PROGRESS OF JAERI NEUTRON SCIENCE PROJECT

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Neutron Science Project was started at Japan Atomic Energy Research Institute since 1996 for promoting futuristic basic science and nuclear technology utilizing neutrons. For this purpose, research and developments of intense proton accelerator and spallation neutron target were initiated. The present paper describes the current status of such research and developments.

I. INTRODUCTION

At the middle of 1970's, JAERI has initiated preliminary study for the partitioning and transmutation of long-lived radio-nuclides which are produced in nuclear power generation. In 1988, the Atomic Energy Commission set the long term partitioning and transmutation R&D program "OMEGA", i.e., Options Making Extra Gain from Actinide and fission products. In the course of discussion on proton accelerator development for the OMEGA project, it was recognized that neutron scattering community desires to have very high neutron source strength, two order of magnitude stronger than that of existing ones. This future source is also discussed in conjunction with continuation of JAERI role as a neutron supplier in future, because JAERI has been one of major neutron suppliers for basic science community in Japan with its research reactor JRR-3M.

Combining requirements of basic and nuclear sciences, JAERI had started the Neutron Science Project in 1996. The Neutron Science Project at JAERI is now preparing a conceptual design for a research complex utilizing spallation neutrons, including a high intensity pulsed and cw spallation neutron source. After completion of accelerator and facility constructions, the project will involve researches, utilizing neutrons, for basic science and technology development of accelerator transmutation of long-lived nuclides associated with nuclear power generation.

II. SCOPE OF NEUTRON SCIENCE PROJECT [1]

The Neutron Science Project aims at pushing researches, utilizing neutrons, for basic science and technology development of accelerator transmutation. The projects includes R&D and construction of an 8 MW (1.5 GeV, 5.3 mA) super-conducting proton linac, a 5 MW target station with compression storage rings to allow short neutron pulses for neutron scattering research, and research facilities for transmutation engineering, neutron physics, material irradiation, medical isotopes production, spallation RI beam production for exotic nuclei investigation.

Basic science in the Neutron Science Project covers neutron scattering researches such as structural biology for investigating the structure and dynamics of biological molecules, advanced material science (e.g., under extreme conditions), high-energy neutron science (e.g., spallation phenomena), nuclear cross-section measurements for transmutation study, heavy-ion science for creating unstable heavy nuclei through spallation, and synthesis of super heavy extremely-neutron-rich nuclei. Muon facility is also possible but has not been investigated yet in detail.

For nuclear energy research, a reduction of environmental impact of disposal in a deep geologic formation of high level long-lived radio-wastes from reprocessed fuels is the key question for nuclear transmutation technology. These long- lived activities are actinides such as Np-237, Am-241, Am-243 and Cm-244 and fission products such as Tc-99 and I-129. The nuclear transmutation is carried out mainly by fast neutron fission for minor actinides. The system consists of sub-critical core with minor actinides fuels centered by spallation neutron target. For development of the system, research and developments will be made by this facility complex.

With rather high power beam for nuclear transmutation study, material irradiation facility is also considered which aims at material development for fusion reactor and nuclear transmutation system. Possibility of radio-isotope production facility utilizing lower energy proton beam from the low energy part of accelerator is also investigated.

III. ACCELERATOR AND RESEARCH FACILITY COMPLEX

Figure 1 shows preliminary layout of facilities planned in Neutron Science Project . A 5 MW of total beam power of 8 MW is led to neutron scattering facility and the rest is to the facilities for thermo-hydraulics and material developments. For neutron scattering facility, two proton compressor rings are considered for full beam power at the final stage. In addition, a small amount of beam is shared to neutron physics and spallation RI beam facilities. The schematic diagram of the accelerator complex is shown in Fig.2 and its specifications are summarized in Table 1.[2] The R&D items of the accelerator complex is accelerator components, RF power, cryogenic refrigerator and so on. The R&D of the low energy part up to RFQ has already been continued for several years and the 80 mA peak current with 10% duty has been achieved. The two compression rings are considered for 5MW beam current with specification in Table 2.

Neutron scattering facility is considered with higher priority in the project, because many attractive research areas are expected for basic science. The concept of facility layout is shown in Fig.3. As the facility is considered to be open for asia-oceanea region as well as domestic researchers, neutron beam lines is designed as many as possible. The present case can take 32 beam lines for three kinds of neutron energies which are equally shared. One of the beam lines is dedicated to hot (irradiated) samples for researching radiation effect. The building is designed as a large open space to handle shielding/moderator assembly. Because the target station is surrounded by 5.5-6 m-thick iron and 1m-thick concrete shield, the radiation control of the experimental hole is accessible for rad-worker.

A plan of research and development for accelerator-driven transmutation system is divided into four phases, i.e., basic research, engineering development, technology demonstration and commercial plant. In the current JAERI program, only basic and engineering phases are included. The basic phase is focusing to build up the data base for designing experimental and demonstration plants. The experimental plant is planned to be 30 MW thermal power in the second phase in which a small amount of minor actinide fuel is burned. For the first phase, thermo-hydraulic test with 1-2 MW beam power and reactor physics experiment with zero beam power around 1 W are considered. A concept of the thermo-hydraulic test facility is shown in Fig. 4. The proton beam is bent by 90 degree to the target core assembly which is simulating the target assembly for transmutation systems, e.g., typically tungsten rods cooled by Na. The facility includes thick shielding iron comparable to the neutron scattering facility and Na coolant loop. The reactor physics facility is similar to critical assembly which was used for fast reactor studies, because transmutation system is also considered to use a fast neutron spectrum. Only a difference from a fast reactor is sub-critical system. The time transient and response of sub-critical system will be studied by techniques of reactor physics experiment.

Neutron physics study including nuclear data for high energy region is also interested for transmutation physics. For this study, pulsed high energy neutron facility can be accompanied with a TOF facility. This study requires 10 mA beam with a few ns pulse width. With the thermo-hydraulic test facility, the proton and neutron irradiation facility can also be combined because both utilize 1-2MW beam. These integration will make the common utility effective, i.e., cooling system, shielding, waste management and so on.

Besides the facilities mentioned above, by utilizing the existing Tandem Van de Graff accelerator, spallation products can be accelerated up to a few ten MeV/u together with the super-conducting cavity booster. A 10 mA of beam is used for production of trans-actinide isotopes from depleted Uranium Carbide target. This facility can be constructed only by adding target and on-line mass separator. A necessary modification of the existing facility was investigated for this facility.

By extracting a proton beam about 200 MeV at the low energy stage of the accelerator, many kinds of radio-isotopes (RI) can be produced for medical use. This energy range is suitable for creating a variety of RIs and eliminating undesirable RIs by spallation reaction. The facility should include chemical lab for separation of RI.

Muon utilization is one of the attractive application of high energy proton beam. The establishment of this facility is strongly requested from the muon science community in Japan, however, a practical design work has not been involved yet. This might be considered in the further design work.

IV. PROGRESS OF RESEARCH AND DEVELOPMENT

For the low energy part, the negative ion extraction from the volume type source is tested and 10 mA was obtained. The fabrication design of cw-RFQ test machine with 5.3 mA as well as 30 mA for pulse mode was started. For cw operation mode, the design parameters of DTL and SDTL were also investigated. To reduce RF power consumption and heat, low accelerator gradient is considered as 1.5 MeV/m. From the viewpoint of mechanics and beam dynamics, the end point energy was determined to 100 MeV.

The development of super-conducting cavity linac for 100 MeV to 1.5 GeV was started in 1996. The cavity fabrication is one of the key issues development, in which the mechanical strength and surface conditioning are concerned. The single test cavity was fabricated by cold rolling and press of pure Niobium metallic sheet with electron beam welding. In 1997, the vertical cavity test for b=0.5 (145 MeV) was successfully conducted with the maximum field strength of 24 MV/m at 4.2K and 44 MV/m at 2.1K. The multi-cavity with five cavities is being fabricated in this year for the next step.

The injection scheme is specially critical to compress the beam to shorter pulse less than 1 ms, because the conventional technology using charge stripping foil has a limit by heating up to accept the high current beam. In JAERI project, two ring scheme is considered for the reference design for 5 MW operation. However, the two ring increase the cost and makes another problem for fast beam switching and merging. To solve the problem of charge exchange foil, new charge exchange system, the LUCE method, the Laser Undurator Charge Exchange has been proposed.[3] In this scheme, an undulator is used for a foil as a stripping magnet but a charge exchange is made by two steps from H^- to H^0 and H^0 to H^+. The first step stripping is made by the undulator for Lorenz stripping and in the second step, a resonance excitation by laser is used together with Lorenz stripping by the second undulator.

A conceptual design study of target/moderator/reflector system has been extensively performed by neutronic calculations.[4] The study includes optimization of material, shape, size and relative positions for neutronic performance. The present configuration of target/moderator is shown in Fig5. The result showed clearly that mercury target is superior to Pb-Bi target. For the cryogenic moderators, reduction of nuclear heating is one of the key issues. For this purpose, a pre-moderator concept was extensively studied as well as neutron flux intensity and pulse width.

Thermo-hydraulic studies for solid and liquid targets have been performed.[5] The 1.5MW solid target of tungsten was studied for capability of heat removal so that operating temperature below 180 C was confirmed. For the mercury target, two concept of cross and return flows are investigated so that the maximum flow rate of 1.5 m/s and temperature rise of 171 C were obtained for 5MW beam.

For the cryogenic moderator, super-critical hydrogen (1.5 MPa and 20 K) was adopted so that temperature rise must be kept less than 3 degree even for peaking position in nuclear heating. These flow analysis and experimental confirmation study was started.

For material development, a test program of thermal shock, radiation damage and corrosion/erosion was being prepared.[6] The 1 J/pulse laser injection system is considered for studying stress wave phenomena. For radiation damage, triple ion beam irradiation is planned to simulate gas production dominant condition. The mercury loop test is prepared for corrosion/erosion test in off beam condition. Experimental study of neutronics and thermodynamics of mercury target is performed at AGS facility in Brookhaven National Laboratory of USA under the ASTE collboration.[7] By this experiment, design codes are checked in comparison.

V. SAFETY AND NUCLEAR DATA ISSUES

Radiation safety is the important issue for operation of the accelerators and target systems. The detailed design of shielding structure has not been performed. At the present stage, a guide line concept is being developed, e.g., the accelerator components should be maintained without remote handling. The criteria of radiation protection should be based on the regulation law, but there exist new cases compared to the previous radiation facilities, especially on the transmutation facility. These new problems should be discussed in Japanese community including the government authority.

As for nuclear data required for the project, there are two kinds of areas, i.e., nuclear design of the target and radiation shielding design. The calculation tools are commonly high energy transport codes, such as, NMTC/JAERI and HETC. Those codes include elastic cross section for a collision probability as well as a simplized shielding code. Most frequently used data is a nuclide production cross section library which is required to estimate induced radio-activities and nuclear transmutations. For a shielding purpose, high energy proton induced reactions, e.g., (p,xn), is necessary to estimate neutron production from beam line components.

VI. CONCLUDING REMARKS

The JAERI Neutron Science Project is progressed more than expected, regardless of short period after starting the project. Especially the development of accelerators has been considerably progressed in the super-conducting cavity. The target development is under preparation for thermo-hydraulic and mechanical test devices, while a neutronics study has been progressed for optimizing target/moderator shape and configuration. As for international collaborations, the ASTE collaboration on the mercury target has started at BNL.

The total design of accelerator complex and the target system will be completed soon as the first round concept. On the other hand, a radiation safety assessment has just started at this April. The research and development phase will be continued for the next three years and then a check and review of the project is obligated by the government before moving to the construction phase.

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Table 1 Specification of Linac

Energy	1. 5GeV
Ion source	negative and positive hydrogen
Current 1st stage:	pulse: 1mA(Ave.), 16.7mA (peak)
2nd stage:	cw&pulse:5.3mA(Ave), 30mA(peak)
Accelerator type	
low energy	RFQ,DTL/SDTL (norm., 200MHz)
high energy	Super-conducting linac (600MHz)

Table 2 Compression Ring

Maximum Power	2.5 MW
Repetition	50Hz
Harmonic number	1
Chopping factor	0.6
Circumference	185.4 m
Number of proton	2.08×10^{14} protons

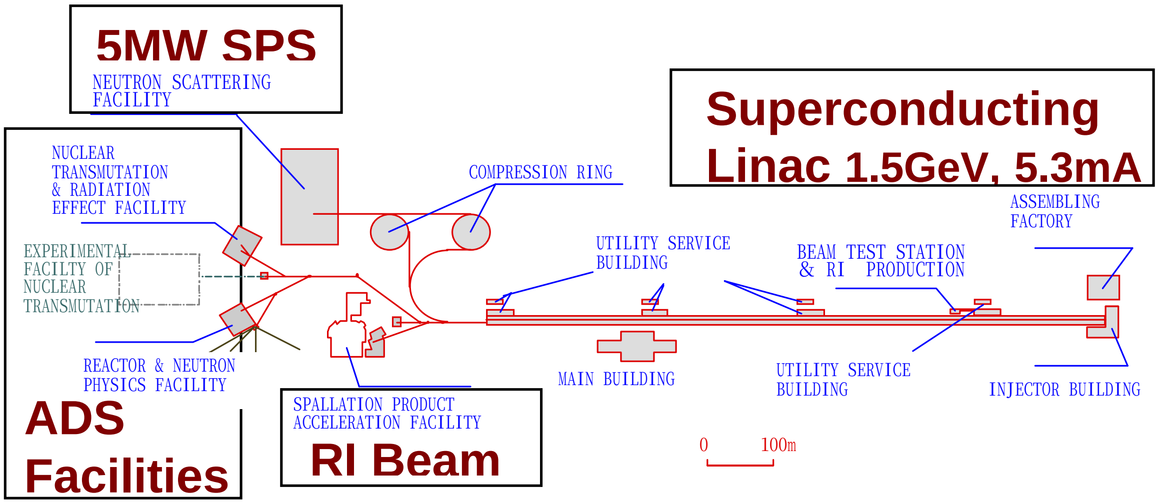

Figure 1 Preliminary Layout of Facility Complex

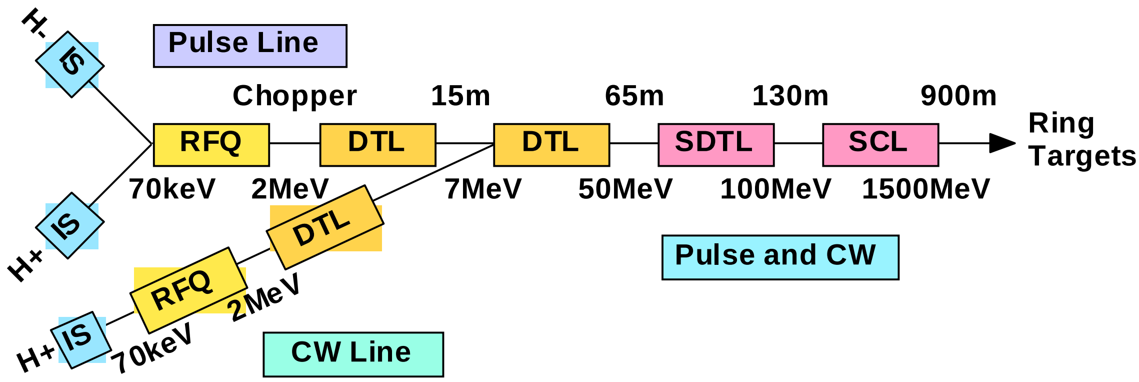

Figure 2 Schematic Diagram of Accelerator Configuration

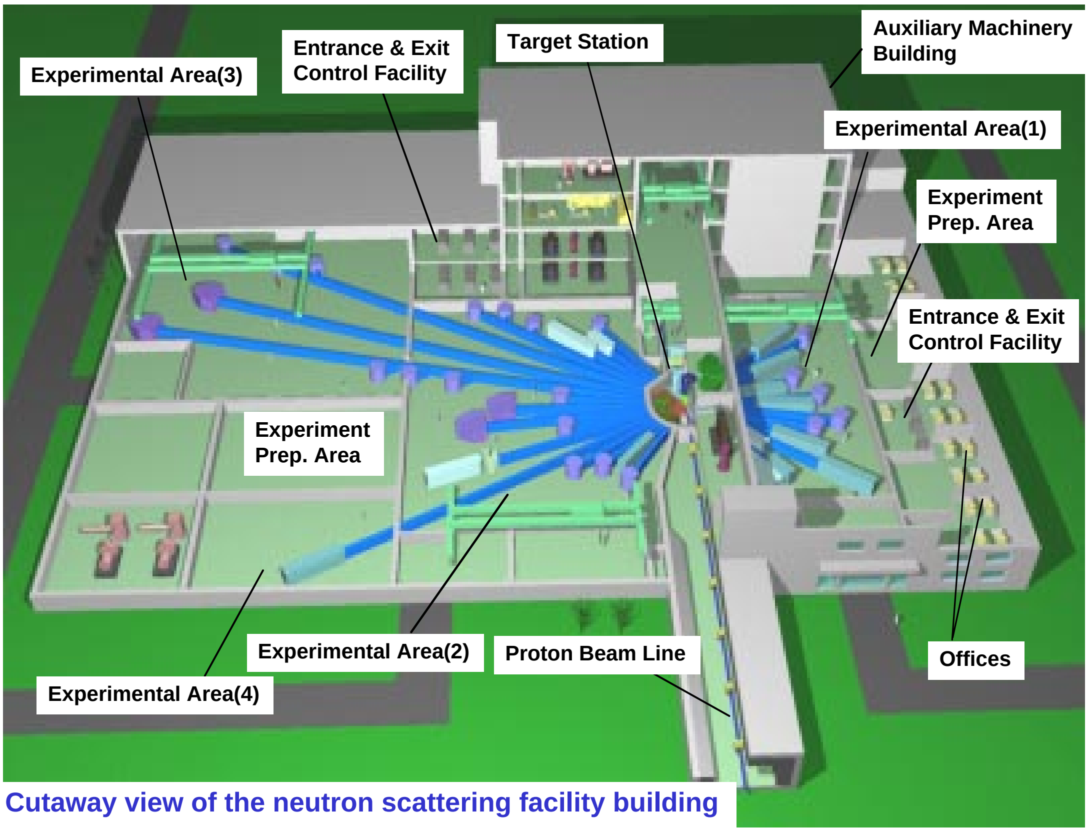

Figure 3 Concept of Neutron Scattering Facility

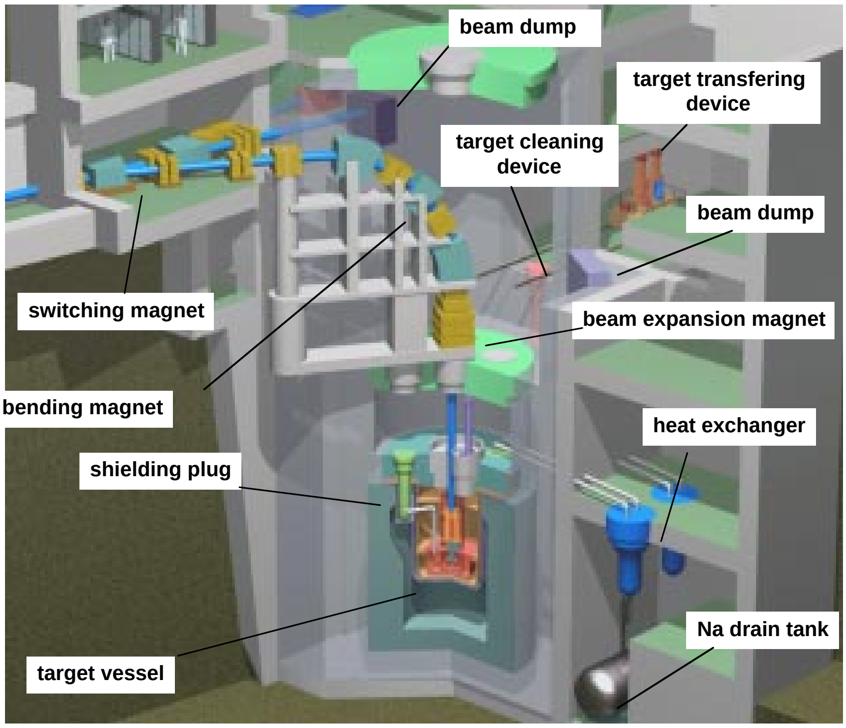

Figure 4 Concept of Transmutation Research Facility for Thermo-Hydraulics Test

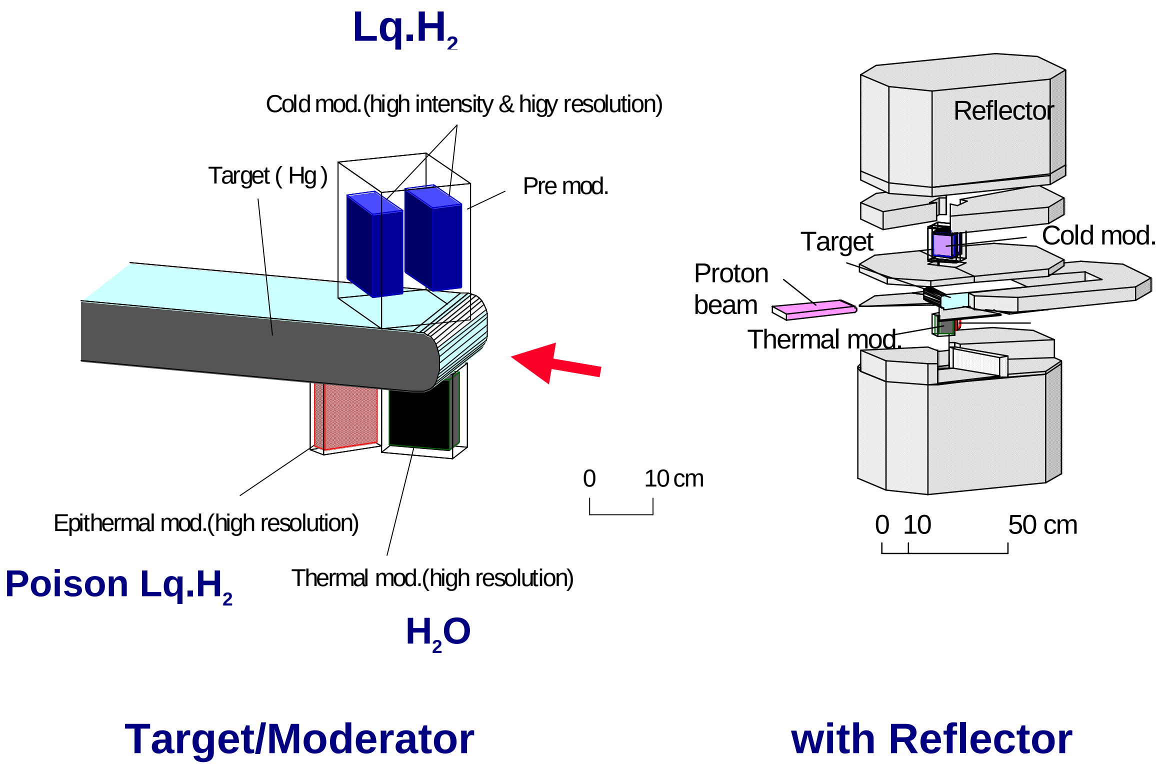

Figure 5 Target/Moderator Concept for Spallation Neutron Source of Neutron Scattering