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Exponential Experiment for the Determination of Neutron Effective Multiplication Factor of PWR Spent Fuel

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ABSTRACT

An exponential experiment system composed of neutron detector, signal analysis system and neutron source (Cf-252, 4x10^7 n/s) has been installed in the storage pool of PIEF at KAERI in order to experimentally determining neutron multiplication factors of PWR spent fuel assemblies. The neutron detector and source are inserted in the control rod guide tube of the C15 assembly in Kori unit 1 which was loaded in PIEF storage pool for the measurement of axial neutron flux distributions. The measurements are carried out when the detector or the neutron source is scanned in the axial direction and other one is fixed at 180 cm from the bottom end of the assembly. Both of the measured neutron distributions appeared in the similar exponential decay form and the exponential decay constants(γ) are determined to be 0.152 the for detector scanning and 1.65 for the source scanning, respectively. The neutron effective multiplication factor for the assembly is estimated to be 0.480 and 0.441 for both exponential decay constants, respectively.

I. INTRODUCTION

An exponential experiment has been contributed to predict the critical buckling by extrapolating the buckling of a small system which is in extremely subcritical state. Recently Suzaki has applied the experiment to the subcriticality estimation for FCA, TCA and LWR spent fuel and confirmed that the experiment can be used to obtain the neutron effective multiplication factor for the subcritical system in order to validate criticality calculation code[1-4]. It is reported that the reactivity related to the neutron effective multiplication factor is proportional to the exponential decay constant of the axial neutron flux of fuel assembly, which is expressed by $1-1/k_{eff}=K\gamma^2$ where K is a reactivity-buckling conversion factor which can be determined by a diffusion code[3,4] or a criticality experiment[4]. The experimentally measured k_{eff} was reported to be consistent with the calculated k_{eff} with Monte Carlo method[5] by 3 %[3].

The exponential experiment system has been installed in the PIEF (Post Irradiation Examination Facility) pool at KAERI (Korea Atomic Energy Research Institute) in order to determine the neutron multiplication factor for the PWR spent fuel loaded in the pool. The aim is to validate criticality calculation code and finally contribute to the implementation of the actinide plus fission product burnup credit. In this paper, a preliminary performance analysis of the exponential system is carried out; the measurements of the axial background neutron distribution in C15, J14 and J44 assemblies and the determination of the exponential decay constants for the C15 assembly. The characteristics of the system components are described in section II. The axial neutron background distribution and the neutron effective multiplication factor determination are shown in section III.

2. SYSTEM COMPONENT CHARACTERISTICS AND STABILITY TEST

2.1. Equipment Specifications.

The exponential experiment system has been installed in the PIEF storage pool as shown in Fig.1. The system consists of neutron source (Cf-252, 10 mCi), a neutron detector of fission chamber type and electronic equipments and the PC including spectrum analysis program. The neutron detector is extremely small, ϕ6.3 x 25.4 mm and the fission chamber type in which 93 wt% U-235 is coated inside the chamber. The detector is inserted in ϕ9.5 stainless steel tube which can be loaded into the control rod guide tube of the PWR spent fuel assembly. The Cf-252 neutron source is a powder type contained in the stainless steel cylinder of ϕ6.8 x 10 mm size. The activity and intensity are about 10 mCi and 4 x 10^7 n/s, respectively. The neutron source is inserted in a ϕ9.2 x 50 mm capsule and welded. The capsule is connected ϕ6 x 10 mm stainless steel bar which can be loaded into the control rod guide tube of the spent fuel assembly located at the PIEF storage pool ten meter deep.

The neutron detecting signal passes a pre-amplifier and a main-amplifier and transmits to the MCA and finally the neutron counts can be read in the PC with counting analysis software. Although the MCA cannot display neutron spectrum unlike the gamma spectrometer, it is useful to discriminate the noises due to the gamma-ray.

2.2. Cutoff Channel Setup

A response test of the exponential experiment system to the Cf-252, 4x10^7 n/s was carried out. The analysis result of the MCA for the experiment is shown in Fig. 2. Several peaks appeared in the lower channel from 20 to 30. The peeks seem to result from the gamma-ray, which is similar to the fact reported in the previous result[4]. The gamma-ray effects should be removed by setting the cutoff channel in order to correctly count the neutrons[6].

Although the cutoff channel was setup based on the response to neutron from Cf-252, the test for spent fuel assembly shows that there are a lot of noises which seem to be gamma-rays emitted from spent fuel. The neutron counts measurement at 63 cm from the bottom end of fuel for the J14 assembly are shown in Fig. 3. As shown in Fig. 3 the noise appeared near channel 130. In the case of the C15 assembly the noise appeared near the channel 190. For discrimination of all noises occurred, the minimum cutoff channel of the MCA has been chosen to be 200.

2.3. Neutron Source Storage

The neutron source storage has been fabricated for storing the neutron source unloaded from the control rod tube of PWR spent fuel assembly when the exponential experiment is finished, as shown in Fig. 4. For minimizing the neuron expose to the experimenters, the storage is composed of two shielding walls so that the inner shielding of the storage wall may move together with the handling equipment when the neutron source is transported between the storage and the assembly. Shielding analysis for the neutron source was carried out using MCNP code[7].

3. Exponential Experiment for PWR Spent Fuel Assembly

Design specifications and burnup histories of the C15 and J14 assemblies of Kori unit 1, the J44 assembly of Kori unit 2 which are employed in this experiment are listed in Table 1, together with P14 of Japan. The cross section of the C15 assembly storage rack is sketched in Fig. 5. Control rod guide tubes, measured guide tube and vacant positions are shown in the Figure.

3.1. Axial Background Neutron Flux Distribution Measurement

The background neutron flux in the axial direction has been measured for 3 minutes and 5 ~ 10 cm interval. The neutron counts for C15 and J14 assemblies from Kori unit 1 are compared with Cs-137 gamma scanning and P14 of a reactor in Japan in Fig. 6. Three assemblies of the 14x14 array fuel are the same from Westinghouse. As shown in Table 1, assembly-wise burnup values of the C15, J14 and P14 assemblies are about 32, 38 and 40 GWd/tU, respectively. The cooling time is about 19.5, 12.7 and 13.5 years, respectively. Since the difference of cooling times of J14 and P14 assemblies is much less than Cm-244 half-life of 18.11 years and Cm-244 is the main neutron source in PWR spent fuel above 3 year cooling as shown in the ORIGEN2[8] calculation results in Fig. 7, the effects of the different cooling time seems to be negligible.

P14 has a higher burnup than J14, so that Cm-244 amount in P14 is expected to be less than that in J14. But the neutron count rate of J14 is higher than that of P14, as shown in Fig. 6. It seems to be due to the Characteristics of exponential experiment system. Since the exponential decay constant is dependent on only the relative neutron count rate, the difference is not significance at the final result. Since, in the case of C15 assembly, the cooling time is much longer than other two assemblies, J14 and P14 and the burnup is less than those of two assemblies, the neutron count is much lower than other two assemblies. But the dip points, spacer grid locations of C15 is perfectly consistent with two other assemblies, J14 and P14. It means that this system is correctly operated, so that the exponential experiment is believed to be properly designed and established. The neutron counts for the C15 and J14 assemblies are compared with Cs-137 gamma scanning results in the Fig. 6 for the determination of the spacer grid locations. The spacer grid locations determined using neutron rate are exactly consistent with that determined from Cs-137 gamma scanning results. These results indicate that that the exponential experiment system is reliable to measure the neutrons emitted from PWR spent fuel.

3.2. Axial Neutron Distribution Measured with Neutron Source Loading

When Cf-252 neutron source is loaded in a control rod guide tube of the C15 assembly, axial neutron distribution has been measured. The detector has been scanned in the axial direction from the position of neutron source by 3 or 5 cm interval where the neutron source is located at 180 cm from the bottom end of the C15 assembly. Alternatively the detector is fixed on the 180 cm from the bottom end of the C15 assembly and the neutron source has been scanned in the axial direction from the detector location by the same interval. The measuring neutron distributions together with the axial background neutron distribution are shown in Fig. 8. The true neutrons derived from the neutron source, which are used for the determination of the exponential decay constants, are obtained by the subtraction of the background neutron counts which are presented in Fig. 6, from the measured neutron counts.

3.3. Determination of Neutron Effective Multiplication

The exponential decay constants at the measurement points have been evaluated and presented in Fig. 9. Through averaging the values shown in Fig. 9, the exponential decay constants have been determined to be 0.152 for detector scanning and 0.165 for the source scanning, respectively. The measured exponential constants seem to be correctly determined in the comparison with the previous result[4].

If K, reactivity-buckling factor is assumed to be 44.6 evaluated in the previous result, the neutron effective multiplication factors(k_{eff}) for both exponential constants are determined to be 0.480 and 0.441, respectively using the equation of $1-1/k_{eff}=K\gamma^2$, where γ is the exponential decay constant. The k_{eff} values are roughly inconsistent with $k_{eff}=0.48761\pm0.00359$ which are resulted from MCNP code calculation[9]. Therefore, the exponential experiment system seems to be appropriate for the determination of the neutron effective multiplication factor of PWR spent fuel Assembly.

4. CONCLUSIONS

A exponential experiment system which is composed of neutron detector, signal analysis system and neutron source (Cf-252, 4×10^7 n/s) has been installed in the storage pool of PIEF at KAERI. And the neutron multiplication factors for the C15 assembly of Kori unit 1 loaded in PIEF storage pool were determined using the exponential decay constants measured in the system and the reactivity-buckling constant determined in the previous paper. Through this experiment, it is concluded that the exponential experiment system is setup successfully for the measurement of axial neutron flux distribution to determine the exponential decay constant. Further study on the reactivity-buckling constant, K is needed to correctly determine the experimental neutron effective multiplication factor for PWR spent fuel.

ACKNOWLEDGEMENT

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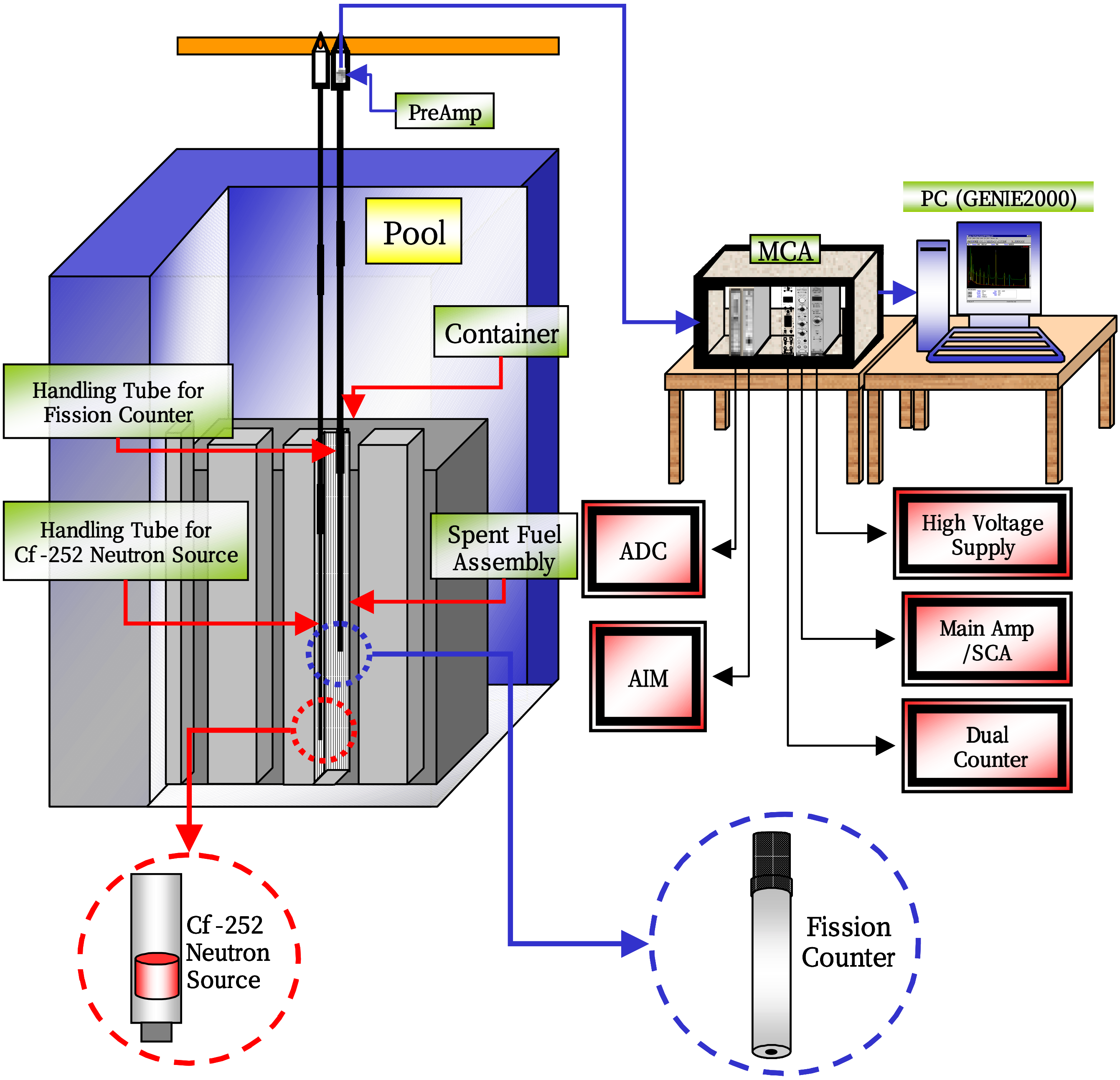

Fig. 1. Exponential Experiment-System Installed in the PIEF Pool.

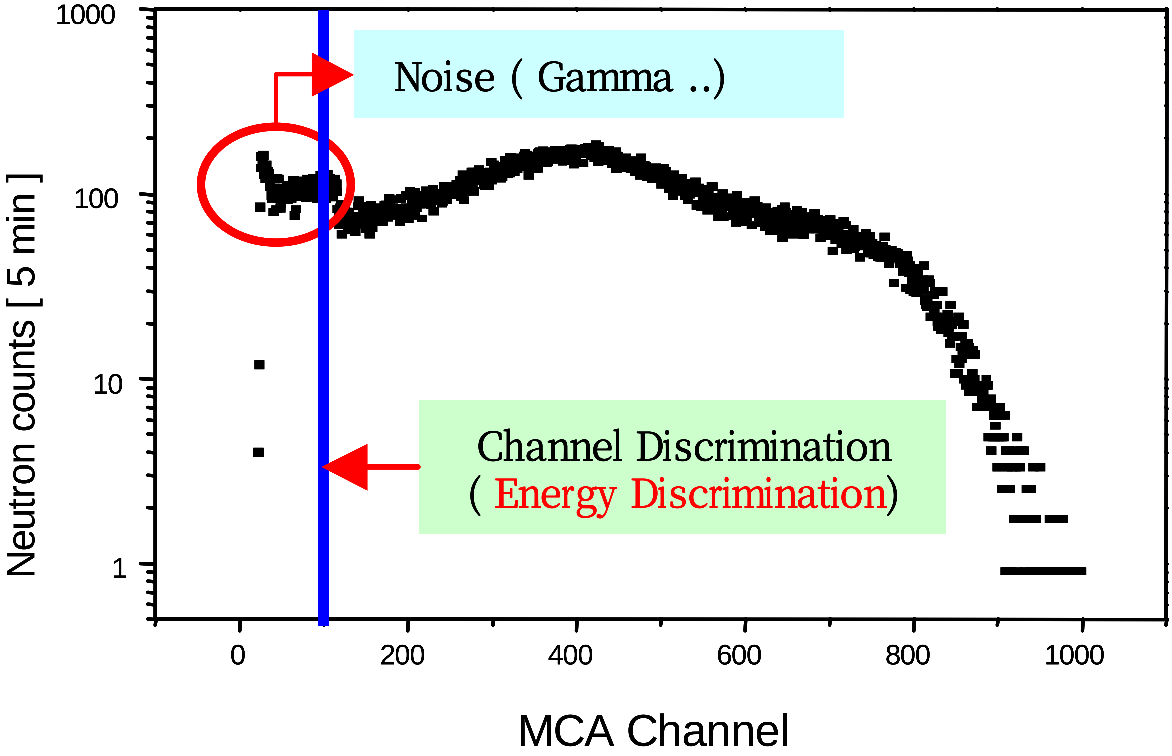

Fig. 2. Neutron from Spontaneous Fisson of Cf-252 Neutron Source

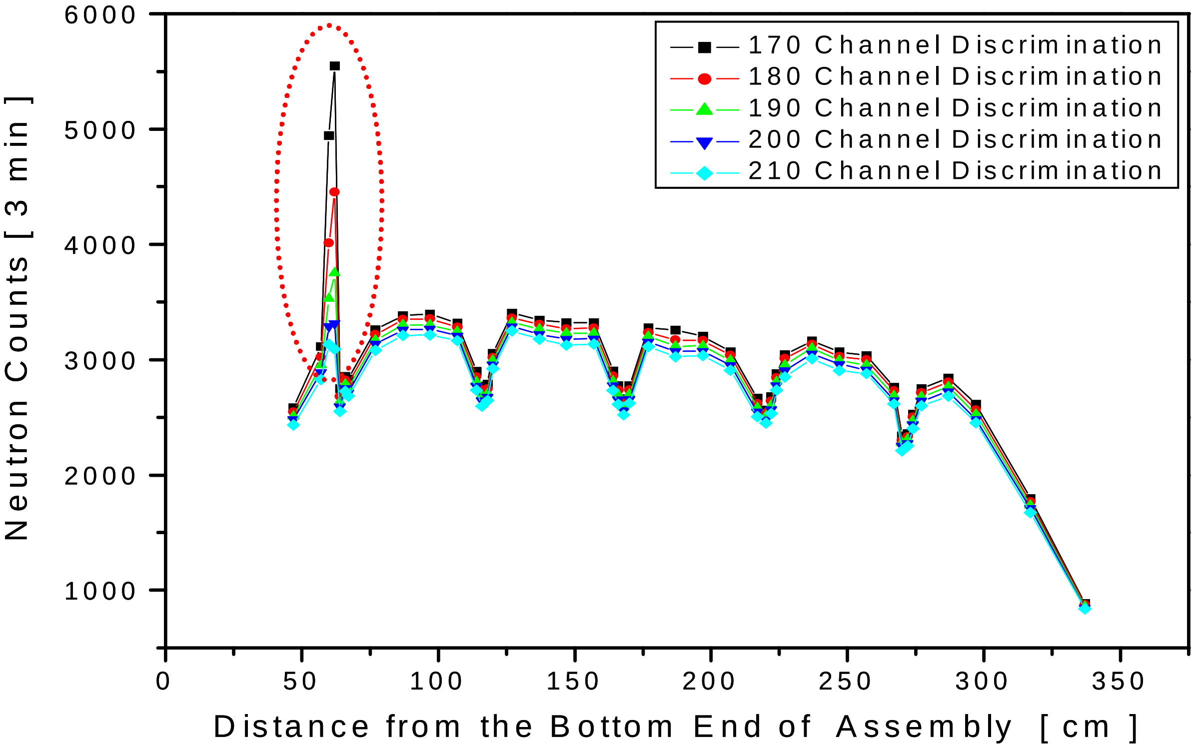

Fig. 3. MCA Channel Discrimination Effects on the Background Neutron Measurements for C15 Assembly.

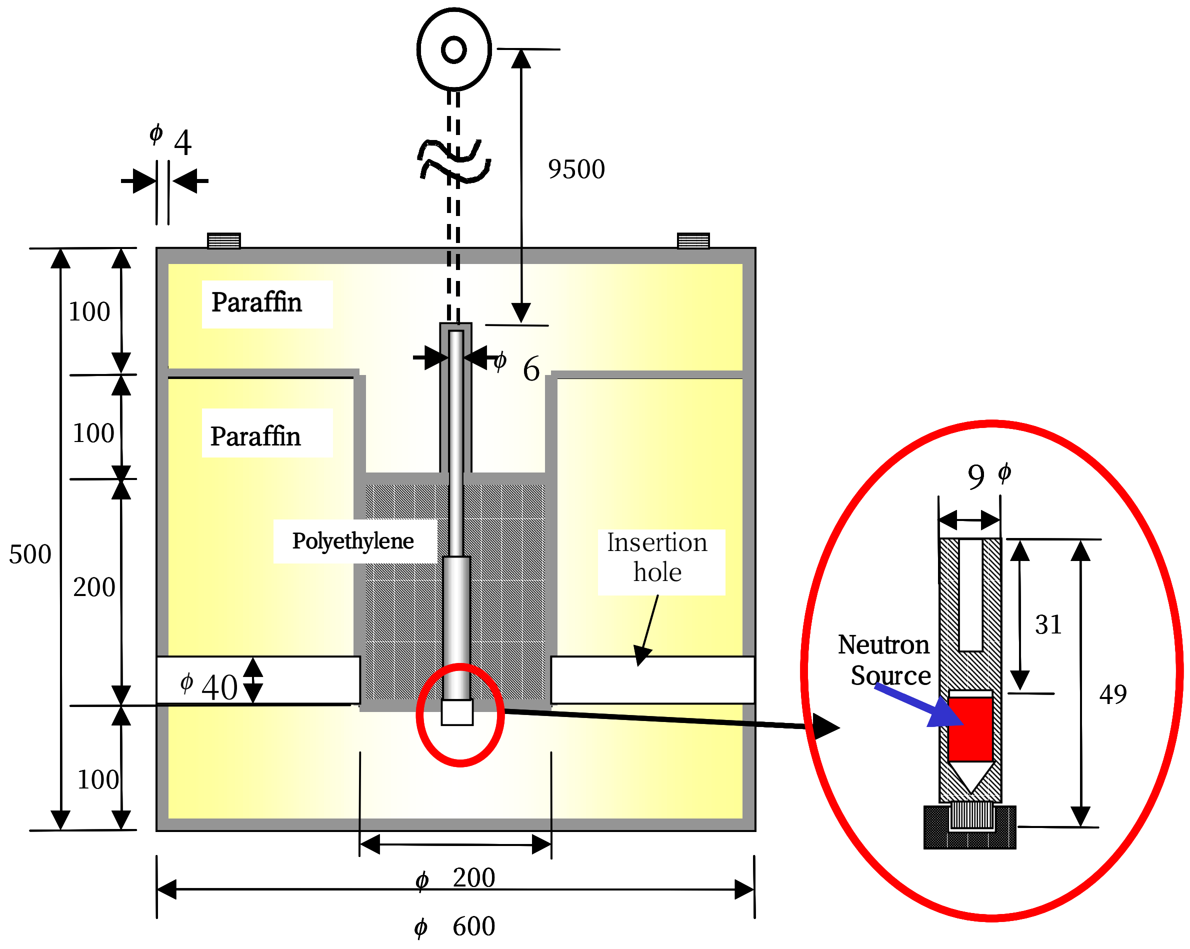

Fig. 4. Design Specifications of Neutron Source.

Table 1. Specifications and Declared Burnup for the PWR Spent Fuel Assemblies

	Assembly ID			
	This Study			Japan
	C15	J14	J44	P14
Fuel Type	14 × 14	14 × 14	16 × 16	14 × 14
Initial Enrichment (wt%)	3.199	3.1968	3.4859	4.3
Burnup	32,000	37,845	35,018	40,200
Discharge Date	1982. 4. 17	1989.1.20	1992.5.29	Cooling time 13.5 year
Active Fuel Length (mm)	3658	3658	3658	-
Control Rod Guide Tube (ID/OD)	12.8/13.7	12.8/13.7	11.05/11.96	-
Space Grid Number and Material	7 Inc/Zry-4	7 Inc/Zry-4vv	8 Inc	7 Inc/Zry-4

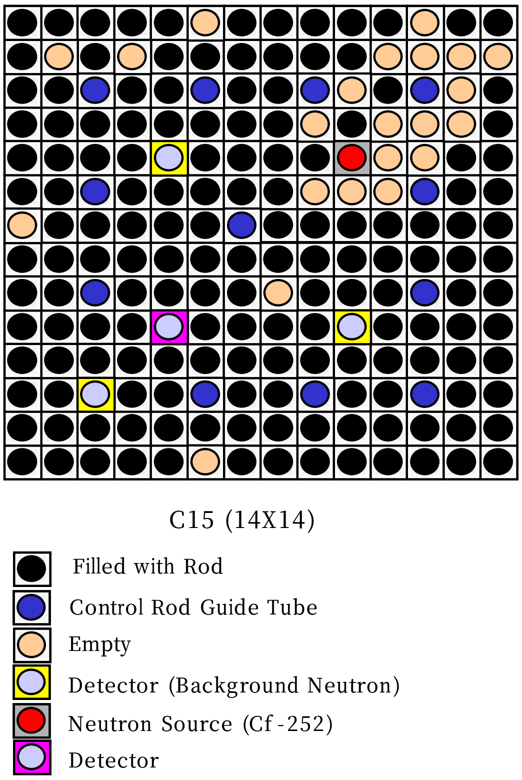

Fig. 5. Cross Sectional View of C15 Assembly.

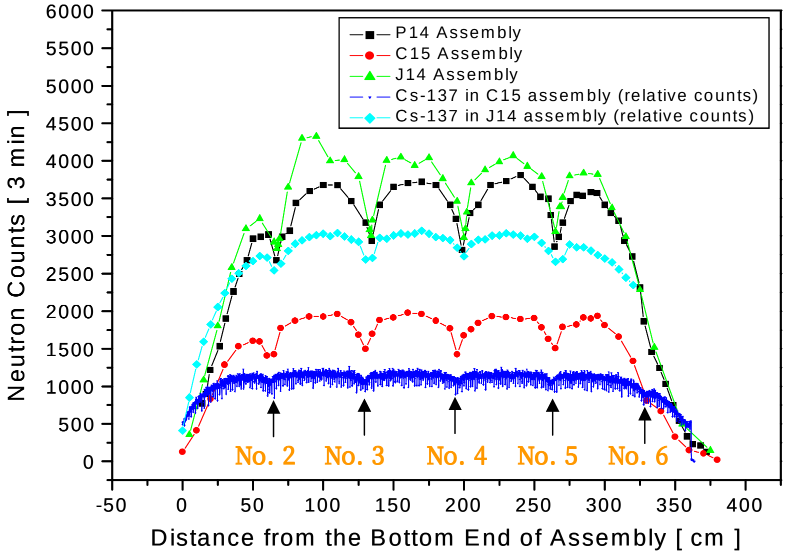

Fig. 6. Comparison of Axial Background Neutron Intensities for 14 x 14 Assemblies.

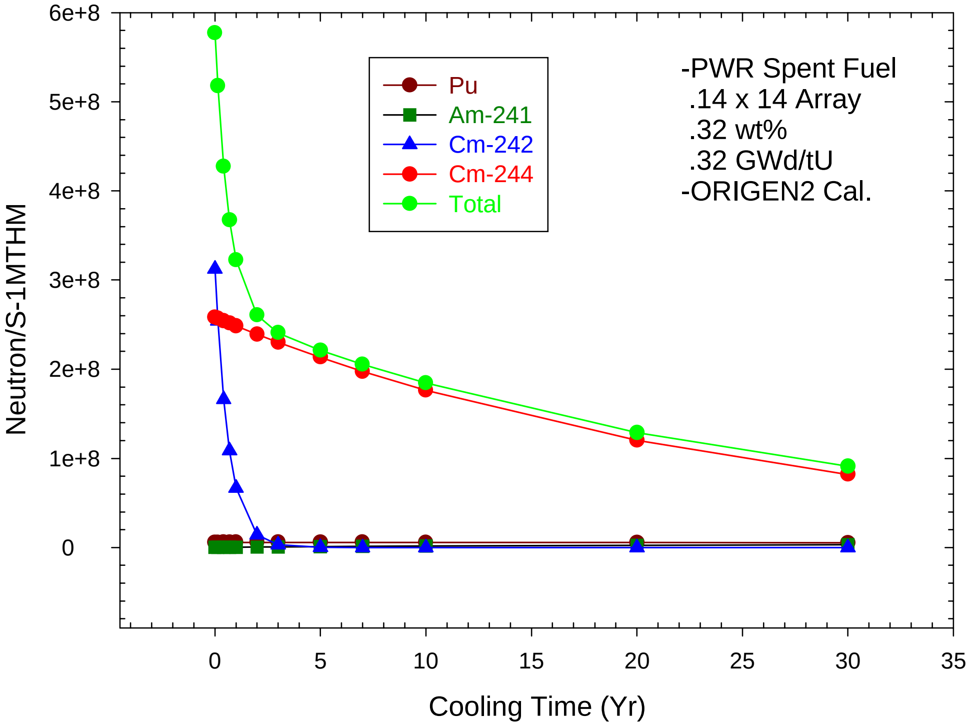

Fig. 7. Comparison of Axial Background Neutron Flux Distribution in C15 and J14 with P14

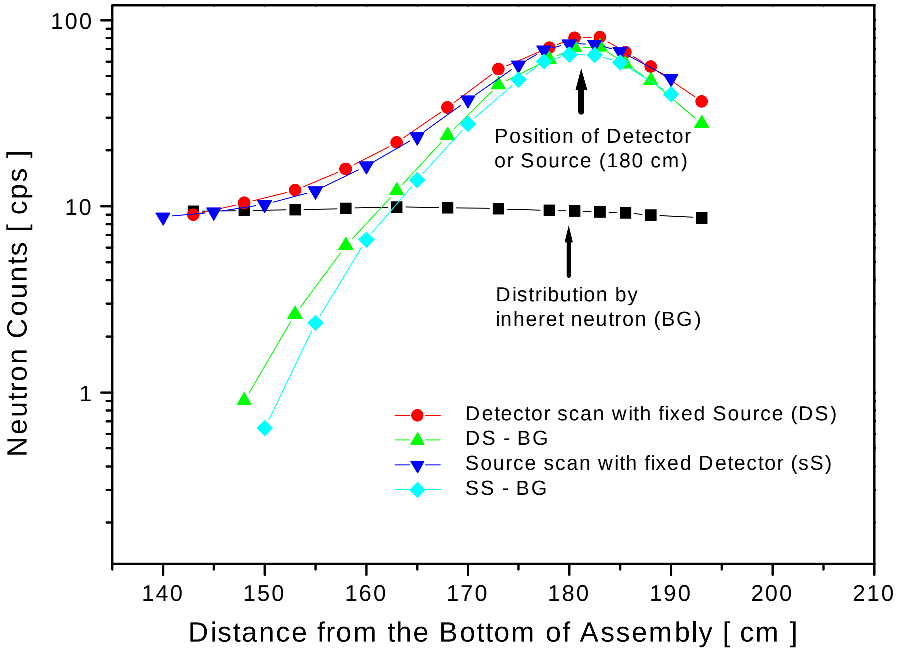

Fig. 8. Exponential Experiment Results for C15 assembly.

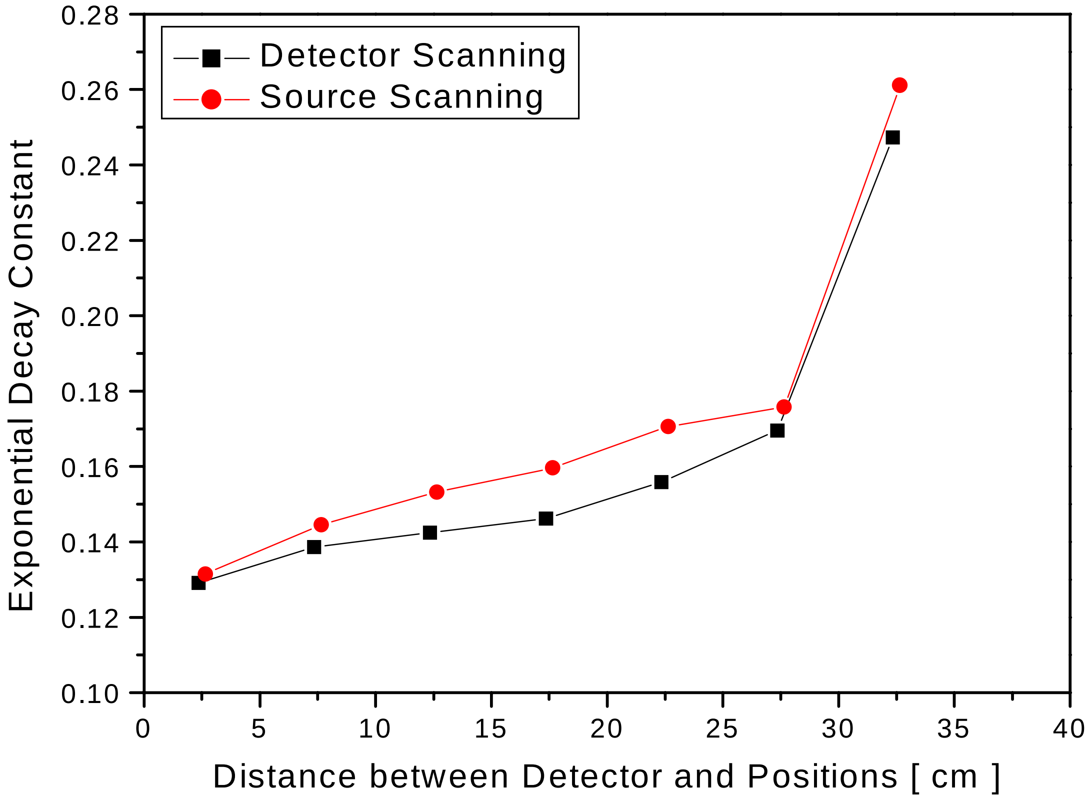

Fig. 9. Exponential Decay Constants Obtained from Axial Neutron Counts for Detector and Source Scanning around 180 cm height of C15 assembly.