CURRENT PLAN OF J-PARC TRANSMUTATION EXPERIMENTAL FACILITY

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Construction of the Transmutation Experimental Facility (TEF) is planned within the framework of J-PARC (Japan Proton Accelerator Research Complex) project. The facility has a critical assembly and a lead-bismuth target connected to a 600 MeV proton beam line. Considering the current J-PARC schedule, we are planning to install the critical assembly with a 30kW beam dump at the first phase and the target facility will be built at the latter phase. Based on this construction plan, JAEA collected the preliminary Letters Of Intent (LOI) for TEF. More than 30 research programs by about one hundred researchers were proposed from all over the world. The proposals spread over wide research fields such as innovative reactor concepts including ADS and FBR, nuclear data, nuclear physics, and so on. A medical application using 30kW dump was also proposed.
According to these many valuable proposals, the re-arrangement of facility layout and the new experimental equipment design are now underway. One of the important R&Ds is to prepare for the application of minor actinide fuels to critical assembly. The development of the technology to handle the high-background minor actinide fuel is being performed. A sensitivity analysis was also performed to determine the efficient fuel composition.

I. INTRODUCTION

Japan Atomic Energy Agency (JAEA) performs a design study of the accelerator-driven system (ADS) to transmute minor actinides and long-lived fission products extracted from high-level radioactive waste (Ref. 1). To solve technical difficulties to design ADS, construction of Transmutation Experimental Facility (TEF) is planned under the framework of J-PARC (Japan Proton Accelerator Research Complex) project (Ref. 2). Figure 1 illustrates the site plan of the J-PARC. TEF consists of two buildings; Transmutation Physics Experimental Facility (TEF-P) (Ref. 3) to measure the neutronics of subcritical systems by using critical assembly, and ADS Target Test Facility (TEF-T) (Ref. 4) to take material irradiation data in flowing lead-bismuth (Pb-Bi) eutectic alloy environment. At the TEF-T, a Pb-Bi spallation target will be installed. Using these two facilities, basic physical properties of subcritical system and engineering tests of spallation target will be studied.

Research and development (R&D) for several important technologies required to build the facilities are also performed, such as laser charge exchange technique to extract very low power beam for reactor physics experiments, Minor Actinides (MA) loading into critical assembly and so on. The objectives of the facilities, the latest design concept, and key technologies to construct TEF are described in the present report.

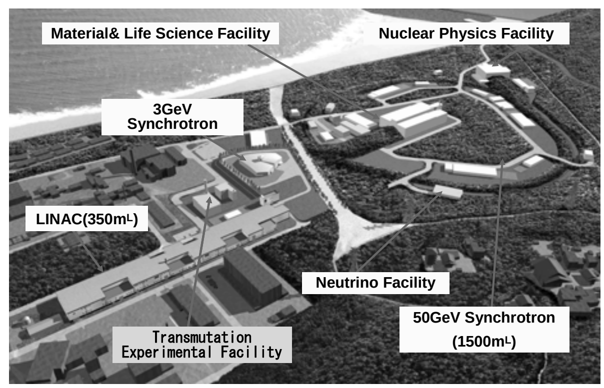

Fig. 1 Site plan of J-PARC Project

II. OVERVIEW OF THE TEF

To study the basic characteristics of the ADS and to demonstrate the feasibility from the viewpoints of the reactor physics and the spallation target engineering, JAEA plans to build the TEF in JAEA/Tokai site under a framework of the J-PARC Project directed by JAEA and High Energy Accelerator Research Organization (KEK).

TEF consists of two buildings: TEF-P and TEF-T as shown in Fig. 2. TEF-P is a zero-power critical facility where a low power proton beam is available to research the reactor physics and the controllability of the ADS. It also has an availability to measure the reaction cross sections of MA, structural materials and so on. TEF-T is planned as a material irradiation facility which can accept a maximum 600 MeV-200 kW proton beam into the Pb-

Bi eutectic alloy spallation target. This section describes the outline and major objectives of the TEF-P and TEF-T.

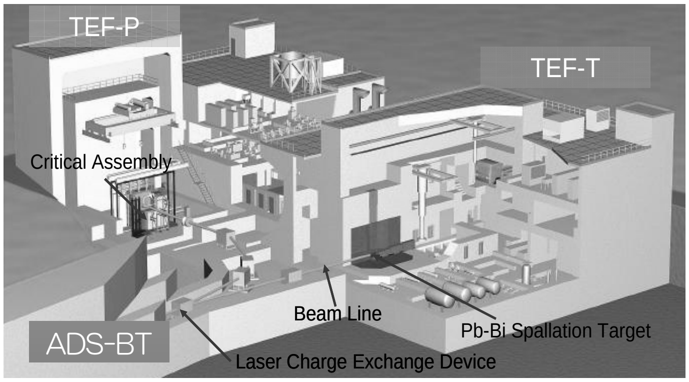

Fig.2 Transmutation Experimental Facility

II.A. Outline of TEF-P

Several experiments to investigate neutronic performance of ADS have been performed worldwide. One of them is called as a MUSE program (Ref. 5). MASURCA, a critical assembly with fast neutron spectrum in France, is used with a DT and DD neutron source and a solid target. In Japan, subcritical experiments were performed at the Fast Critical Assembly (FCA) in JAEA/Tokai with a Cf-252 neutron source and a DT neutron source. Many experimental studies have been performed to the neutronics of the spallation neutron source with various target material such as lead, tungsten, mercury and uranium. These experiments for spallation target are also useful to validate the neutronic characteristics of ADS.

There have been, however, no subcritical experiments combined with a spallation source. The purpose of the TEF-P is divided roughly into three subjects;

(1) reactor physics aspects of the subcritical core driven by a spallation source,

(2) demonstration of the controllability of the subcritical core including a power control by the proton beam power adjustment, and

(3) investigation of the transmutation performance of the subcritical core using certain amount of MA and LLFP. Following section describes the detail of these experimental items.

For the preparation of fuel, since tons of low-enriched uranium or plutonium are necessary to make the core critical or near-critical (e.g. k-eff = 0.95) in the fast neutron system, we expect to use the plate-type fuel of the FCA. Various simulation materials for modelling fast reactor and ADS such as lead and sodium for coolant, tungsten for solid target, ZrH for moderator, B4C for absorber, and AlN for simulating nitride fuel will be prepared. Therefore, TEF-P is designed with referring to FCA; the horizontal table-split type critical assembly with a rectangular lattice matrix. The proton beam can be introduced horizontally from the center of the fixed half assembly.

In the experiment with the proton beam, k-eff of the assembly will be kept less than 0.98. One proton with energy of 600 MeV produces about 15 neutrons by the spallation reaction with heavy metal target such as lead. The 10 W proton beam corresponds to the source strength of $1.5x10^{12}$ neutrons/s, which is strong enough to measure the power distribution at the deep subcritical state such as k-eff = 0.90.

In the conceptual design of the facility, the shielding property for high energy neutrons is calculated. About 2m thickness of concrete shield is necessary even when the core is surrounded by about 1m of lead reflector. Safety aspect of the facility is also extensively studied. The prompt critical accident can be terminated without fuel melting by the reactor scram system with multiplicity and variety. The unexpected introduction of the 10 W beam into the critical state also can be terminated safely with the reactor scram.

In the viewpoint of the neutronics of the subcritical system, power distribution, k-eff, effective neutron source strength, and neutron energy spectrum will be measured by changing subcriticality and spallation neutron source position, parametrically. The target material will be altered with Pb, Pb-Bi, W, and so on. The reactivity worth is also measured for the case of the coolant void and the intrusion of the coolant into the beam duct. It is desirable to make the core critical in order to ensure the quality of experimental data of the subcriticality and the reactivity worth.

For the demonstration of hybrid system, feedback control of the thermal power is examined by adjusting the beam intensity. Operating procedures at the startup/shutdown, beam trip and re-start are also examined.

As for the transmutation characteristics of MA and LLFP, fission chambers and activation foils are used to measure the transmutation rates. The cross section data of MA and LLFP for high energy region (up to several hundreds MeV) can be measured by the Time of Flight (TOF) technique with the proton beam of about 1ns pulse width. Several kinds of MA and LLFP samples are also prepared to measure their reactivity worth, which is important for the integral validation of cross section data.

Installation of a partial mock-up region of MA nitride fuel with air cooling is considered to measure the physics parameters of the transmutation system. The central rectangular region (28cm x 28cm) will be replaced with a hexagonal subassembly which can partially install the pin-type MA fuel around the spallation target as shown in Fig. 3.

The distinguished points of TEF-P in comparison with existing experimental facilities can be summarized as follows: (1) both the high energy proton beam and the nuclear fuel are available, (2) the maximum neutron source intensity of about 10^{12} n/s is strong enough to perform precise measurements even in the deep subcritical state (e.g. k-eff=0.90), and, is low enough to easily access to the assembly after the irradiation, (3) wide range of pulse width (1ns - 0.5ms) can be available by the laser charge exchange technique described later, (4) MA and LLFP can be used as a shape of foil, sample and fuel by installing an appropriate shielding and a remote handling devise.

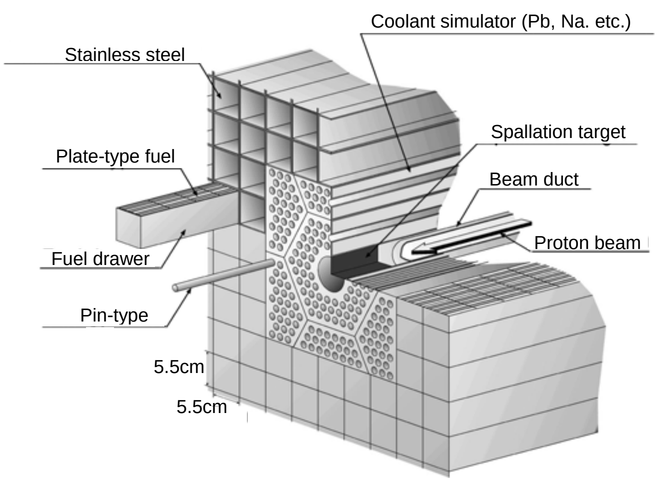

Fig.3 TEF-P assembly with partial loading of pin-type fuel

II.B. Outline of TEF-T

JAEA proposes the Pb-Bi target/cooled ADS as a primary candidate. Pb-Bi is one of the alternative options of the coolant of fast reactor and it also has a function of liquid spallation target simultaneously in the ADS. There are, however, many technical issues to use Pb-Bi safely. To solve these technical difficulties, several R&D programs are proposed. Material irradiation experiment in stagnant Pb-Bi environment has been performed at the SINQ facility in Paul Scheller Institute (PSI), Switzerland. MEGAPIE project (Ref. 6) successfully finished the target operation at PSI and feasibility of Pb-Bi target with low temperature operation was demonstrated. According to the limitation of existing equipments of the facility and machine time, experimental data obtained from these programs are not enough. To obtain more experimental data cyclopaedically, TEF-T plans to prepare the database required for ADS design.

Another important component for ADS is a beam window. Beam window forms a boundary between an accelerator and a subcritical core. It suffers heavy irradiation of proton and spallation neutron, mechanical stress caused by the pressure difference between the accelerator and flowing Pb-Bi target, thermal stress arising from heat deposition of high energy particles and beam transients (startup/shutdown and beam trip) and chemical interaction with Pb-Bi. It is important to prepare the database to estimate a lifetime of the window. So that, the experiments to obtain the design database for beam window are also the important mission of TEF-T.

TEF-T mainly consists of a Pb-Bi spallation target, a secondary cooling circuit, and an access cell to handle the spent target vessel and irradiation test pieces. Pb-Bi is filled into a double annular cylindrical tube made by type 316 stainless steel. An effective size of the tube is about 15cm diameter and 3 to 4 meter long. Several kinds of target head are planned and designed according to the objective of the experiment. One of the target vessels is designed to irradiate samples in the flowing Pb-Bi environment.

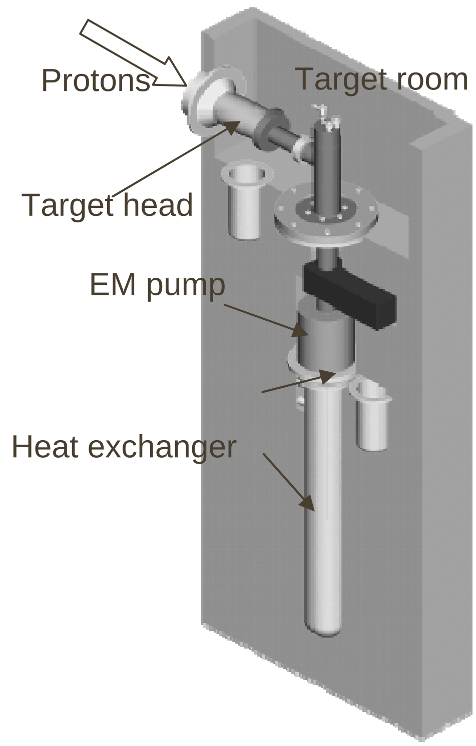

Fig.4 Sealed annular type spallation target for TEF-T

A primary Pb-Bi loop is designed to allow Pb-Bi flow up to 2 meter per second of velocity and 450 degree centigrade of the maximum temperature. A type 316 stainless steel was tentatively selected as a structural material of the target vessel for preliminary design study. Target vessel is a sealed double annular cylindrical tube with a 90 degree bend section. Conceptual figure of the target is illustrated in Fig. 4. Pb-Bi is circulated by electro-magnetic pump (EM pump) that is completely separated from the target tube. By using this newly designed target, target can be replaced quickly and easily by withdrawing the target tube in upward direction from heat exchanger electro-magnetic flow meter, and EM pump. The access cell has functions to manage the spent/new target tube, to clean up residual Pb-Bi to reduce exposure dose by the spallation products, and to pick up irradiated material test pieces by using remote handling devices.

A preliminary analysis of the Pb-Bi target neutronics was performed. Pb-Bi (45%Pb-55%Bi) is filled in a cylindrical vessel made by type 316 stainless steel. Average Pb-Bi temperature is assumed to 400 degree centigrade. Thickness of the vessel is set to 1 mm. A sample holder for the irradiation samples, which are to be installed in the target, is not considered at this analysis. From the result of analysis by ATRAS code system (Ref. 7), the annual DPA (Displacement per Atom) of type 316 stainless steel sample partially gives more than 10 DPA per year.The Pb-Bi target of TEF-T has enough performance to irradiate samples at ADS operating condition by adjusting the beam profile.

A shielding analysis of the spallation target was also done by MCNPX code (Ref. 8) and DUCT-III code (Ref. 9). It was observed that about 6m of thickness (3m of Iron and 3m of concrete) were required as a biological shield around the target. An extra shield wall (1m of concrete) and a bending magnet must be attached at the proton beam injection section of the target to suppress the backscattered neutron streaming throughout the proton beam duct.

III. R&D FOR TEF-P CONSTRUCTION

III.A. Low Power Proton Beam Extraction by Laser

For the neutronics experiments using TEF-P, low reactor power less than 1kW is feasible in the viewpoint of convenience of experimental settings. To perform the experiments at TEF-P in such reactor power, with the k-eff around 0.97, incident proton beam must be the order of 10W. It is also important to keep and represent the experimental condition especially for the injected proton beam. Because the J-PARC accelerator focused on much more high beam power, the high-reliable low-power proton beam extraction device is indispensable. For the extraction of low power proton beam, development of the laser charge exchange technique is now underway. The laser charge exchange technique is firstly used for the beam profile monitor and is applicable only for H^- beam. When the laser beam injected to H^- beam, the charge of H^- beam crossed with laser beam changes into neutral and these neutral particles does not sense the magnetic field of bending magnet and completely separated with remaining H^- beam at the exit of the bending magnet. However, it is well-known, the pre-neutralized H^0 is produced by collision with remaining gas in accelerator tube and transported with main proton beam. To use such technique to the H^- beam with pre-neutralized protons, total power of the extracted beam is not be predictable. To avoid the pre-neutralized beam, we are trying to make laser injection and beam bending simultaneously in one magnet. When the laser is injected in the magnetic field of the bending magnet, pre-neutralized beam goes straight along the beam inlet direction and can be separated from the clean low power proton beam at the exit of the bending magnet.

A first demonstrative test of the laser charge exchange technique was carried out at KEK (Ref. 10). The Nd:YAG laser using a pulse width of 20nsec, beam energy of 500mJ (repetition rate of 25Hz) have been installed in J-PARC Medium Energy Beam Transport to measure current profile of high intensity H^- beam. It was confirmed that the photo stripped electron signal corresponded to the reduction of the beam current detector signal at downstream. The results of transverse profile measurements were also consistent with wire scanner signals of upper and downstream. The H^- beam components intercepted by 0.8mm height laser beam have been estimated by transverse profile measurement, and agree with photo detached fraction (Faraday cup and current detector's signal). The calculation results also show the complete (>99%) neutralization ratio with 130 mJ Nd:YAG laser for 3 MeV H^- beam. Thus the complete (>95%) photo neutralization fraction for a 130mJ (repetition frequency of 5Hz) 1,064 nm Nd:YAG laser pulse on a 15 mA, 3 MeV H^- beam could be confirmed practically.

The second test was carried out at the JAEA-Tokai site. A prototype H- ion source for J-PARC LINAC (70keV-5uA) and the same Nd:YAG laser source were used. A bending magnet with laser injection port was newly attached to the test line to extract H^0 beam during the beam bending. Figure 5 shows the experimental layout. There were limited beam control devices (two steering magnets), the beam was defocused and 50% of the proton beam was already neutralized at the exit of the bending magnet. However, by using movable beam slit in front of the micro channel plate detector to suppress the pre-neutralized beam, the neutralized proton beam signal related to the laser injection trigger was observed.

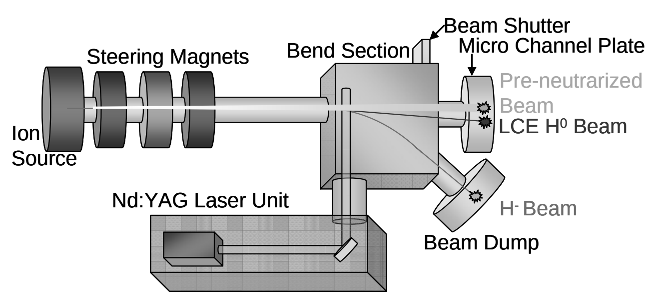

Fig. 5 Layout of 2nd Laser Charge Exchange Test

III.B. Minor Actinide Fuel Handling Method

The critical assembly are planned to be installed at TEF-P facility and has similar geometrical configuration with existing FCA (Fast Critical Assembly) at JAEA/Tokai site. To use MA-bearing fuel in TEF-P, the availability and limitation were surveyed. A trial manufacture of the coolant simulation block and conceptual study of remote fuel loading method of the pin-type MA fuel were performed. By using specified MA fuel loading zone configuration, effectiveness of the integral experiments using MA fuel were evaluated.

At first, the availability and experiences of MA usage in JAEA were surveyed and there were actual achievement by inclusion of Np and Am-241 into MOX fuel up to 5%. There were also had several experiences of irradiation in fast neutron spectrum field and proved the soundness of fuel pellet. That means these fuel has enough quality to use them in zero power critical assembly. From the viewpoint of actual experiences, preparation of low Np-237 and/or Am-241 contained (up to 5%) MOX fuel is reasonable as a first step of MA usage. By using this kind of fuel, to simulate neutron energy spectrum of ADS/FR, about 0.03 m^3 of driver zone (25cm X 25cm X 60cmL) is required.

To load a pin-type fuel into FCA-type critical assembly, coolant simulation block is indispensable which has high coolant filling factor and appropriate air gap to cool MA pin fuel. Trial manufacture of coolant simulation block to simulate lead-bismuth coolant was performed. Figure 6 shows the trial coolant simulator block. It is realized that filling factor of coolant in the block was about 97% and can be increased by improve the manufacturing accuracy around fuel pin guide tube.

To handle the MA-bearing fuel, remote handling device is required to protect the experimenters from radiation exposure by MA. However, to keep ideal experimental condition, handling head of fuel pin have to be manufactured as small as possible. At now, following two methods are under consideration; a mechanical method using small rubber and a method using electromagnetic coil. Fuel handling test by mechanical method was performed using coolant simulation block mentioned above and enough performance to handle the pin-type fuel was demonstrated. For the next step, the other method using electromagnetic coil is under preparation.

Taking into account the specification of MA fuel loading zone in TEF-P critical assembly, the effectiveness of integral neutronic experiments using MA fuel is evaluated. The improvement of neutronic analysis accuracy and kinds of experiments which are effective to analysis precision were studied. To evaluate the improvements of neutronic analysis accuracy, cross section adjustment was performed by using SAGEP code (Ref.11) and JENDL-3.3 based cross section library. From the results summarized in Table.1, the significant reduction of the analytical error of actual ADS caused from cross section library was observed by addition of seven TEF-P hypothetical experiments (criticality, sodium void reactivity and Doppler coefficient) (Ref.12). It was also observed that covariance of MA cross section must be verified.

TABLE. 1 Effect of MA fuel experiments

Experiment Item	MA5% mixed MOX Fuel FR			(MA, Pu)N + ZrN Fuel ADS		
	Initial	After Adjustment		Initial	After Adjustment	
		233 data	233 + 7 data		233 data	233 + 7 data
k-eff	1.1	0.30	0.27	1.1	0.74	0.68
Coolant Void Reactivity	2.4	1.6	1.4	5.8	3.8	3.0
Doppler Reactivity	3.8	2.2	1.7	4.9	4.0	2.8

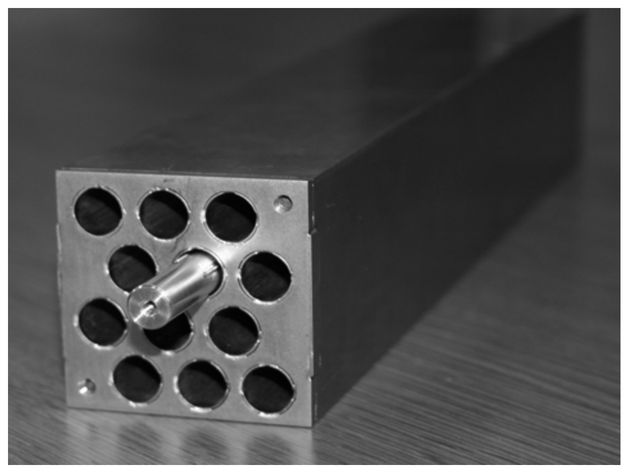

Fig.6 Trial Coolant simulation block

IV. PRELIMINARY LETTERS OF INTENT

The TEF program is still not funded officially, the Project Team called for preliminary Letters of Intent (LOI) for experiments at the TEF in the year of 2006. The purposes of preliminary LOI are: (1) to know which groups have an interest in this activity and what contributions from them can be expected, (2) to reflect new ideas and proposals on the specifications and the layout of TEF including the beam dump, and, (3) to establish an appropriate collaboration scheme between J-PARC and the anticipated outside users.

Figure 7 shows the results of preliminary LOI. Thirty seven proposals were received in total. The experiments for both ADS and MA-loaded FBR were

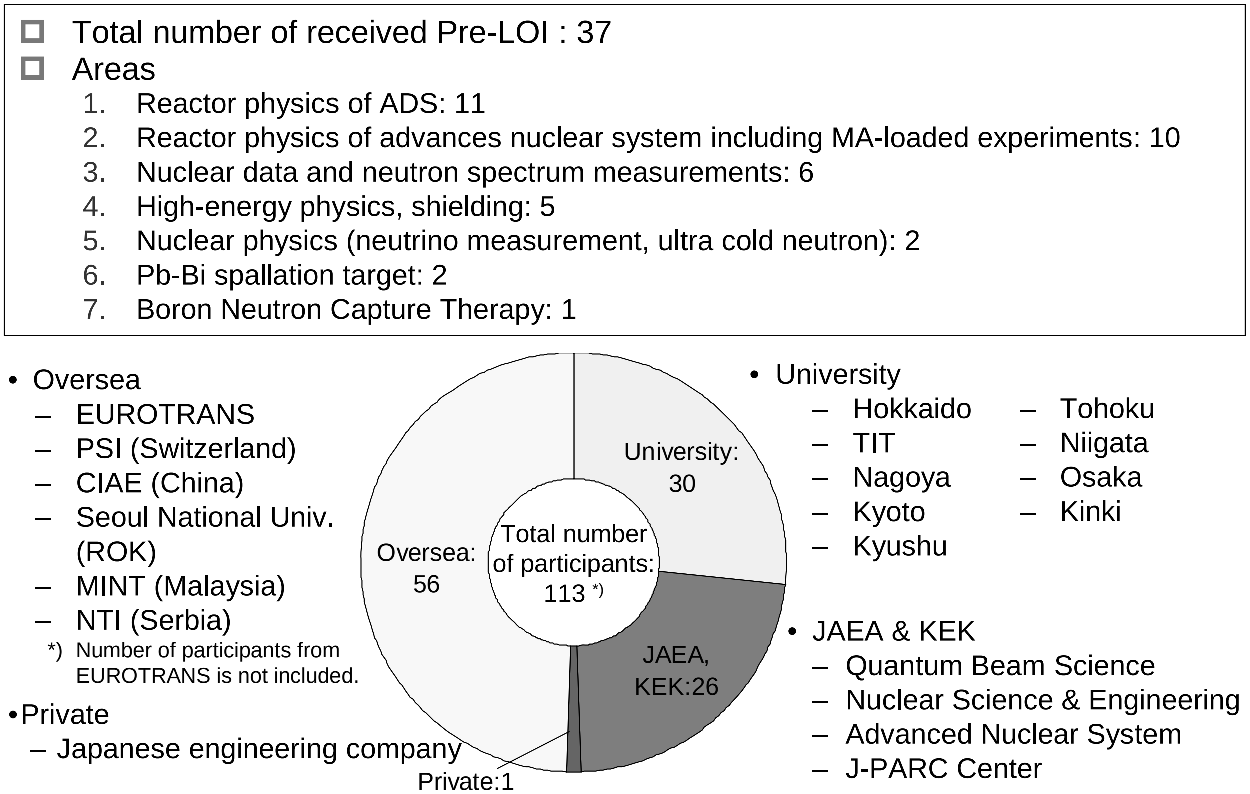

Fig.7 Result of Preliminary LOI

mainly proposed. In other fields, proposals were for nuclear data measurement, high energy physics, LBE spallation target technology, and miscellaneous researches using protons and neutrons at the beam dump. Although the detailed discussions for the proposals have not been started yet, it is clear that TEF can serve as a basic experimental platform for the nuclear science, engineering, and applications. The project is still open to accept other proposals.

V. CONCLUSIONS

To perform the design study of the MA-loaded fast system for transmutation of long-lived nuclides, the construction of TEF is proposed under the J-PARC Project. TEF consists of two buildings: TEF-P and TEF-T. These buildings are connected by the beam transport, which includes a special device to extract very low power proton beam.

TEF-P is a critical assembly, which can accept the 600 MeV - 10 W proton beam for the spallation neutron source. The purposes of TEF-P are the experimental validation of the data and method to predict neutronics of the fast subcritical system with spallation neutron source, the demonstration of the controllability of subcritical system driven by an accelerator, and the basic research of reactor physics for transmutation of MA and LLFP.

TEF-T is a facility to prepare the database for engineering design of ADS using 600 MeV - 200 kW proton beam and the Pb-Bi spallation target. The purposes of TEF-T are R&D for the irradiation damage of the beam window, the compatibility of the structural material with flowing liquid Pb-Bi and the operation of the high power spallation target.

Along to the design study of the TEF, R&D for the components required for TEF, such as laser charge exchange technique to extract very low power proton beam and test manufacturing of MA fuel handling devices were performed. From the experimental result of the laser charge exchange technique, beam extraction in the magnetic field is successfully demonstrated with J-PARC prototype ion-source. The significant improvement of analysis accuracy of actual ADS was expected by critical experiment with MA fuel at TEF-P.

The preliminary letters of intent were called to encourage the project. More than hundreds of researchers are proposed the experimental program using TEF.

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