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CRITICAL EXPERMENTS AND ANALYSIS ON THORIUM AND NATURAL URANIUM TEST ASSEMBLIES IN UTR-KINKI FOR NUCLEAR DATA EVALUATION

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Abstract: Integral critical experiments on thorium and natural uranium test assemblies which are installed in the center of internal graphite reflector of UTR-KINKI, Kinki University Reactor, have been performed. The experiments include (1) Measurement of the reactivity effect of the space between thorium metal plates or natural uranium metal plates in the test assembly and (2) Measurement of detailed relative vertical neutron flux distributions in the assembly. Analytic calculation by JAERI Thermal Thermal Reactor Standard Code System for Reactor Design and Analysis (SRAC Code System) was also performed. The calculated results agree fairly well with the measured values when JENDL-3T and ENDF/B-V nuclear data files were used.

(critical experiment, thorium, natural uranium, reactivity effect, JENDL-3T, ENDF/B-V, SRAC)

Introduction

The recent renewed interest in alternative fuel cycles has stimulated the investigation of the neutronic data of thorium which have not yet been well established. Since late 1970's, critical experiments on thorium test assemblies have been made at several institutes around the world to check the evaluated neutronic data files of thorium. In 1980, Atomic Energy Research Institute of Kinki University started an program to complement a series of critical experiments planned and performed at KUCA, Kyoto University Critical Assembly/1,2,3/. In this paper, we present some of the results of our critical experiments which have been made in UTR-KINKI and of the analytic calculation with SRAC Code System/4/.

Experimental

General discription of UTR-KINKI

UTR-KINKI is a light water moderated and cooled, graphite reflected, heterogenous, highly enriched uranium reactor with 46cm-separated two-slab fuel arrangement. It has a total of 12 fuel elements, each containing 12 aluminum-clad, flat MTR-type fuel plates. The design of UTR-KINKI was developed from "Argonaut" research reactor. The critical mass is approximately 3,018g of U-235. The output power is 1.0W and the maximum thermal neuton flux at the center of the internal graphite reflector is about 1.5 × 10^7 n/cm^2/sec.

The 46-cm wide internal graphite reflector region between the two fuel tanks has almost flat and isotropic thermal neutron flux distribution and an enlarged vertical stringer (16.4cm square and 122cm long) at the center of the internal reflector can be withdrawn to provide the space for insertion of thorium or natural uranium test assemblies. Due to the small power and low residual radioactivity of UTR-KINKI, "dry access" to the experimental region in the core is possible. This feature allows us to set up and unload the thorium or natural uranium test assembly into the core easily and safely. Fig. 1 shows the reactor cross section (north to south) and Fig. 2 shows the core plan of UTR-KINKI.

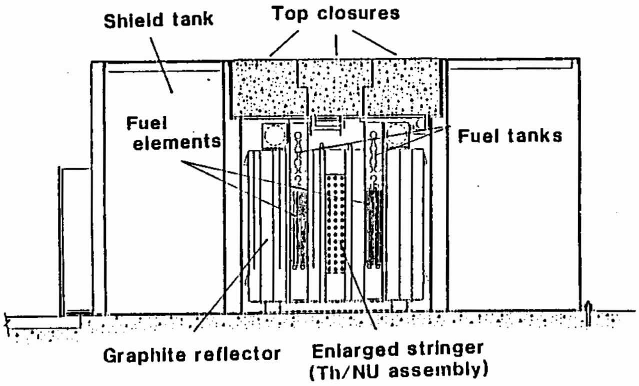

Fig. 1 Reactor cross section of UTR-KINKI

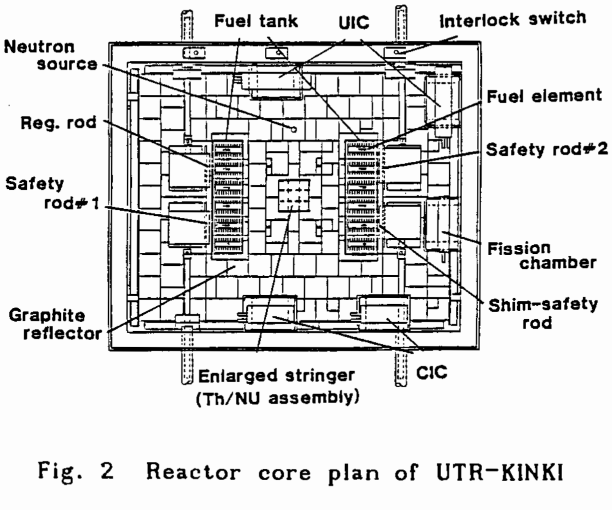

Fig. 2 Reactor core plan of UTR-KINKI

Thorium and natural uranium test assemblies

The thorium and natural uranium test assemblies used in this experiment consist of nine square pillar elements, 55.3mm square and 73cm long, tightly packed in 3-row and 3-line configuration. Each assembly was inserted into the vacant space which was provided by withdrawal of the enlarged central vertical stringer in the internal graphite reflector. At the top and the bottom of each assembly, graphite blocks 24.5cm in height were placed. Fig. 3 shows the detailed construction of enlarged vertical stringer and thorium or natural uranium test assembly.

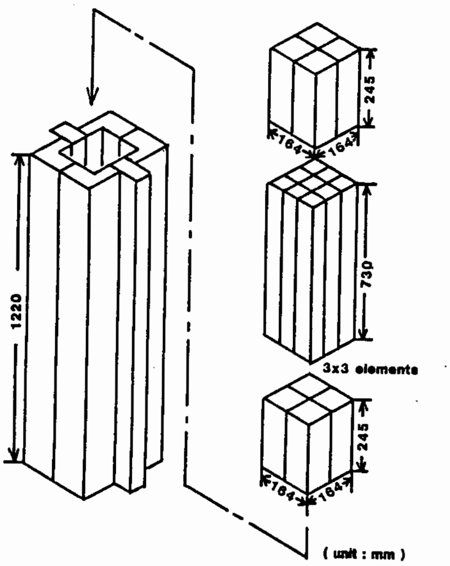

Fig. 3 Details of enlarged stringer and thorium / natural uranium test assembly

In the case of thorium test assembly, five square thorium metal plates, 1/8" in thickness, were loaded into the central region of each element at regular intervals together with square graphite plates with different thickness. The remaining space were filled with graphite plates. Each element was enclosed with 55.3mm square and 73cm long aluminum sheath, 51.3mm square inside and 1.5cm thick. In the case of natural uranium test assembly, each thorium metal plate was replaced by a pile of three square natural uranium metal plates, 1mm in thickness. All of the graphite and metal plates are 2" sqaure. The total amount of thorium and natural uranium loaded in each assembly is 4.1 kg and 6.7 kg, respectively.

The thorium test assemblies were named Th-1, Th-2, Th-3, Th-4 and Th-5 according to the intervals between the thorium metal plates, ½", 1", 2", 3" and 4", respectively. The natural uranium test assemblies were also named NU-1, NU-2, NU-3, NU-4 and NU-5 in the same manner as in the case of thorium assembly. The loading patterns of thorium or natural uranium metal plates and graphite plates in the thorium or natural uranium elements are shown in Fig. 4 and Fig. 5.

Measurement of reactivity effect

Reactivity effect of each thorium and natural uranium test assembly was measured as the difference of excess reactivity between the reference core and individual core loaded with thorium or natural uranium test assembly. As the reference core, standard core configuration with no thorium

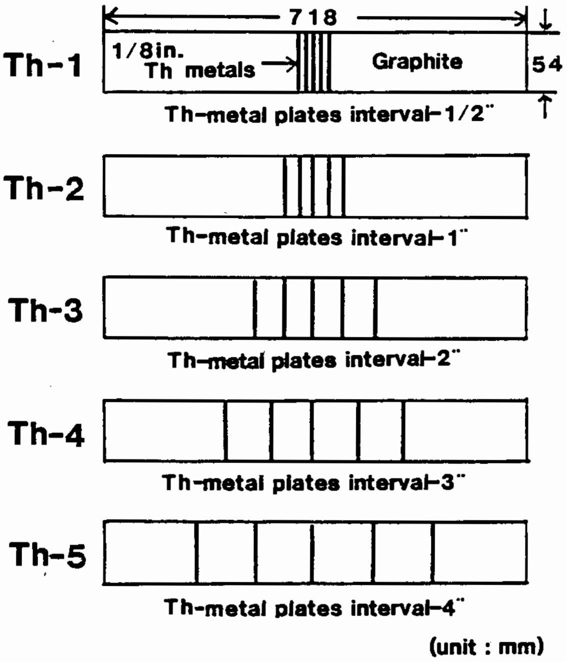

Fig. 4 Loading patterns of thorium elements

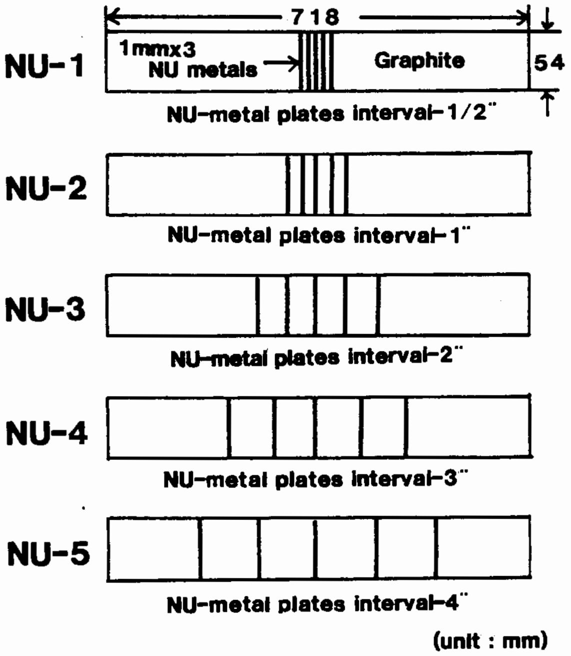

Fig. 5 Loading patterns of natural uranium elements

nor natural uranium metal plates was chosen. The positive period method was used in the measurement of excess reactivity. The effective delayed neutron fraction, 7.658 × 10^{-3}, and neutron life time, 1.499 × 10^{-4}sec., were used for deriving reactivity from period.

Measurement of relative neutron flux distributions in thorium and natural uranium assemblies

Relative neutron flux distribution along the vertical center line in each test assembly was measured by bare gold foil activation method. Gold foils 0.05mm in thickness were placed at regular intervals between metal or graphite plates in the central element of each assembly and irradiated for 1.5 hours at 1W. After irradiation, relative induced radioactivities of bare gold foils were measured by automatic well-type scintillation counter.

Analytic calculation by SRAC Code System

Analytic calculation on reactivity effect and neutron flux distribution (reaction rates of bare gold foils) were performed by SRAC Code System. The system consists of neutron cross section libraries and auxiliary processing codes, neutron spectrum routines, a variety of transport routines, 1D-, 2D- and 3-D diffusion routines, dynamic parameters, etc. The fundamental group constant library has been produced from several nuclear data files including JENDL-2 and JENDL-3T with the energy group structure of 107-group (48-group for thermal and 74-group for fast energy ranges, respectively, with 15 overlapping groups).

The reactivity effect of each thorium and natural uranium test assembly was calculated by the following procedures:

(1) Unit cell calculation for multigroup constants by collision probability method in 1-D slab geometry. Energy group structure : Fast neutron energy range, 22 groups, thermal neutron energy range, 31 groups.

(2) Multi-group core calculation for few group constants by 1-D diffusion code in cylindrical geometry. Energy group structure : Fast energy range, 5 groups, thermal energy range, 5 groups.

(3) Few group core calculation by 3-D diffusion (CITATION) in X-Y-Z geometry. Energy group structure : 10 groups (fast 5-group, thermal 5-group).

The reaction rate of bare gold foils placed along the central line of center element of each thorium and natural uranium test assembly was calculated by the similar procedures described above, except that for few group core calculation, 2-D (R, Z) TWOTRAN transport code using 16-group (fast 11 and thermal 5 groups) constants were employed.

The details of calculation procedures including the two-dimensional (R, Z) model for core configurtion have been reported elsewhere/5, 6/.

Results and discussion

Reactivity effects of thorium and natural uranium ssemblies

The experimental and calculated results of the reactivity effects of Th-1, Th-2, Th-3, Th-4 and Th-5 assemblies are tabulated in Table 1. The reactivity effect is expressed as the difference of excess reactivity between the reference core and the individual core loaded with thorium test assembly. The measured values agree fairly well with the calculated results

Table 1 Measured and calculated values of reactivity effects of various thorium assemblies

Th assembly	Th metal Plate interval	Reactivity differences ($-\Delta k \times 10^{-3}$)			C/E	
		Exp. value	Cal. value			
			J-2 (10-G)	J-3T(10-G)	J-2 (10-G)	J-3T (10-G)
Th-1	1/2″	4.76	4.51	4.69	0.946	0.985
Th-2	1″	5.01	4.81	5.03	0.961	1.005
Th-3	2″	5.19	4.95	5.25	0.954	1.012
Th-4	3″	5.06	4.77	5.11	0.943	1.010
Th-5	4″	4.75	4.42	4.84	0.930	1.019

Table 2 Measured and calculated values of reactivity effects of various natural uranium assemblies

NU assembly	NU metal plate interval	Reactivity difference ($+\Delta \rho \times 10^{-3}$)		C/E
		Exp. value	Cal. value	
NU-1	1/2″	2.26	2.06	0.912
NU-2	1″	2.39	2.19	0.918
NU-3	2″	2.57	2.35	0.914
NU-4	3″	2.64	2.63	0.995
NU-5	4″	2.62	2.61	0.996

especially when JENDL-3T nuclear data file was used. The cross section data of thorium in JENDL-2 give somewhat lower C/E values on reactivity effect so far as the critical experiment on thorium test assemblies in UTR-KINKI is concerned. The reactivity effect of thorium test assemblies has its maximum negative value in Th-3 assembly.

The experimental and calculated results of the reactivity effects of NU-1, NU-2, NU-3, NU-4 and NU-5 assemblies are tabulated in Table 2. The reactivity effect is expessed ina similar way as in the case of thorium test assembly. The measured values agree very well with the calculated results in NU-4 and NU-5, but there are some discrepancies in NU-1 ~ NU-3 test assemblies when the combination of ENDF/B-V and ENDF/B-IV nuclear data files was used. The reactivity effect of natural uranium assemblies has its maximum positive value in NU-4 assembly.

Relative neutron flux distribution in thorium and natural uranium assemblies

Some of the examples of relative neutron flux distribution along the vertical center line in each thorium and natural uranium test assemblies measured by reaction rate of bare gold foils inserted at regular intervals in the central element are shown in Figs. 6 and 7.

The measured values agree very well with the calculated results for both thoium and natural uranium test assemblies.

Acknowledgement

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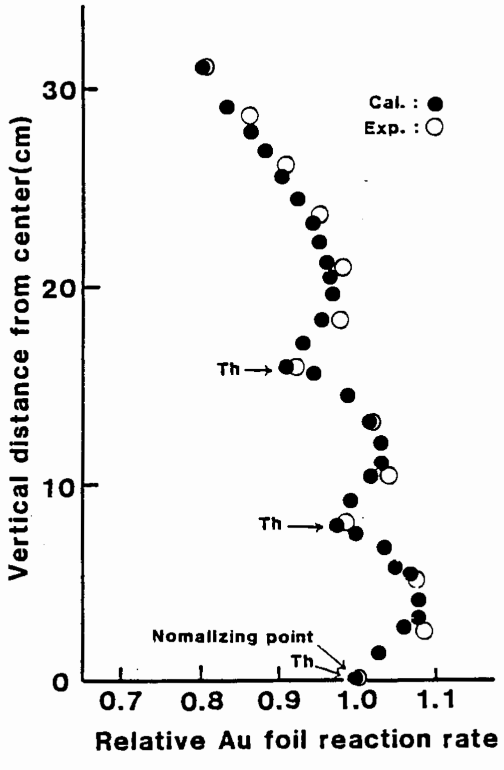

Fig. 6 Relative Au foil reaction rate distribution in Th-4 assembly (metal plate interval —— 3")

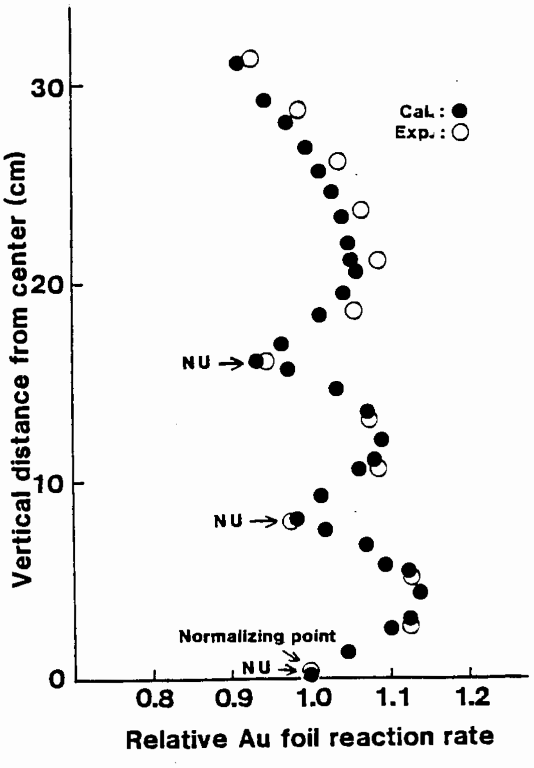

Fig. 7 Relative Au foil reaction rate distribution in NU-4 assembly (metal plate interval —— 3")