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Neutronic Calculations for Modification of Kinki University Reactor from HEU to LEU Fuels

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The Kinki University Reactor (UTR-KINKI) is a modified Argonaut type, light water-moderated zero power reactor with highly enriched (90 wt. %), uranium-aluminum alloy flat MTR plate type fuel. Neutronic calculations were performed on UTR-KINKI to examine the feasibility of replacing the current HEU fuels with low enriched (19.75 wt. %) fuels without changing the main core dimensions and configurations other than the fuel element. The effect of reducing the fuel enrichment on the nuclear characteristics including the neutron spectrum and the neutron flux distribution around the experimental cavity of UTR-KINKI are investigated. It is concluded from the present neutronic calculation that the LEU fuel is feasible for UTR-KINKI without any significant reduction or changes in the reactor performance.

KEYWORDS

LEU (low enriched uranium), neutronic calculation, SRAC Code System

1. INTRODUCTION

The Kinki University Reactor, UTR-KiNKI,[1] is a modified Argonaut type, light water-moderted and graphite-reflected, zero power (1W) reactor. The reactor is heterogeneous in design and consists of twelve fuel boxes in two slab arrangement separated by 46 cm internal graphite reflector. The overall dimensions of the reactor core, placement of the fuel boxes relative to other regions, along with the experimental cavity in the internal graphite reflector are indicated on the horizontal cross-sectional view of the core of UTR-KINKI in Fig. 1.

The UTR-KiNKI currently employs a highly-enriched (90 wt %), uranium-aluminum alloy, flat MTR-type plate fuel. Investigation were performed to examine the feasibility of replacing the HEU fuel of current UTR-KINKI with low-enriched (nominal 20 wt. %) silicide or aluminide fuel without changing the main core configurations other than the fuel element.

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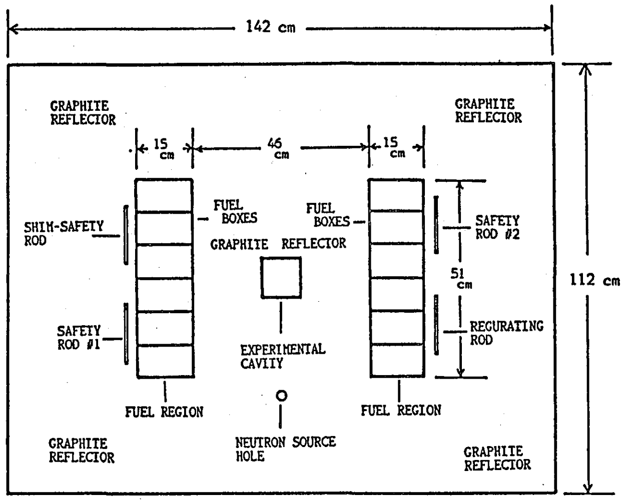

Fig. 1 Horizontal cross-sectional view of UTR-KINKI core

The primary reason for studying conversion of the UTR-KINKI to the LEU fuel is the concern with safeguards associated with the HEU plate fuel. The second reason for conversion is the need to reduce exposure dose of experimenters during frequent critical approach experiments. The third reason for converting to LEU fuel is related to the plan to introduce some neutron spectrum modifying materials around the experimental cavity at the center of internal graphite reflector to establish a "modified spectrum neutron field" for radiation biological researches. Such a change would be difficult with the current HEU fuel because the introduction of substantial amount of spectrum modifying material into the core causes the reactor subcritical and we have only limited amount of HEU fuel.

The study is concerned with the use of both LEU silicide (U_3Si_2-Al) and aluminide (UAl_x-Al) dispersion fuels from the point of view of the present commercial fuel fabrication bases. The technical data on silicide and aluminide fuel matrix supplied by C. E. R. C. A., France were used for neutronic calculations. For uranium enrichment, 19.75 % was selected and for uranium loading in the fuel matrix, 3.8 g-U/cc for silicide and 2.0g-U/cc in the case of aluminide, were selected as conservative values, respectively. The neutronic investigations was done under the following conditions: (1) Main core dimensions and configuration including the size and thickness of each fuel plate of UTR-KINKI except the water gaps between the fuel plates, i. e. the number or fuel plates per element, must be exactly same as in the current HEU core. (2) The change of neutron spectrum around the experimental cavity in the center of the internal graphite reflector should be minimum.

2. METHOD OF CALCULATION

Neutronic calculation was performed using SRAC Code System.[2] The system, JEARI Thermal Reactor Standard Code System for Reactor Design and Analysis, was developed at Japan Atomic Energy Research Institute and its adaptability to complex core configuration has been demonstrated through many benchmark experiments. SRAC Code System consists of neutron cross section libraries and auxiliary processing codes, neutron spectrum routines, a variety of transport and diffusion routines, dynamic parameters and cell burn-up routines,.

The fundamental group constant library was produced mainly from ENDF/B-IV nuclear data file with the energy structure of 107-group (48-group for thermal and 74-group for fast energy ranges, respectively, with 15 overlapping groups). The transport cross-sections for the P_0 transtort calculation were calculated by the B_1 approximation, and the diffusion coefficients were obtained assuming $D=1/(\Sigma_{tr})$. The resonance absorption for heavy nuclides was calculated by a table look-up method for the neutron energy above 130.04 eV and a collision probability method using ultra-fine energy points of 4,600 for neutron energy between 130.07 and 0.68256 eV. The user library was constructed with a energy group structure of 50 groups (23 fast groups and 27 thermal groups).

The unit cell calculation for multi-group constants was performed by collision probability method in 1-D slab geometry for fuel region composed of fuel meat (U_3Si_2-Al for silicide dispersion fuel and UAl_x-Al for alumnide dispersion fuel), aluminum cladding and light-water. Multi-group (fast 31 and thermal 10 groups or fast 5 and thermal 5 groups) core calculation was performed by 2-D diffusion code (CITATION) in X-Y geometry and by 2-D tansport code (TWOTRAN) in R-Z geometry.

3. RESULTS OF NEUTRONIC CALCULATIONS

The results of preliminary calculitions on the minimum critical masses of LEU with reducing water gaps between the fuel plates of each fuel element are shown on Table 1. In general, the minimum critical masses of LEU are several per cent larger in the case

Table 1. Minimum Critical Masses for LEU fuel cores

Water gap	Critical Mass (LEU 19.75%)	
	Silicide (U_3Si_2−Al)	Aluminide (UAl_x−Al)
1.016cm (12 plates per element)	3,420g U−235 17,330g U	3,670g U−235 18,590g U
0.660cm (17 plates per element)	3,500g U−235 17,620g U	3,750g U−235 18,990g U
0.500cm (21 plates per element)	3,850g U−235 19,220g U	4,060g U−235 21,070g U

of aluminide dispersion fuels than silicide fuels.

The effects of reducing fuel enrichment on the nuclear characteristics including neutron spectrum and thermal neutron flux distribution around the experimental cavity at the center of internal graphite reflector of UTR-KINKI were also investigated. The results show that there are no significant change in the neutron spectrum and the thermal neutron flux levels in the fueled region of LEU core are about 10 % lower than that of current HEU core. However, they are much more flat in the internal graphite reflector region than that of HEU core. In the current HEU core, neutron spectrum in the experimental cavity at the center of internal graphite reflector has an excellent 1/E neutron spectrum over wide energy range. The calculated neutron spectra of this region are almost unchanged, both for silicide and aluminide LEU fuel core. Fig. 2 shows the neutron spectrum of this region in the current HEU core and Fig. 3 shows the neutron spectra in the LEU silicide core.

The modified neutran spectrum in the experimental cavity at the center of internal graphite reflector due to the introduction of spectrum modifying materials were also investigated. By replacing part of the graphite reflector with some spectrum modifying

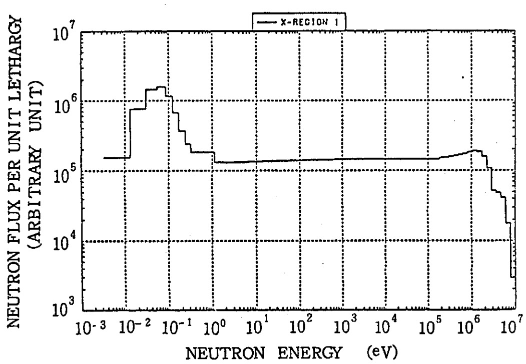

Fig. 2 Neutron spectrum in the experimental cavity of UTR-KINKI, HEU fueled core

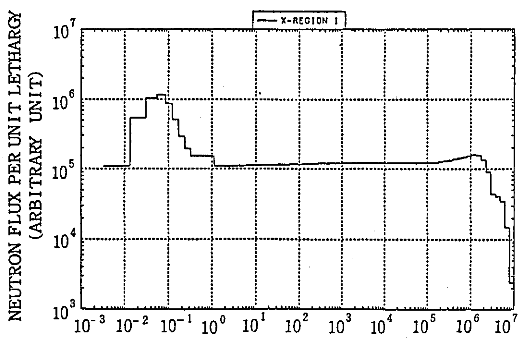

Fig. 3 Neutron spectrum in the experimental cavity of UTR-KINKI, LEU silicide fueled core

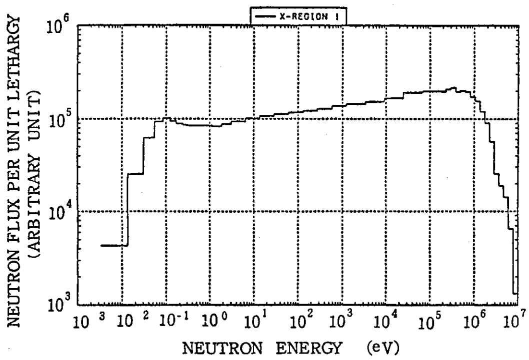

Fig. 4 Modified neutron spectrum in the experimental cavity with stainless steel modifier, LEU core

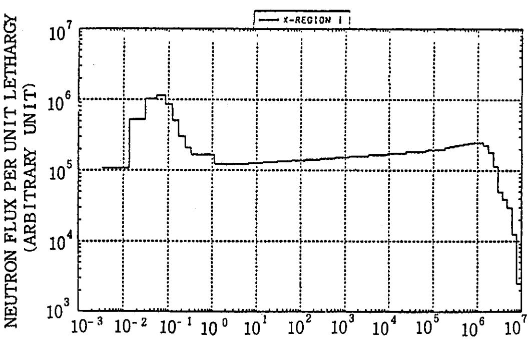

Fig. 5 Modified neutron spectrum in the experimental cavity with bithmus modifier, LEU core

materials, such as bismuth, aluminum, lead or stainless steel blocks, etc., significant modification of neutron spectrum can be attained. But these spectrum modifying materials have large negative reactivity vales, i.e. about -2.5% $\Delta k/k$ for 3.82 cm thick stainless steel blocks and about -0.05% $\Delta k/k$ for bismuth blocks of same thickness. Nevertheless, by increasing the loading of fuel plates per element, these large negative reactivity can be compensated without serious troubles. Figs. 4 and 5 show the "modified" neutron spectrum in the experimental cavity of UTR-KINKI when 3.82 cm thick stainless steel blocks or bithmus blocks were inserted around the experimental cavity in center of the internal graphite reflector.

Some of the results of core calculations other than the results mentioned above are as follows: (1) The temperature effect of reactivity in the LEU core is slightly more negative than that in HEU core, both for silicide and aluminide fuels. (2) The value of β/l in LEU core is approximately equivalent to that in HEU core.

4. CONCLUSION

The results of the present neutronic investigation show that the conversion of UTR-KINKI from HEU fuel to LEU fuel is quite feasible without changing any main core dimensions or configurations except the number of fuel plates per element. The effects of reducing fuel enrichement on the main nuclear characteristics of UTR-KINKI including the neutron spectrum in the experimental cavity and neutron flux distribution in the internal graphite reflector are very small and provide no problem in the application of UTR-KINKI.

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