

Fast Reactor Designing Study for Proliferation Resistance and Physical Protection Enhancement

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SAGARA-Laboratory

Laboratory of Advance Nuclear Energy

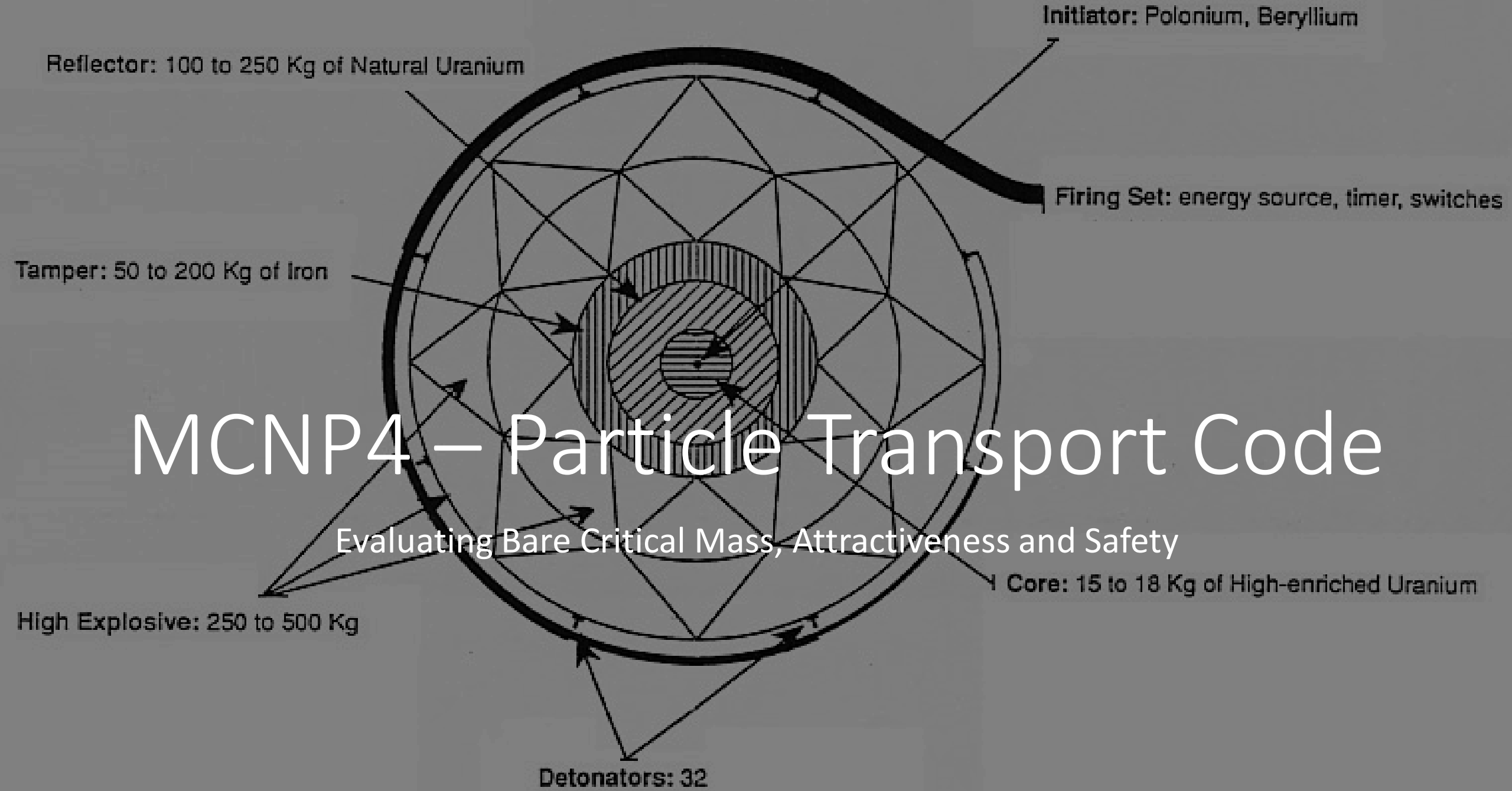
Tokyo Institute of Technology Summer Program

Research Plan and Objectives

- MCNP4 particle transport code
 - Critical mass and heat content calculations
 - Neutron transport calculations
 - Nuclear material attractiveness methodology
- Research on fast spectrum reactor designing for Minor Actinides (MA) transmutation and for High Proliferation Resistance.
- Neutronics analysis of a Fast Spectrum Reactor core design:
 - Reactivity and burnup calculation by the combination of a 2-D deterministic code, SLAROM-JOINT-CITATION, for full scale fast spectrum core designing and performance evaluation
- Learning of the Plutonium (Pu) fuel cycle in Japan. This will include the research of the underlying physics of the Pu fuel cycle.

Important Definitions:

- Proliferation Resistance
 - is that characteristic of an NES that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices.
- Physical Protection
 - is that characteristic of an NES that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices (RDDs) and the sabotage of facilities and transportation by sub-national entities and other non-Host State adversaries.



Schematic diagram of an implosion bomb similar to the one designed by Iraq

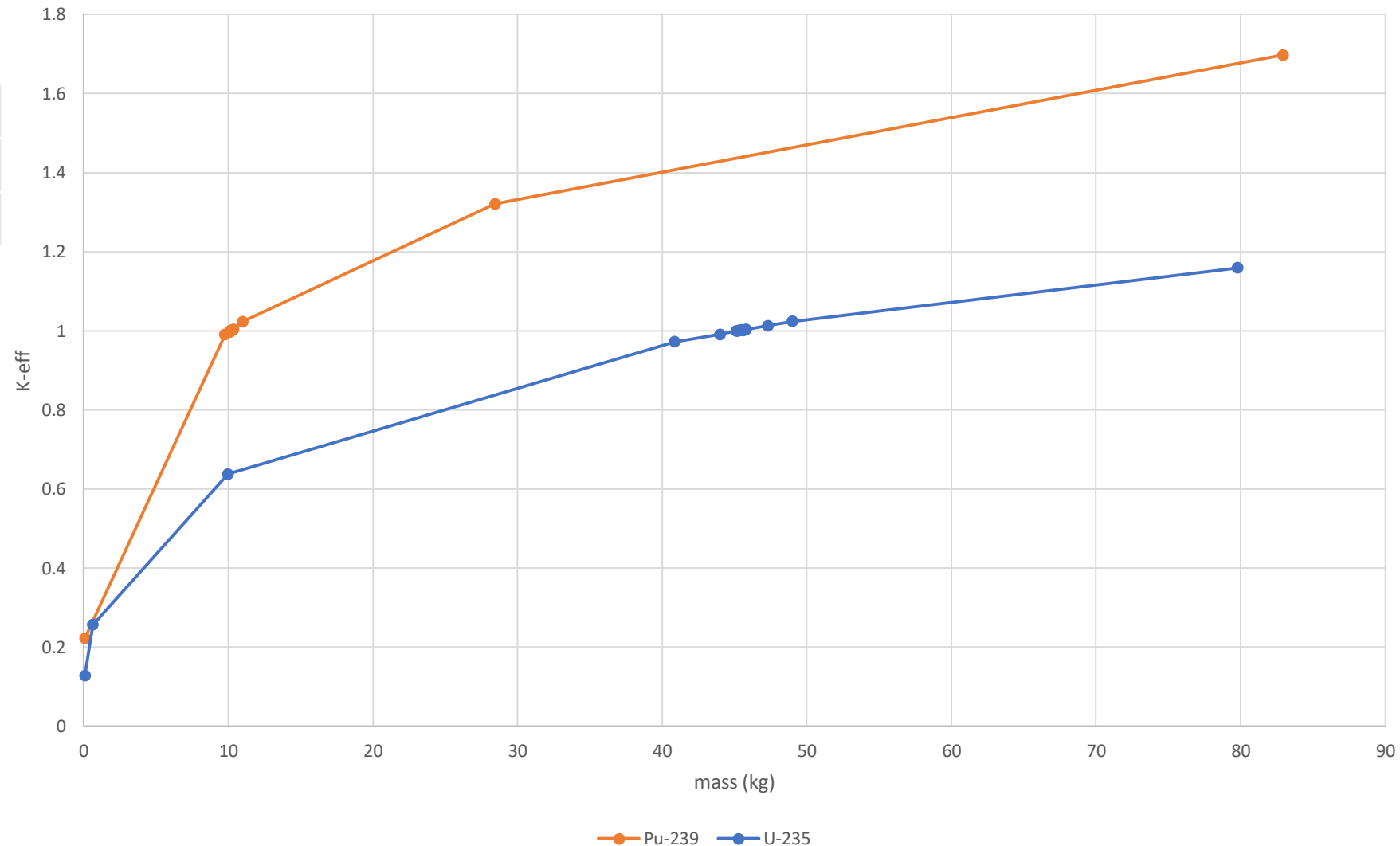
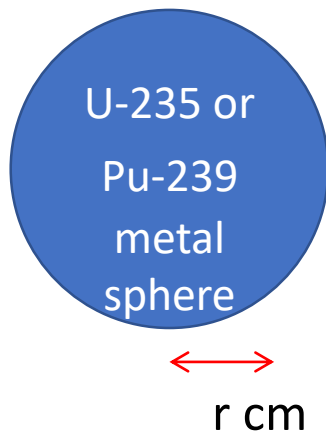
Bare Critical Mass



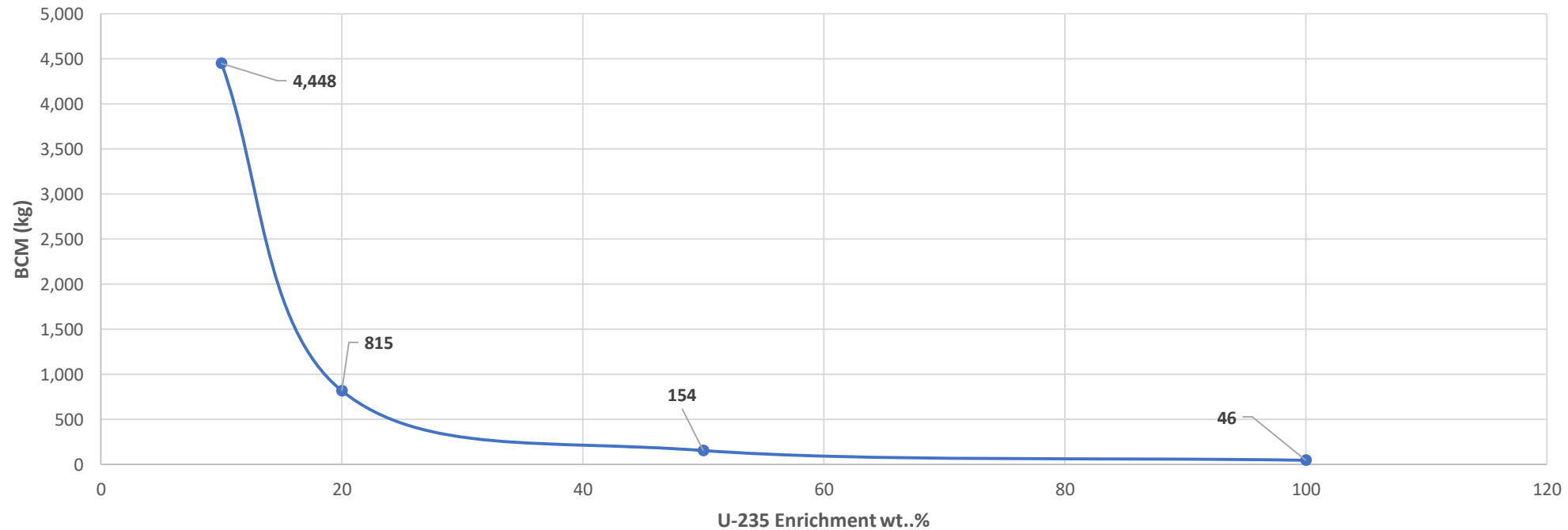
Exercise 1: BCM of U-235 and Pu-239

Isotope	radius (cm)	k-eff
U-235	8.28	1.00054
Pu-239	4.96	1.00018

BCM U-235 = **45.29 kg**
BCM Pu-239 = **10.12 kg**

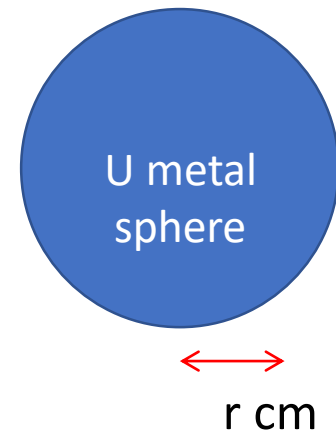


Exercise 2: BCM of different U-enrichment



Mass density:
U-metal 19.05 g/cc

Enrichment (wt..%)	BCM (kg)	k-eff	radius (cm)
0.72	-	0.43197	-
5	-	0.94089	-
10	4448	1.00092	38.2
20	815	0.99948	21.7
50	154	0.99907	12.45
100	46	1.00042	8.3



Exercise 3: BCM of different material forms of Uranium

Nuclide: U-235

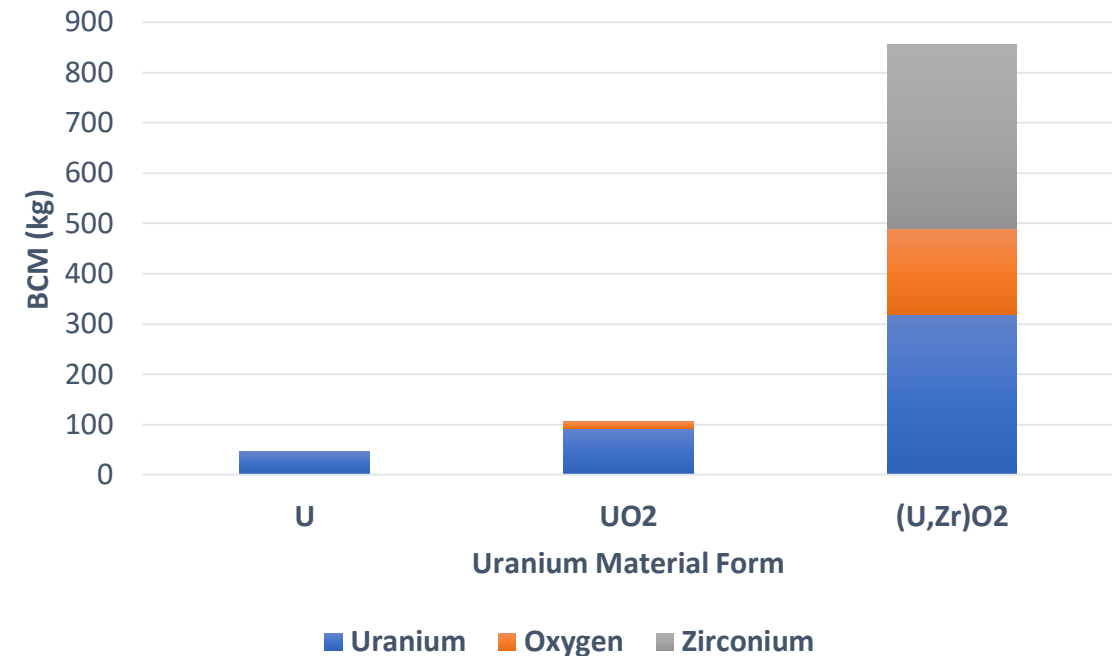
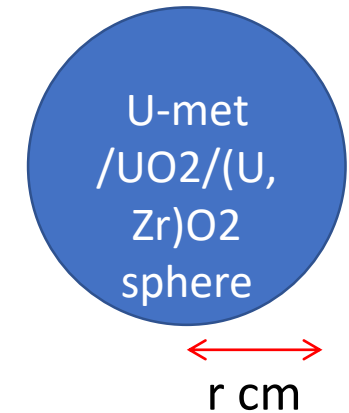
Material form: U-Metal, UO₂, (U,Zr)O₂

Mass density: U-metal 19.05 g/cc, UO₂ 10.96g/cc,
(U,Zr)O₂ 6.0g/cc, U:Zr=1:3 in atom

BCM U-Metal = **45.63 kg-U**, 45.63 kg-total

BCM UO₂ = **92.44 kg-U**, 104.87 kg-total

BCM (U,Zr)O₂ = **318.08 kg-U**, 854.82 kg-total

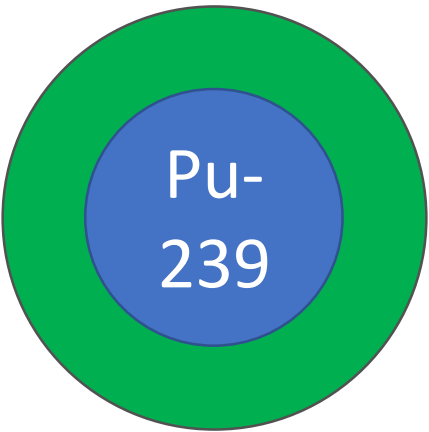


Exercise 4: CM with reflector

Material : Pu239-Metal with reflector

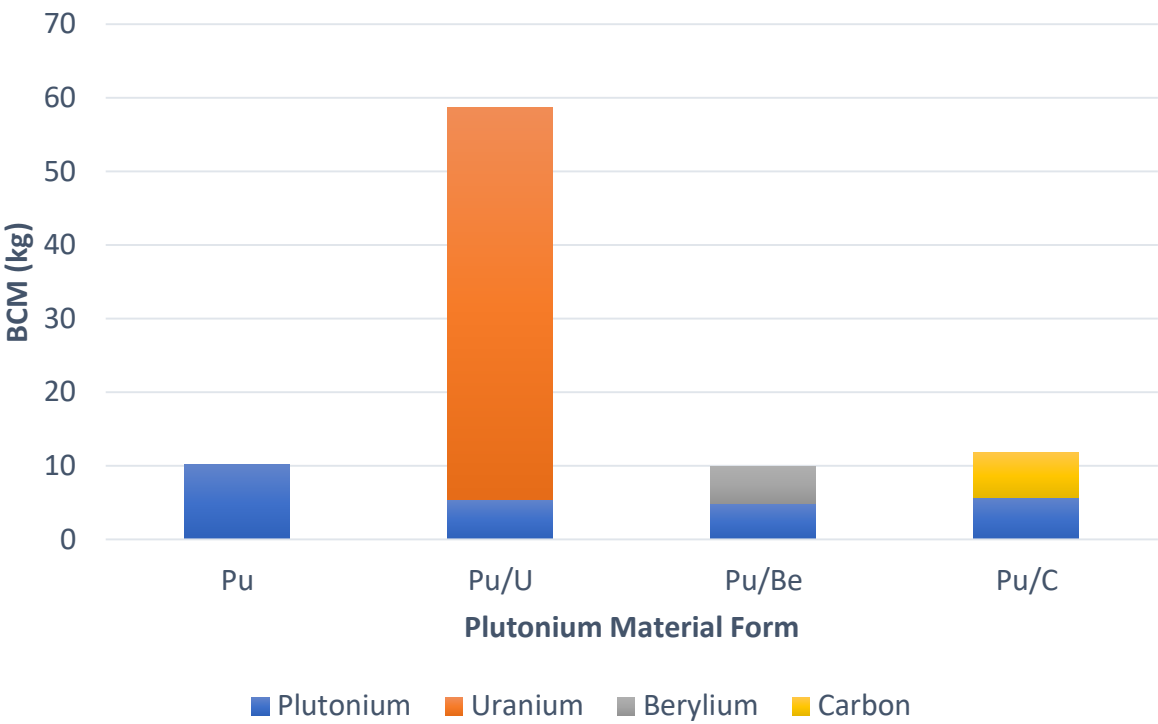
Mass density: Pu-metal 19.80g/cc

Reflector : U-metal 19.05g/cc, Be-metal 1.85g/cc,
 Graphite 2.10g/cc



- CM Bare Pu = **10.12 kg-Pu**, 10.12 kg-total
- CM Pu/U= 5.39 kg-Pu, 58.76 kg-total
- CM Pu/Be= 4.92 kg-Pu, 9.92 kg-total
- CM Pu/C= 5.72 kg-Pu, 11.74 kg-total

	Pu	Pu/U	Pu/Be	Pu/C
Radius	4.96	4.02/9.02	3.9/8.9	4.1/9.1
Capture CS	-	2.683	0.008603	0.0035



Exercise 5: Attractiveness

Material : bare Pu-Metal, Pu-239, Pu238

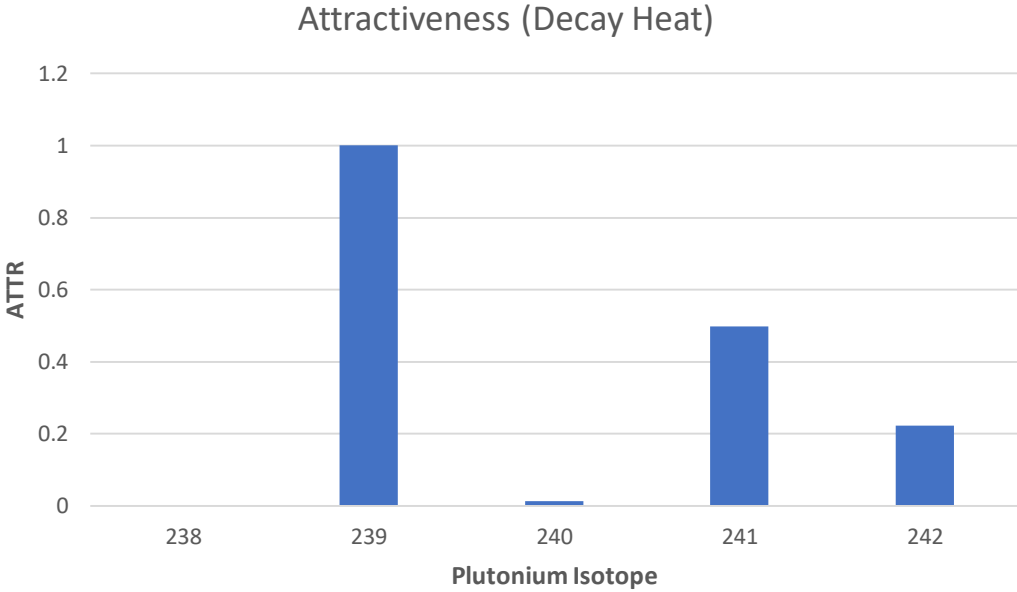
Mass density: Pu-metal 15.80g/cc

with delta-phase

Rossi-alpha:

$$\alpha = \frac{k-1}{l}$$

$$ATTR = \frac{\left(\frac{\alpha(\infty,1)}{\alpha^{239}(\infty,1)}\right)^{n=1,2,3}}{\frac{DH_{CM}}{DH_{CM}^{238}} + \frac{SN_{CM}}{SN_{CM}^{238}} + \frac{RD_{CM}}{RD_{CM}^{238}}}$$



Isotope	Decay heat (W/kg)	SN (n/g/s)
²³⁸ Pu	567	2660
²³⁹ Pu	1.93	0.0226
²⁴⁰ Pu	7.06	1030
²⁴¹ Pu	3.4	0.0493
²⁴² Pu	0.12	1720

Isotope	radius (cm)	mass (kg)	k-inf	l (abs)	alphaN	decayN	ATTR	ATTR(N)
238	5.96	14.01	2.81324	1.27E-08	0.96	1.00000	0.9627619	0
239	6.22	15.93	2.95061	1.31E-08	1.00	0.00387	258.4596560	1
240	9.02	48.57	2.23078	4.57E-08	0.18	0.04316	4.1926093	0.012543
241	6.58	18.85	2.90547	1.23E-08	1.04	0.00807	129.1969948	0.498003
242	11.3	95.50	1.9642	7.68E-08	0.08	0.00144	58.5002960	0.223449

Exercise 6: Criticality Safety of Chemical Process in Pulse column

Material : Pu and U in solution

Mass density: Water solution, fix with 1.0g/cc

Pulse Column: Variable Diameter (cm), infinite column

Parameters: Pu density, U-Pu composition

Material Form	radius (cm)	k-eff
Pu(-0.2)	27.8	1.00095
Pu(-1.0)	13.4	0.99959
PuU (0.72/7.2)	21.44	0.99954
PuU (0.36/7.2)	28.75	1.00049
PuU (0.5/8)	25.18	1.00018

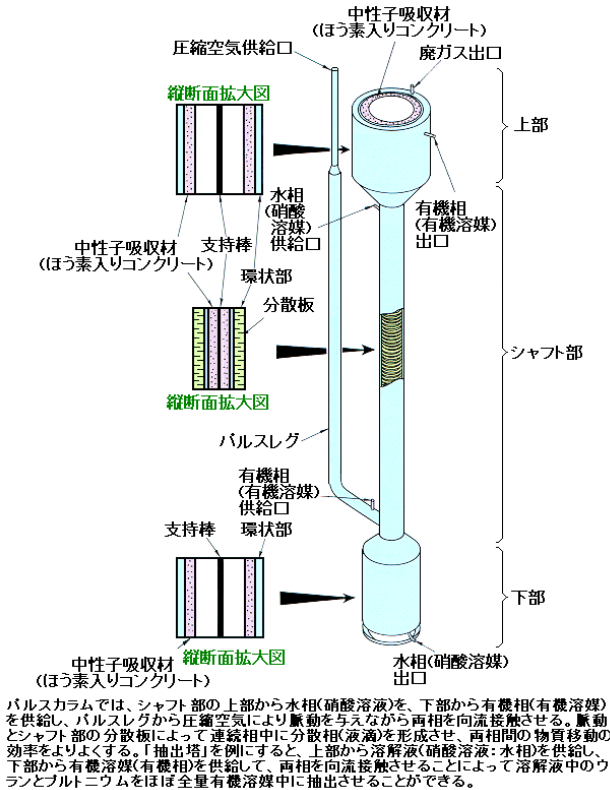
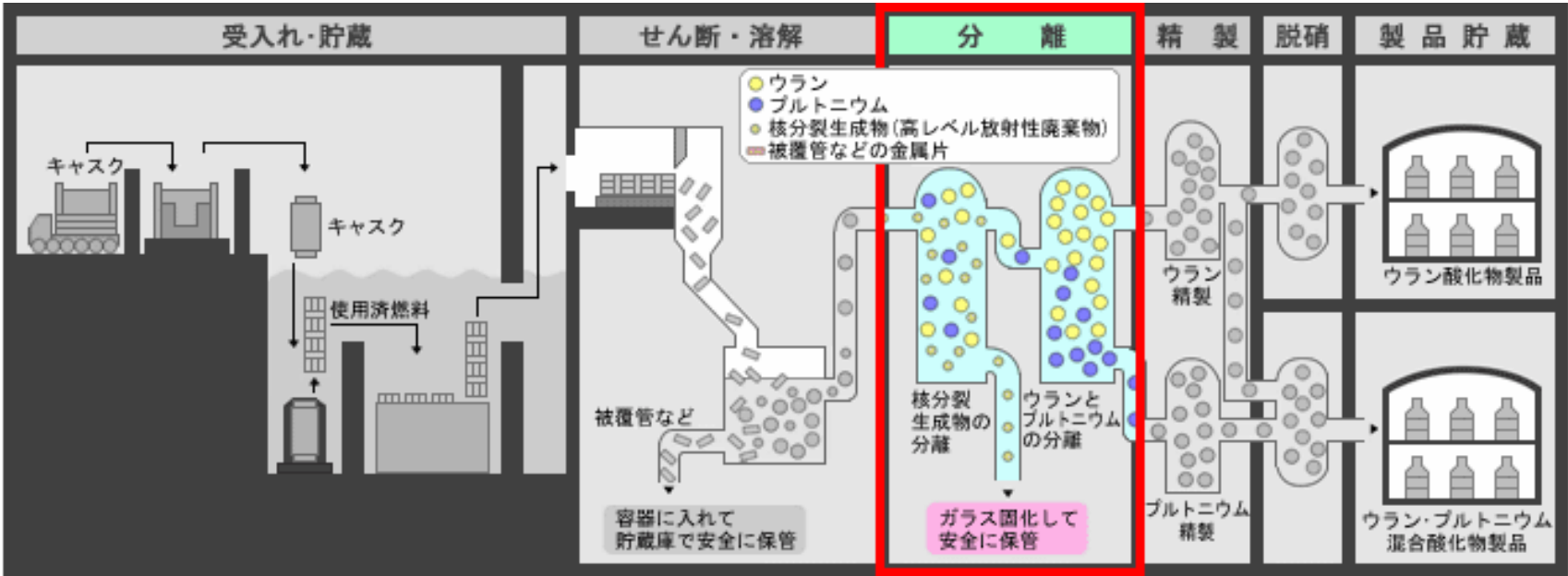


図8 六ヶ所再処理工場の環状型パルスカラム概要図
[出展]日本原燃(株):パンフレット「六ヶ所再処理工場の概要」、(2000年6月)p.14



SLAROM-JOINT-CITATION

Nuclear Reactor Core Analysis Code

-  Inner Core Fuel
-  Outer Core Fuel
-  Radial Blanket
-  SUS Shielding
-  Zr-H Shielding
-  Primary Control Rods
-  Backup Control Rods

Japan Sodium-cooled Fast Reactor (JSFR)

Item	Unit	Specification
a. Plant		
Reactor thermal power	MW _{th}	3570
Coolant temperature (inlet/outlet)	°C	395/550
Fuel/colant/structure	vt. %	43.9/30.3/25.8
Subassembly pitch	mm	206.0
b. Fuel		
Fuel material		TRUO ₂ -UO ₂
Pu enrichment in HM (inner core/outer core)	wt. %	18.3/20.9
²³⁵ U enrichment	wt. %	0.2
Refueling patern		four-batch
Irradiation time per one batch	day	800
Core diameter/core height	m	5.38/1.0
c. Blanket		
Blanket fuel material		UO ₂
²³⁵ U enrichment	wt. %	0.2
Pattern of fuel exchange		four-batch
Thickness of axial blanket (upper/lower)	m	0.2/0.2

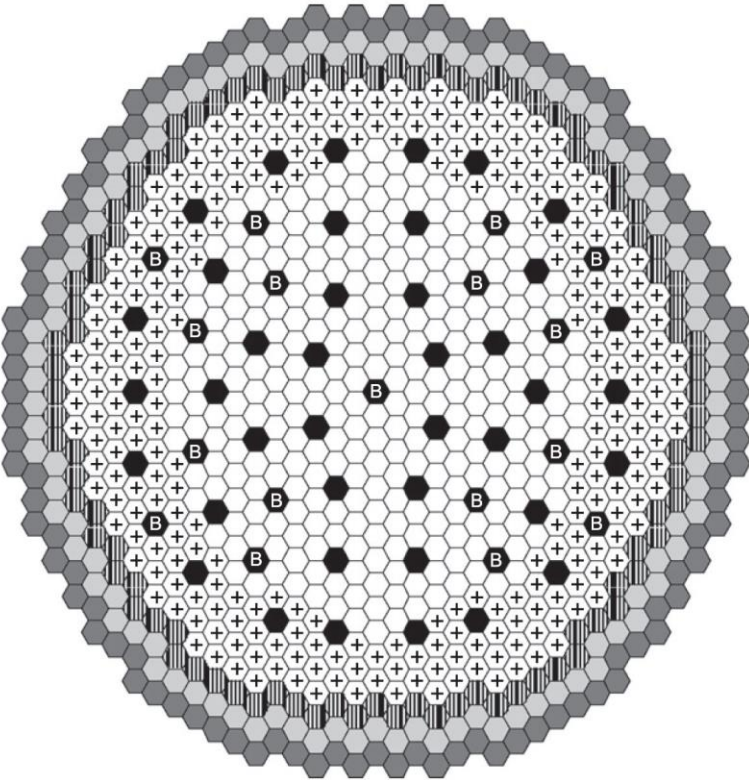
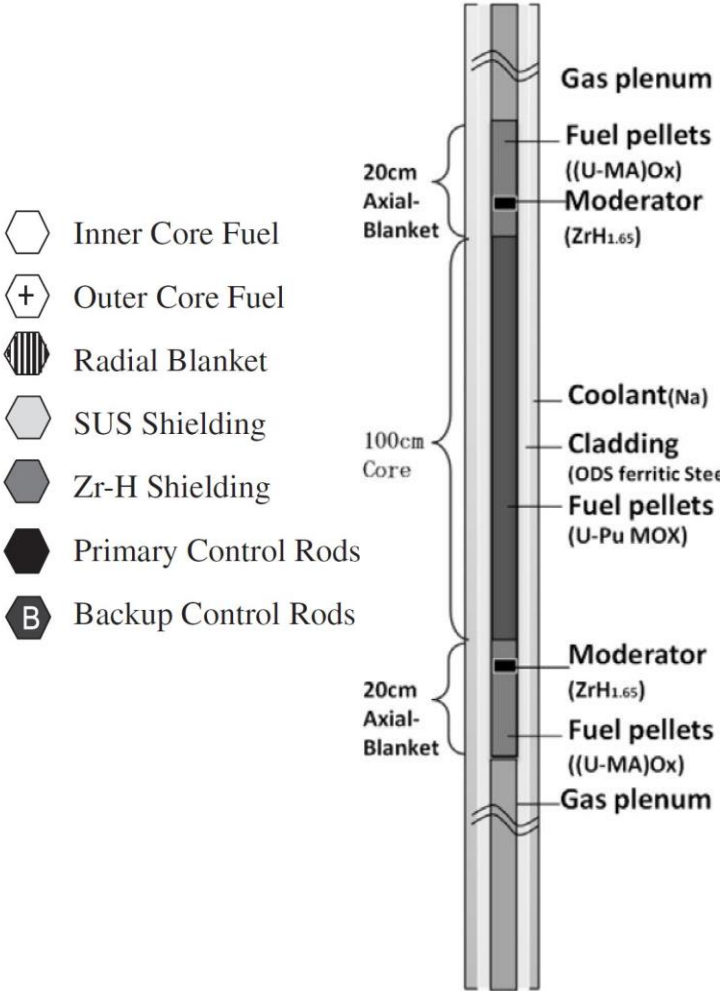
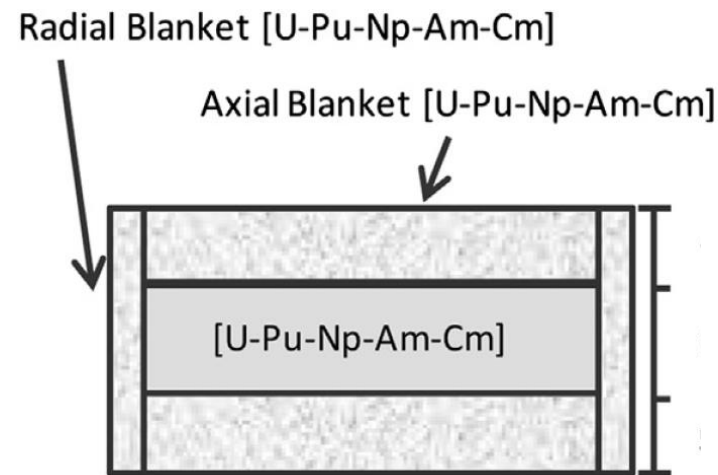
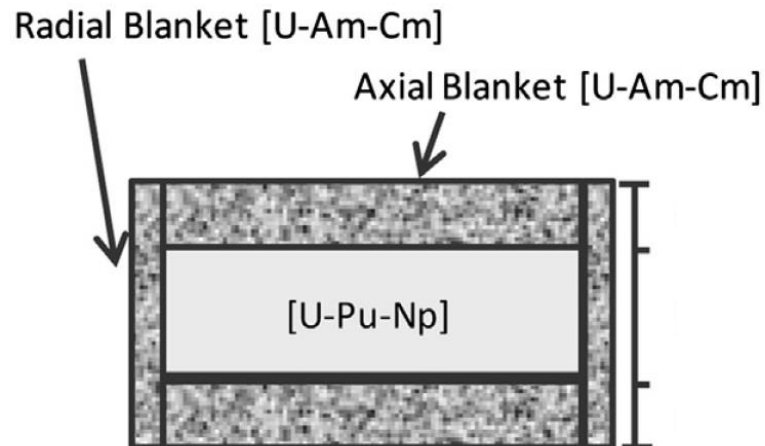
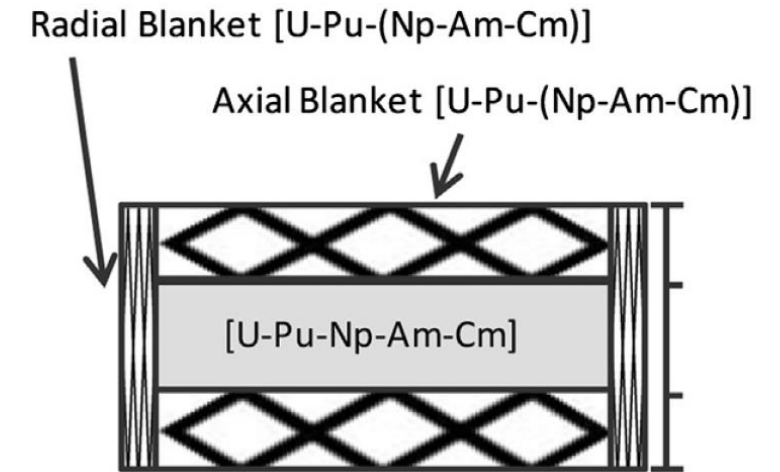
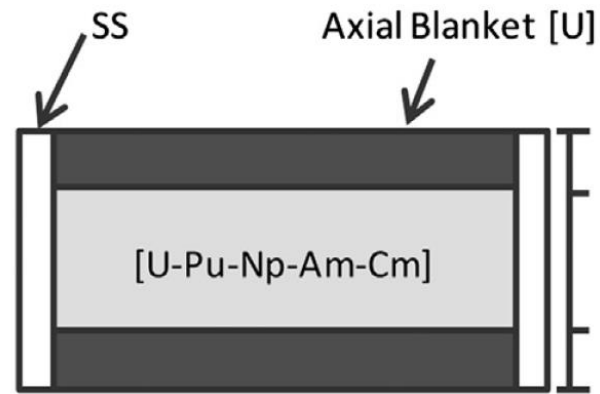
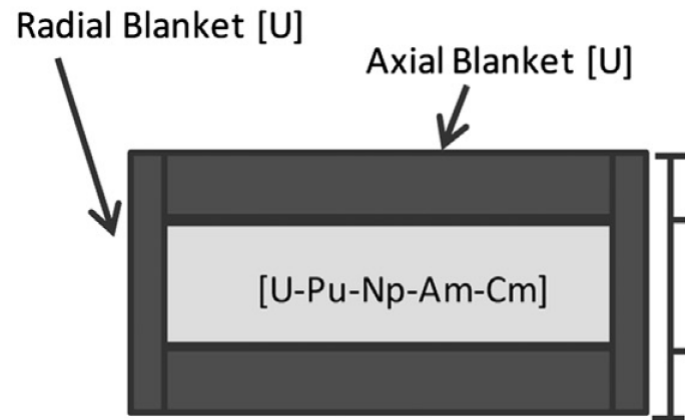


Fig. 1a. Core layout (horizontal view).



(Sagara et al., 2005).

Core design approaches



Nuclide	Composition (wt..%)
^{238}Pu	1.1
^{239}Pu	54.1
^{240}Pu	32.1
^{241}Pu	4.3
^{242}Pu	3.9
^{237}Np	0.5
^{241}Am	2.0
^{243}Am	1.0
^{244}Cm	1.0

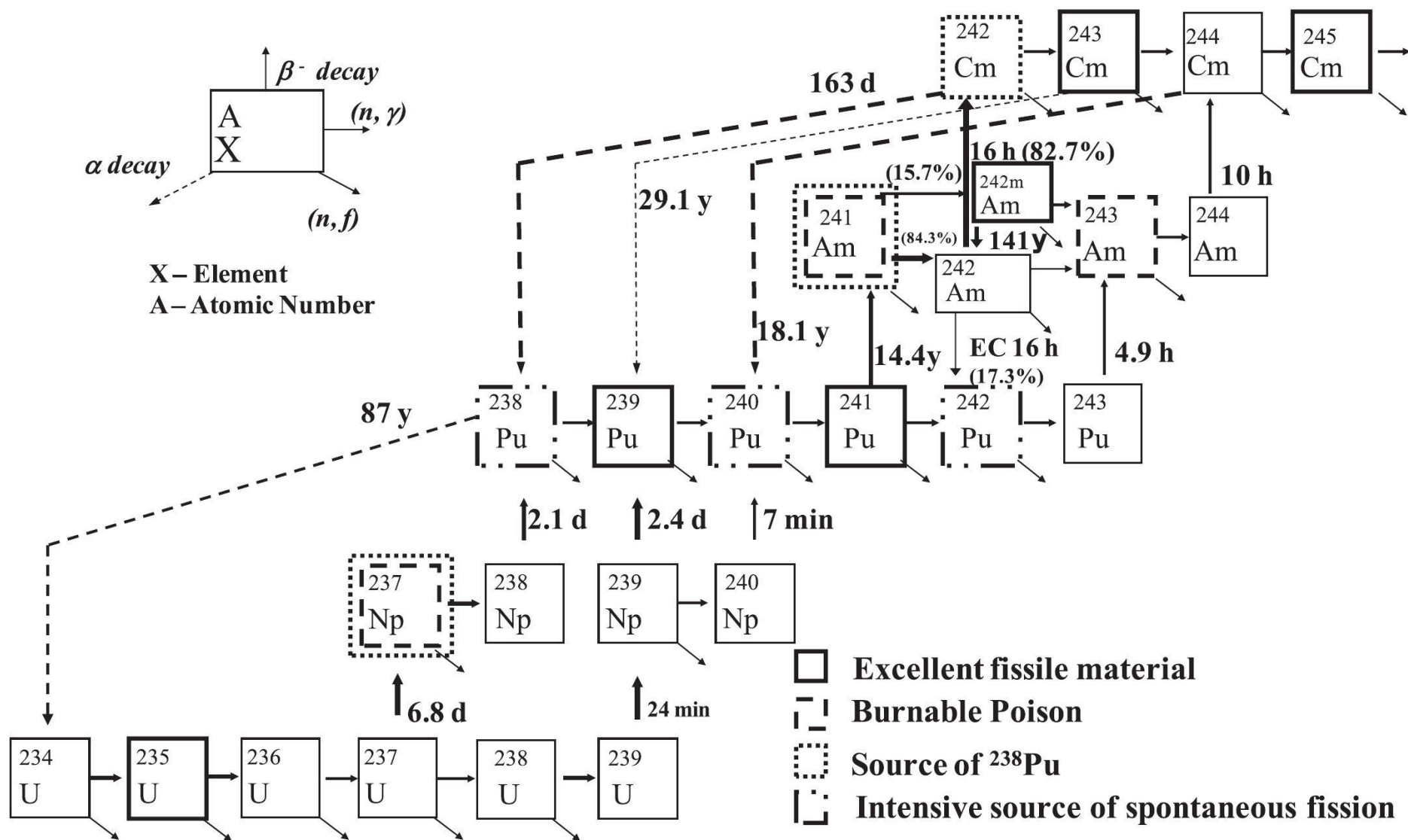
SLAROM-JOINT-CITATION

- SLAROM-UF
 - Cell homogenization calculation
 - Fast power reactor
 - Fast critical assembly
 - Using the Japanese Evaluated Nuclear Data Library (JENDL-3.2)
- JOINT-FR
- CITATION
 - Nuclear reactor core analysis code system
 - Neutron diffusion theory
 - Two-dimensional RZ diffusion theory
 - Depletion Chain
 - Multi-cycle analysis

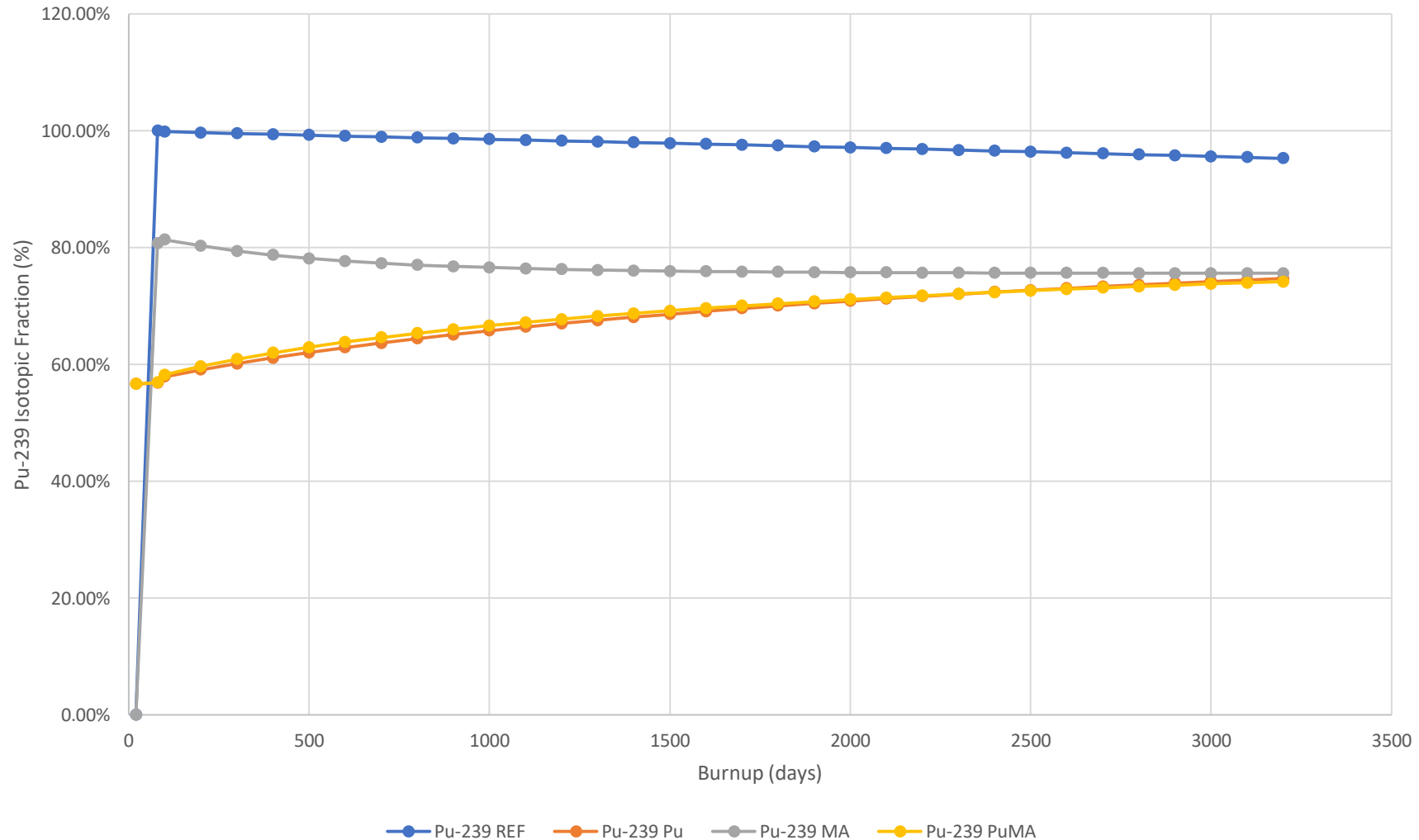
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	7.5	10.82	16.73	24.19	34.20	46.26	61.72	80.83	103.88	131.47	164.15	202.51	246.21	295.91	352.28	416.01	486.78	565.28	652.21	748.28	854.21	970.78	1098.61	1238.41	1390.88	1556.71	1736.61	1930.38	2138.81	2362.61	2602.51	2858.28	3130.61	3419.28	3725.01	4048.51	4390.51	4751.51	5132.28	5533.51	5956.01	6400.51	6867.78	7358.51	7873.51	8413.51	8978.28	9568.51	10185.01	10828.28	11500.01	12202.01	12935.01	13700.01	14497.51	15328.28	16193.51	17095.01	18033.51	19010.01	19926.28	20883.51	21882.51	22924.01	23999.01	25098.51	26223.51	27375.01	28553.51	29759.01	30993.51	32257.01	33549.51	34871.51	36224.01	37607.51	39022.01	40468.51	41947.01	43458.51	44993.01	46552.51	48136.51	49745.51	51380.01	53041.51	54730.01	56447.51	58194.51	59972.01	61780.51	63620.01	65491.51	67395.01	69331.51	71299.51	73299.51	75332.01	77398.51	79499.01	81634.51	83795.01	85981.51	88194.01	90433.51	92700.01	94994.51	97317.01	99668.51	102049.01	104459.51	106899.51	109370.01	111871.51	114404.01	116968.51	119565.01	122195.51	124859.01	127556.51	130288.01	133054.51	135856.01	138693.51	141567.01	144477.51	147425.01	150409.51	153431.01	156491.51	159590.01	162727.51	165903.01	169117.51	172370.01	175661.51	178992.01	182362.51	185773.01	189224.51	192717.01	196250.51	199825.01	203441.51	207099.01	210798.51	214539.51	218322.01	222146.51	226013.01	229921.51	233872.01	237865.51	241902.01	245982.51	250106.01	254273.51	258485.01	262740.51	267040.01	271383.51	275771.01	280203.51	284681.01	289204.51	293774.01	298389.51	303051.01	307759.51	312515.01	317318.51	322169.01	327067.51	331994.01	336948.51	341930.01	346939.51	351977.01	357043.51	362137.01	367258.51	372407.01	377583.51	382787.01	388018.51	393278.01	398565.51	403879.01	409219.51	414587.01	419981.51	425403.01	430852.51	436329.01	441833.51	447365.01	452924.51	458512.01	464127.51	469770.01	475440.51	481139.01	486866.51	492621.01	498403.51	504214.01	510053.51	515920.01	521814.51	527736.01	533685.51	539663.01	545668.51	551701.01	557761.51	563849.01	569964.51	576107.01	582277.51	588475.01	594699.51	600951.01	607230.51	613537.01	619871.51	626233.01	632622.51	639039.01	645483.51	651955.01	658454.51	664981.01	671535.51	678117.01	684726.51	691364.01	698029.51	704721.01	711439.51	718184.01	724955.51	731754.01	738580.51	745434.01	752315.51	759225.01	766163.51	773129.01	780122.51	787144.01	794193.51	801271.01	808377.51	815512.01	822674.51	829865.01	837084.51	844332.01	851608.51	858912.01	866243.51	873603.01	880990.51	888405.01	895846.51	903315.01	910811.51	918336.01	925889.51	933471.01	941071.51	948690.01	956327.51	963984.01	971659.51	979354.01	987067.51	994799.01	1002549.51	1010318.01	1018105.51	1025912.01	1033737.51	1041582.01	1049446.51	1057330.01	1065233.51	1073157.01	1081100.51	1089063.01	1097045.51	1105048.01	1113070.51	1121113.01	1129175.51	1137258.01	1145360.51	1153483.01	1161625.51	1169788.01	1177970.51	1186173.01	1194395.51	1202638.01	1210900.51	1219183.01	1227485.51	1235808.01	1244150.51	1252513.01	1260895.51	1269298.01	1277720.51	1286163.01	1294625.51	1303108.01	1311610.51	1320133.01	1328676.51	1337240.01	1345823.51	1354427.01	1363050.51	1371694.01	1380358.51	1389043.01	1397747.51	1406472.01	1415217.51	1423983.01	1432769.51	1441577.01	1450405.51	1459255.01	1468126.51	1477019.01	1485933.51	1494869.01	1503826.51	1512805.01	1521805.51	1530828.01	1539872.51	1548939.01	1558027.51	1567138.01	1576270.51	1585425.01	1594602.51	1603803.01	1613027.51	1622275.01	1631546.51	1640841.01	1650159.51	1659501.01	1668866.51	1678255.01	1687667.51	1697103.01	1706562.51	1716045.01	1725551.51	1735082.01	1744637.51	1754218.01	1763824.51	1773457.01	1783116.51	1792802.01	1802514.51	1812253.01	1822018.51	1831810.01	1841628.51	1851473.01	1861344.51	1871242.01	1881166.51	1891117.01	1901095.51	1911092.01	1921107.51	1931142.01	1941196.51	1951270.01	1961363.51	1971477.01	1981600.51	1991744.01	2001908.51	2012093.01	2022297.51	2032522.01	2042766.51	2053031.01	2063315.51	2073620.01	2083945.51	2094291.01	2104657.51	2115045.01	2125453.51	2135883.01	2146334.51	2156807.01	2167301.51	2177817.01	2188354.51	2198913.01	2209493.51	2219995.01	2230518.51	2241064.01	2251632.51	2262224.01	2272839.51	2283479.01	2294143.51	2304832.01	2315545.51	2326284.01	2337048.51	2347838.01	2358653.51	2369494.01	2380360.51	2391253.01	2402172.51	2413118.01	2424090.51	2435089.01	2446114.51	2457166.01	2468244.51	2479349.01	2490481.51	2501642.01	2512831.51	2523049.01	2534295.51	2545570.01	2556873.51	2568206.01	2579568.51	2590960.01	2602381.51	2613833.01	2625315.51	2636829.01	2648374.51	2659951.01	2671559.51	2683199.01	2694870.51	2706574.01	2718310.51	2729979.01	2741680.51	2753414.01	2765180.51	2776979.01	2788810.51	2800674.01	2812570.51	2824499.01	2836460.51	2848454.01	2860481.51	2872542.01	2884636.51	2896764.01	2908925.51	2921120.01	2933349.51	2945613.01	2957911.51	2970245.01	2982614.51	2995019.01	3007459.51	3019935.01	3032446.51	3044994.01	3057577.51	3070197.01	3082853.51	3095546.01	3108275.51	3121041.01	3133843.51	3146683.01	3159560.51	3172475.01	3185427.51	3198418.01	3211447.51	3224516.01	3237624.51	3250772.01	3263959.51	3277187.01	3290455.51	3303764.01	3317113.51	3330504.01	3343935.51	3357408.01	3370922.51	3384478.01	3398075.51	3411715.01	3425397.51	3439123.01	3452892.51	3466706.01	3480564.51	3494467.01	3508414.51	3522406.01	3536442.51	3550524.01	3564651.51	3578824.01	3593042.51	3607306.01	3621615.51	3635970.01	3650370.51	3664816.01	3679307.51	3693845.01	3708429.51	3723059.01	3737734.51	3752456.01	3767224.51	3782039.01	3796899.51	3811806.01	3826759.51	3841760.01	3856818.51	3871935.01	3887109.51	3902341.01	3917630.51	3932978.01	3948384.51	3963849.01	3979373.51	3994957.01	4010599.51	4026301.01	4042062.51	4057884.01	4073766.51	4089709.01	4105713.51	4121779.01	4137906.51	4154096.01	4170348.51	4186664.01	4203043.51	4219486.01	4235992.51	4252563.01	4269198.51	4285899.01	4302665.51	4319498.01	4336397.51	4353364.01	4370398.51	4387500.01	4404669.51	4421907.01	4439214.51	4456591.01	4474038.51	4491557.01	4509147.51	4526809.01	4544543.51	4562350.01	4580229.51	4598182.01	4616208.51	4634309.01	4652484.51	4670735.01	4689061.51	4707464.01	4725943.51	4744499.01	4763132.51	4781844.01	4800634.51	4819504.01	4838453.51	4857483.01	4876594.51	4895787.01	4915061.51	4934418.01	4953857.51	4973379.01	4992984.51	5012674.01	5032448.51	5052308.01	5072253.51	5092285.01	5112403.51	5132609.01	5152903.51	5173287.01	5193760.51	5214324.01	5234978.51	5255724.01	5276561.51	5297491.01	5318513.51	5339629.01	5360839.51	5382145.01	5403547.51	5425047.01	5446645.51	5468343.01	5489141.51	5510041.01	5531043.51	5552149.01	5573359.51	5594675.01	5616097.51	5637627.01	5659265.51	5680993.01	5702821.51	5724751.01	5746783.51	5768919.01	5791159.51	5813505.01	5835957.51	5858517.01	5881185.51	5903963.01	5926851.51	5949851.01	5972963.51	5996189.01	6019529.51	6042985.01	6066557.51	6090247.01	6114055.51	6137984.01	6162033.51	6186204.01	6210496.51	6234911.01	6259449.51	6284113.01	6308902.51	6333818.01	6358861.51	6384033.01	6409334.51	6434767.01	6460332.51	6486031.01	6511864.51	6537833.01	6563938.51	6590182.01	6616565.51	6643089.01	6669754.51	6696563.01	6723516.51	6750616.01	6777863.51	6805259.01	6832805.51	6860504.01	6888357.51	6916367.01	6944534.51	6972861.01	7001349.51	7029991.01	7058788.51	7087743.01	7116856.51	7146130.01	7175565.51	7205164.01	7234928.51	7264859.01	7294957.51	7325226.01	7355666.51	7386280.01	7417069.51	7448036.01	7479182.51	7510511.01	7542024.51	7573724.01	7605612.51	7637692.01	7669965.51	7702435.01	7735103.51	7767973.01	7801046.51	7834326.01	7867814.51	7901514.01	7935428.51	7969559.01	8003908.51	8038479.01	8073273.51	8108295.01	8143546.51	8179030.01	8214748.51	8250704.01	8286900.51	8323340.01	8359926.51	8396662.01	8433550.51	8470694.01	8508096.51	8545760.01	8583688.51	8621884.01	8660349.51	8699088.01	8738103.51	8777399.01	8816978.51	8856845.01	8896992.51	8937425.01	8978146.51	9019159.01	9060466.51	9102072.01	9143979.51	9186192.01	9228714.51	9271450.01	9314403.51	9357579.01	9400980.51	9444611.01	9488475.51	9532577.01	9576919.51	9621506.01	9666340.51	9711425.01	9756764.51	9802362.01	9848221.51	9894346.01	9940739.51	9987405.01	10034346.51	10081468.01	10128874.51	10176570.01	10224559.51	10272847.01	10321437.51	10370335.01	10419543.51	10469067.01	10518910.51	10569079.01	10619577.51	10670411.01	10721584.51	10773093.01	10824941.51	10877134.01	10929676.51	10982574.01	11035832.51	11089457.01	11143454.51	11197831.01	11252594.51	11307751.01	11363308.51	11419274.01	11475655.51	11532460.01	11589695.51	11647370.01	11705492.51	11764071.01	11823114.51	11882631.01	11942629.51	12003118.01	12064105.51	12125600.01	12187611.51	12249148.01	12311220.51	12373838.01	1

(Naganuma et al., 2005).

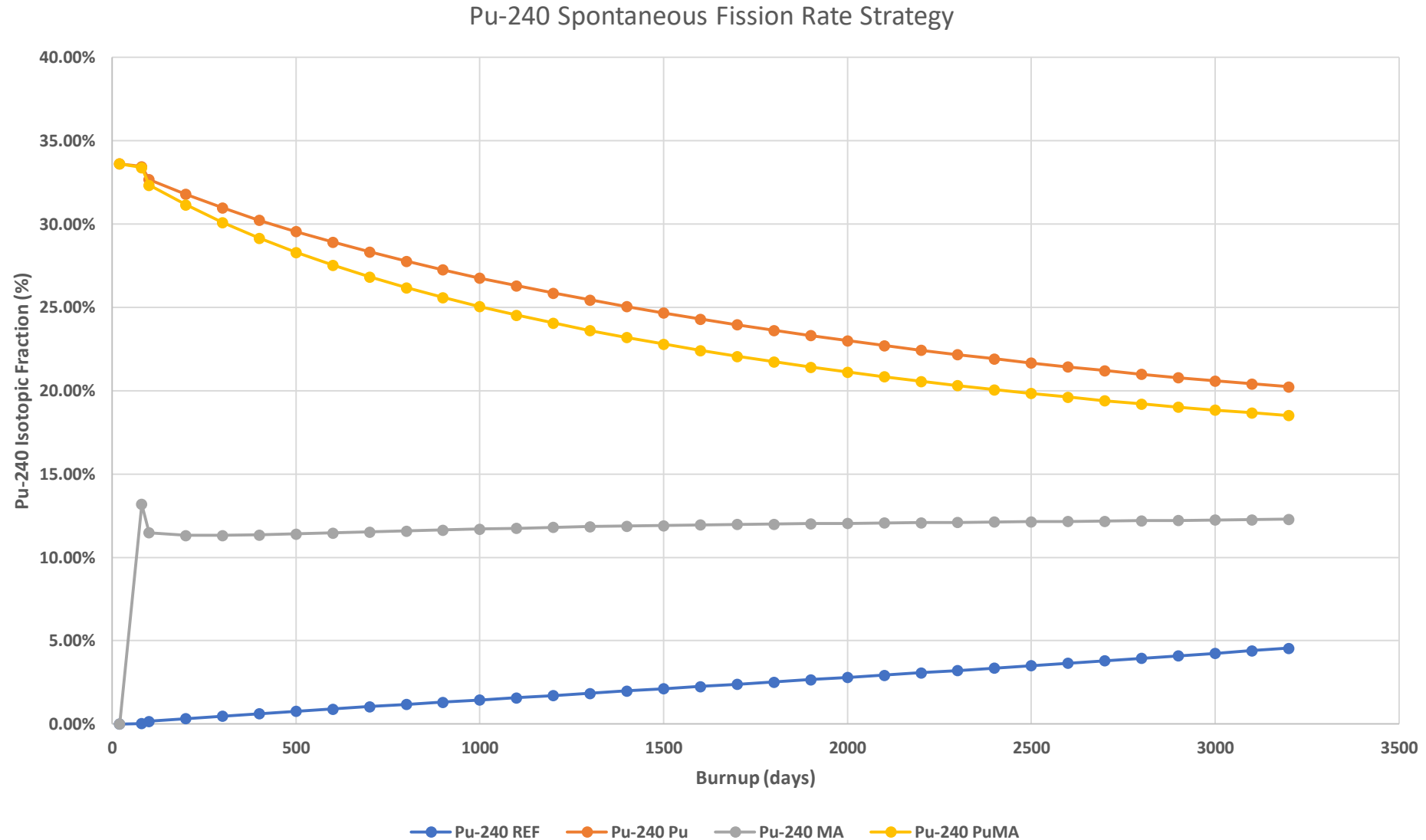
Decay Chain



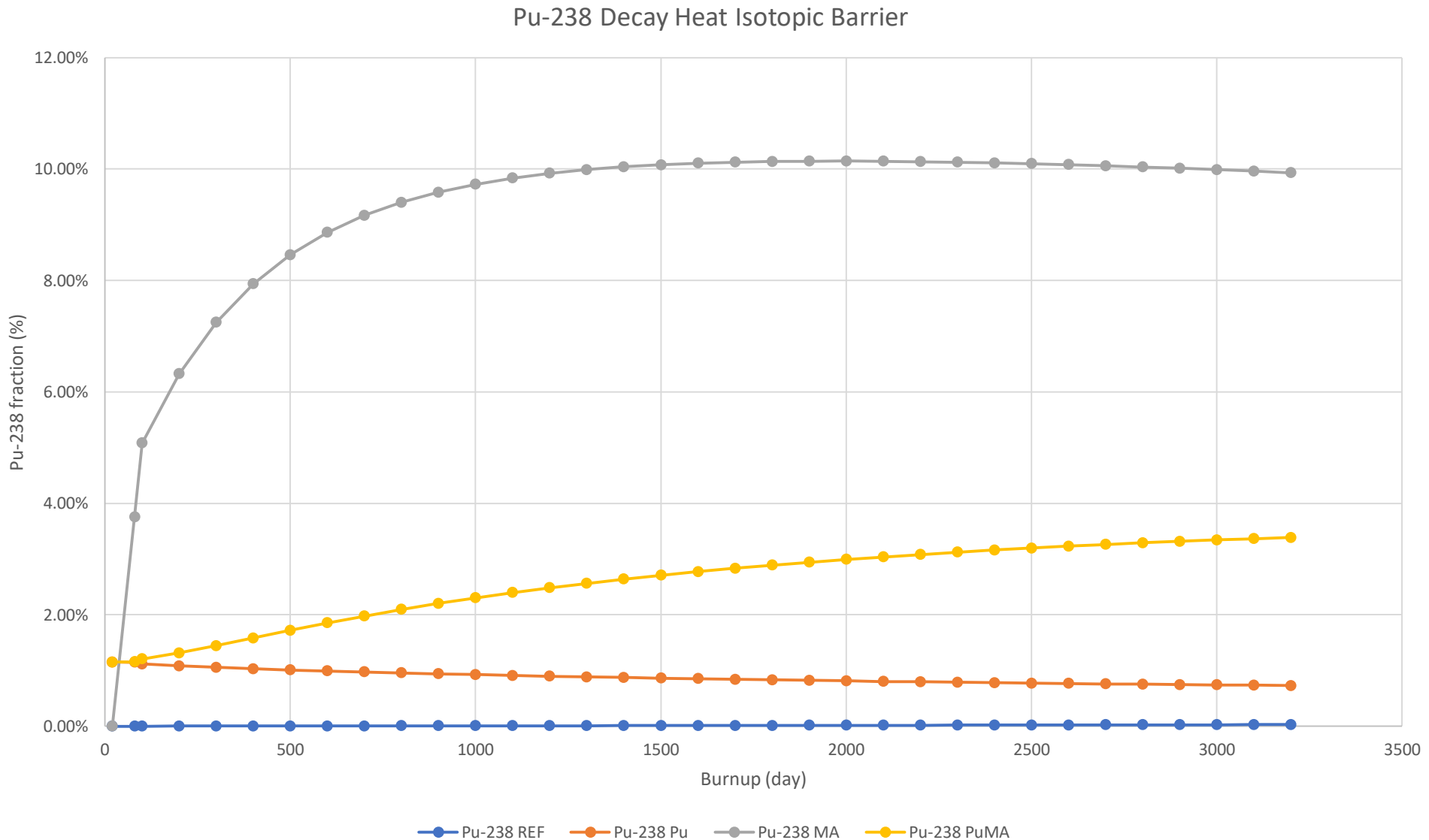
Pu-239 Isotopic Fraction remains high throughout cycle



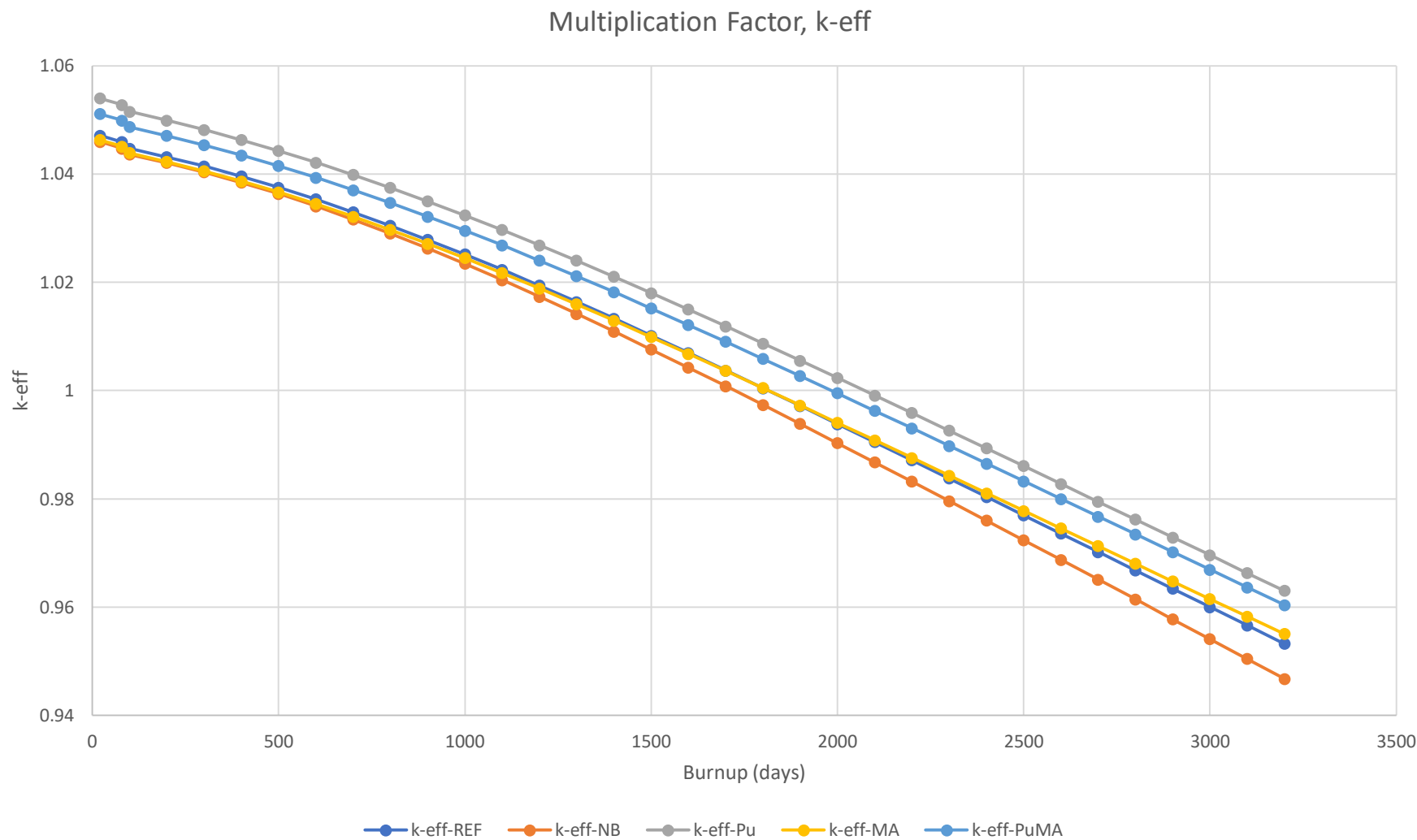
Spontaneous Fission Rate Strategy (Pu-240)



Decay Heat Isotopic Barrier Strategy (Pu-238)



Initial Reactivity is mostly unchanged



Case	Initial K-eff	Change (%)
REF	1.0471084	-
No Blanket	1.0459388	0.11
Pu loading	1.0539622	-0.77
MA loading	1.0463084	0.73
PuMA loading	1.0510942	-0.46

Case	VRC	Change (%)
REF	0.00022537	-
No Blanket	0.00021632	-4.02
Pu loading	0.00023405	8.20
MA loading	0.00022602	-3.43
PuMA loading	0.00023156	2.45

Specifications and core characteristics

Item	Unit	HBC	Blanket Free	Pu Loading	Am/Cm Loading	Pu/MA Loading
a) Plant						
Axial Blanket Thickness (upper/lower)	cm	20/20	20/20	20/20	20/20	20/20
Breeding Ratio		1.12	1.04	1.07	1.09	1.08
Transmutation Rate	%	-	-	-	17.00	16.02
Initial Pu Fissile Inventory	[t/GWe]	9.395	9.395	10.446	9.392	10.095
Pu Reduction Ratio		-0.0874	-0.0393	-0.0565	-0.1027	-0.0720
Discharge Burnup						
Core	GWd/t	139.6	87.4	83.3	84.2	83.7
Total	GWd/t	52.0	59.2	52.0	52.0	52.0
Void Reactivity Coefficient		1.83E-04	1.67E-04	0.00E+00	1.87E-04	1.91E-04
Blanket TRU enrichment	[wt.%]	-	-	3	-	2
Blanket MA fraction	[wt.%]	-	-	-	5	2

Isotopic composition in discharged fuel

Item	HBC		Blanket Free		Pu Loading		Am/Cm Loading		Pu/MA Loading	
	Core + AB	RB	Core + AB	RB	Core + AB	RB	Core + AB	RB	Core + AB	RB
<i>Pu isotopic composition (wt%)</i>										
²³⁸ Pu	1.36	0.03	1.35	-	1.40	0.73	2.46	9.93	1.81	3.39
²³⁹ Pu	57.95	95.27	57.96	-	57.27	74.68	56.64	75.58	57.00	74.16
²⁴⁰ Pu	32.16	4.55	32.17	-	32.68	20.23	32.24	12.28	32.53	18.52
²⁴¹ Pu	4.67	0.00	4.67	-	4.72	0.02	4.62	0.00	4.68	0.02
²⁴² Pu	3.86	0.00	3.86	-	3.94	0.02	4.04	0.02	3.98	0.02
<i>MA isotopic composition (wt%)</i>										
²³⁷ Np	8.79	59.4	8.8	-	8.73	12.22	9.75	11.54	9.31	11.45
²³⁸ Np	0.01	0.0	0.0	-	0.01	0.00	0.01	0.00	0.01	0.00
²³⁹ Np	1.54	36.9	1.6	-	1.39	2.44	0.57	0.09	0.90	0.24
²⁴¹ Am	38.52	3.5	38.5	-	39.63	50.68	38.19	42.12	38.70	42.31
^{242m} Am	2.36	0.0	2.3	-	2.35	1.30	2.09	1.20	2.21	1.30
²⁴² Am	0.01	0.0	0.0	-	0.01	0.00	0.01	0.00	0.01	0.00
²⁴³ Am	22.04	0.0	22.0	-	21.83	17.54	21.20	22.04	21.42	21.58
²⁴² Cm	1.82	0.1	1.8	-	1.76	0.76	1.24	0.55	1.45	0.61
²⁴³ Cm	0.32	0.0	0.3	-	0.30	0.05	0.21	0.04	0.25	0.05
²⁴⁴ Cm	20.68	0.0	20.7	-	20.26	13.77	23.16	20.85	22.05	20.71
²⁴⁵ Cm	3.40	0.0	3.4	-	3.27	1.18	3.24	1.52	3.31	1.68
²⁴⁶ Cm	0.51	0.0	0.5	-	0.46	0.04	0.34	0.05	0.40	0.06



Research Laboratory Visit

Tsuruga, Fukui Prefecture

Monju Japanese Sodium-Cooled Fast Reactor

Fukui Prefecture



Fast-Spectrum Reactor Characteristics

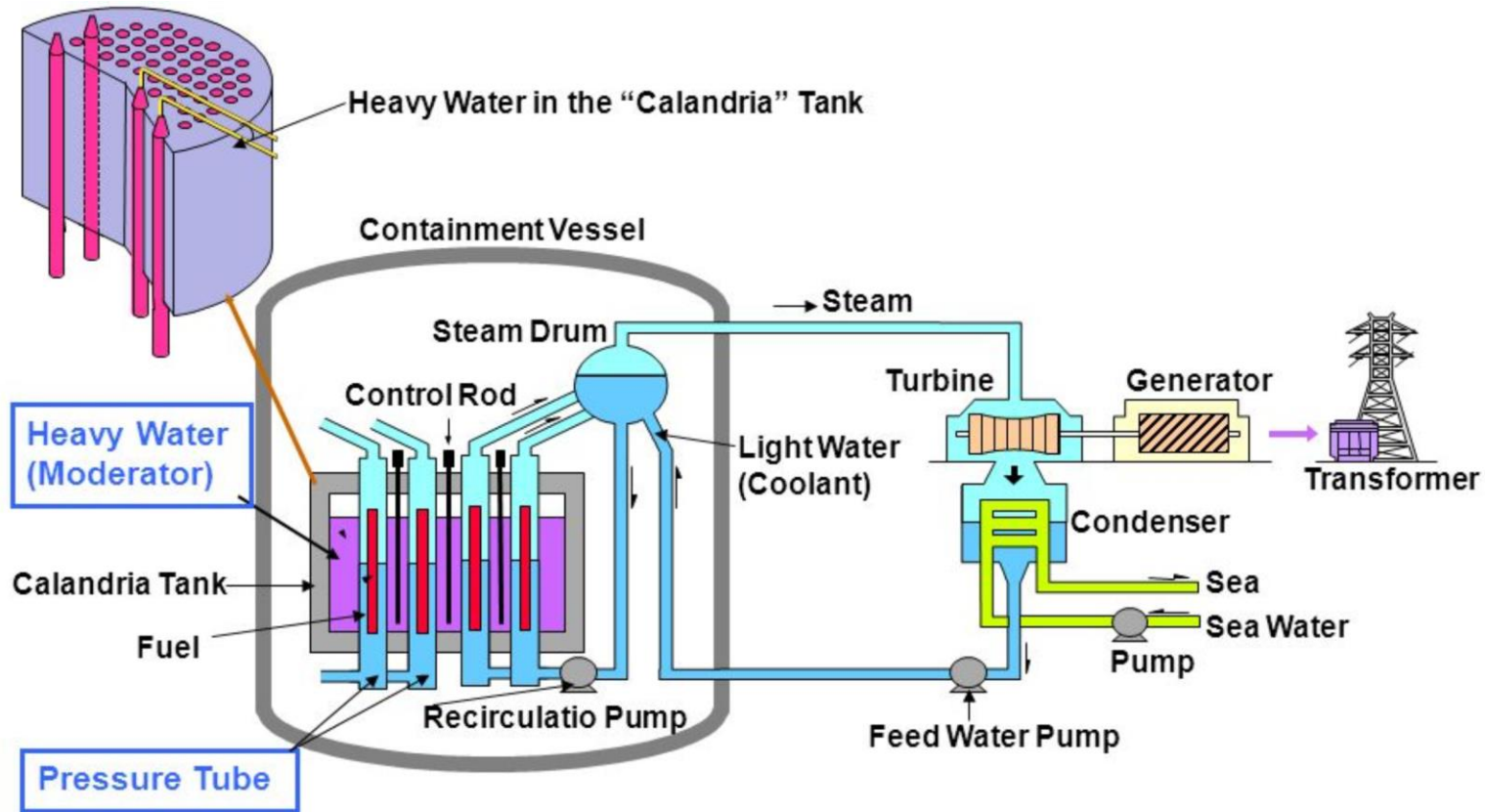
- Sodium Cooled
- MOX-fueled
- Loop-type
- 280 MWe and 714 MWt
- Breeding ratio of 1.2
- Currently undergoing decommissioning process



A photograph of the Fugen Advanced Thermal Reactor in Fukui Prefecture, Japan. The reactor is a large, white, cylindrical structure with a red dome, situated on a hillside. It is surrounded by other industrial buildings and infrastructure, including power lines and a body of water in the foreground. The background shows a forested hillside under a cloudy sky.

Fugen Advanced Thermal Reactor

Fukui Prefecture



Fugen Nuclear Power Station, JAEA-4

Advanced Thermal Reactor

- 165 MWe (557 MWt)
- Demonstration reactor
- Pressure Tube Type Core
- Heavy Water Moderator
- Boiling Light Water Coolant

A missile is shown in the process of launching from a grassy field. The missile is dark and slender, pointing upwards. At its base, a massive, bright white and yellow plume of fire and smoke is being ejected, creating a large, billowing cloud that spreads across the horizon. The background is a dark, cloudy sky, suggesting dusk or dawn. The overall scene conveys a sense of power and technological advancement.

World Politics and Nonproliferation in the Nuclear Age

A photograph of a nuclear power plant at night. The scene is dominated by a large, white, hyperboloid cooling tower on the left, which is illuminated with red lights along its top edge. To its right, there are several other structures, including a tall, thin chimney and a large, rectangular building. The entire facility is lit up with various lights, including yellow and green ones. The lights are reflected in a body of water in the foreground, creating a shimmering effect. The sky is dark with some clouds. The word "Questions?" is written in white, sans-serif font in the center of the image.

Questions?

Acknowledgements

Professor Hiroshi SAGARA

Tokyo Tech summer program staff

Laboratory colleagues

Tokyo Institute of Technology

UC Berkeley

Japan Student Services Organization (JASSO)