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RADIATION SAFETY STUDIES AT TOHOKU UNIVERSITY CYRIC

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Abstract - A brief introduction is presented on the radiation safety studies at Tohoku University Cyclotron & Radioisotope Center. Studies on two subject are described; (1) measurement of the thick target neutron yield and radioisotope production / activation cross section for ten's of MeV neutrons and ions using K=110 Tohoku University cyclotron to provide basicdata for accelerator shielding, and (2) development of techniques for high sensitive radiation detection and profile measurement using an Imaging Plate which is a high sensitive two-dimensional radiation sensor. Application of the Imaging Plate techniques to localization of very weak radioactivity and to neutron profile measurement is described.

INTRODUCTION

The Cyclotron & Radioisotope Center of Tohoku University (CYRIC) is a joint research center of Tohoku University and consists of a cyclotron accelerator facility, apparatus for nuclear medicine and pharmacy and radioisotope laboratory [1]. Using the beams or radioisotopes provided by the cyclotron, research works are undertaken over wide areas from physics, engineering to life science. Research on the application of the positron emission tomography (PET) to nuclear medicine is one of the main activities in CYRIC. Recently, the cyclotron was upgraded in energy (K=110), beam current and beam species. Now proton energy is as high as 90 MeV, and beam current up to 300μA is planed for p,d ions using negative ions. Various heavy ions should be available. Using the intense beam, installation of an intense moderated neutron filed is also planned for applied purposes, like neutron capture therapy, and activation analysis and so on.

In Fig.1, shown is the layout of the cyclotron building of CYRIC. Beams accelerated by the cyclotron is transported to one of the five target-rooms (TR) which are equipped with each experimental apparatus. In the TR-1, a radioisotope production target is setup with an automatic sample transport system. In the room, a baby cyclotron (Ep = 12, Ed = 6 MeV) is also set up and used routinely for radioisotope production for PET. In the TR-3 and 4, beam courses and detectors for nuclear spectroscopy and material damage studies are equipped. TR-5 is used for neutron experinent using a beam swinger system and a neutron time-of-flight system.

In CYRIC, therefore, radiation management is one of the important tasks to ensure the safety of works conducted in the laboratory. In addition, research works are required to upgrade methods and techniques for radiation management. In particular, new devices having high sensitivity and/or spatial information is important for the purposes.

For the above reasons, we are conducting studies to upgrade (1) the data and method for accelerator shielding, and (2) the radiation detection technique required for safety management. The latter will provide new possibility also for application of radiations by extending the ability of radiation sensing.

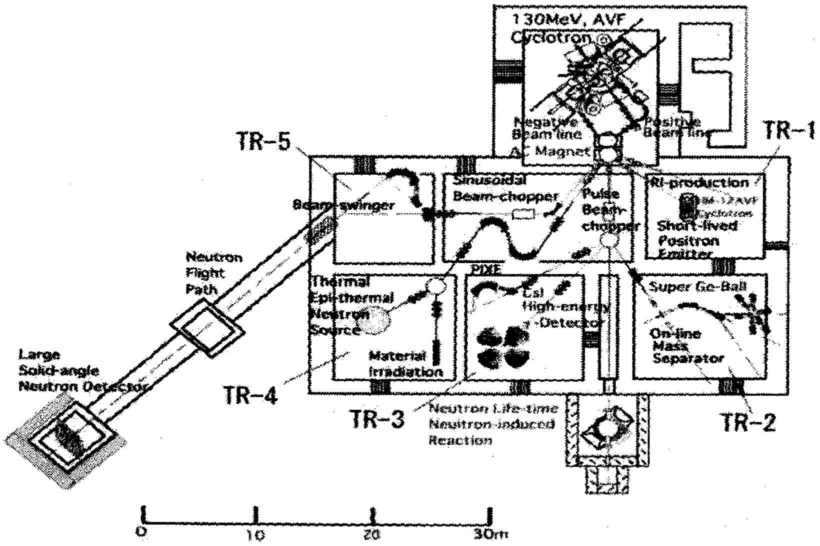

Fig.1. layout of the cyclotron building of CYRIC, Tohoku University [1].

MEASUREMENT OF NEUTRON EMISSION AND ACTIVATION CROSS SECTIONS

In the shielding design of medium- to high-energy accelerators, neutrons produced by the interaction of energetic ions with accelerator parts e.g., beam tubes in the beam transport system, activation of accelerator parts and building parts are the biggest concern because they are main sources of radiation dose inside and outside the building.

To reduce the radiation dose and cost of facility construction, it is important to establish the data base for neutron production from accelerator materials, and activation and/or radio-nuclide production by ions and neutrons in accelerator environment. However, experimental data that are useful for engineering purposes are very scarce, in particular for neutron-induced activation. It is the motivation of our experiment for neutron production and activation measurements.

1. Neutron Production Experiments

Experiments have been started using the TOF method in TR-5 that is equipped with a beam swinger system and a flight path up to 44 m. The swinger-TOF system is very effective for neutron emission measurements because it enables neutron angular-distribution measurement with detectors fixed in the neutron flight path. According to upgrading of the cyclotron, the beam swinger and related components were also modified.

Experiments are in progress at 50 MeV for the (p,n) reaction of C, Al, and Ta which are of great interest as a beam dump, low-activation accelerator components, and a neutron production target, respectively. Experiments are in progress also on the ^{7}Li, ^{9}Be(d,n) reactions at 20-40 MeV region which are required for the design of an intense neutron source for fusion reactor materials irradiation test, IFMIF. Angle dependent neutron spectra from thick targets are measured as a function of emission angle. At present, the measured neutron energy range is restricted above around 8 MeV or so, because a beam chopping system that reduces the beam pulse rate to the levels appropriate for TOF experiments is not available. By the completion of the chopping system, the measurements will be extended to lower neutron energy of a few MeV or lower. More details and experimental results are presented in another paper for this symposium (Aoki et al).

2. Activation Measurements

Neutron activation measurements are also carried out in TR-5. Activation samples are set inside the neutron collimator in the forward angle relative to the incident beam.

Measurements are in progress for C, Al, Cu using the ^{7}Li(p,n) source. The ^{7}Li(p,n) source is not purely mono-energetic but also associated with a continuous spectrum neutrons attributed to the multi-body breakup reactions. For the reason, activation due to non mono-energetic component should be corrected for. Therefore, the experiment is desirable to be performed step by step from low energy side to enable the background correction in a self-consistent manner. For the reason, experiments have been done for En=28, 45 and 65 MeV neutrons.

The activities are measured with a high pure calibrated Ge detector and the neutron flux on the sample is measured by the TOF method with neutron detector calibrated by the proton-recoil telescope [2].

Activation measurements for charged particle beams are of interest too because they are directly related to the activation of accelerator components. Activation for ion beams can be done efficiently in TR-1 using the sample-transfer system. More details and experimental results are presented in another paper in the symposium (Hagiwara et al.).

APPLICATION OF IMAGING PLATE TECHNIQUES

The imaging plate (IP) is a two dimensional radiation imaging sensor with very high sensitivity developed by Fuji film Inc. IP is based on the photo-stimulated-luminescence and has marked advantages compared with conventional X-ray films, 1) very high sensitivity by one to three decade, 2) very good spatial resolution down to 25μm, 3) larger dynamic range of sensitivity by more than two decade, 4) good linearity between the sensitivity and the radiation dose, 5) compatibility with computer processing because of digitized image data, 6) reusability, 7) freedom in sizes, 8) easy and short data handling, and so on [3-5].

Owing to these advantages, IP has been applied to various purposes on radiation detection. It has been used not only to photons but also for charged-particles and neutrons. It is very useful in the field of radiation safety because it enables detection and localization of very weak radiation that is difficult to detect with other conventional radiation detectors. IP has been applied for measurement of personal dose in medical fields and radiation detection in liquid radioactive waste [3-5]. It should be noted, however, that there exist a rather serious problem of fading, i.e, the decay of the data with time. This makes difficult the application of IP to accumulated dose measurement over a long period. Nevertheless, owing to its high sensitivity, IP has been successfully applied to personal dose measurement for short period [3-5].

In the following, several examples are presented which indicate the potentials of IP; 1) application of IP to detection and localization of radioactive contaminations, 2) measurement of spatial distributions of induced activity, and 3) measurement of neutron profile and spatial distribution.

1. Detection and localization of radioactive contamination

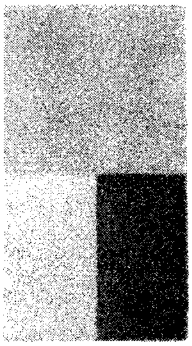

Fig.2. IP image for four Pb blocks

The high sensitivity and position sensitivity of IP is useful for finding and localization of radioactivity or radioactive contamination. In our case, we applied IP to identify a weakly contaminated Pb block which was used for shielding of a Geγ-ray detctor. The contamination was about 0.04 cps in the Ge spectrum which is too weak to identify with conventional detectors like GM counters, but disturbed the measurement seriously of low activity samples. For the measurement, IP of BAS-III type (20 cm×40 cm) was contacted to the Pb blocks in a light-tight black envelope for about twelve hours. The irradiated IP was scanned by the BAS-1000 analyzer and processed by MaxBAS (Ver.2).

Figure 2 shows and example of IP image for Pb blocks. The blacked image indicates the activities. In the figures, one Pb block proves to include appreciable amount of activities which was traced to be ^{210}Pb by the γ-ray spectra. The contaminated Pb block was identified by the black points in image

2. Spatial distribution measurement of induced activity

Measurement of spatial distribution of radiation is required frequently. Conventional radiation counters are not generally suitable for such purposes because of finite and fixed volumes. Imaging Plate is useful for such purposes because of its high sensitivity and position sensitivity. Its freedom in shapes is also great advantage. Therefore, IP provides a powerful tool for distribution measurement of weak activities which is difficult to detect by conventional detectors, e.g., activities in concrete wall for shielding. Such measurement will be important in the near future for clearance of radioactive wastes.

In figs.3, shown is an example of activity distribution measurement in concrete block (50 cm×50 cm×100 cm) which was used for shielding of the cyclotron beam transport system. This image was obtained by contacting IP to the concrete block for about four hours. The image indicates clearly the position dependence of activities.

Figure 4 shows similar image for a rack of accelerator equipment. The blackened area indicates the existence of activity induced mainly by secondary neutrons produced by impingement of the cyclotron beam. It should be noted that the density of the activity is too weak to detect by conventional counters but should be evaluated for waste management because of their large volumes.

It is desirable to know the absolute activity from the PSL (photo-stimulated luminescence) values of IP. For the purpose, studies are in progress on the relation between the activities and observed PSJ, fading and so on.

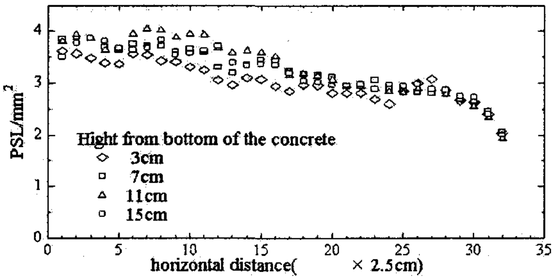

Fig.3: Activity distributions in concrete block.

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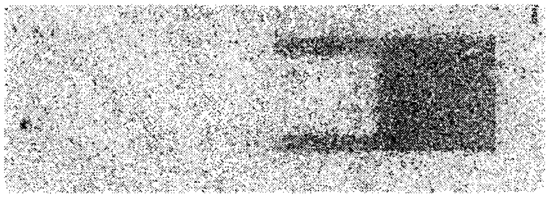

Fig.4. IP image for a rack of accelerator apparatus.

3. Measurement of neutron spatial distribution and profile

IP has no sensitivity to neutrons. Nevertheless, it can be used for spatial measurement of thermal and fast neutrons if appropriate converters are employed to convert neutrons to charged particles or photons. We have applied IP to neutrons in two ways: 1) combining IP with activation foils (^{197}Au), and 2) combining IP with polyethylene as a converter of fast neutrons to recoil protons.

In the first application, many gold foils were placed in the target room of a baby cyclotron in CYRIC used for isotope production for PET. Activities by the ^{197}Au(n,γ)^{198}Au and ^{197}Au(n,2n)^{196}Au were expected to detect thermal neutrons and fast neutrons, respectively.

Ninety-eight gold foils, 1-cm-diam by 0.1-cm-thick, were irradiated for two-hours during radioisotope production using 12 MeV protons of 27 μA. Foils with and without Cd covers were irradiated as a pair of foils. They were placed every 1.5 m. After cooling time of about 12 hours, the irradiated foils were contacted to a large IP keeping the relative location of each foil to project the activation to IP PSL. Therefore, the images in IP directly correspond to the spatial distribution of activities induced in gold foils. By this technique, neutron spatial distributions can be measured readily. Similar technique was applied by Toyoda et al. to measure concrete activities in a cyclotron room in KEK [6]. In the present measurement, activity due to ^{197}Au(n,2n)^{196}Au was too low to employ for measurement of fast neutrons.

Figure 5 shows the results of measured activity distributions. The figure indicates very clearly the spatial distribution of thermal neutrons, which can be used for estimation of activities induced in the concrete structures of the building. By taking the difference of images between foils with and without Cd cover, distributions of thermal and epi- thermal neutrons are obtained separately.

For fast neutron profile measurement, polyethylene plates were placed in front of IP. In this IP-CH2 configuration, IP detects recoils protons emitted from the polyethylene radiators by the H(n,p)n reaction which is most promising for fast neutron detection owing to the largest cross-sections and long range of protons in polyethylene. The latter makes possible to employ thick radiators to enhance the sensitivity. By taking the difference between data with and without a radiator, the effect of γ -ray backgrounds can be eliminated because of long penetrability of γ-ray s [7].

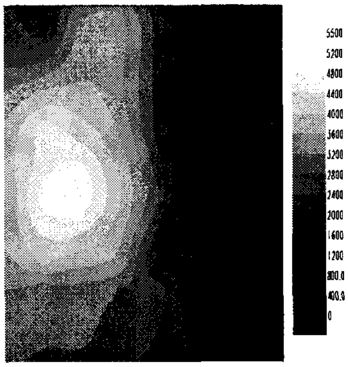

Fig.5. Thermal neutron distributions in cyclotron room.

We have studied the properties of IP-CH2 for 1) response to neutron energy, 2) fading property, 3) response to radiator thickness, 4) dynamic range, and for 5) spatial resolution. We observed that polyethylene radiators with thick ness close to the range of recoil protons are most effective, and spatial resolution less than 1 mm is achieved even for 5 and 15 MeV neutrons whose range is relatively long [7].

We applied IP-CH2 to fast neutron profile measurement and fast neutron radiography with appropriate parameters found in the test measurements. By the method, we measured the neutron beam profile of 5 to 15 MeV neutrons passed through a collimator, and radiography of bulk media for which thermal neutron radiography is difficult to apply.

We found further that it is possible to reduce the deformation of images caused by neutrons scattered in the media by separating the media from IP-CH2 detector [8]. The neutron scattering effect is more serious for fast neutrons than for thermal neutrons because of the much smaller absorption to total cross-section ratio.

Figure 6 shows an example of neutron images after step sample for 5 MeV neutrons: The image clearly corresponds to the thickness of the samples with little deformation. Therefore, IP-CH2 method is very promising for fast neutron profile measurement and radiography.

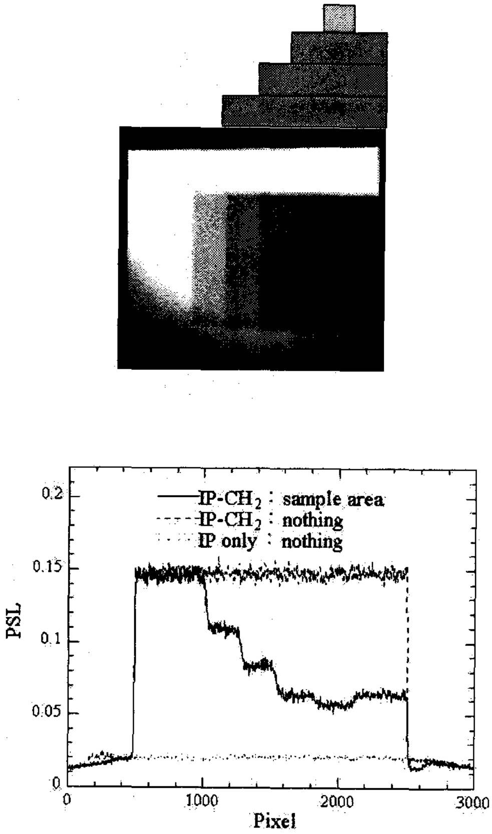

Fig.6. Fast neutron transmission image for step sample [8]

SUMMARY & OUTLOOK

A short summary is presented on the research works for basic nuclear data required for accelerator shielding and for application of Imaging Plate to radiation safety at Cyclotron & Radioisotope Center, Tohoku University. With the improvement of accelerator systems, the former experiments will be extended to other elements and to wider energy range both in incident and outgoing energies.

Imaging plate technique provides very powerful tool for detection and localization of radioactivity and radioactive contaminations that are difficult to find by other techniques. Further studies will be continued to develop the techniques.

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