UTILIZATION POSSIBILITIES OF THORIUM AS NUCLEAR FUEL

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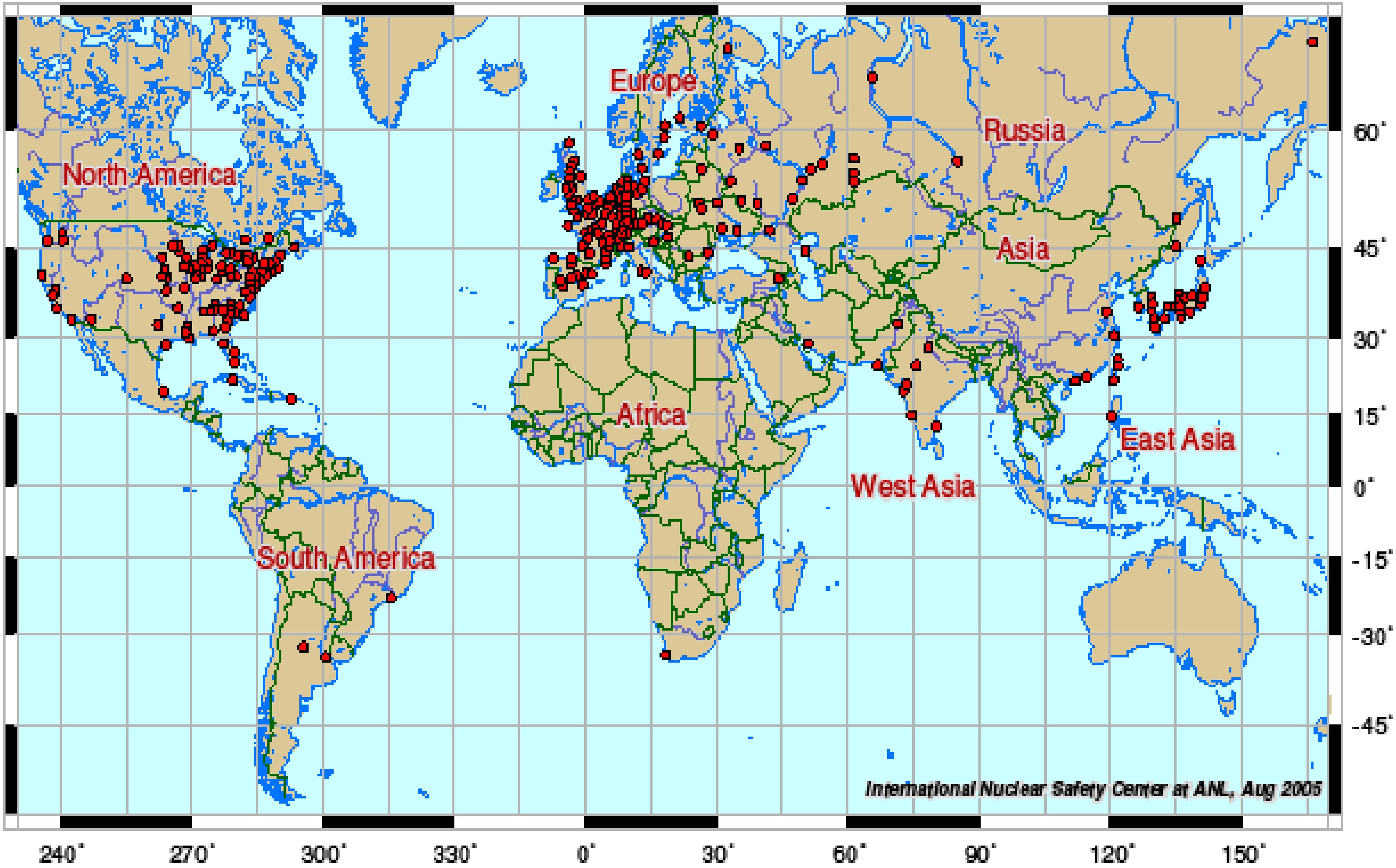


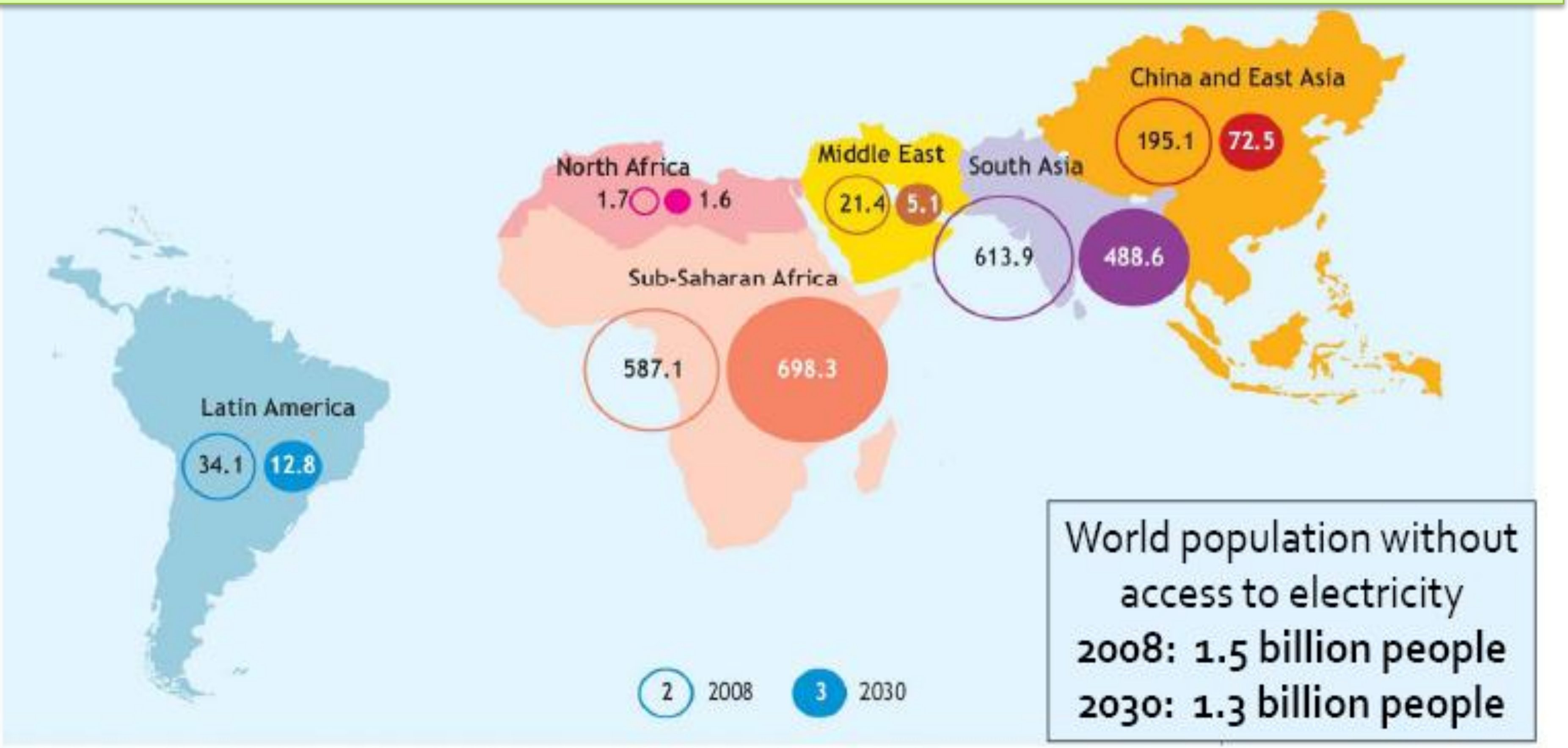
International Nuclear Safety Center at ANL, Aug 2005

WORLD NUCLEAR POWER PLANTS CONCENTRATION

World Energy Outlook 2009

Number of people without access to electricity in the Reference Scenario (millions)

750 000 000 people have even not seen electrical light throughout their life !!!



World population without access to electricity
2008: 1.5 billion people
2030: 1.3 billion people

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

$35 billion per year more investment than in the Reference Scenario would be needed to 2030 – equivalent to just 5% of global power-sector investment – to ensure universal access

Conventional nuclear reactors operate on once-through basis

Exploitation capability of nuclear resources

- ~ 1 % of the uranium resources will be used with plutonium recycle in LWRs
- Thorium reserves, 3 times abundant than uranium reserves are **not used**!!!

Sustainable nuclear economy must use all nuclear resources!!!

ESTIMATES OF THORIUM RESOURCES

COUNTRY	EXTRACTABLE(<80USD/KG) SOURCES,TON OF THORIUM (Geoscience Australian Estimated, 2006)	ECONOMICALLY .EXTRACTABLE SOURCES, TON OF THORIUM (USGS Mineral Commodity Summary,1999)
AUSTRALIA	**452000**	**300000**
BRAZIL	**221000**	**16,000**
CANADA	**44000**	**100000**
EGYPT	**100000**	
GREENLAND	**54000**	
INDIA	**319000**	**290000**
NORWAY	**132000**	**170000**
RUSSIA FED	**75000**	
S. AFRICA	**18000**	**35000**
TURKEY	**344000 (780000)**	
USA	**400000**	**160,000**
VENEZUELA	**300000**	
OTHER	**33000**	**95000**
WORLD	**2492000**	**1200000**

1. Alternative mixed fuels in CANDU reactors
2. Nuclear Fusion Energy
3. Accelerator Driven Systems

- **Typical burn up values in CANDU reactor, LWR, FBR and HTR are of the order of <10000 (~7.000), 30.000 to 40.000, and 100.000 MW.D/MT, respectively.**

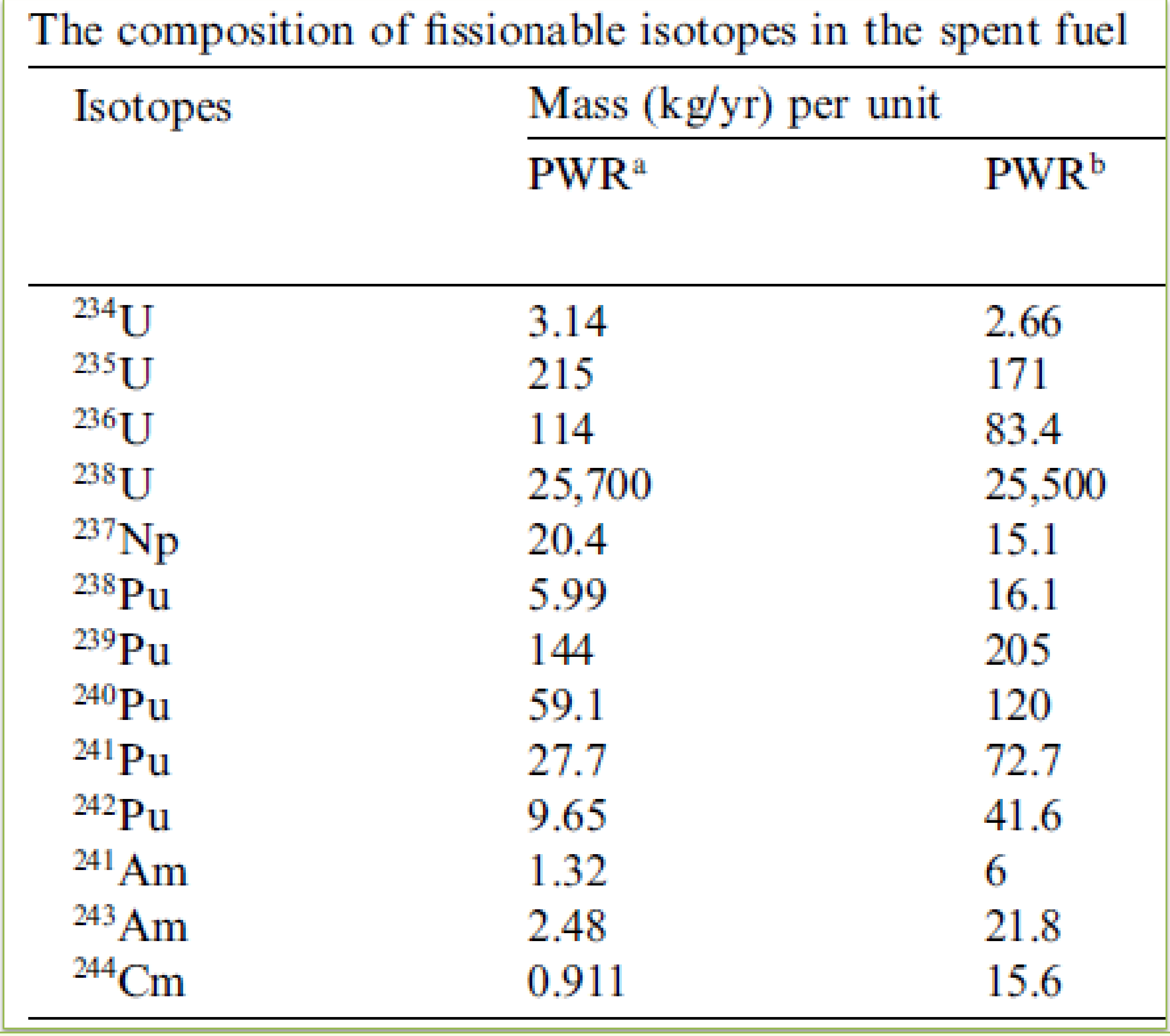
Extended burn up and long operation periods are possible with alternative fuels in CANDU Reactors (conventional technology) and HTR (Generation-IV)

- **LWR spent fuel**
- **Reactor Grade Plutonium**
- **Minor Actinides**

Civilian nuclear power plants have produced nearly **1,700 tons of reactor-grade plutonium**, of which about 274 tons have been separated and the rest is stored at reactor sites embedded in spent fuel

Nuclear power plants in the European Union (~ 125 GW) produce yearly approximately **2500 tons of spent fuel**, containing about **25 tons of plutonium and 3.5 tons of the “minor actinides (MA)” neptunium, americium, and curium and 3 tons of long-lived fission products**

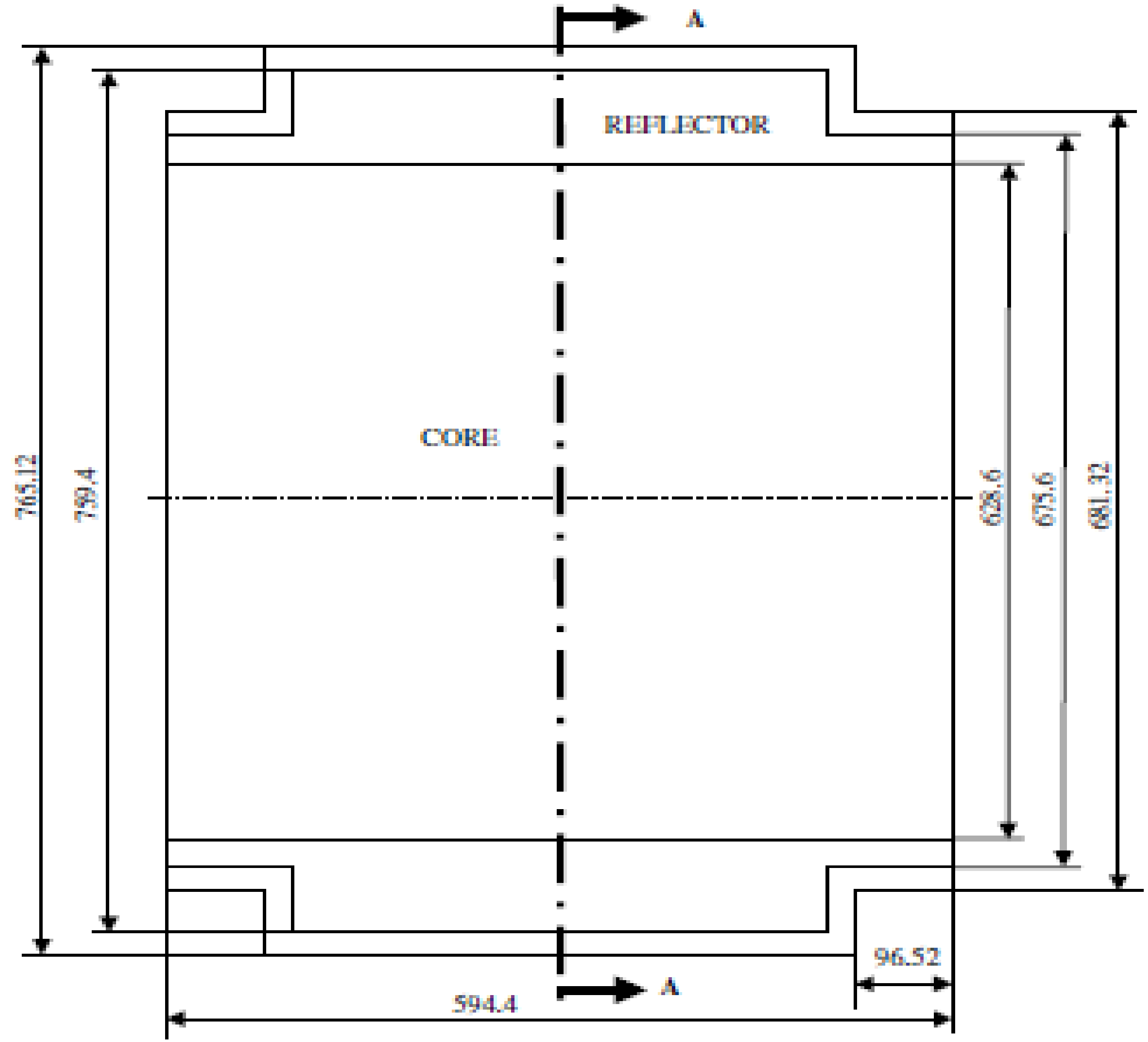
Re-utilization of LWR spent fuel in CANDU reactors



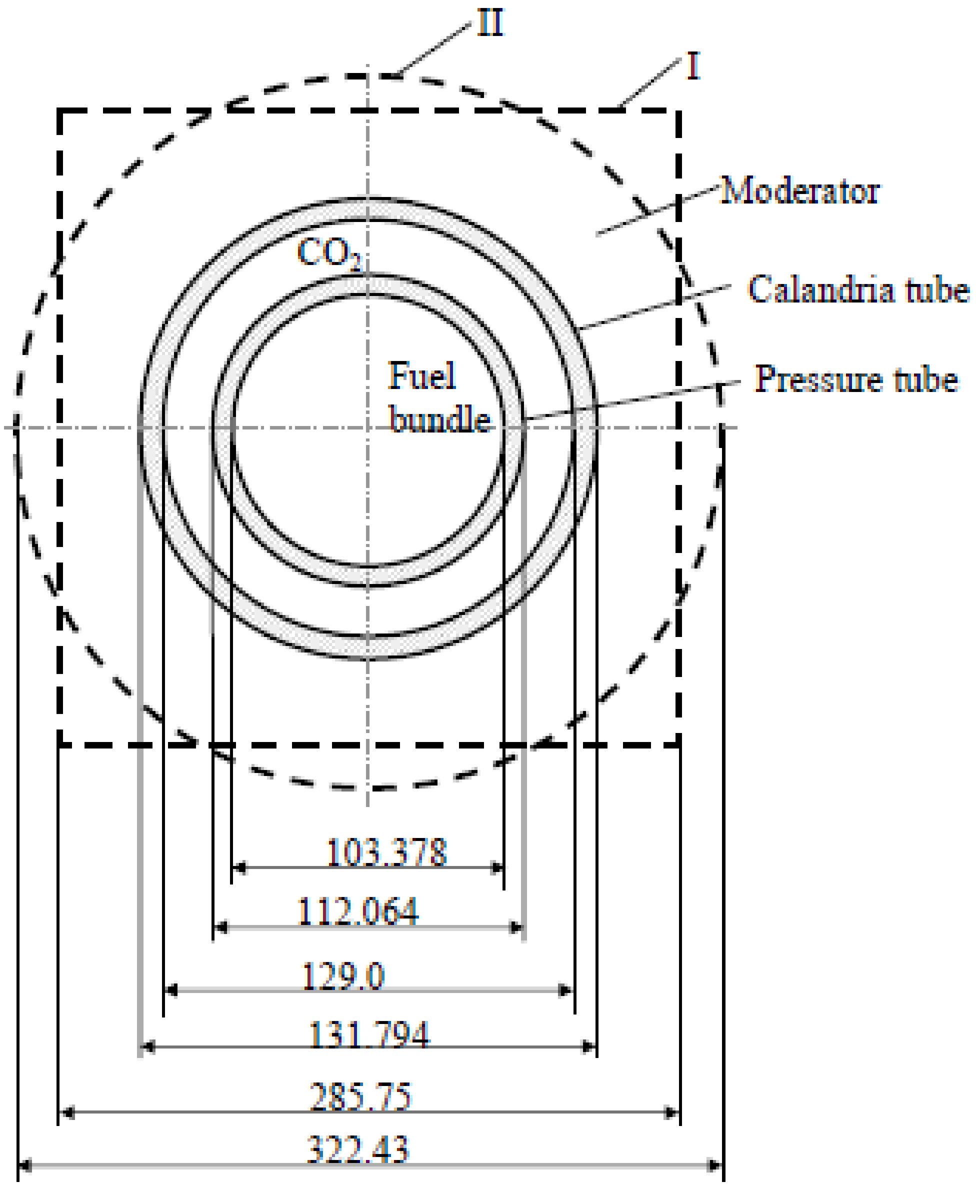
The composition of fissionable isotopes in the spent fuel

Isotopes	Mass (kg/yr) per unit	
	PWR[a]	PWR[b]
^{234}U	3.14	2.66
^{235}U	215	171
^{236}U	114	83.4
^{238}U	25,700	25,500
^{237}Np	20.4	15.1
^{238}Pu	5.99	16.1
^{239}Pu	144	205
^{240}Pu	59.1	120
^{241}Pu	27.7	72.7
^{242}Pu	9.65	41.6
^{241}Am	1.32	6
^{243}Am	2.48	21.8
^{244}Cm	0.911	15.6

b) Pressurised-water reactor waste fuel with plutonium recycle, 1000-MWel reactor, 80% capacity factor, 33 MWd/kg, 32.5% thermal efficiency, 150 days after discharge.Manson, B., Pigford, T. H., Levi, H. W. "Nuclear Chemical Engineering", New York: McGraw-Hill, 1981



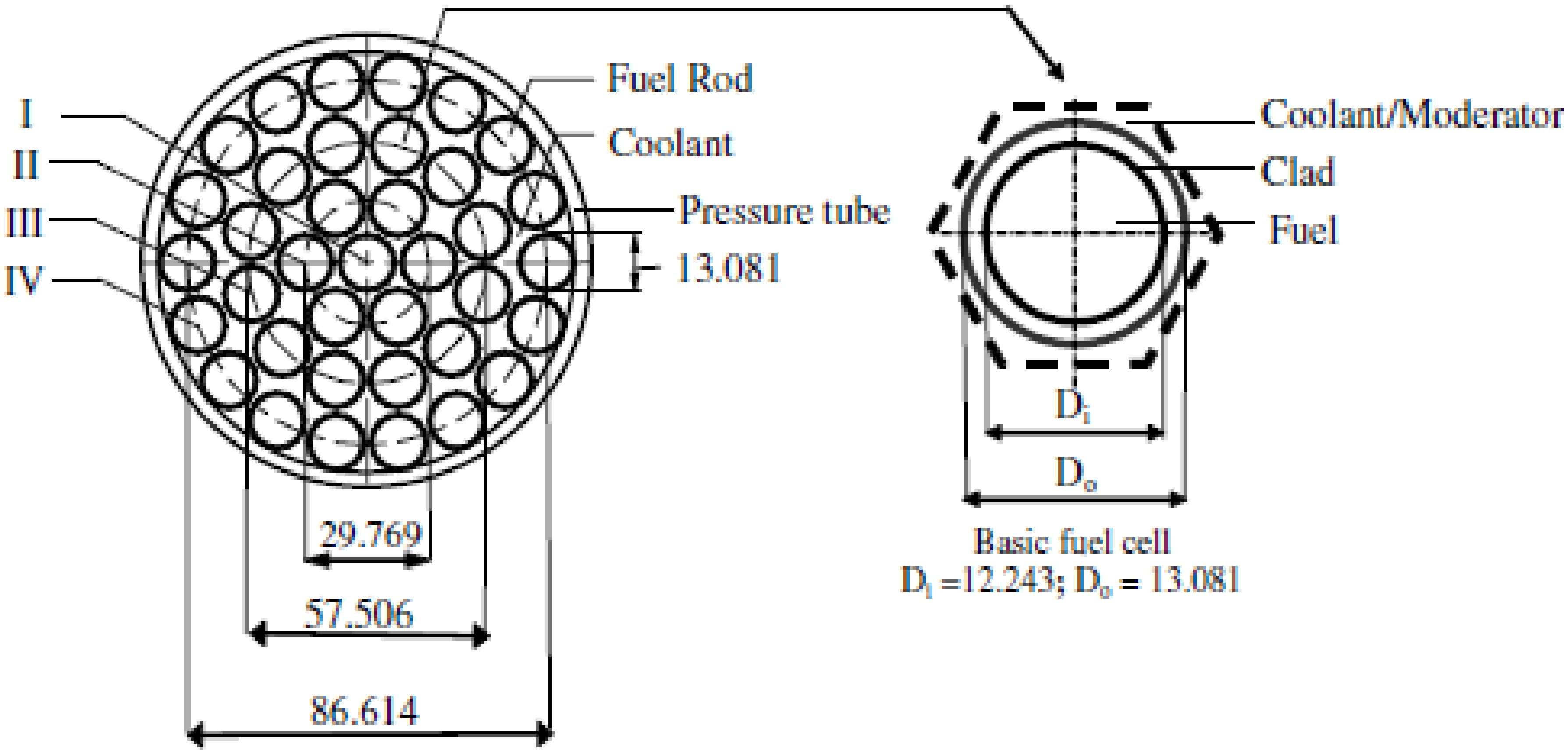
CANDU GENTILLY-II design (388 fuel channels)



Cross sectional view of one fuel channel

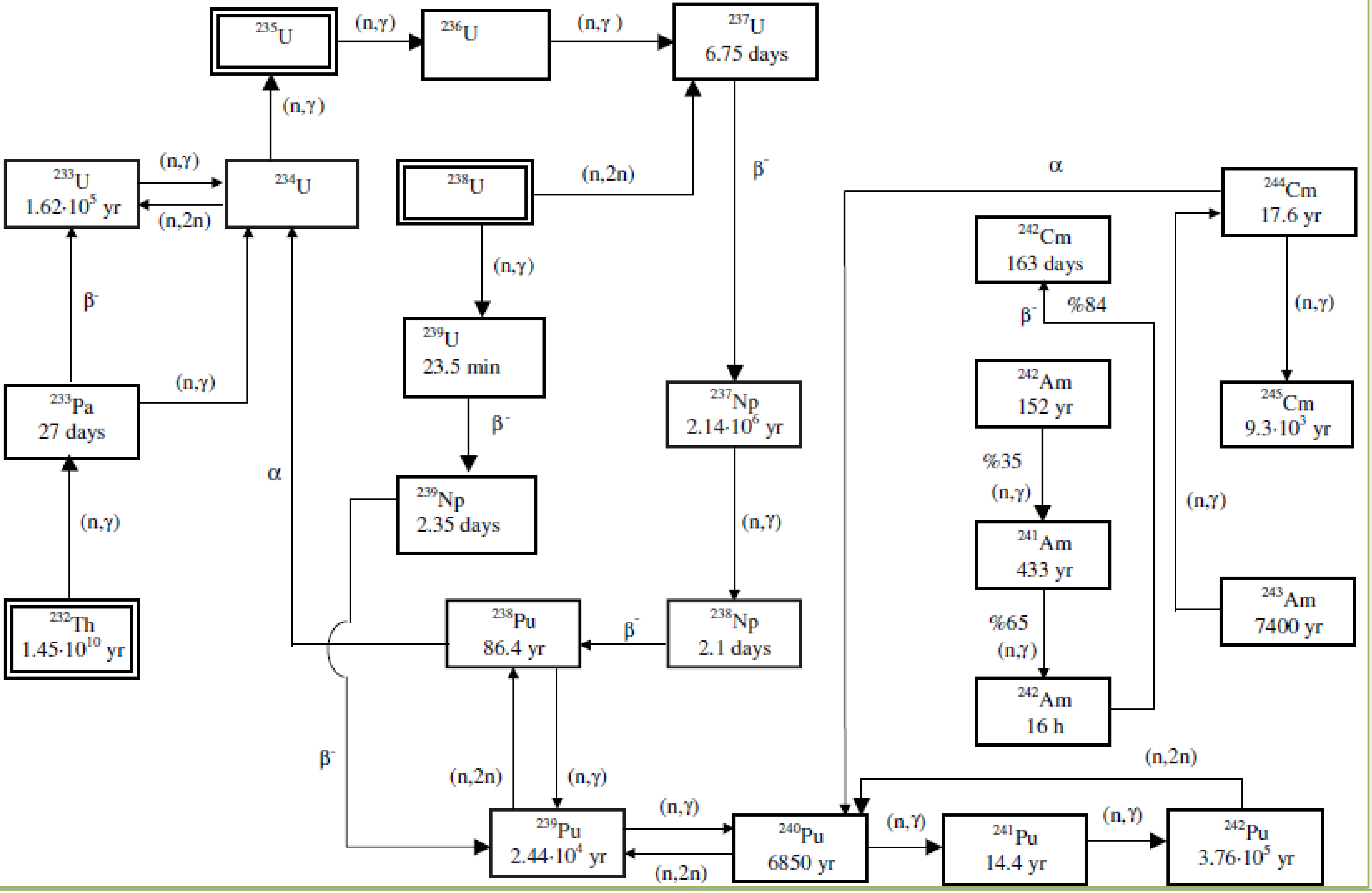
I- Original CANDU square lattice cell.

II- Equivalent diameter, used in calculations

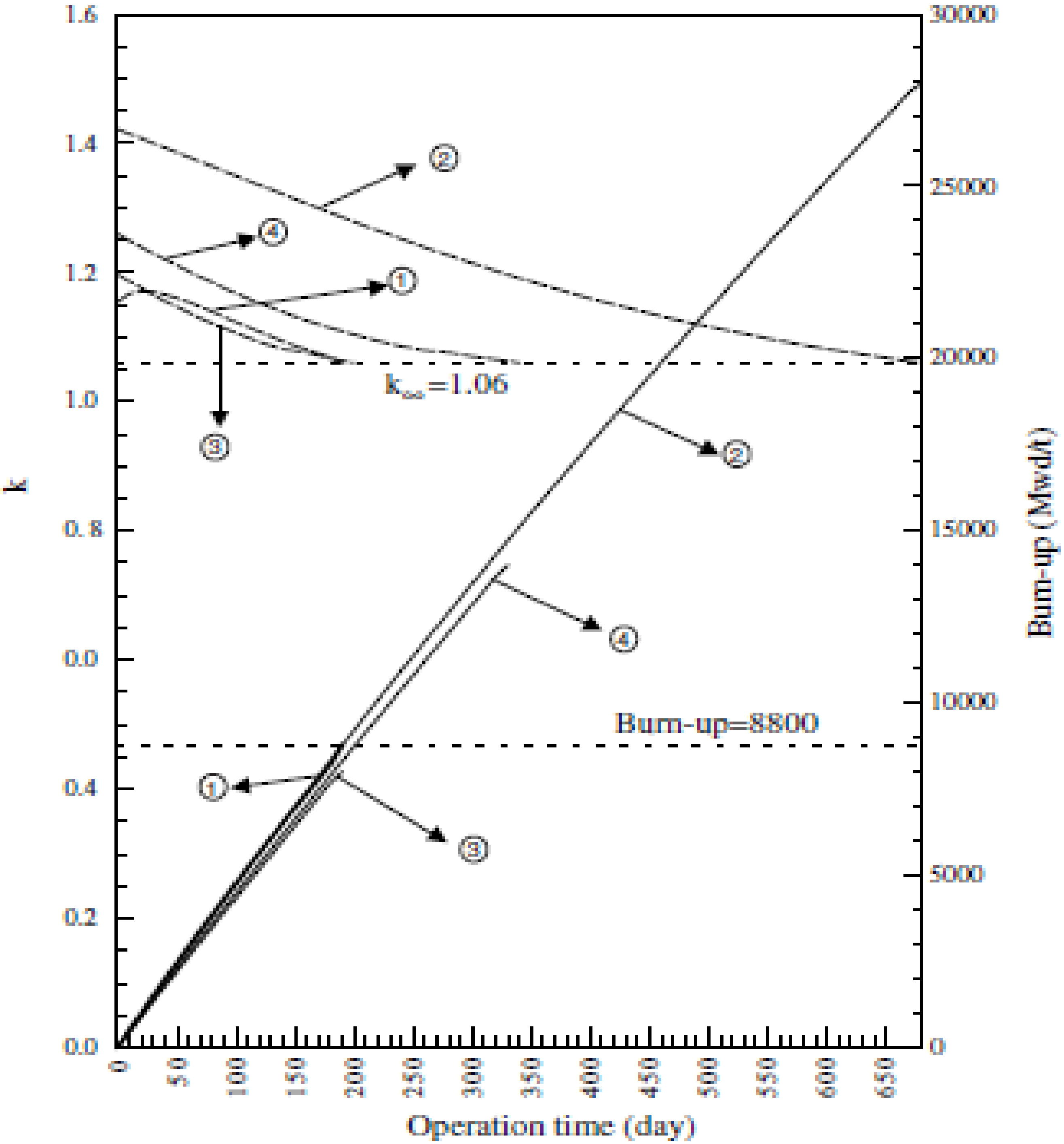


Placement of 37-fuel rods in the bundle
(Dimensions are in millimeters, not in scale)

- Mode ①: 100 % natural UO_2 as the basic reference fuel in the present CANDU reactors.
- Mode ②: 100 % LWR spent fuel as a potential fuel to realize an extended burn-up in CANDU reactors.
- Mode ③: 50 % LWR spent fuel + 50 % ThO_2 as an attempt to exploit thorium reserves.
- Mode ④: 60 % LWR spent fuel + 40 % ThO_2 as a similar attempt with a higher fissile inventory to realize a higher burn-up grade than in item 3.



Major nuclear reactions and radioactive transformation processes in the course of plant operation

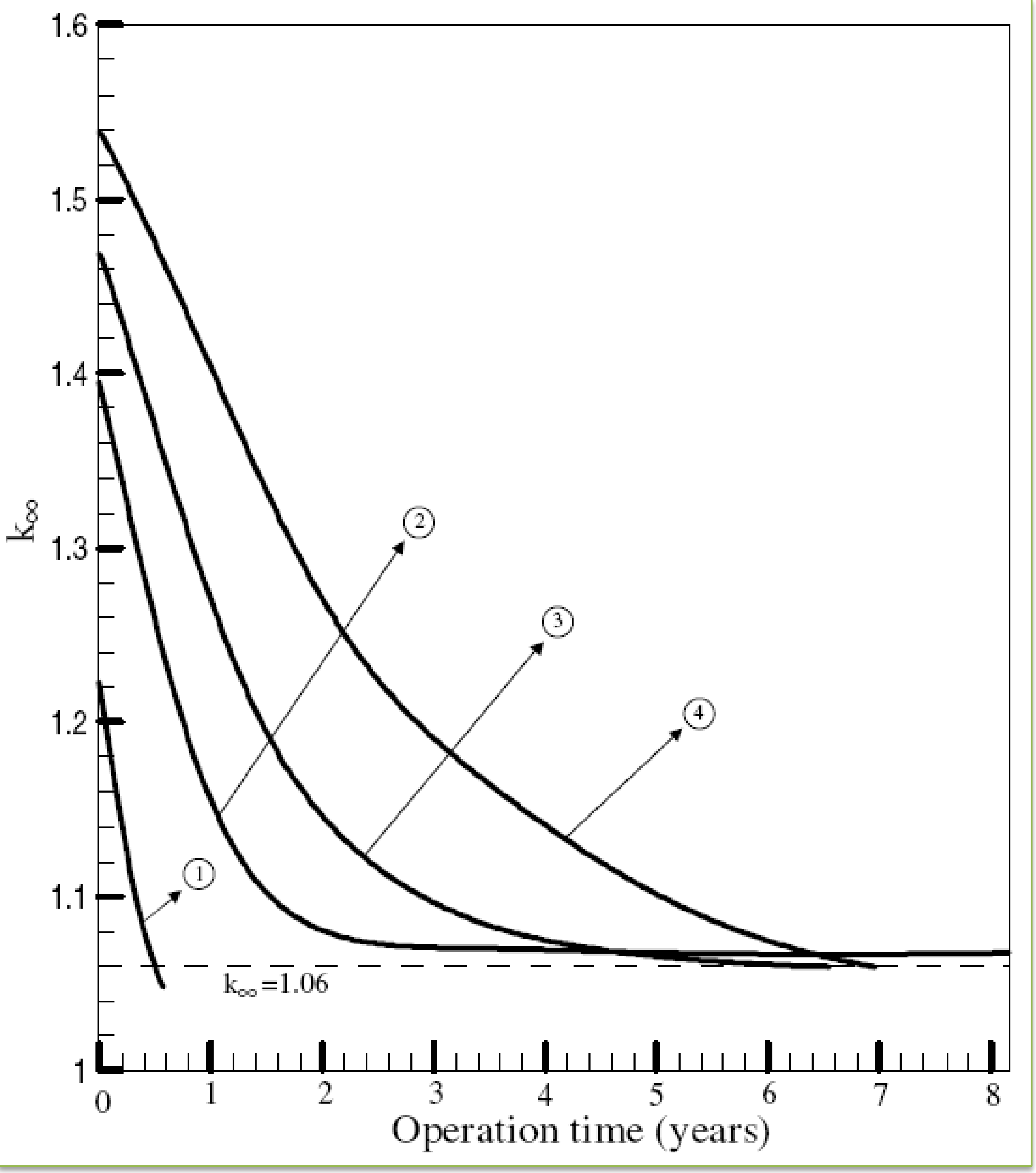

1.6
1.4
1.2
1.0
0. 8
0.0
0.4
0.2
0.0
k
30000
25000
20000
15000
10000
5000
0
Burn-up (Mwd/t)
②
④
①
③
k∞=1.06
②
④
Burn-up=8800
①
③
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Operation time (day)

INCREASED FUEL BURN UP IN A CANDU THORIUM REACTOR USING REACTOR GRADE PLUTONIUM

The composition of the reactor grade plutonium

ISOTOPES	Reactor grade plutonium initial [%]
^{238}Pu	1.0
^{239}Pu	62.0
^{240}Pu	24.0
^{241}Pu	8.0
^{242}Pu	5.0

IAEA, Potential Of Thorium Based Fuel Cycles to Constrain Plutonium and Reduce Long Lived Waste Toxicity, IAEA-TECDOC-1349, International Atomic Energy Agency, Vienna, Austria, p.55, Table 3.3.6 (2003).



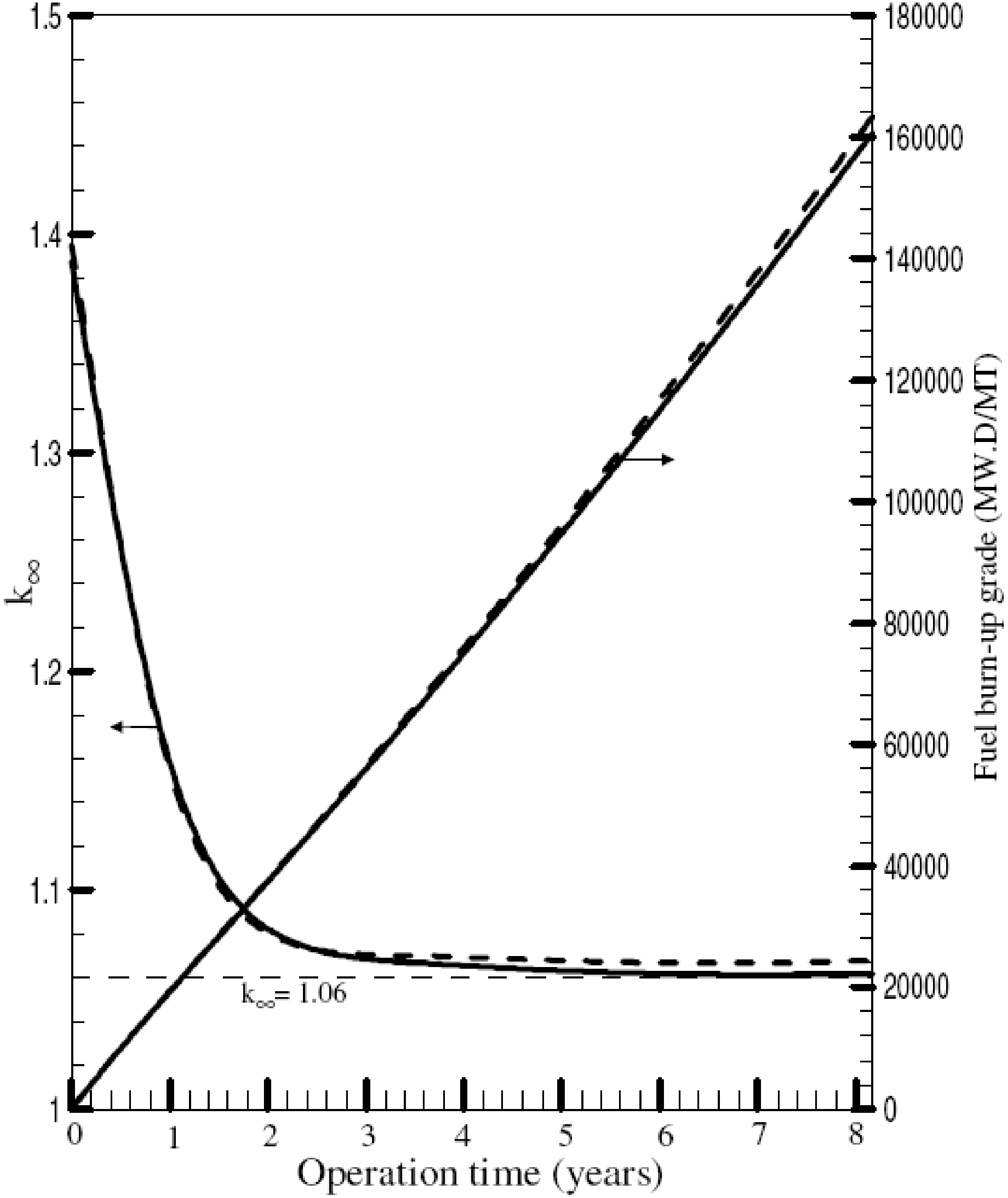
Lattice criticality k_∞

(1) 98 % ThO_2 + 2 % PuO_2

(2) 96 % ThO_2 +4 % PuO_2

(3) 94 % ThO_2 + 6 % PuO_2

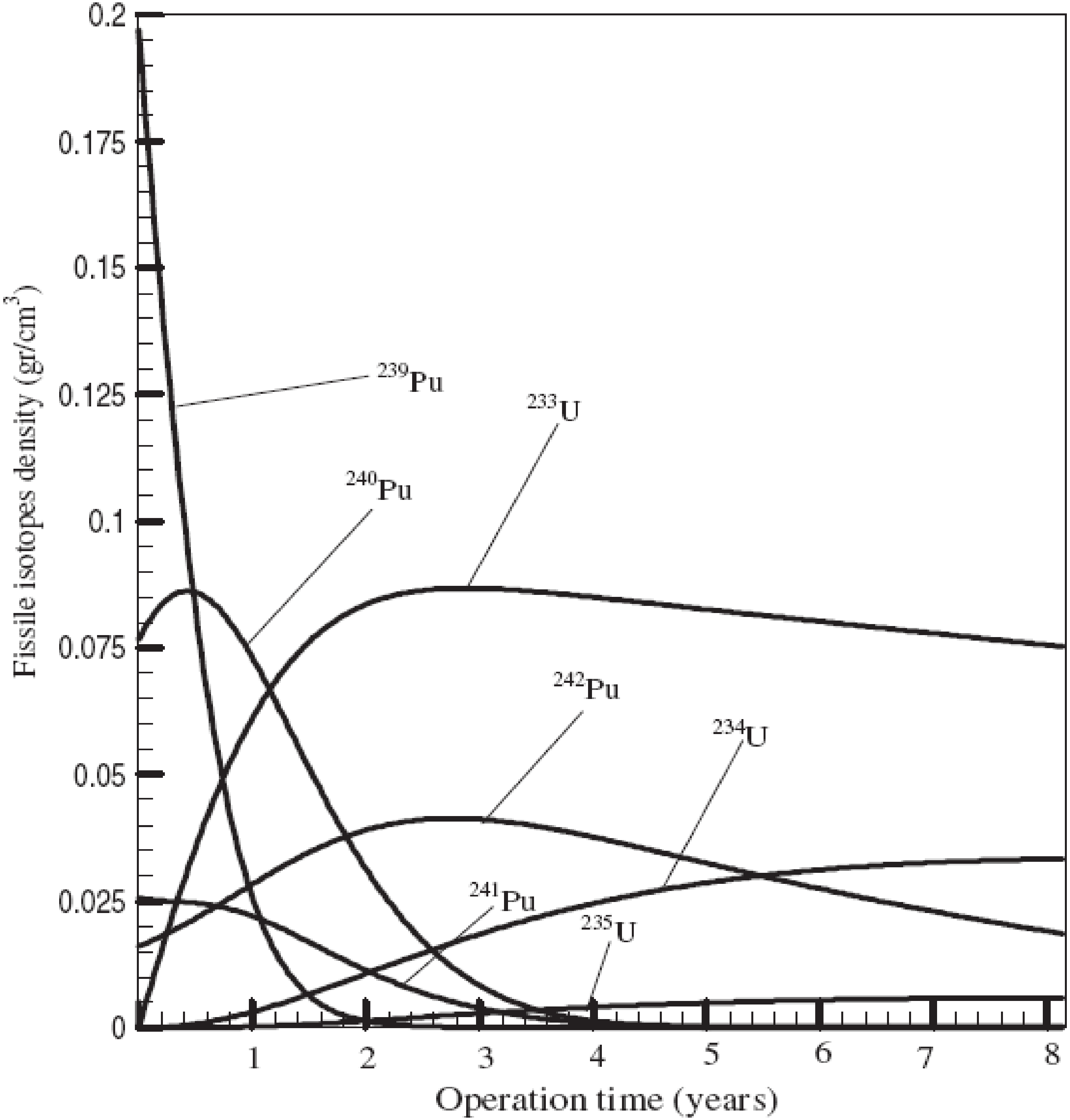
(4) 90 % ThO_2 + 10 % PuO_2



Lattice criticality k_∞ and fuel burn-up grade

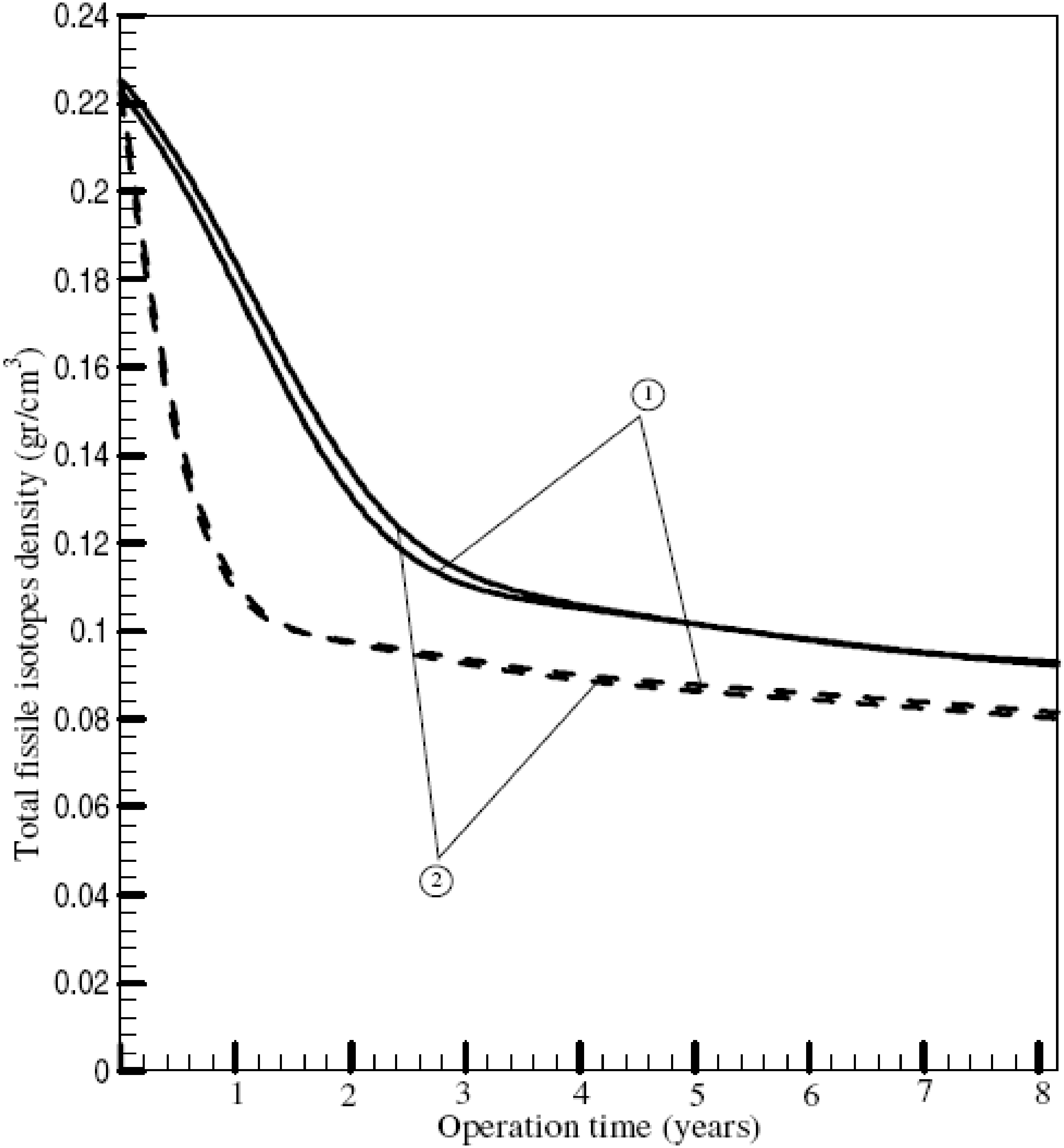
— 91 % ThO_2
+ 5 % UO_2 + 4 % PuO_2

---- 96 % ThO_2
+ 4 % PuO_2



Density variations of the main fissionable isotopes in the peripheral fuel row with

96 % ThO_2 + 4 % PuO_2



Accumulated densities of fissile isotopes ($^{233}U + ^{235}U + ^{239}Pu + ^{241}Pu$)

(1) 96 % ThO_2 + 4 % PuO_2 ;

(2) 91 % ThO_2 + 5 % UO_2+ 4 % PuO_2

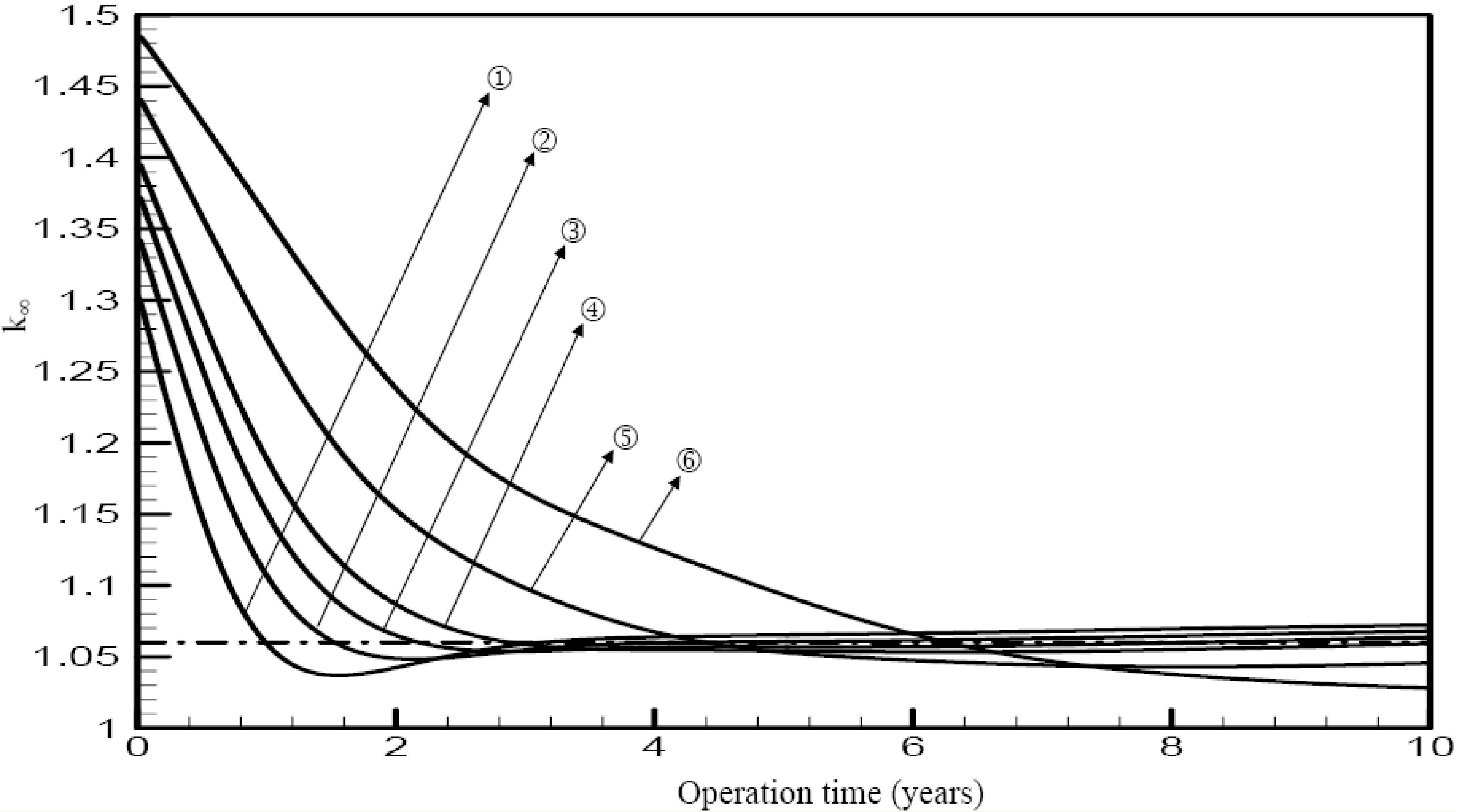
— central fuel row

- - - peripheral fuel row

MINOR ACTINIDE BURNING IN A CANDU THORIUM REACTOR

ISOTOPES	Mass (kg/year) per unit PWR
^{237}Np	15.1
^{238}Pu	16.1
^{239}Pu	205
^{240}Pu	120
^{241}Pu	72.7
^{242}Pu	41.6
^{241}Am	6
^{242m}Am	0.00793
^{243}Am	21.8
^{244}Cm	15.6
^{245}Cm	1.74

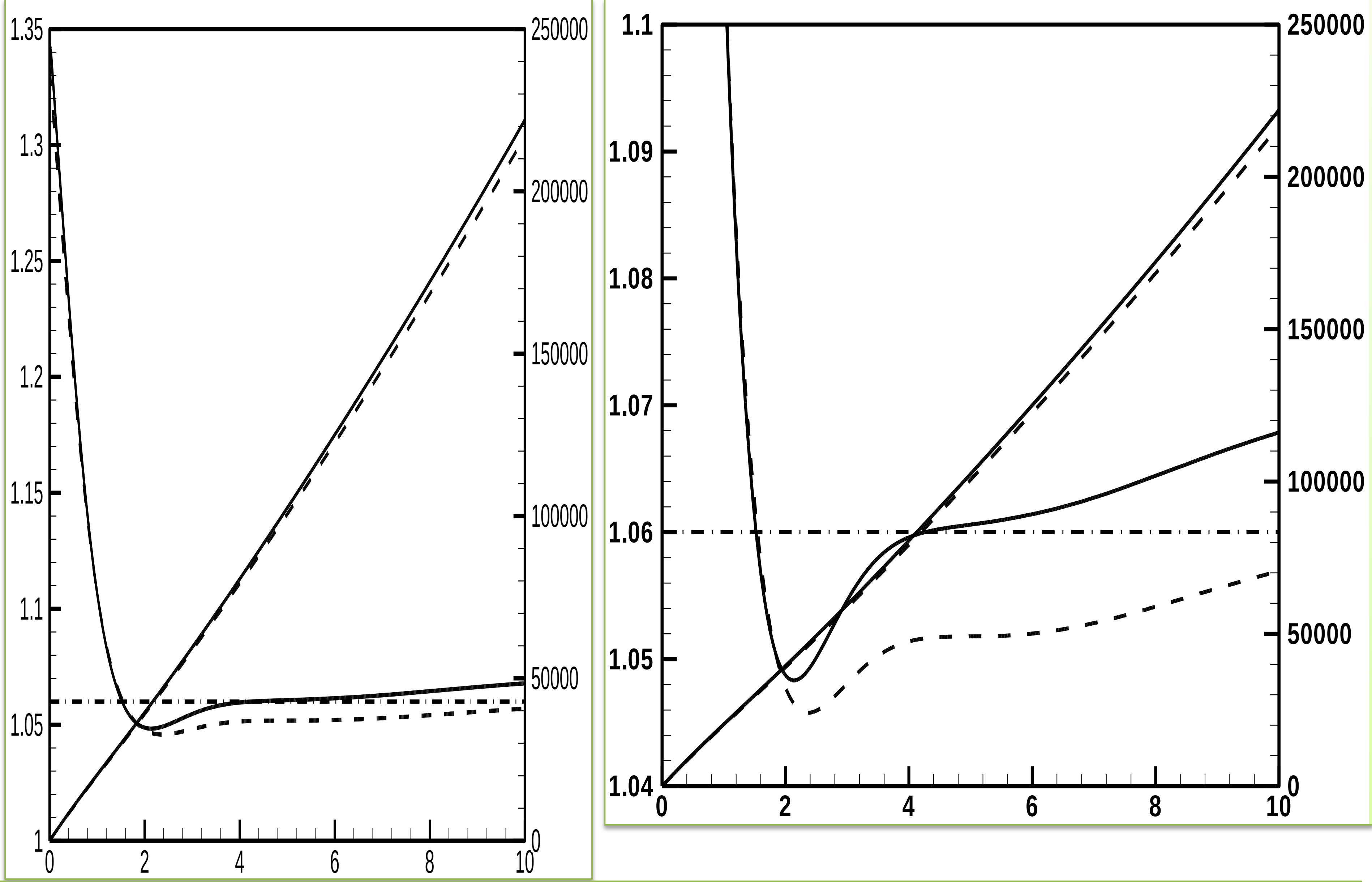
Composition of MA in the spent fuel of a light water reactor
Pressurised-water reactor, fuel with plutonium recycle, 1000-MW$_{el}$ reactor, 80% capacity factor, 33 MW.D/kg, 32.5 % thermal efficiency, 150 days after discharge (Nuclear Chemical Engineering, p. 370, Table 8.5)



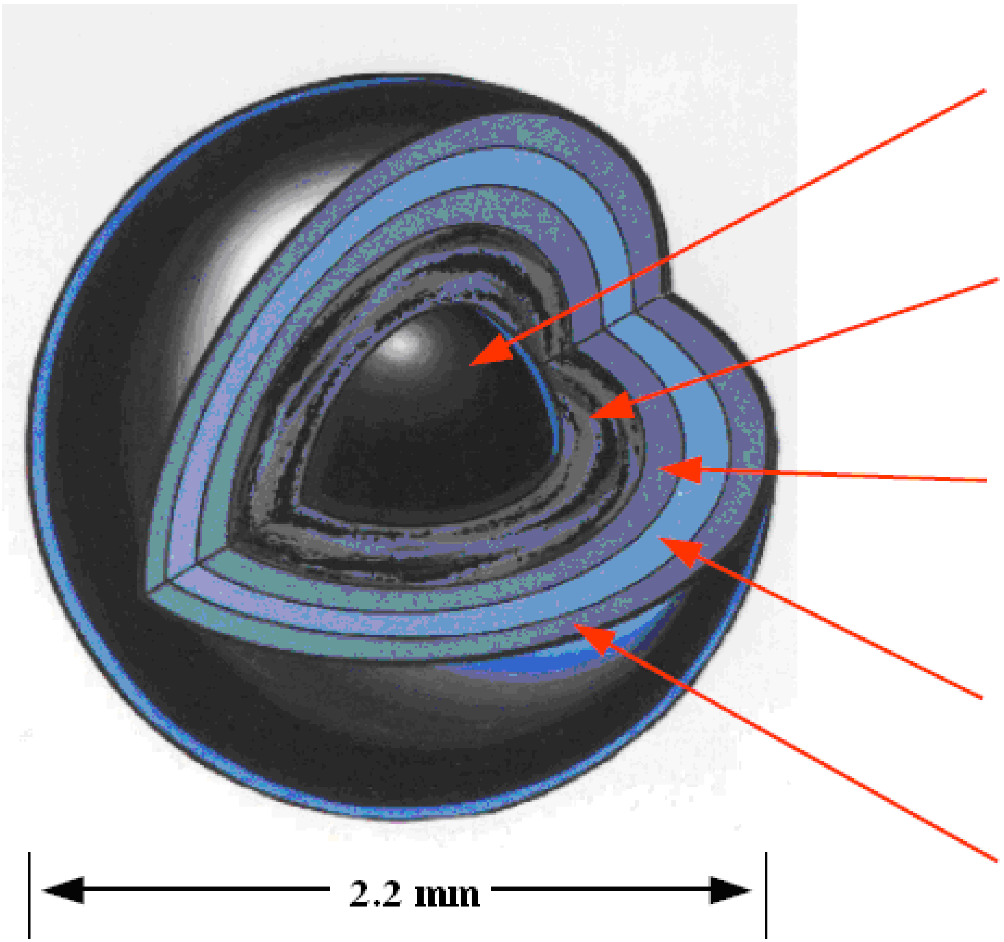
Temporal variation of the lattice criticality k_∞

①: % 96 ThO_2 + % 4 MAO_2; ②: % 95 ThO_2 + % 5 MAO_2; ③: % 94 ThO_2 + % 6 MAO_2

④: % 93 ThO_2 + % 7 MAO_2; ⑤: % 90 ThO_2 + % 10 MAO_2; ⑥: % 85 ThO_2 + % 15 MAO_2



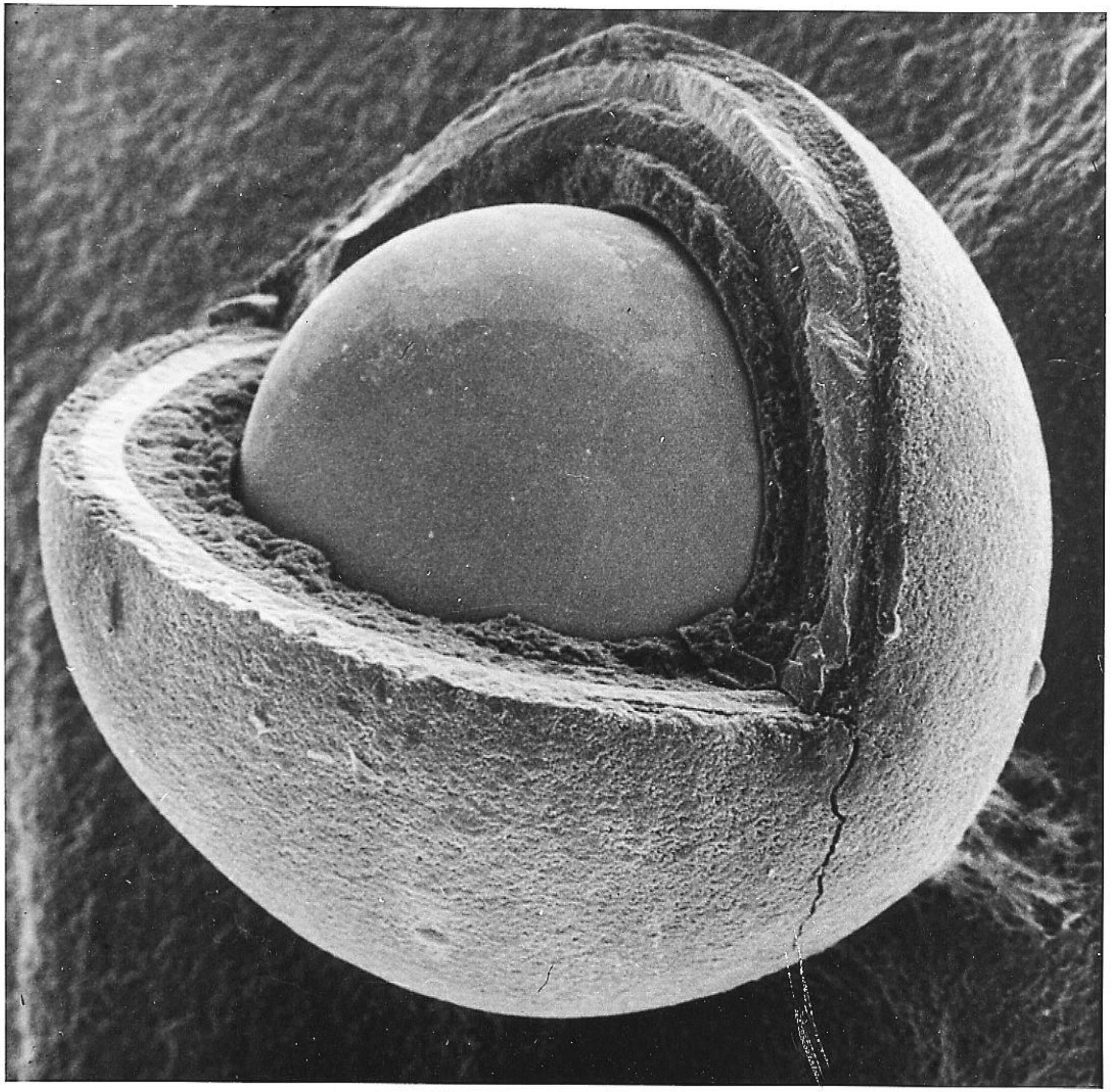
Variation of the lattice criticality k_∞ and the fuel burn-up grade
solid line: % 95 ThO_2 + % 5 MAO_2; dashed line: % 90 ThO_2 + % 5 MAO_2 + % 5 UO_2



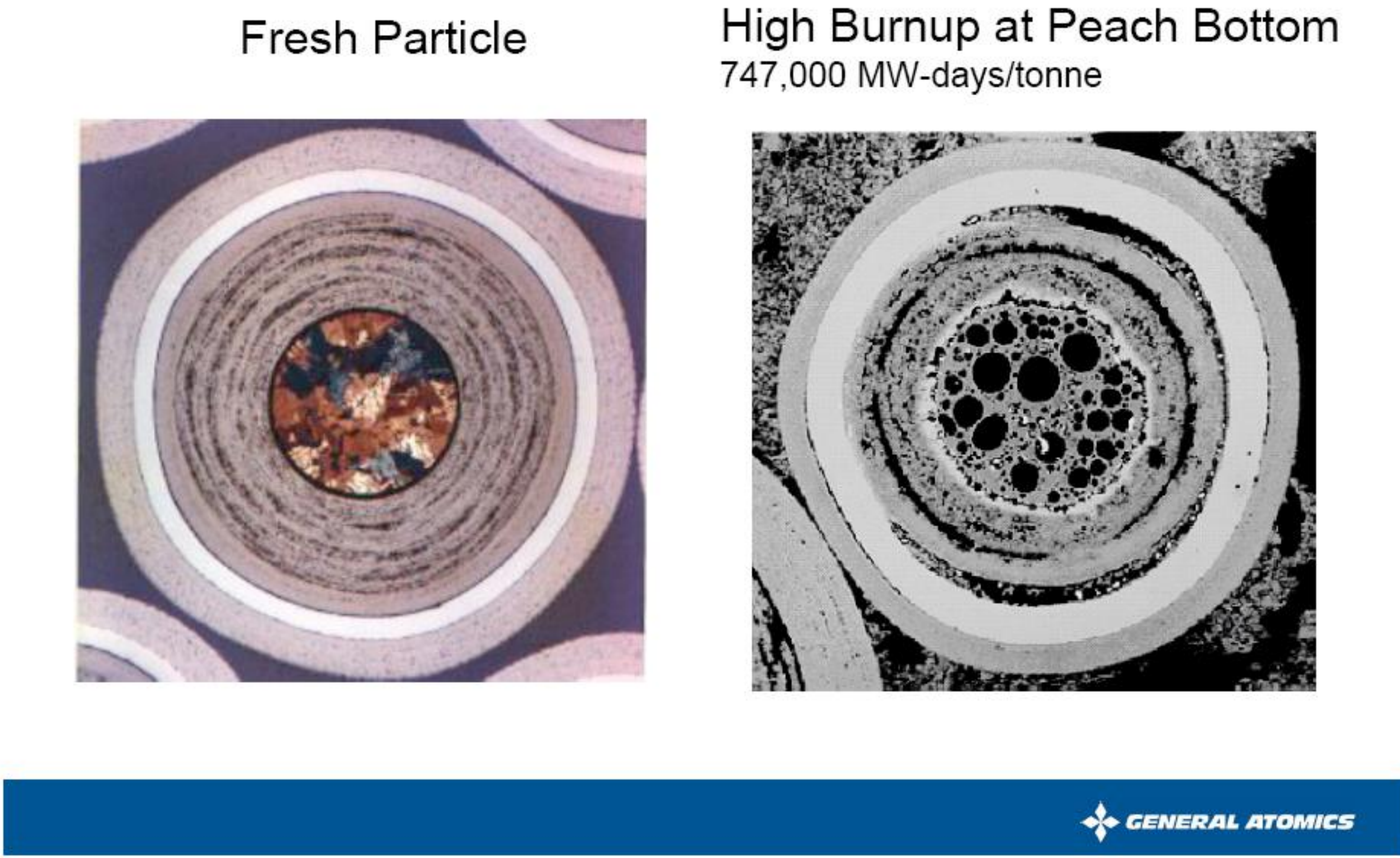
COMPONENT/PURPOSE

- **Fuel Kernel**
  - Provide fission energy and neutrons
  - Retain fission products
  - Control particle oxygen potential
- **Buffer layer (porous carbon layer)**
  - Attenuate fission recoils
  - Void volume for fission gases
  - Accommodates kernel swelling
- **Inner Pyrocarbon (IPyC)**
  - Prevent Cl attack of kernel during manufacture
  - Provides structural support for SiC
  - Retains gaseous fission products
- **Silicon Carbide (SiC)**
  - Primary load bearing member
  - Retain gas and metal fission product
- **Outer Pyrocarbon (OPyC)**
  - Provides structural support for SiC
  - Retains gaseous fission products
  - Provide bonding surface for compacting

TRISO coating provides structure stability and contains fission products



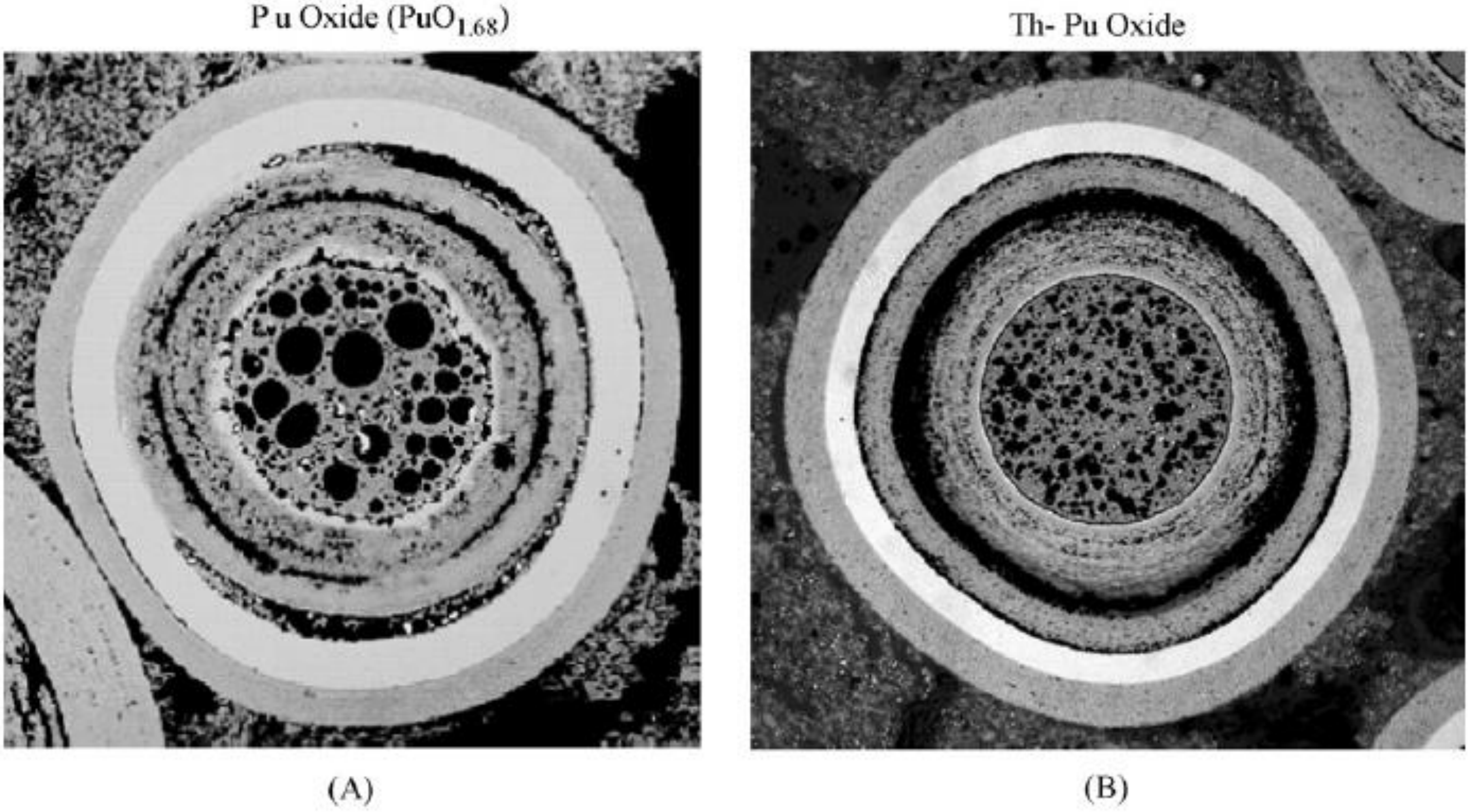
Fissile/Fertile fuel particle (large kernel)



Fresh Particle

High Burnup at Peach Bottom
747,000 MW-days/tonne

Very high burn up in ceramic-coated (TRISO) fuel, experimentally demonstrated at Peach Bottom-1 MHR


Pu Oxide ($PuO_{1.68}$)

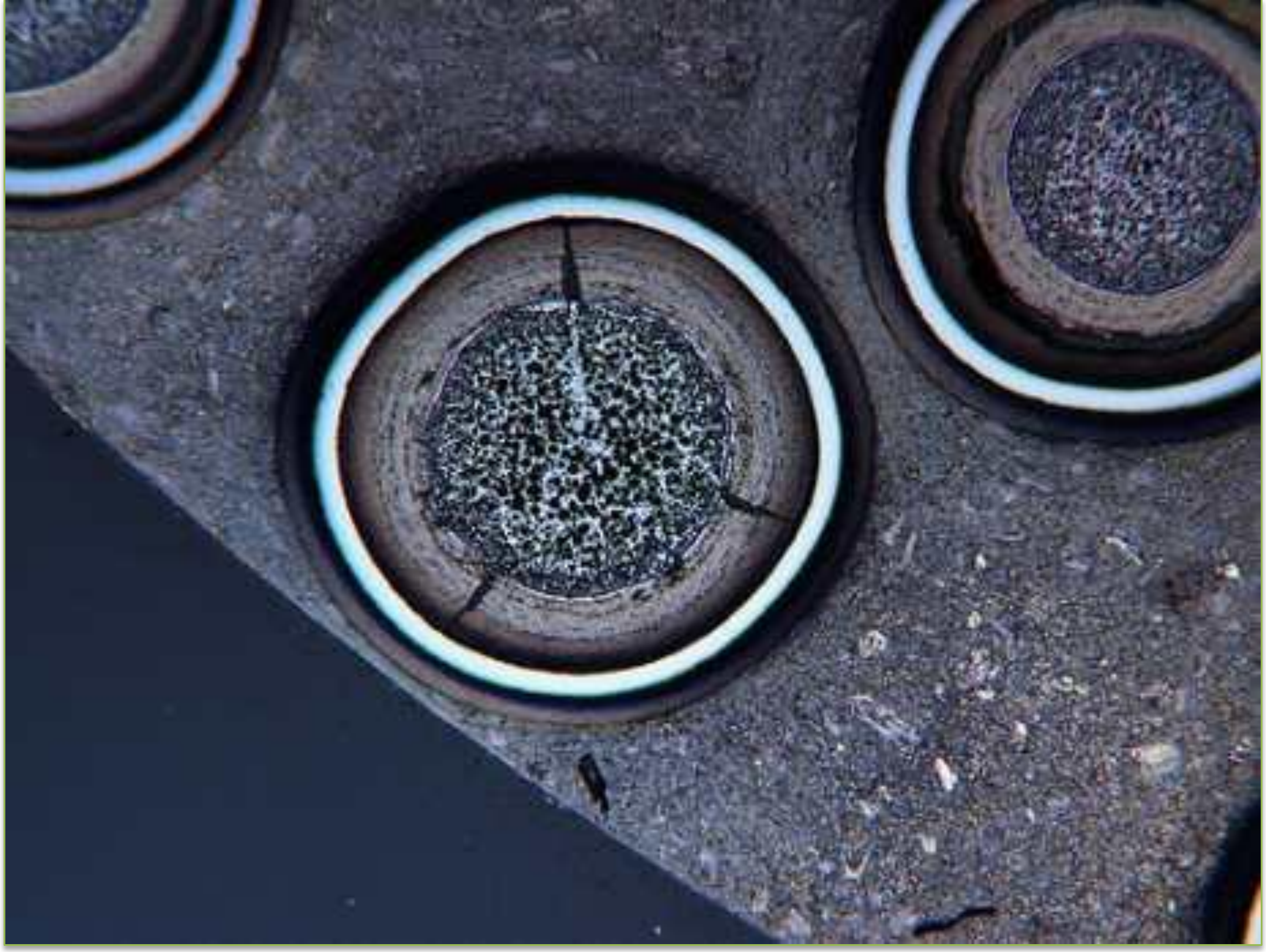
Th- Pu Oxide

(A)

(B)

Deep burn up in ceramic-coated (TRISO) fuel, as demonstrated at Peach Bottom-1 MHR (> 95 % ^{239}Pu transmuted)

A) 650 000 MW.d/tonne B) 180 000 MW.d/tonne



Microscopic cross-section of Triso fuel particles (Image INL) httpwww.world-nuclear-news.orgENF-Triso_fuel_triumphs_at_extreme_temperatures- (1800 oC)

Three years of studies by teams at the US Department of Energy's Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL) have found that most fission products remain inside irradiated Triso particles even at temperatures of 1800°C - more than 200°C hotter than in postulated accident conditions.

Various projects around the world are developing high-temperature gas-cooled nuclear reactors which use TRISO-type fuel, building on many years of research. The fuel itself was developed primarily in Germany during the 1980s. The US teams have been studying their version of the fuel since 2002, and the findings have direct implications for the safety for advanced high-temperature reactors

Substantial Quantities of Coated Particles have been Fabricated at facilities throughout the world

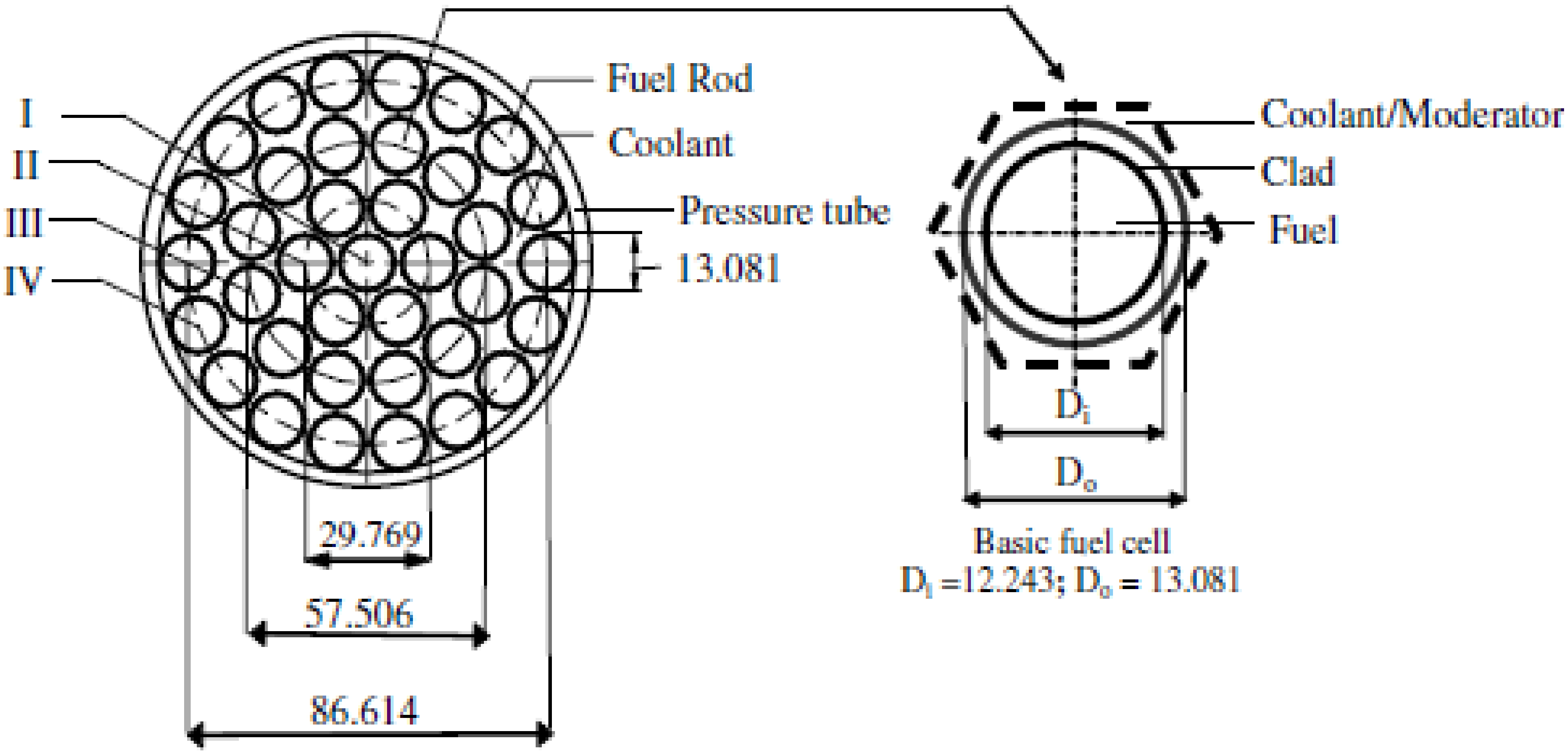
Reactor/ Manufacturing	Country	Fuel Description		U/Th Quantity (kg)
ROVER/GA & LANL	US	BISO	Extrusions	14,000
DRAGON	UK	BISO/TRISO	Compacts	1,000s
Peach Bottom I/GA	US	BISO	Compacts	3,500
UHTREX/GA & LANL	US	TRISO (Early)	Extrusions	200
Fort St. Vrain	US	TRISO	Compacts	33,400
AVR	Germany	BISO/TRISO	Spheres	2,200
THTR/Nukem	Germany	BISO	Spheres	7,700
CNPS/GA	US	TRISO	Compacts	94
HTTR/NFI	Japan	TRISO	Compacts	900
HTR-10	China	TRISO	Spheres	140
Russia, Belgium, France Korea, India, South Africa	various	BISO/TRISO	-----------	Small

>60,000 kg

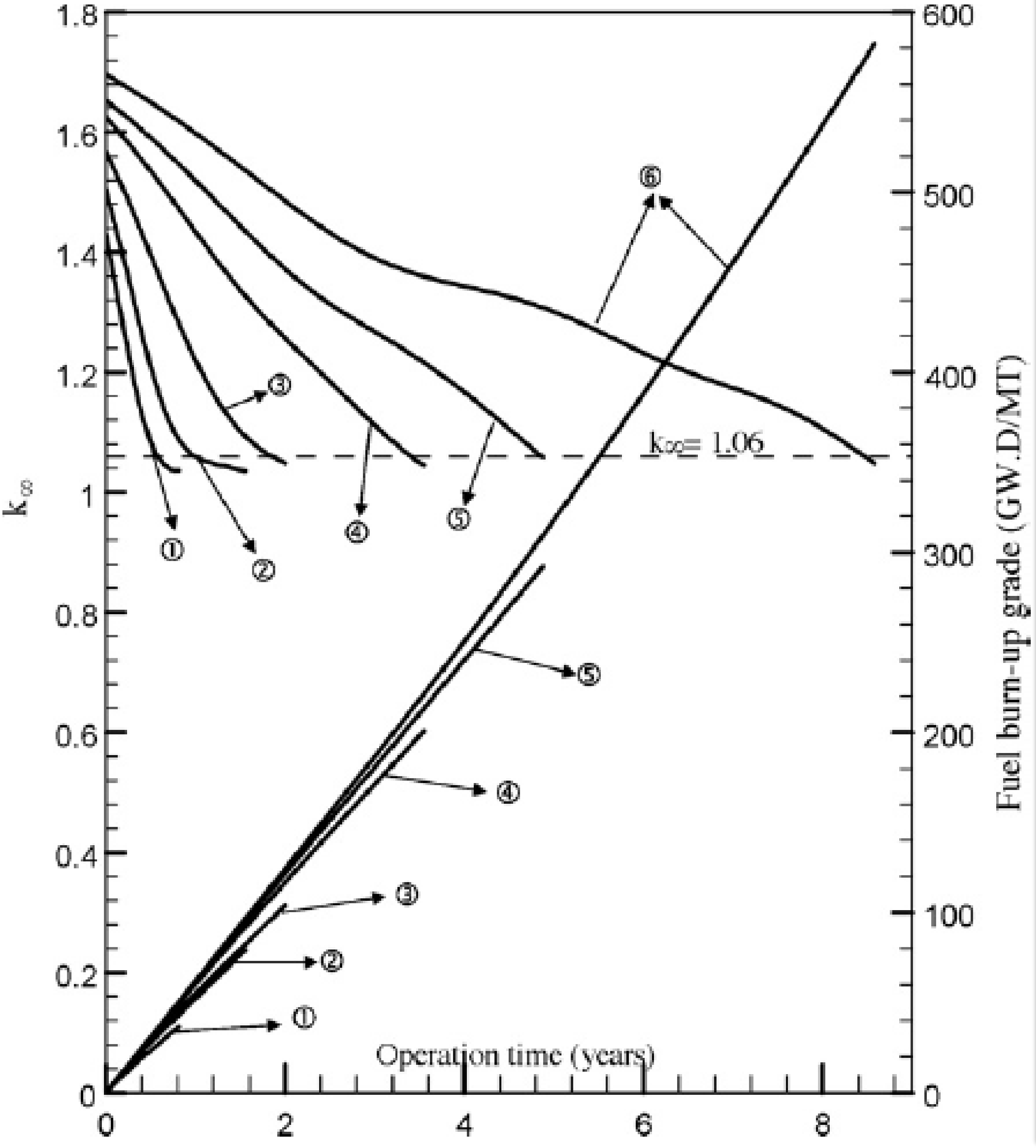
Composition and dimensions of basic TRISO fuel particle
(Sefidvash, et al., 2007)*

Composition and dimensions of basic TRISO fuel particle

Material	Density (g/cm^3)	D_{in} (cm)	D_{out} (cm)	Volume (cm^3)	Volume Fraction	Mass (g)
ThO2	10	0	0.158	0.002064	0.370427	0.020642
PYC (porous)	1	0.158	0.176	0.000789	0.141573	0.000789
PYC (dense)	1.8	0.176	0.18	0.000199	0.035708	0.000358
SiC	3.17	0.18	0.2	0.001135	0.203606	0.003598
OPyC	1.8	0.2	0.22	0.001386	0.248685	0.002496
Average	5.00319		0.22	0.005573		0.02788



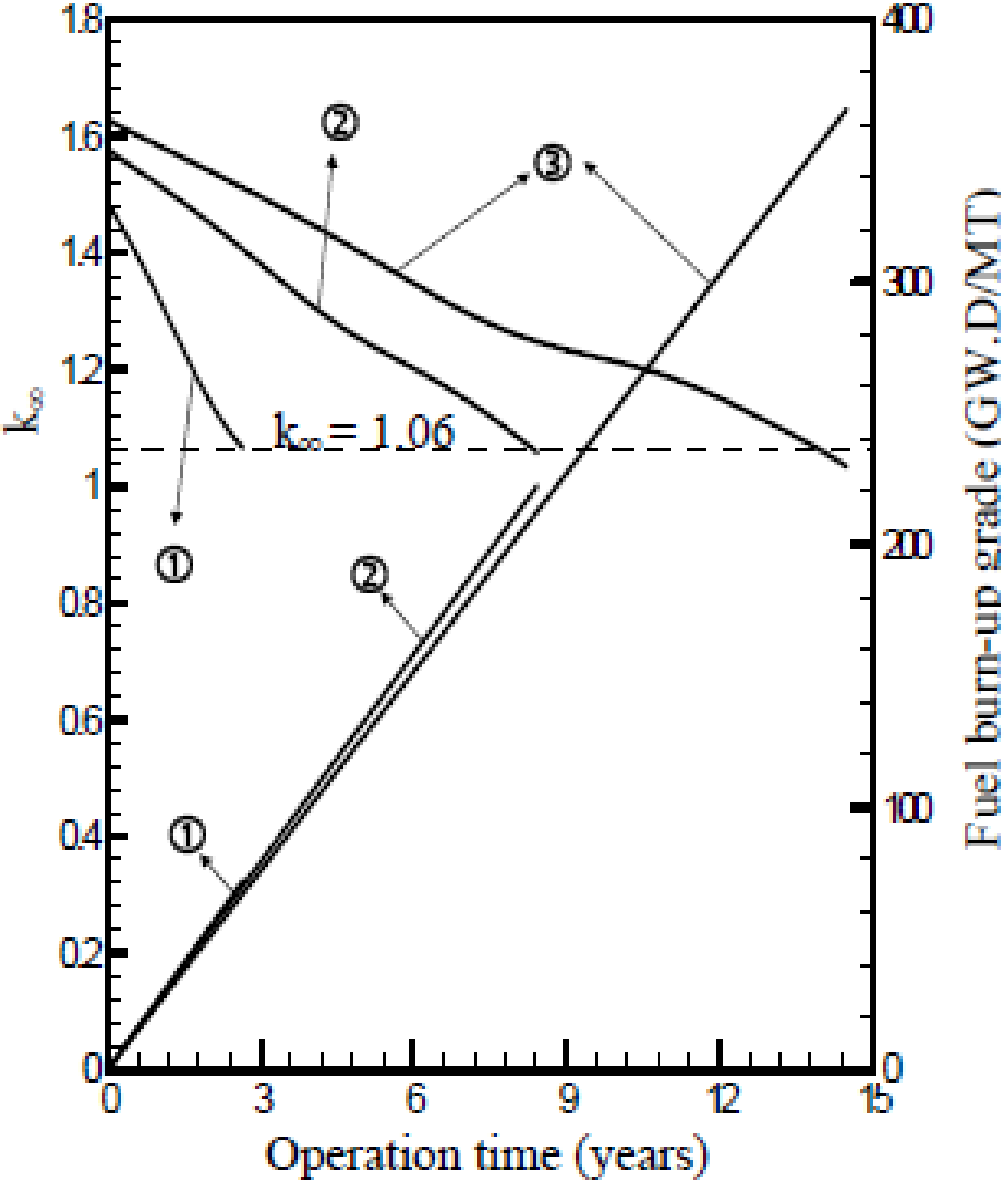
Placement of 37-fuel rods in the bundle (Dimensions are in millimeters, not in scale)



Temporal variation of the lattice criticality k_∞ and fuel burn-up grade

($RG-PuO_2/ThO_2$mixed fuel)

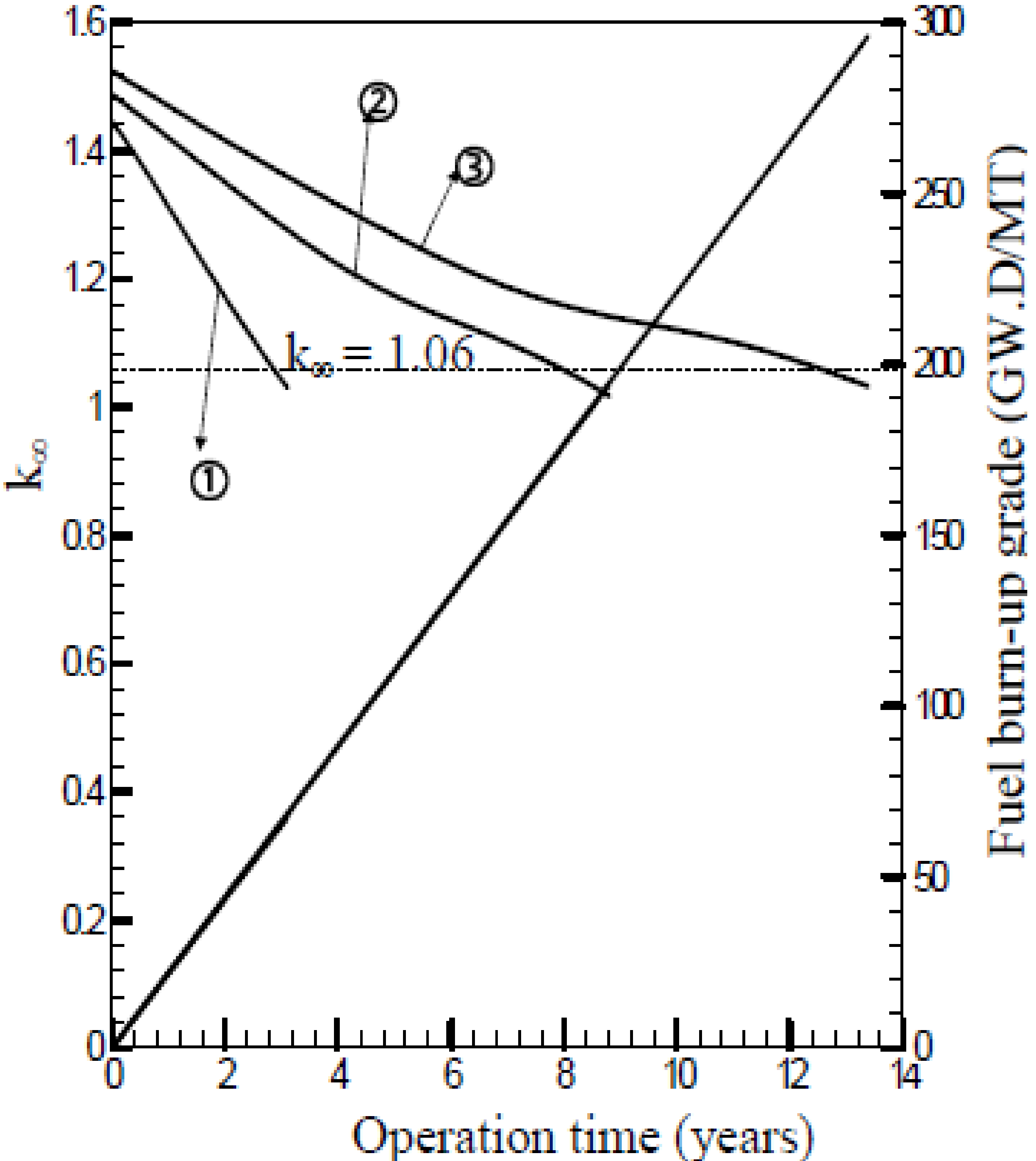
①: 4 % $RG-PuO_2$
②: 6 % $RG-PuO_2$
③: 10 % $RG-PuO_2$
④: 20 % $RG-PuO_2$
⑤: 30 % $RG-PuO_2$
⑥: Row # I: 100 % $RG-PuO_2$
Row # II: 80 % $RG-PuO_2$
Row # III: 60 % $RG-PuO_2$
Row # IV: 40 % $RG-PuO_2$



Temporal variation of the lattice criticality k_∞ and fuel burn-up grade

(Mixed fuel: RG-PuC + ThC)

①: 10 % RG-PuC + 90 % ThC
②: 30 % RG-PuC + 70 % ThC
③: 50 % RG-PuC + 50 % ThC + 60 % ThO_2



Temporal variation of the lattice criticality k_∞ and the fuel burn-up grade

①: 90 % UC+10 % MAC;

②: 70 % UC+30 % MAC;

③: 50 %UC+50 % MAC

Nuclear Fusion Energy

- Magnetic fusion energy (MFE)
- Inertial fusion energy (IFE)
- Muon catalyzed fusion

Nuclear fusion fuels

- $^{2}H_{1}$ (**D**); $^{3}H_{1}$ (T); **$^{3}He_{2}$**

Tritium is an artificial radioactive element!!!

- $^{3}H_{1} \rightarrow {}^{3}He_{2} + {}^{0}\text{ß}_{-1}$ ($T_{½}$ = 12.323 a)

A tiny amount of D in 1 liter of natural water releases as much fusion energy as equivalent to 300 liters of gasoline. Fusion energy availability for 100’s of thousand years!!!

“T” production.

- $^{6}Li_{3} + {}^{1}n_{0} \rightarrow {}^{3}H_{1}$ (T) $+ {}^{4}He_{2} + 4.784$ MeV
- $^{7}Li_{3} + {}^{1}n_{0} \rightarrow {}^{3}H_{1}$ (T) $+ {}^{4}He_{2} + {}^{1}n_{0}' + 2.467$ MeV

Pertinent fusion reactions

- **$\underline{^{2}H_{1}\ (D) + {}^{3}H_{1}\ (T) \rightarrow {}^{4}He_{2} + {}^{1}n_{0} + 17.6\ MeV.}$**

- $^{2}H_{1}$ (D) + $^{2}H_{1}$ (D) → $^{3}H_{1}$ + $^{1}H_{1}$ + 4.03 MeV (50 %)

- $^{2}H_{1}$ (D) + $^{2}H_{1}$ (D) → $^{3}He_{2}$ + $^{1}n_{0}$ + 3.27 MeV (50 %)

- $^{2}H_{1}$ (D) + $^{3}He_{2}$ → $^{4}He_{2}$ + $^{1}H_{1}$ + 18.3 MeV (*)

(*) neutron free; extremely clean energy!!!
Direct energy conversion with high conversion efficiency possible!!!

Nuclear fusion fuels

- Natural fuels: **D** (isotopic fraction in natural water: **150 ppm**) (1 liter see water contains 300 liters gasoline equivalent D)
- **$^3He_2$** (isotopic fraction in natural helium: **1.38 ppm**).

Abundant $^3He_2$ on the Moon (10^9 kg),

in the Jupiter atmosphere (10^{22} kg),

Saturn atmosphere (10^{22} kg),

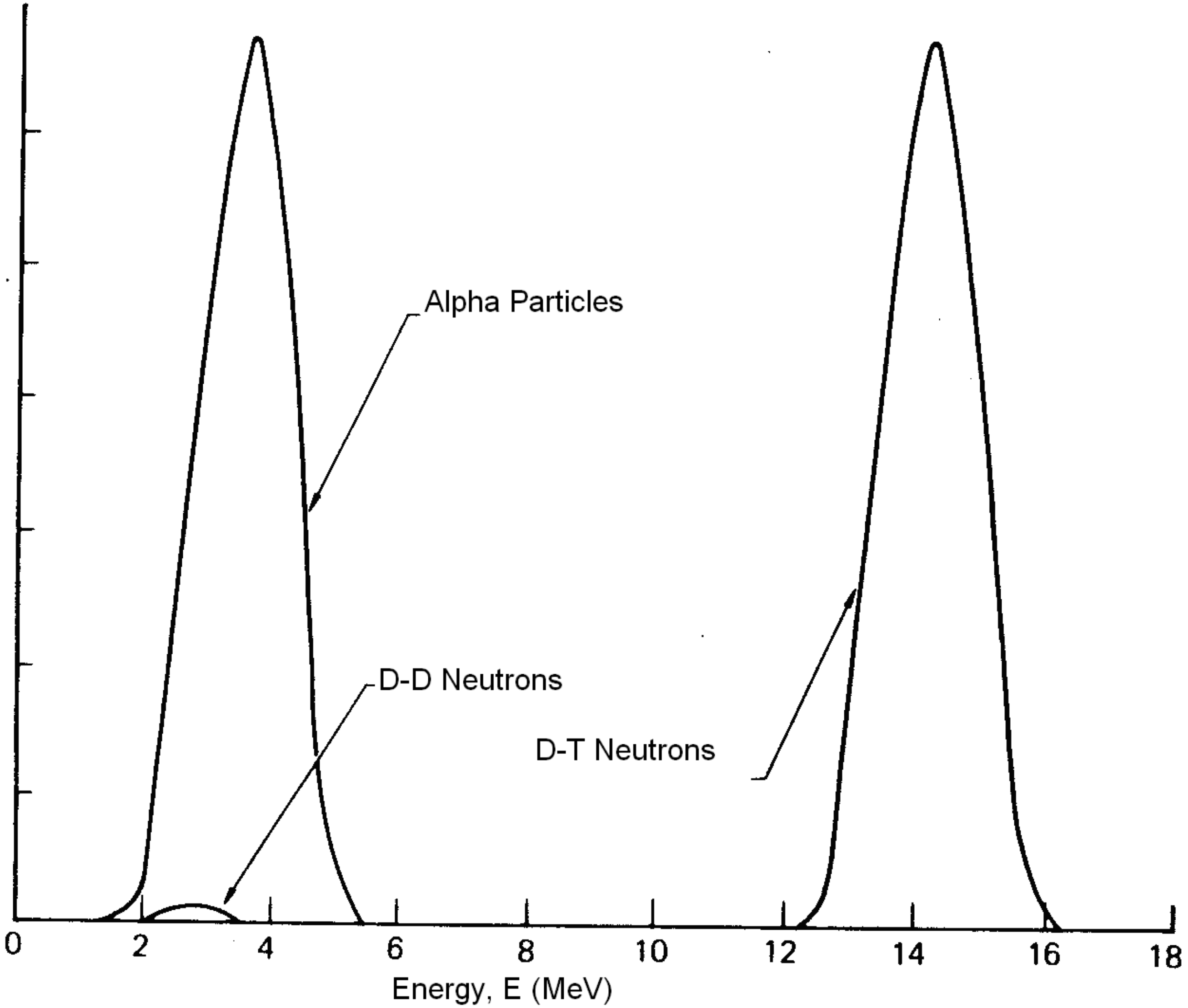
Uranus atmosphere (10^{20} kg) and

Neptune (10^{20} kg) atmosphere.

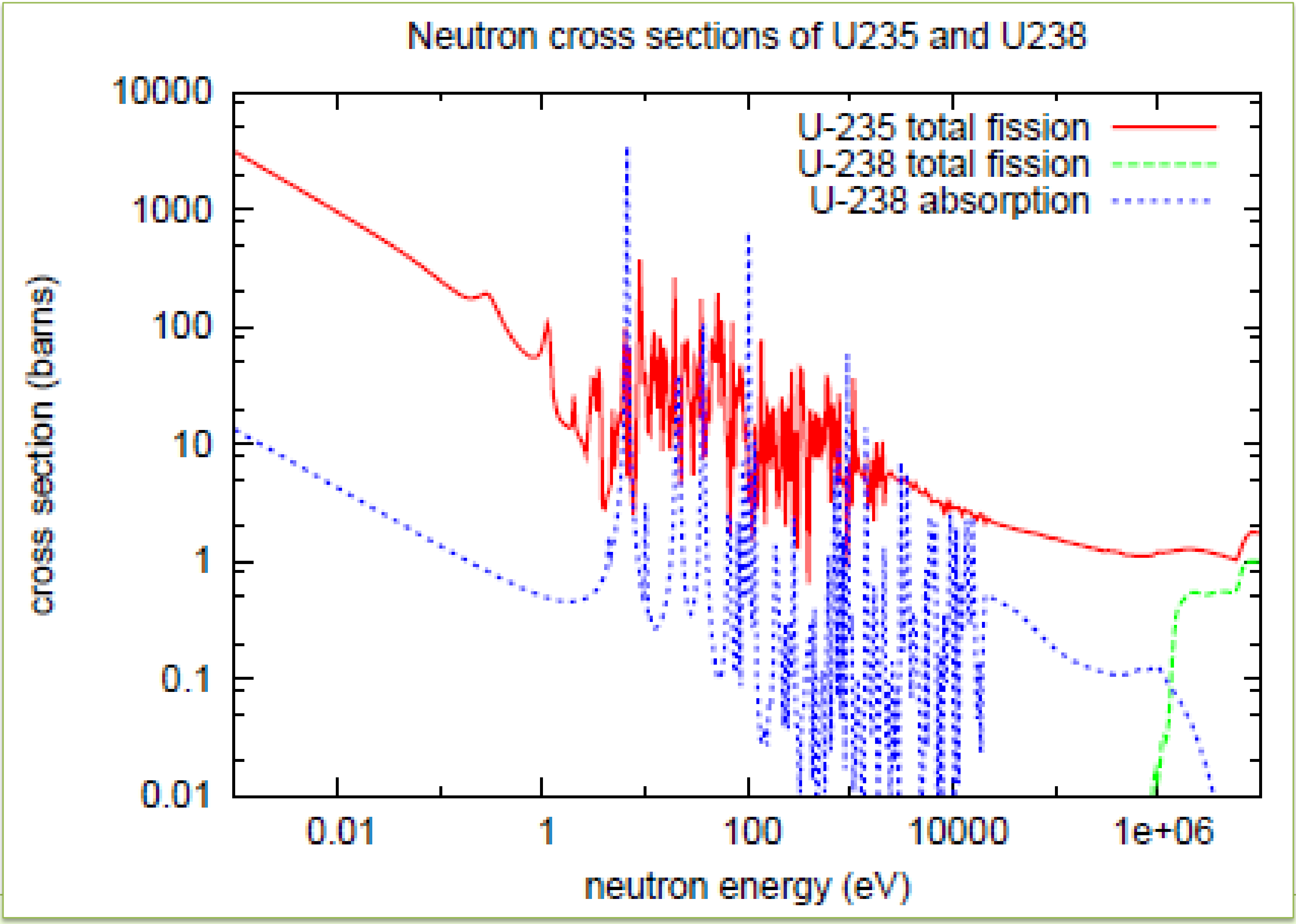
Fusion energy is available for 100’s of millions years!!!

Fusion-Fission (Hybrid) Reactors

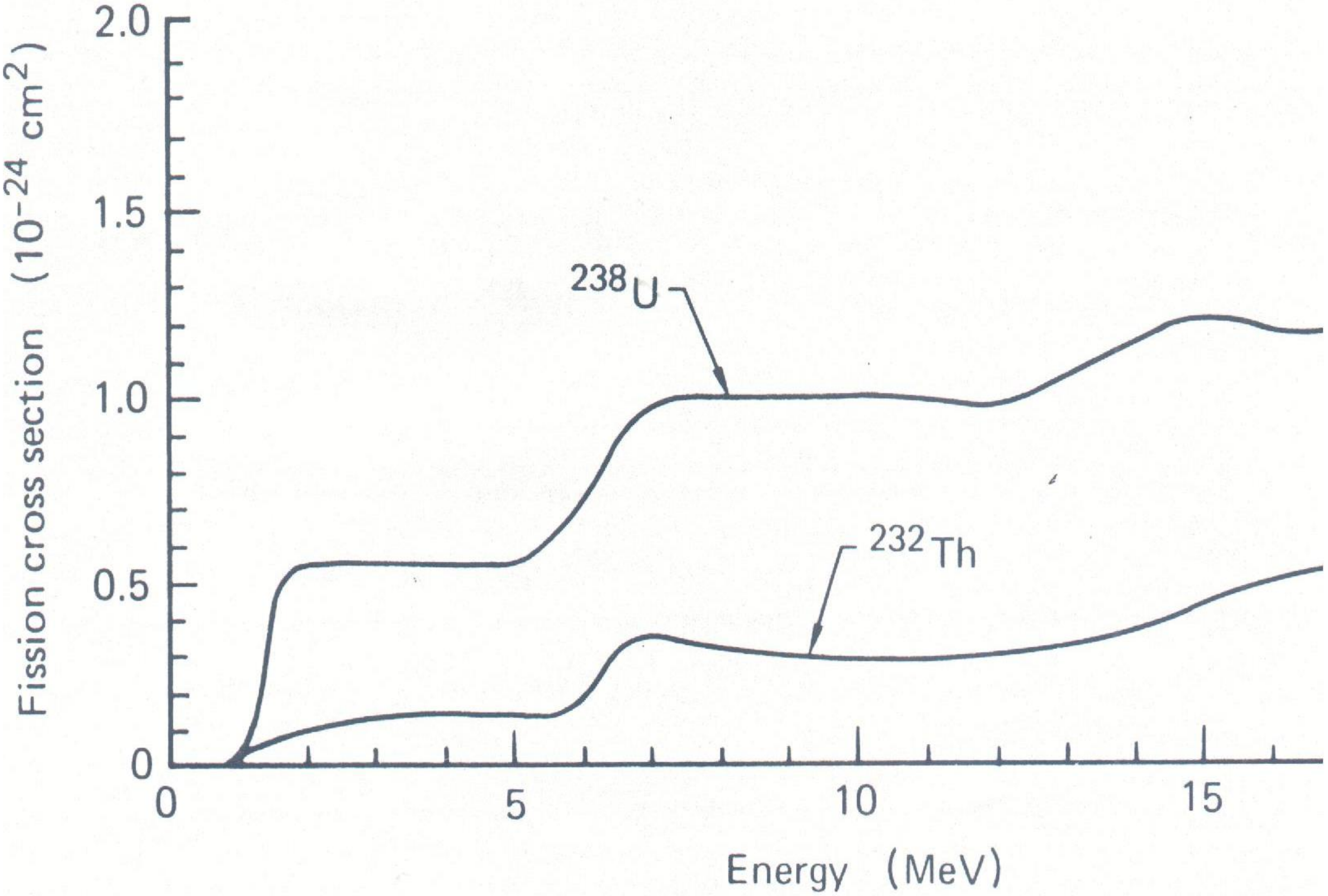
Energy multiplication and fissile fuel production in a fusion-fission (hybrid) reactor could lead earlier market penetration of fusion energy for commercial utilization.



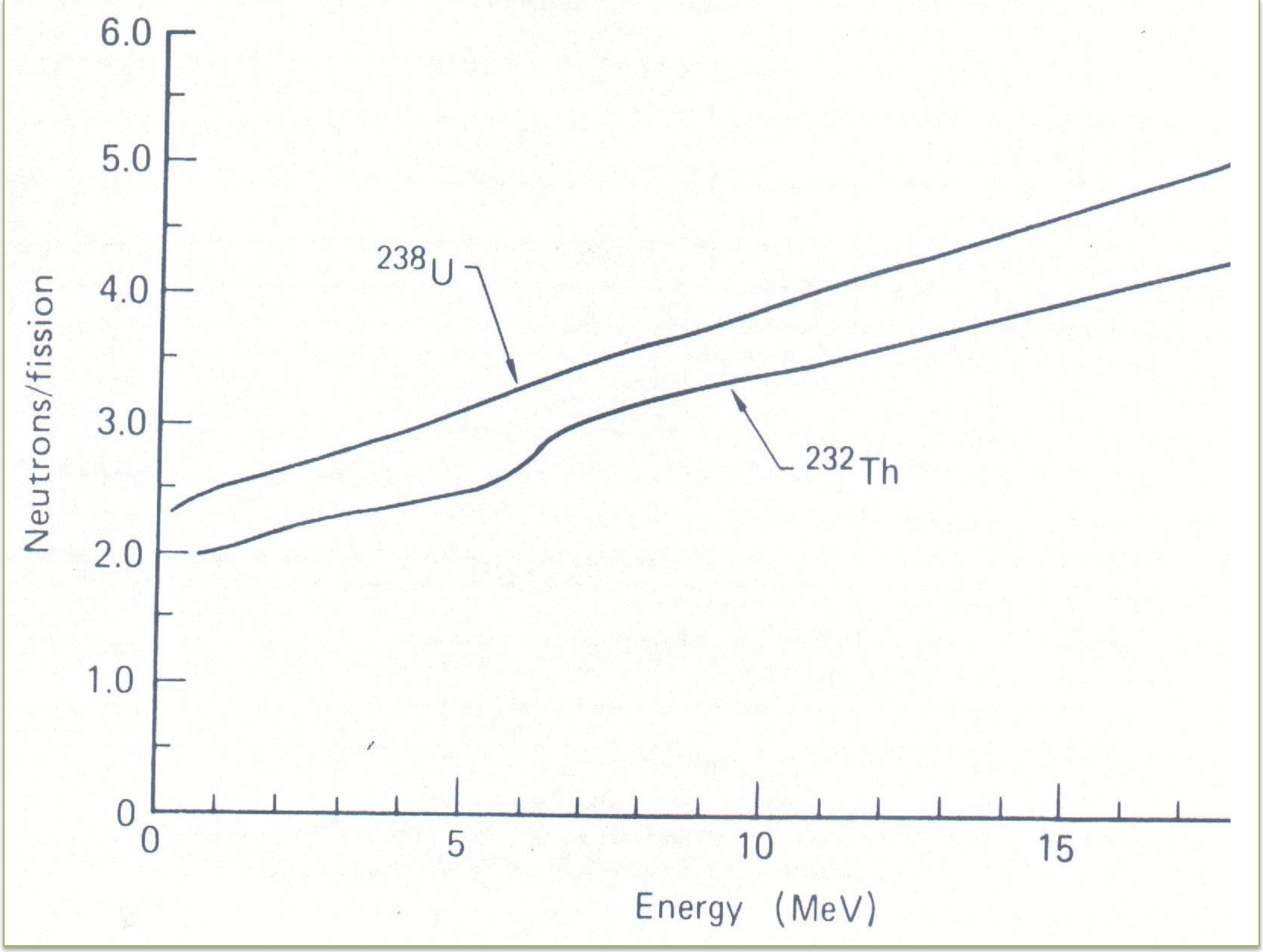
Neutron and α-particles spectrum at a plasma temperature of 70 keV



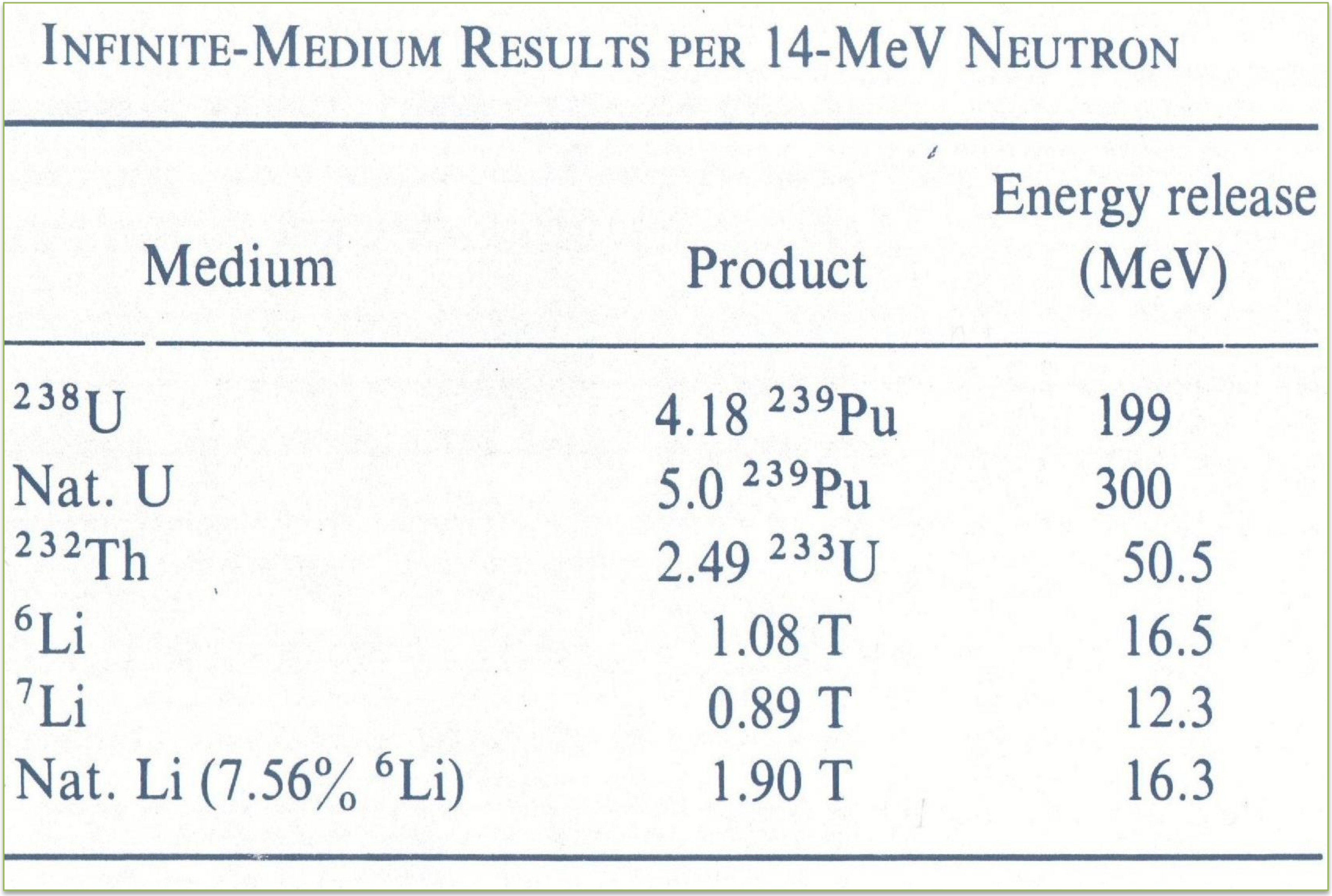
Fission cross sections of ^{235}U and ^{238}U



Fission cross sections of ^{238}U and ^{232}Th

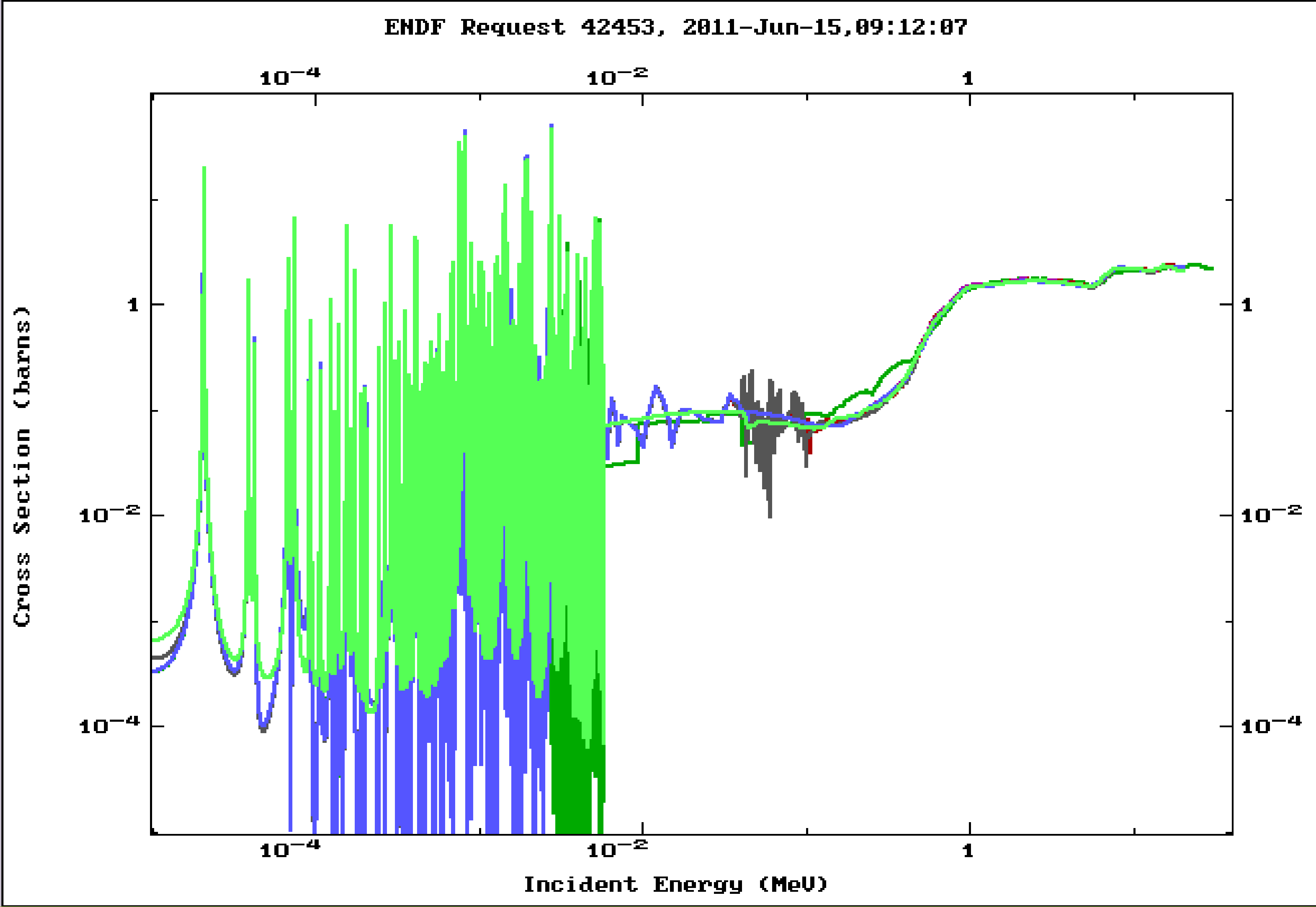


Neutron/fission (ν)

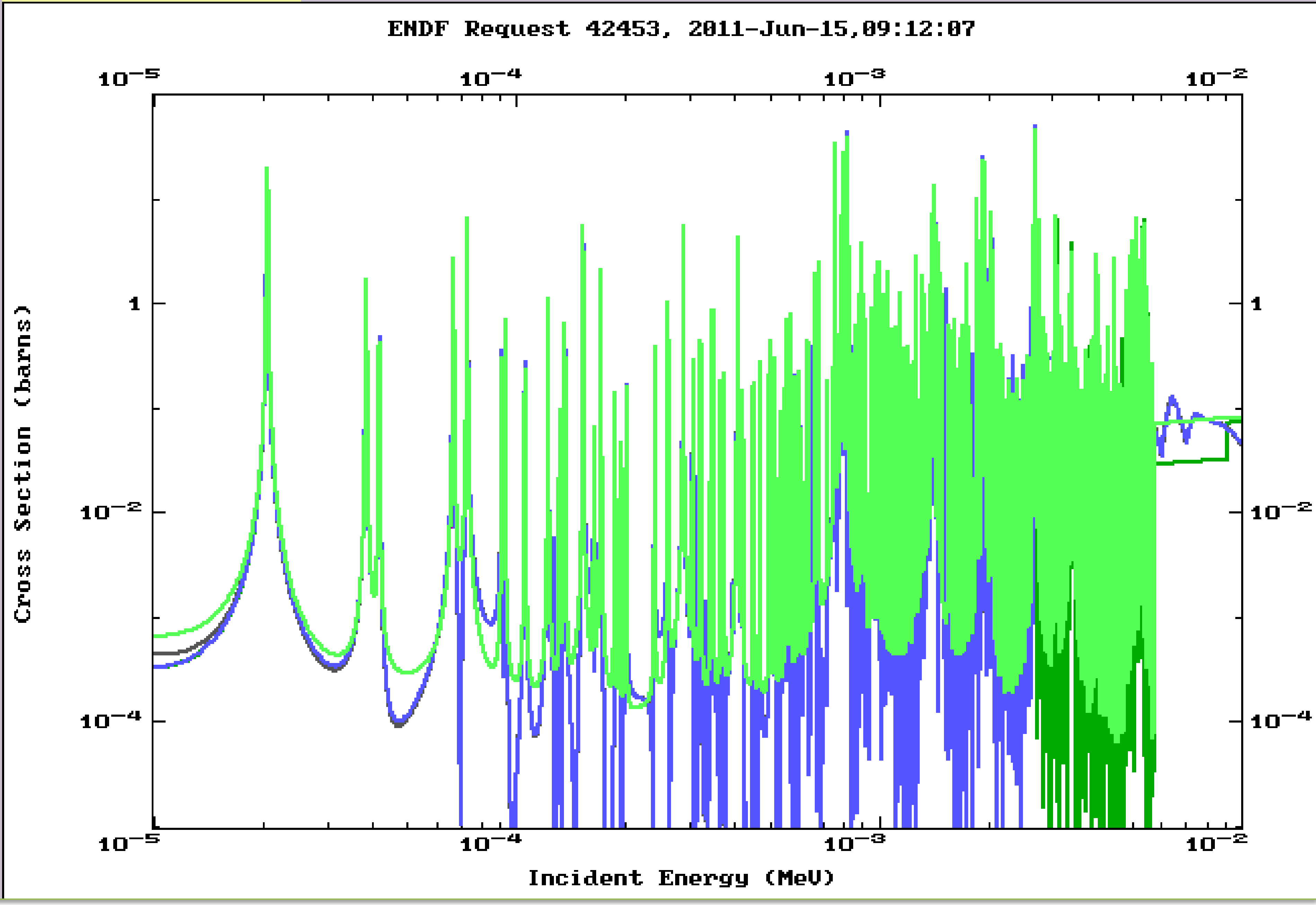


INFINITE-MEDIUM RESULTS PER 14-MeV NEUTRON

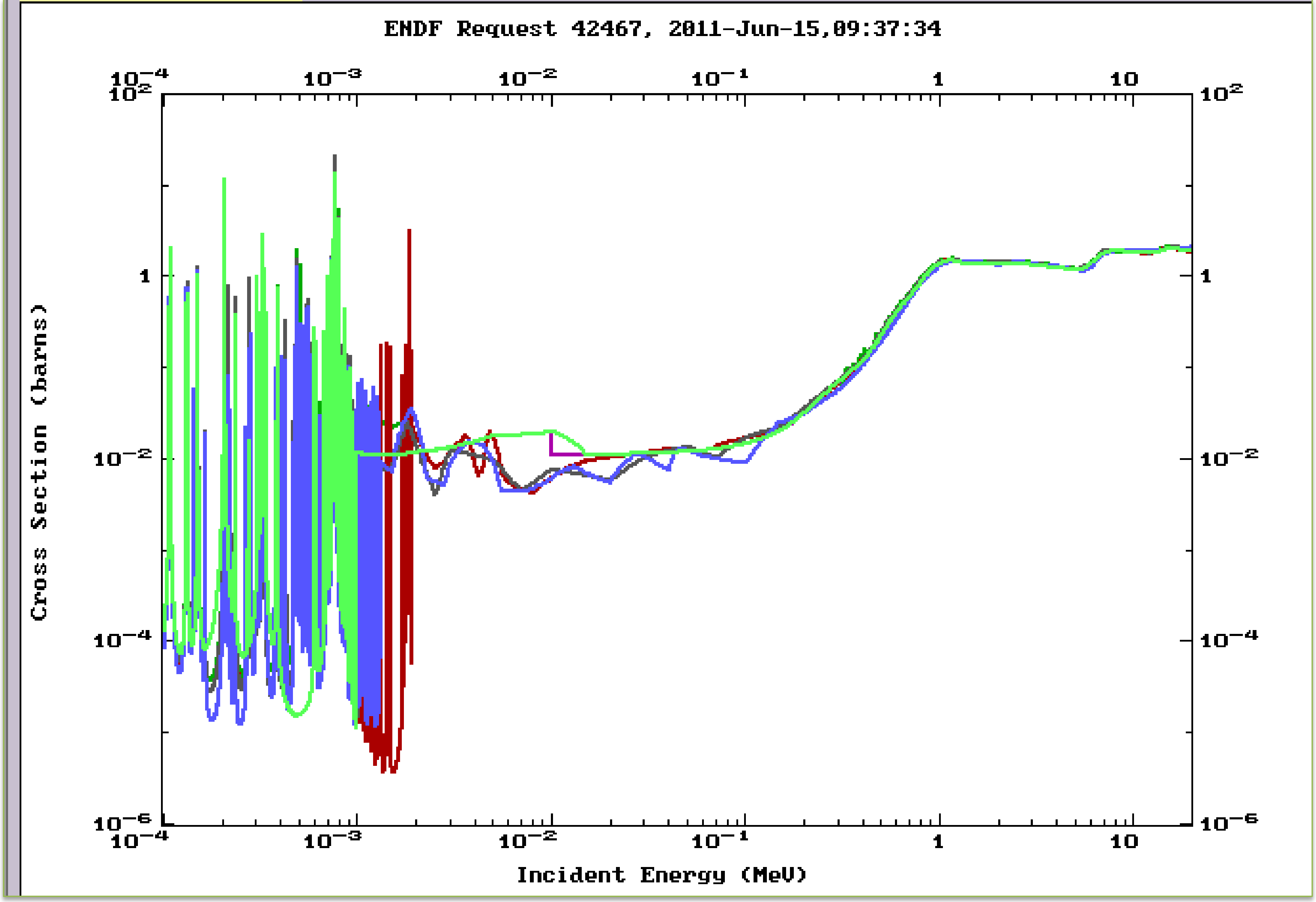
Medium	Product	Energy release (MeV)
^{238}U	4.18 ^{239}Pu	199
Nat. U	5.0 ^{239}Pu	300
^{232}Th	2.49 ^{233}U	50.5
^{6}Li	1.08 T	16.5
^{7}Li	0.89 T	12.3
Nat. Li (7.56% ^{6}Li)	1.90 T	16.3



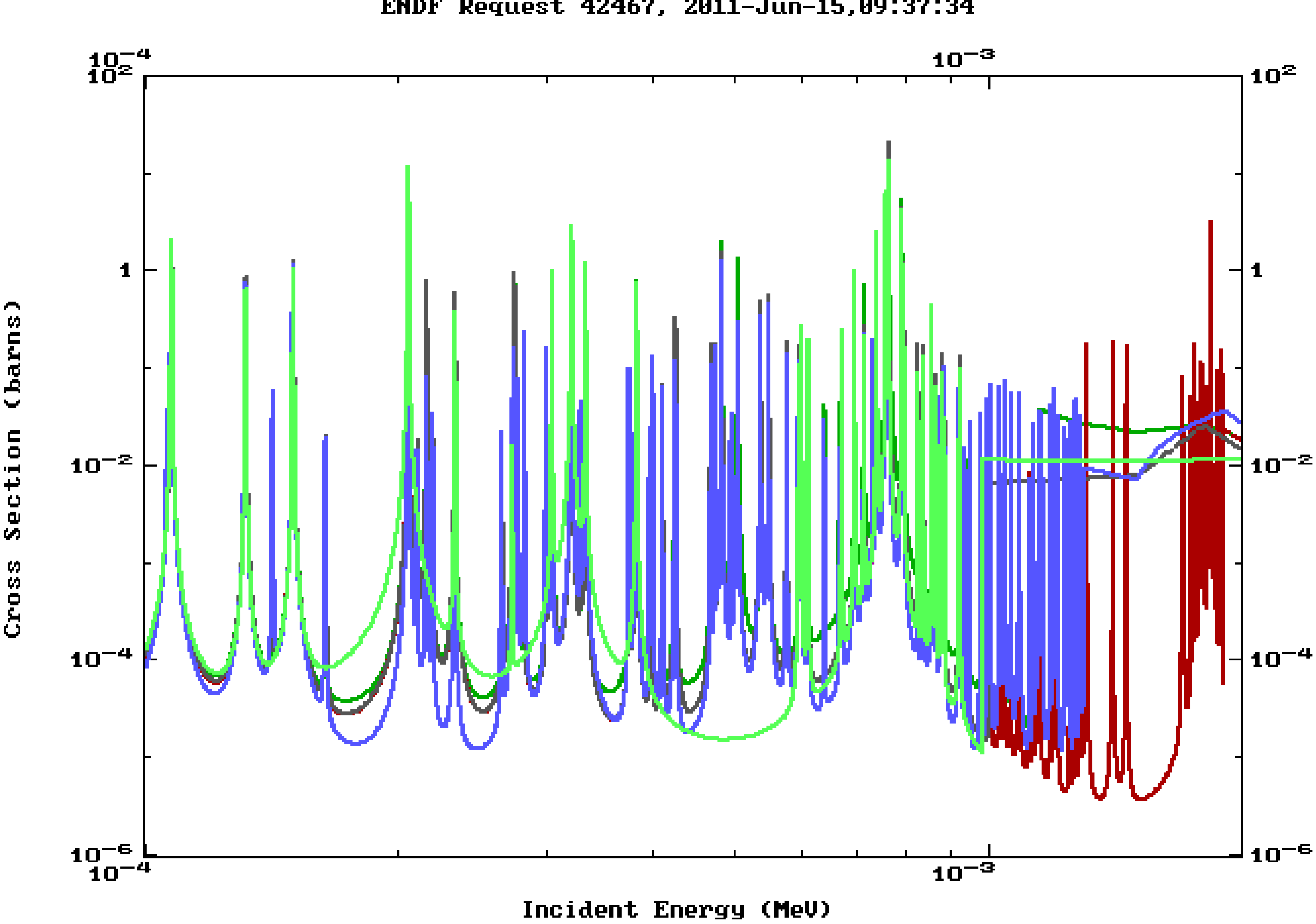
Fission cross sections of ^{240}Pu < 30 MeV



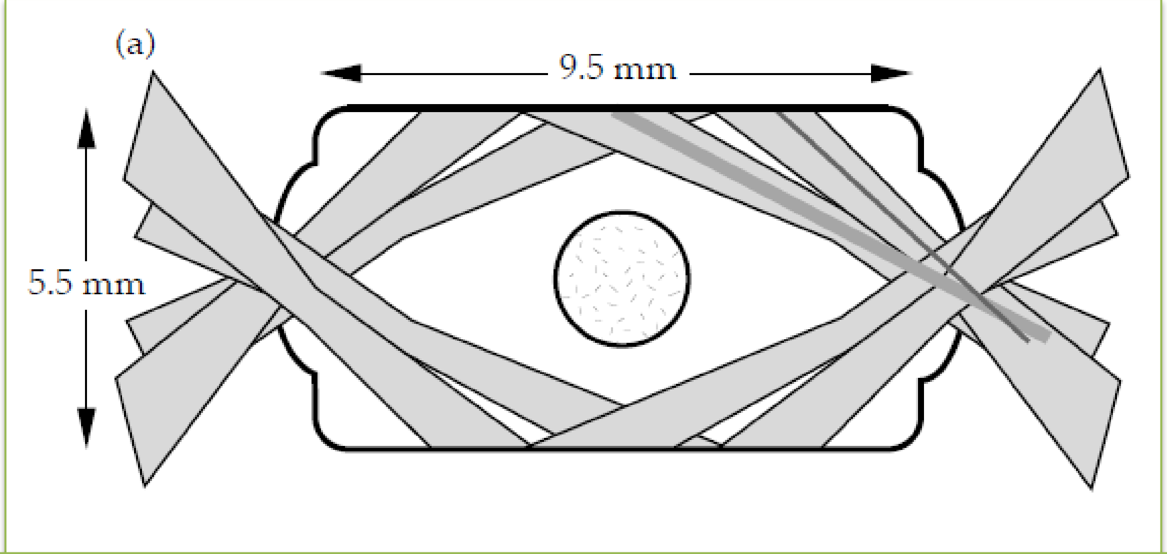
Fission cross sections of ^{240}Pu (10 to 10000 eV)

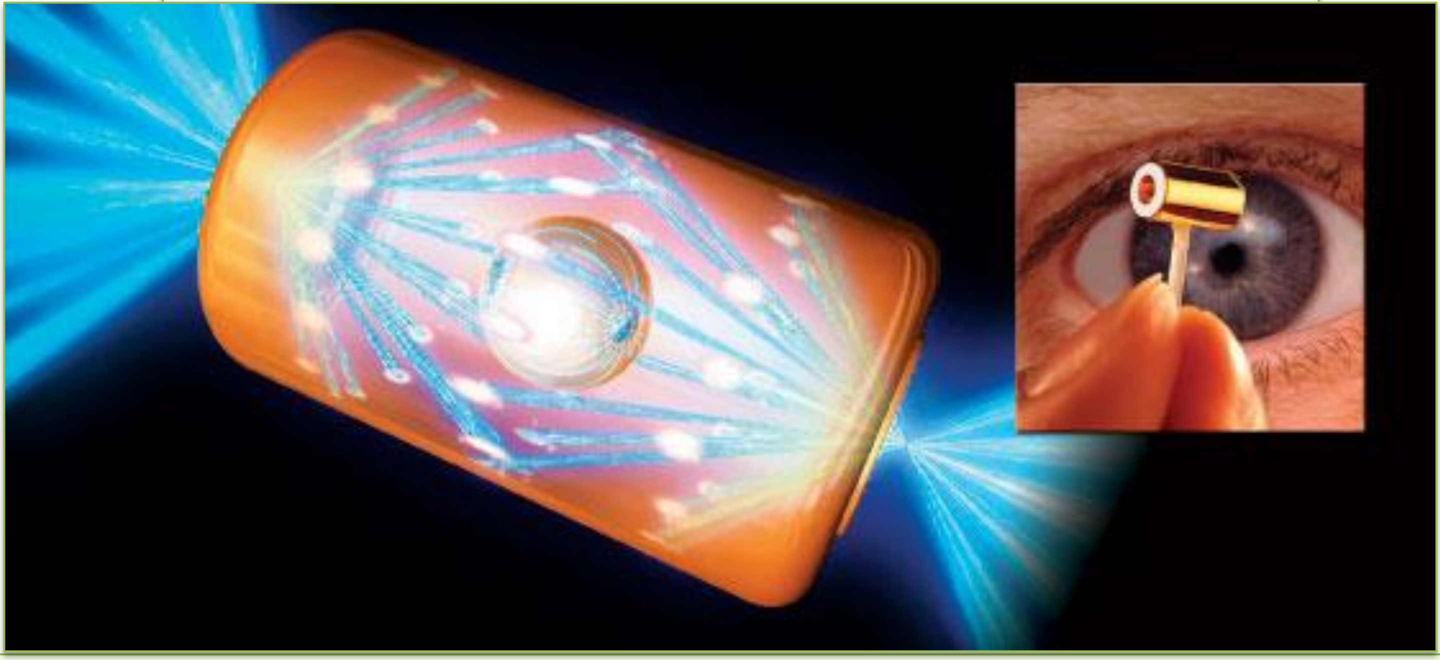


Fission cross sections of ^{242}Pu < 20 MeV



Fission cross sections of ^{242}Pu (10 to 2000 eV)





Target and illumination geometry for baseline NIF target design

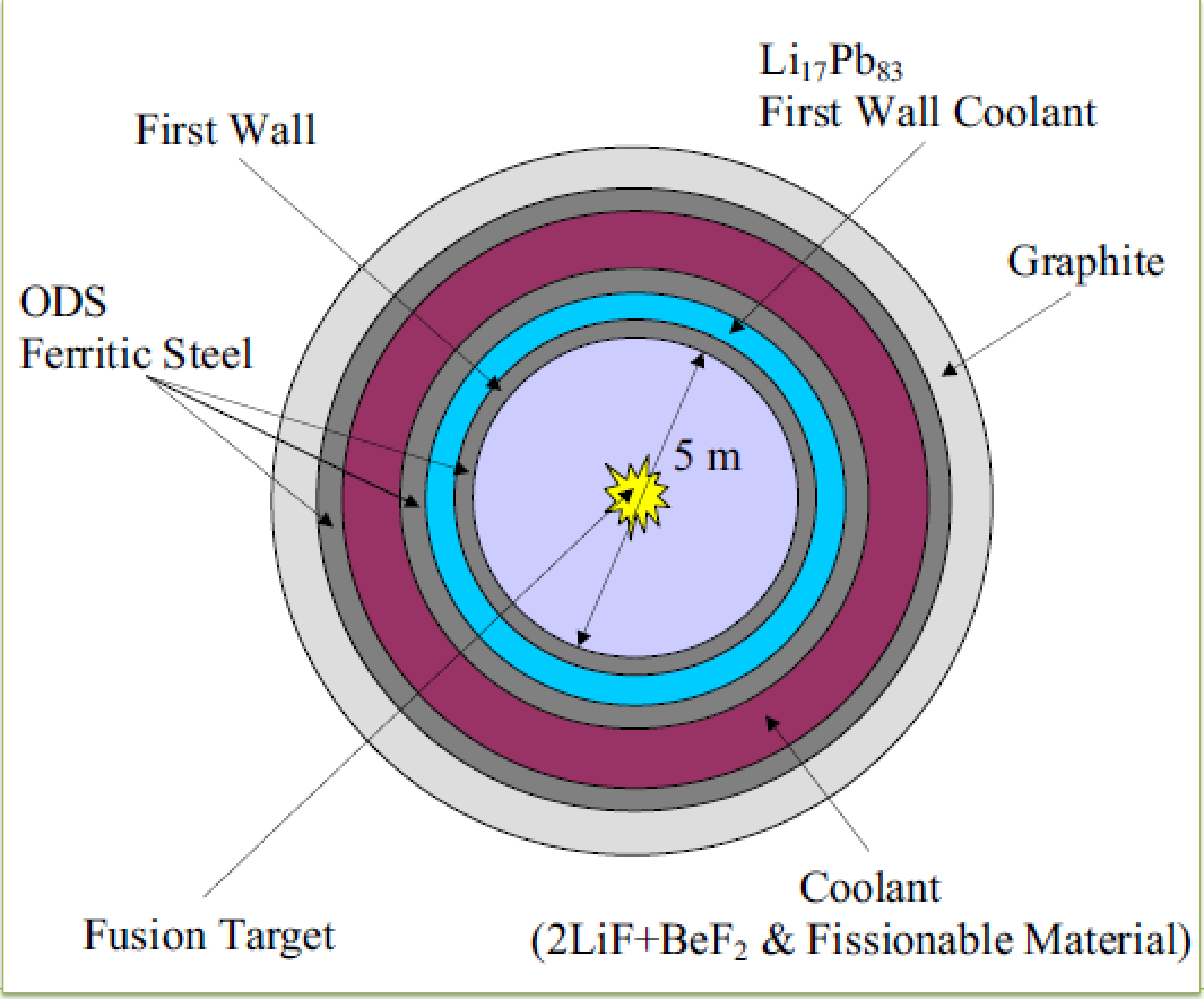
General view of the National Ignition Facility (NIF)

Fusion driver power: 500 MW_{th}

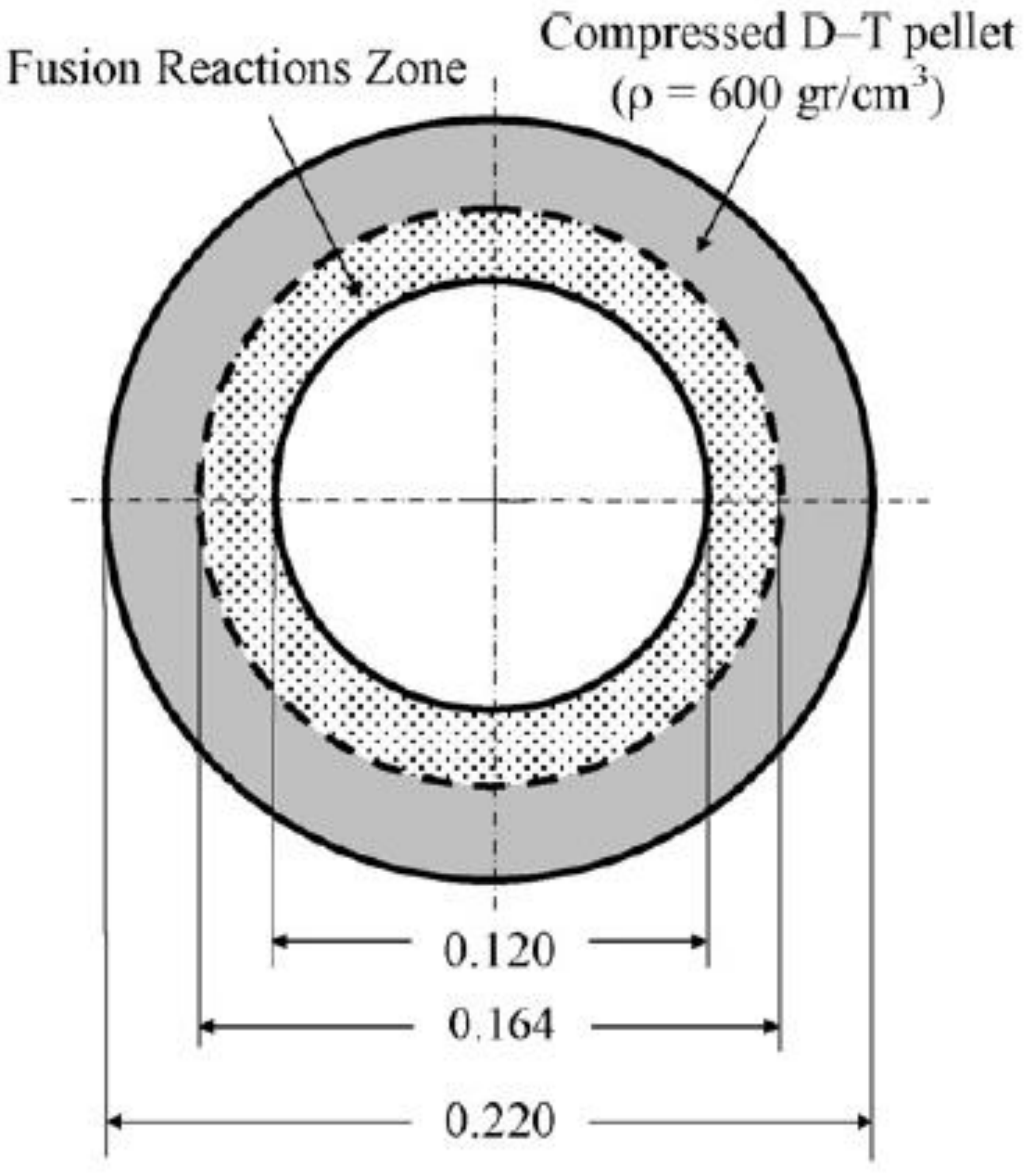
Neutron source strength: $1.774 \times 10^{+20}$ (14 MeV-n/sec)

Plant factor: 100 %

Neutron transport calculations: SCALE6.1 code using 238 energy groups cross sections.



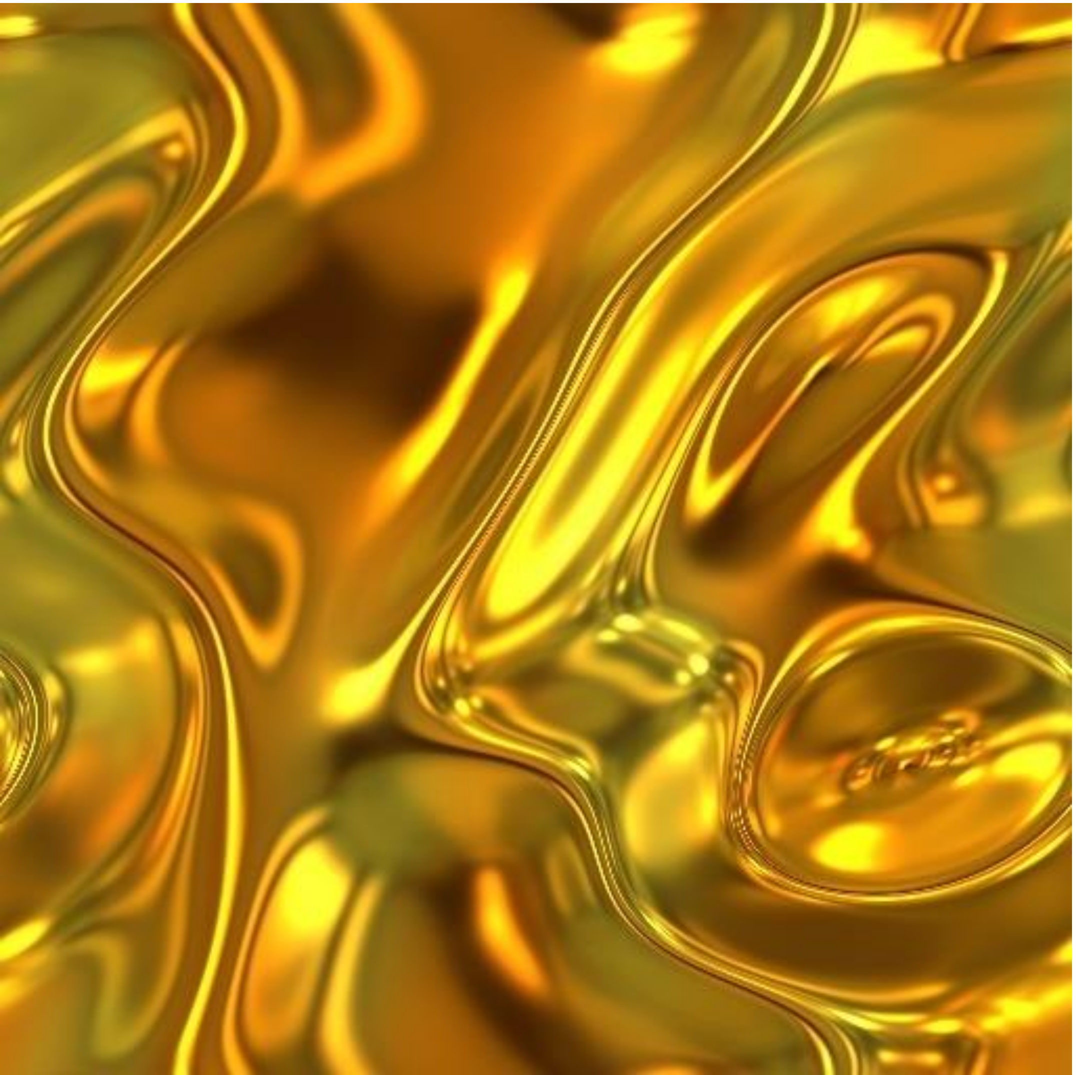
Modified LIFE engine in the proposed design



Geometrical model of the compressed fuel pellet

(Dimensions are in mm and not to scale)

Liquid Fluoride Thorium Reactor fuel is dissolved in liquid.



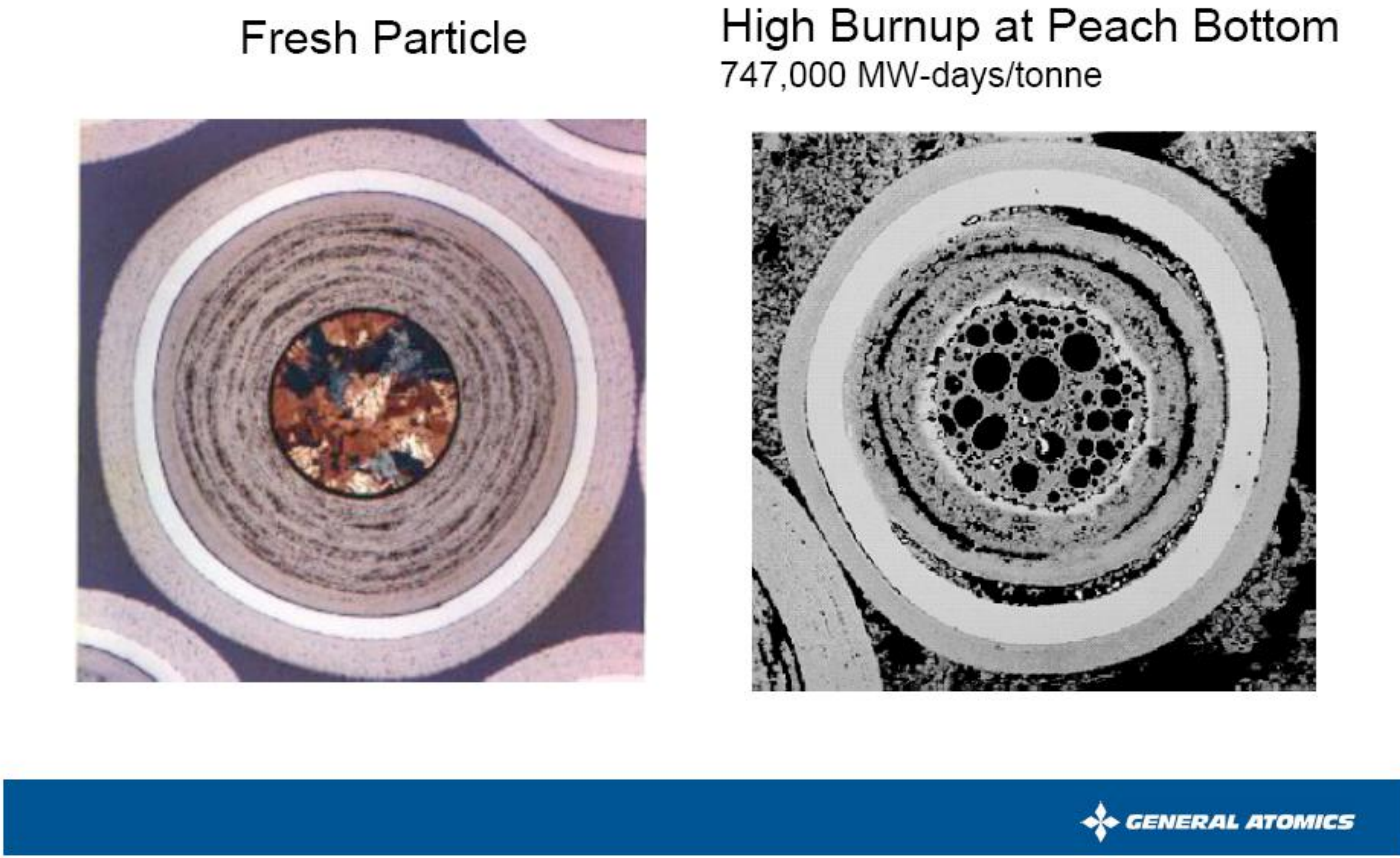
Molten fluoride salt mix: LiF and BeF_2

Excellent heat transfer

Continuous chemical processing

Atmospheric pressure

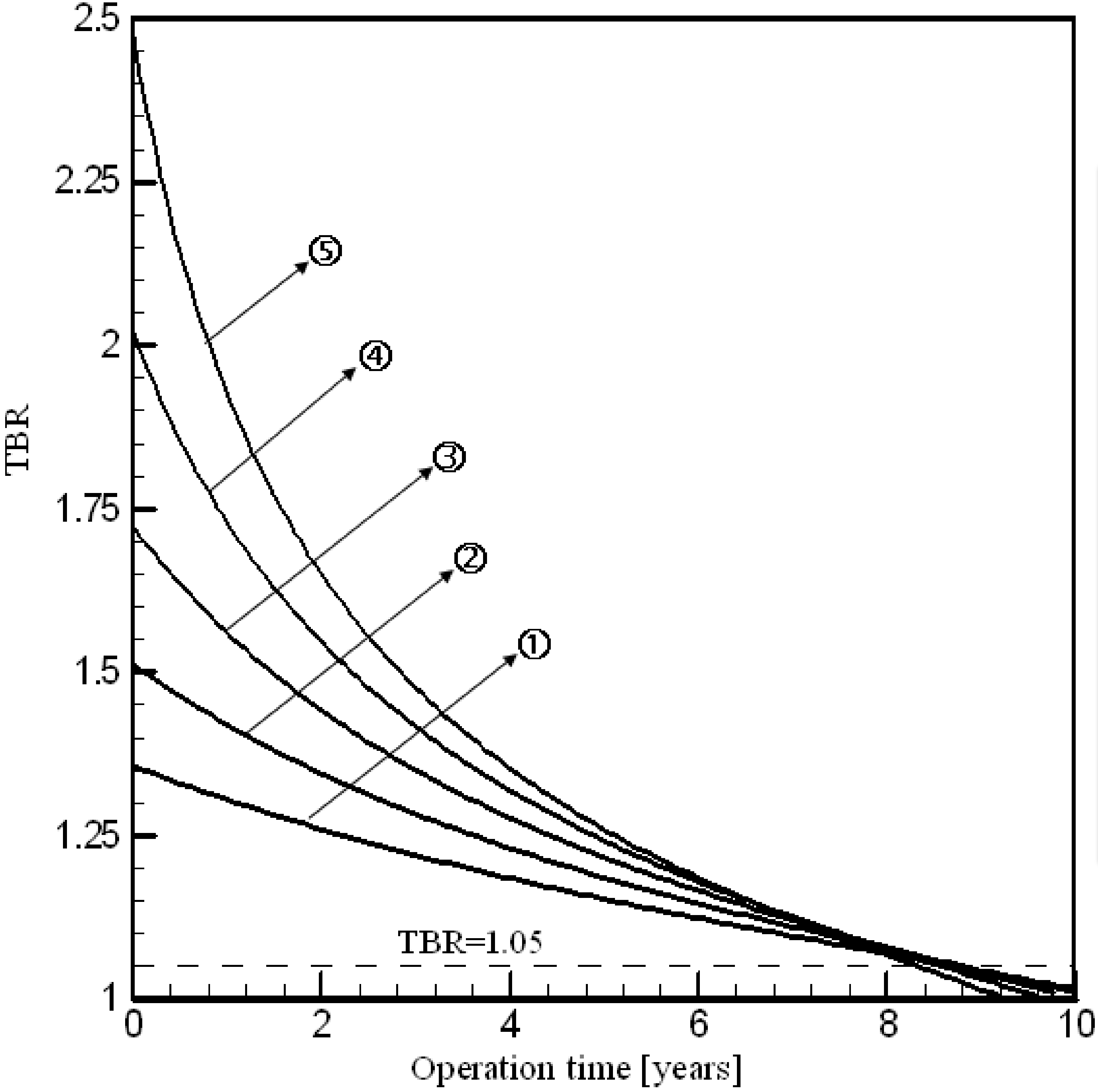
Room temp solid



Fresh Particle

High Burnup at Peach Bottom
747,000 MW-days/tonne

Very high burn up in ceramic-coated (TRISO) fuel, experimentally demonstrated at Peach Bottom-1 MHR

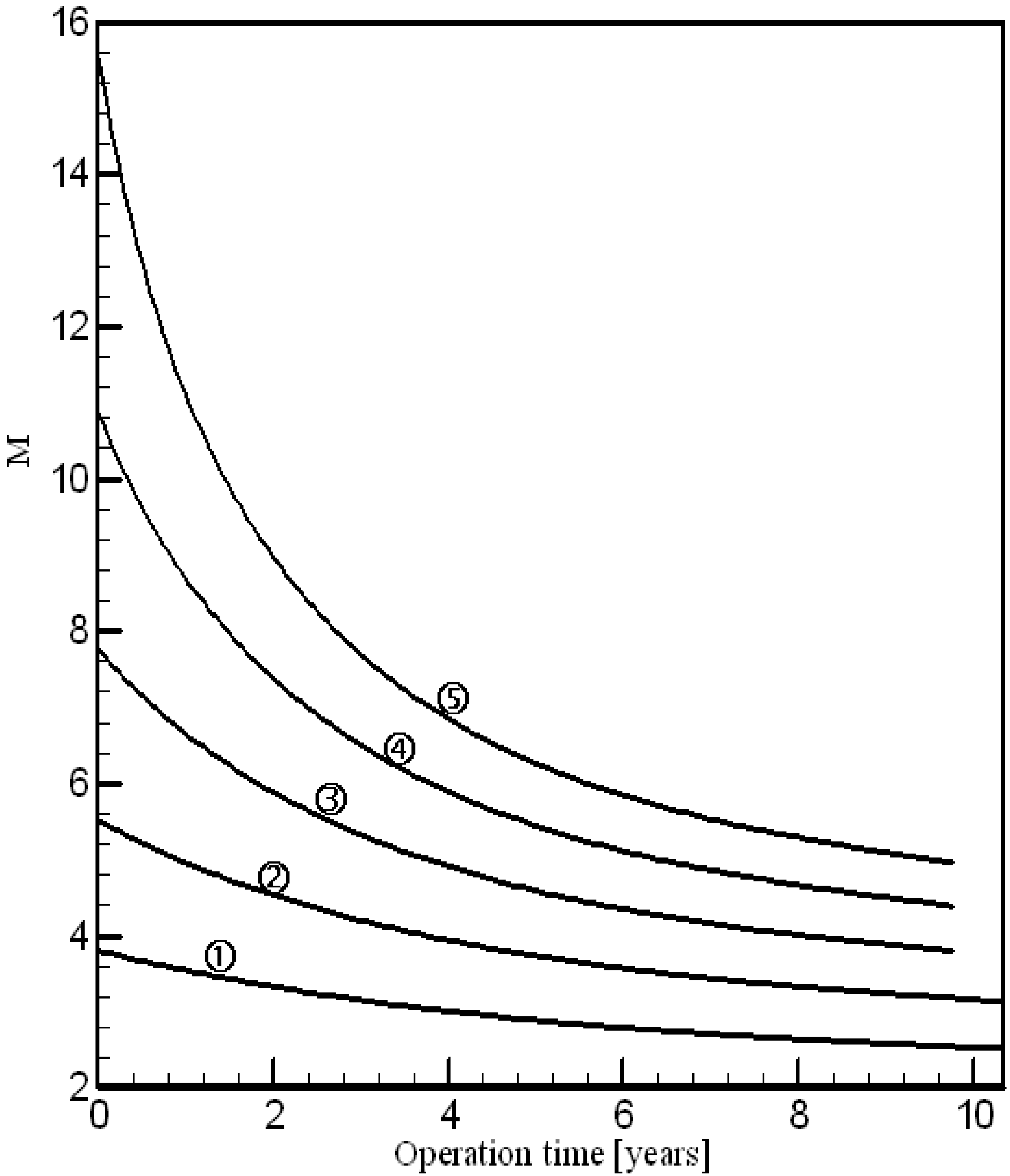


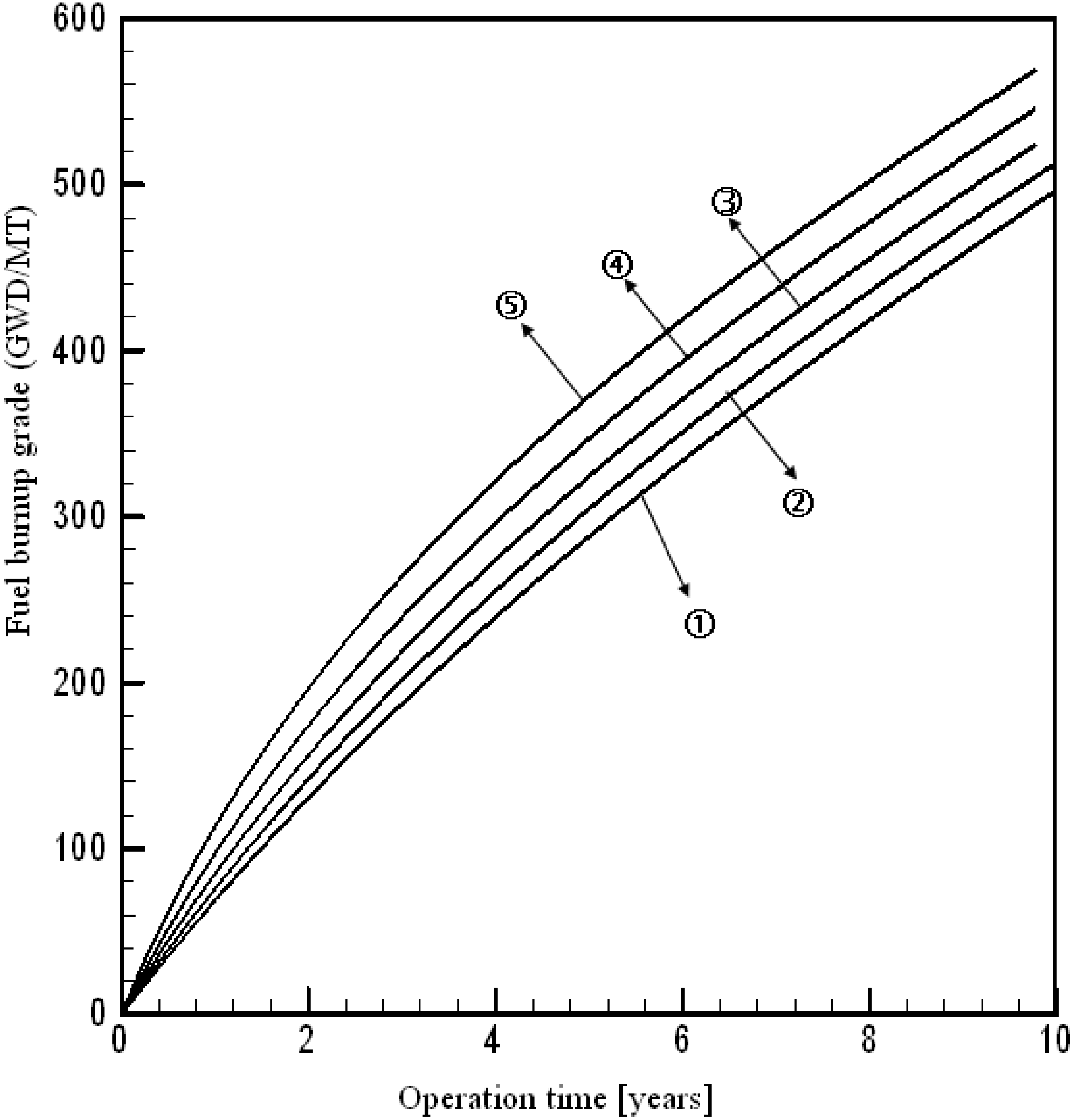
Temporal variation of tritium breeding ratio (RG-Pu)

$$M = 1 + \frac{200MeV * <\Phi \bullet \Sigma_f> + gamma\ heating + 4.784MeV * T_6 - 2.467MeV * T_7}{14.1MeV}$$

$<\Phi \bullet \Sigma_f> = \iint \Phi \bullet \Sigma_f dEdV$: Total integral fission rate

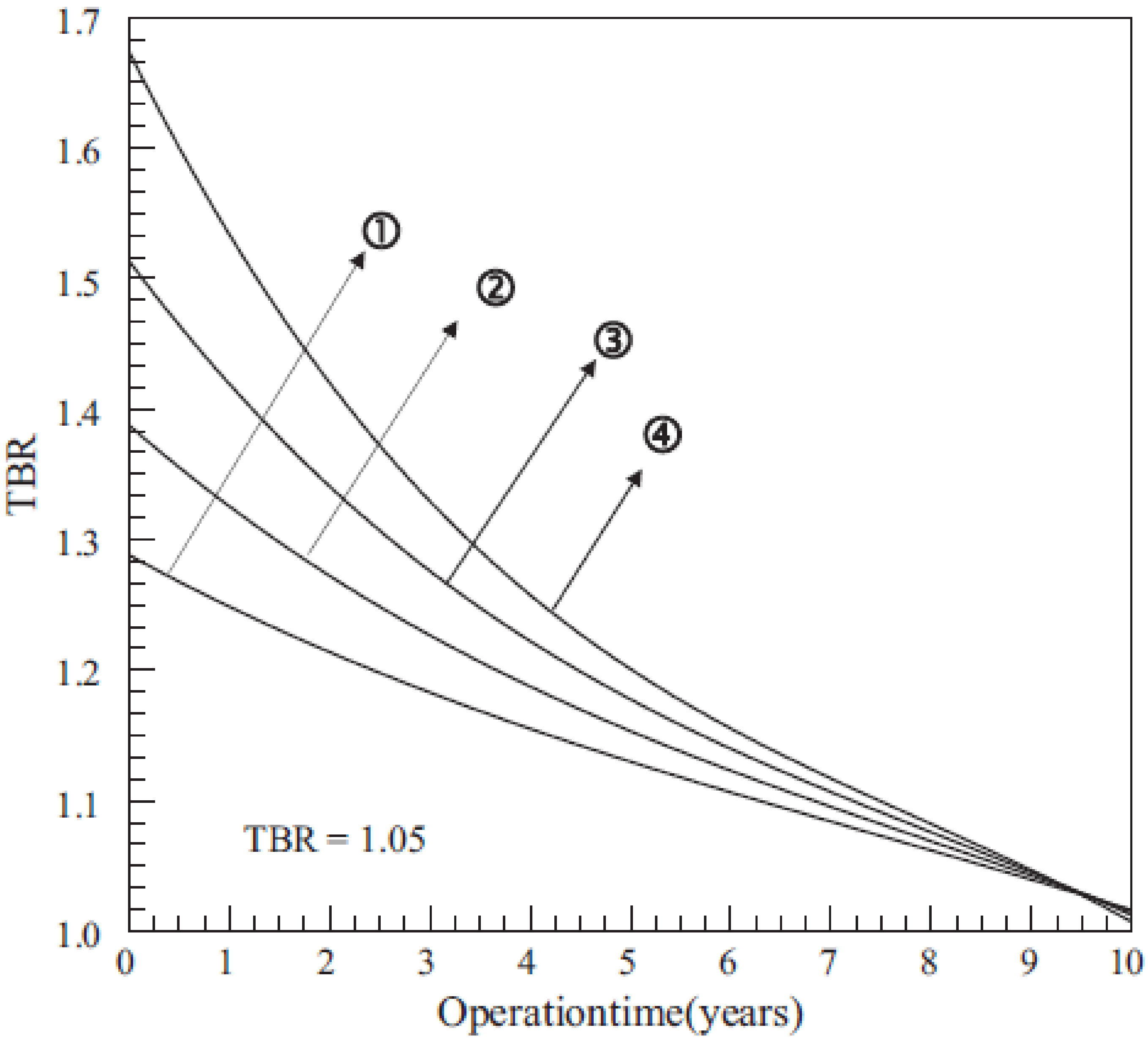
Temporal variation of blanket energy multiplication factor (M) (RG-Pu)

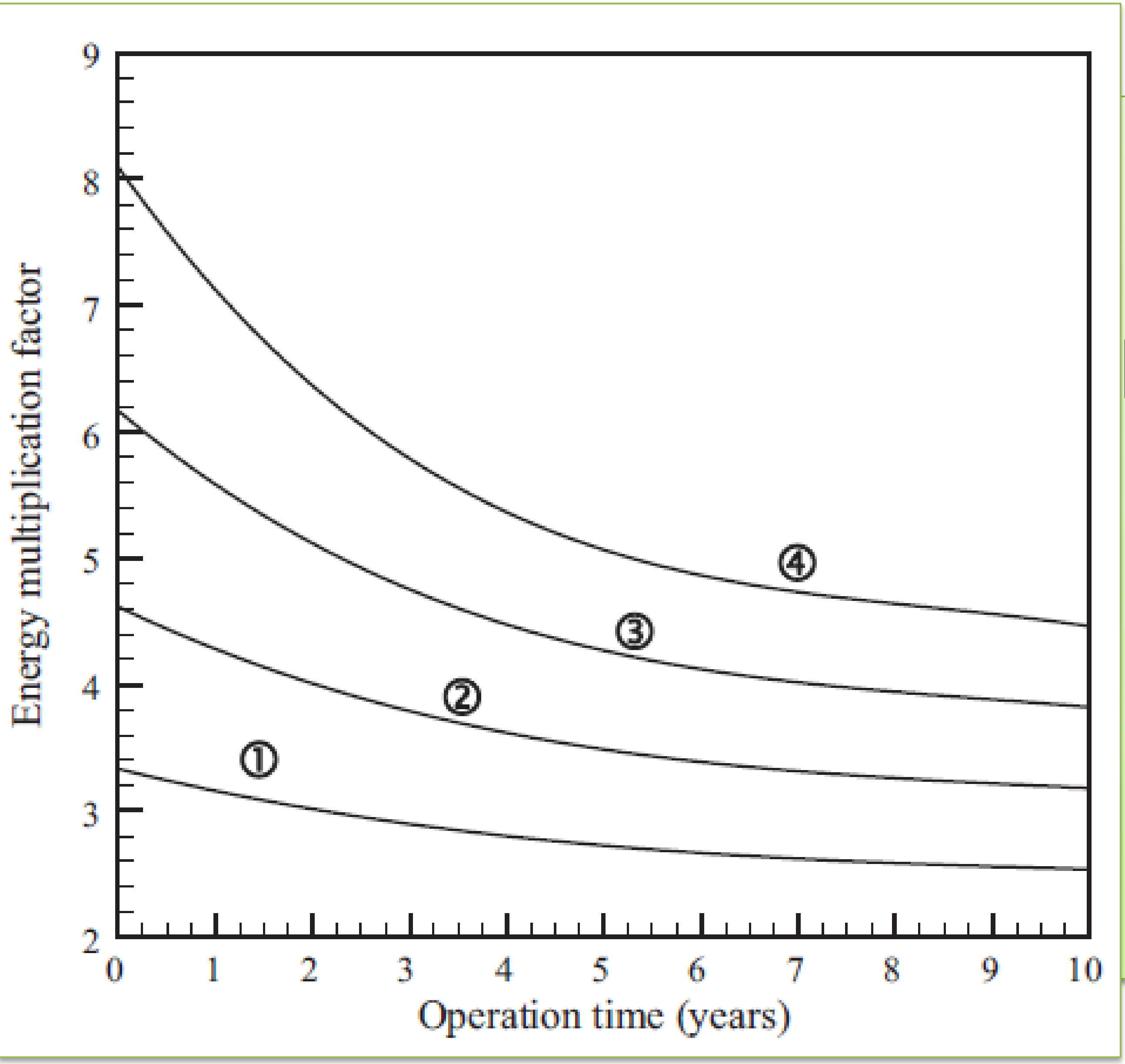




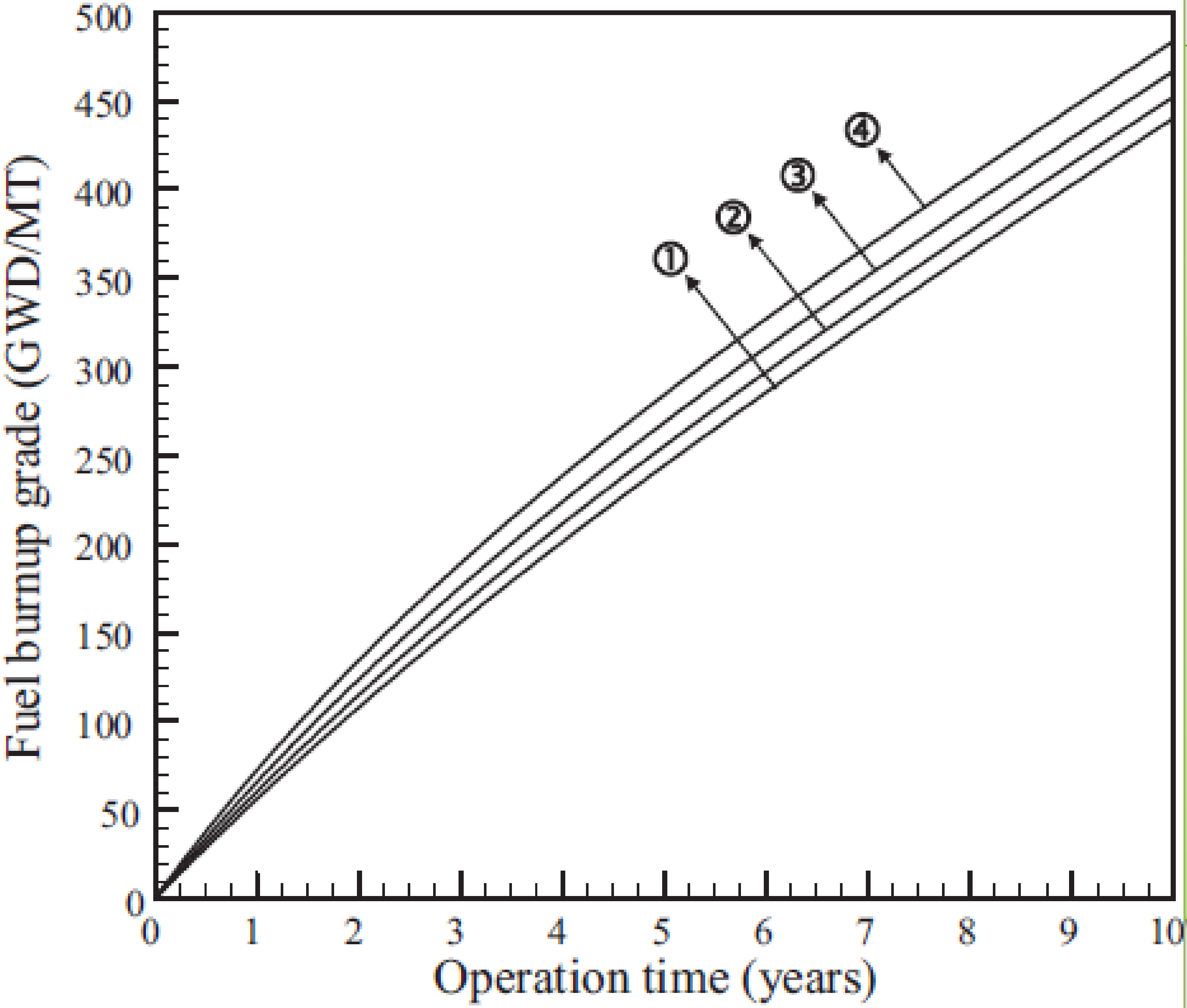
Time evolution of fuel burn up grade (RG-Pu)

Temporal variation of tritium breeding ratio (Minor Actinides)





Temporal variation of blanket energy multiplication factor (M) (Minor Actinides)



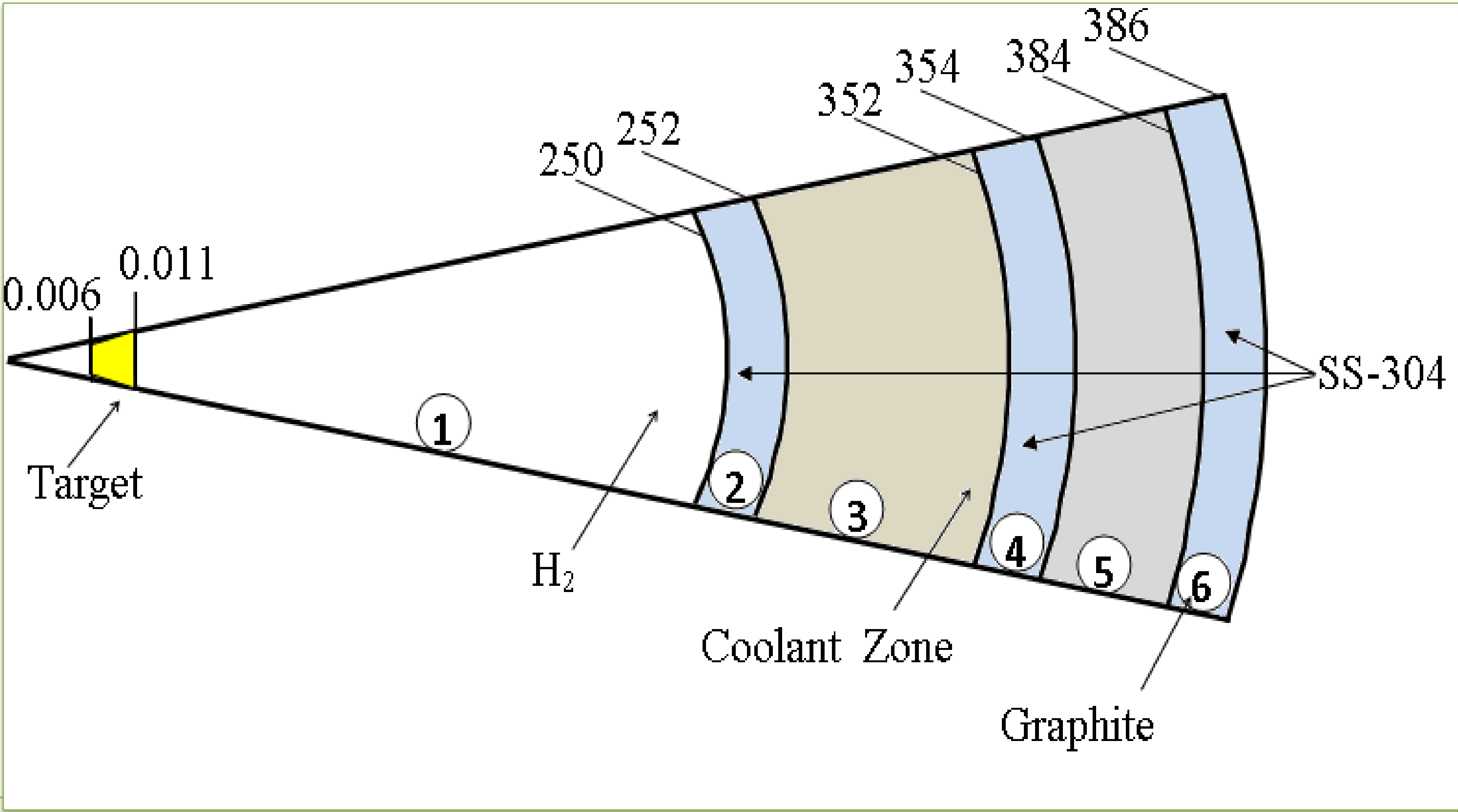
Time evolution of fuel burn up grade (Minor Actinides)

Fusion driver power: 500 MW_{th}

Neutron source strength: $1.774\times10^{+20}$ (14 MeV-n/sec)

Plant factor: 100 %

Neutron transport calculations: MCNPX-2.7.0 using continuous energy cross sections.



Geometrical model of the lithium cooled blanket

(Dimensions are in mm and not to scale)

① % 1 ThO_2 + % 99 Nat-Li (1.57 tones of thorium at startup)

② % 2 ThO_2 + % 98 Nat-Li (3.15 tones of thorium at startup)

③ % 3 ThO_2 + % 97 Nat-Li (4.72 tones of thorium at startup)

④ % 4 ThO_2 + % 96 Nat-Li (6.29 tones of thorium at startup)

⑤ % 5 ThO2 + % 95 Nat-Li (7.87 tones of thorium at startup)

⑥ % 10 ThO2 + % 90 Nat-Li (15.74 tones of thorium at startup)

Neutron multiplication reaction rates in the blanket

V_{TRISO} [%]	^{232}Th(n,2n)	Li(n,2n)	Total (n,2n)	^{232}Th(n,f)
0	0	2.0072E-02	2.0072E-02	0
1	3.0914E-03	1.9684E-02	2.2776E-02	8.4789E-04
2	6.1161E-03	1.9294E-02	2.5410E-02	1.6794E-03
3	9.0784E-03	1.8914E-02	2.7992E-02	2.4954E-03
4	1.1983E-02	1.8542E-02	3.0525E-02	3.2981E-03
5	1.4828E-02	1.8176E-02	3.3004E-02	4.0838E-03
10	2.8119E-02	1.6406E-02	4.4525E-02	7.7876E-03

Lithium burn up:

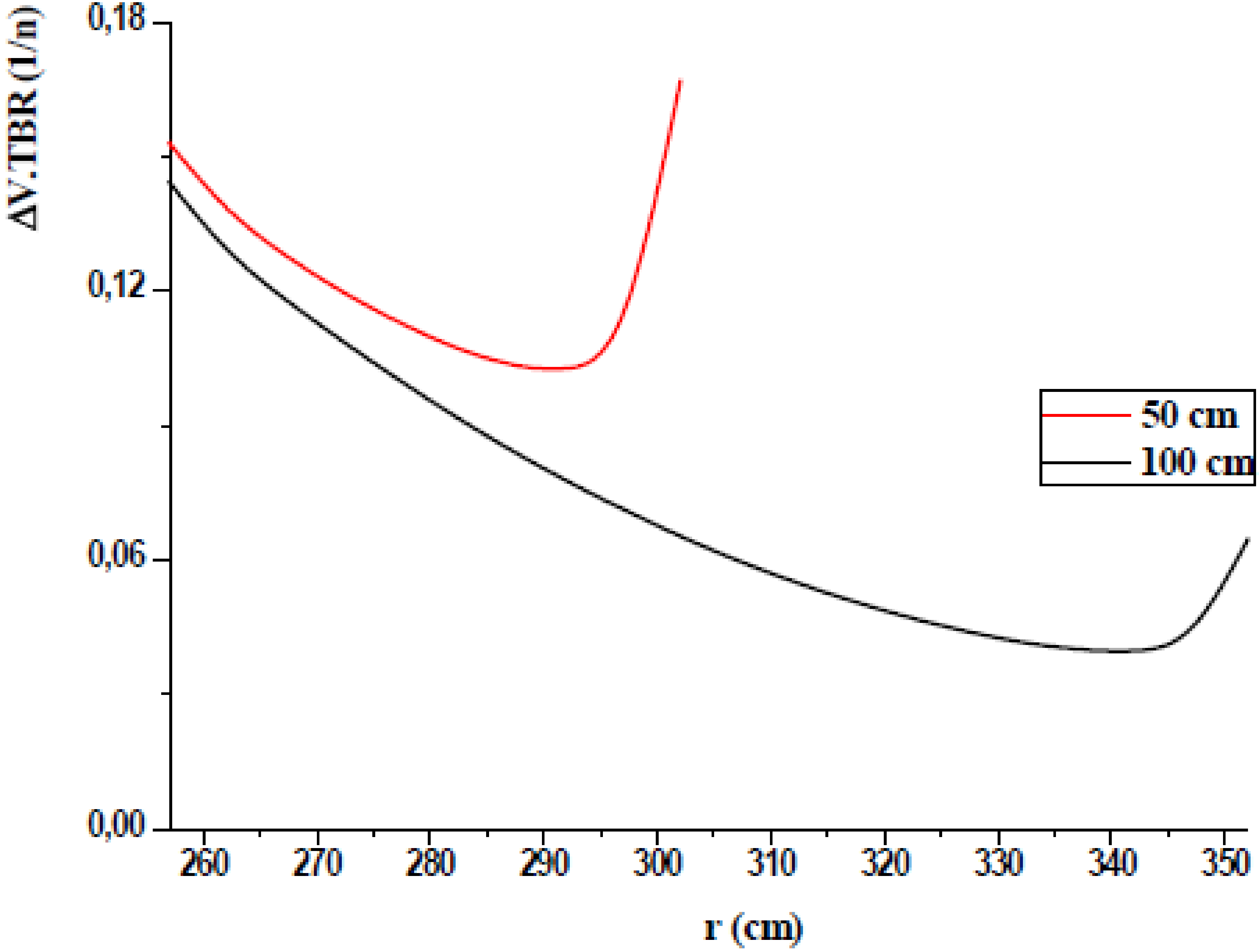
~50 kg/year ^{6}Li

~22.5 kg/year ^{7}Li

Initial lithium charge: 34.58 tonnes

Tritium production/neutron in the presence of thorium in the lithium coolant

V_{TRISO} [%]	ΔR_{Li} = 50 cm			ΔR_{Li} = 100 cm		
	T_6	T_7	TBR	T_6	T_7	TBR
0	0.8909	0.3462	1.2371	1.0544	0.4216	1.4760
1	0.8899	0.3390	1.2290	1.0510	0.4107	1.4618
2	0.8894	0.3321	1.2215	1.0482	0.4004	1.4485
3	0.8883	0.3254	1.2137	1.0448	0.3904	1.4352
4	0.8869	0.3190	1.2059	1.0418	0.3809	1.4227
5	0.8871	0.3126	1.1997	1.0390	0.3714	1.4104
10	0.8807	0.2815	1.1622	1.01998	0.3274	1.3474



ΔV.TBR (1/n.cm^3) in coolant zone

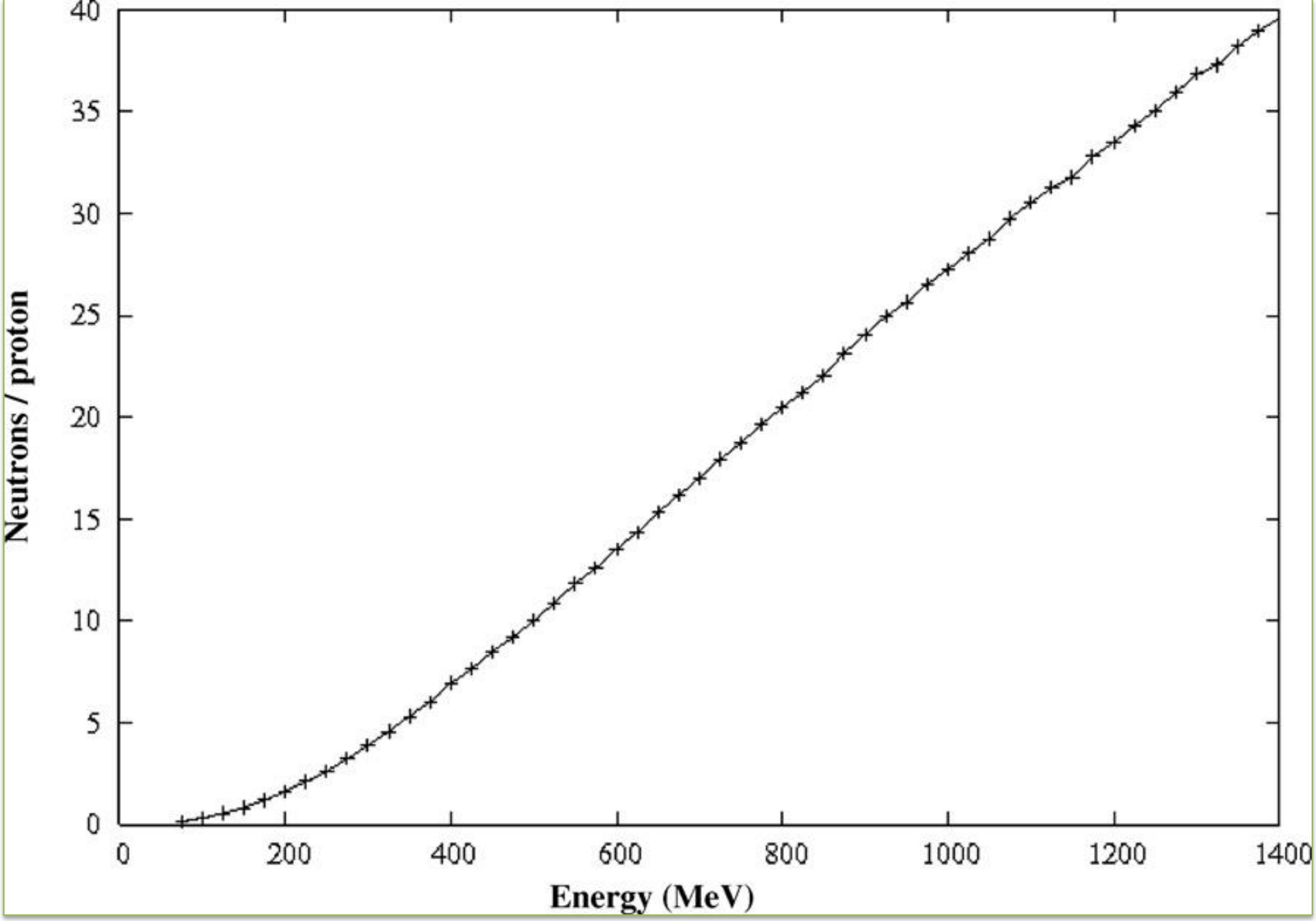
Total fissile fuel production

V_{TRISO} [%]	ΔR_{Li} = 50 cm		ΔR_{Li} = 100 cm	
	^{232}Th(n,γ)/n	^{233}U(kg/a)	^{232}Th(n,γ)/n	^{233}U (kg/a)
1	7.9680E-03	17.22	9.6224E-03	20.80
2	1.5309E-02	33.09	1.8827E-02	40.70
3	2.2508E-02	48.66	2.7836E-02	60.17
4	2.9702E-02	64.21	3.6856E-02	79.67
5	3.6902E-02	79.77	4.5865E-02	99.15
10	7.3880E-02	159.71	9.1550E-02	197.9

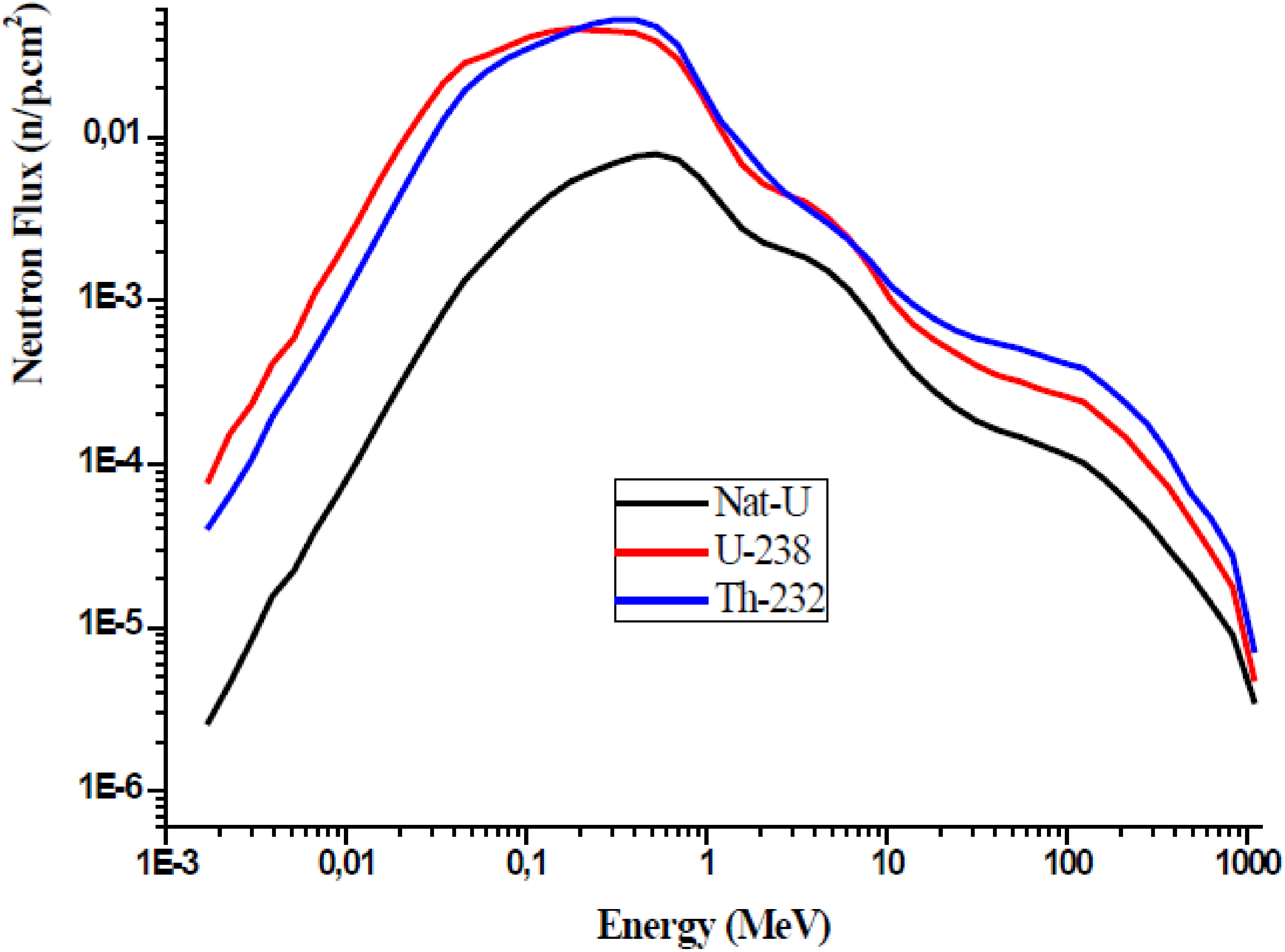
Total heating and energy multiplication/neutron in the hybrid blanket with variable TRISO (ThO_2) volume in the coolant, ΔR_{Li} = 50 cm [MeV/n]

Zone #	V_{TRISO} [%] Material	0	1	2	3	4	5	10
1	Fusion fuel	3.6696	3.6698	3.6695	3.6696	3.6696	3.6695	3.6694
3	S-304 Steel	1.2142	1.1985	1.2021	1.2047	1.2108	1.2174	1.2455
4	Coolant	9.8584	10.1116	10.329	10.535	10.732	10.919	11.784
5	S-304 Steel	0.6508	0.6083	0.5902	0.5728	0.5587	0.5440	0.4874
6	Graphite	1.4395	1.3992	1.3645	1.3268	1.2960	1.2632	1.1153
7	S-304 Steel	0.2260	0.2225	0.2190	0.2123	0.2079	0.2046	0.1862
	Total	17.059	17.21	17.374	17.521	17.675	17.817	18.488
	M	1.2098	1.2206	1.2322	1.2426	1.2536	1.2636	1.3112
	k_{eff}	0.173	0,181	0,188	0,195	0,202	0,209	0.273

ACCELERATOR DRIVEN SYSTEMS



Neutron yield per proton in a lead–bismuth thick target



Spallation neutron spectrum **in infinite medium** by incident 1 GeV proton

FUEL	^{232}Th(n,f)/p	E_f/p (GeV)	k_∞	^{232}Th(n,γ)/p ^{233}U/p
^{232}Th	2,75408	0,473	0,321	48,3568

FUEL	^{238}U(n,f)/p	E_f/p (GeV)	k_∞	^{238}U(n,γ)/p ^{239}Pu/p
^{238}U	11,4455	2,075	0,675	69,0129

FUEL	^{235}U(n,f)/p	^{238}U(n,f)/p	Total (n,f)/p	E_f/p (GeV)	k_∞	^{238}U(n,γ)/p ^{239}Pu/p
Nat-U	4,7068	13,181	17,888	3,241	0,764	78,0450

Fission rate, fission energy release, k_∞ and ^{239}Pu production **in infinite medium** per incident 1 GeV proton

CONCLUSIONS

CANDU reactors could enable utilization of thorium with presently available technology

Very high burn up levels (up to 400 000 MW.D/MT) could be attained for a given fuel mass, which would reduce drastically the fuel fabrication and nuclear fuel reprocessing costs as well as the residual nuclear waste mass per unit energy output.

Utilization of nuclear waste as useful fuel will lead to negative fuel cost.

Plutonium component in the fuel remains always non-prolific.

YOU ARE ALL INVITED TO ATTEND

NURER2014, 4th INTERNATIONAL CONFERENCE ON NUCLEAR AND RENEWABLE ENERGY RESOURCES , Antalya, Türkiye,

20-23 October 2014 http://nurer2014.org/

ICENES2015, 17th INTERNATIONAL CONFERENCE ON EMERGING NUCLEAR ENERGY SYSTEMS, May 2015, Türkiye

http://www.icenes2015.org/