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Study of accelerator transient on ADS operation using TRACY (Transient experiment critical facility)

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The experiments simulated the dynamic behavior of ADS were performed by using TRACY (the transient experiment critical facility) and Pulsatoron (the pulse neutron generator). The experiments for three ADS operation patterns with two subcritical cores were conducted and the time responses of the three neutron detectors were measured. The results by those experiments clearly show the dynamic behavior of ADS for neutrons and/or reactivity insertion. Although the experiments were analyzed by a one-point kinetics code, one-point kinetics calculation was not sufficient to reproduce the measured time responses of the detectors. The experiments were also analyzed by a modified method combined with a one-point kinetics code and a continues energy Monte-Carlo code. The result by the modified method agreed well with the measured responses of all the three detectors. The present experimental and analysis works lead to supply the benchmark data for studying the dynamic behavior of ADS and to provide an advanced dynamic code combined with the one-point kinetics code and the continuous Monte-Carlo code.

KEYWORDS: accelerator driven system, ADS, subcritical core, dynamics, TRACY, experiment, beam trip, shut down, Monte-Carlo code

1. Introduction

Accelerator-driven system (ADS), which is the hybrid system of an accelerator and a subcritical core, has been studied for transmuting minor actinides (MA) and long-lived fission products (LLFP) in high-level waste from nuclear power plants [1][2][3]. ADS have very large flexibility to core design such as fuel composition, core arrangement and operating procedure. ADS also have inherent safety since ADS is operated under subcritical condition and a reactor can be stopped immediately by shutting a proton beam off.

For ADS, the reliability of accelerator operation is a critical problem. Since the subcritical core of ADS is driven by an accelerator, the instability of accelerator directly influences on the dynamic behavior of ADS. If troubles of the accelerator such as beam trip or sudden beam induction occur, core power will be largely varied and it may result in core damage. It has to know the dynamic behavior of a subcritical core for those variations or troubles of an accelerator. On the other hand, reactivity insertion by various factors still has large effect to the dynamic behavior of ADS although the core of ADS is subcritical. The experimental study for reactivity variation should be taken up

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in the study of the dynamics behavior of ADS.

Recently, for ADS or a subcritical core, some studies have been performed by an analytical work. However, there are few reports by an experiment work. Especially, there is no experimental study directly concerning the dynamic behavior of ADS. The experimental data are indispensable for investigating the ADS dynamics. This situation inspires us to perform an experimental study by using a small research reactor and a pulse neutron generator. The present paper describes about the experiments which simulate the typical dynamic behaviors of ADS. The experiment was conducted using TRACY (Transient experiment critical facility) in JAERI (Japan Atomic Energy Research Institute). The measured data by the experiment are analyzed to provide benchmark data for studying the dynamics of ADS.

In Japan, a research project (J-PARC) for constructing an ADS experimental facility with a critical assembly jointed to a proton linear accelerator is in progress by JAERI and KEK (High Energy Accelerator Research Organization). The present study aims for supplying the experimental data to the ADS experimental facility of J-PARC.

2. Experiment

2.1 Subcritical core

The experimental core employed here is TRACY, which is originally utilized for simulating criticality accidents in a fuel processing facility with a transient rod, which can realize rapid positive reactivity insertion. TRACY is a tank type reactor fueled with low-enriched uranyl nitrate aqueous solution. Figure 1 shows the vertical view of TRACY and Table 1 shows the specification of TRACY. The diameter and the height of the core tank is about 50 cm and 210 cm, respectively. The transient rod for step reactivity insertion by pulse withdrawal is located inside the guide tube at the center of the core tank. The maximum reactivity inserted by the transient rod is 3$. Ramp reactivity insertion is also available in TRACY by feeding fuel solution to a cylindrical core tank.

Fig.1 Vertical view of TRACY

Table 1: Major specification of TRACY

Core	500mmΦ cylindrical tank
Fuel	Uranyl nitrate aqueous solution (9.98wt% U235 enriched) Maximum uranium concentration: 500 gU/liter
Maximum excess reactivity	Static operation mode: 0.8 $ Transient operation mode: 3 $
Maximum power	Static operation mode: 10 kW Transient operation mode: 5 GW
Maximum energy	32 MJ/Experiment

2.2 Neutron generator

TRACY is equipped with a pulse neutron generator (Pulsatoron), which produces 14MeV neutrons by D-T reaction. Using this Pulsatoron, we have performed the experiments that simulate various beam variations. It should be noted that this Pulsatoron has the following limitations; (1) the maximum duration of neutron generation is only 90 seconds and (2) the maximum repetition rate of neutron generation is 100 pulses per second. These limitations affect to the experiments as shown below.

2.3 Detector

Three He-3 proportional counters and one compensated ionization chamber (C.I.C.) were located outside the core tank and measured the time variations of neutron flux. The locations of the detectors are shown in Fig.2. In the present experiments, all detectors were folded by a polyethylene sheet with the thickness of 1 cm. Signals from the detectors are recorded with a 16000 channel MCS (Multi Channel Scalar) with the time mesh of 10 msec. The data plotted in graph are obtained after 0.5 sec time bunching.

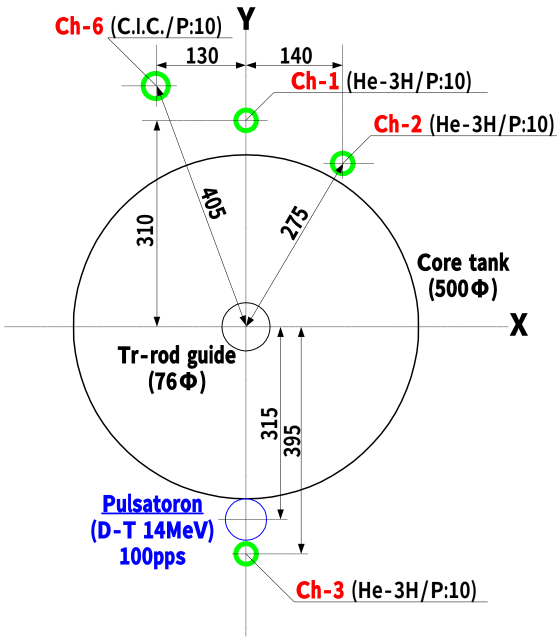

Fig.2 Experimental arrangement using TRACY and Pulsatoron

2.4 Experiment overview

In this experiment, we have employed two cores with the different subcriticality of –3.1$ and –1.4$. For those subcritical levels, the steady core state was made by inducing neutrons by Pulsatoron. For those subcritical steady states, by using Pulsatoron and the transient rod, we have simulated the following ADS operation variations;

Case (1): Start and Stop the beam inducted to a subcritical core
Case (2): Insert and withdraw reactivity to a subcritical core
Case (3): Shutdown the beam induced to a subcritical core
after reactivity insertion

The patterns of those simulations were explained in Fig.3 with the operation of the transient rod and the Pulsatoron.

Case (1) and Case (2) are valuable for understand the dynamic behavior of a subcritical core for beam and reactivity variation. Case (3) simulates shutdown operation of ADS after reactivity insertion transient.

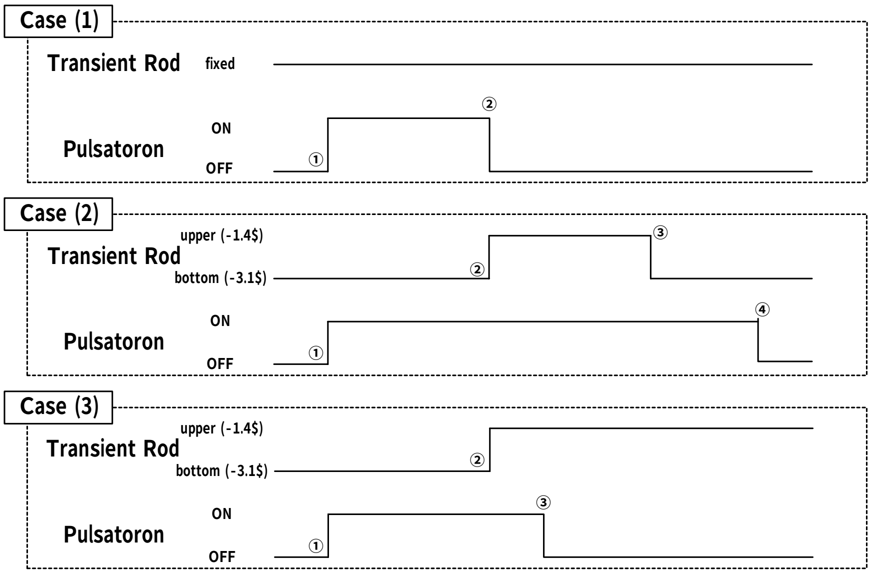

Fig.3 Experimental patterns simulating ADS operation

3. Experimental results

This section describes the results of the three experimental cases for the core with the subcritical level of 3.1$. Fig. 4 (a), (b) and (c) show the time variations for Case (1)-(3) measured by the three He-3 proportional counters.

3.1 Case (1)

Case (1) is the case that neutron generation started at about 20 sec (①) and stopped at about 65 sec (②). From the figure, it is confirmed that a subcritical core is derived directly by the operation of the outer neutron source. The comparison with analytical results is described at the next section.

In the experiment, the step rising of the detector count was expected after turning on Pulsatoron at the point (①). However, as shown in the figure, the slow rising of the neutron counts on time is shown at the point (①). Similar behavior is observed for the all cases for other cases. This slow and irregular behavior is due to the temperature of the neutron tube of Pulsatoron.

3.2 Case (2)

In Case (2), first, a steady state of a subcritical core was prepared by turning Pulsatoron on at about 10 sec (①). To the core, the reactivity of about 1.7$ was inserted by withdrawing the transient rod at about 25 sec (②). The reactivity was withdrawn by dropping the transient rod at about 75 sec (③) and Pulsatoron was stopped at about 100 sec (④). This case gives the knowledge about the behavior of a subcritical core when reactivity was inserted and withdrawn. In Fig.4 (b), step rising and falling with reactivity insertion and withdrawal are observed at (③) and (④). The comparison with analytical results is also described at the next section.

3.3 Case (3)

In Case (3), a steady state of a subcritical core was also made by turning on Pulsatoron at about 10 sec (①). To the core, the reactivity of about 1.7$ was also inserted by withdrawing the transient rod at about 75 sec (②). After that, the subcritical core was shut down by turning the Pulsatoron off at about 100 sec (③). The result for this case is observed in the Fig.4 (c). It is confirmed that turning the accelerator off stops a subcritical core of ADS immediately in theory.

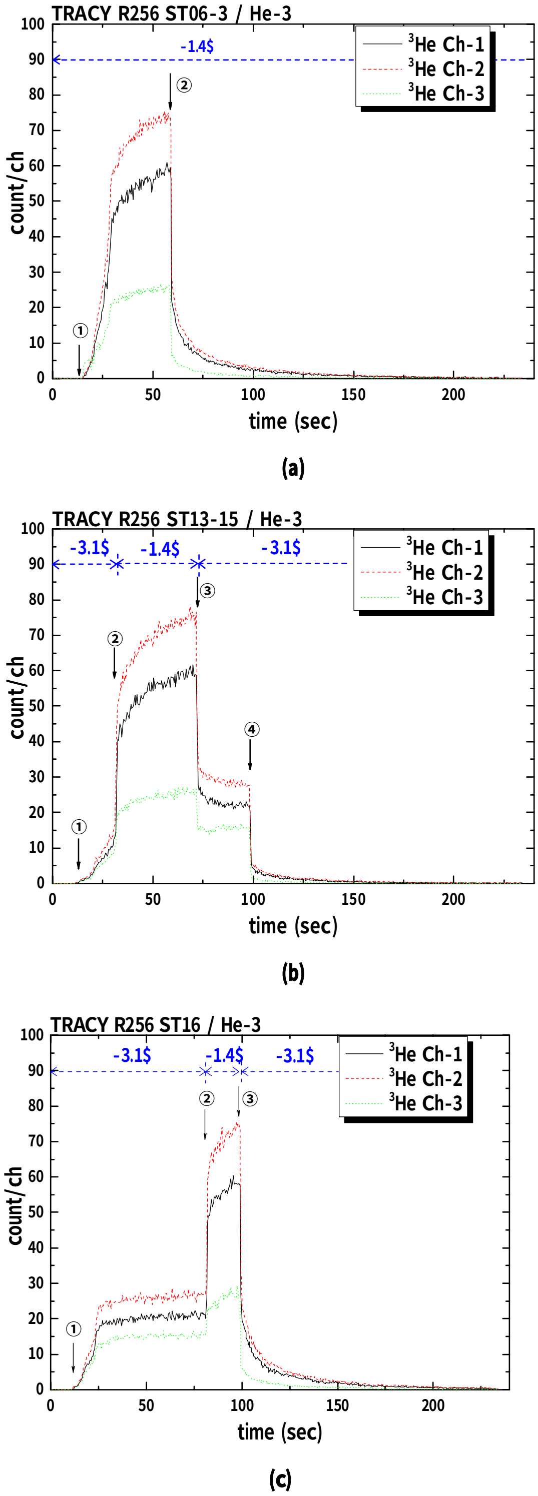

Fig.4 Time spectrum measure by He-3 detectors for Case (1)-(3)

4. Analysis

For those experiments, analyses were made by the one-point kinetics method, or examined other existing methods by the quasi-static method using transport or diffusion theory and a modified method by using the Monte-Carlo method together with the one-point kinetics method.

4.1 One-point kinetics method and other examined method

First, analysis by the one-point kinetics model was performed. As a typical result, Fig.5 shows the results of Case (2) mentioned above. The results were normalized at the time of about 100 sec (see figure). As shown in Fig.5, the calculation result did not agreed with the experimental results for the three detectors although one-point method is adequate for the total core power. This disagreement is inevitable because the difference in the location of three detectors could be taken into account by the one-point kinetics method. Other method should be examined for analyzing the present experiments. The calculation method accompanied with the flux distribution calculation is required to treat the difference of the detector locations and to analyze the precise response of the detectors. However, for analyzing the present experiments, the diffusion calculation is not appropriate since the detectors

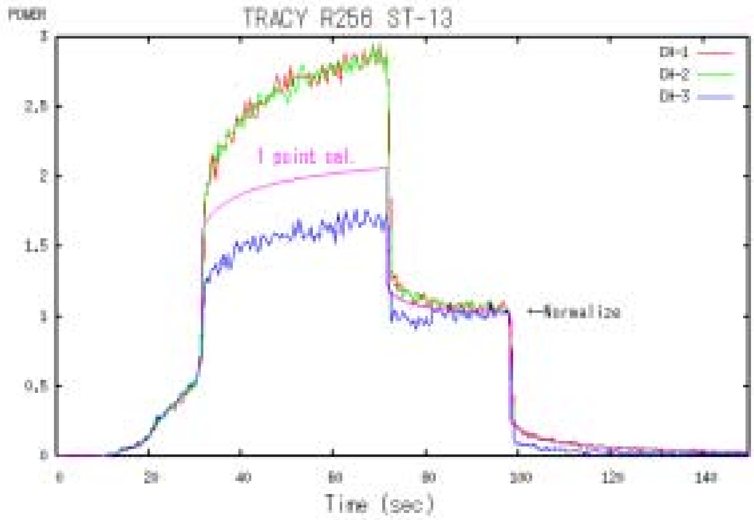

Fig.5 Analysis result for Case (2) by one-point kinetics method

were located in the air outside the outer boundary of core. The transport calculation is required. Furthermore, to consider the geometries and the structures of the detectors and the Pulsatoron precisely, the two-dimensional code is not adequate. The three-dimensional code is needed. Then, the code must have the capacity of calculating the fine energy spectrum to calculate the detector response in detail.

To analyze the present experiment, a three-dimensional transport dynamics code with fine energy structure is expected, however, no such code exists. Therefore, we examined the following modified calculation method using a continuous energy Monte-Carlo code.

4.2 Modified method using Monte Carlo code

MVP is a continuous energy Monte-Carlo code. Using the MVP [2], the modified method combined with the Monte-Carlo code and the one-point kinetics code can be realized. The modified method will calculate the precise resonance of a detector located everywhere and obtain the fine energy spectrum considering the precise geometry and the exact structure. The modified method is the code expected for analyzing the present experiment. In this study, to confirm the effectiveness, the analysis using this modified method is examined for the present experiment.

Figure 6 shows the experimental geometry simulated in the modified method calculation. The 14MeV neutrons were generated at the position of Pulsatoron. Fixed source calculation was carried out by MVP with the cross-section library of JENDL-3.3.

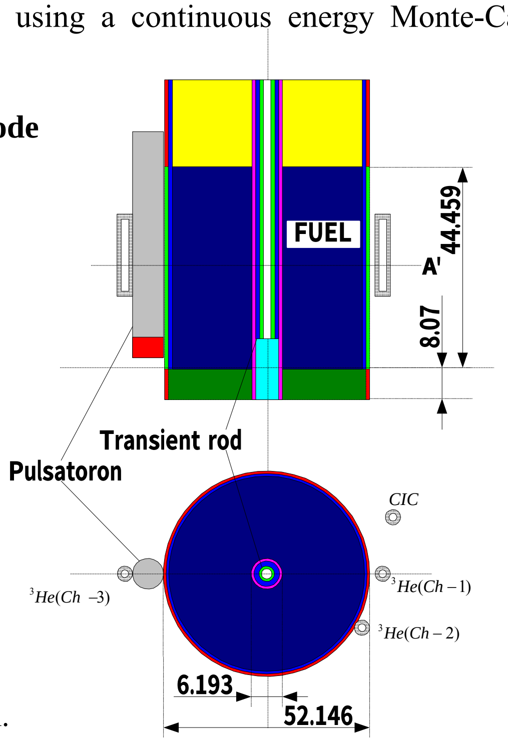

Fig.6 MVP calculation geometry

The calculated energy spectra for the three detectors are shown in Fig.7. This figure shows that the energy spectrum of CH-3 placed close to Pulsatoron is different from those of CH-1 and CH-2, which are located at the opposite side to CH-3. The spectrum of CH-3 has a large high-energy peak near 14 MeV. The difference of the energy spectra of the three detectors results in the difference of the time responses of the detectors. The correcting factors made by this result apply to one-point kinetics theory.

Figure 8 shows the analysis result for Case (2) by the modified method. It is confirmed that the result agreed well with the time responses of the three detectors. The modified method combined with the one-point kinetics theory and the continuous Monte-Carlo code can reproduce the precise detector response with different locations in a subcritical core.

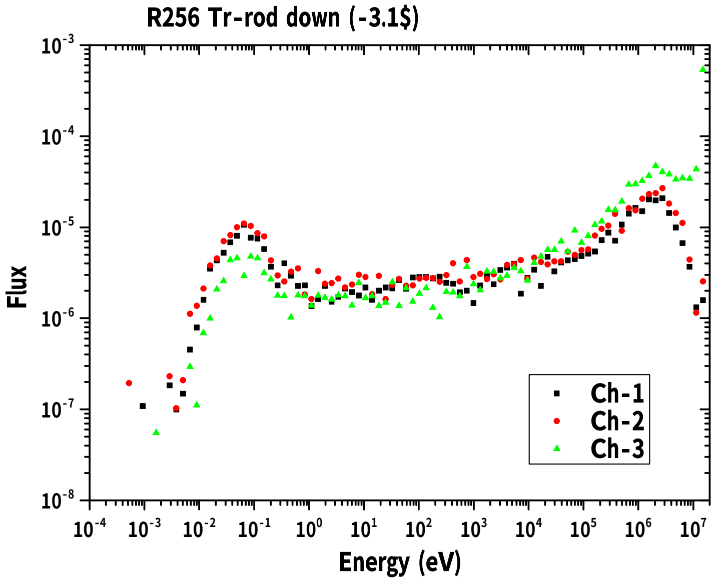

Fig.7 Calculated energy spectrum at He-3 detectors by the modified method using MVP

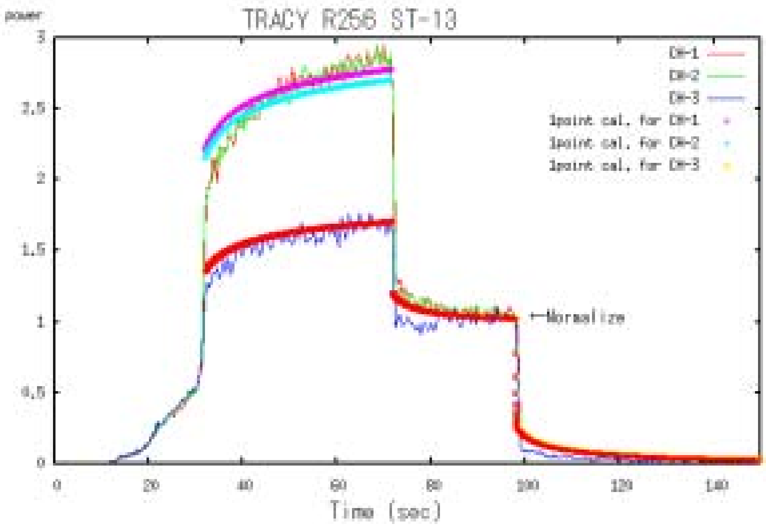

Fig.8 Calculated time response of He-3 detectors by the modified method using MVP

The calculation of the modified method in this study is not automatically combined with the two codes yet. Since this study shows the effectiveness of the modified method combined with the two codes, it is important to pursue this modified method and develop a new code to realize the effective method for studying the dynamic behaviors.

5. Conclusion

The experiments simulated the dynamic behavior of ADS were performed by using TRACY (the transient experiment critical facility) and Pulsatoron (the pulse neutron generator). The experiments for three operation patterns with two subcritical cores were conducted and the time responses of the three neutron detectors were measured. The results by those experiments clearly show the dynamic behavior of ADS for neutrons and/or reactivity insertion.

The experiments were analyzed by a one-point kinetics code, however, one-point kinetics calculation was not sufficient to reproduce the measured time responses of the detectors. The experiments were also analyzed by a modified method combined with a one-point kinetics code and a continues energy Monte-Carlo code. The result by the modified method agreed well with the measured responses of all the three detectors. The method combined with the one-point kinetics code and the continuous Monte-Carlo code can reproduce the precise detector response with different locations in a subcritical core.

The present experimental and analysis works was useful for supplying the benchmark data to study the dynamic behavior of ADS. In near future, the benchmark data will be supplied after adding new experiments for subcritical cores with different subcritical levels and by improving the neutron generator. The method combined with the one-point kinetics code and the continuous Monte-Carlo code should be pursued to develop a new code it is important to pursue this modified method and develop a new code to realize the effective method for studying the dynamic behaviors of ADS.

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