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ウラン燃料のＦＣＡ高速炉心における遅発臨界時の即発中性子減衰定数

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２０％濃縮ウランを燃料とする７個のＦＣＡ炉心について，遅発臨界時における即発中性子減衰定数，α_c，をパルス中性子法により直接測定した。従来から問題になつていたα_cの実験値と計算値との差は，計算にＪＡＥＲＩ－ＦＡＳＴ断面積セットを用いることにより大巾に減少した。また，この差の原因の一つは，計算によるエネルギースペクトルと実際の体系内でのエネルギースペクトルとの差にあることが推定され，α_cが高速炉体系のエネルギースペクトルに関する積分データの一つとして有用であることがわかつた。

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The prompt neutron decay constants at delayed critical of seven uranium fuel fast assemblies of FCA were directly measured by the pulsed neutron method. The discrepancy between the experiment and the calculation observed hitherto has been reduced a great deal by use of JAERI-FAST 25 group set for the calculations. One of the causes of the discrepancy is concluded to be the difference between the calculated spectrum and the actual spectrum in systems.

目 次 な し

1. Introduction

On fast reactor systems, the prompt neutron decay constant at delayed critical, α_c, is one of the important integral data as well as criticality. For the prompt neutrons in the multiplying system at delayed critical, the balance of neutrons of velocity, v, is expressed as

$$[\chi(v)\nu(v)\ \Sigma_f(v)\{1-\beta_{eff}\}-\Sigma_a(v)-D(v)B^2-\Sigma_{sc}(v\to v')]\phi(v)$$

$$+\int\Sigma_{sc}(v'\to v)\phi(v')dv' = -\frac{\alpha_c}{v}\phi(v) \qquad (1)$$

by the point reactor diffusion model. In Eq. (1), α_c is the prompt neutron decay constant at delayed critical and other symbols are conventional ones. The term of the neutron decay, $-\alpha_c/v$, in Eq. (1), can be regarded as a fictious negative absorption to keep the neutrons at balance. Therefore, the effect of 1/v absorber can be estimated by the measurement of α_c. The α_c can be thus used to know the neutron energy spectrum integrally and to check the adoptability of a multi-group constants used in the calculations.

As reported hitherto, the calculated α_c is usually very much larger than the experimental values.[1] The similar discrepancy up to 30 percent has been observed also at a few assemblies loaded in Fast Critical Assembly (FCA) of JAERI.[2] The measurements of α_c has been continued on various kinds of FCA uranium fuel assemblies. A few improvement on the calculation were also made. A one-dimensional S_n code named SNKPARAM[3] was written to calculate kinetic parameters and a 25 group cross section set, JAERI-FAST, was newly developed.[4] In Ref. 2, the calculations were performed by a diffusion code, KPARAM[5] with ANL-635 16 group set[6] and ABBN 25 group set.[7] Since the difference between the calculated spectra and the actual spectra in the systems has been suspected as a cause of the discrepancy of α_c, it is very useful to compare the calculated α_c by JAERI-FAST set with the experimental results about many FCA Assemblies. This comparison provides one of the data to check the validity of JAERI-FAST set.

2. Method of measurement and FCA Assemblies

The pulsed neutron technique was applied to the measurement of α_c . The experimental procedure of pulsed neutron experiment for the fast reactor system was described in another issue.(8) The α_c was measured directly as follows. At first, the system is kept at delayed critical. Then, the control rods are removed out from the system to reduce its power. After the power goes down to the sufficiently low leve, the control rods are inserted to the position of the delayed critical. Soon after that, the injection of pulsed neutrons and the measurement are started. The measurement is terminated before the delayed component masks the prompt neutron decay. The period of time for the measurement is about 100 seconds in most cases. This process is repeated several times since, usually, the counting rate is not sufficiently high with a single measurement.

The α_c's thus obtained agree very well with the α_c's obtained by the extrapolation from the α's measured at subritical. They also agree well with those measured by Rossi-α method.

The α_c was measured on seven uranium fuel assemblies loaded in FCA. Their configurations are summarized in Table 1. Most of the assemblies are cylindrical cores. Exceptional cores are Assemblies I-5 and III-2. They are spherical cores. The core Assemblies I-1, I-2, I-5 and I-6 were composed only by 20% enriched uranium metal besides stainless steel of the assembly machine. Those of Assemblies I-4 and III-2 consist of 20% enriched uranium metal and graphite. Assembly III-1 is a core for the preliminary mock-up for an experimental fast reactor using only uranium fuel instead of plutonium.

The core is usually surrounded by a natural uranium metal blanket. Exceptions are Assemblies I-5 and I-6. Assembly I-5 is a bare core and whose blanket shown in Table 1 is a stainless steel lattice of the assembly machine. The lattice was taken into account at the calculation. Assembly I-6 has a blanket of graphite, whose thickness is 25 cm.

The details of each assembly are described in other issues on the critical experiments.(9)-(13)

3. Calculation of α_c

A one-dimensional S_n code, SNKPARAM, was written based on the code DTF-4[14]. It calculates the effective delayed neutron fraction, β_{eff}, and the prompt neutron generation time, Λ_p, by the perturbation theory. The prompt neutron decay constant can be calculated from these two constants by

$$\alpha = \frac{K(1-\beta_{eff}) -1}{K\Lambda_p} \qquad (2)$$

The delayed neutron data by Keepin[15] were used for JAERI-FAST calculations.

4. Comparison between experimental and calculated results

The experimental results of α_c are compared with the results of the calculations in Table 2.

The results by S_n calculations are usually larger than those by diffusion calculations by several percent. This makes the discrepancy between the experimental results and the calculational ones larger. The calculations by JAERI-FAST set reduce the discrepancy considerably comparing with the results by ANL-635 set. Especially, in the two cases of spherical assemblies of I-5 and III-2, the difference between the experimental results and the calculated values are only a few percent. JAERI-FAST set provides also good agreement about the critical mass.

The neutron energy spectrum at the center of Assembly I-5 was calculated by DTF-4 with JAERI-FAST set and it was compared with the spectrum by ANL-635 set in Fig. 1 since the difference in the energy spectrum has been suspected as one of the causes of the discrepancy. The spectrum by JAERI-FAST set is much softer than that by ANL-635 set. Usually, spectra are calculated softer in the order of ANL-635 set, ABBN set and JAERI-FAST set.[16] This order of softening of the spectrum matches with the order of the degree of the agreement of α_c between experiments and calculations.

The spectrum at the center of Assembly I-5 was measured by ^{3}He proportional counter.[17] The measured spectrum is also shown in Fig. 1 and it agrees very well with the calculated spectrum by JAERI-FAST set. The measured spectrum by ^{3}He proportional countor also agree weel with the calculated spectrum by JAERI-FAST set in the cases of Assemblies I-1 and IV-1.(17),(18)

Agreement of the order of the softening of the spectrum with the order of the matching and the agreement of the measured spectrum with the soft spectrum by JAERI-FAST set provide supports for the estimation that one of the causes of the discrepancies may be the difference in the spectrum.

There still remain the discrepancy larger than 10 percent for five assemblies and the more detail analysis such as two-dimensional calculations will be required in the future.

5. Conclusion

Prompt neutron decay constants at delayed critical of seven uranium fuel fast reactor assemblies were directly measured by the pulsed neutron method. The discrepancy in α_c between experiments and calculations was reduced a great deal by use of JAERI-FAST 25 group set. One of the main causes of the discrepancy was estimated as the difference between the calculated energy spectrum and the actual apectrum from the good agreement of the measured spectrum of Assembly I-5 with the calculated spectrum by JAERI-FAST set.

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Table 1 Assembly Configurations

FCA Assembly	Composition of material (v/o)												Dimension (cm)			Critical mass (kg of ^{235}U)
	Core							Blanket					Core radius	Core length	Blanket thickness	
	^{235}U	^{238}U	C	Al	Al_2O_3	SUS 304	void	^{235}U	^{238}U	C	SUS 304	void				
I - 1	16.5	66.2	0	0	0	10.8	6.5	0.60	83.6	0	10.8	5.0	17.0	35.6	30	94.9
I - 2	16.5	66.2	0	0	0	10.8	6.5	0.60	83.6	0	10.8	5.0	18.2	35.6	10	110.5
I - 5$^+$	16.5	66.2	0	0	0	10.8	6.5	0	0	0	10.8	89.2	25.1	—	85	208.9
I - 6	16.5	66.2	0	0	0	10.8	6.5	0	0	84.2	10.8	5.0	15.9	35.6	25	78
I - 4	12.3	49.7	20.7	0	0	10.8	6.5	0.60	83.6	0	10.8	5.0	20.6	35.6	30	124.8
III - 1	7.39	29.71	0	9.6	15.9	21.4	16.5	0.60	83.6	0	10.8	5.0	34.4	61.0	20	303.0
III - 2$^+$	6.19	24.81	51.7	0	0	10.8	6.5	0.60	83.6	0	10.8	5.0	39.1	—	27.8	263.4

+ Spherical core

Table 2 α_c of FCA assemblies of uranium fuel

Assembly	Cross section set	Calculation method	Critical mass (Kg ^{235}U)		Kinetic parameters				
					Calculation			Experiment	
			Calculation	Experiment	β_{eff} (10^{-3})	Λ_p (10^{-8} sec)	α_c, cal (10^5 sec^{-1})	α_c, exp (10^5 sec^{-1})	α_c.cal / α_c.exp
I − 1	ANL-635	Dif	102.2	94.9 ±0.3	7.35	4.36	1.69	1.28 ±0.03	1.32
	ANL-635	Sn	93.4		7.33	4.19	1.75		1.37
	ABBN	Dif	93.1		7.28	4.51	1.61		1.26
	JF	Sn	95.9		7.21	4.82	1.50		1.17
I − 2	ANL-635	Dif	122.8** (δ=0cm)	110.5 ±0.7	7.47	3.70	2.02	1.40 0.05	1.44
	JF	Sn	112.1*		7.22	4.47	1.62		1.16
I − 4	ANL-635	Dif	134.0	124.8 ±0.5	7.36	6.02	1.22	0.90 ±0.01	1.36
	ABBN	Dif	121.0		7.32	6.25	1.17		1.30
	JF	Sn	126.1		7.19	6.81	1.06		1.18
I − 5 (Sphere)	ANL-635	Dif	240.9 (δ=2.5cm)	208.9 ±1.0	7.51	3.28	2.29	1.70 ±0.05	1.35
	ANL-635	Sn	216.4		7.38	3.09	2.39		1.41
	ANL-635	Sn	198.0*		7.38	3.35	2.20		1.29
	JF	Sn	213.6		7.20	3.71	1.94		1.14
	JF	Sn	197.0*		7.19	4.09	1.76		1.03
I − 6	ANL-635	Dif	96.1	78.0 ±1.0	7.42	240	0.31	0.28 ±0.02	1.11
	ABBN	Dif	80.5		7.49	234	0.32		1.14
III − 1	ANL-635	Dif	309.4	303.0 ±0.9	7.23	10.3	0.702	0.54 ±0.01	1.30
	JF	Sn	309.4		7.11	12.0	0.594		1.10
III − 2 (Sphere)	ANL-635	Dif	261.9	263 ±1	7.27	17.1	0.425	0.273 ±0.008	1.56
	ABBN	Dif	—		7.36	19.7	0.374		1.37
	JF	Sn	308.3		7.04	25.0	0.281		1.03

* Calculation with a lattice reflector
** δ is the extrapolation length used in calculations.

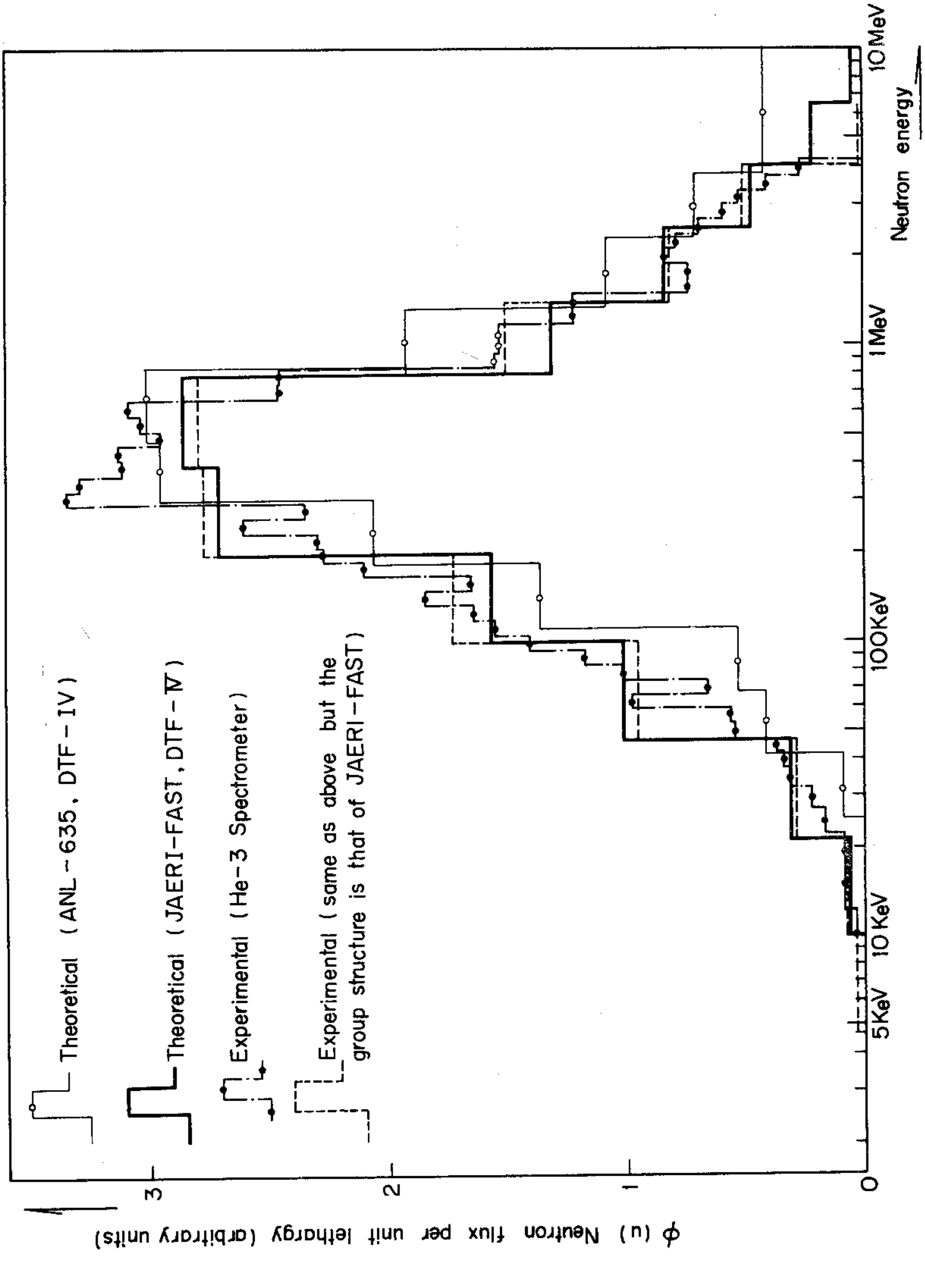

Fig. 1 Comparison between experimental and theoretical neutron energy spectra of FCA I-5