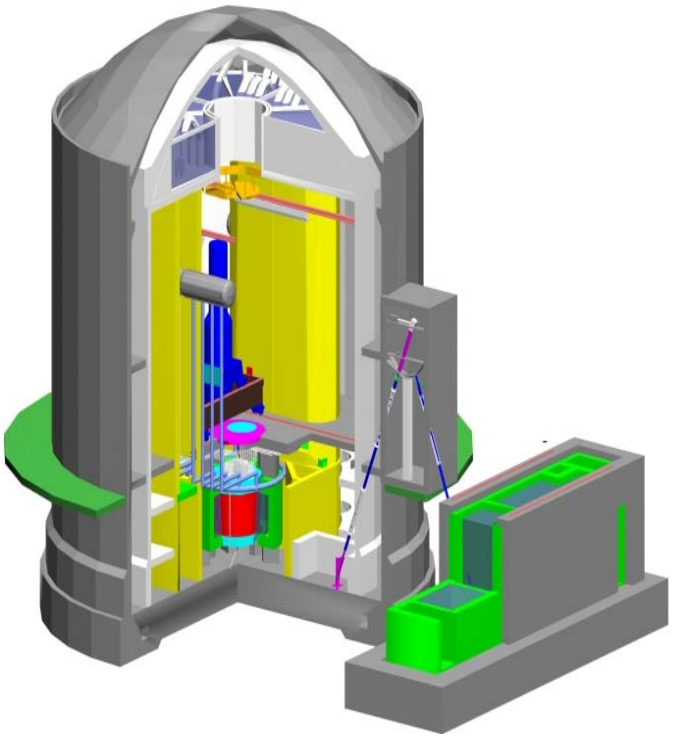

Advanced Heavy Water Reactor

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Design objectives of AHWR

The Advanced Heavy Water Reactor (AHWR) is a unique reactor designed in India for the large scale commercial utilisation of thorium and integrated technological demonstration of the thorium cycle

Design objectives / Challenges

- **Maximise the power from thorium**
  - Maximise the in-situ burning of ^{233}U
- **Negative power coefficient**
- **Heat removal through Natural Circulation**
  - **Uniform coolant flow ; flat radial power distribution , short active core height**
  - **Low power density**
  - **Bottom peaked axial power/flux distribution**
- **Fuel cycle aspects**
  - **Self-sustainance in ^{233}U**
  - **Plutonium as make-up fuel ; minimise the Pu inventory and consumption**
  - **Maximise the burnup**

Physics design criteria

- **Maximize power from thorium**
- **Core averaged negative void coefficient of reactivity at operating conditions.**
- **The discharge burnup of the fuel should be greater than 30 GWd/Te.**
- **Minimize consumption of plutonium.**
- **Initial plutonium inventory should be as low as possible.**
- **The system should be self-sustaining in ^{233}U.**
- **The total thermal power to the coolant should be 920 MW.**

- **Thermal hydraulic considerations of uniform coolant flow**
  - Local peaking factor has to kept within the TH margins
  - Suitable enrichments
- **Better TH margins - Higher MCHFR**
  - Relatively bottom peaked power distribution
- **Axially graded fuel pins (Outer pins)**

Properties of thorium

Major Advantages

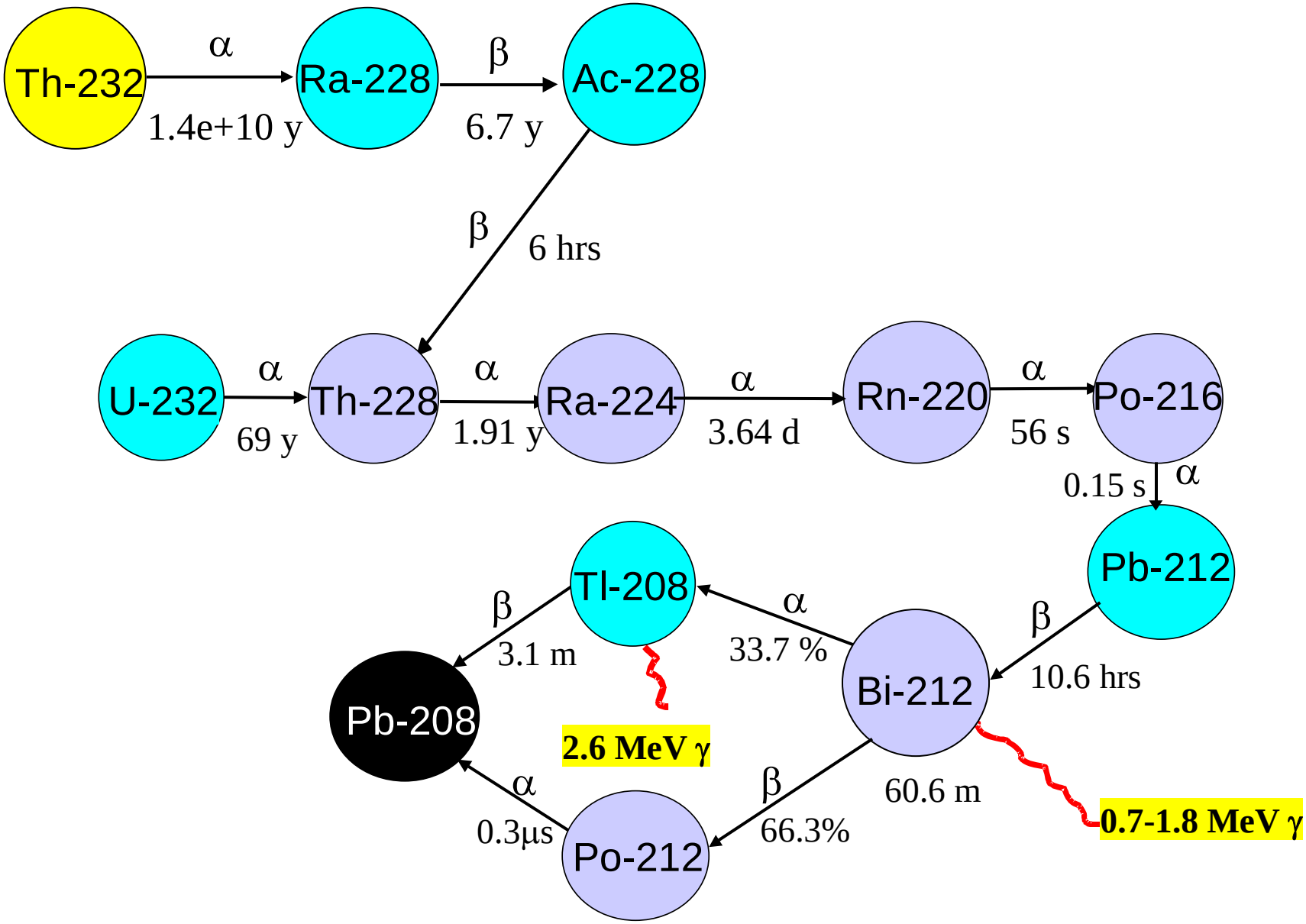
- Availability
- Improved nuclear characteristics
- Improved technological performance compared to UO_2
  - Stable crystal structure
  - Higher thermal conductivity
  - High melting point
  - lower thermal expansion coeff.
  - Improved fuel behaviour
  - Dimensional stability at high burn-up
- Reduced generation of actinides in Th-U-233 cycle

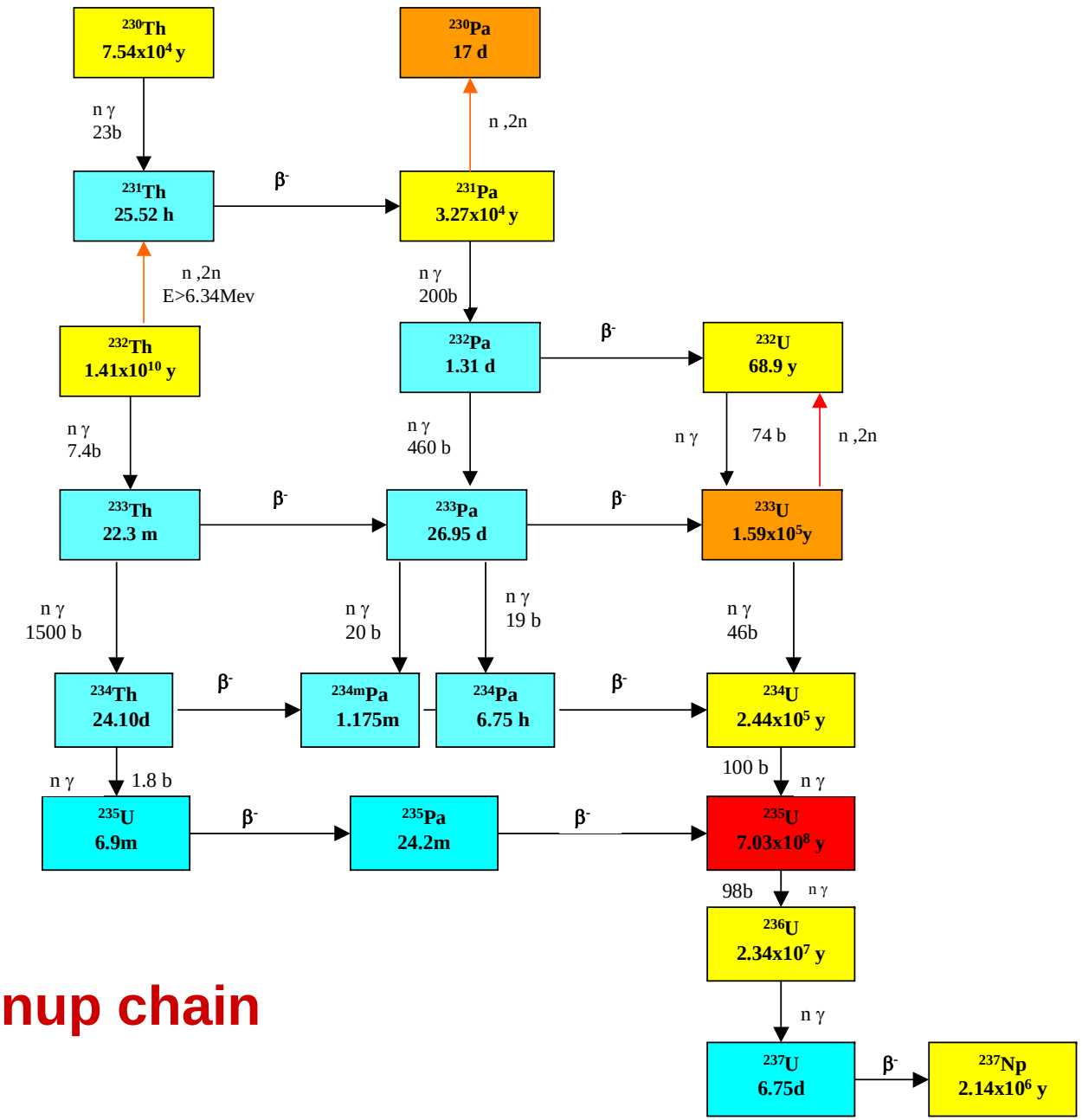
Major disadvantages

- Reactor safety
  - Low delayed neutron fraction β_{eff}
- Reactor operation
  - Photoneutron production (start-up)
- Radiation problem

  --Association of U^{232} with U^{233}
  - Reactor control problem due to Pa^{233}
- Reprocessing issues
  - Dissolution of thorium fuel is more difficult than uranium fuel, due to its high material stability

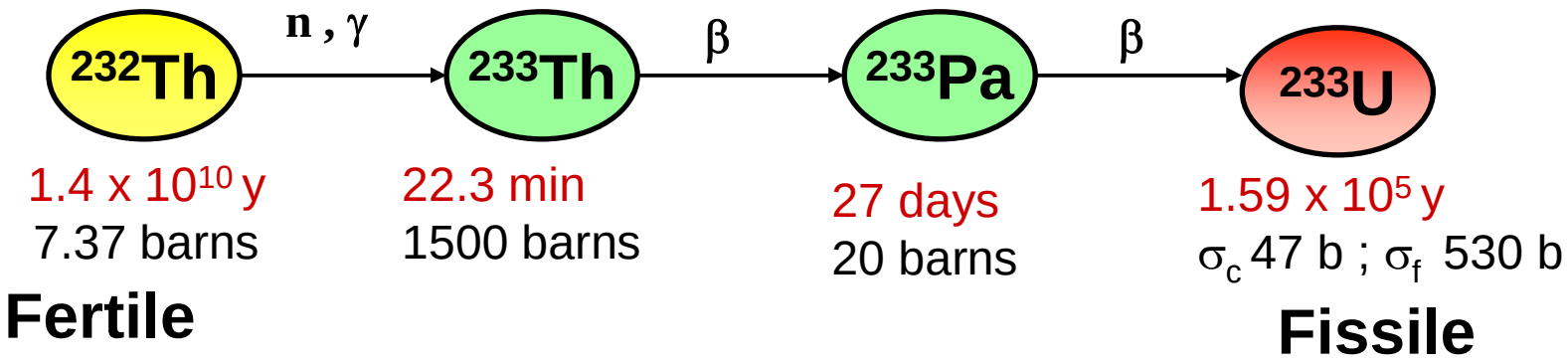
Thorium decay chain

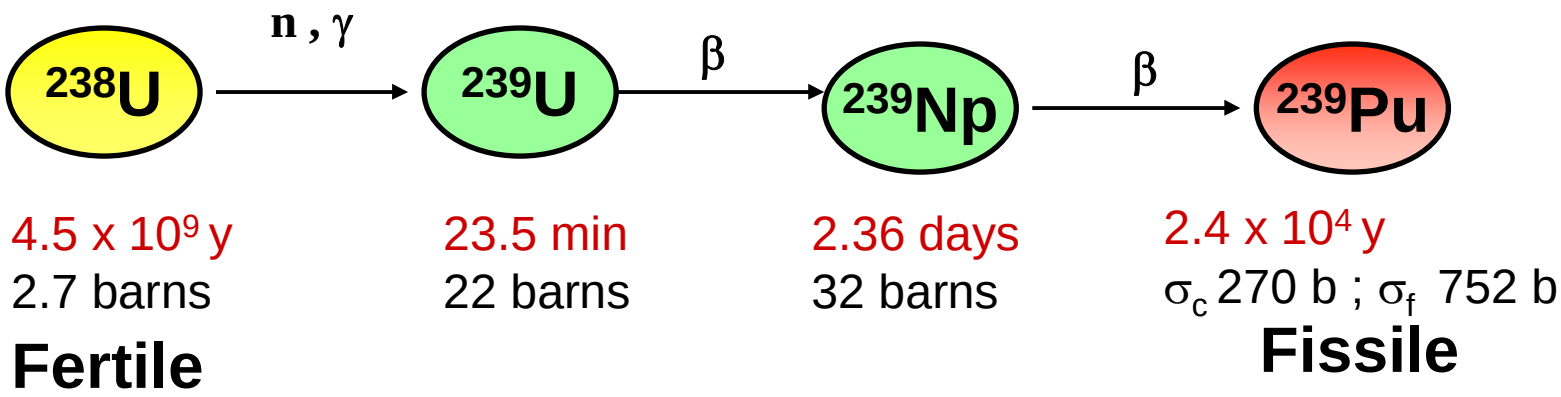




Thorium burnup chain

Comparison of fertile species ^{238}U and ^{232}Th

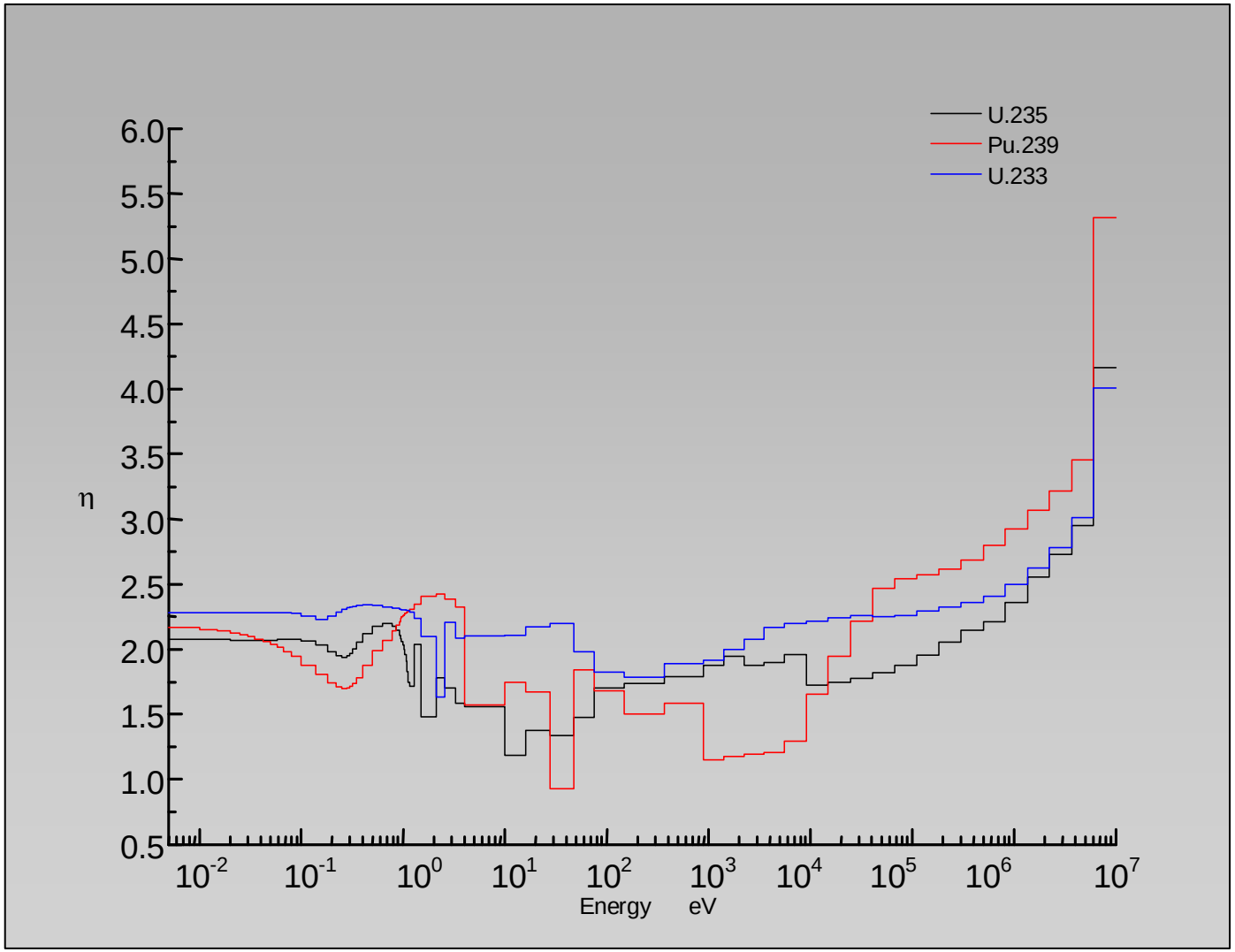




Neutronic properties of some fissile and fertile isotopes

		^{233}Pa	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{239}Np	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Thermal Data												
σa b (0.025 eV)	7.4	41.46	571.01	95.77	678.40	6.00	2.73	80.0	1013.04	290.08	1375.37	30.00
σ	7.4	41.46	45.99	95.77	101.30	6.00	2.73	80.0	271.19	290.02	367.81	30.00
σf b (0.025 eV)	0.0	0.0	525.11	0.0	577.10	0.0	0.0	0.0	741.85	0.0	1007.56	0.00
α			0.0874		0.1755				0.3656		0.3651	
ν			2.498		2.442				2.880		2.936	
η			2.300		2.077				2.109		2.151	
Resonance Integral (0.625 eV – 10 MeV)												
Absorption (barns)	85.78	858.83	883.73	632.16	380.13	348.82	273.57	0.0	445.15	8494.02	686.76	1118.65
Capture (barns)	85.20	857.0	135.10	627.96	130.22	346.55	272.37	0.0	168.58	8486.17	112.41	1115.00
Fission (barns)	0.58	1.83	748.63	4.20	249.91	2.27	1.20	0.0	276.57	7.85	574.35	3.65
α			0.1805		0.5210				0.6096		0.1957	

Comparison of eta for different fissile isotopes ^{233}U, ^{235}U and ^{239}Pu



AHWR D5 lattice

D5 lattice consisting of 54 fuel pins placed in three arrays of 12, 18 and 24 pins in each array and a central displacer region

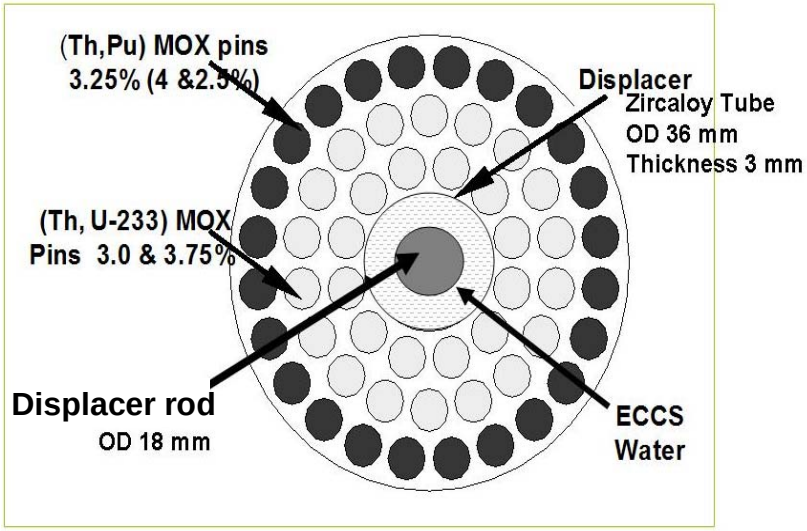
Fuel composition :

Ring 1 – (Th,U)MOX - 3.0 % ^{233}U (12 pins)
Ring 2 – (Th,U)MOX - 3.75 % ^{233}U (18 pins)
Ring 3 – (Th,Pu)MOX – 4.0% Pu (24 pins) (Lower)
2.5% Pu (24 pins) (Upper)
3.25 % Pu (average)

Displacer region – (Zircalloy-2 rod)

Pu composition :
Discharge composition of Pu from PHWR at 6700 MWd/T

Core average discharge burnup : 34000 MWd/T



Cross section of AHWR D5 cluster

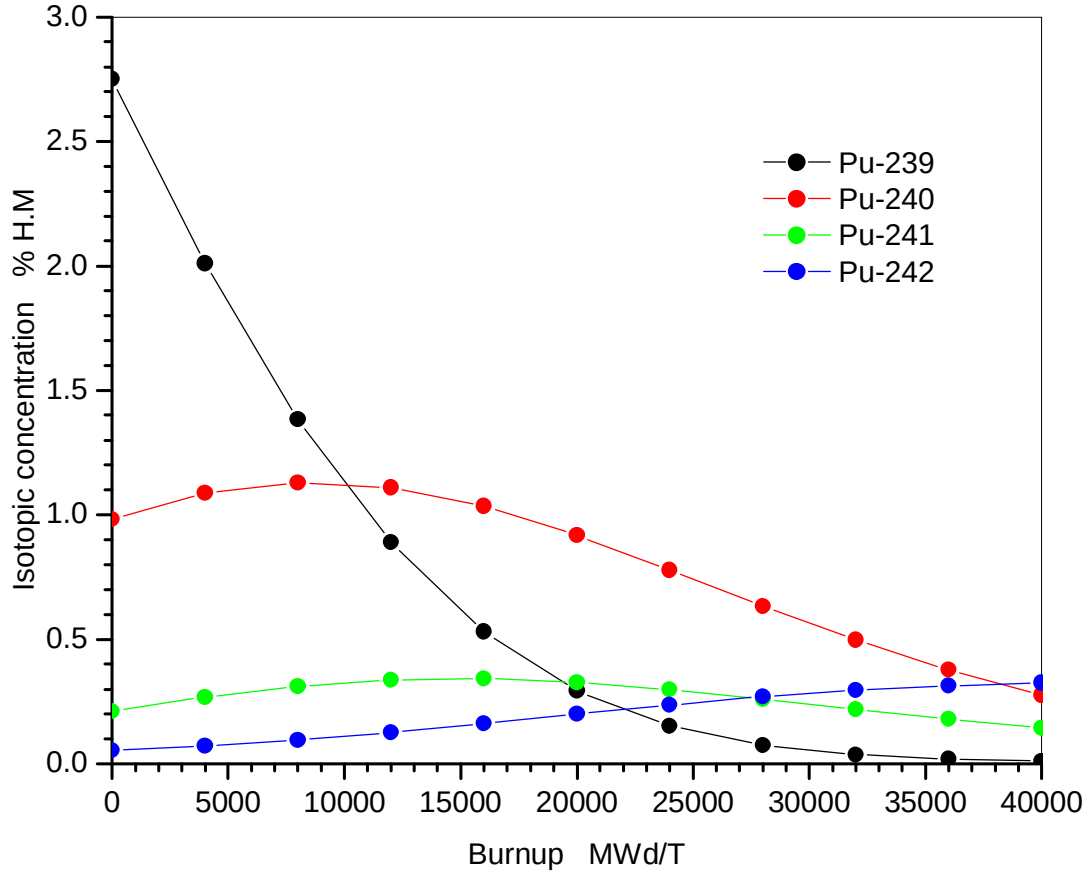
Plutonium burning in AHWR

- Placing the Pu pins in the outer ring where it sees a significant thermal flux is responsible of Pu burning

- Initially the plutonium isotopes contribute about 46 % of the total absorptions and this reduces to 15 % at the end of the cycle.

- ^{239}Pu absorptions reduces by about 90 % at discharge due to its depletion.

- In the initial core cluster, the burnups achievable are relatively low and hence lower burning



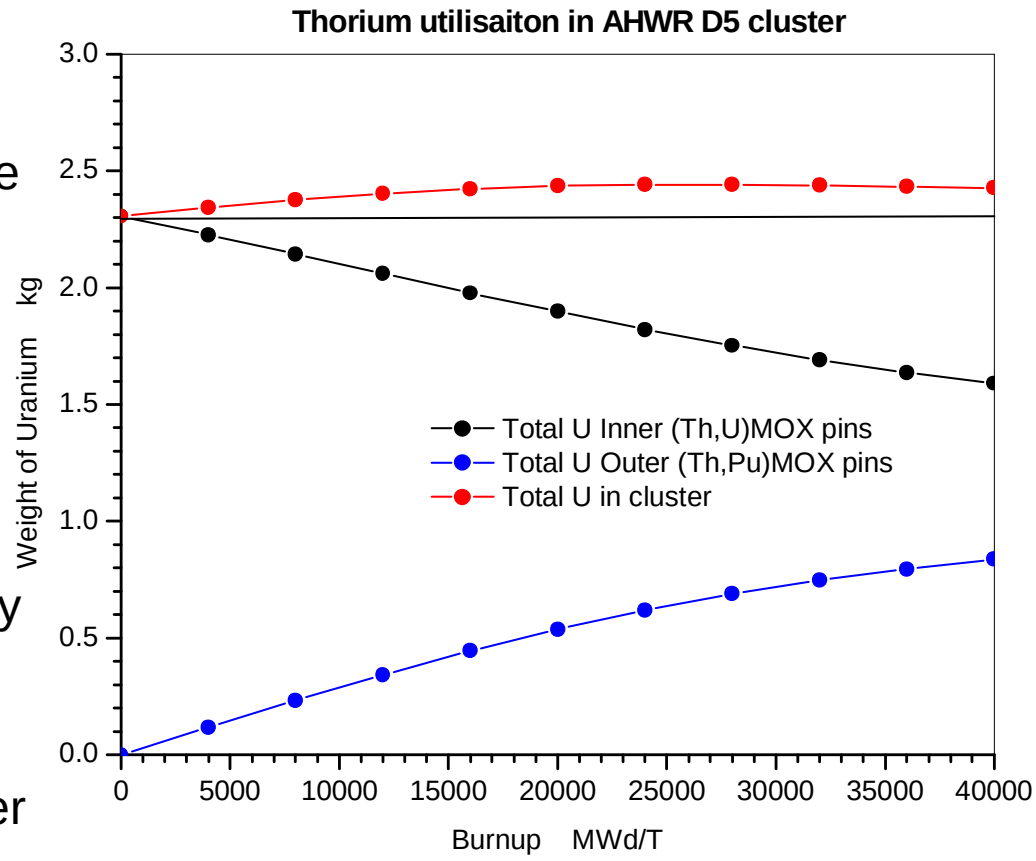
Plutonium burning in the composite cluster

Discharge composition of the Pu fuel

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Initial (PHWR)		68.79	24.6	5.26	1.35
Composite cluster	1.84	2.28	37.33	22.31	36.24

Uranium : In-situ generation and burning

- (Th,Pu) MOX pins placed in well thermalised spectrum to maximise ^{233}U production
- Self-sustenance in ^{233}U can be achieved by proper neutron spectrum
- Fuel utilisation has to be traded off with TH parameters and safety parameters like negative void reactivity
- At core average burnup, the power from Th-^{233}U is about 65- 70 %



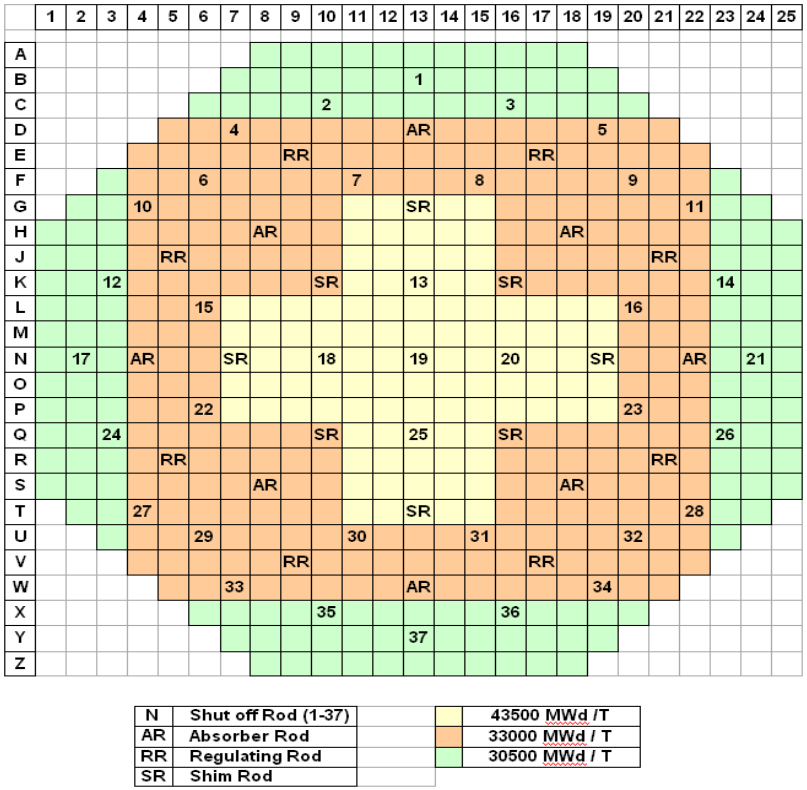
Cluster averaged U compositions

	^{232}U	^{23}U	^{234}U	^{235}U	^{236}U
Composite cluster	**0.16**	**81.61**	**14.80**	**2.68**	**0.35**

Salient features of the core design

- Boiling light water cooled
- Heavy water moderated
- Fuel cycle based on (Th,U) and (Th,Pu)
- Axially graded fuel for bottom peaked flux distribution for better TH characteristics
- on power fuelling
- Two independent fast acting S/D systems

- Total No. of channels - 513
- No. of fuel channels - 452
- Fuelling rate (annual) - 82 (ch)
- Average dis. burnup - 34000 MWd/t



Core layout of AHWR equilibrium core

Optimised core power distribution

	13	12 14	11 15	10 16	9 17	8 18	7 19	6 20	5 21	4 22	3 23	2 24	1 25
A	1.86	1.72	1.65	1.6	1.52	1.52							
B	**SOR**	1.87	1.77	1.9	1.71	1.62	1.8						
C	1.9	1.83	2.08	**SOR**	2.07	1.89	2.01	2.07					
D	**AR**	1.82	1.99	2.16	2.04	2.12	**SOR**	2.1	2.08				
E	1.92	2.02	2.25	2.12	**RR**	2.06	2.24	2.24	1.97	2.07			
F	2.36	2.42	**SOR**	2.27	2.02	1.94	2.2	**SOR**	2.23	2.09	2.06		
G	**SR**	2.37	2.27	2.12	1.92	1.83	1.95	2.2	2.24	**SOR**	2.01	1.8	
H	2.34	2.17	2.08	2.1	1.91	**AR**	1.83	1.94	2.06	2.12	1.88	1.61	1.5
I	2.38	2.19	2.16	2.39	2.08	1.91	1.91	2.02	**RR**	2.03	2.06	1.7	1.5
J	**SOR**	2.39	2.37	**SR**	2.39	2.1	2.12	2.26	2.11	2.15	**SOR**	1.89	1.58
K	2.4	2.23	2.21	2.37	2.16	2.08	2.27	**SOR**	2.24	1.98	2.07	1.75	1.62
L	2.42	2.24	2.23	2.39	2.19	2.17	2.36	2.41	2.02	1.81	1.82	1.86	1.69
M	**SOR**	2.42	2.4	**SOR**	2.36	2.34	**SR**	2.36	1.92	**AR**	1.88	**SOR**	1.84

Zone		**Exit burnup MWd/ T**
1		**43500**
2		**33000**
3		**30500**

SAFETY FEATURES OF AHWR

- **The main aim of AHWR design is to make the void reactivity –ve (in order to gain extra degree of safety)**
- **To achieve this it is a nightmare for the designer but a delight for the operator.**
- **Different approaches for making the void reactivity negative.**

  1) Addition of some slowly burnable absorber in the displacer region of the fuel cluster.

  2) Decrease the lattice pitch.

THANK YOU