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CURRENT STATUS OF ACCELERATOR RADIATION SAFETY IN JAPAN

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INTRODUCTION

In Japan, a number of medium-to-high energy accelerators are now operating and under construction or planned for use in various fields. For electron accelerators, two big synchrotron radiation rings are at High Energy Accelerator Research Organization, KEK(2.5 GeV) and at Japan Synchrotoron Radiation Research Institute, JASRI(8 GeV). The B factory has just been operated at KEK. For hadron and heavy ion accelerators, the Institute of Physical and Chemical Research, RIKEN are now constructing the radioactive beam factory using heavy ion beams of separate sector cyclotron. For medical use, the heavy ion synchrotron, HIMAC has been operated at the National Institute of Radiological Sciences, NIRS and the similar synchrotron, HIMAC has been constructed at the Cancer Research Center of Hyogo Regional Government.

The proton therapy machines are now constructing at other three institutes. Very recently, the Japanese Government approved to construct the high-intensity proton accelerator complex of 3 GeV for intense neutron source and 50 GeV for nuclear/elementary physics as a joint project of KEK and Japan Atomic Energy Research Institute, JAERI. Fig. 1 shows the locations of there accelerators in Japan.

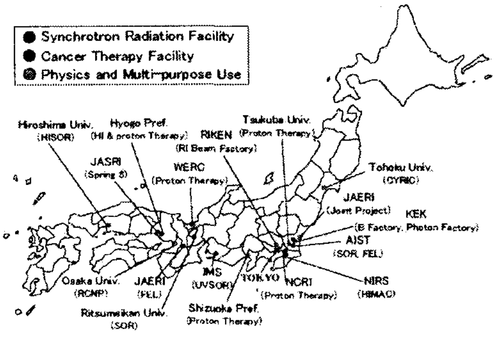


Fig. 1. Map of present and planned high-to- medium energy accelerator facilities

For the radiation safety of there high energy accelerator facilities, the shielding design is essentially important and the following items are necesary, that is, source term estimation, bulk shielding calculation, residual radioactivity evaluation, skyshine and streaming problems. Among of there items, the data on source term and residual radioactivity are especially needed for heavy ion projectiles. Our group(Tohoku Univ., KEK, RIKEN, NIRS) has been doing the systematic study on secondary neutrons and residual activities produced by high-energy heavy ions using the HIMAC and RIKEN accelerators. We have also done the neutron deep penetration experiments for bulk shielding at the ISIS synchrotron facility of Rutherford Appleton Laboratory, UK, and at HIMAC by using the newly-developed high-energy neutron spectrometers. The analytical formulas are presented to estimate the source neutrons produced by heavy ions and their transport through the bulk shield, skyshine and streaming.

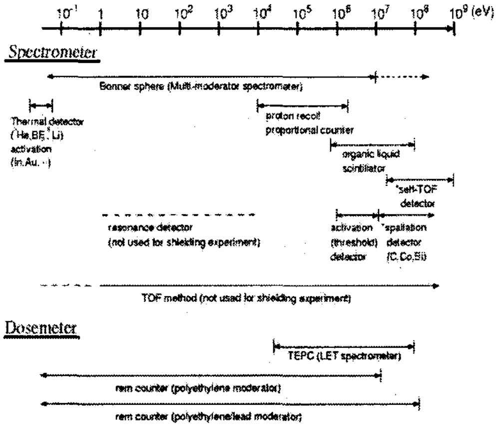
For operating there intense neutron-producing facilities, the exposure of radiation workers and possibly nearby inhabitants is also indispensably important; external exposure due to neutrons of strong penetrability and internal exposure due to residual radioactivities induced in air, underground water, soil and concrete. It has been quite needed to develop personal neutron dosemater for external exposure and the experimental data of their radioactivities induced by neutrons. We have also developed wide-energy range personal neutron dosemeters and started to measure the neutron cross sections of the elements in air, water and soil.

Here, in this paper, the newly-developed spectrometers and personal neutron dosemeters are presented.

HIGH-ENERGY NEUTRON SPECTROMETERS

Table 1 shows the neutron detectors in the present use[1]. Only multi-moderator spectrometer, Bonner sphere, has been widely used especially in the shielding and environmental measurements, since it cal detect neutrons over the wide energy range of thermal to MeV, despite of poor energy resolution. As seen in Table 1, there is a strong need to develop new neutron spectrometers in the high energy region above about 100MeV with better energy resolution. We have developed two types of high energy neutron spectrometers, 1)Bi Spallation detecter[2] and 2)self-TOF detector[3,4]

Table 1. Neutron detectors now in use



1. Bi spallation detector[2]

The neutron reaction cross sectins of Bi in the energy region from 20 to 210 MeV were measured by irradiating these samples in the p-Li quasi-monoenergitic neutron fields at INS(Institute for Nuclear Study, University of Tokyo), TIARA(Takasaki Ion Accelerators for Advanced Radiation Application, Japan Atomic Energy Research Institute) and RIKEN.

From the experiments, we could identify the radionuclides produced by ^{209}Bi(n,3n) to ^{209}Bi(n,12n) reactions. Fig. 2 indicates the cross section data of ^{209}Bi(n,2n) to ^{209}Bi(n,12n) reactions which have already been analyzed, in comparison with the ENDF/B-VI high energy file data calculated by the ALICE code.

Our data are generally in good agreement with them. This Fig. clearly shows that the excitation functions of Bi(n,xn) reactions have simple and similar shapes, and the threshold energies differ at about 8 MeV interval from 15 MeV up to 90 MeV, which indicates that these reactions are quite useful for high energy neutron spectrometry.

2. Self-TOF detector[3,4]

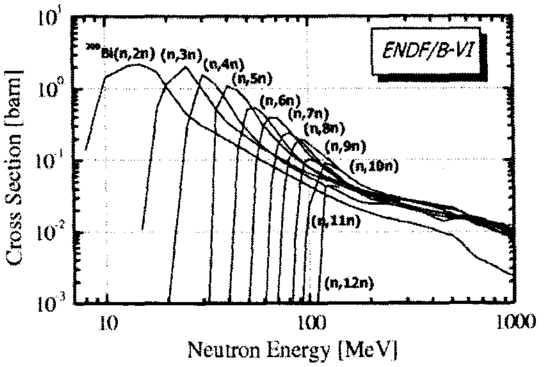


Fig. 2. Calculated cross section data of ^{209}Bi(n.xn) reaction(x=2～12)

We developed a new type detector, called 'Self-TOF detector', for high-energy neutron spectrometry behind shields. The Self-TOF detector consists of twenty pieces of radiator detectors(each 10cm × 10cm × 0.6cm), a start counter(10cm × 10cm × 0.5cm) and a stop counter of nine segments(each 20cm × 20cm × 5cm) composed of all NE-102A plastic scintillators. The schematic drawing of the detector is given in Fig. 3.

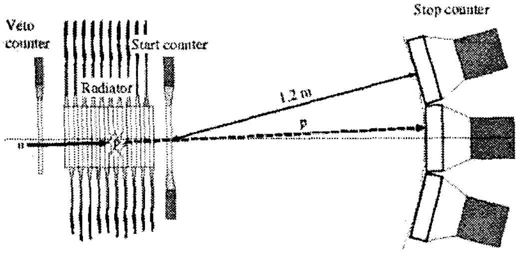


Fig. 3. Schematic drawing of the Self-TOF detector

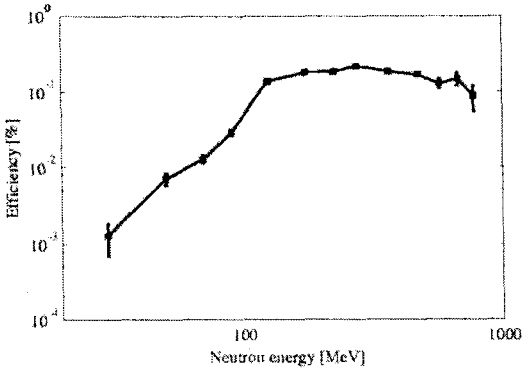


Fig. 4. @Neutron detection efficiency of the Self-TOF detector

An in-coming neutron produces charged particles in twenty radiators, and then the charged particles emitted in the forward direction reach any one of nine stop counters through the start counter. The energy of the charged particle is determined by using the TOF method between the start and stop counters. In this detector, we selected only proton events from H(n,p) and C(n,p) reactions to obtain the detector response function. The neutron energy spectrum can be obtained from the measured proton energy spectrum using the FERDO-U unfolding method with the response functions.

This detector has relatively high detection efficiency to high-energy neutrons, as shown in Fig. 4 and could give neutron energy spectra above 100 MeV with the energy resolution of 10 to 40%

PERSONAL NEUTRON DOSEMETERS

We have developed two types of wide-energy range personal neutron dosemeters, passive dosemeter using CR39 track detector and real-time dosemeter using two Si semiconductor detectors.

1. Si Semiconductor Dosemeter[5]

The dosemeter uses two silicon semiconductor detectors(a fast-neutron sensor and a slow-neutron sensor). The fast neutron sensor is a 10 ×10mm p-type silicon crystal on which an amorphous silicon hydride is deposited. The slow neutron sensor is also a 10×10mm p-type silicon on which a natural boron layer is deposited around an aluminum electrode to detect α and Li ions from the ^{10}B(n,α)^{7}Li reaction. Both sensors are in contact with 80μm-thick polyethylene radiators to produce recoil protons from the H(n,n)p reaction. The slow neutron sensor has some sensitivity for fast neutrons but is mainly used to measure neutrons with energy less than 1 MeV while the fast neutron sensor measures neutrons with energy in the MeV region. Fig. 5 show the external view of the commercial dosemeter.

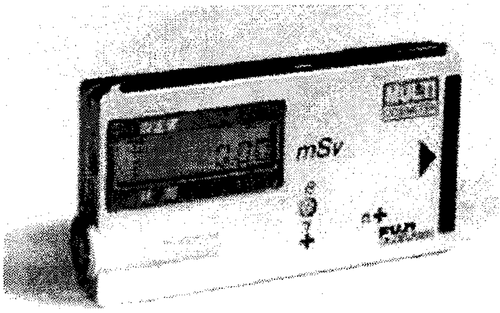


Fig. 5. External view of the multi-functional personal dosemeter NRN

The energy response of our dosemeter to neutrons was measured in the thermal neutron field at the Institute of Radiation Measurement (IRM), in a monoenergetic neutron field ranging from 8 keV to 15 MeV at FNL(Fast Neutron Laboratory) of the Department of Quantum Science and Energy Engineering, Tohoku University, and in a 22 MeV quasi-monoenergetic neutron field at CYRIC(Cyclotron and Radioisotope Center), Tohoku University. The responses of fast-and slow-neutron sensors to fluence as a function of neutron energy are shown in Fig. 6.

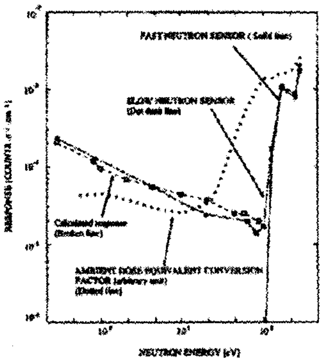


Fig. 6. Dosemeter response to fluence as a function of neutron energy with the ambient dose equivalent conversion factor described in ICRP 51

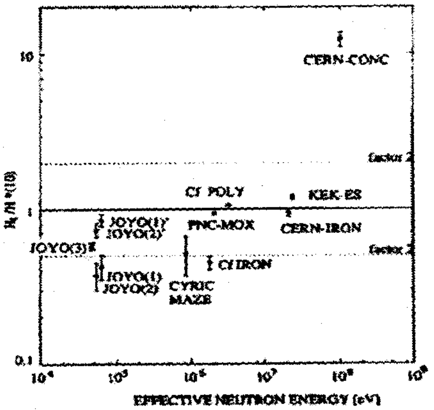


Fig. 7. Ratio of neutron dose equivalent Ht estimated by our dosemeter to the ambient dose equivalent H*(10)by the rem counter

The detector performance tests in actial neutron fields with various energy spectra were performed in the following six fields: (1) in a $^{252}C_f$ source field with iron or polyethylene moderator at CYRIC, (2) in the underground maze of the AVF cyclotron at CYRIC, (3) in the high-energy neutron reference fields behind the iron and concrete shields of the high-energy accelerator test facility at CERN, (4) on the outer surface of the concrete shield of the electron synchrotron (ES) at Tanashi Branch, KEK (High Energy Accelerator Research Organization), (5) close to the glove box of the MOX(Mixed Oxide) fuel handling facility at Tokai Works, PNC(Power Reactor and Nuclear Fuel Development Corporation), and (6) on the upper reactor pit of the experimental fast reactor 'JOYO' at O-arai Engineering Center, PNC. In these experiments, the dosemeter was always attached to the acrylic phantom.

The ratios of neutron dose equivalent Ht estimated by our dosemeter to the ambient dose equivalent, H*(10), by the rem counter at ten measuring points in these six neutron fields are shown in Fig. 7 as a function of the dose-weighted effective energy of these fields.

Based on these field tests shown in Fig. 7, we verified that our dosemeter estimates the neutron dose equivalent with a factor of 2 margin of accuracy except in a few cases.

2. CR39 Track Dosemeter[6]

The CR39 plastic has higher sensitivity than the NTA film for lower energy neutrons, however many background etch-pits appear on the surface of non-irradiated CR39 plastic. In order to depress this background contamination, we diminished it by dyeing the CR39 plastic before etching with a KOH solution. The number of background etch-pits per cm2 decreased about a factor of 10 after dyeing. The CR39 dosemeter is contacted with two kinds of radiators, one is a 0.2mm thick boron nitride for measuring low energy neutrons and the other is a 1mm thick polyethylene for measuring fast neutrons.

The energy response of the CR39 etch-pits behind the two radiators were measured with the monoenergetic neutron field in the energy range of 8 keV to 15MeV at FNL, graphite-moderated thermal neutrion fields at the Electro-Techinical Laboratory and IRM, and the quasi-monoenergetic neutron field of 22 and 33 MeV at CYRIC. In these experiments the dosemeter was also attached on a ellipsoidal water phantom.

Fig. 8 shows the weighted sum of the energy response of the dosemeter with two radiators, boron nitride(BN) and polyethylene (poly), in order to give a best fit to the ICRP publ. 51 response curve[7].

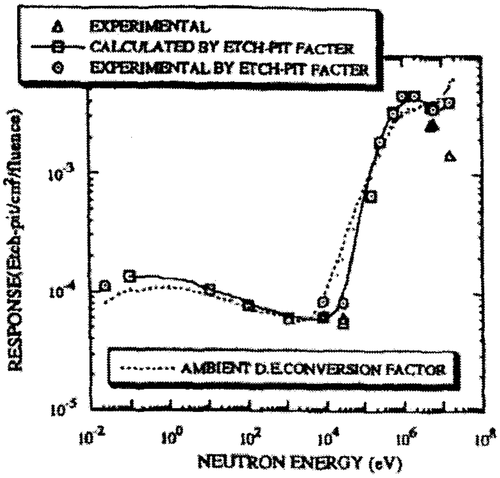


Fig. 8. Energy response of the wide-range CR39 dosemeter

The data at thermal, and 8 keV up to 15 MeV energies are the measured results (shown in white circles and triangles), and the data between thermal and 8 keV energies are the calculated results with the Monte Carlo method (in white squares). Good agreement between experiment and calculation can be seen and the energy response of this dosemeter well fits the ICRP publ. 51 response curve in the energy range lower than about 10 MeV. In order to improve the energy response above 10 MeV, the weighting factor was further increased only for the etch-pits having a diameter larger than 20μm, considering that the diameter of etch-pits increases with neutron energy. The thus-adjusted energy response of the dosimeter is also shown as white square signs in Fig. 8 and indicated much better agreement with the ICRP publ. 51 response curve above 10 MeV.

CONCLUSION

We have developed two types of high energy neutron spectrometers, and active and passive personal neutron dosemeters. The two spectrometers are now in use for neutron spectrometry at accelerator facilities and these two dosemeters is now commercially available.

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