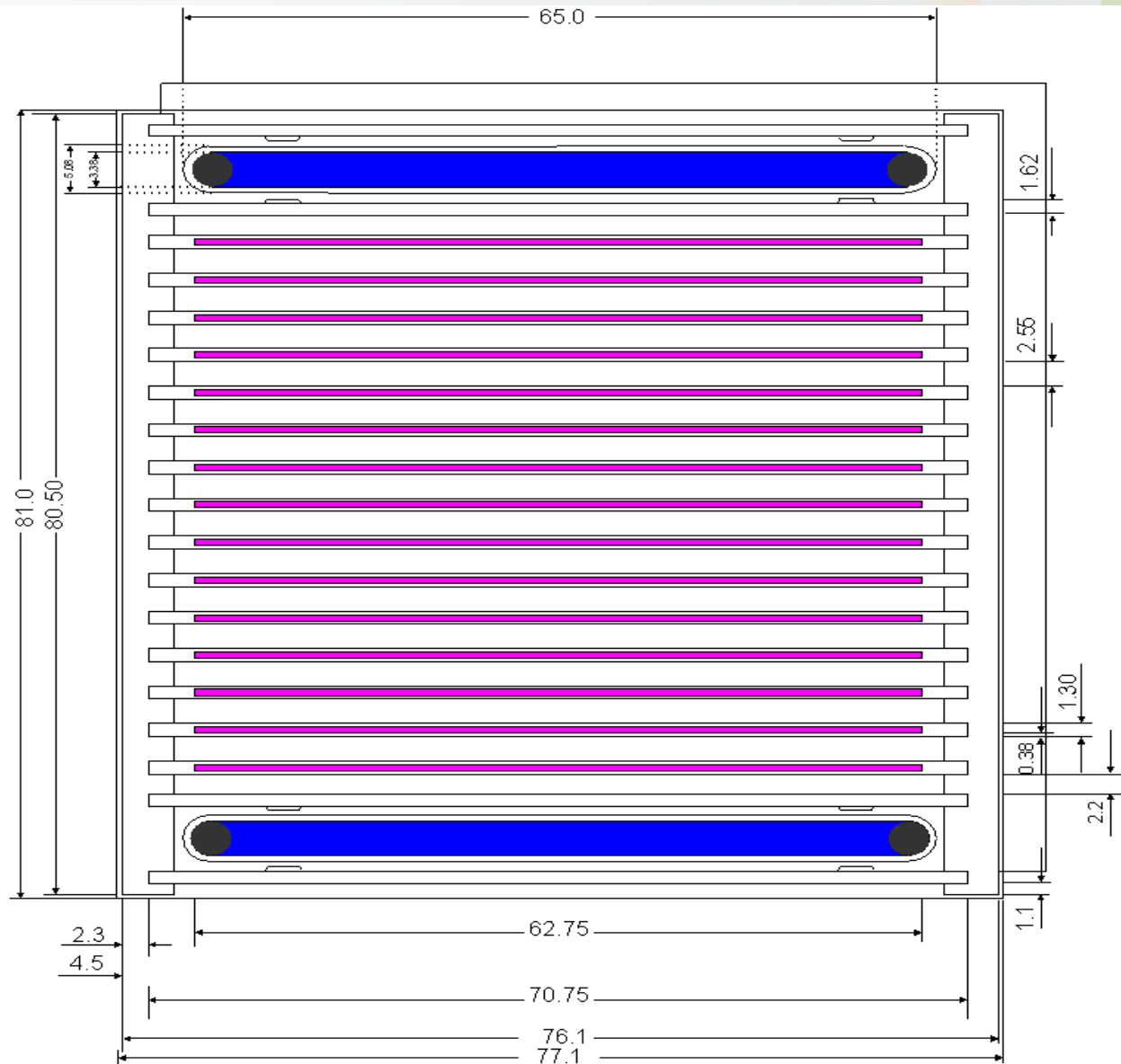
CORE CONFIGURATIONs OF TRIGA2000



The Fuel of TRIGA2000



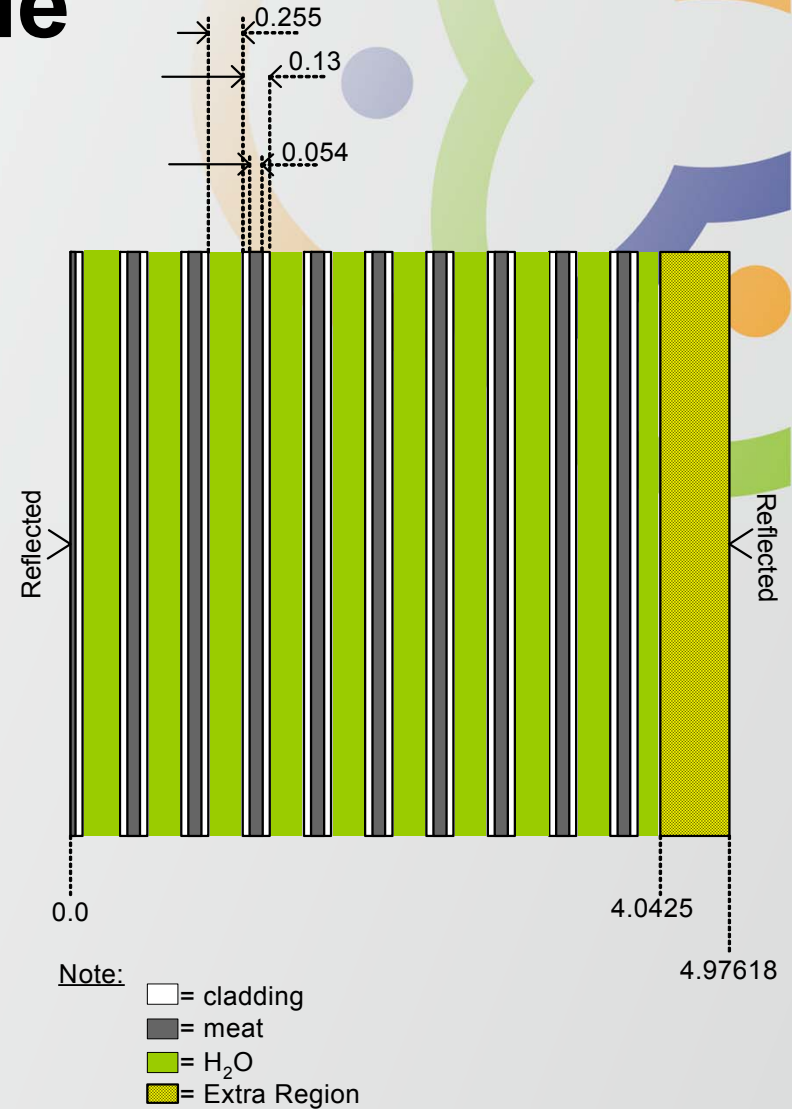
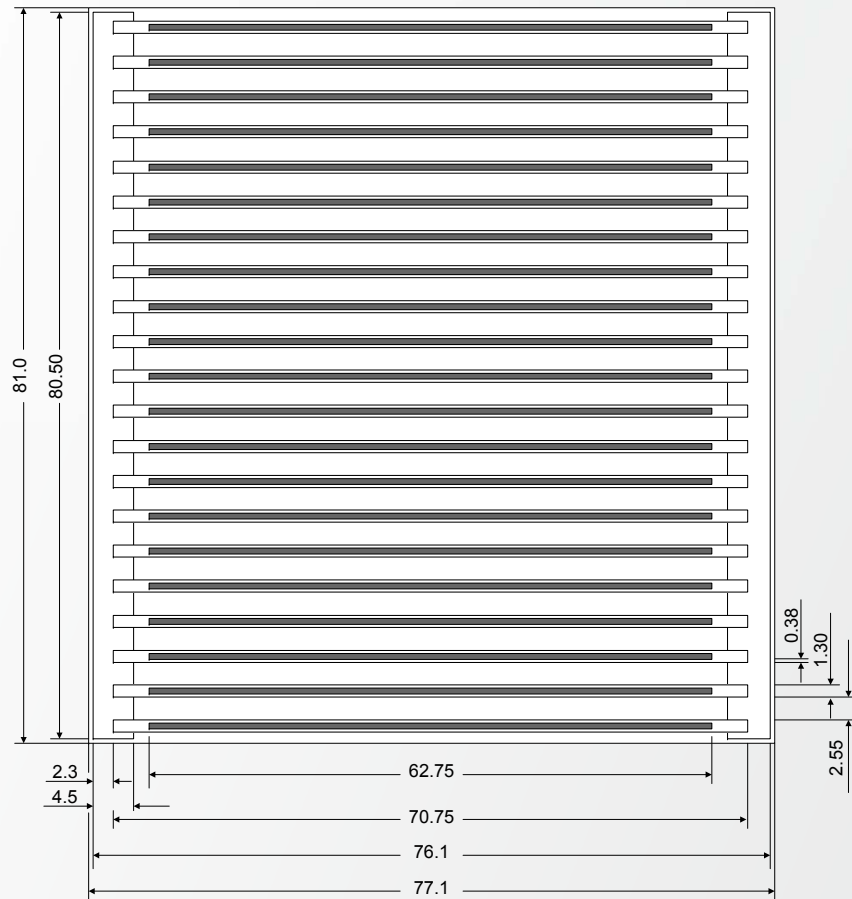
Control Rod Assembly

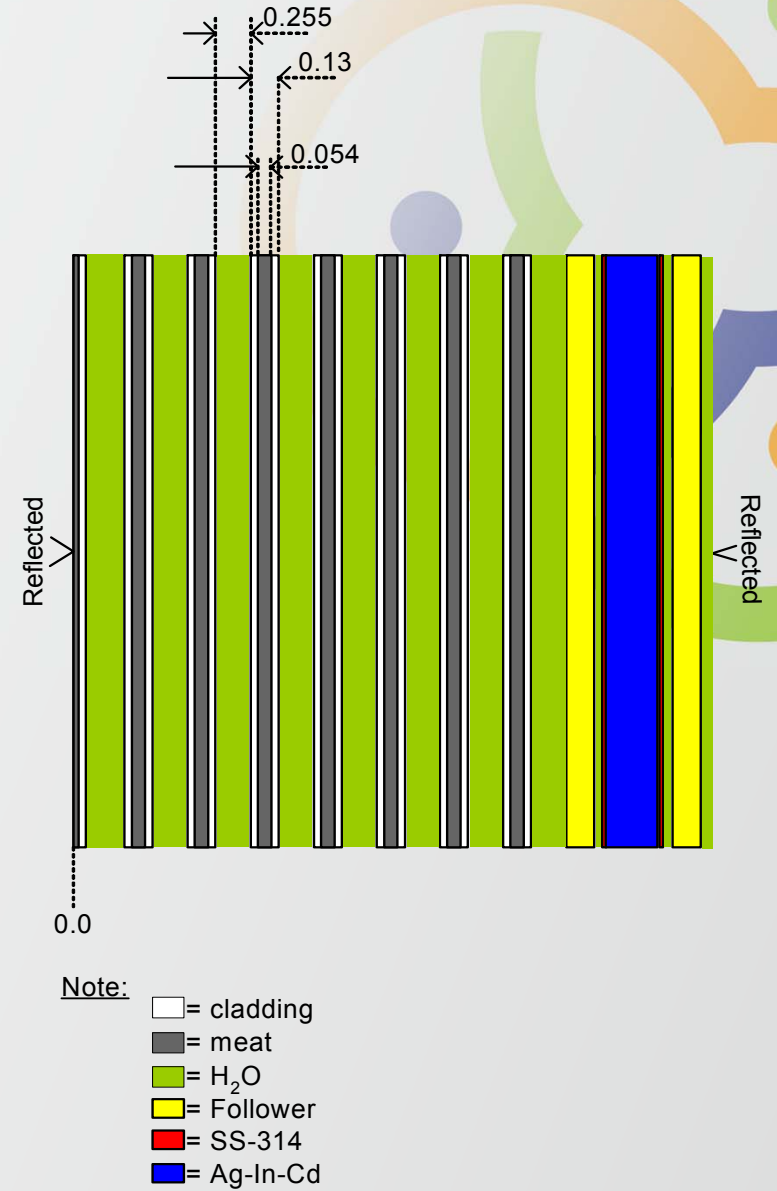
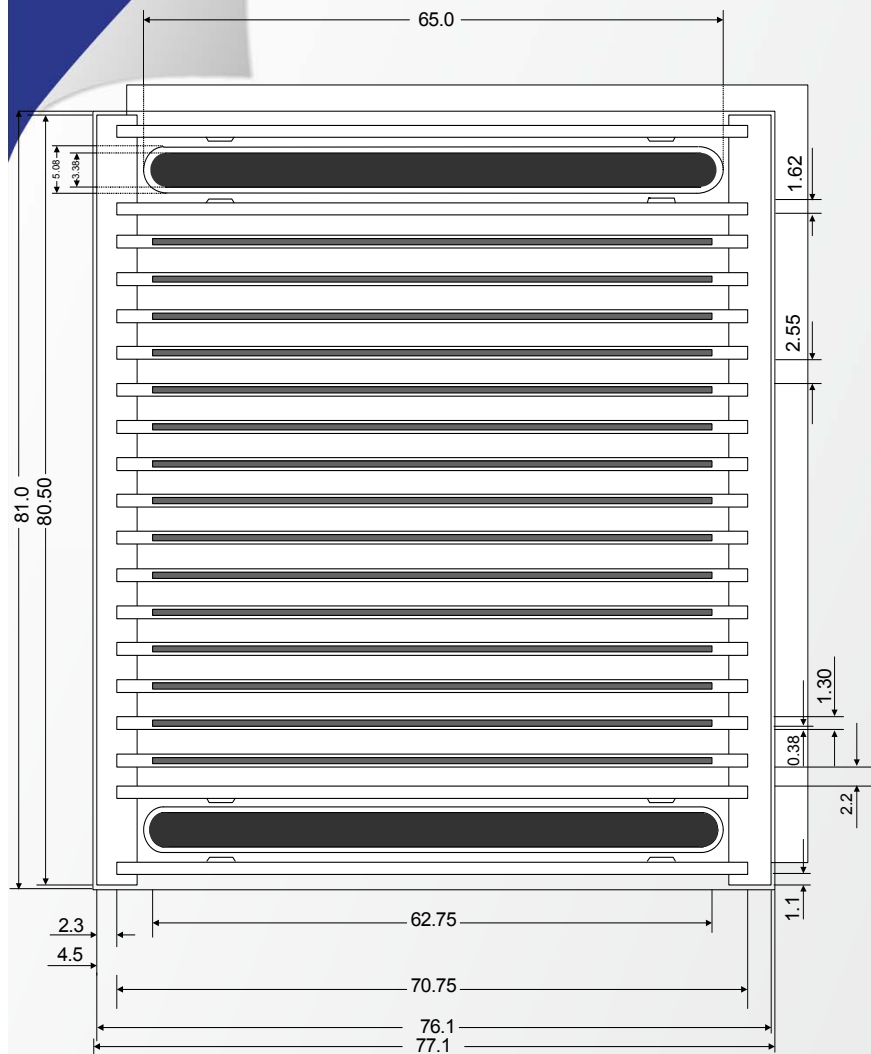


NEUTRONIC CALCULATION FOR TRIGA2000 CORE

- 1. Macroscopic Cross-section generation (cell calculation) by WIMSD-5B code (ENDF.VII)**
- 2. Core Calculation by BATAN-FUEL code (Diffusion method)**

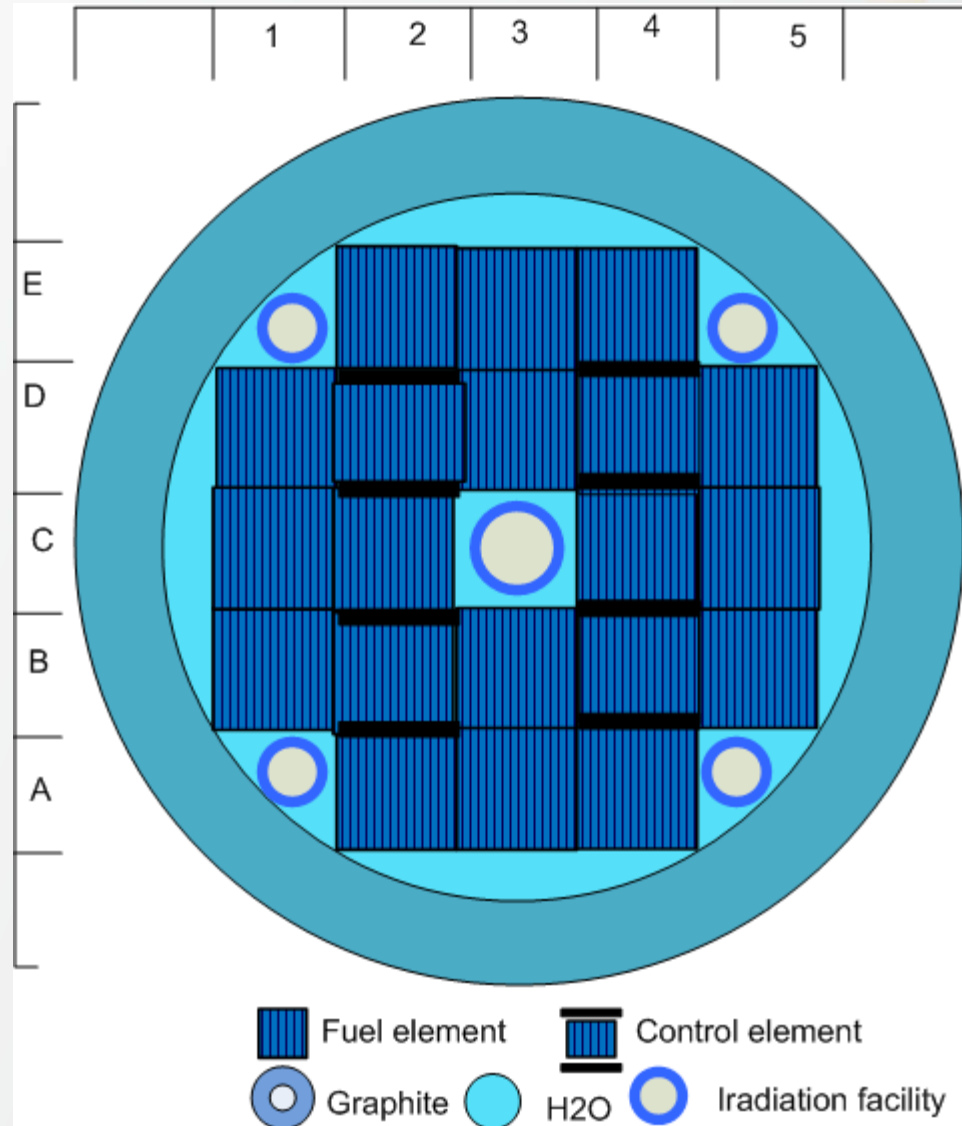
Cross section generation by WIMSD-5B code





Control rod Assembly (Ag-In-Cd)

The first alternative TRIGA2000 core



Result and Discussion

. Macroscopic cross-section for non-fission materials (AGInCd)

Energy group	D_g	Σ_a	$\nu\Sigma_f$	$\Sigma_{g \text{ to } g'=1}$	$\Sigma_{g \text{ to } g'=2}$	$\Sigma_{g \text{ to } g'=3}$
1	2.26850E+00	1.41360E-03	0.00000E+00	5.92130E-02	0.00000E+00	0.00000E+00
2	1.00139E+00	7.36140E-03	0.00000E+00	5.11510E-02	0.00000E+00	0.00000E+00
3	4.93491E-01	1.53510E-01	0.00000E+00	3.43100E-02	0.00000E+00	0.00000E+00
4	2.41319E-01	4.87770E-01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

Macroscopic cross-section for non-fission material (Be)

Energy group	D_g	Σ_a	$\nu\Sigma_f$	$\Sigma_{g \text{ to } g'=1}$	$\Sigma_{g \text{ to } g'=2}$	$\Sigma_{g \text{ to } g'=3}$
1	1.94796E+00	7.35385E-03	0.00000E+00	1.18552E-01	5.99131E-02	8.43455E-06
2	6.69540E-01	1.26937E-05	0.00000E+00	4.74633E-01	2.32091E-02	0.00000E+00
3	5.08909E-01	4.72810E-05	0.00000E+00	6.39608E-01	1.53411E-02	0.00000E+00
4	5.07702E-01	7.84785E-04	0.00000E+00	2.94699E-04	6.55474E-01	0.00000E+00

Macroscopic cross section for non-fission (graphite)

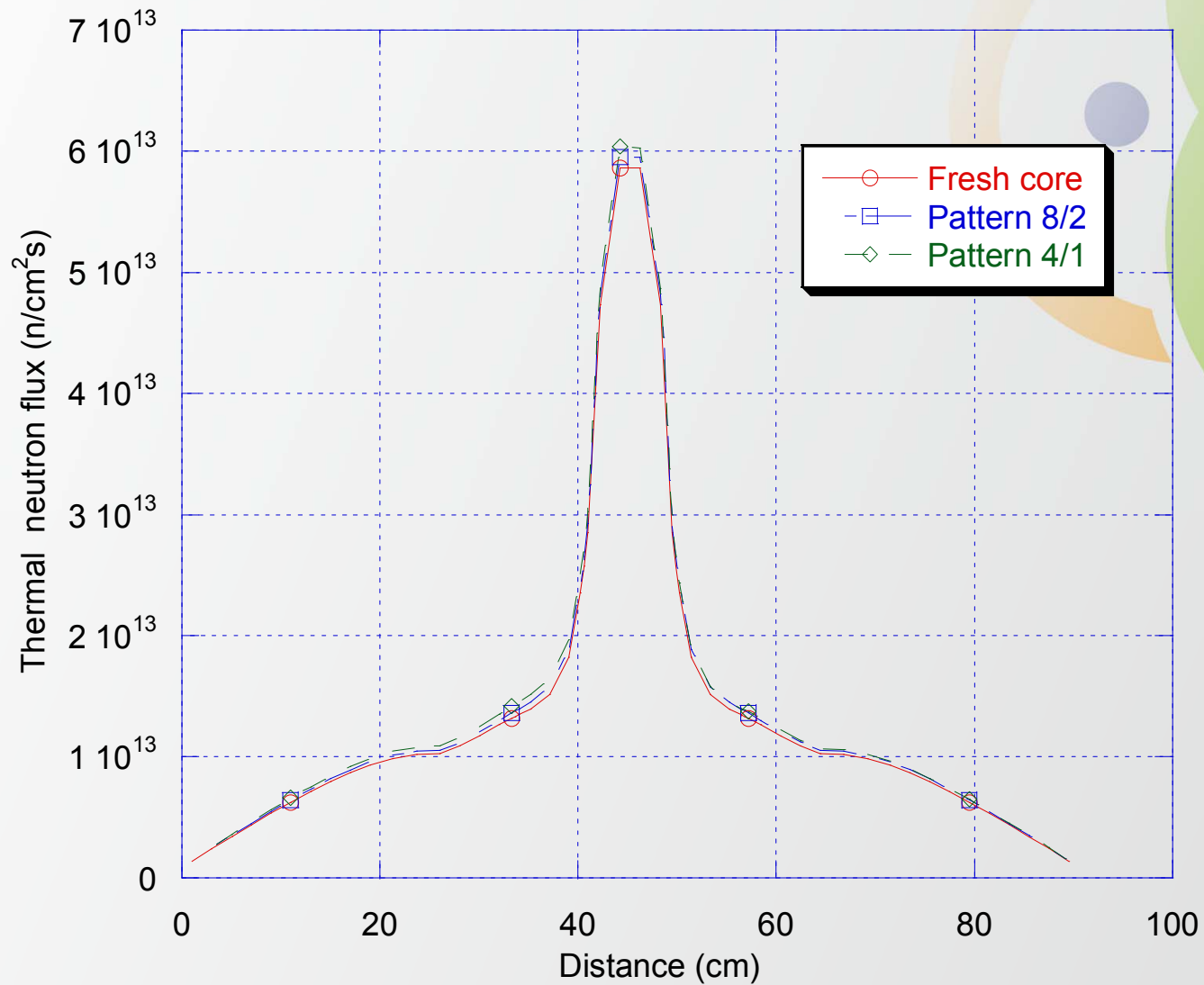
Energy group	D_g	Σ_a	$\nu\Sigma_f$	$\Sigma_{g \text{ to } g'=1}$	$\Sigma_{g \text{ to } g'=2}$	$\Sigma_{g \text{ to } g'=3}$
1	2.23968E+00	8.02347E-05	0.00000E+00	1.29425E-01	2.32091E-02	5.88262E-08
2	1.04930E+00	1.09865E-07	0.00000E+00	3.09617E-01	8.05511E-03	0.00000E+00
3	8.96887E-01	1.16702E-05	0.00000E+00	3.65858E-01	5.78632E-03	0.00000E+00
4	8.55159E-01	1.87828E-04	0.00000E+00	2.63336E-04	3.89340E-01	0.00000E+00

NEUTRONICS PARAMETER

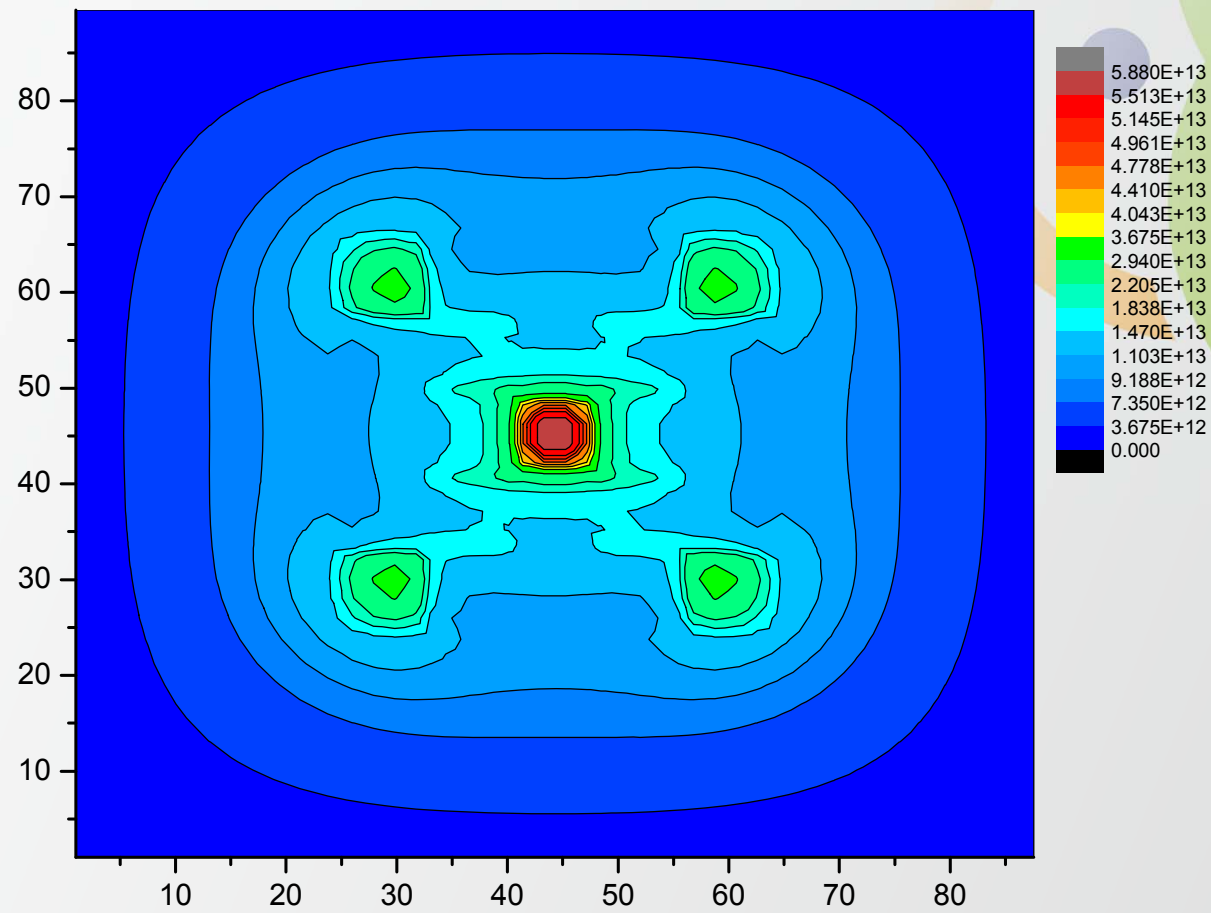
Reactivity Balance	Fresh	Equil 8/2	Equil 4/1
Uranium Density (g/cc)	2.96	2.96	2.96
Power, MW/ Cycle length, days	2/245	2/160	2/100
Reactivity in one cycle, $\% \Delta k/k$	4.542	2.860	1.762
Reactivity of Xe+Sm, $\% \Delta k/k$	6.827	2.328	2.360
<i>Cold to hot</i> , $\% \Delta k/k$	0.501	0.528	0.547
Experiment and Xe Override, $\% \Delta k/k$	1.0759	1.155	1.130
Excess Reactivity, $\% \Delta k/k$	8.404	7.202	6.321
The control rods worth , $\% \Delta k/k$	-19.573	-19.989	-20.03
Shut-down Reactivity (<i>stuck rod</i>), $\% \Delta k/k$	-4.171	-5.6360	-6.499
Power density (W/cc)	28.305	28.305	28.305
Average radial FPD	1.2971	1.268	1.2475
Max Burn-up discharged , %	16.401	18.122	22.407

NEUTRON FLUXES in the TRIGA core

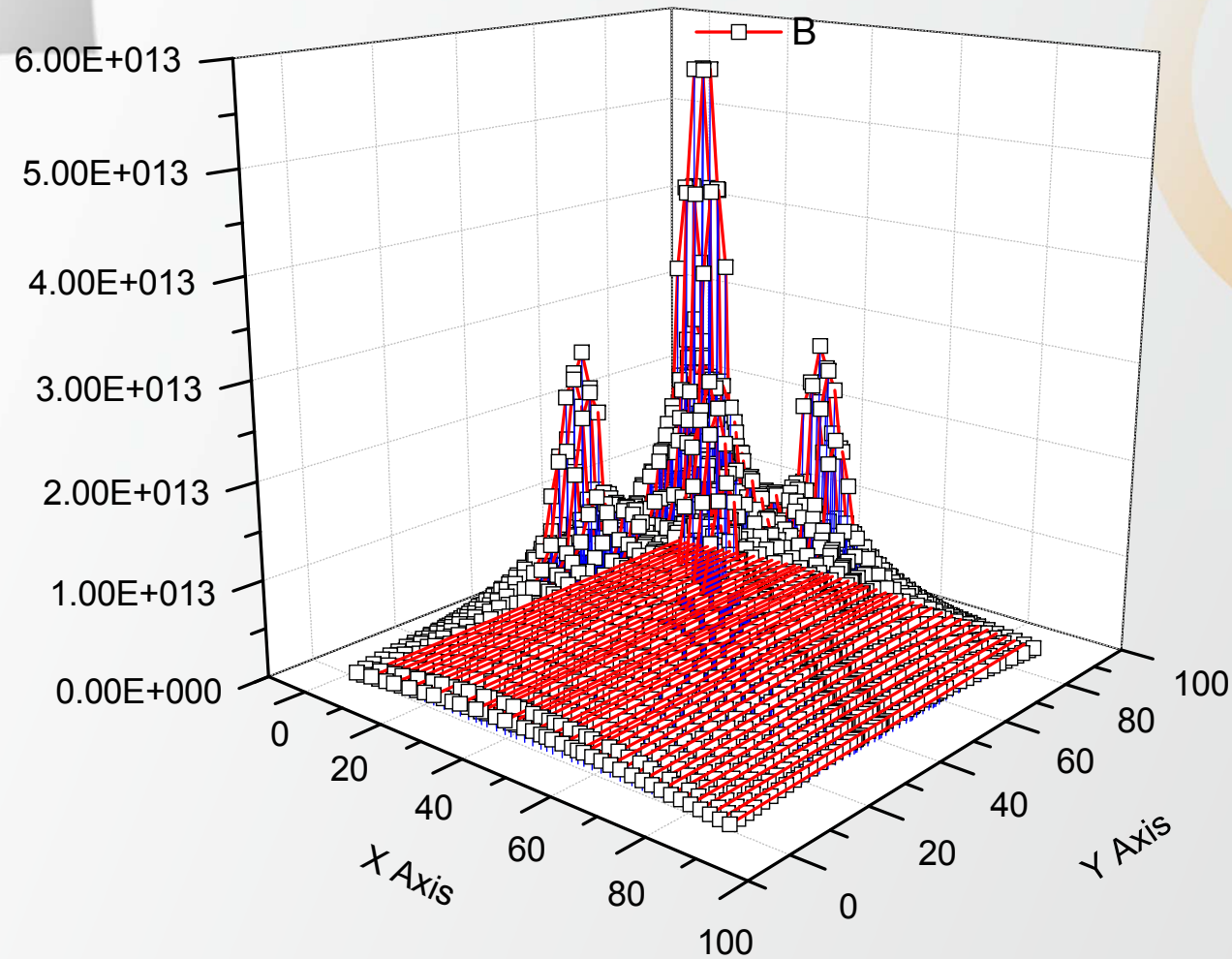
Neutron	Max neutron fluxes, 10^{13} neutron $\text{cm}^{-2} \text{s}^{-1}$		
	Fresh	Equil 4/1	Equil 8/2
In the center of the core			
Fast neutron , $> 0,821$ MeV	1.209	1.215	1.226
epithermal, $0,625 \text{ eV} < E < 0,821$ MeV	1.393	1.404	1.419
Thermal, $< 0,625 \text{ eV}$	5.866	5.949	6.040
In the irradiation position			
Fast neutron, $> 0,821$ MeV	0.499	0.513	0.533
epithermal, $0,625 \text{ eV} < E < 0,821$ MeV	0.674	0.692	0.717
Thermal, $< 0,625 \text{ eV}$	2.984	3.062	3.168
At the reflector (graphite)			
Fast neutron, $> 0,821$ MeV	0.566	0.386	0.382
Ephitermal, $0,625 \text{ eV} < E < 0,821$ MeV	0.602	0.615	0.613
Thermal, $< 0,625 \text{ eV}$	1.402	1.435	1.442



• Comparison thermal neutron fluxes in different core fuel management

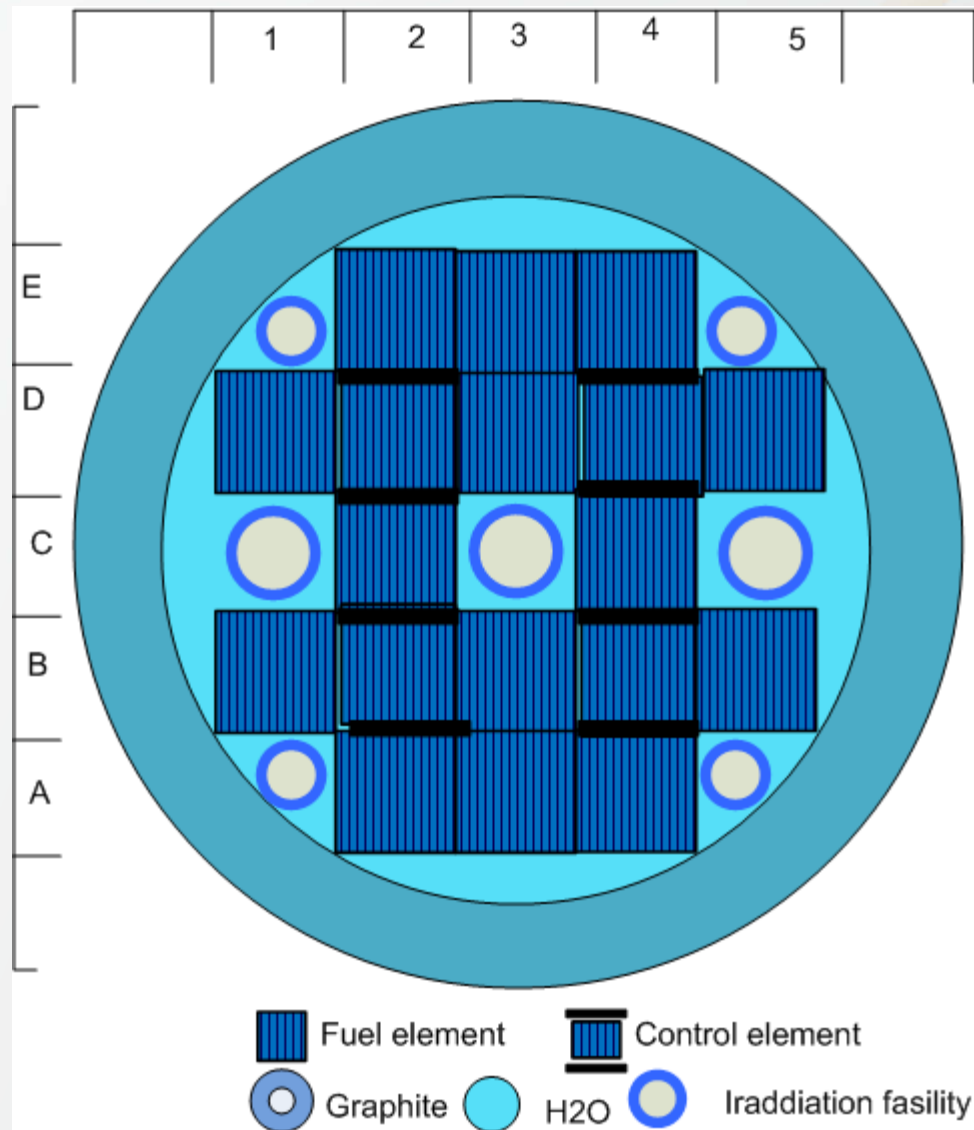


Contour of neutron fluxes in the TRIGA2000 core



Thermal neutron flux mapping

The second alternative TRIGA2000 core

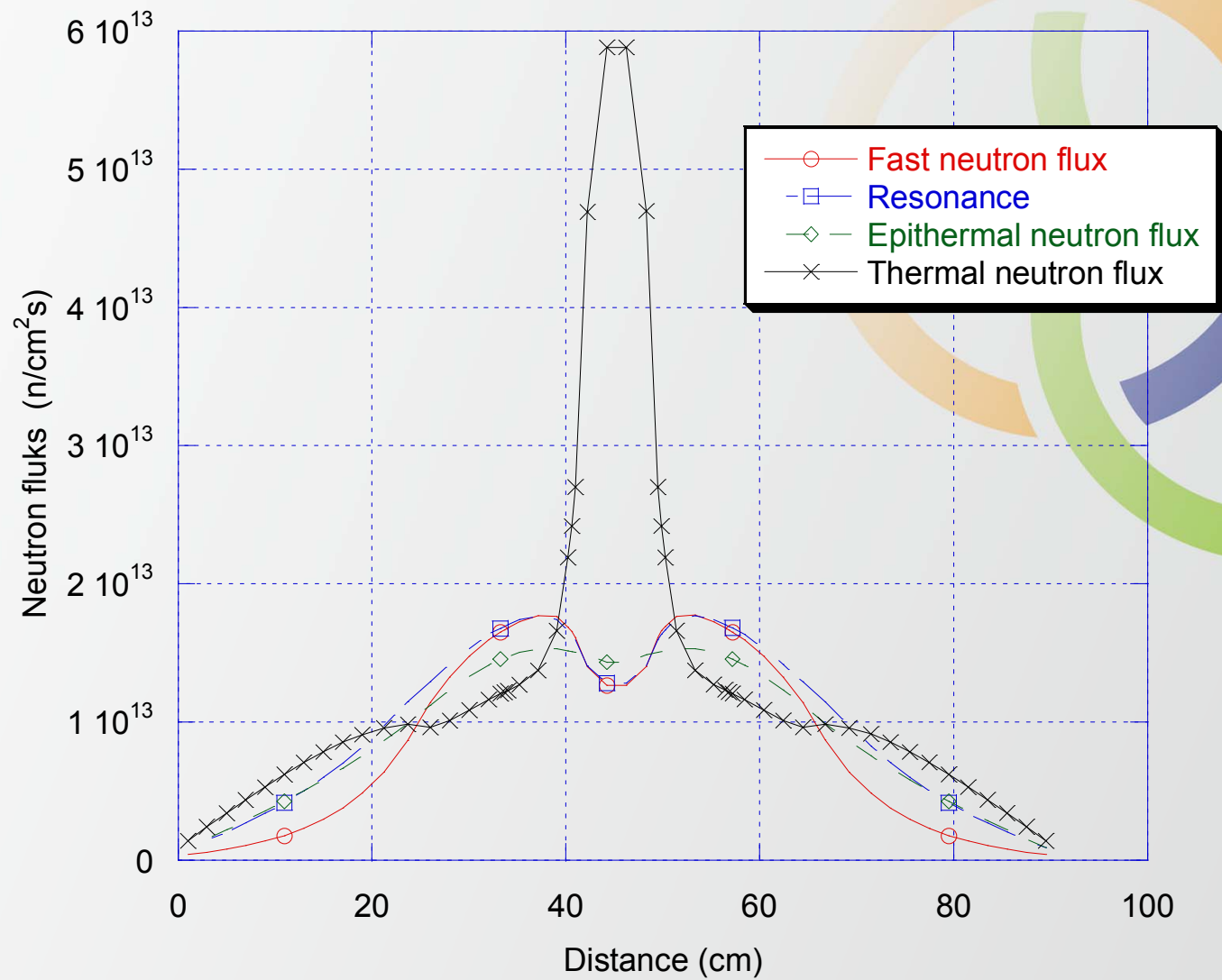


NEUTRONIC PARAMETER

Reactivity Balances	values
Fuel density , g/cc	3.55
Power, MWth / Cycle length , days	2/210
Reactivity in one cycle, $\% \Delta k/k$	3.654
Reactivity for Xe+Sm, $\% \Delta k/k$	2.165
<i>Cold to hot</i> , $\% \Delta k/k$	0.490
Experiment and Xe. <i>override</i> , $\% \Delta k/k$	1.161
Excess reactivity, $\% \Delta k/k$	7.472
Control rods reactivity worth, $\% \Delta k/k$	-19.83
Shut down reactivity (<i>stuck rod</i>), $\% \Delta k/k$	-5.212
Power density (W/cc)	31.663
Max radial FPD	1.339
Max burn-up exchanged , %	13.591

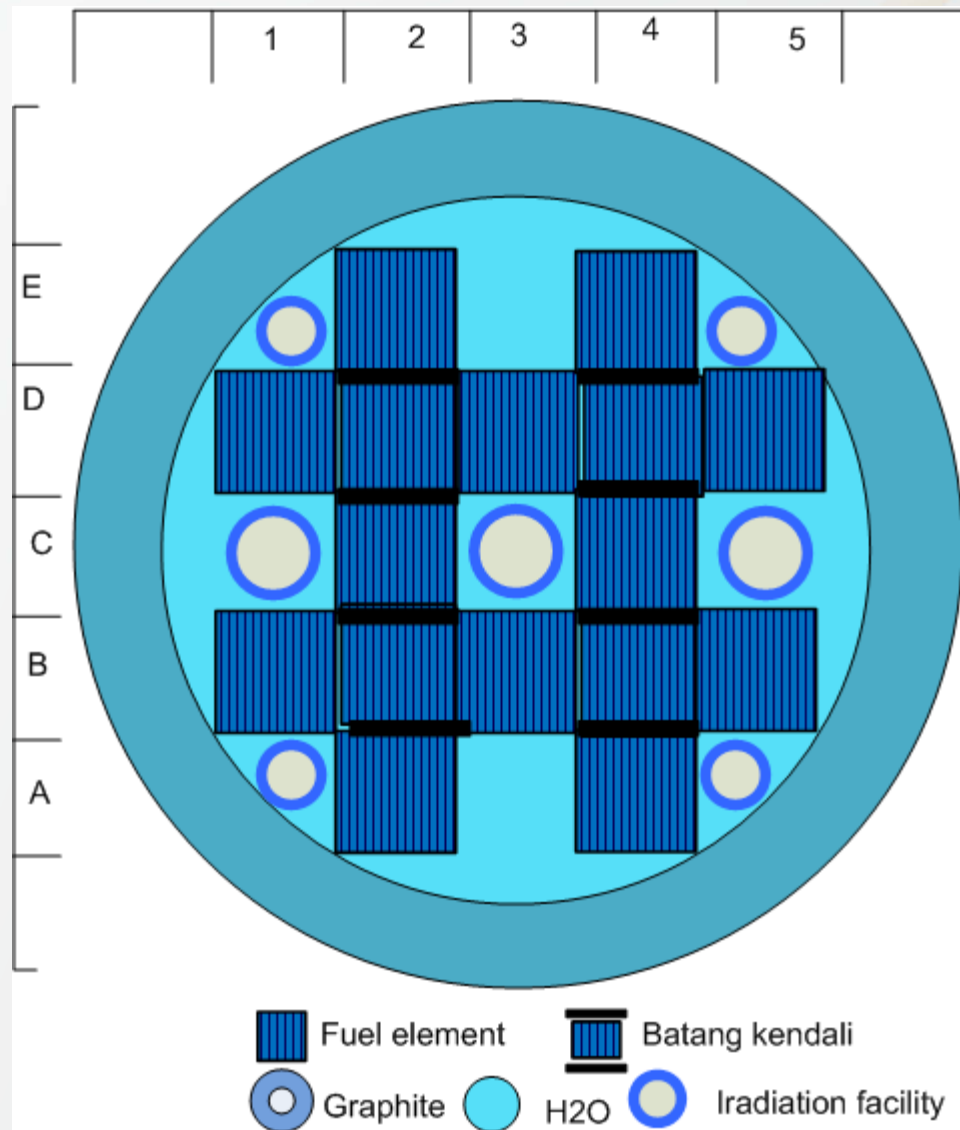
NEUTRON FLUXES in TRIGA2000 core

Neutron fluxes /Energy	Max. neutron fluxes, 10^{13} neutron $\text{cm}^{-2} \text{s}^{-1}$
In the center of the core	
Fast neutron $> 0,821 \text{ MeV}$	1.263
Epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	1.434
Thermal, $< 0,625 \text{ eV}$	5.880
In Irradiation position	
Fast neutron, $> 0,821 \text{ MeV}$	0.707
Epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	0.882
Thermal, $< 0,625 \text{ eV}$	3.820
At reflector (graphite)	
Fast neutron $> 0,821 \text{ MeV}$	0.524
epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	0.734
Thermal, $< 0,625 \text{ eV}$	1.698



Neutron fluxes distribution, grid of 5 x 5 with 14 fuels 4 control rods

The third alternative TRIGA2000 core

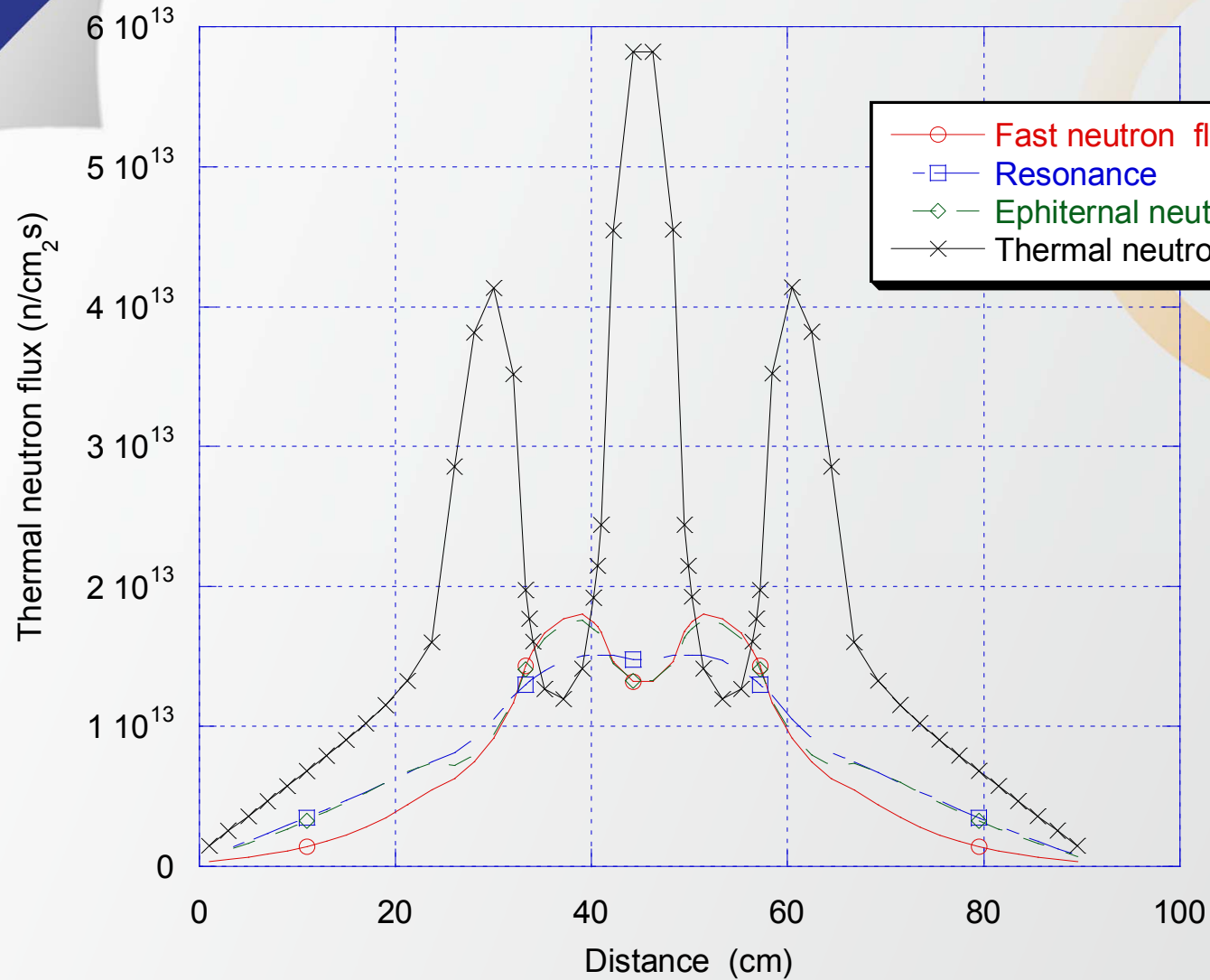


NEUTRONIC PARAMETER

Reactivity balances	Values
Fuel density , g/cc	4.8
Power, MWth / Cycle length , days	2/255
Reactivity in one cycle, $\% \Delta k/k$	4.954
Reactivity for Xe+Sm, $\% \Delta k/k$	1.9138
<i>Cold to hot</i> , $\% \Delta k/k$	0.4429
Experiment and Xe. Override, $\% \Delta k/k$	1.2561
Excess reactivity, $\% \Delta k/k$	7.3115
Control rods reactivity worth, $\% \Delta k/k$	-19.198
Shut down reactivity(<i>stuck rod</i>), $\% \Delta k/k$	-4.9050
Power density (W/cc)	37.044
Max radial FPD	1.2578
Max. Burn up discharged, %	13.629

Neutron Fluxes in TRIGA2000 core

Neutron fluxes/energy	Max neutron fluxes 10^{13} neutron $\text{cm}^{-2} \text{s}^{-1}$
In the center of core	
Fast neutron, $> 0,821 \text{ MeV}$	1.320
Epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	1.473
Thermal, $< 0,625 \text{ eV}$	5.824
In the irradiation position	
Fast neuron, $> 0,821 \text{ MeV}$	0.756
epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	0.931
Thermal, $< 0,625 \text{ eV}$	3.898
At the reflector (graphite)	
Fast neutron , $> 0,821 \text{ MeV}$	0.562
epithermal, $0,625 \text{ eV} < E < 0,821 \text{ MeV}$	0.770
Thermal, $< 0,625 \text{ eV}$	1.676



Neutron fluxes distribution in the core 5 x 5 grids
with 12 fuels and 4 control elemens

The fuel temperature reactivity coefficient of the TRIGA Bandung

Fuel temperature (°C)	K-eff	Core Reactivity (ρ)	$\Delta\rho$	fuel temperature reactivity coef.
20	1.050071	4.7684	-0.0441	-8.11E-03
40	1.049606	4.7262	-0.0422	-2.11E-03
60	1.049154	4.6852	-0.0410	-2.05E-03
100	1.048291	4.6067	-0.0785	-1.96E-03
180	1.046698	4.4616	-0.1451	-1.81E-03

Moderator temperature (°C)	K-eff	Core Reactivity(ρ)	$\Delta\rho$	Moderator temperature reactivity coeff.
20	1.050071	4.7684	-0.1754	-7.99E-03
40	1.048350	4.6122	- 0.1562	- 7.81E-03
55	1.047089	4.4973	- 0.1149	- 7,66E-03
80	1.045033	4.3093	- 0.1880	- 7,52E-03

Value of delayed neutron fraction TRIGA Bandung

Group	Delayed neutron fraction , β_k	Delayed neutron decay constants, λ_k (s ⁻¹)
1.	2,58752E-04	1,29000E-02
2.	1,52629E-03	3,11000E-02
3.	1,67876E-03	1,34000E-01
4.	2,64197E-03	3,31000E-01
5.	7,53047E-04	1,26000E+00
6.	2,94488E-04	3,21000E+00
Total delayed neutron fraction: 7.15331E-03		
Total delayed neutron decay constant: 7,84341E-02 s ⁻¹		
Prompt neutron generation time: 5.22862E-05 s		
Average neutron life time : 5.98283E-05 s		

CONCLUTION

Neutronic calculation for triga2000 core design need be continued for thermohydrolic parameter. Neutronic parameter also need feedback from thermalhydrolic calculation.



Thank you for attention.





Kepala BATAN dan rombongan melihat langsung uji coba operasi Reaktor TRIGA 2000 di PSTNT BATAN Bandung, 23 April 2015.

HASIL PERHITUNGAN

- Agar laju dosis di permukaan air kolam reaktor tidak lebih dari 2,5 mrem/jam pada daya 2 MW_{th}, → jeluk air kolam perlu diperdalam lagi dengan menambah kolom air vertikal setinggi minimal $\Delta h = (592,0 - 487,7) \text{ cm} = \mathbf{104,3 \text{ cm}}$.
- Jika dikenakan batasan laju dosis 1,0 mrem/jam pada daya 2 MW_{th}, maka perlu tambahan kolom air minimal setinggi $\Delta h = \mathbf{132,8 \text{ cm}}$.
- Untuk Δh setinggi **150 cm** seperti yang telah terpasang sekarang sehingga jeluk totalnya = $(488,7 + 150) \text{ cm} = \mathbf{637,7 \text{ cm}}$, → laju dosis di permukaan kolam = 0,759 mrem/jam → masih cukup aman (*secure*) dan selamat (*safe*) bagi pekerja radiasi dengan batasan laju dosis 2,5 mrem/jam.

Tebal minimal perisai radiasi reaktor riset Triga Mark II dengan daya 2 MW agar laju dosisnya tidak lebih dari 0,25 mrem/jam adalah:

- Arah radial: $t_{\text{rad}} = \underline{\underline{309 \text{ cm}}}$ (sekarang: $(696,0 - 198,1) \text{ cm} / 2 = 248,95 \dots \text{ cm}$ beton)

* Arah aksial: $h_{\text{axi}} = \underline{\underline{793 \text{ cm}}}$ (sekarang: $487,7 \dots \text{ cm}$ air dari permukaan teras)