



An INDEPTH Analysis of Spent Pebbles

By: Ben Impson, Zeyun Wu, and Braden Goddard

Presented at ANS Student Conference 2024, Fuel Cycles, Waste Management, and Decommissioning: II, Penn State

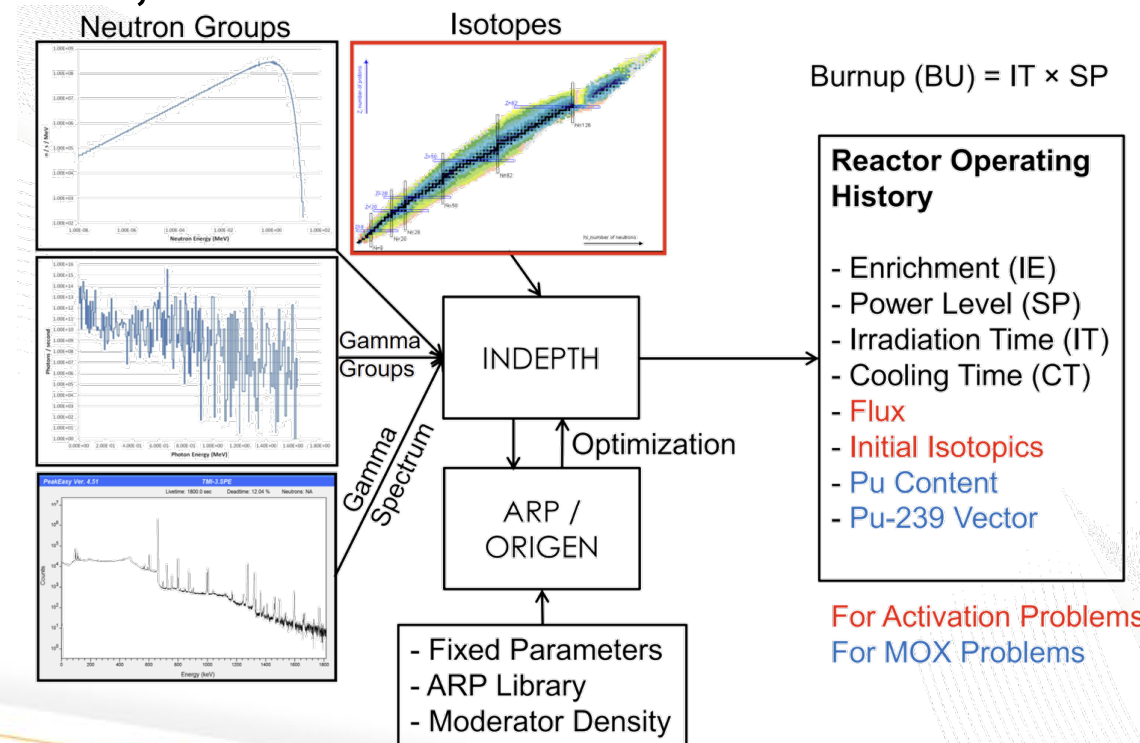


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What is INDEPTH?

INverse DEPLEtion THeory code [1]

Takes isotopic data, turns it into initial reactor conditions using ORIGIN [2]



What INDEPTH Looks Like

indepth-gui: version 1.5.0-dev

File Help

Sample import

Run setup

Run INDEPTH

Compare INDEPTH outputs

View individual INDEPTH run outputs

Isotope inventory input

	Isotope ID	Mass	Mass uncertainty
1	Kr-85	112.285	11.2285
2	Sr-90	2640.03	264.003
3	Zr-95	174.211	17.4211
4	I-131	2.08966	0.208966
5	Xe-134	7346.85	734.685
6	Cs-137	5781.34	578.134
7	Ba-140	15.0819	1.50819
8	Sm-151	46.5284	4.65284

Add row Remove row Import CSV

Ratio Add this sample

Isotope inventory input

Sample 1	Sample 2
U-233: 0.000791...	Kr-85: 112.285 (...)
U-234: 9.2594 (0...	Sr-90: 2640.03 (...)
U-235: 24811.7 (...)	Zr-95: 174.211 (...)
U-236: 21259.1 (...)	I-131: 2.08966 (...)
U-237: 2.2876 (0...	Xe-134: 7346.85...
U-238: 762705 (...)	Cs-137: 5781.34...
Np-236: 0.0005...	Ba-140: 15.0819...
Np-237: 2088.6...	Sm-151: 46.528...
Np-238: 0.0005...	
Np-239: 0.0408...	
Pu-238: 1278.37...	
Pu-239: 7274.88...	
Pu-240: 4711.96...	
Pu-241: 4038.46...	
Pu-242: 4323.8 (...)	
Pu-244: 0.19184...	
Am-241: 86.861...	
Am-242: 0.6223...	
Am-243: 874.52...	
Cm-242: 83.494...	
Cm-243: 2.9202...	

Remove selected samples Remove all samples

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Input data

Fuel type and library

Select State:

- Thailand
- Turkey
- Ukraine
- United Arab Emirates
- United Kingdom
- United States of America
- Uzbekistan
- Venezuela (Bolivarian Republic of)
- Viet Nam

Select reactor:

	State	Facility	Reactor type	Reactor c
137	United States of...	Yankee NPS	PWR	Power
138	United States of...	Zion-1	PWR	Power
139	United States of...	Zion-2	PWR	Power
140	United States of...	Xe-100	HTGR	Power

Include reactor classes:

☒ Power reactors

☐ Research reactors

SCALE fuel model to use in calculation: Unknown

Optimization parameters

Parameter	Optimize?	Initial value	Minimum value	Maximum value
1 Specific power (MWth/tHM)	<input checked="" type="checkbox"/>	72.9927	1	72.9927
2 Initial enrichment (wt %)	<input checked="" type="checkbox"/>	15.5	0	0
5 Irradiation time (days)	<input checked="" type="checkbox"/>	2192	10	3000
6 Cooling time (years)	<input checked="" type="checkbox"/>	8.21355	0.0273785	76.6598

Moderator density 1.05

Add this reactor

☒ Automatically update optimisation parameters on reactor/fuel model update

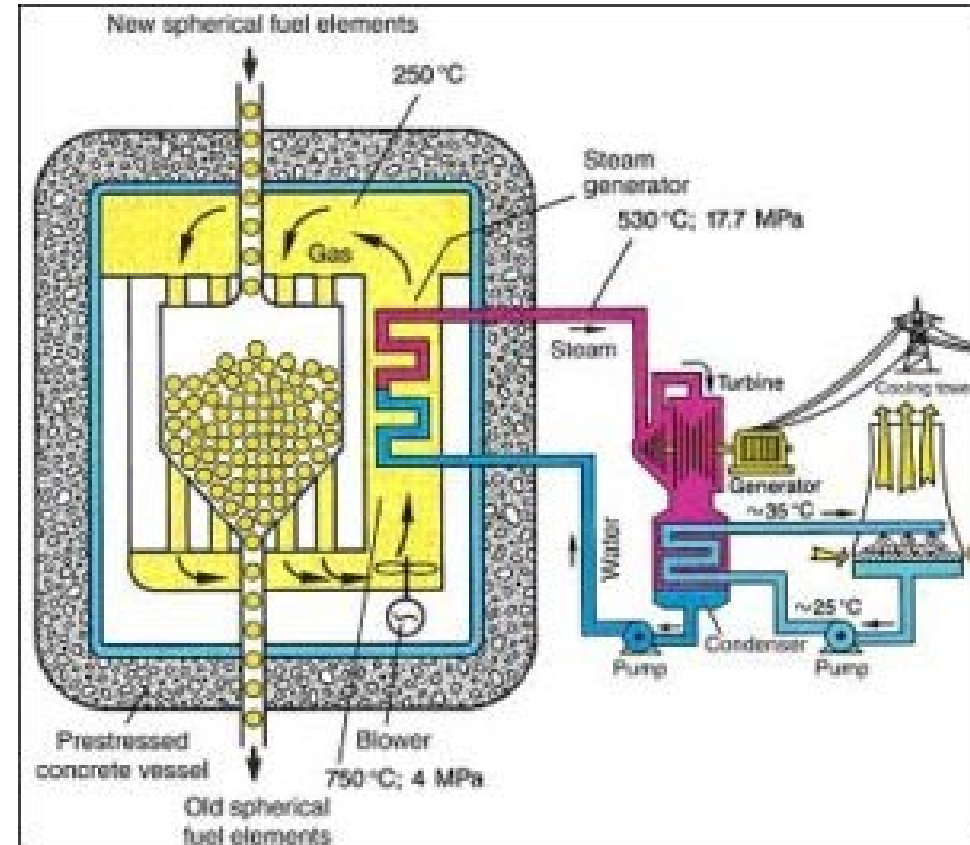
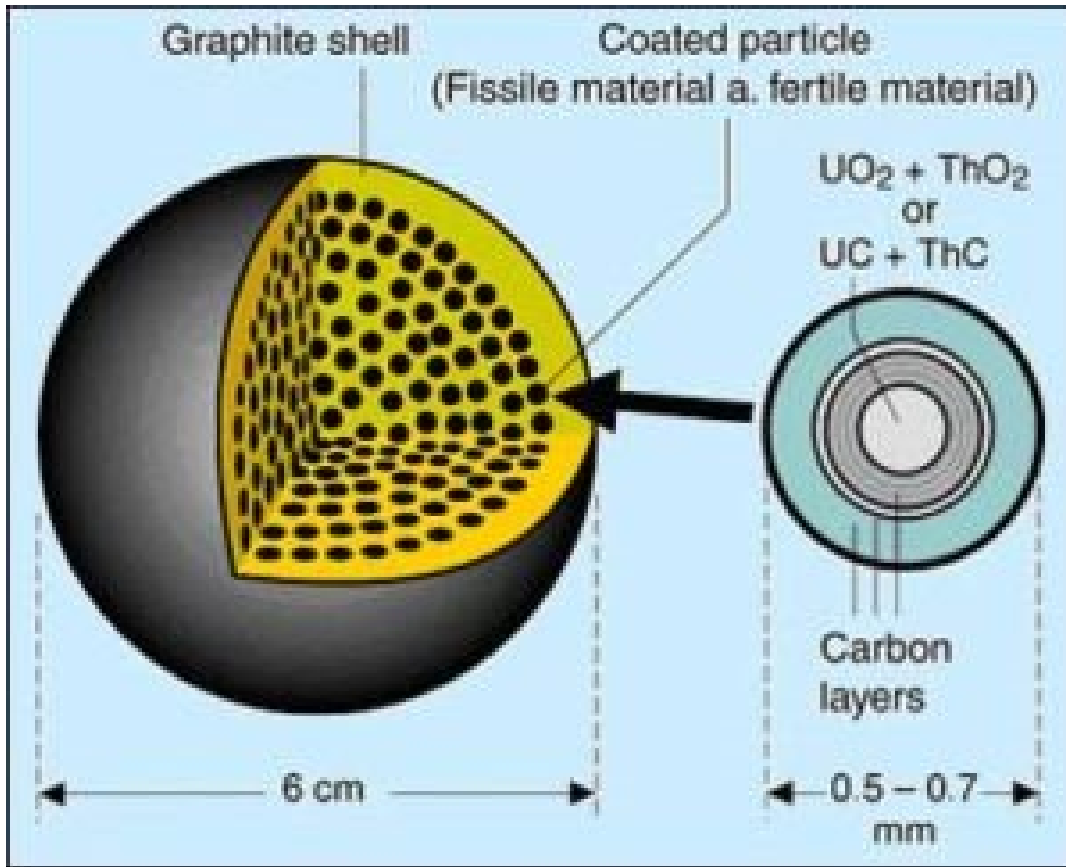
Reactor inputs

	Reactor 1
Reactor name	United States of...
Fuel model	pblr
Specific power (MWth/tHM)	1-> 350 (72.9927)
Initial enrichment (wt %)	1-> 19.99 (15.5)
Plutonium concentration (%)	N/A (not MOX ...)
Plutonium-239 concentration (%)	N/A (not MOX ...)

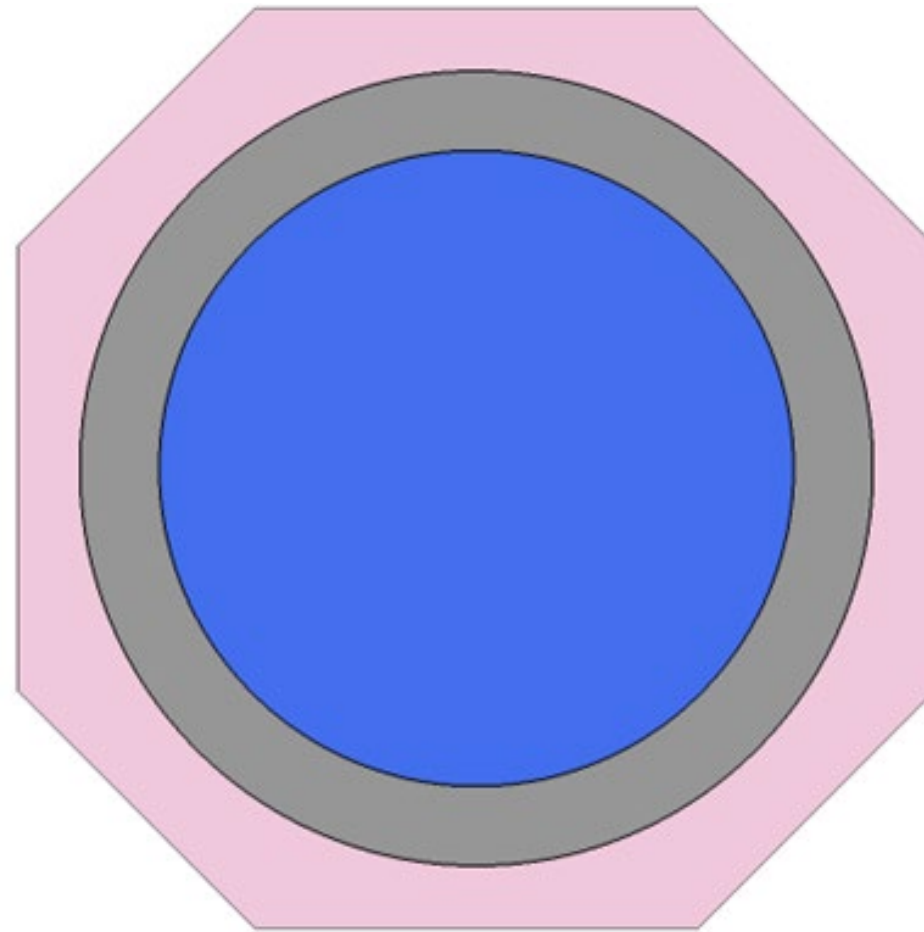
Remove selected reactors

Remove all reactors

What does a real pebble look like?



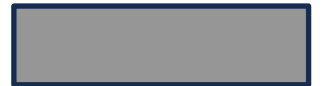
SCALE Libraries [4][5]



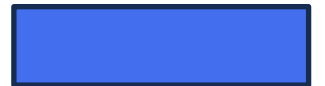
Helium



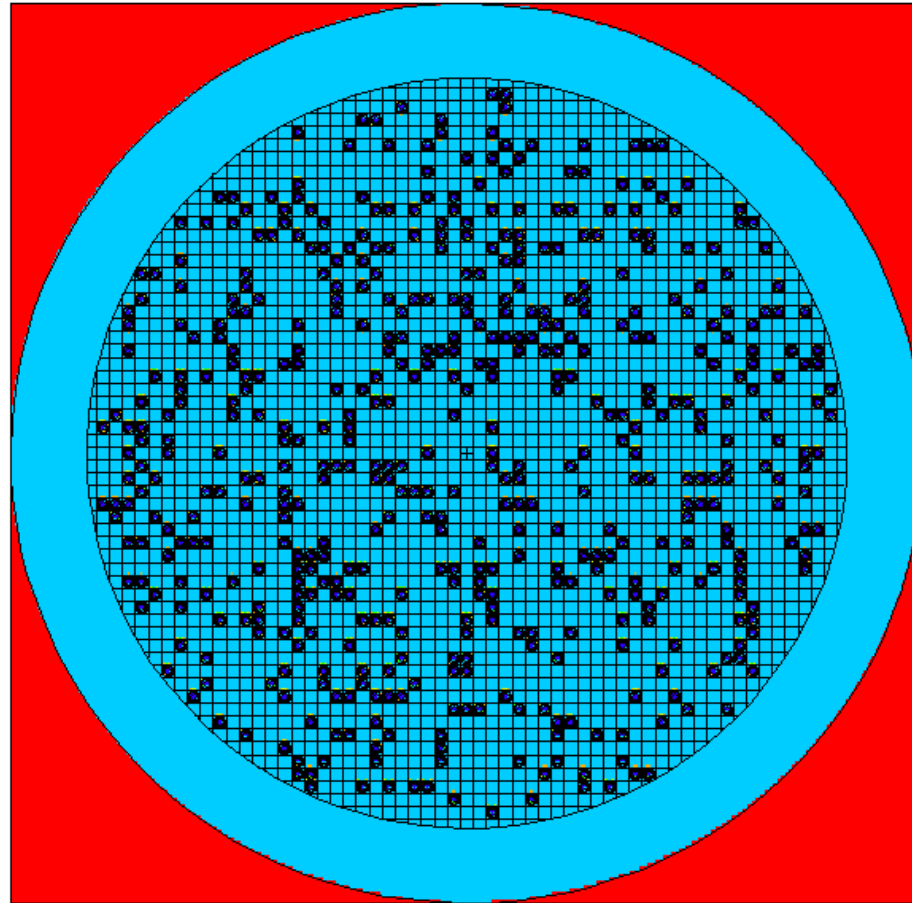
Graphite Shell



Fuel Region



MCNP Pebble Model [6][7]



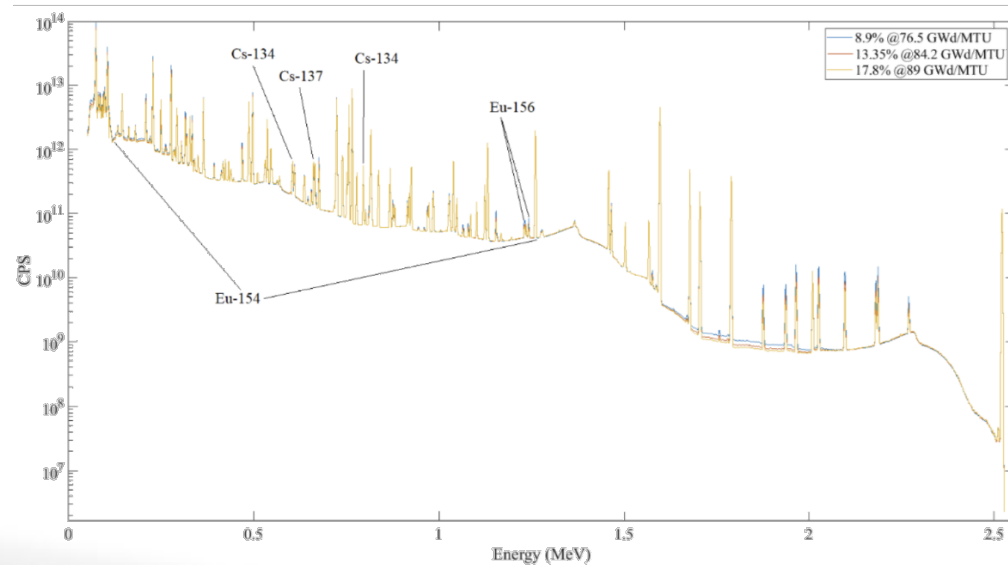
Which isotopes do you use?

Things HPGe detectors like

- Gamma emitters
- Fission products like ^{137}Cs
- Gamma emitting actinides like Am and Cm

Things INDEPTH likes

- Actinides, particularly ^{235}U
- Large isotope inventories
- Lots of data improve speed and accuracy



Gamma Spectrum of spent pebble [8]

Depletion Conditions

Condition	Enrichment	Burn Time	Cooling Time
Value	15.5%	1304 days	30 days

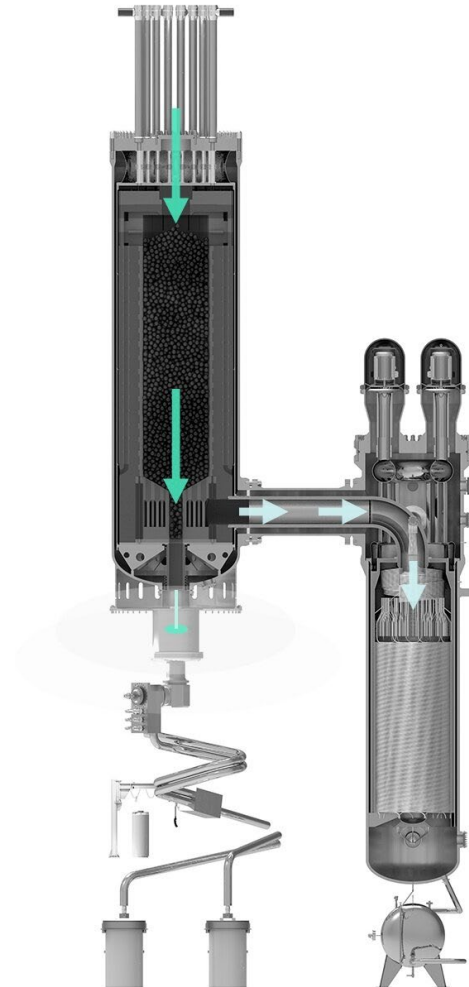
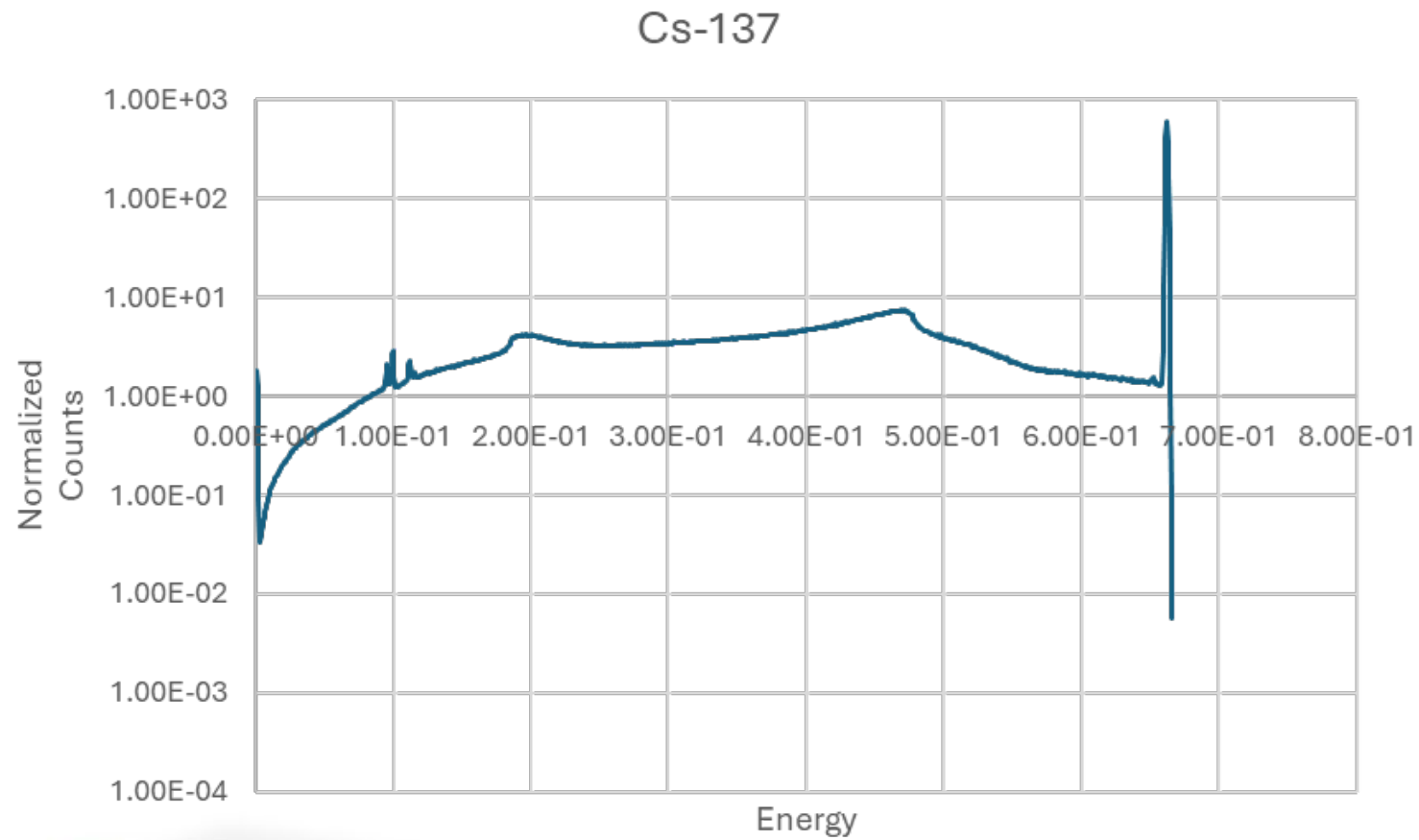
Isotope and Elemental Cases

Case 1	Case 2	Case 3	Case 4
U, Pu	U, Pu, Am, Cm, Np	Am, Cm, Np	Select Fission Products (Kr-85, Sr-90, Zr-95, I-131, Xe-134, Cs-137, Ba-140, Sm-151)

Results with different Elemental combinations

Combination of Isotopes	Irradiation Time (days)	Cooling Time (days)	Enrichment (%)
Case 1	990	9340	12.2
Case 2	2003	47	15.4
Case 3	2164	159	12.4
Case 4	1126	3373	11.3
Operational Conditions	1304	30	15.5

In progress work



Acknowledgement

INDEPTH created by Brandon Grogan, who also contributed the training materials

SCALE Pebble model created by Jonathan Wing of UTK, who also helped with the library generation.

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References

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- [8]. Gariazzo, Claudio, and Sunil Chirayath. "Assessing a Comprehensive Material Control and Accounting Approach for Safeguarding Pebble-Fueled Reactors." IAEA, 2023.



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