# Present Status of FRS of JAERI

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## 1. Preface

The Facility of Radiation Standards (FRS) of the Japan Atomic Energy Research Institute (JAERI) was established in the year 1980 for the purpose of centralized management on calibration and performance tests of radiation measuring instruments for radiation protection in JAERI. In this facility, various irradiation apparatus and sources for X ray, gamma ray, beta ray and neutron have been so far equipped, and the necessary calibration fields for each radiation, which are traceable to the national standards, have been developed through R&D activities. Then, there were increasing needs of using mono-energetic neutron sources for type tests of neutron measuring instruments and research activities for radiation protection. The construction of an additional facility with an accelerator for generating neutrons and some irradiation rooms was planned in 1998, and the Facility of Calibration Standards for Neutron (FCSN) was completed and licensed for operation in January 2001. This renewed FRS including FCSN is about to start operation as an integrated calibration standards facility. In FRS, calibration and tests are carried out for a large variety of radiation measuring instruments such as surveymeters, personal dosimeters, contamination monitors, area monitors and released radioactivity monitors. This facility is used not only for calibration of the instruments owned by JAERI, but also of those owned by other firms through the Institute of Radiation Measurements.

The ion source and high voltage units of 4MV Pelletron installed in FCSN are still under arrangement. Soon after finishing the arrangement, mono-energetic neutron calibration fields will be developed, and their traceablity to the national standards will be established with the cooperation of AIST. Finally, the neutron energy range from 8 keV to 20 MeV will be covered until 2005. And also, development of another type of neutron calibration field by the accelerator, that is, spectrum-changeable neutron calibration field, is planned for calibration of neutron dosimeters. At present, most of R&D activities are shared for generating quality mono-energetic neutrons and for computationally analyzing neutron calibration fields.

## 2. Scope of neutron calibration fields in FCSN

(1) Mono-energetic neutron calibration field

In order to obtain the mono-energetic neutrons, protons and deuterons are accelerated up to 4 MeV by using the Pelletron accelerator and bombard various targets to bring on nuclear reactions with neutron emission. The nuclear reactions employed for neutron production are $^{45}Sc(p,n)^{45}Ti$, $^{7}Li(p,n)^{7}Be$, $^{2}H(d,n)^{3}He$, $^{3}H(p,n)^{3}He$ and $^{3}H(d,n)^{4}He$. Figure 1 illustrates a cross-sectional view of neutron irradiation room and accelerator room at FCSN and Fig. 2 shows a photograph of the neutron irradiation room. The size of the irradiation room is 16.5m × 11.5m × 12.3m. The targets, located at the near centre of the room, are made of thin vacuum-deposited materials for Sc and LiF, a gas cell for D target, and titanium tritide (T-Ti) targets. In order to reduce scattered neutrons from the floor, the target assemblies are supported 1.5m high from an aluminium grating elevated at mid-height of the room.

For establishing the traceability of the mono-energetic neutron calibration fields to the national standards, it is necessary to determine exact neutron fluences by absolute measurement techniques. According to the neutron energy, four types of detectors are being developed at FCSN as shown in Table 1. The mono-energetic neutron fields in the energy ranges of 50keV ~ 2MeV and 3MeV ~ 7MeV will be prepared by using $^{7}Li(p,n)^{7}Be$ and $^{2}H(d,n)^{3}He$ reactions until 2003. And then by employing $^{45}Sc(p,n)^{45}Ti$, $^{3}H(p,n)^{3}He$ and $^{3}H(d,n)^{4}He$ reactions, the mono-energetic neutron calibration field with the neutron energy range from 8keV to 20MeV will be completely established until 2005.

(2) Spectrum-changeable neutron calibration field

Neutron dose equivalents measured by various neutron dosimeters are influenced by parameters such as conversion factors of neutron fluence to dose equivalents, energy response of the dosimeter and the difference of neutron energy spectrum in working place and in calibration field. There is a possibility to overestimate or underestimate the dose equivalents considerably in case that the dosimeter does not have a good energy response and the energy spectrum in the working place to be measured is quite different from that in calibration field. For the accurate estimation of neutron dose equivalents, it is important to calibrate dosimeters in the field whose energy spectrum is similar to that in the working place. Therefore FCSN will be equipped with spectrum-changeable neutron calibration fields, which simulate typical neutron spectra in working places. They will be used for realistic calibration of neutron dosimeters.

At the moment, we are collecting and analyzing data of various neutron energy spectra in working places and energy response information of dosimeters. These data are taken from various reports, *e.g.*, IAEA Technical Report Series No. 318[1)], compendium of neutron spectra and detector responses for radiation protection purposes, and so on. By analyzing these data, spectra will be categorized in source type, spectrum shape, energy range and so on. The spectra to be simulated for the realistic calibration will be determined based on these results.

In the spectrum-changeable neutron calibration field, the objective spectrum suited for the calibration will be produced by bombarding protons or deuterons from 4MV Pelletron to suitable targets surrounded by various kind of neutron moderators and absorbers (Fig. 3). Those target assembly will be designed and optimized with a Monte Carlo simulation code system, MCNP-ANT, as mentioned below. Then the detailed design of the field will be determined by experiments.

3. Development of Monte Carlo code system (MCNP-ANT)

The MCNP-ANT (MCNP for Accelerator Neutron Target) code system consists of a newly developed Monte Carlo program for calculating the transport of charged particles and the neutron production and an existing neutron transport code, MCNP version 4B[2)]. The newly developed program can deal with protons and deuterons up to an energy of 4MeV as incident charged particle. The slowing down and scattering of the charged particles in matter are simulated by the method used in SRIM(TRIM) program[3),4)], which is one of the most widely used programs for transport calculation of ions in matter. The history of resultant recoil particles from the interaction is also traced. The reactions of $^{2}H(d,n)^{3}He$, $^{3}H(d,n)^{4}He$, $^{3}H(p,n)^{3}He$, $^{7}Li(p,n)^{7}Be$, $^{7}Li(p,n)^{7}Be^{*}$ and $^{45}Sc(p,n)^{45}Ti$ are available in the code system. The differential cross-sections of $^{2}H(d,n)^{3}He$, $^{3}H(d,n)^{4}He$, $^{3}H(p,n)^{3}He$, $^{7}Li(p,n)^{7}Be$ and $^{7}Li(p,n)^{7}Be^{*}$ and neutron energies as functions of incident particle energies are taken from the data of Liskien and Paulsen[5),6)]. For $^{45}Sc(p,n)^{45}Ti$ reaction, which has many narrow resonances, the experimental data are taken from the literature[7)], and the neutron production is assumed to be isotropic in the center-of-mass system. The energy and direction of a produced neutron are determined so that they are consistent with the kinematics of the reaction. Figure 4 shows an outline of the calculation flow of the code system.

Neutrons of undesired energy (background neutrons) stems from the interaction of the incoming charged particles with matter other than the intended target isotope. We have been trying to treat these reactions in the code system. The cross-sections of these reactions were calculated by ALICE-F code[8)] and incorporated into MCNP-ANT as an attempt.

To demonstrate the applicability and reliability of the code system, a number of representative calculations have been performed. The results are discussed in comparison with the measured or theoretically calculated data. The results of the calculations for typical mono-energetic neutron calibration fields indicate generally good agreement with the experimental ones[9)] as shown in Table 2.

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Table 1 Detectors to be used for absolute measurement of neutron fluence in the mono-energetic neutron calibration fields

| Neutron Energy | 8keV~1MeV | 1MeV~5MeV | 5MeV~20MeV |
|---|---|---|---|
| Detector | Proton Recoil Proportional Counter or Si SBD with $^6$LiF radiator | Si SBD with polyethylene radiator | Proton Recoil Telescope |

Table 2 Comparison of energy spread and neutron fluence for mono-energetic neutron sources between calculated with MCNP-ANT and measured by Baba *et al*[9].

| Source reaction | Target/ Backing | Neutron energy | Energy spread | | Neutron fluence at 10cm ($cm^{-2} \cdot \mu C^{-1}$) | |
|---|---|---|---|---|---|---|
| | | | MCNP-ANT | Baba *et al.* | MCNP-ANT | Baba *et al.* |
| $^3H(d, n)^4He$ | Ti-T / Cu | 15 MeV | 400 keV | ~500 | $1.4\times10^5$ | $8.0\times10^4$ |
| $^7$Li(p, | LiF / Pt | 550 keV | 55 keV | ~50 keV | $2.5\times10^4$ | $3.2\times10^4$ |
| $^7$Li(p, | LiF / Pt | 250 keV | 60 keV | ~50 keV | $6.5\times10^3$ | $1.0\times10^4$ |

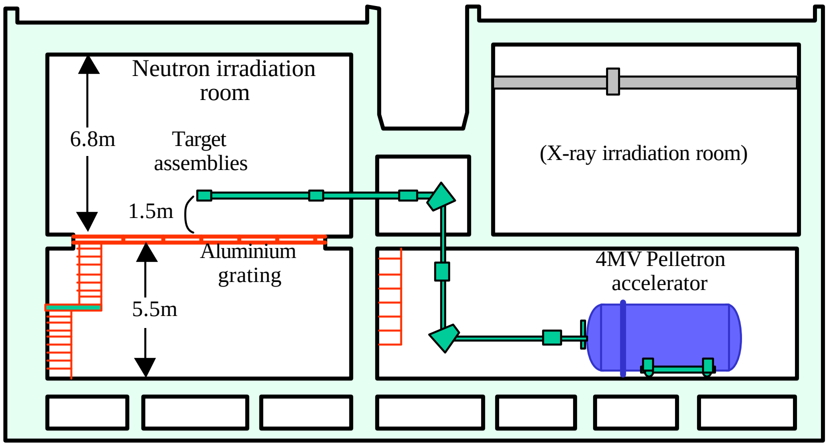


Fig.1 Cross-sectional view of neutron irradiation room and accelerator room at FCSN

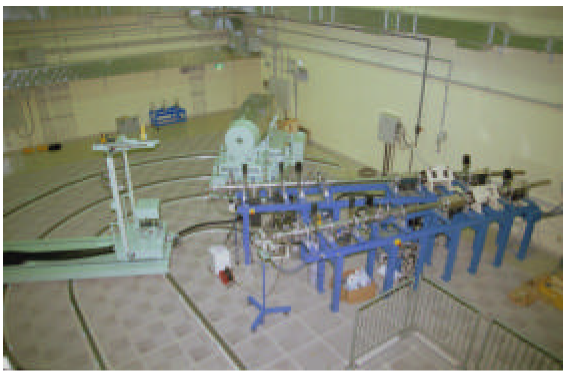

Fig.2 Photograph of neutron irradiation room at FCSN calibration field

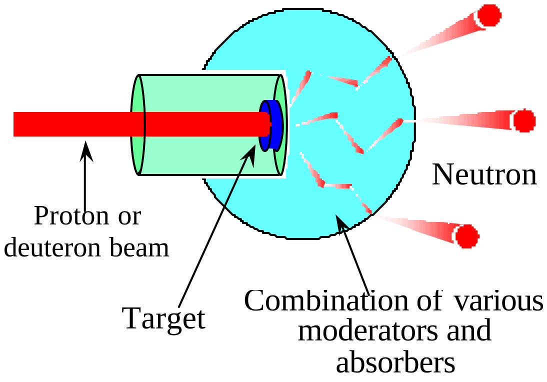


Fig.3 Conceptual view of target assembly
for spectrum-changeable neutron

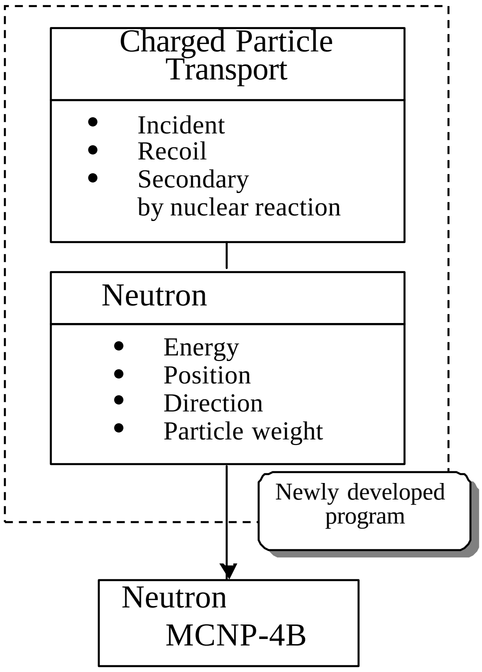


Fig.4 Outline of calculation flow of MCNP-ANT code system.