ASSESSMENT OF FEASIBILITY OF CONVERTING RUSSIAN ICEBREAKER KLT-40 REACTORS FROM HEU TO LEU FUEL

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ABSTRACT

The use of high-enriched uranium (HEU) in reactor fuel creates dangers of theft or diversion of the HEU to weapons use. As a result, since 1978, there has been a major international effort to convert HEU-fueled research and test reactors to low-enriched uranium (LEU) and a considerable amount of experience has been accumulated in this area. But no similar effort has yet been mounted to convert ship-propulsion reactors. Based on the information available about the KLT-40 reactor used on Russian nuclear-powered icebreakers, we have carried out a preliminary study and conclude that these reactors could be fueled with LEU without reducing core life.

Introduction

The use of high-enriched uranium (HEU) in reactor fuel creates dangers of theft or diversion of the HEU to weapons use. As a result, since 1978, there has been a major international effort to convert HEU-fueled research and test reactors to low-enriched uranium (LEU containing less than 20% ^{235}U), which is not considered a directly weapon-useable material [1]. No similar official effort has yet been mounted to convert ship and submarine-propulsion reactors [2]. Currently Russia has 6 nuclear-powered icebreakers and one container ship which have in total 11 KLT-40 reactors [3]. In accordance with estimations these actively operating reactors require production and transportation at least 500 kg of HEU nuclear fuel annually. Moreover, the Russian nuclear agency “Rosatom” considering the use a KLT-40 reactor to power the floating nuclear power plants for use in remote areas of a country [4], as well as to supply a floating power plants to other countries [5]. If so, the production of HEU fuel for KLT-4- type reactors would increase and transportation of fuel will go out from the Russian territory.

In this light, an assessment of feasibility of converting KLT-40 reactor from HEU to LEU fuel looks reasonable. This paper presents results of our preliminary and limited study on the principal feasibility of operation of a reactor core, similar in many parameters to the KLT-40 reactor, with the use of LEU fuel containing 20% of ^{235}U. Calculating of reactivity as a function of burnup we have estimated the energy production capacity of LEU fuel for a several core models.

Core model

With the exception of several publications the design information about the KLT-40 reactor used on Russian nuclear-powered icebreakers is not available. In our calculations we have used core model developed on the base of information on the core design of the Russian container ship *Sevmorput* that was provided by the Soviet government to the Norwegian government in connection with a port visit to Tromsø in 1990 [6]. These data are presented in the Table 1.

Table 1. Data on the design of the Sevmorput KLT40 reactor core

Power	135 thermal megawatts (MWt)
Mass of ^{235}U	150.7 kg in 90-percent enriched uranium in uranium-zirconium alloy
Active core height	H_0 = 1.00 meters
Radius	R_0 = 0.606 meters
Heat transfer area of the fuel	233 m^2
Fuel assemblies	241: 6 cm in diameter in a triangular lattice with 7.2 cm center-to-center spacing
Control	19 control rods in each of 16 fuel assemblies
Neutron absorbing rods	Natural gadolinium
Neutron source for startup	BeO, gamma absorption produces neutrons
Fuel rod outer diameter/spacing	0.58 cm/ 0.7 cm
Peak/average power	radial = 1.27; axial = 2.07
Maximum fuel-surface temperature	335 ^oC
Input/output water temperature	278/312 ^oC
Operating period	10,000 equivalent full-power hours (417 days)

In some cases different information is available from other sources. A publication by the Norwegian Bellona Foundation cites a communication from the Murmansk Shipping Company, the operator of the nuclear-powered icebreakers, to the effect that the enrichment of the icebreaker fuel is currently 30-40%, not 90% [7]. For our model we have assumed that the current enrichment of the icebreaker cores is 40%.

There is no published information on the geometry and size of fuel rods for the KLT-40 reactor. Therefore, take into account that high heat-tension in the center of KLT-40 core (~10^6 Wt/m^2) required an effective heat transition, we have assumed a cruciform geometry for fuel rods. Such type of fuel rods is used in Russian research reactor that operates with similar coolant temperatures and similar heat-tension to that in the Sevmorput reactor [8]. The cruciform shape decreases the thickness of fuel meat for a given fuel-rod volume and hence provides an effective temperature drop across the meat. The cross section of fuel rod is shown in Fig 1.

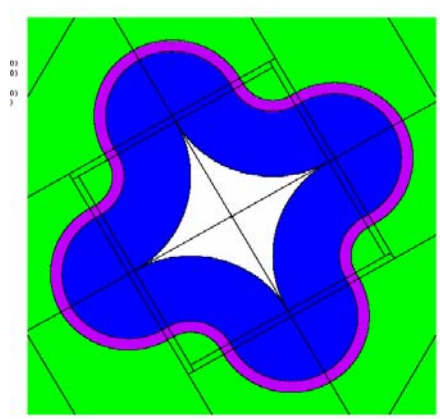

Figure 1. Cross section of fuel rod
Blue – fuel meat
Violet – cladding
White – empty volume

For all variants of core model that were considered the cladding of the fuel rods and gadolinium pins is 0,017 cm-thick stainless steel. The fuel meat was assumed to be made up of aluminum-uranium alloy or of the cermet fuel (UO_2 + aluminum).

A design of fuel assemblies was chosen based on the assumption that reactor core contains 241 fuel assemblies, each 6,8 cm in diameter in a triangular lattice with 7,2 cm center-to-center spacing. (See Figure 2).

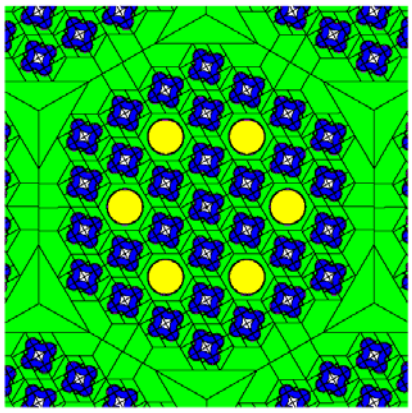

Figure 2. Cross section of fuel assembly.
Blue – fuel rods
Yellow- burnable neutron-absorbing rods

Each fuel assembly contains 31 fuel rods and 6 neutron-absorbing rods. The neutron-absorbing rod is the stainless steel tube filled up by natural gadolinium. The outer diameter of tube is 0,54 cm, and its thickness is 0,014 cm.

Method and results of calculation

All calculations of the value of the core neutron multiplication factor, k_{eff}, were performed with a Monte Carlo code MONTEBURNS 1,0 [9]. At each step of calculations this program is linking the results of calculations performed by the neutron-transport code MCNP B1 with ORIGEN2.1 code. The MCNP B1 code performs calculations of the various nuclear reactions and provides the characteristic of neutron flow. The library of this program contains neutron cross-section data as a function of the energy for all nuclear isotopes that are exist in the reactor core. The ORIGEN2.1 code calculates depletion and buildup of isotopes in the fuel [10].

Table 2 gives the core parameters assumed in four different variants (we only show data that differs from that given in Table1). The coolant temperature was assumed to be 300 ^{o}C in all calculations. Also shown are densities of the fuel meat and of its contained uranium, along with the atomic ratio of aluminum to uranium in the meat for the cases where it was assumed to be uranium-aluminum alloy.

In addition to input data, Table 2 also shows calculated results for k_{eff} at beginning of core life and at 417 days for each model. It will be seen that the reactivity is higher at 417 days than at beginning of fuel life because the decline in neutron poisoning has more than offset the effect of the consumption of ^{235}U.

Table 2. Parameters and calculated k_{effs} for the four models

	Model No. 1		Model No. 2		Model No. 3		Model No. 4	
Core active height (m)	0.9		0.9		0.9		0.9	
Core radius (m)	0.45		0.6		0.6		0.6	
Fuel pin spacing (cm)	0.7		0.81		0.81		0.81	
Fuel pin max. dia. (cm) -- fin thickness (cm) -- meat area (cm^2)	0.58 0.23 0.140		0.81 0.23 0.221		0.81 0.15 0.146		0.81 0.23 0.221	
Total densities (gm/cc) --40% enrichment --20% enrichment (LEU)	6.13 9.79		4.86 7.17		5.97 9.46		4.69 6.69	
U densities (gm/cc) --40% enrichment --20% enrichment (LEU)	3.60 (U-$Al_{6.2}$) 7.19 (U-$Al_{3.2}$)		2.27 (U-Al_{10}) 4.53 (U-$Al_{5.1}$)		3.44 (U-$Al_{6.5}$) 6.88 (U-$Al_{3.3}$)		UO_2-Al 2.27 4.53	
K_{eff} after full-power days	0	417	0	417	0	417	0	417
--40% enrichment	1.07	1.13	1.15	1.23	1.13	1.25	1.12	1.23
--20% enrichment	1.05	1.08	1.13	1.20	1.10	1.22	1.10	1.19

Figure 3 shows k_{eff} burnout curves for Model 2. The k_{eff} values for the 20% enrichment are slightly below those for the 40% enrichment case because of neutron absorption by the added ^{238}U. (The quantity of ^{235}U in the core is the same in both cases.) However, once again, the gap closes at high burnup because of the greater amount of plutonium bred by neutron capture in ^{238}U in the LEU fuel.

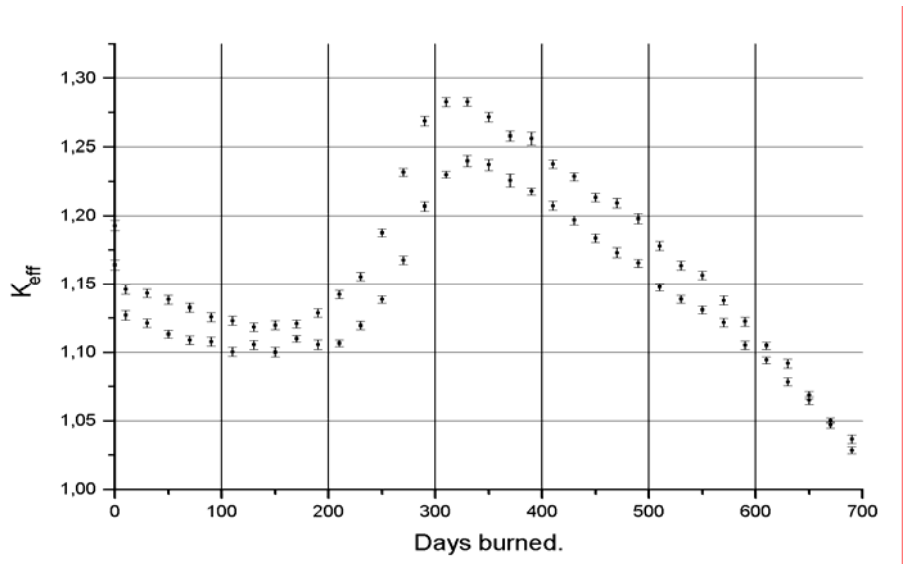

Figure 3. K_{eff} for model №2 core.
(Curve above is for 40% enriched uranium. Curve below for 20%)

Conclusions

Our results suggest that the KLT-40 type reactors can be fueled with LEU without decreasing the lifetime of the core if fuels with the uranium density assumed could operate to the burnup assumed. The uranium densities required by model 2 and 4 about the same: 4,5 g/cm^3.

References

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