DISPOSING HIGH-LEVEL TRANSURANIC WASTE IN SUBCRITICAL REACTORS

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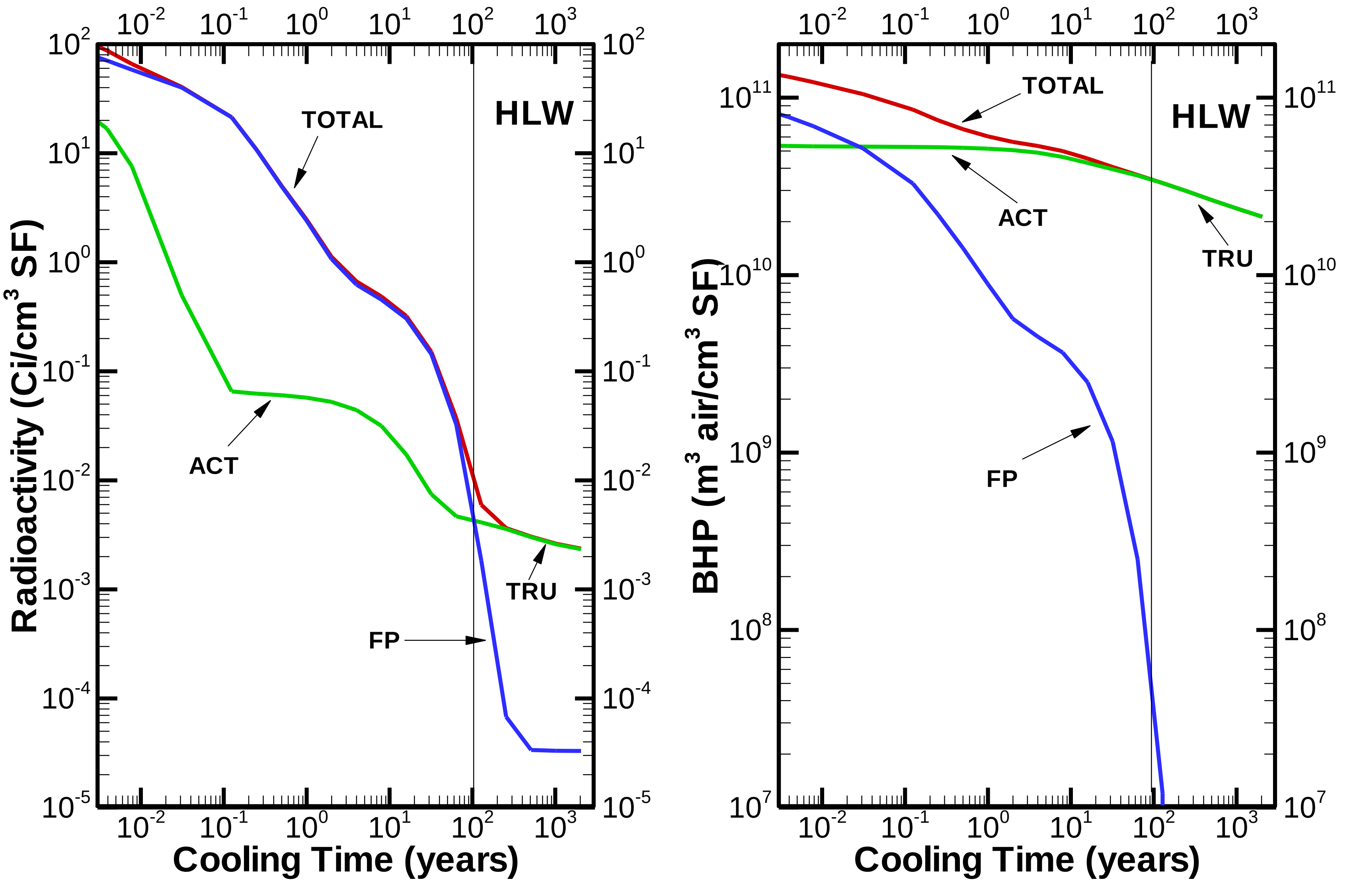
High-Level Waste (HLW)

- In the world, the nuclear electric capacity is nearly 340 gigawatts-electric (GWe)
- It produces spent fuel (SF) roughly amounting to 8000 tonnes heavy metal (tHM) per year (A typical LWR with 1GWe is about 20-25 tHM per year)
- The spent fuel is comprised of 93-94% of the mass of uranium oxide (mostly U-238, only 0.8% U-235), about 3-5% fission products, ~1% plutonium (Pu) and about 0.1-0.2% the minor actinides (MA)
- Most of radiotoxicity of high-level waste (HLW) is come from actinides of transuranic elements (TRU) especial to Pu.



Spent Fuel from a modern LWR with 1GWe of 18 month operation

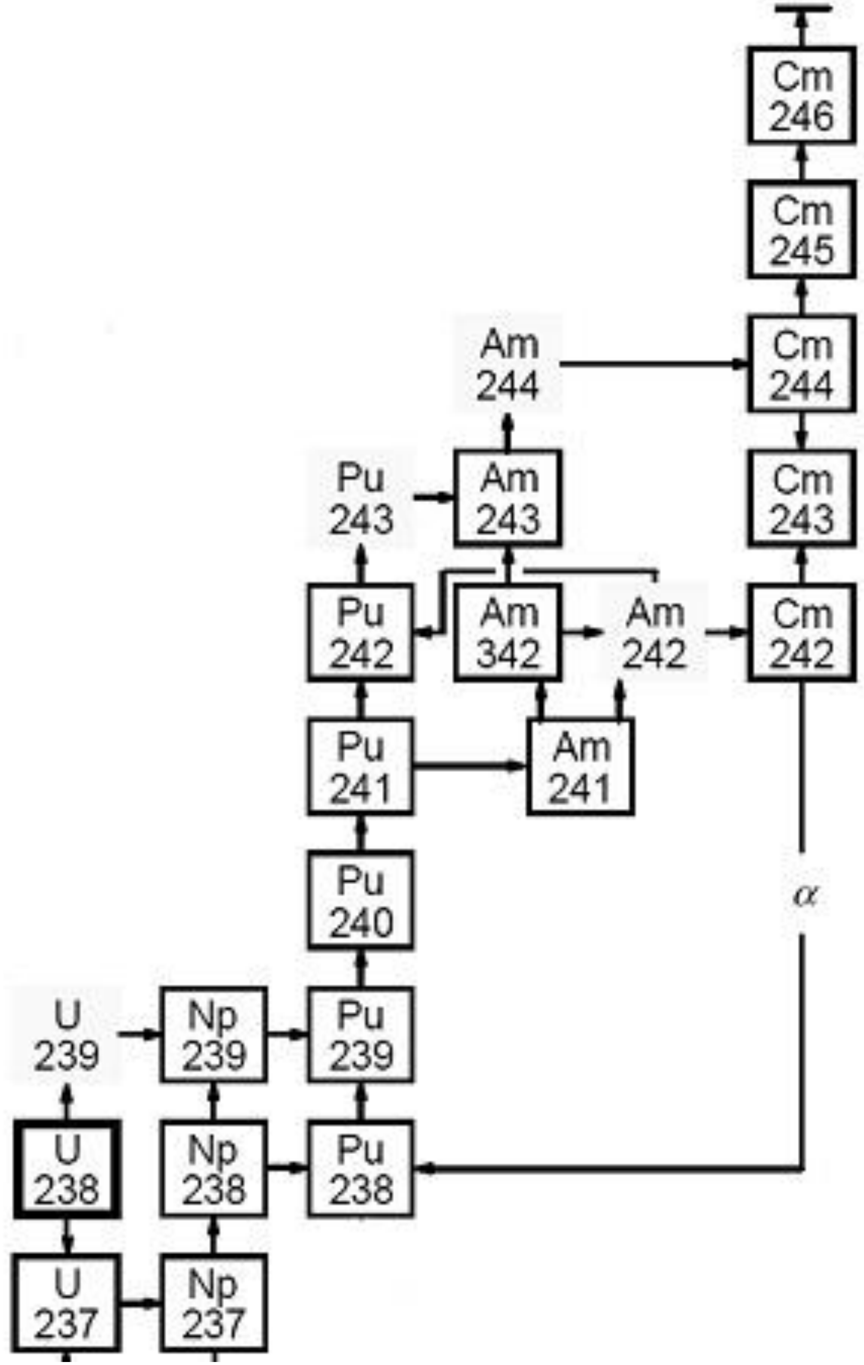
High-Level Waste of TRU properties from LWR spent fuel.

Actinide Isotope	Atomic fraction	Half life (y)	Decay mode
Np-236	7.3147E-08	1.5310E+05	β
Np-237	7.3435E-02	2.1454E+06	α
Np-239	1.7966E-08	6.4547E-03	β
Pu-238	2.6630E-02	8.7760E+01	α
Pu-239	4.5452E-01	2.4127E+04	α
Pu-240	2.6288E-01	6.5656E+03	α
Pu-241	9.2059E-03	1.4299E+01	β
Pu-242	5.7352E-02	3.7376E+05	α
Pu-244	1.1055E-05	8.1156E+07	α
Am-241	9.2075E-02	4.3290E+02	α
Am-242	1.9452E-09	1.8287E-03	β
Am-242m	1.6305E-04	1.4109E+02	γ
Am-243	2.0530E-02	7.3749E+03	α
Cm-242	3.9434E-07	4.4641E-01	α
Cm-243	2.7573E-05	2.9120E+01	α
Cm-244	2.1100E-03	1.8123E+01	α
Cm-245	8.6423E-04	8.5057E+03	α
Cm-246	1.9336E-04	4.7633E+03	α
Cm-247	3.7225E-06	1.5610E+07	α
Cm-248	4.2804E-07	3.4824E+05	α

Fuel Cycle

- open, with direct disposal of spent fuel in the water.
- closed, with the reprocessing of spent fuel.
- Traditional closed fuel cycles only recycle uranium and plutonium (MOX). MA is treated as wastes.
- Because the MOX fuels have Uranium, it will breed to more plutonium and MA.
- The spent fuel of MOX can not be recycled due to the current technology and high cost. It means that the fuel cycle is not a real closed cycle, it only use SF once and can not decrease HLW.

Decay Chain and Neutron Reaction of U-Pu fuel cycle in the LWR



Actinide Burning

Actinides chemically separated from spent fuel to convert them to short-lived radionuclides or stable elements.

With actinide burning, all of the actinides are to be destroyed.

A fuel cycle that burns all actinides is significantly different from a traditional fuel cycle. It is these differences that lead to consideration of different reactors and fuel cycles for this mission.

Many work (paper) about Actinide Burning

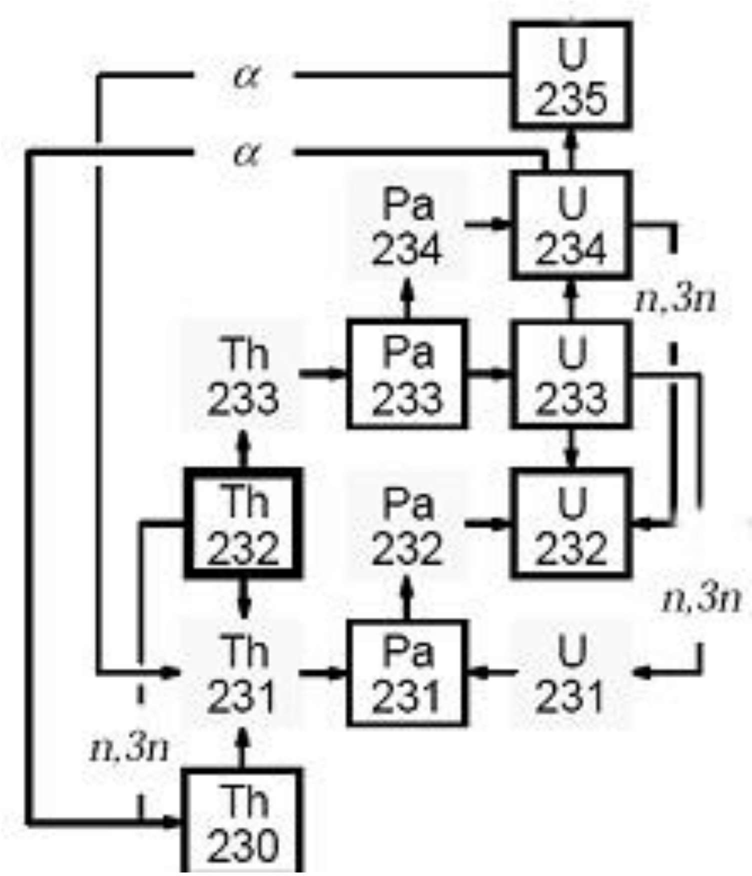
- MA burning in LWR or CANDU
- Actinide burning in molten salt reactors (MSRs, liquid-fueled reactors)
- Actinide burning in a lead-bismuth-cooled critical fast reactor
- Z-pinch fusion driver to transmutation of TRU
- etc

My work Focus

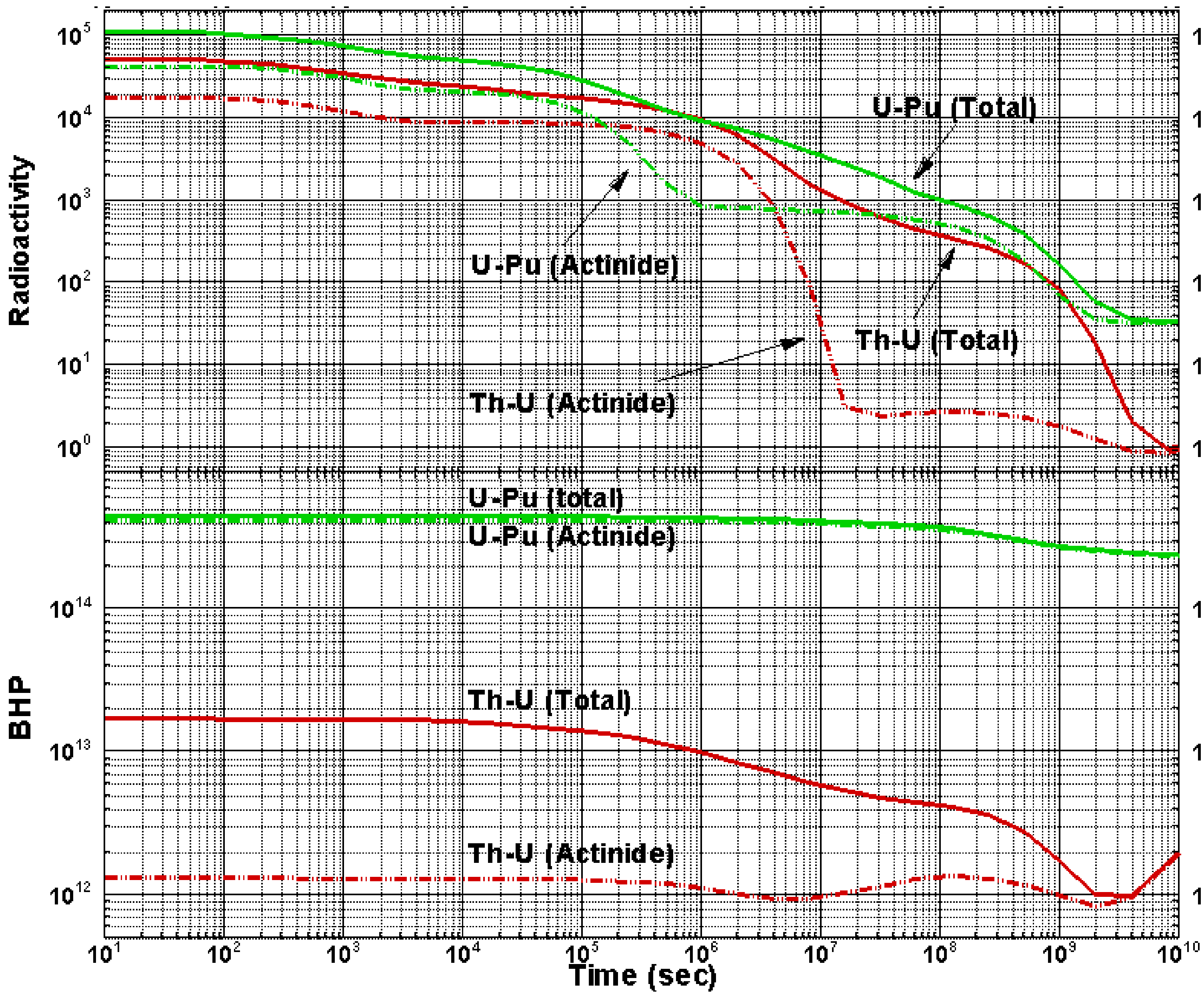
- Here, we will propose a new concept of actinide burning with thorium-uranium (Th-U) cycle in the external fusion neutron source (14.1Mev)
- A fusion-fission subcritical reactor (FFSR) can be driven by various external neutron sources, such as ITER, Z-Pinch, ICF or even ADS.

Advantages of Th-U cycle

- less TRU, less radiotoxicity
- Naturally, there is only one isotope of Th-232 with stable chemical character
- Th-U cycle provides breeding U-233 within a long operation time (>20 years)
- Reach a deep burnup
- Thorium is cheaper.



Decay Chain and Neutron Reaction of Th-U cycle

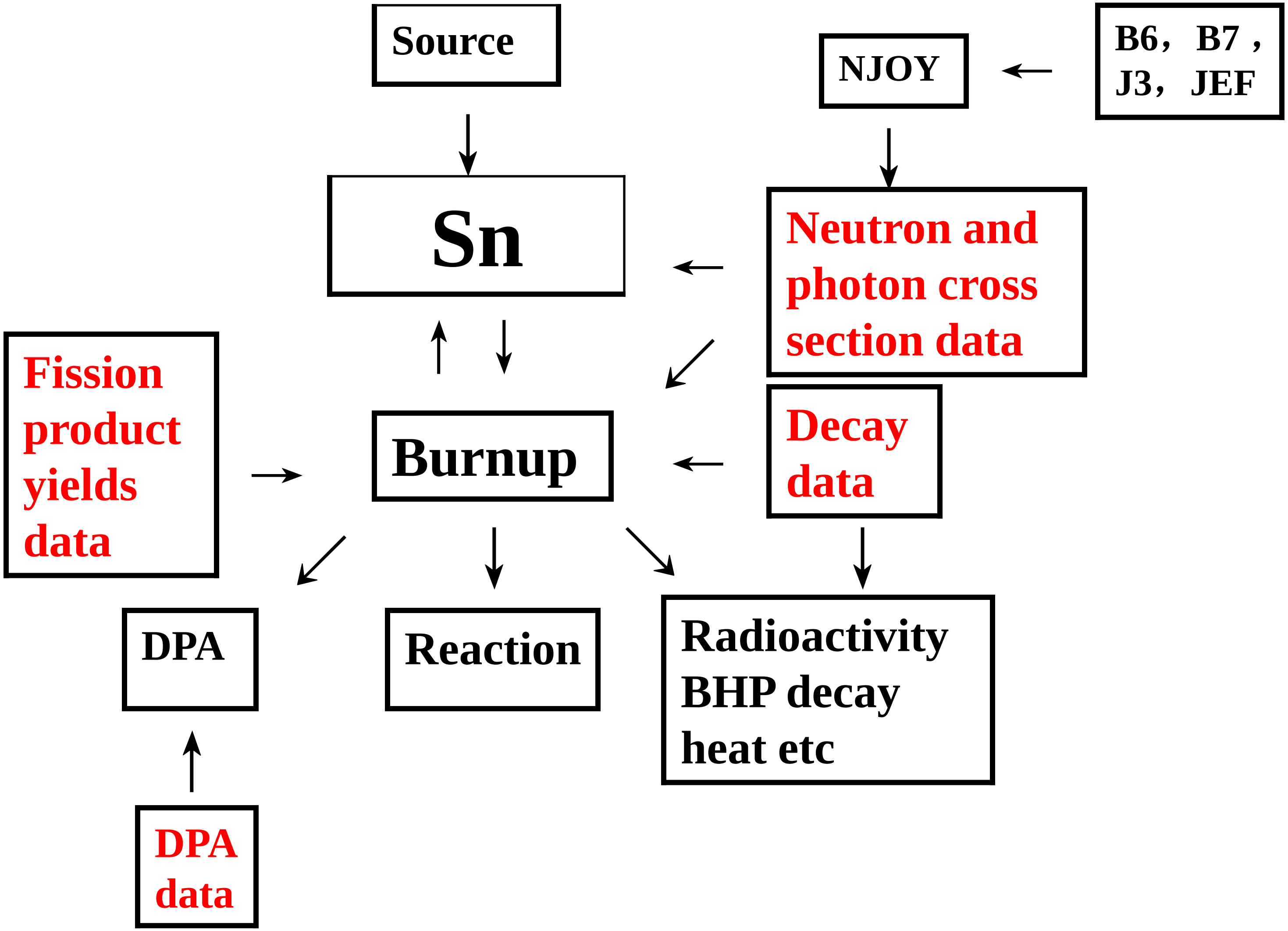


Radioactivity and BHP value of U-Pu and Th-U cycle

Code: OneSn_Burn

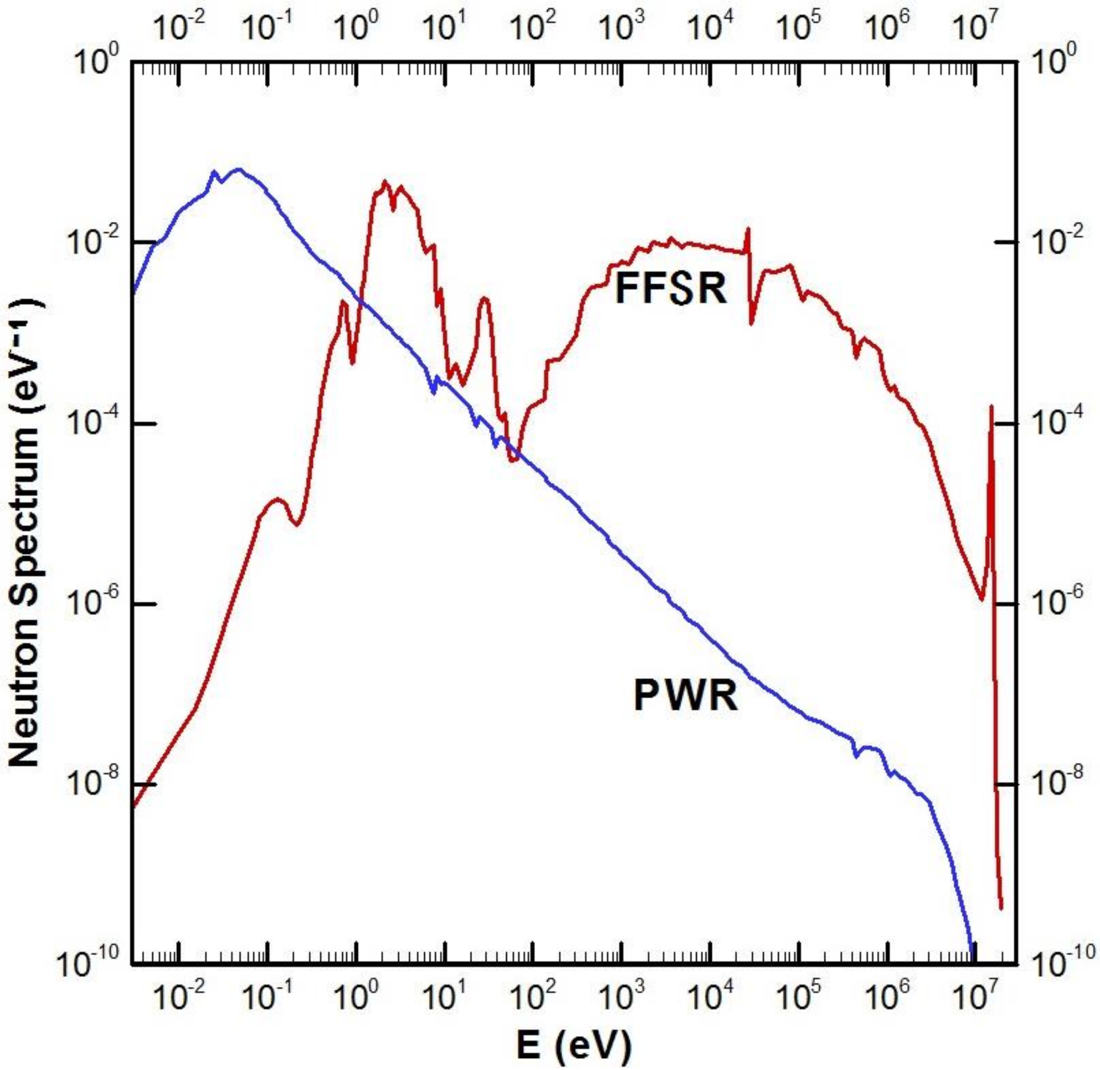
- One-dimension Sn neutron-Photon Transport and Burn-up calculation code
- OneSn_Burn has several data libraries (1) 172 group neutron cross section for 501 nuclei; (2) 32 group photon cross section for all 1-100 elements; (3) 3468 isotopes of decay library; (4) 33 actinides fission product yields library; (5) misc data library for Biological Hazard Potential (BHP) calculation and material neutron and photon radiation damage (DPA) calculation.

OneSn_Burn Code

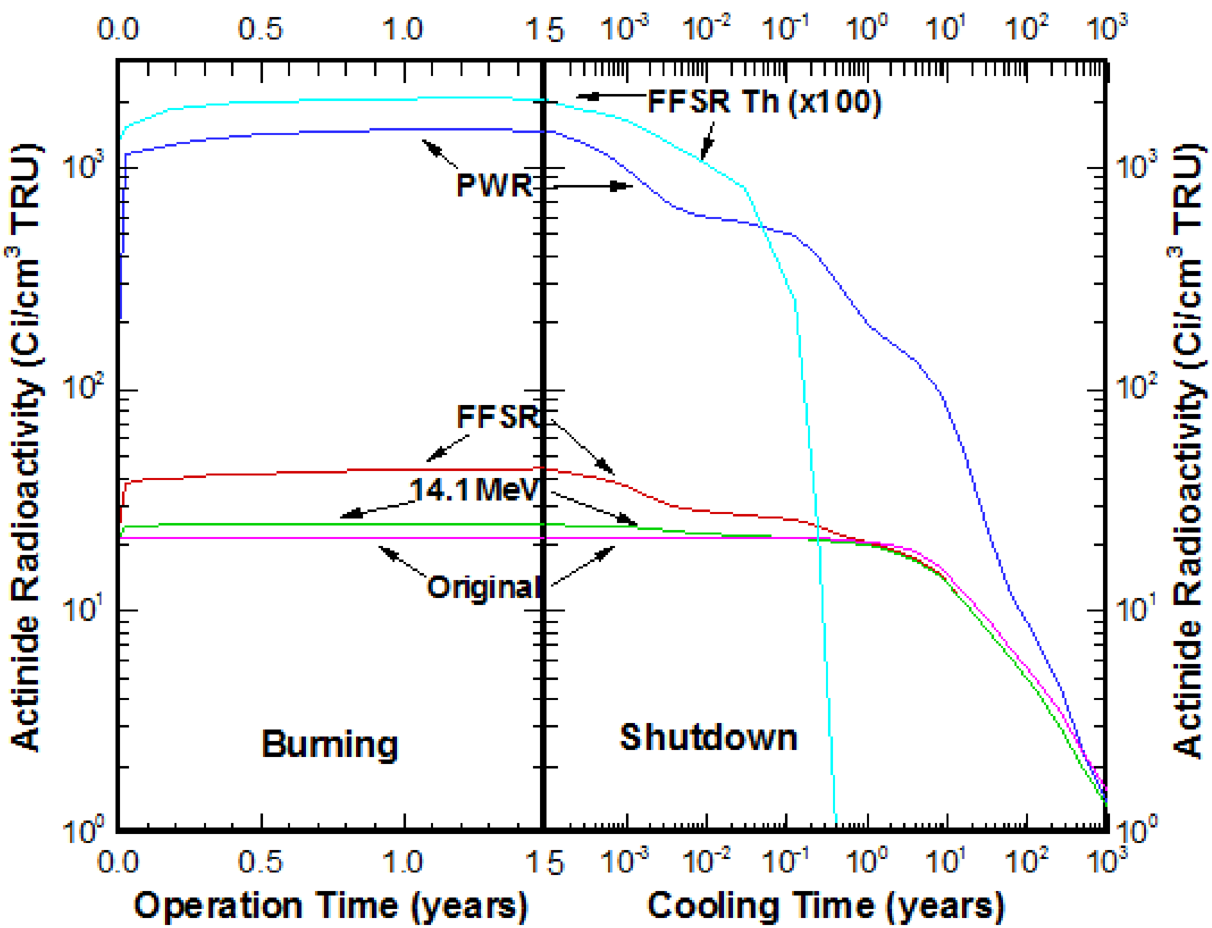


Model: HLW TRU Fuel

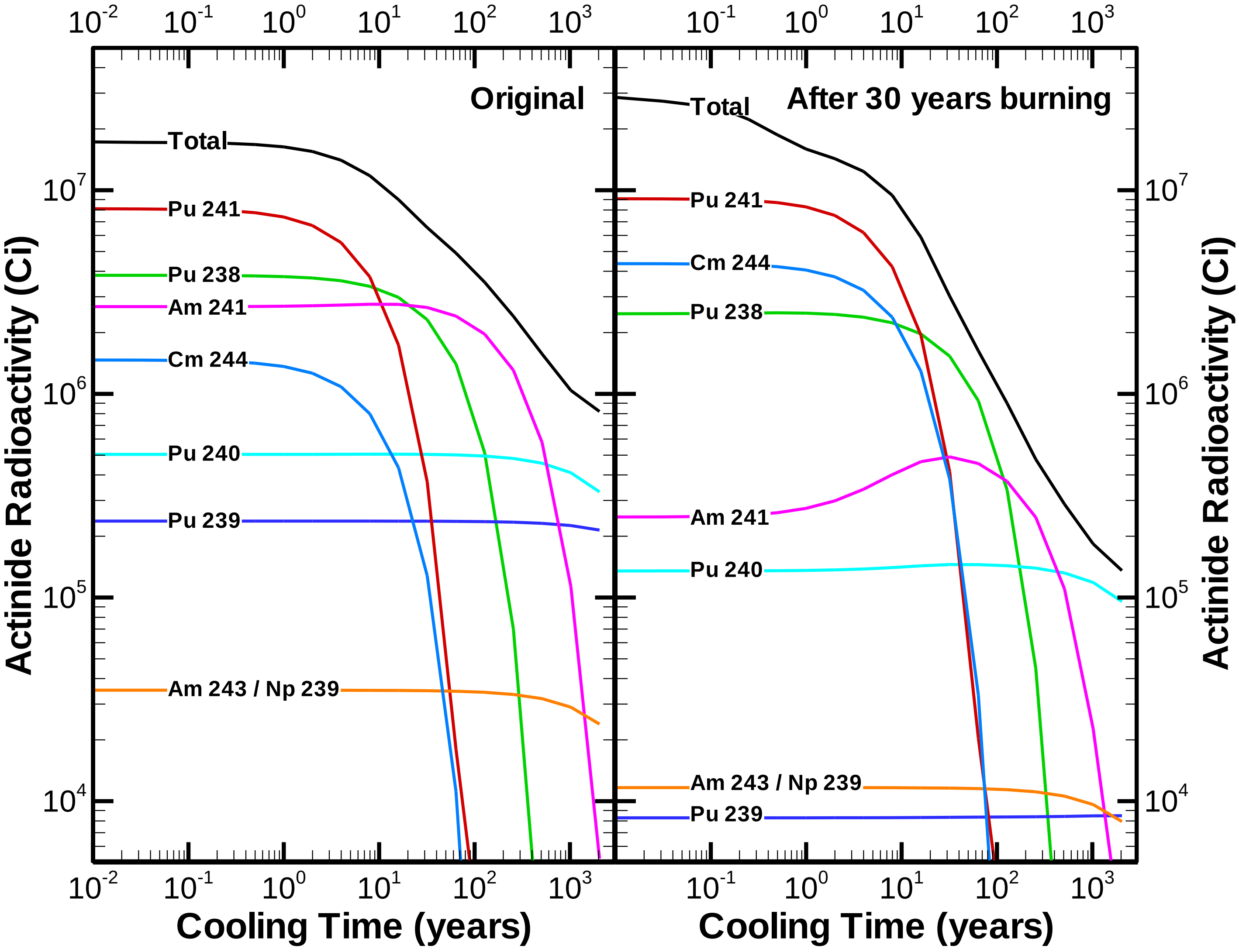
- TRU fuel is made by thorium base materials and put Pu and MA (see table) which separated from spent fuel of pressure water reactor (PWR) into thorium metal.
- Coolant is liquid-lead and it keeps the neutron spectrum hard
- Put TRU fuel into FFSR to burn (Keff = 0.8-0.85).
- With a long time (30 years or more) operation, it will decrease Pu and MA.
- Output power (energy), some of these use to maintain neutron sources.



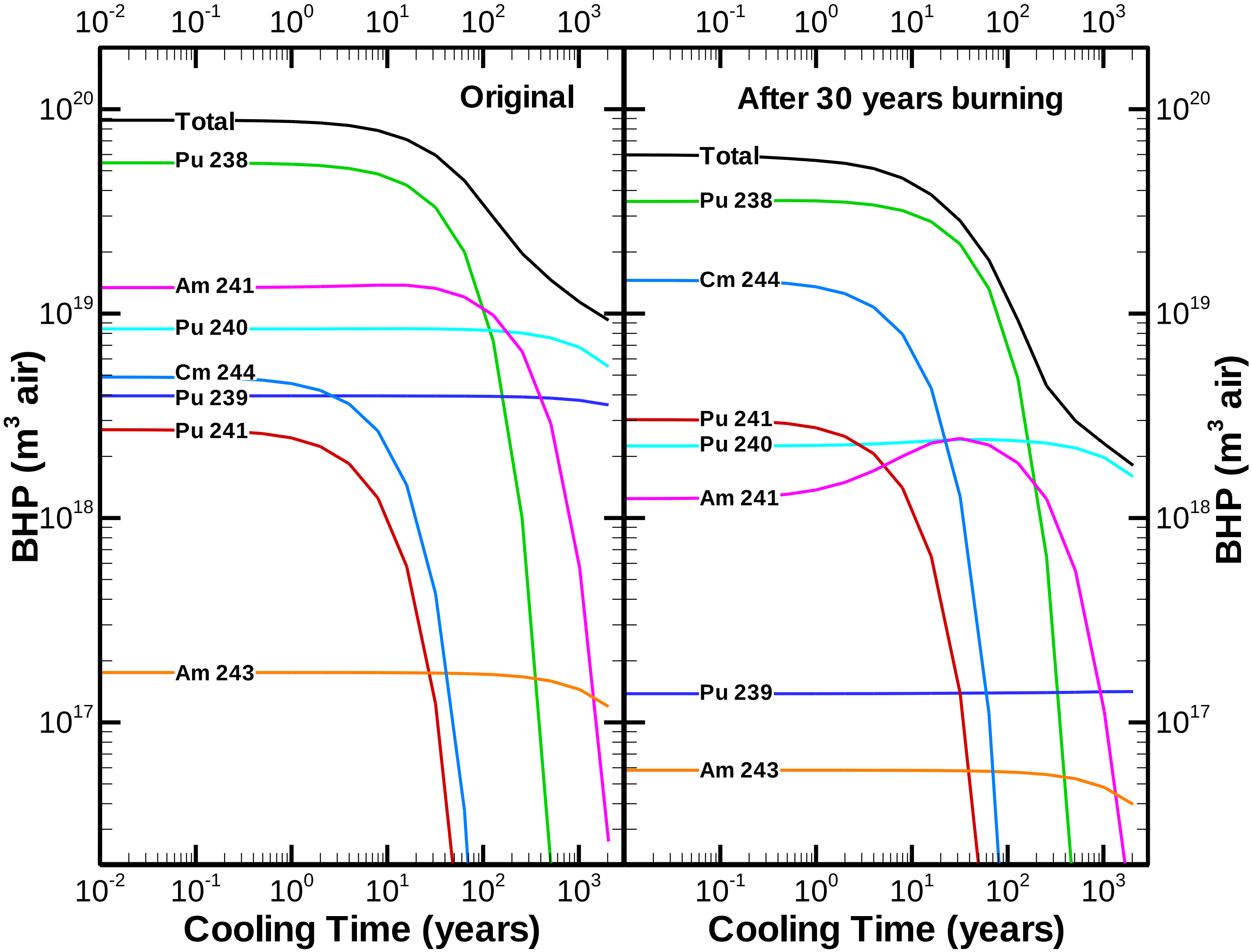
The neutron spectrum, the blue line is the PWR spectrum and the red line is FFSR spectrum. The PWR spectrum is calculated by PWR fuel and the FFSR spectrum is calculated by TRU fuel with 14.1MeV neutron source. All calculation is done by OneSn_Burn code.



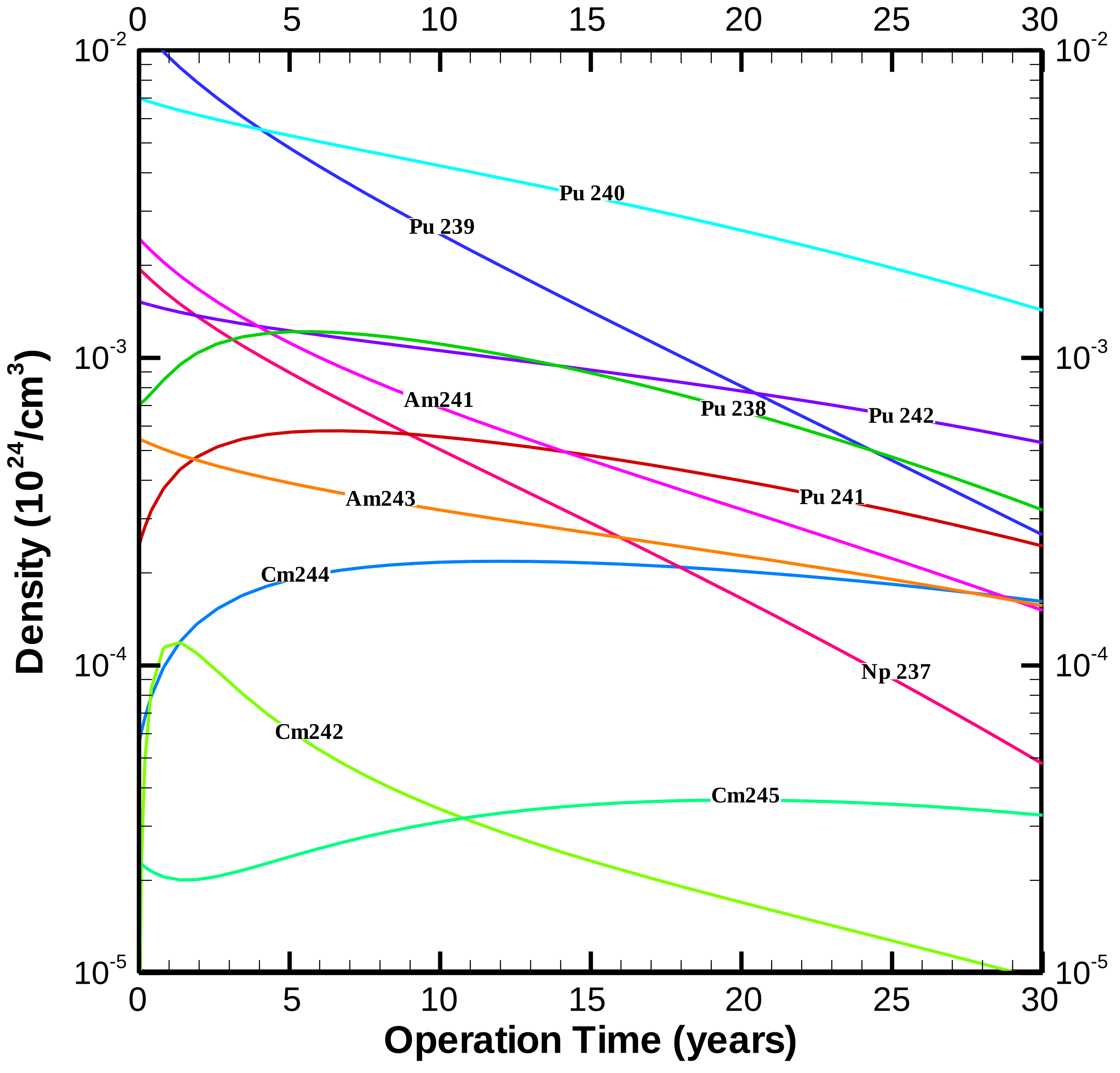
Actinide radioactivity of TRU fuel during burning and shutdown. Left figure is burning with a constant neutron flux (1.0E+14 n/s/cm3) for 1.5 years, and then, shutdown (no neutron flux) for cooling at right figure. The blue, red and green lines denote the results calculated by different neutron spectrum of PWR, FFSR and single energy 14.1MeV, respectively. The purple line is the original value line with TRU unirradiated (no neutron flux). The cyan line which multiply a factor of 100 is Th-232 result by FFSR spectrum (the original value of Th-232 is almost zero).



Actinide radioactivity of TRU fuel vs. cooling time, left figure is the original TRU fuel and right figure is TRU fuel after 30 years burning at FFSR with the constant power 3000Mwe heat.



BHP of TRU fuel vs. cooling time, left figure is the original TRU fuel and right figure is TRU fuel after 30 years burning at FFSR with the constant power 3000Mwe heat.



Density of some long term TRU elements vs. the operation time.

Analysis

- Above 3-5Mev, (n,γ) cross section of most TRU elements is more smaller than that of (n,f) (n,xn) (n,p/t/α) cross section,
- Above 0.1MeV, (n,γ) cross section of most TRU elements is more smaller than that of fission (n,f) cross section.
- Below 10eV, (n,γ) reaction is dominant and it is the only reaction of some TRU elements.
- The key of 'Actinide Burning' is TRU fission, so the important condition is the hard neutron spectrum.
- Such a hard spectrum, comes from fusion, accelerator or fast reactor, seems to more efficient than the soft one.
- Actinide burning needs a very long time (>30 years) of reactor operation, Th-U cycle can extend the operation time and get deep burnup.

Conclusion

- In the calculation, FFSR is very good to burning Np-237, Pu-239 and Am-241, a little burning to Pu-240, but fail to Pu-238, Pu-241 and Cm-244. Because about 90% of TRU fuel mass consist of Pu-239, Pu-240, Am-241 and Np-237, FFSR seems to successful to actinide burning.
- Pu-238 seems to very important to BHP (relative to human hazard) until to 100 cooling years and how to reduce Pu-238 is worth to further study.

Thank you