CO3-1

Heat Transfer Enhancement in Reflooding Process on SUS304 Rod with Film-coated Surface

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INTRODUCTION: From the view of severe accident management of light water reactors, it is important to increase the reflooding velocity during a loss of coolant accident (LOCA). In this study, the heat transfer enhancement on a thin film-coated surface of SUS304 rod during reflooding process was investigated. A thin film layer was deposited on the half-circumference or whole outer surface of the SUS304 rod by the vacuum evaporation method with the thickness ranging 5-500 nm. Four kinds of coated film material, i.e. titanium, germanium, zircaloy-2 and silicon were tested. The effect of film-coated surface on the heat transfer enhancement was verified by quenching experiments.

EXPERIMENTS: The diagram of the experimental set-up is shown in Figure 1. The test section consists of a test rod, outer tube made of quartz glass and a guide pipe connected to the test rod. The detail of the test rod is shown in Figure 2. The test rod was made of SUS304 with the length of 150mm and the outer diameter of 24mm. At locations TC1-TC3 of the test rod, K-type thermocouples (ϕ 0.5mm) were spot welded at their end flush with the rod surface and guided through the hole inside the rod to measure the temperature during the quenching. The test section was radiation-heated by a couple of semi-cylindrical ceramic fiber heaters (200V, 750W×2) surrounding the outer tube. A water tank kept at a constant temperature (80^{o}C) was connected to the bottom of the test section, at which a shutter was mounted and was closed during the heat-up of the test rod to prevent the moisture from water tank to enter the test section. The initial temperature of quenching experiments was 450^{o}C at TC-1. Quenching experiments on the SUS304 rod with and without film-coated surface were carried out respectively to investigate the heat transfer enhancement induced by the coated film.

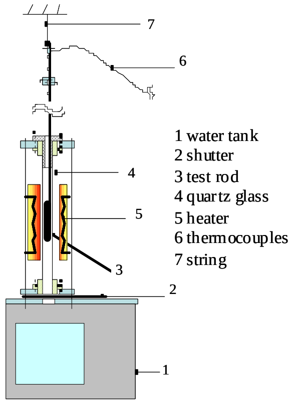

Figure 1 Diagram of the experimental set-up

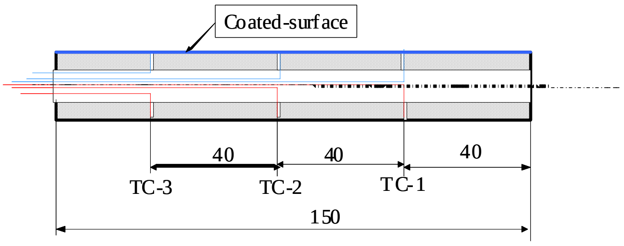

Figure 2 Details of test rod and thermocouples

RESULTS: Transient temperature traces during quenching processes with the coated-films of zircaloy-2, germanium and silicon are shown in Figure 3. It is indicated that the reflooding velocity is increased clearly by the coated-film. The transient quenching results several coating materials are shown in Figure 4. It is indicated that the increase of the reflooding velocity is affected by the thickness of the coated film very much. In the range of 5~500nm of the thickness, the thicker the film is, the faster the reflooding. The mechanism of the heat transfer enhancement was discussed in view of the roughness, the wettability of the coated surface, and the minimum film boiling temperature, but it is not made clearly yet. It is seemed that the heat transfer enhancement is related to the surface wettability at high temperature conditions, which should be studied in the next step.

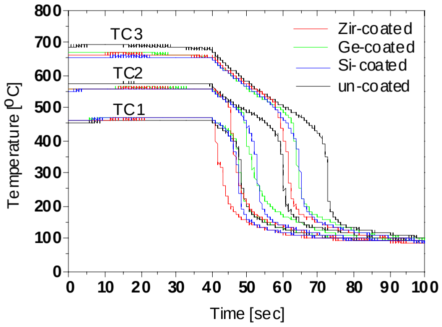

Figure 3. Transient temperatures for coated rods.

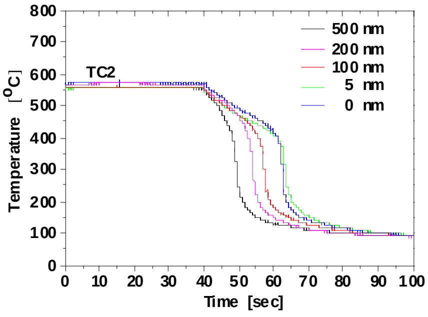

Figure 4 Effect of the thickness of coated film.

REFERENCE:

[1] J. ZHANG, T. YODO, M. HINO and K. MISHIMA, N6P1102, NTHAS6, Okinawa, Japan, November 24-27, 2008.

採択課題番号 20031　　SUS304 ロッド被膜の再冠水過程における伝熱促進　　共同通常
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CO3-2 Development of Subcriticality Measurement for Accelerator-Driven Reactor (III)

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INTRODUCTION: An accelerator-driven subcritical reactor system has been constructed in A-loading facility of the KUCA and a series of pulsed neutron, control drop, accelerator beam trip and restart experiments have been performed to develop the methods of these subcriticality measurement methods. The preliminary results of pulsed neutron experiment are showed in this report.

EXPERIMENTS: These experiments were performed in a reactor system referred to as A3/8"P36EU(3). A tritium target was placed outside polyethylene reflector and pulsed neutron beam was emitted from the target. As neutron detectors for these experiments, four BF_3 counters referred to as BF#1 ~ BF#4. The experiments were carried out in three subcritical states. The subcriticality of the state was adjusted by changing control rod pattern. These control rod patterns are showed in Table 1.

Table 1 Control rod patterns and reference reactivity

Pattern	Rod Position			Reactivity
	C1	C2, C3	S4~S6	[%Δk/k]
A	L.L.	U.L.	U.L.	-0.276
B	L.L.	L.L.	U.L.	-0.636
C	L.L.	L.L.	L.L.	-1.577

L.L.:Lower Limit, U.L.: Upper Limit

RESULTS: Table 2 shows the prompt-neutron decay constants and the reactivity inferred from these constants. The following conventional equation was fitted to measured decay data *N(t):*

$$N(t) = A_0 e^{\alpha_0 t} + C. \tag{1}$$

In this table, detector-position dependence, *i.e.* spatial dependence can be significantly observed.

In the fitting, alternatively, neutron count decay data of just after the pulsed neutron generation, e.g. the data of less than 0.002 sec were omitted to exclude effects of a transient process such as the neutron thermalization or the decay of higher degree harmonics of neutron flux distribution[1]. This technique, referred to as "Mask technique", was also applied to reduce the spatial dependence. The result is shown in Table 3. This mask technique is successful. The fundamental reactivity is consistent with reference one shown in table.

Secondly, we examine the higher harmonics contribution omitted in the above mask analysis. From measured decay data, fundamental component was removed and the residual was fitted to exponential function, whose decay constant was the constant of a spatial harmonics. Table 4 shows the decay constant, the reactivity and the eigenvalue separation of the spatial mode. The eigenvalue separation is independent of rod pattern, *i.e.* subcriticality.

Table 2 Conventional analysis for pulsed neutron experiment

Rod Pattern	Neutron Detector	Conventional Method	
		α_0 [1/s]	ρ_0 [%Δk/k]
A	BF#1	3629 ± 50	-16.05 ± 0.68
	BF#2	229.3 ± 2.1	-0.299 ± 0.042
	BF#3	197.7 ± 1.5	-0.153 ± 0.036
	BF#4	173.9 ± 3.8	-0.043 ± 0.036
B	BF#1	3673 ± 51	-16.25 ± 0.69
	BF#2	352.9 ± 3.9	-0.872 ± 0.065
	BF#3	299.0 ± 1.3	-0.622 ± 0.053
	BF#4	242.4 ± 4.9	-0.359 ± 0.049
C	BF#1	4071 ± 24	-18.09 ± 0.73
	BF#2	670.3 ± 9.3	-2.342 ± 0.126
	BF#3	487.9 ± 1.8	-1.497 ± 0.087
	BF#4	370.2 ± 7.7	-0.952 ± 0.075

Table 3 Mask analysis for pulsed neutron experiment

Rod Pattern	Neutron Detector	Mask Method	
		α_0 [1/s]	ρ_0 [%Δk/k]
A	BF#1	215.6 ± 2.0	-0.236 ± 0.039
	BF#2	212.8 ± 1.2	-0.223 ± 0.038
	BF#3	213.7 ± 1.6	-0.227 ± 0.039
	BF#4	217.6 ± 1.4	-0.245 ± 0.039
B	BF#1	304.6 ± 1.9	-0.644 ± 0.055
	BF#2	303.2 ± 1.0	-0.642 ± 0.054
	BF#3	306.8 ± 1.5	-0.658 ± 0.055
	BF#4	308.9 ± 1.0	-0.668 ± 0.055
C	BF#1	513.5 ± 3.2	-1.616 ± 0.092
	BF#2	500.1 ± 1.8	-1.554 ± 0.089
	BF#3	504.0 ± 2.6	-1.572 ± 0.090
	BF#4	502.6 ± 1.8	-1.565 ± 0.089

Table 4 Second-mode reactivity and eigenvalue separation

Rod Pattern	Neutron Detector	α_2 [1/s]	ρ_2 [%Δk/k]	$(E.S.)_2$ [%Δk/k]
A	BF#3	3144 ± 376	-13.80 ± 1.83	13.57 ± 1.83
	BF#4	3040 ± 88	-13.32 ± 0.68	13.08 ± 0.68
B	BF#3	3292 ± 677	-14.49 ± 3.19	13.83 ± 3.19
	BF#4	3262 ± 80	-14.35 ± 0.69	13.68 ± 0.69
C	BF#3	3424 ± 619	-15.10 ± 2.93	13.53 ± 2.93
	BF#4	3401 ± 101	-14.99 ± 0.76	13.43 ± 0.77

REFERENCE:

[1] Tonoike, K., *et. al.*, *J. Nucl. Sci. Technol.*, **39**, 1227 (2002).

採択課題番号 CA20103　加速器駆動未臨界炉における未臨界度測定高度化のための　共同通常
基礎実験（Ⅲ）
（近大・原研）橋本憲吾（近大院・総合理工）谷中　裕、三好温子
（京大・原子炉）卞　哲浩、三澤　毅、市原千博、中村　博

CO3-3 Reactor Noise Analysis based on Time-Series Data with High Time Resolution

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INTRODUCTION: Many reactor noise measurements have been conducted and reported so far. Kitamura performed the noise experiments taking advantage of the time-series data of pulse train from the neutron detector.[1] In this measurement, the time-series data of pulse train was used for the noise analysis by Feynman-α and Rossi-α method to evaluate the prompt neutron decay constant α_p. The data acquisition system with a time resolution of 100 nsec by the first-in-first-out (FIFO) memory was tested in order to investigate the applicability to the subcriticality measurement such as the noise analysis.

In addition to that, the inverse kinetics method was also used to the time-series data of pulse train to measure the subcriticality.

EXPERIMENTS: A series of experiments was carried out in the KUCA-B core using the polyethylene moderator.

Three Control rods (C1 to C3) and three safety rods (S4 to S6) are arranged as shown in Fig.1.

The noise measurement was conducted for the following conditions, -0.27$, -0.61$, -1.24$ and -3.10$ (Case1 to 4). The time-series data obtained by accumulation of pulse signal from all detectors (Ch.1 to 7) was processed to evaluate α_p.

A rod drop experiment was also carried out for the analysis by the inverse kinetics method. The initial state before the rod drop was -0.27$. Subcritical states after the rod drop were -1.15$ (C3 drop) and -3.10$ (C1, C3 and S4 drop) respectively for each measurement. The reference values were determined by the control rod worth based on the rod drop experiment from the critical state using the integral method.

The delayed criticality was achieved by approximately 61.5% of C1 withdrawn position while other control rods fully withdrawn.

RESULTS: The results of Feynman-α were in good agreement with Rossi-α results within a reasonable range for Case1 to 4 as shown in Fig.2. The results of the rod drop experiment are shown in Table.1. The results showed that some detectors gave the reasonable values corresponding to the reference value, which depended on the location of the detectors.

It was demonstrated that the applicability of the tested data acquisition system to the measurement of subcriticality was confirmed and validated by a series of these experiments.

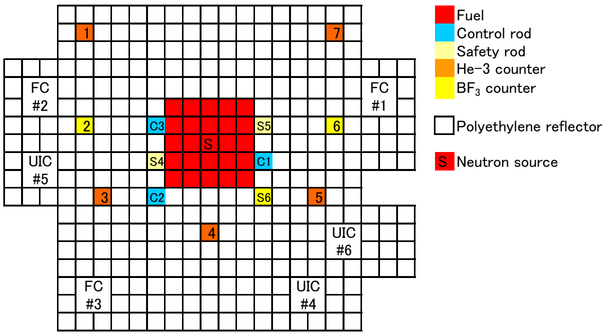

Fig. 1. KUCA Core-B configuration

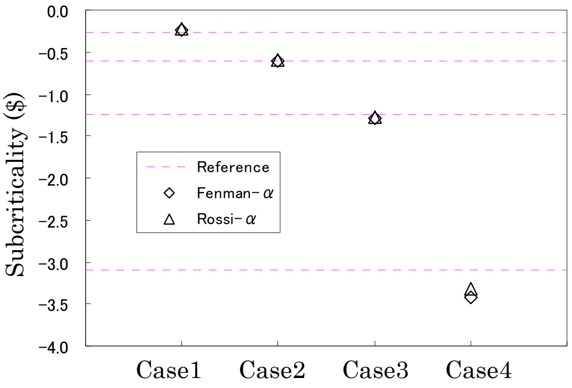

Fig. 2. Results of Feynman-α and Rossi-α

Table 1. Results of rod drop measurement

Reference($)	Detector Ch.	Measred Subcriticality*1 ($)
−1.15	Ch1	−1.351
	Ch2	−1.320
	Ch3	−1.172
	Ch4	−1.087
	Ch5	−1.081
	Ch6	−1.094
	Ch7	−1.049
−3.10	Ch1	−3.275
	Ch2	−3.861
	Ch3	−3.643
	Ch4	−3.266
	Ch5	−3.277
	Ch6	−3.091
	Ch7	−3.142

*1 Sabcriticality measured by the inverse kinetics method

REFERENCE:

[1] Y. Kitamura, *et al.*, *J. Nucl. Sci. Technol.*, **36**[8] (1999) 653-600.

採択課題番号 CA20105　　高時間分解能データ処理を活用した炉雑音測定　　共同通常
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（京大・原子炉）三澤　毅

CO3-4 Nuclear Materials Identification by Neutron Noise Analysis Method

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INTRODUCTION: In the Feynman-α method, the Y curve is measured to evaluate the α value by the next formula,

$$Y(T) = Y_{\infty}\left(1-\frac{1-e^{-\alpha T}}{\alpha T}\right).$$

The α value shows a dependency on the subcriticality, so that the Feynman-α method is usually regarded as one of the techniques for subcriticality measurement. On the other hand, in the present study, the Feynman-α method is applied to the development of a new technique for identification of nuclear materials, especially a small amount of highly enriched ^{235}U that might be hidden in baggage or cargo containers. In this new technique, the Y_∞ value plays an important role, because it takes a positive value owing to the multiplicity of neutrons emitted in the fission reaction of ^{235}U. However, Feynman-α experiments have not been performed with a small amount of highly enriched ^{235}U so far, as far as the authors know. Thus, the authors performed a Feynman-α experiment with a small amount of highly enriched ^{235}U.

EXPERIMENTS: In Fig. 1, the nuclear instrumentation system employed is illustrated. The data acquisition system is an updated one of that reported in Ref-[1] and can record time-series data of pulse trains coming from up to 12 neutron detectors simultaneously.

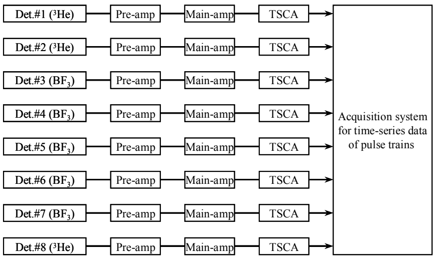

Fig. 1. Illustration of nuclear instrumentation system.

As shown in Fig. 2, six "F" elements were arranged. The compositions of elements used in the present study, i.e., "F", "D*x*" (*x*=1~8), and "P" are given in Fig. 3. According to an eigenvalue calculation by the MVP code and the JENDL-3.3 library, the effective multiplication factor of such arrangement was about 0.04. In the Case-1, the six "F" elements were surrounded by eight "D*x*" elements that included ^{3}He and BF$_3$ detectors. In the Case-2, the Case-1 arrangement was further surrounded by twelve "P" elements that worked as the reflector. The extraneous neutron source was an Am-Be. In this report, experimental results with respect to these two cases are given.

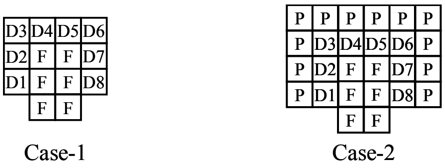

Fig. 2. Arrangements of elements (Cases-1, and –2).

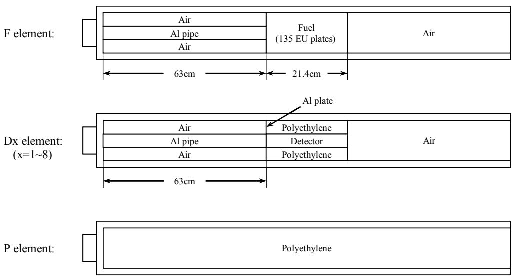

Fig. 3. Illustration of elements used in present study.

RESULTS: As a result, clear Y curves could not be observed with regard to the Case-1. On the other hand, the Y curves with regard to the Case-2 could be obtained successfully. Figure 4 shows examples of the Y curves with respect to the Case-2. Each curve in this figure was obtained from different 10 minutes long measurements. From these facts, it was confirmed that, by using plural neutron detectors and introducing polyethylene reflectors, the Y_∞ value can be determined even under the situation that the effective multiplication factor is very low.

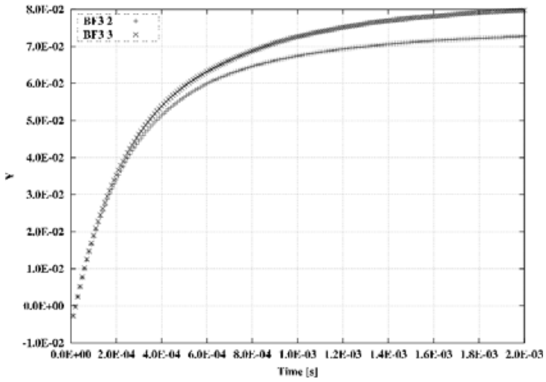

Fig. 4. Measured Feynman's Y-curves (Case-2).

REFERENCE:

[1] Y. Kitamura, *et al.*, J. Nucl. Sci. & Technol., **36** (1999) 653-660.

採択課題番号 CA20106 中性子雑音解析法による核物質探知 共同通常
（名大院・工）山根義宏、北村康則、多田健一、岩田智樹、小池啓基、新谷政弘、小玉泰寛、菅原 慶
（京大・原子炉）三澤 毅、市原千博

CO3-5 Quantification of Neutron and γ Ray Fields for Subcriticality Determination

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INTRODUCTION: In a subcritical system, yield ratio of γ rays to neutrons, *(G/N)*, is related to the subcritical multiplication factor k_{sub} as follows [1].

$$\left(G/N\right)=\left(1-k_{sub}\right)\left(G/N\right)_{prim}+k_{sub}\left(G/N\right)_{2nd}$$

Here $(G/N)_{prim}$ and $(G/N)_{2nd}$ are the ratios for radioactive decay and chain reactions, respectively. In the condition where $(G/N)_{prim}$ and $(G/N)_{2nd}$ are independent to subcriticality, *(G/N)* linearly relates to k_{sub}. In order to identify the condition and to develop quantification methods of *(G/N)* and k_{sub}, neutrons and γ rays were measured in subcritical systems in the KUCA-C core.

EXPERIMENTS: Subcritical cores of 4 rows x 2 or 1 columns of C35 fuel assemblies were mocked up (Fig. 1). The cores were driven with ^{252}Cf of 7.7x10^{5}Bq inserted near the center of the core. In order to measure γ rays, a BGO scintillator was set 35cm outside the core. Measured pulse heights were calibrated to energy with mono-energetic γ rays of H(n,γ) reactions (2.22MeV) and of the Am-Be source (4.44MeV). To quantify neutron leakage from the core, thermal neutron flux distributions were measured outside the core with ^{6}Li scintillation fibers assuming proportional reaction rates between H(n,γ) and ^{6}Li(n,t) reactions. 2.22MeV γ rays of the H(n,γ) reactions were also masured with a NaI(Tl) scintillatior which is shielded from direct γ rays from the core with a Pb shadow bar.

RESULTS: Pulse height spectra measured with the BGO are shown in Fig. 2. The spectra of the cores consist of prominent peaks (2.22, 7.7MeV and its single escape), bumps (around 1.6MeV and 2.6MeV) and a continuum part (3-7MeV). By comparison of them to spectra in no ^{252}Cf or no fuel conditions, those bumps are considered γ rays from accumulated FP or activated materials in the assemblies. Since yields of those bumps potentially vary with time, only higher energy γ rays (>3MeV) from fissions should be quantified to estimate the subcriticality of cores. 7.7MeV γ rays correspond to Al(n,γ) reactions in the fuel assemblies or the frame of control rods. Subcriticality of a core strongly depends on the number ratio of neutrons absorbed inner core to those outside core. Thus the neutron absorption in the frame of control rods is anticipated to influence $(G/N)_{2nd}$. Accordingly, some subtraction schemes of the Al(n,γ) components from the total spectra should be developed.

In Fig. 3, a count rate distribution of the fiber on vertical direction outside the core is compared to averaged vertical distribution of H(n,γ) reactions calculated by the MCNP-5 code. By an agreement of the both distributions, experimental determination of H(n,γ) reaction distribution is available with the ^{6}Li scintillation fiber. 2.22MeV γ rays of H(n,γ) reactions in water outside the core were measured with the NaI(Tl) shielded by the shadow bar. Count rates were 1.1 and 6.8 cps for the 4rows x 1 and 2 cores, respectively. Thus it is available to quantify neutron leakage for those subcritical cores.

With the obtained knowledge and results described above, more sophisticated measurement schemes will be proposed to determine *(G/N)* and k_{sub}.

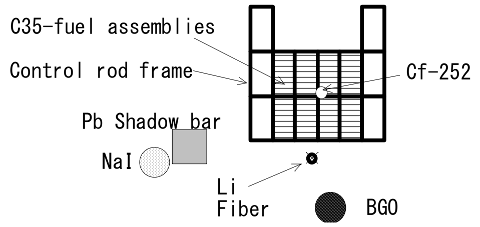

Fig. 1. Schematic view of experimental setup.

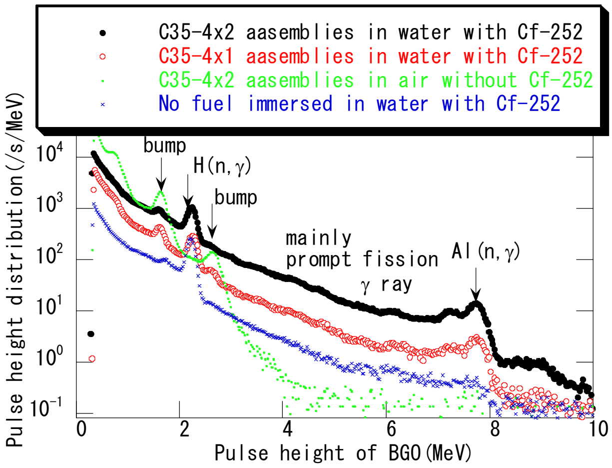

Fig. 2. γ ray pulse height spectra measured outside core.

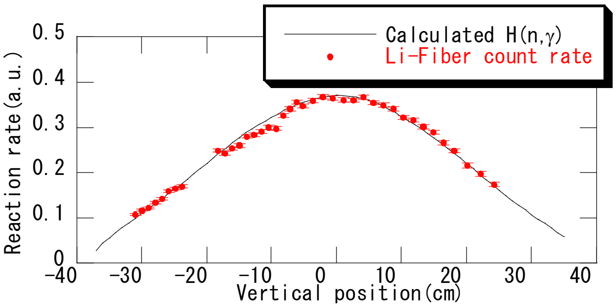

Fig. 3. Vertical distribution of neutron absorption.

REFERENCE:

[1] Y. Nauchi et al., *Proc. PHYSOR2002, Seoul, Korea, October 7-10, 2002*, 1C-03 (CD-ROM).

採択課題番号 CA20107　未臨界度測定に向けた中性子場とγ線場の定量に関する研究　　共同通常
（電中研）名内泰志、亀山高範、園田　健（京大・原子炉）宇根崎博信