4. Effective Cross Sections of U-235 and Au in a TRIGA-Type Reactor Core

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ABSTRACT

The dependence of effective cross sections of gold and uranium for neutron spectrum in Rikkyo University Reactor (TRIGA Mark- Ⅱ, RUR) fuel cell was studied using computer calculations. The dependence of thermal neutron spectrum with temperature was also investigated. The effective cross section of gold in water of the fuel cell at 32 ℃ was 90.3 barn and the fission cross section of U-235, 483 barn. These two values are similar to the cross sections for neutron energy of 0.034 eV.

INTRODUCTION

The TRIGA fuel of RUR consists of a homogeneous mixture of uranium and zirconium hydride. The atomic ratio of zirconium to hydrogen in the zirconium hydride is 1 to 1.6. The hydrogen atoms in the meat are the main neutron moderator and is quite strongly bound in the zirconium hydride lattice. The movement of the hydrogen atoms in the zirconium hydride lattice can be described by the broaden Einstein oscillator model (1) . According to this model, the oscillation of hydrogen atoms can be described by a combination of the standard Einstein (optical) mode and the acoustic mode.

Binding of the hydrogen atoms has given rise to a unique moderating properties as followings :

(1) Under the optical vibration mode, the hydrogen atoms can only occupy certain discrete energy levels of (n + 1/2) hω. Since the product hω (n is a positive integer, h is Plank's constant and ω the lowest frequency of the vibration model) is about 0.14 eV, the hydrogen atoms in zirconium hydride can slow down neutrons in the steps of 0.14 eV but can not slow down neutrons having energy lower than 0.14 eV.

(2) On the other hand, neutrons with energy lower than 0.14 eV can receive energy after colliding with hydrogen atoms, resulting in up-scattering of thermal neutrons. Up-scattering of thermal neutrons in TRIGA reactor is greater than light water moderated reactor, because the hydrogen atoms in water are only weakly bound and able to slow down neutrons to the energy lower than 0.14 eV.

(3) In the acoustic vibration mode, the collective motion of hydrogen and zirconium atoms can be represented by a nuclide having a heavy effective mass. This provides the zirconium hydride lattice behaves in a less effective way in slowing down the neutrons to the energies below 0.14 eV .

Based on the above characteristics, the LIBP and THERMOS computer code[2)][3)] were used to calculate the thermal neutron spectrum in a TRIGA fuel cell. Thermal neutrons were divided into 30 groups. Thermal neutron energy structure in THERMOS is shown in Table 1.

The moderating properties affects the thermal neutron spectrum in the reactor core. The main objective of the present study is to investigate the effect of thermal neutron spectrum to obtain effective cross sections in the reactor core of RUR.

RUR FUEL CELL

RUR reactor uses aluminium cladded fuel rods containing 8.5 w/o (weight percent) uranium and with a fuel section length of 34.56 cm (14 inch). The dimension and composition of the fuel cell of RUR are shown in Table 2.

	Upper boundary		Mid point		Mesh width	Group
	Energy(eV)	Velocity	Energy(eV)	Velocity	Velocity	
1	0.00057	0.15	0.00023	0.1	0.1	1
2	0.00158	0.25	0.00101	0.2	0.1	
3	0.00310	0.35	0.00228	0.3	0.1	
4	0.00512	0.45	0.00405	0.4	0.1	
5	0.00765	0.55	0.00632	0.5	0.1	
6	0.01069	0.65	0.00911	0.6	0.1	
7	0.01423	0.75	0.01240	0.7	0.1	
8	0.01828	0.85	0.01619	0.8	0.1	
9	0.02283	0.95	0.02049	0.9	0.1	
10	0.02789	1.05	0.02530	1.0	0.1	
11	0.03346	1.15	0.03061	1.1	0.1	
12	0.03953	1.25	0.03643	1.2	0.1	
13	0.04611	1.35	0.04276	1.3	0.1	
14	0.05319	1.45	0.04959	1.4	0.1	2
15	0.06078	1.55	0.05692	1.5	0.1	
16	0.07384	1.7084	0.06699	1.6273	0.15835	
17	0.08970	1.8829	0.08138	1.7935	0.17453	
18	0.10896	2.0752	0.09886	1.9767	0.19236	
19	0.13236	2.2873	0.12009	2.1787	0.21201	
20	0.16078	2.5209	0.14688	2.4013	0.23367	3
21	0.19531	2.7785	0.17721	2.6466	0.25754	
22	0.23726	3.0623	0.21527	2.9169	0.28386	
23	0.28821	3.3752	0.26150	3.2150	0.31285	
24	0.35011	3.7252	0.31776	3.5434	0.34482	
25	0.42530	4.1000	0.38588	3.9054	0.38004	
26	0.51664	4.5189	0.46875	4.3044	0.41887	4
27	0.62759	4.9806	0.56942	4.7441	0.46166	
28	0.76238	5.4894	0.69171	5.2288	0.50883	
29	0.92611	6.0502	0.84026	5.7630	0.56081	
30	1.12500	6.6683	1.02070	6.3517	0.61810	

Table 1. Neutron Energy Structure in THERMOS

Region	Radius (cm)	Volume fraction	Nuclide	Atomic density ($\times 10^{24}$ atoms/cm^3)
Fuel meet	1.7985	0.6082	U-235 U-238 Zr H(ZrH)	2.5665×10^{-4} 1.0258×10^{-3} 3.7171×10^{-2} 5.9474×10^{-2}
Clad	1.8745	0.0525	Al	6.0200×10^{-2}
Water	2.3062	0.3393	H O	6.7000×10^{-2} 3.3500×10^{-2}

Table 2. RUR Fuel Cell

RESULTS AND DISCUSSION

Figure 1 shows the thermal neutron flux distributions of four energy groups in the fuel cell. In the table, 30 thermal neutron groups were put into four broad groups. The four groups were :

Group 1 : 0.0006 eV ~ 0.046 eV
Group 2 : 0.046 eV ~ 0.132 eV
Group 3 : 0.132 eV ~ 0.425 eV
Group 4 : 0.425 eV ~ 1.125 eV

The thermal neutron flux distributions in the TRIGA fuel cell vary sensitively with temperature. Neutron distribution with respect to temperature is also shown in Figure 1.

The neutron spectra at three positions in the fuel cell are shown in Figure 2, and compared with a Maxwell distribution with the peak energy of 0.025 eV. The three positions were :

1 : Center of the fuel cell r=0.00 cm
2 : mid point of the clad r=1.8365m
3 : mid point of the water r=2.0903m

The neutron spectrum in a TRIGA fuel cell differs from the one in a reactor core which gives the neutron flux of the Maxwell distribution. The peak energy of the neutron spectrum shifts towards higher energy and the neutron flux of very low energy is more intense than the Maxwell distribution.

The effective cross sections of gold and uranium in a RUR fuel cell were calculated using the obtained neutron spectrum. The results are shown in Table 3.

irradiation point	center in the meet	in the clad	water	Maxwell distribut.
total cross section gold, (barn)	72.5	84.0	90.3	105
fission cross section, U-235, (barn)	366	442	505	700
energy corresponding cross section (eV)	0.055	0.040	0.032	0.025

Table 3. Effective Cross Section of gold and Uranium

REFERENCES

1) G. W. Carriveau, Single Differential Cross Section of Zirconium Hydride, GA-8345, 1967

2) A Thermalization Transport Theory Code for Reactor Lattice Calculations, BNL-5826.

3) T. Ise, Y. Nakahara, M. Akimoto, JAERI-M 5730, 1974

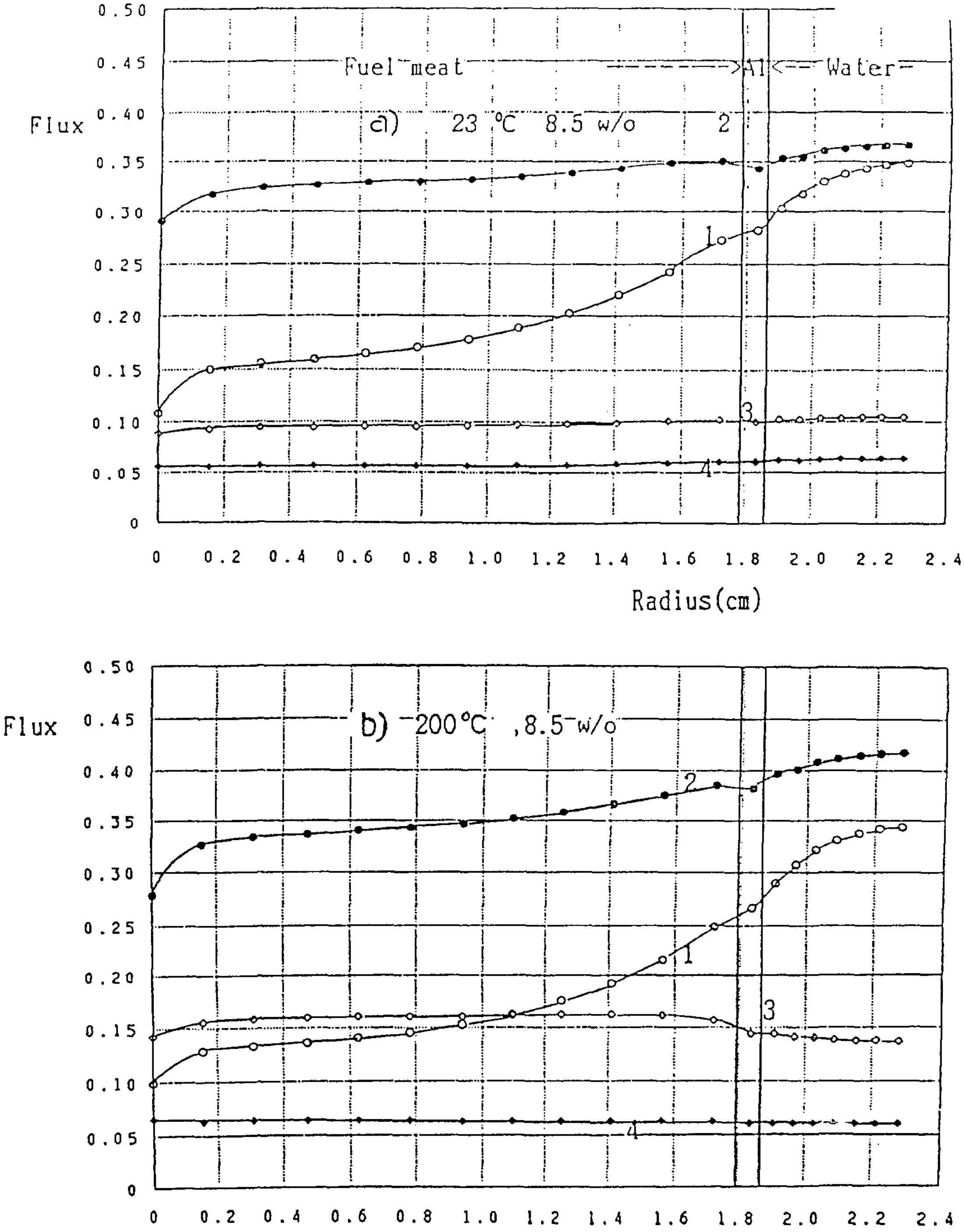

Figure 1. Neutron distribution in the fuel cell at various fuel meat temperatures. The numbers on the graphs correspond to the neutron groups.

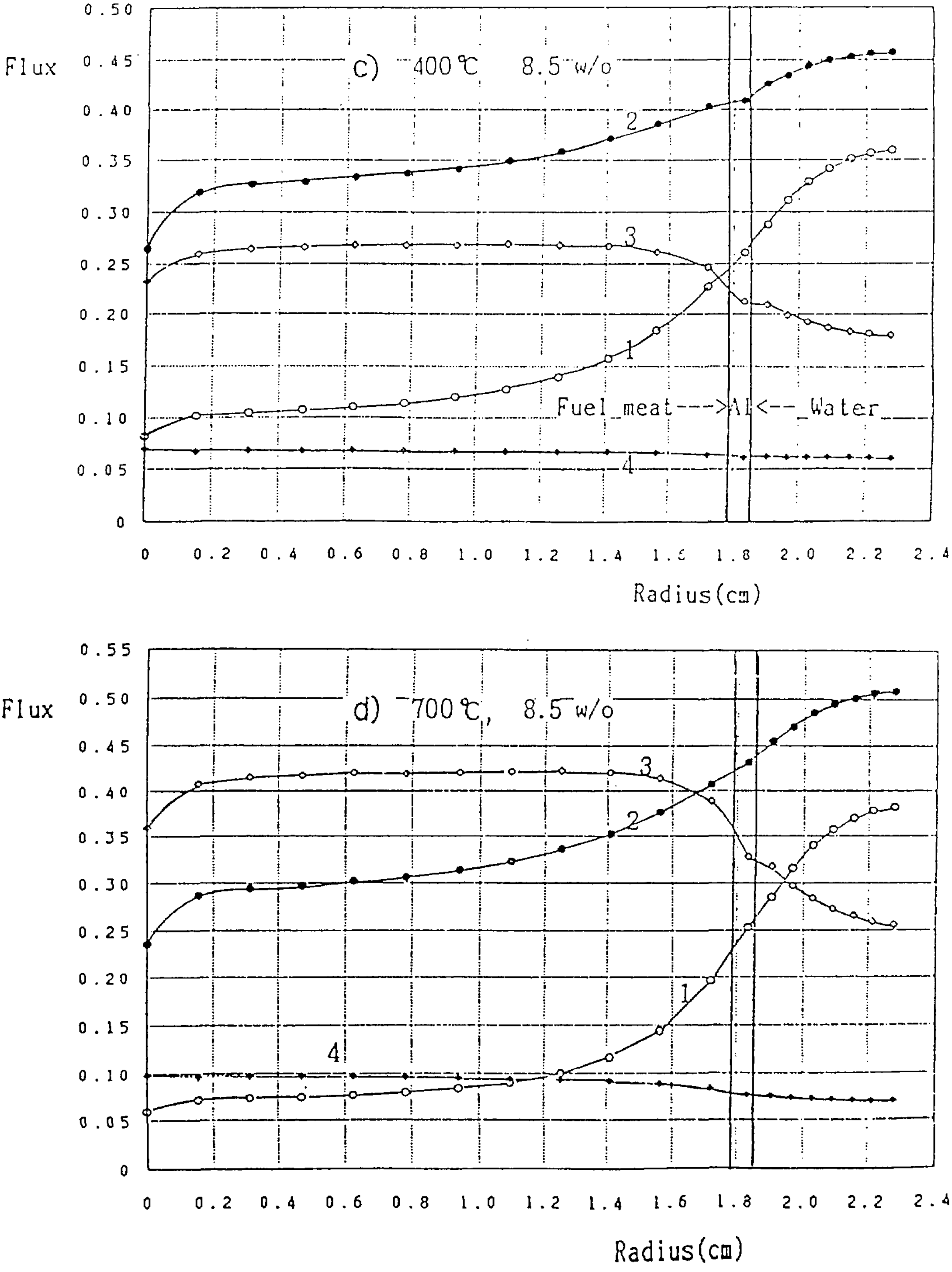

Figure 1 Continued

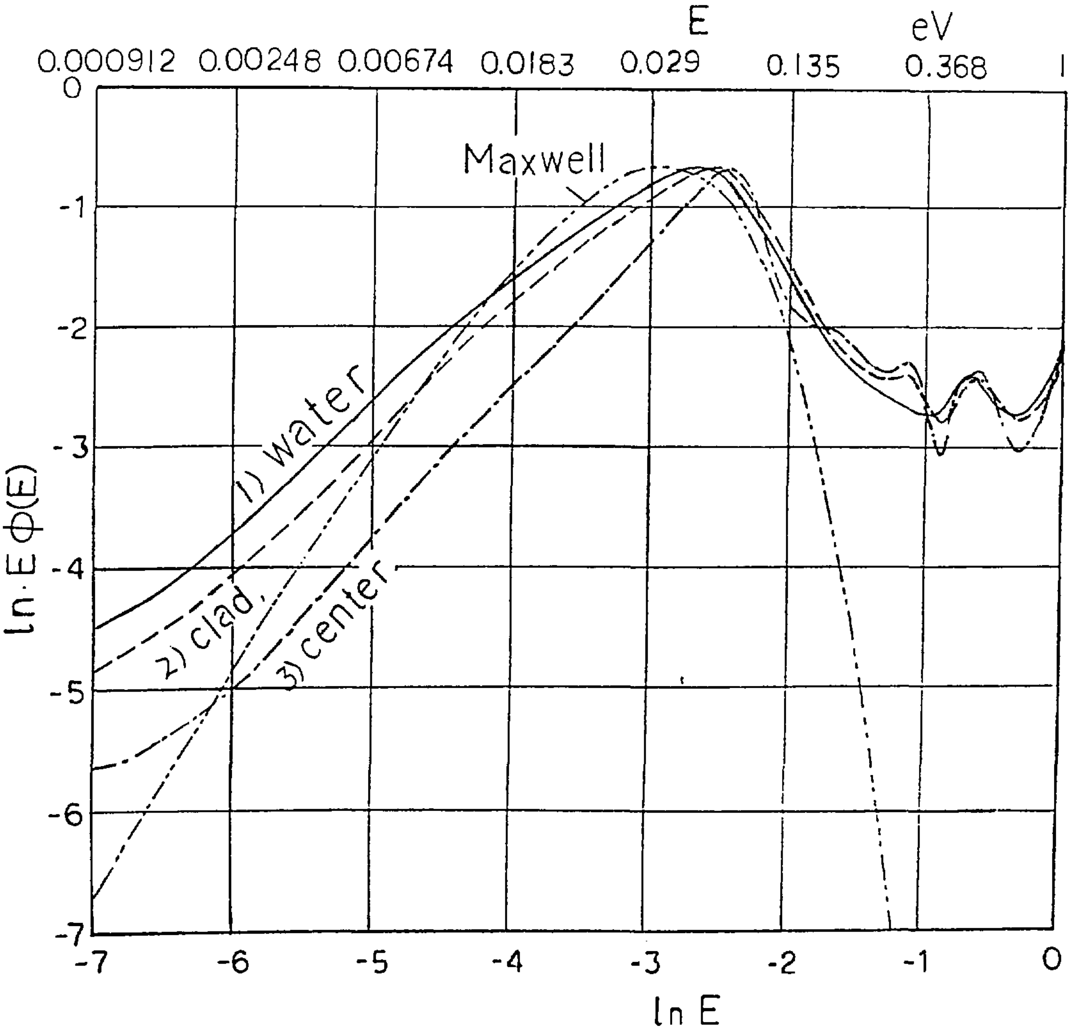

Figure 2. Neutron spectra at three positions in the fuel cell and the Maxwell distribution