PRESENT STATUS OF NEUTRON FACTORY PROJECT AT KURRI

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Abstract

A final goal of the Neutron Factory Project in Kyoto University Research Reactor Institute (KURRI) is to establish a new neutron source of accelerator driven subcritical reactor (ADSR) as a substitute for the current research reactor KUR. A ring cyclotron system has become a main candidate for the accelerator system. A neutronics design study has intensively been carried out to examine the nuclear features of a research reactor type ADSR. Moreover, an experimental study on the ADSR was initiated in 2000 by using the Kyoto University Critical Assembly (KUCA), where a subcritical assembly can be driven by 14 MeV neutrons. It was found that the nuclear features of ADSR are dominated by the neutron multiplication process in the subcritical core.

1 INTRODUCTION

In KURRI, a final goal of the Neutron Factory Project proposed as a future plan in 1996 [1] is to establish a new neutron source of ADSR for the joint use program among Japanese universities as a substitute for the KUR.

Presently, a ring cyclotron system has become a main candidate in place of a linear accelerator system adopted in the original plan of the project by taking into account the construction cost and the space in the KURRI site. The project can be divided into two phases. In the first phase, a 70 MeV ring cyclotron is introduced for the basic experimental study on the ADSR in combination with the KUCA. Based on the results of the first phase, the second phase will be the introduction of a 500 MeV ring cyclotron for the construction of the ADSR as a new neutron source for the joint use program.

A conceptual design study has been carried out [2-5] to examine the nuclear features of a research reactor type ADSR by introducing the MCNPX code [6] in 1999.

A basic experimental study on the ADSR was also initiated formally in 2000 by using the KUCA [5,7], where a subcritical nuclear fuel assembly can be driven by 14 MeV neutrons.

2 PRESENT STATUS OF NEUTRON FACTORY PROJECT

At the end of the last year 2000, a scientific advisory committee of the Ministry of Education, Science, Sports and Culture (Monbusho) in Japan completed a report entitled “what the research reactor of university should be”. This report mainly dealt with the KUR, since the KUR is the largest research reactor of university in Japan.

The report concluded that, as a result of evaluation on scientific activities in KURRI including management, the further development in research is anticipated on the basis of fruits from the current activities. This report also concluded as follows for the future scope of KURRI: (1) Since the KUR is a valuable facility for research and the further development in research can be expected, it is appropriate to continue the operation of KUR. Then, it is necessary to reduce intentionally the uranium enrichment of fuel from 93% to 20%. (2) Concerning the basic study on a new neutron source in KURRI, it is desirable to develop the present research further by introducing a higher energy accelerator for the KUCA. It means that the first phase of the Neutron Factory Project was formally approved to be adequate. However, the second phase is still open, since the High Intensity Proton Accelerator Project proposed jointly by the Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) has already been initiated in Japan. (3) Since a considerable preparation time is generally needed for the complete shut down and the discontinuation procedure of nuclear reactor, this kind of activity for the KUR should be necessary in consideration of the status in research from a medium- and long-term point of view.

In response to the report, KURRI settled the following policies: (1) The operation of KUR will be continued for a while; the highly enriched uranium (HEU) fuel will be used until March 2006, and the low enriched uranium (LEU) fuel after April 2006. (2) The preparation will be initiated from now for the coming discontinuation of the KUR in the future. (3) Through the full equipment of the KUCA and the introduction of the 70 MeV ring cyclotron shown in Table 1, KURRI will intentionally promote the research including new topics. Namely, the basic experimental study on the ADSR will be promoted to a further stage by using neutrons with higher energy than 14 MeV, and the new research will be initiated in the fields of medical treatment, material science including the irradiation effects of materials and so on. For reference, a draft for the arrangement of the 70 MeV ring cyclotron in a new building is shown in Fig. 1.

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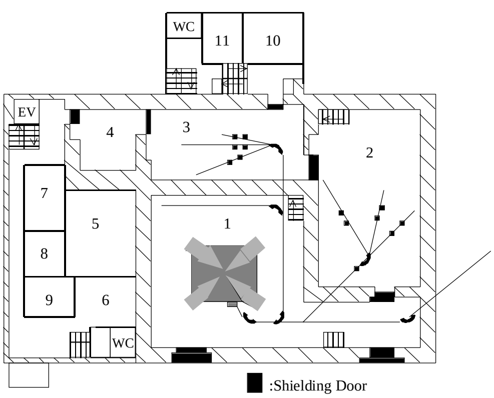
Table 1: Specification of 70 MeV Ring Cyclotron

Ion Source	
Type	Multicusp Ion Source
Maximum Current	10 mA
Extraction Energy	50 keV
RFQ	
Injection Energy	50 keV
Output Energy	400 keV
Operation Mode	CW
Average Beam Current	5 mA
Frequency	50 MHz
RF Power	100 kW
Total Length	2 m
Ring Cyclotron	
K Value	70
Injection Radius	0.31 m
Extraction Radius	3.42 m
Injection Energy	400 keV
Output Energy	70 MeV
Maximum Beam Current	2 mA
Number of Sectors	4
Magnet Weight	720 ton
Frequency	50 MHz
RF Power	200 kW



1: Ring Cyclotron Room
2: Materials Irradiation Room
3: RI Production Room
4: Medical and Biological Irradiation Room
5: Surgical Operation Room
6: Waiting Room
7: Preparation Room
8: Administration Room
9: Medical Doctor Room
10: Analyzing Room
11: Preparation Room

Figure 1: Horizontal arrangement of the 70 MeV ring cyclotron in the accelerator building.

Then, KURRI provided a draft of budget for the fiscal year 2002 including the full equipment of the KUCA and the introduction of the 70 MeV ring cyclotron. Now, this draft has been submitted to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan[2] through the administration of Kyoto University. At the same time, KURRI began the negotiation with the local public; Kumatori-cho where KURRI is located, Izumisano-shi and Kaizuka-shi which are neighbouring cities, and Osaka-fu to where the above town and cities belong. This negotiation is inevitable before submitting budget from the MEXT to the Ministry of Finance in a framework of the agreement with the local public; this process has successfully been completed in August 2001.

3 CONCEPTUAL NEUTRONICS DESIGN STUDY OF THE ADSR

By introducing the MCNPX code from LANL, a conceptual design study on the ADSR has been carried out through the neutronics calculation. Here, it was assumed that the proton beam were incident upon a bulk target settled at the centre of the KUR core [2].

The examination on the nuclear features of the research reactor type ADSR was executed by varying the design parameters. As a result, the following conclusions were obtained: (1) There is no big difference in the main shape of neutron spectrum obtained by either the eigenvalue or the fixed source calculation because of the neutron multiplication process caused by the fission chain reaction in the subcritical core, although the eigenvalue calculation can not take into account the spallation neutrons. (2) The neutron flux level in the core becomes larger with increasing k_{eff} and incident proton energy, although there is no remarkable change in the shape of neutron spectrum in the core. (3) The thermal power and the neutron flux level in the ADSR become higher than those in the KUR when the incident proton energy is selected to be 500 MeV. (4) The target material has a certain impact on both the thermal power and the neutron flux level because of the difference in the ability of either the neutron yield or the absorption of target. (5) The power distribution in the core does not strongly depend on either the subcriticality or the proton energy, and both the eigenvalue and the fixed source calculations give a similar power distribution.

The time-dependent behaviour of neutrons after the proton pulse injection was also examined to obtain an image of the reactor dynamics [5], although the effect of delayed neutrons can not be taken into account in the MCNPX calculation. The time-dependent behaviour after the pulse injection of 14 MeV neutrons was also examined in consideration of the experiments at the KUCA. As a result, the following conclusions were obtained: (1) Neutrons with energy of more than 20 MeV decay out rapidly in the period of less than 0.02 μs after the pulse injection. (2) Neutrons with energy of 1 eV - 20 MeV are dominant and decay rather rapidly in the period of less than several μs. (3) Neutrons with energy of less than 1 eV increase rather rapidly in the same period as mentioned above. (4) Neutrons with energy of either 1 eV - 20 MeV or less than 1 eV show the similar behav-Iour of decay after around 10 μs, which indicates that the neutron spectrum in the core reaches the asymptotic spectrum. (5) These phenomena indicate that the diffusion process of source neutrons is terminated in around

[2] In accordance with a reorganization of ministries and agencies in Japan, Monbusho was combined with the Science and Technology Agency (STA) to become the Ministry of Education, Culture, Sports, Science and Technology (MEXT) at January, 2001.

10 μs, and the neutron multiplication process by the fission chain reaction becomes dominant after that time in the ADSR. (6) The shape of neutron spectrum becomes approximately identical to that of the subcritical core after around 10 μs. (7) No essential difference between the 500 MeV proton and the 14 MeV neutron injection is observed in the time-dependent behaviour of neutrons.

4 BASIC EXPERIMENTS ON THE ADSR IN THE KUCA

A series of basic experiments on the ADSR was formally initiated in 2000 by using the combination of a solid moderator core and a Cockcroft-Walton type accelerator in the KUCA [5,7]. A tritium target settled outside a polyethylene moderated/reflected core loaded with the HEU fuel was bombarded by deuteron beam of around 200 keV to generate 14 MeV pulse neutrons.

Two types of optical fiber detectors developed originally by C. Mori *et al*. [8] were used in the KUCA experiments; the ThO_2 detector was employed to monitor 14 MeV neutrons, and the ^{6}Li enriched LiF detector to measure the neutron flux level in the core. The subcriticality was systematically varied to examine the dependence of the neutron multiplication and the neutron decay on k_{eff}. To measure the neutron flux level, the LiF detector was axially traversed with a constant speed to facilitate the conversion from the time-dependent neutron counts to the reaction rate distribution. For the neutron decay measurement, the arc pulse of the accelerator was used as a trigger signal. The analysis of the KUCA experiment was executed by using a continuous Monte Carlo code MVP [9] based on the JENDL-3.2 library [10] with reducing ^{235}U number density of fuel by about 5%, since a certain bias had been observed in the criticality analysis of the HEU fuelled core [11].

It was found that the neutron multiplication is approximately expressed as a function of $1/(1-k_{eff})$ for the present KUCA experiment. Although a large difference between the measured and calculated behaviours in the neutron decay was observed, this discrepancy can be explained in consideration that the MVP calculation can not take into account the effect of delayed neutrons:

5 CONCLUSIONS

The following conclusions can be derived:

(1) The nuclear features of the ADSR are practically determined by those of a subcritical core because of the neutron multiplication process caused by the fission chain reaction.

(2) The accuracy both for the measured and calculated subcriticality has an essential importance for the design study on the ADSR. The requirement for the precision of neutronics calculation would become more severe than that for the conventional nuclear reactor, since the neutron multiplication does not depend on k_{eff} but roughly on $1/(1-k_{eff})$.

6 ACKNOWLEDGEMENT

The KUCA experiments were performed as a joint study among Prof. Toshikazu Takeda's group of Osaka Univ., Prof. Yoshihiro Yamane's group of Nagoya Univ. and KURRI. The present study is partially supported by the Grant-in-Aid for Scientific Research (A) from the MEXT and the JAERI's Nuclear Research Promotion Program (JANP).

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