Some Recent Work at NDS, RPDD, BARC

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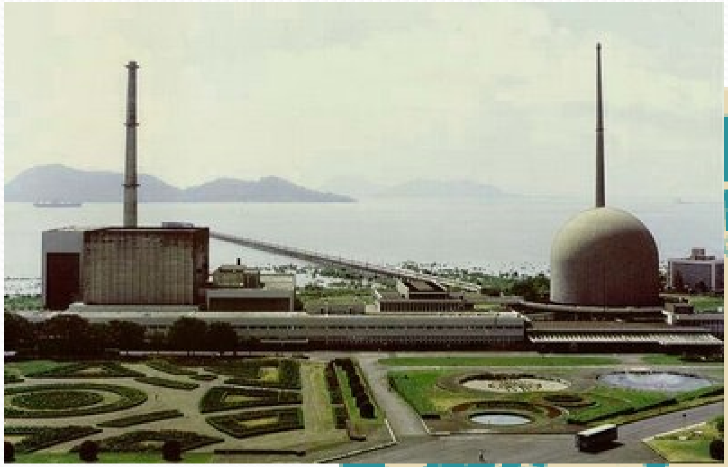
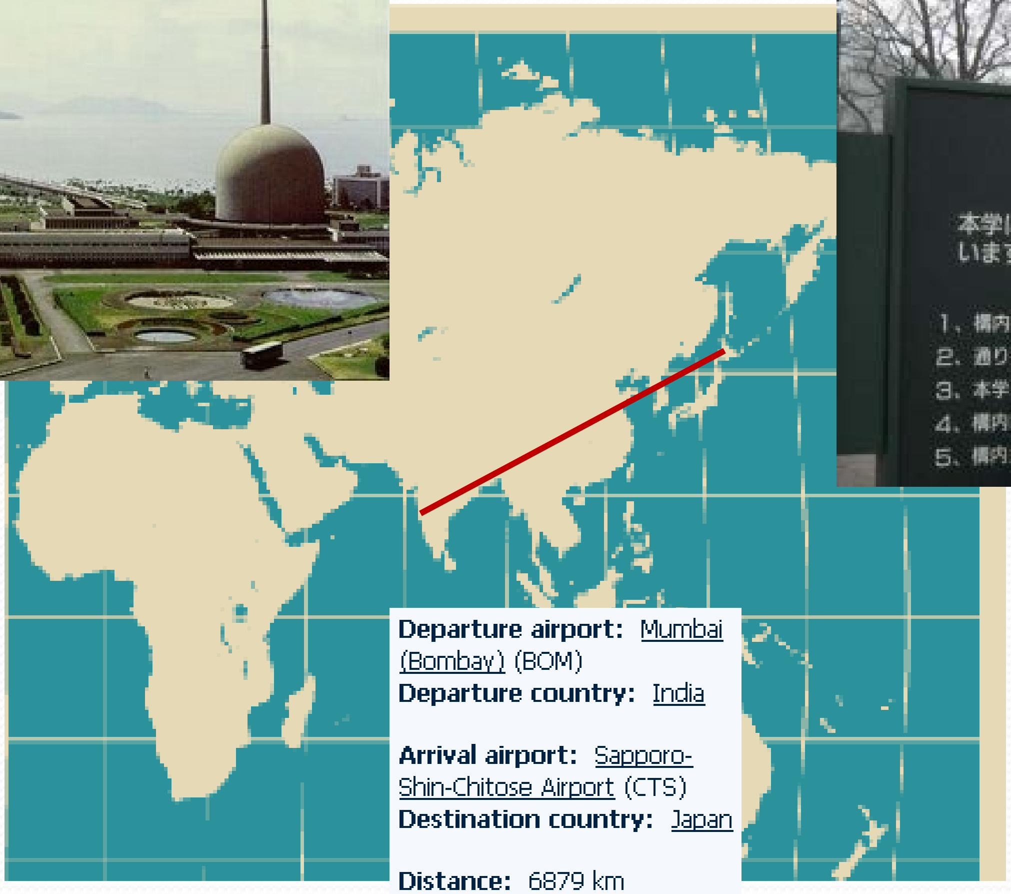




Some of my recent involvements

- Photo-fission of actinides –applications
- Thorium utilization (eg. EPR)
- Dhruva n_ToF Facility
- Fusion-fission hybrid

Need for proliferation Monitoring

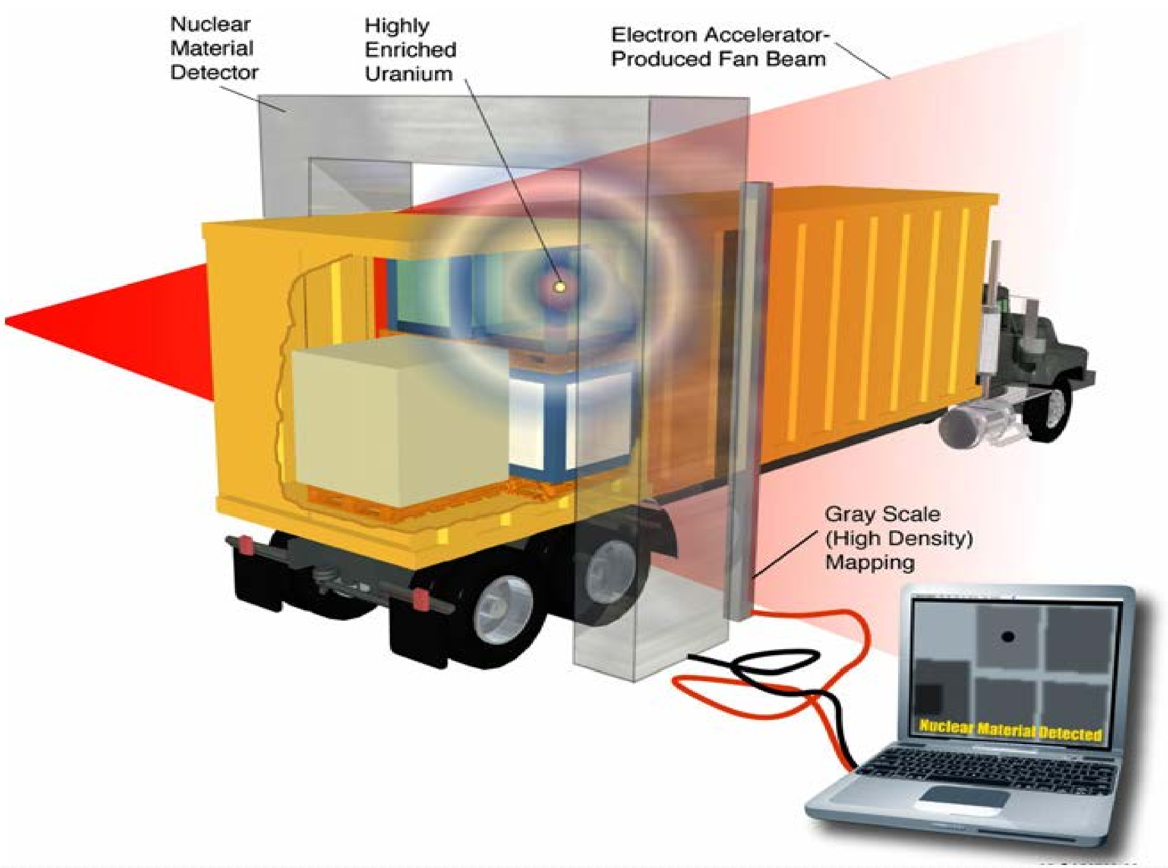
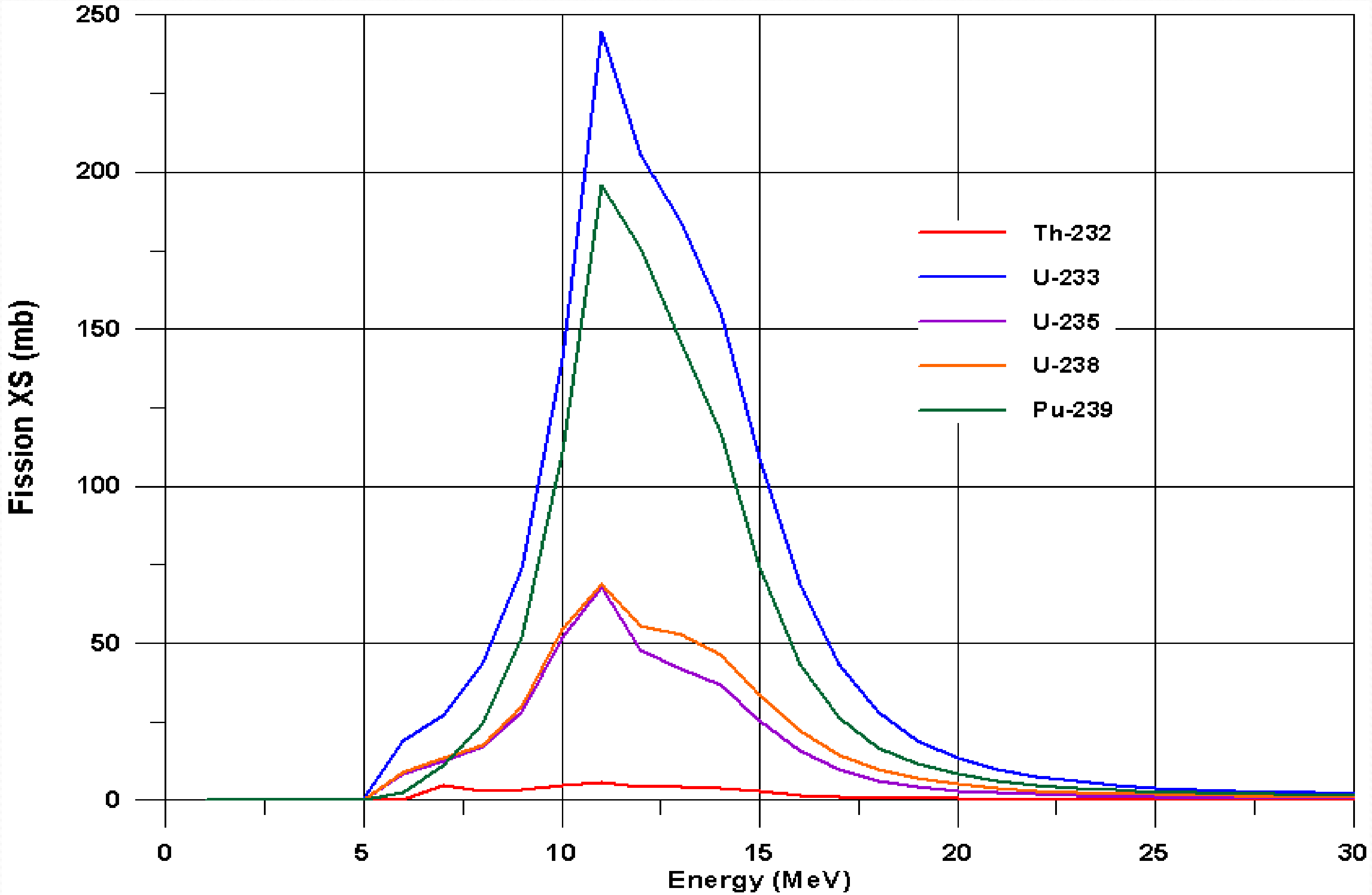


Photo-Fission is a good option

- No/Minimal Activation
- Even heavily shielded cargo can be probed
- Delayed gamma have characteristic signature

Actinide Fission XS. (TALYS, A. Koning et.al.)

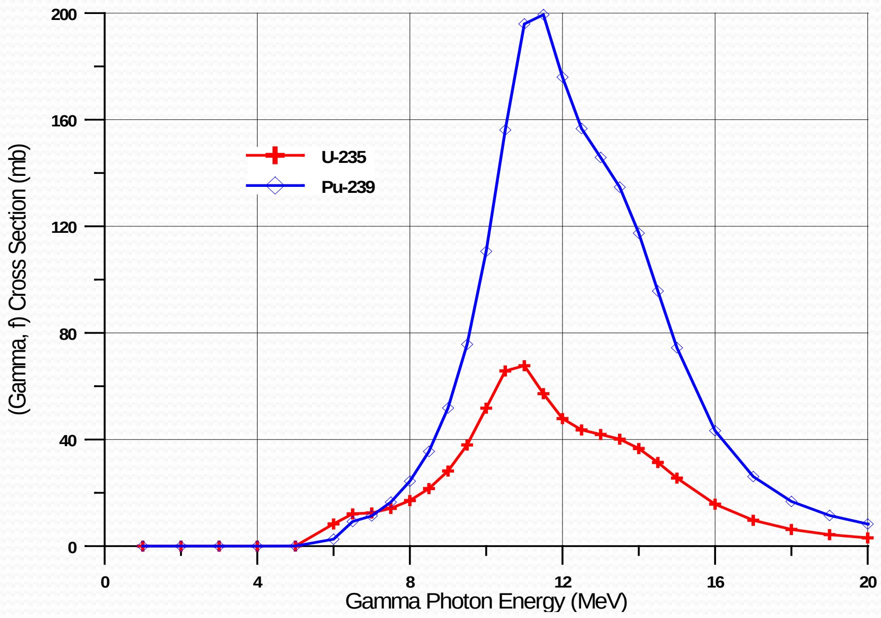


(Experimental Fission Barrier Parameters)

Electron energy = 10 MeV
Beam Current = 100 mA
Beam Frequency = 100 Hz
Pulse width = 10 E-06 s

Nominal beam power is 1000 W or 1 KW which is carried from source to target by ~ 6.2415E+014 electrons per second each having energy 10 MeV (1.60219E-012 J).

Photo-fission of actinides



Bremsstrahlung spectrum

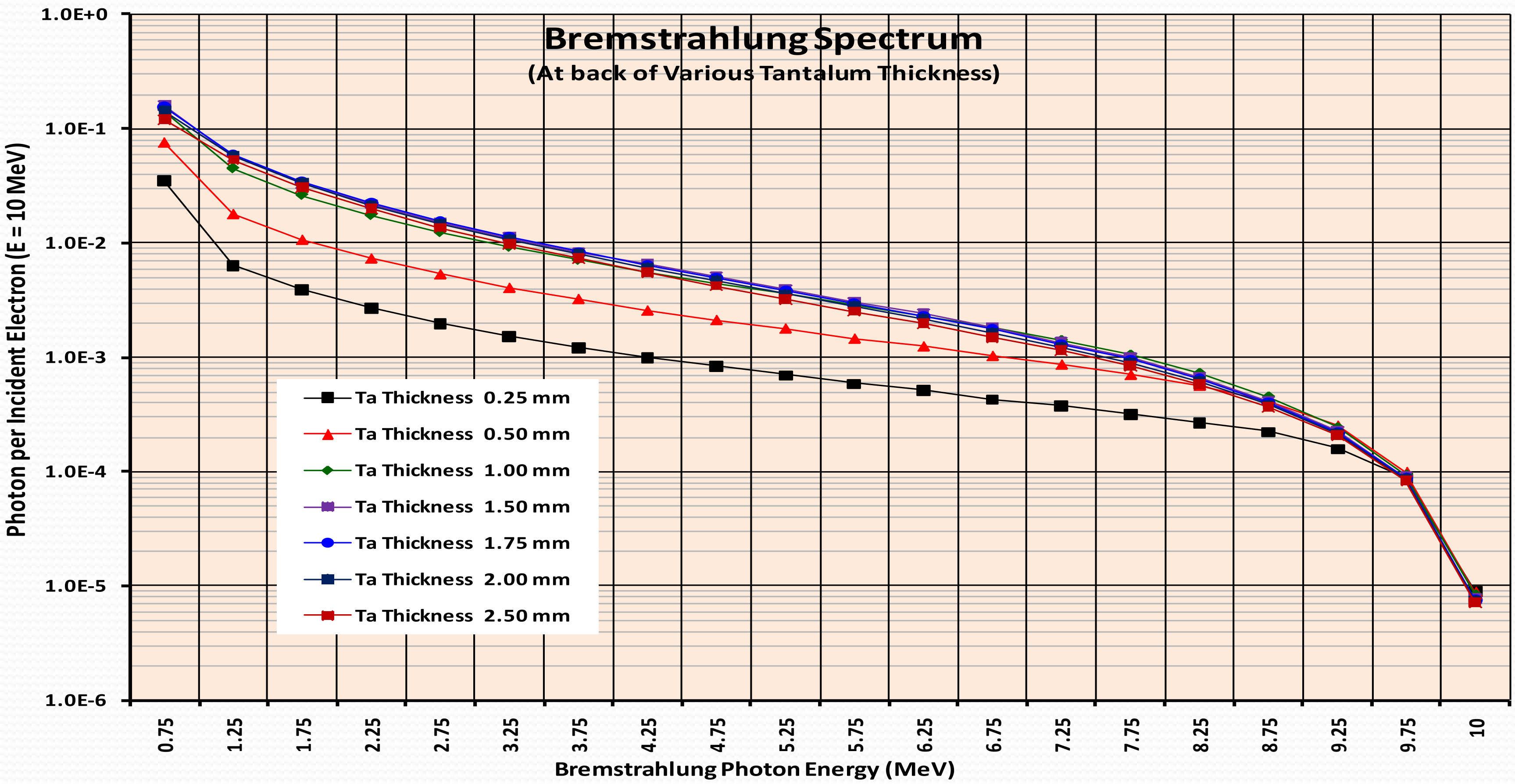
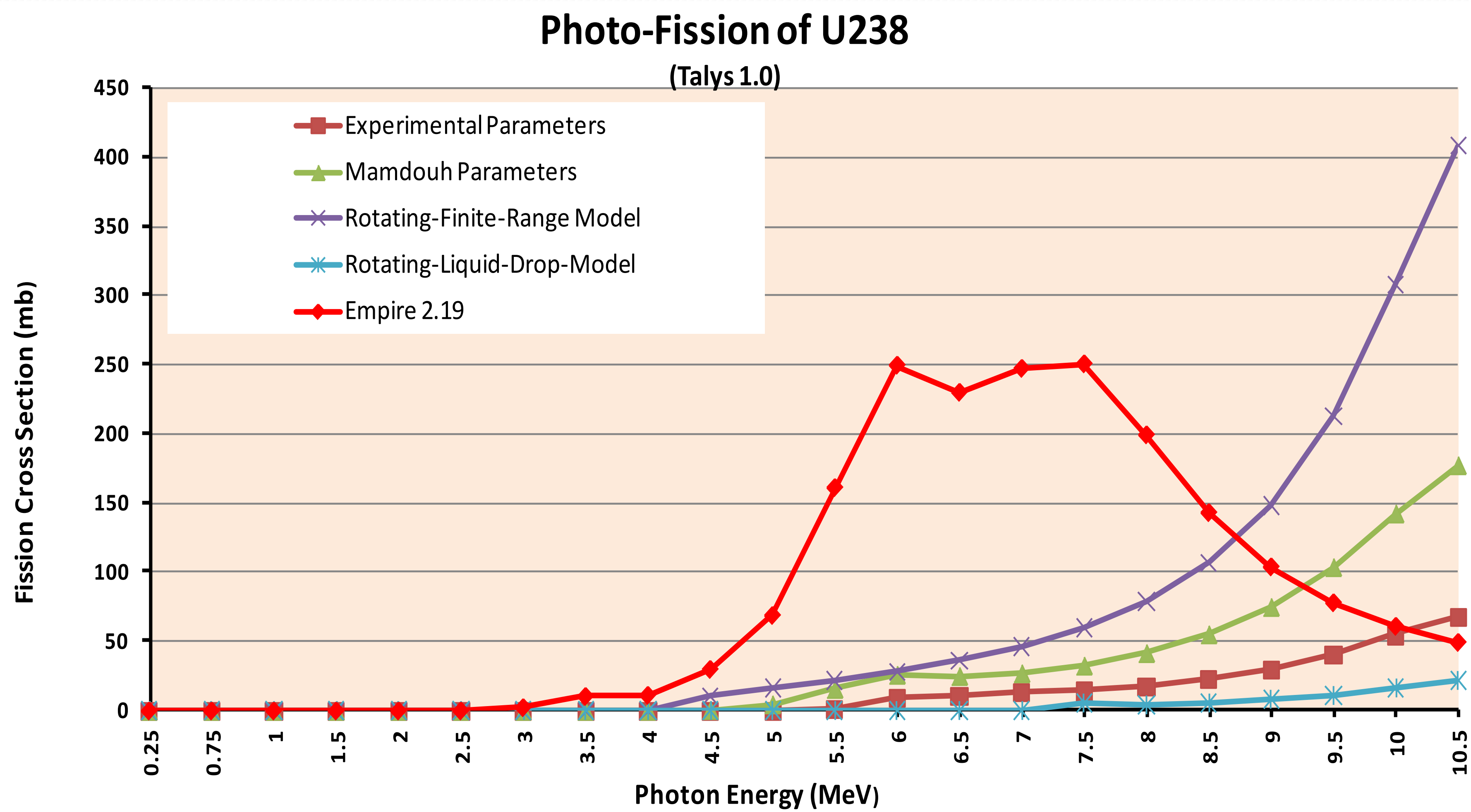


Photo-fission Cross section (U238)



Reaction Rates in a 5mm thick sample

Energy (MeV)	Photon/electron	Photo-fission XS (mb)	Reaction Rate per electron	Reaction Rate for 10 MeV 100mA beam
7.50E-01	1.44E-01	0.000E+00	0.000E+00	0.000E+00
1.25E+00	4.46E-02	0.000E+00	0.000E+00	0.000E+00
1.75E+00	2.61E-02	0.000E+00	0.000E+00	0.000E+00
2.25E+00	1.74E-02	0.000E+00	0.000E+00	0.000E+00
2.75E+00	1.24E-02	0.000E+00	0.000E+00	0.000E+00
3.25E+00	9.21E-03	0.000E+00	0.000E+00	0.000E+00
3.75E+00	7.08E-03	0.000E+00	0.000E+00	0.000E+00
4.25E+00	5.54E-03	2.384E-04	6.340E-11	3.960E+04
4.75E+00	4.42E-03	9.479E-03	2.011E-09	1.256E+06
5.25E+00	3.57E-03	1.424E-01	2.440E-08	1.522E+07
5.75E+00	2.84E-03	1.373E+00	1.872E-07	1.168E+08
6.25E+00	2.32E-03	8.981E+00	1.000E-06	6.243E+08
6.75E+00	1.81E-03	1.093E+01	9.496E-07	5.922E+08
7.25E+00	1.41E-03	1.330E+01	9.001E-07	5.598E+08
7.75E+00	1.05E-03	1.419E+01	7.152E-07	4.456E+08
8.25E+00	7.26E-04	1.739E+01	6.060E-07	3.782E+08
8.75E+00	4.52E-04	2.253E+01	4.888E-07	3.053E+08
9.25E+00	2.44E-04	3.003E+01	3.517E-07	2.193E+08
9.75E+00	9.39E-05	4.070E+01	1.834E-07	1.146E+08
1.00E+01	8.47E-06	5.470E+01	2.224E-08	1.389E+07
	SUM =			3.386E+09

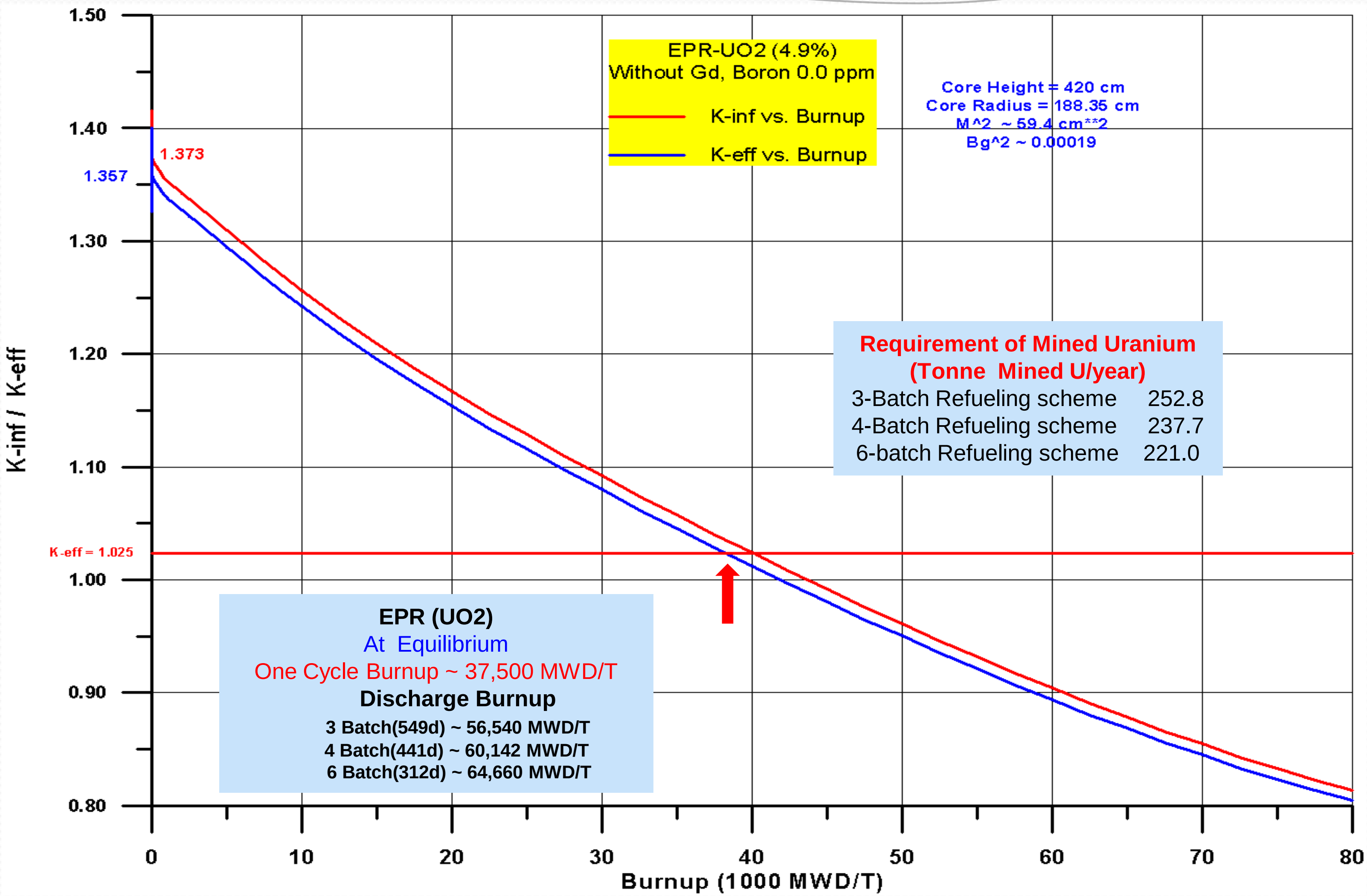
Enough Fission to detect delayed neutrons and delayed gamma

European Pressurized Water Rx

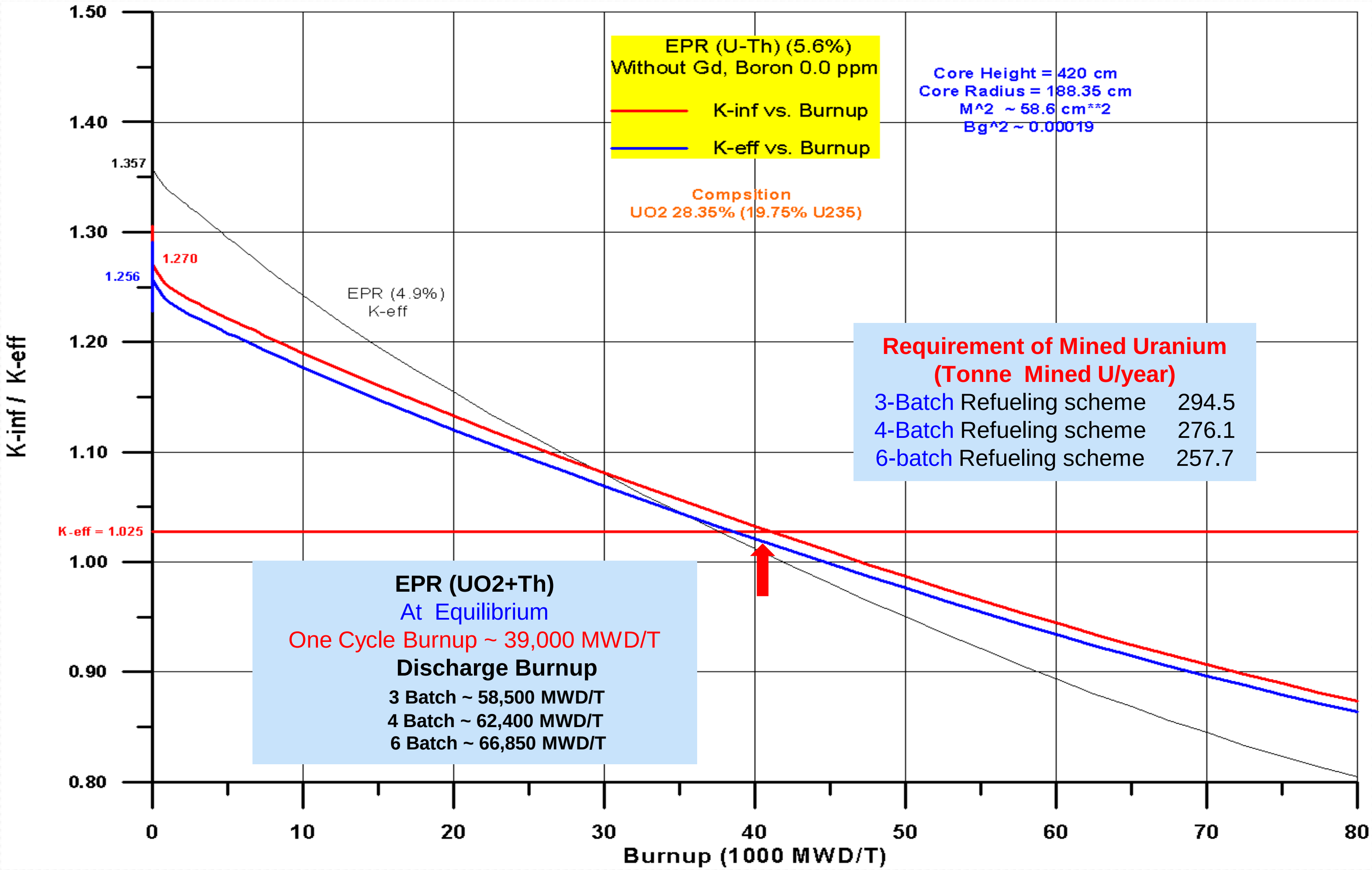
- Reduce Generation Cost
  - By increasing Burnup
    - Reduced Xenon poisoning
    - Reduced Doppler feedback
    - Heavy reflector used
  - By increasing Plant availability
    - Large flexibility for loading schemes IN/OUT OUT/IN
    - Different cycle lengths (batch size) possible for Fuel management
    - Stretched – out operation of up to 70 EFPD is allowed.
- Increase maneuverability
  - Unscheduled large and fast power variations over the range of 20-100% RP.
  - Capacity for permanent primary and secondary control in range of +/- 12.5% between 50 – 100% RP.

– Nominal EPR considers very flexible fuel management schemes. It considers different batch sizes (3-batch, 4-batch and 6-batch) of different durations (24 months, 18 months and 12 months).

Burnup Characteristic of EPR-1650



EPR-1650 (UO2+Th) 5.6% Fissile



Increasing fissile content to 5.6% in Thorium EPR the burnup characteristics matches with that of nominal EPR. Mined Uranium Utilization still remains lower than that for nominal EPR however this configuration can de taken for further study.

Discharge Burnup and Mined Uranium Utilization

Fuel Management	Discharge Burnup (MWD/T)			
	EPR-U (4.9%)* 37,500**	EPR-UTh (5.6%) 39,000	EPR-UTh (6.0%) 42,500	EPR-UTh (7.0%) 51,200
3 Batch	56,540	58,500	63,750	76,800
4 Batch	60,142	62,400	68,000	81,900
6 Batch	64,660	66,850	72,850	87,700

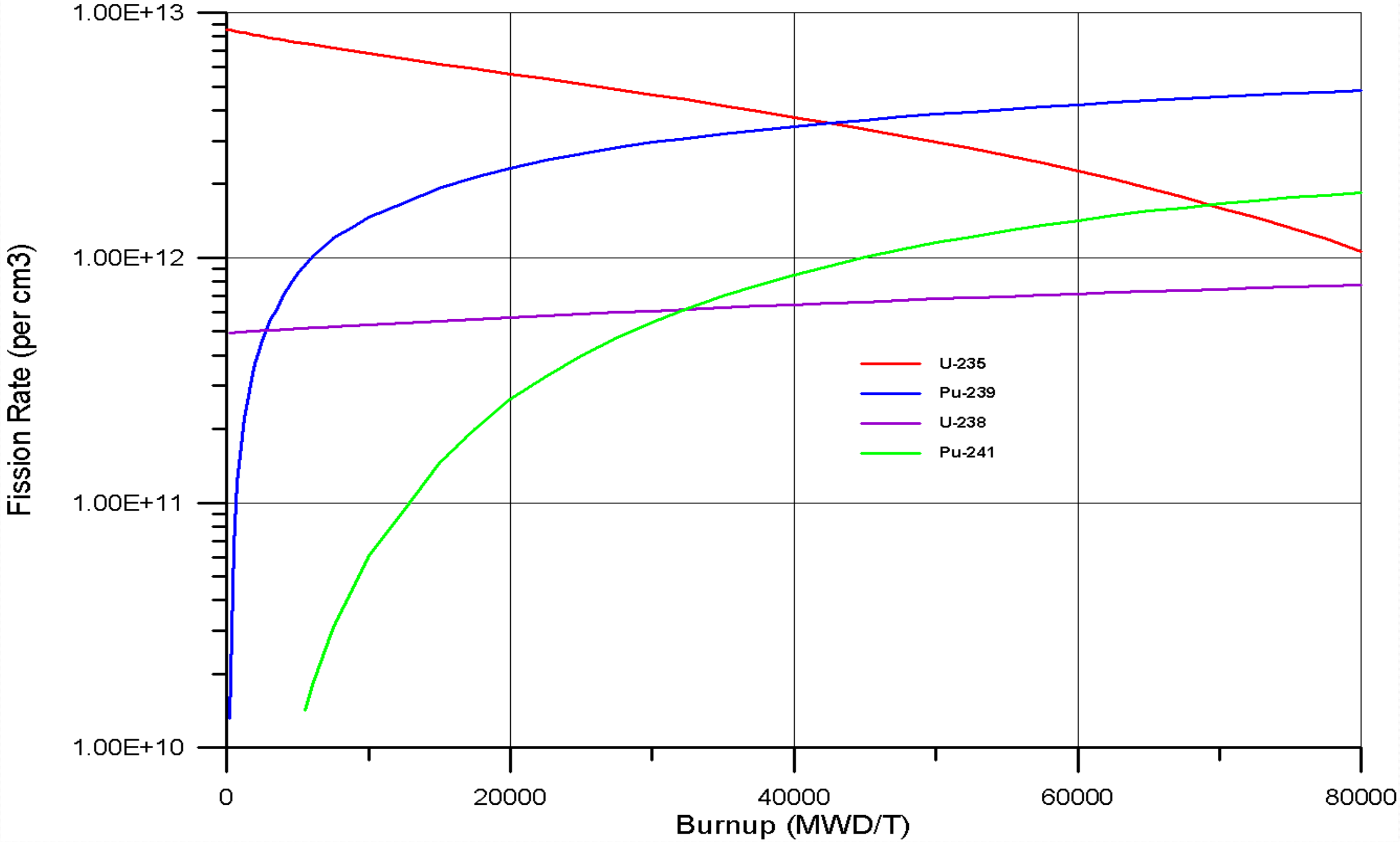
*'EPR core design', G. Sengler et al, Nuclear Energy and Design, 187 (1999) 79-119

** Equivalent One Cycle Burnup

Fuel Management	Mined Uranium Utilization (MWD/T mined U)			
	EPR-U (4.9%)*	EPR-UTh (5.6%)	EPR-UTh (6.0%)	EPR-UTh (7.0%)
3 Batch	6,136	5,373	5,467	5,643
4 Batch	6,526	5,731	5,831	6,018
6 Batch	7,017	6,140	6,247	6,444

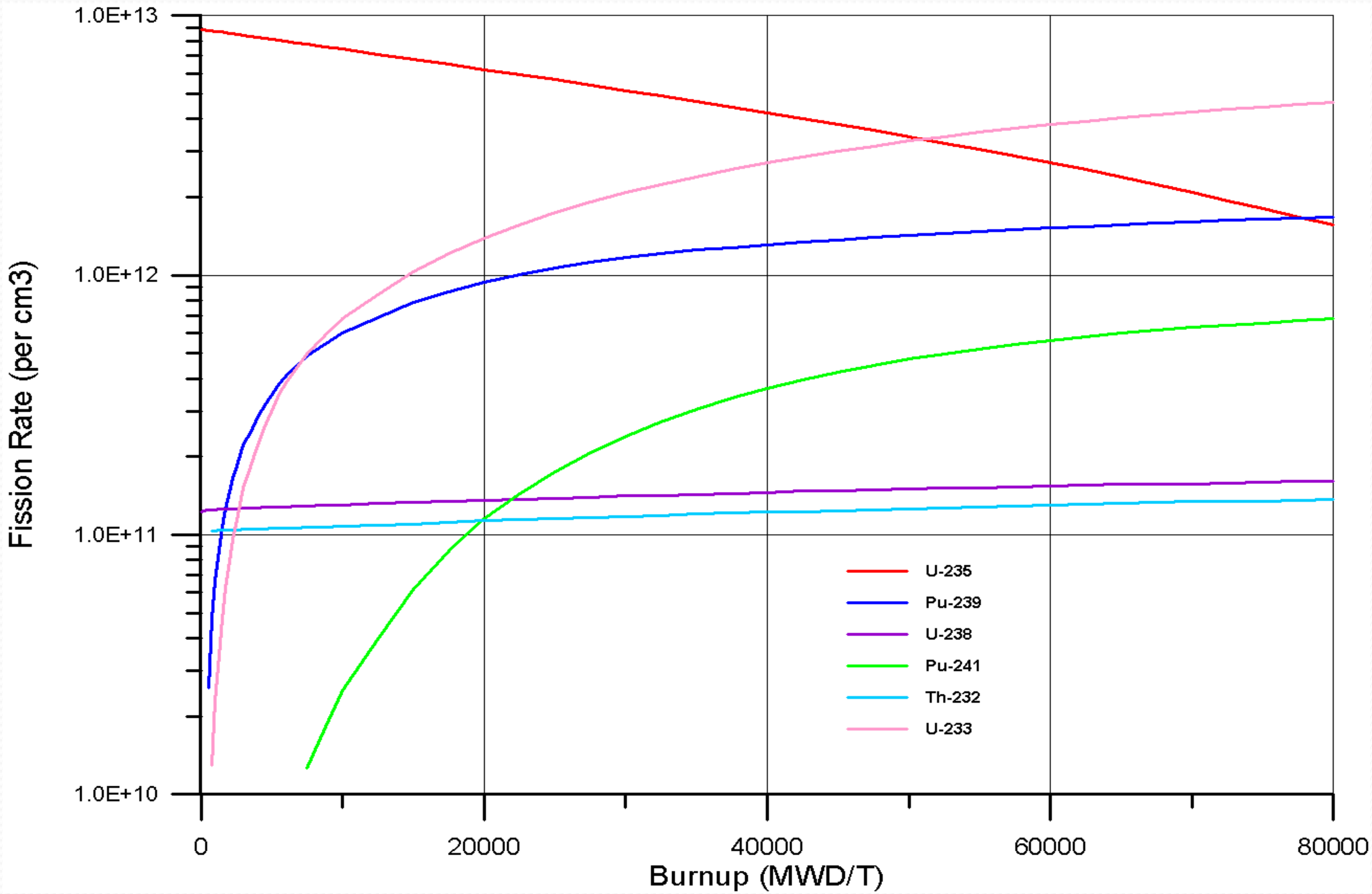
Discharge burnup achievable with 5.6% thorium EPR is comparable with that of Nominal EPR. Also in 6-Batch refueling scheme in this configuration gives mined uranium utilization comparable to nominal EPR.

Various Fission Rates EPR-U (4.9%)



In nominal EPR the fission rates of Pu239 and U235 are comparable at burnup of 42000 MWD/T

Various Fission Rates EPR-U+Th (5.6%)



In thorium EPR (5.6%) the fission rates of U233 and U235 are comparable at burnup of 45000 MWD/T. Pu239 fission rates remains significantly low during whole cycle.

Plutonium Vector 3-Batch Refueling Scheme

Plutonium produced (kg/TWeh)						
	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-total
EPR-U (4.9%)	0.6612	12.990	5.9324	3.9367	1.9411	24.800
EPR-U+Th (4.9%)	0.5141	5.3357	1.8363	1.7676	0.7629	9.7011
EPR-U+Th (5.6%)	0.6562	4.9334	1.7707	1.7313	0.8588	9.2946
EPR-U+Th (6.0%)	0.7190	4.8550	1.7635	1.7299	0.8903	9.2387

Percent Composition of the Plutonium Vector at Disch. Burnup						
	Pu-238 (%)	Pu-239 (%)	Pu-240 (%)	Pu-241 (%)	Pu-242 (%)	Pu-total(g/Kg)
EPR-U (4.9%)	2.668347	52.3795	23.92041	15.87319	7.826987	12.11541
EPR-U+Th (4.9%)	5.299956	55.00174	18.92967	18.22139	7.864074	3.96038
EPR-U+Th (5.6%)	7.061057	53.08267	19.05098	18.62738	9.239742	4.69788
EPR-U+Th (6.0%)	7.782614	52.55127	19.08846	18.72481	9.636446	5.08865
EPR-U+Th (7.0%)	9.487424	51.54744	19.21462	18.84108	10.39805	6.093759

Minor Actinides 3-Batch Refueling Scheme

Minor Actinide produced (gm/TWeh)							
	Am-241	Am-242	Am-243	Cm-242	Cm-243	Cm-244	Total
EPR-U (4.9%)	161.68	2.59	494.62	58.94	1.67	222.82	942.32
EPR-U+Th (4.9%)	68.11	1.12	175.84	22.78	0.55	59.79	328.20
EPR-U+Th (5.6%)	76.15	1.29	231.02	26.72	0.76	95.29	431.22
EPR-U+Th (6.0%)	80.27	1.38	252.20	28.23	0.85	111.35	474.27
EPR-U+Th (7.0%)	89.68	1.59	300.22	31.38	1.06	153.19	577.12

Minor Actinides 4-Batch Refueling Scheme

Minor Actinide produced (gm/TWeh)							
	Am-241	Am-242	Am-243	Cm-242	Cm-243	Cm-244	Total
EPR-U (4.9%)	168.36	2.69	587.23	65.13	1.96	287.40	1112.76
EPR-U+Th (4.9%)	72.38	1.19	212.49	25.56	0.66	78.51	390.79
EPR-U+Th (5.6%)	79.23	1.34	275.40	29.34	0.89	123.45	509.65
EPR-U+Th (6.0%)	82.83	1.42	299.52	30.78	0.99	143.95	559.48
EPR-U+Th (7.0%)	90.95	1.60	353.21	33.69	1.21	196.39	677.04

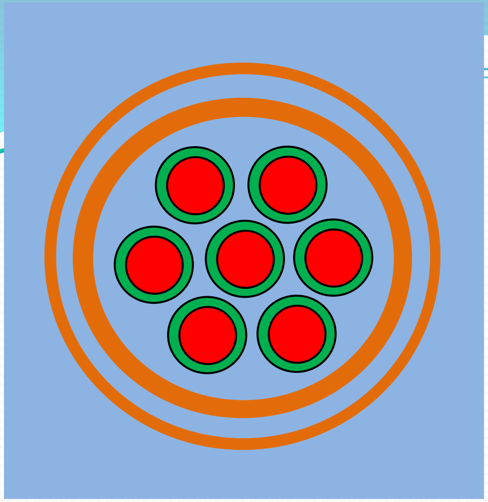
Economy of Fuel : Initial Core EPR-U (4.9%) and EPR-U+Th (5.6%)

- Full Core 4.9% enriched Uranium inventory = 183 T
- Mined uranium Feed Requirement = 1686.5 T
- (Feed Fraction = 0.71%, Tail Fraction = 0.2%)
- Total SWU = 1578893
- Energy requirement
  - **3.87E+12 kWh (Gas Diffusion Method)**
  - **8.68E+10 kWh (Gas Centrifuge Method)**

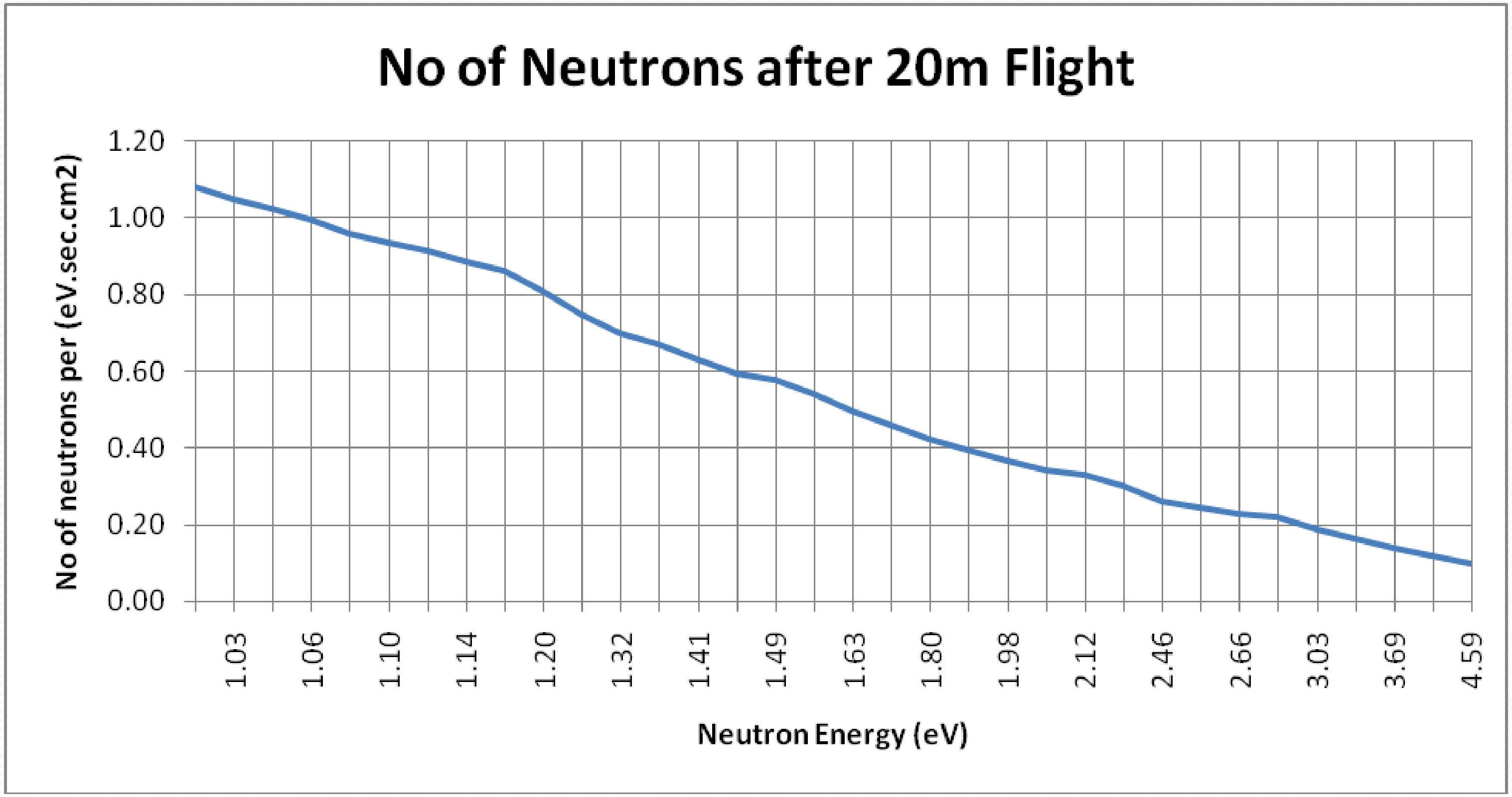
- Full Core 19.75% enriched Uranium inventory = 51.98 T
- Mined uranium Feed Requirement = 1992.56 T
- (Feed Fraction = 0.71%, Tail Fraction = 0.2%)
- Total SWU = 2347410
- Energy requirement
  - **5.75E+12 kWh (Gas Diffusion Method)**
  - **1.29E+11 kWh (Gas Centrifuge Method)**

	EPR-U (4.9%)	EPR-U+Th (5.6%)
Mined uranium Feed Requirement	1686.5 T	1992.56 T
Total SWU	1578893	2347410
Energy requirement	8.68E+10 kWh	1.29E+11 kWh

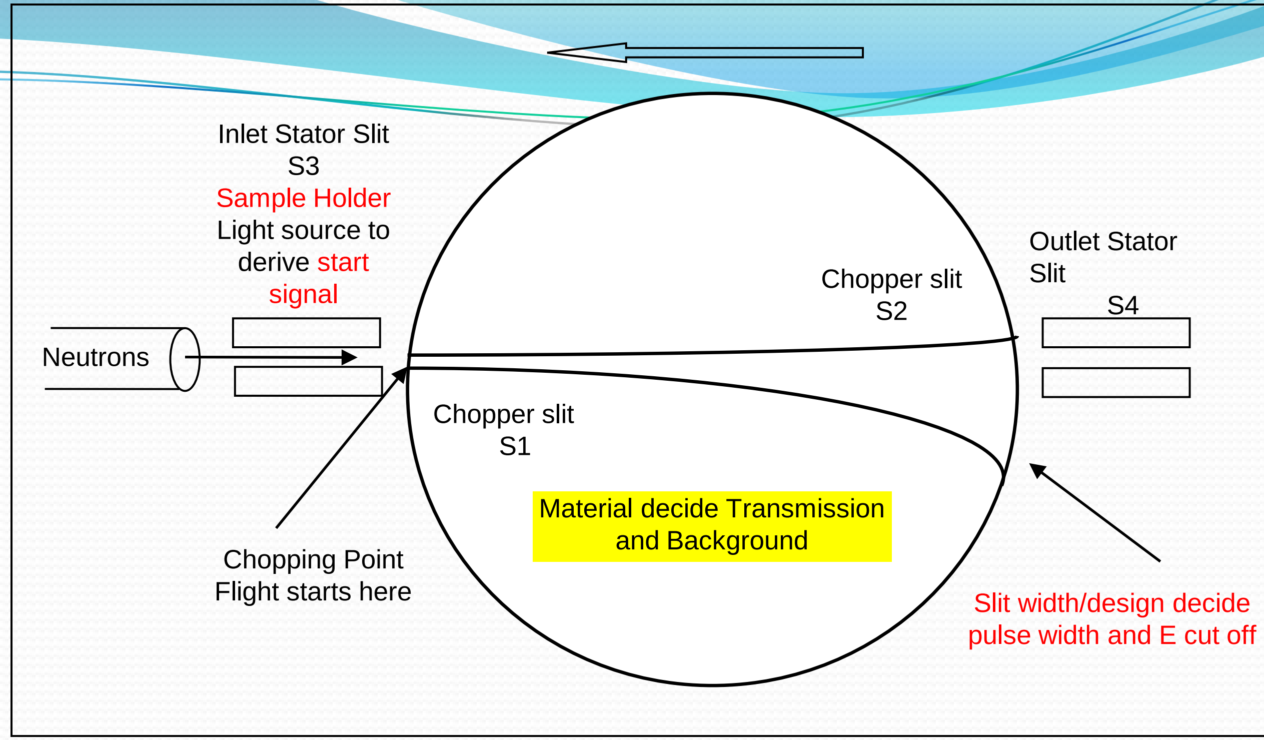
DHRUVA n_Tof



Neutron time of flight experiments facilitate energy discrimination of neutrons from a pulsed source because of their spatial distribution along the flight path making energy dependent cross section measurement possible



Chopper Design



What all we need to know?

- Pulse width
- ToF
- Resolution
- Transmission
- Slit Design

Radius (m.) = 0.3810000
Chopper Slit Widths (m.)=Inlet= 3.0000001E-04 Outlet= 1.2700001E-02
Stator Slit Widths (m.)=Inlet= 3.0000001E-04 Outlet= 8.0000004E-03
Flight Path (m.)= 10.38100

Table of Chopper Parameters for Different Rotation for given Radius, Slit Width
s and Flight Path length

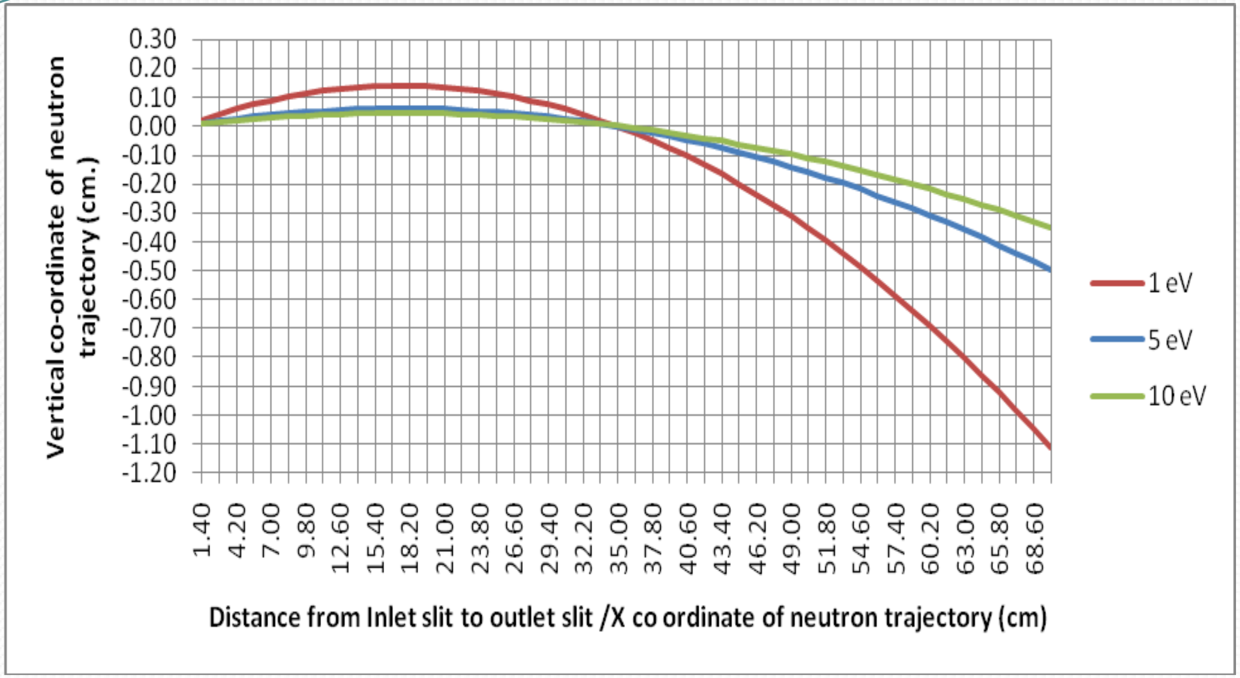
Time of Flight (n_ToF) and Neutron velocity (Vn) isfor neutron of cutoff energy
for given Path Length and Rotationalspeed. Parameters for Different energy are
in next table

Time in micro second velocity in m/s energy in eV

W(RPM)	E1 Cut(eV.)	v1cut(m/s)	Pls Width	T next P	n_T0F	E2Cut(eV)	v2cut(m/s)
1000.0	0.006732	1468.72	518.8	6981.2	7068.1	0.007	1486.998
2000.0	0.026927	2937.43	259.4	3490.6	3534.0	0.028	2973.996
3000.0	0.060586	4406.15	172.9	2327.1	2356.0	0.062	4460.994
4000.0	0.107709	5874.87	129.7	1745.3	1767.0	0.110	5947.992
5000.0	0.168296	7343.59	103.8	1396.2	1413.6	0.173	7434.990

E(eV)	V(m/s)	TOF(mic.S)	V Low(m/s)	V high (m/s)	dV (m/s)	dE(eV)	dE/E (Reso.)	Lamda
0.025	2186.97	4746.76	2186.74	2187.20	4.6069E-01	1.0533E-05	4.2131E-04	1.8088E+00
1.000	13831.59	750.53	13822.38	13840.81	1.8429E+01	2.6647E-03	2.6647E-03	2.8600E-01
5.000	30928.38	335.65	30882.38	30974.52	9.2146E+01	2.9794E-02	5.9587E-03	1.2790E-01
10.000	43739.34	237.34	43647.39	43831.68	1.8429E+02	8.4267E-02	8.4267E-03	9.0441E-02
15.000	53569.53	193.79	53431.67	53708.11	2.7644E+02	1.5481E-01	1.0321E-02	7.3845E-02
20.000	61856.76	167.82	61673.02	62041.60	3.6859E+02	2.3835E-01	1.1917E-02	6.3952E-02
25.000	69157.96	150.11	68928.36	69389.09	4.6073E+02	3.3310E-01	1.3324E-02	5.7200E-02
30.000	75758.75	137.03	75483.32	76036.20	5.5288E+02	4.3788E-01	1.4596E-02	5.2216E-02
35.000	81828.80	126.86	81507.56	82152.59	6.4503E+02	5.5179E-01	1.5765E-02	4.8343E-02

Slit Design



0.0250	61.640	-4.98339
0.0250	62.980	-5.33418
0.0250	64.320	-5.69530
0.0250	65.660	-6.06673
0.0250	67.000	-6.44848

Co-ordinates of Trajectory of Neutrons of energy 3.700000

Evergy(eV)	X(cm.)	Y (cm.)
3.7000	1.340	0.01018
3.7000	2.680	0.01951
3.7000	4.020	0.02799
3.7000	5.360	0.03562
3.7000	6.700	0.04240
3.7000	8.040	0.04834
3.7000	9.380	0.05343
3.7000	10.720	0.05767
3.7000	12.060	0.06106
3.7000	13.400	0.06361
3.7000	14.740	0.06530
3.7000	16.080	0.06615
3.7000	17.420	0.06615
3.7000	18.760	0.06530
3.7000	20.100	0.06361

Chopper disk slit let pass neutrons of acceptable range

Fusion-Fission hybrid

Option for Sustainable Energy source

Nuclear Fission

- Criticality safety
- MA
- LLFP
- Closed end FC cost
- Proliferation issues

Nuclear Fusion

- Source or Sink?
- Very small heat deposition
- Activation issues
- First wall design
- Self sustainability?

Renewable

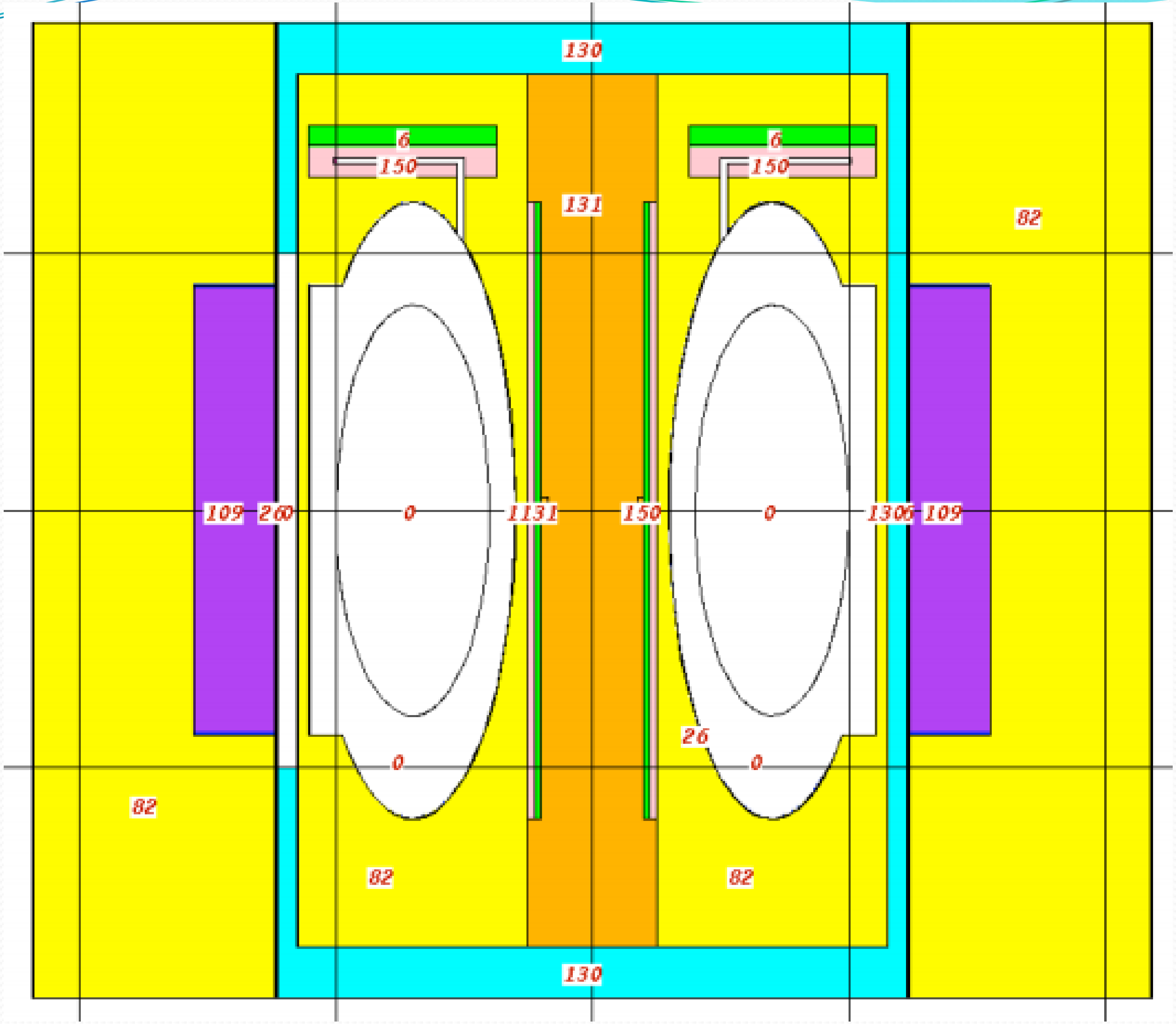
- Can share load but cannot bear load
- No safe/effective energy storage technology

Fusion-Fission Hybrid

- Get rid of criticality safety issue
- Sub Lawson operation possible
- Neutrons can be utilized for fissile breeding and incineration of MA Transmutation of LLFP

What geometry? -Co-axial Cylindrical

- Make provision for
  - Central solenoid coils
  - Toroidal field coils
  - Poloidal field coils
  - Fusion chamber
  - Tritium breeding
  - Cryostat (?)
  - Proper shielding for all these
- Now fission blanket can come


130
6
150
6
150
131
82
109
260
0
1131
150
0
1306
109
26
0
0
82
82
82
130

Can a fusion system drive a **sub-critical** fission system?

Widely accepted answer is Yes it can.
...... if it is not a very big (low neutron density) source.

In a particular FFH design (200 MW of 14.5 MeV neutron power) results in a surface source of ~**1.6E13 n/s.cm2** at the Inner wall of the fission blanket

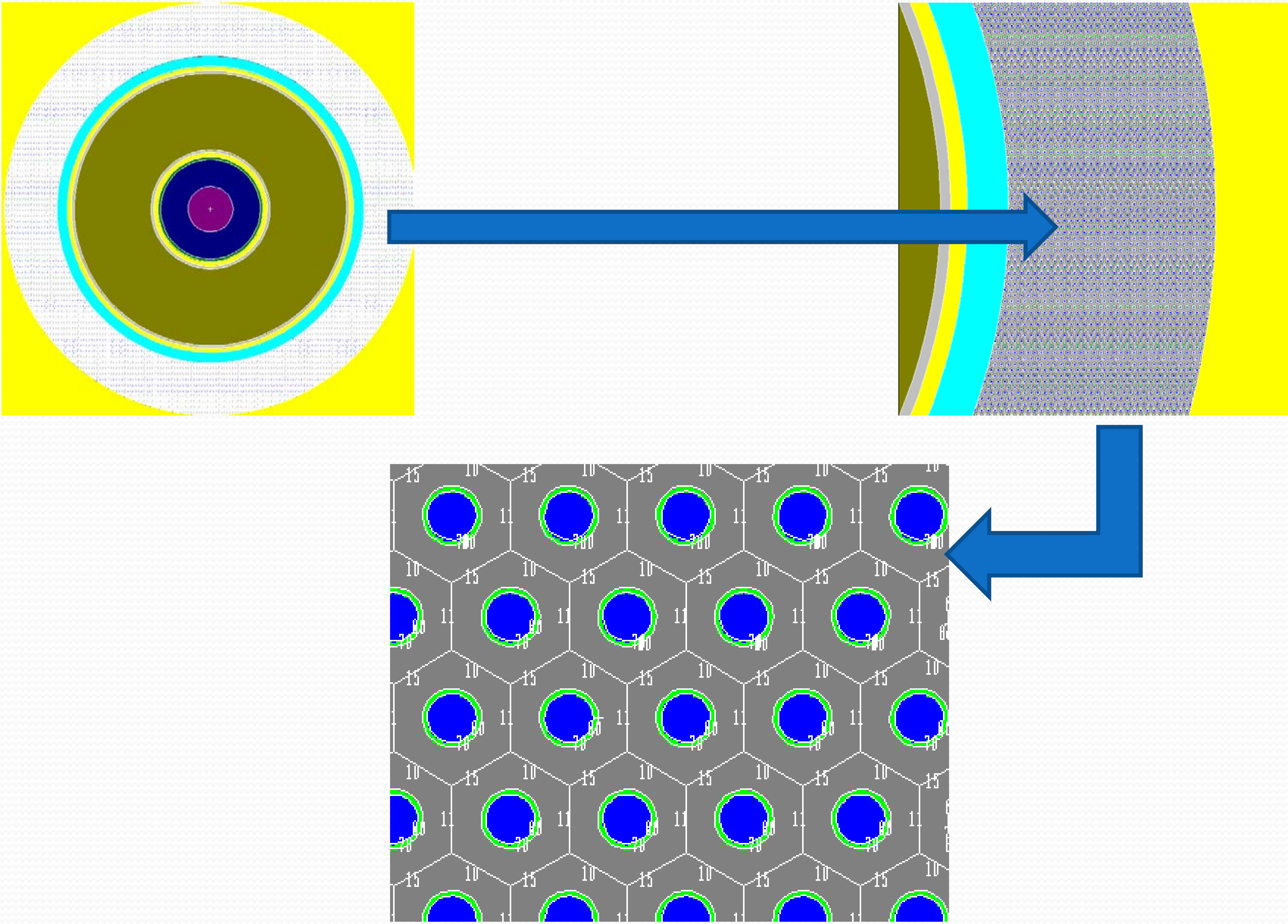
A fission blanket design which offers an area of 2.7e5 cm2 to incoming neutron can intercept **4.4E+018** neutrons/second (~141 MW fission power)

A multiplication of ~21.5 can result in 3000MWt (~ 1000MWe) Fission Power

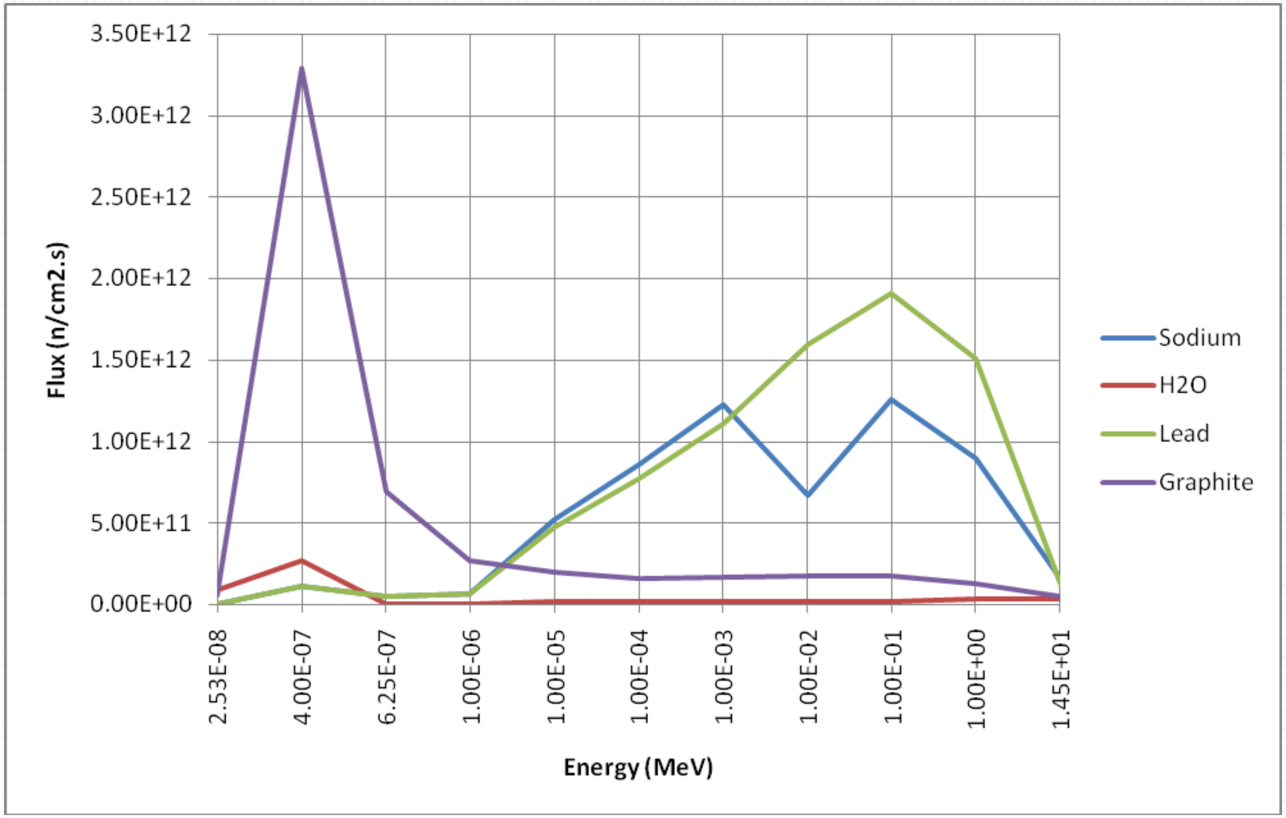
A source multiplication of ~28 can result in 3000MWt (~ 1000MWe) Fission Power and account for 30% leakage losses.

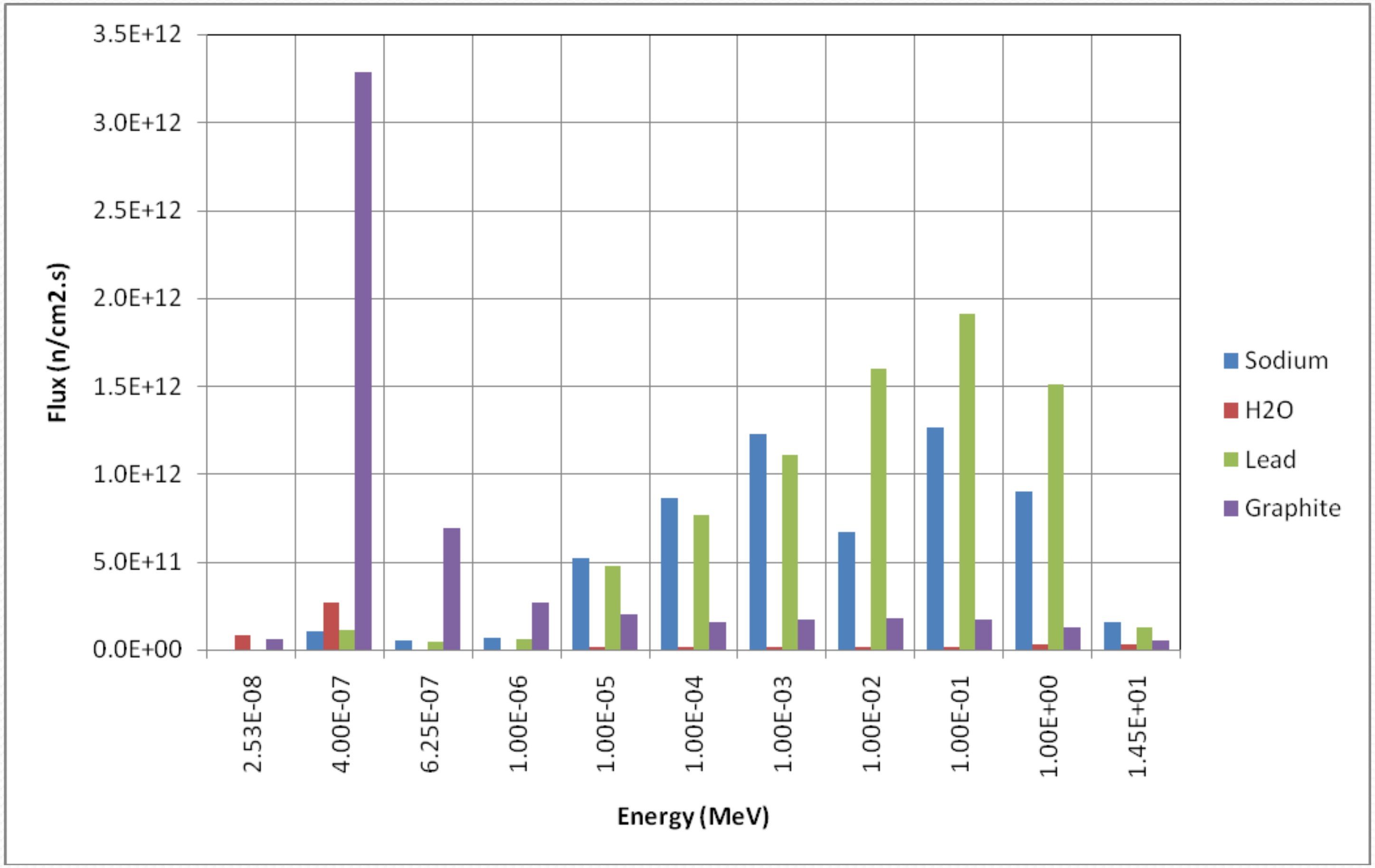
It does look promising but it is not good. Effective Multiplication (required) for hot operating condition will 0.964. Criticality safety issue will still be there

200 MW of 14.5 MeV neutron power ~8.6e18 n/s



Flux Distribution in fission blanket region





Flux (n/cm2.s)
3.5E+12
3.0E+12
2.5E+12
2.0E+12
1.5E+12
1.0E+12
5.0E+11
0.0E+00
2.53E-08
4.00E-07
6.25E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.45E+01
Energy (MeV)
Sodium
H2O
Lead
Graphite

Thank You !