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Accelerator-based Neutron Source and Its Application
加速器による中性子源と応用

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Neutron beam is used for a wide variety of scientific and engineering research, such as materials and life science, and industrial applications. There are three kinds of neutron sources: (1) isotopic neutron source, (2) reactor sources, and (3) accelerator-based neutron sources. Recently, high intensity spallation neutron sources with high energy proton accelerator became to offer similar capabilities to research reactors, as well as a few extra features. In Japan, the JSNS (Japan Spallation Neutron Source) was constructed and operated at J-PARC (Japan Proton Accelerator Research Complex). Moreover, as future utilization of spallation neutron, research and development for accelerator-driven subcritical system have been performed.

1. Introduction

The utilization of neutrons started several years after the discovery of neutron by Chadwick. At present, neutron beam is used for a wide variety of scientific and engineering research, such as materials and life science, and industrial applications. It has been one of the key elements of modern science and technology.

There are three kinds of neutron sources: (1) isotopic neutron source, (2) reactor sources, and (3) accelerator-based neutron sources. Isotopic source using alpha particles emitters and beryllium, and spontaneous fission have fundamental limitations in terms of the maximum intensity. So, reactor sources and accelerator-based source are widely used for science and industrial purposes. Although research reactors have been utilized as intense neutron source for a long time, high intensity spallation neutron sources with high energy proton accelerator recently became to offer similar capabilities to research reactors, as well as a few extra features. In Japan, the JSNS (Japan Spallation Neutron Source) was constructed and operated at J-PARC (Japan Proton Accelerator Research Complex).

In this paper, general description of the JSNS and acceleratod-driven subcritical system (ADS) as future application of spallation neutron source are presented.

2. Spallation Neutron Source and its Application

2.1 *JSNS in J-PARC*

The J-PARC is the multi-purpose research complex, which consists of three accelerators: 181 MeV LINAC, 3 GeV RCS and 50 GeV synchrotoron, and four major experimental facilities: MLF, Nuclear and Particle Physics Facility (Hadron Facility and Neutrino Facility), and Transmutation Experimental Facility [1,2].

The JSNS target station in the MLF was shown schematically in Fig.1[3]. At the center of the station the mercury target is set, which is designed to accept 1-MW proton beam of 333 μA accelerated to 3 GeV by the RCS with a pulse repetition rate of 25 Hz. Mercury is selected as a target from the viewpoint of heat removal in the target vessel and neutrons yield efficiency due to its high weight density of 13.6 kg/m^3 at 300 K and high atomic number of 80. The target system consisting of a heat exchanger, a surge tank and a compact rotated magnetic pump is installed on the target trolley. The target vessel, a so-called cross-flow-type, consists of multi-walled vessels to avoid the mercury leakage into the helium vessel in the case of the

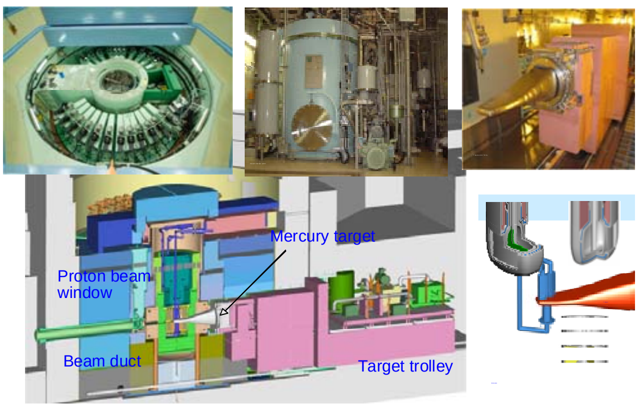

Fig.1 Main components of JSNS at MLF in J-PARC

mercury vessel failure. Supercritical hydrogen is supplied for the three moderators through a cryogenic hydrogen system. [4]

Total 23 neutron beams are extracted from the moderators. The neutron beams are controlled on and off for measurement and sample exchange, respectively, by neutron beam shutters which are equipped independently for each beam line. In May 2008, the JSNS was firstly accepted the proton beam accelerated by the LINAC and 3 GeV RCS accelerators in the MLF. After deliberate adjustment through in-beam commissioning, the MLF was opened for users in Dec. 2008. Until March 2011, the routine operation was carried out with 120 kW.

2.2 *Accelerator-driven Subcritical System (ADS)*

Reduction of burden caused by radioactive waste management is one of the most critical issues for the sustainable utilization of nuclear power. The Partitioning and Transmutation (P&T) technology provides the possibility to reduce the amount of the radiotoxic inventory of the high-level radioactive waste (HLW) dramatically and to extend the repository capacity. The accelerator-driven system (ADS) is regarded as a powerful tool to effectively transmute minor actinides (MAs) in the "double-strata" fuel cycle strategy.

The Japan Atomic Energy Agency (JAEA) has been conducting the research and development (R&D) on ADS as a dedicated system for the transmutation of long-lived radioactive nuclides. The ADS proposed by JAEA [5] is a tank-type subcritical reactor, where lead-bismuth eutectic (LBE) is used as both the primary coolant and the spallation target, as shown in Fig.2. The central part of the core is the spallation target region. In the target region, LBE is flowing from the core bottom. It is assumed to use a super-conducting linear accelerator delivering protons with energy of 1.5 GeV. The system is designed to generate 800 MW of thermal power.

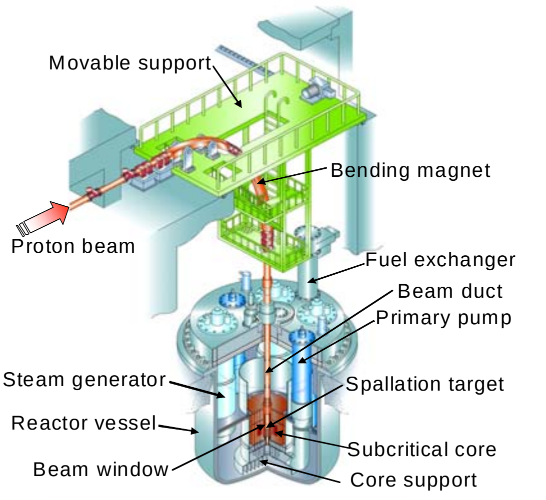

Fig.2 Conceptual design of LBE cooled ADS

For the core fuel, (MA,Pu)-nitride is used. As inert matrix, zirconium-nitride (ZrN) is used with the fuel. To minimize the burnup swing and the power peaking, the fuel region is divided into two zones with the different initial Pu loading. The MA inventory is about 2500 kg. Since the transmutation rate of MA is 250 kg/yr as described before, the relative transmutation efficiency of MA is about 10 %/yr. The maximum keff during whole burnup cycles was set to 0.97. The burnup swing in whole cycles is about 3 %Δk/k. The maximum beam current is 20 mA (30 MW).

To study the basic characteristics of the ADS and to demonstrate its feasibility from viewpoint of the reactor physics and the spallation target engineering, JAEA plans to build the Transmutation Experimental Facility (TEF) in the second phase of J-PARC.

3. Conclusion

For the JSNS, after the proton beam injected into the target in May 2008, we have learned many lessons were learned through expected and unexpected experiences. R&Ds still are needed to solve a sort of issues relating to unexpected results and increase the power.

As the future application of spallation neutron, JAEA has been promoting various R&D activities on ADS. Items of R&D are divided into three technical areas peculiar to the ADS: (1) superconducting linear accelerator, (2) LBE as spallation target and core coolant, and (3) subcritical core design and technology. For these technical areas, various R&D activities are progressing in JAEA.

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