Preliminary exploration of the FastDrum reactor concept

Ondřej Chvála, ochvala@utk.edu, 2016-08-02

This document presents a brief conceptual analysis of the proposed fast critical facility at the new building for the UTK NE department. The first concept analyzed had a shape of cube (mk0), this one has a shape of a cylinder (mk1), analyzed in the same manner as previously.

The purpose of this quick analysis is to get the first rough estimate on the required reactor size and the amount of fuel needed.

FastDrum model description and justification

The FastDrum reactor concept comprises Cartesian, chessboard like, lattice of cylindrical fuel elements and square prisms of lead. This choice is motivated by the desire to roughly approximate GenIV Lead-cooled Fast Reactor (LFR) conditions. The LFR concept is pursued by Westinghouse, European consortium around MYRRHA reactor built in Belgium, it was used in Russian Alpha-class submarines, and it is currently pursued by Russians in SVBR-100 small modular and BREST line of reactors. The other GenIV solid fuel fast reactor concept uses sodium as a coolant, which makes the concept unsuitable for a University research environment.

Cylindrical fuel elements use 19.75% LEU metal with 1mm of stainless steel (304) cladding. Remainder of the fuel lattice channel is filled with air. The fuel elements have the same length as the lattice width. The lattice is roughly bounded by a circle, hence the FastDrum name. The core cylinder is surrounded by a lead layer as thick as the lattice pitch, followed by 1mm air gap, which is surrounded by 304 stainless steel reflector. It is assumed that all neutrons leaving the reflector will be lost in a bioshield, which is not modeled. There are no allowances for control elements, instrumentation, or beam ports, therefore the size and fuel needs are both likely underestimated compared to a more detailed conceptual design.

All modeling is done using Serpent 2.1.26 Monte-Carlo code with ENDF/B-VII nuclear data at room temperature (300K).

Reactor configurations studied

There are two free parameters in this simple model: the fuel radius and the reflector thickness. The size of the fuel/lead chessboard lattice of size N, which is determined by a manual criticality search. The fuel (uranium metal with cladding) diameters studied were 1.27 cm, which is the one used in MYRRHA core mock-up VENUS-F critical assembly; double of that is 1 inch or 2.54 cm; and again double of that 2 inches or 5.08 cm. Two steel reflectors thicknesses were studied, 10cm and 100cm, corresponding to a high leakage and a low leakage core. This is to establish a reasonable range of likely reactor size and fuel needs. No optimization was attempted in this quick study.

For each critical assembly the following parameters were established: the size of the inner lattice, equal to the length of a fuel element, the number of fuel elements needed, the mass of each fuel elements, the total number of fuel elements and their mass, size of the reflector, and the neutron leakage fraction.

Results

The results of the calculations are shown in Tab. 1 below. Core leakage is calculated as the percentage of neutrons born that leak out of the steel reflector into the bioshield.

Case#	Fuel diameter	Reflector	Fuel height	Reactor d.	# of fuel pins	Pin U mass	Total U mass	Leakage %
10	1.27	10	88.5	111.2	1812	0.76	1381.6	34.89
11	1.27	100	78.2	281.0	1396	0.67	941.0	0.34
20	2.54	10	76.5	101.8	324	3.14	1018.0	36.34
21	2.54	100	68.9	274.2	256	2.83	723.9	0.35
30	5.08	10	71.3	101.6	62	12.73	789.2	37.15
31	5.08	100	66.2	276.6	52	11.82	614.3	0.31

Table 1: Simulation results. "Fuel hight" equals to the core radius. "Reactor d." is the diameter of the core including the steel reflector, and equals to the reactor height. All dimension are in cm, all masses are in kg.

Images of the reactor cores studied in XY an YZ cuts are attached separately and identified by the case number. Red is uranium fuel, blue is lead, light gray is air, and darker gray is the stainless steel.

Conclusions

This quick preliminary study has shown that the fast flux critical facility under consideration will need approximately 1 metric tonne of 19.75% LEU fuel. More if closeness to an LFR core is desired, less if larger fuel pins are used. The active core width and height will be approximately 70cm (2.3 feet). The reactor width and high, including the reflector, will be about 2.5 - 3 meters (8-10 feet).

Compared to the mk0 concept (FastCube), the reactor needs little less fuel and is few cm larger.

Additional thoughts

Water ingress into the operational core must be absolutely avoided. Square fuel pins would therefore be better than cylindrical. Scrammed core has to be sub-critical when flooded. This could be accomplished by inserting absorbing rods into steel guide tubes inside some of the lead blocks inside the core lattice. Suitable material for the absorber is boron carbide with highly enriched boron-10. These elements could also serve as control rods. Sub-criticality of the core can be maintained by keeping some of the boron rodlets permanently inserted.

Reactor bioshield could be depleted uranium doped concrete (DUCRETE).

The room would need a water skirt and a sump pump. Under-pressure needs to be maintained in the room by a special ventilation with radiation monitored HEPA filters.

Alternatives to fire sprinklers, such as one based on Argon or Halon 1301, ought to be considered.

Should this reactor serve as a neutron source for the graphite pile, it is desirable to prohibit the neutrons thermalized in the graphite pile from going back to the fast assembly. This can be accomplished by placing a cadmium plate into the beam-port, since cadmium is highly absorptive for slow neutrons only.