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JAERI-Universities Joint Research Project on Radiation Safety in Proton Accelerator Facilities ----- Outline of the Project -----

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JAERI-Universities Joint Research Project has been carried out since 2000 in order to study the radiation safety in high-energy proton accelerator facilities. Eight research groups joined in the project to tackle three major subjects, using a quasi-monoenergetic neutron field at TIARA facility of JAERI. Cross section data of elastic scattering and light charged particle production were measured for several tens MeV neutrons incident to the elements composing the human tissue. Absorbed dose distributions in a PMMA phantom were measured to verify the results calculated by some radiation transport codes. A rem counter-type monitor with a lead breeder layer within its moderator was tested in 40-70 MeV neutron fields. A new method of dose measurement for neutrons with energies from a few MeV to 100 MeV has been developed applying the spectrum weighted function to a liquid organic scintillator. The energy response of neutron track detector and superheated drop detector was examined to develop a neutron dosimeter that is applicable to the energy region more than 20 MeV. In the study on internal dosimetry for airborne radionuclides, particle size distribution of radioactive aerosols and chemical forms of radioactive gases in the air were measured for irradiation of several tens MeV neutrons.

KEYWORDS: JAERI-Universities Joint Research Project, proton accelerator facility, radiation safety, dosimetry, cross section data, high-energy neutron, radiation monitor, dosimeter, radioactive aerosol, radioactive gas

I. Introduction

High-energy and high-power proton accelerators have been developed for use in various fields of study: nuclear physics, life science, material physics and medical applications. As an example, a MW-class proton accelerator complex has been under construction since 2001 as a joint project of the Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Organization (KEK), which includes an intense spallation neutron source, and 3 GeV and 50 GeV proton synchrotrons[1)]. Two other similar projects exist; one has started in the USA[2)] and the other is in the planning stage in Europe[3)].

As shown in **Fig.1**, the following exposure sources should be especially considered in such proton accelerator facilities, in addition to those encountered in conventional nuclear facilities. They are a) high-energy neutrons penetrating thick shield, b) airborne radionuclides generated in the radiation fields, and c) radionuclides induced in the accelerator materials, shield and soil. Some problems resulting from the above exposure sources should be resolved to ensure the safe operation of the facilities and protection of workers and members of the public.

Eight research groups, composed of members of two research institutes and five universities, were established in 2000 within the framework of JAERI-Universities Joint Research Project. They have been tackling three major subjects on radiation safety keeping a good teamwork at the TIARA facility of JAERI. The present paper describes the background and outline of the research project.

II. Characteristics of Exposure in High-energy Proton Accelerator Facilities

1. Exposure to High-energy Neutrons

A major portion of exposure in high-energy proton accelerator facilities is attributable to neutrons penetrating thick shield, which may have a very wide energy spectrum from thermal to GeV order. Knowledge of dose contribution in each energy band is necessary for appropriate dose estimation and efficient radiation control. A calculation was made to evaluate the dose contribution of neutrons that are generated by 3 GeV proton bombardment of an iron target and pass through a thick concrete and soil shield[4)]. Neutrons with energies less than 100 MeV give about 70 % of neutron effective dose, even in a 3 GeV proton accelerator. This means that it is sufficient for radiation protection purpose to focus on neutron energy range at most 100 MeV.

Whereas the methodology is already well established for calculating the dose of neutrons with energies less than 20 MeV, further studies are required for energy region over 20 MeV. Two different types of radiation transport codes can be used to calculate dose for neutrons with energies over 20 MeV up to 150 MeV. One is the conventional neutron transport code coupled with nuclear data library, such as the MCNPX code[5)] with the LA-150 library[6)]. The

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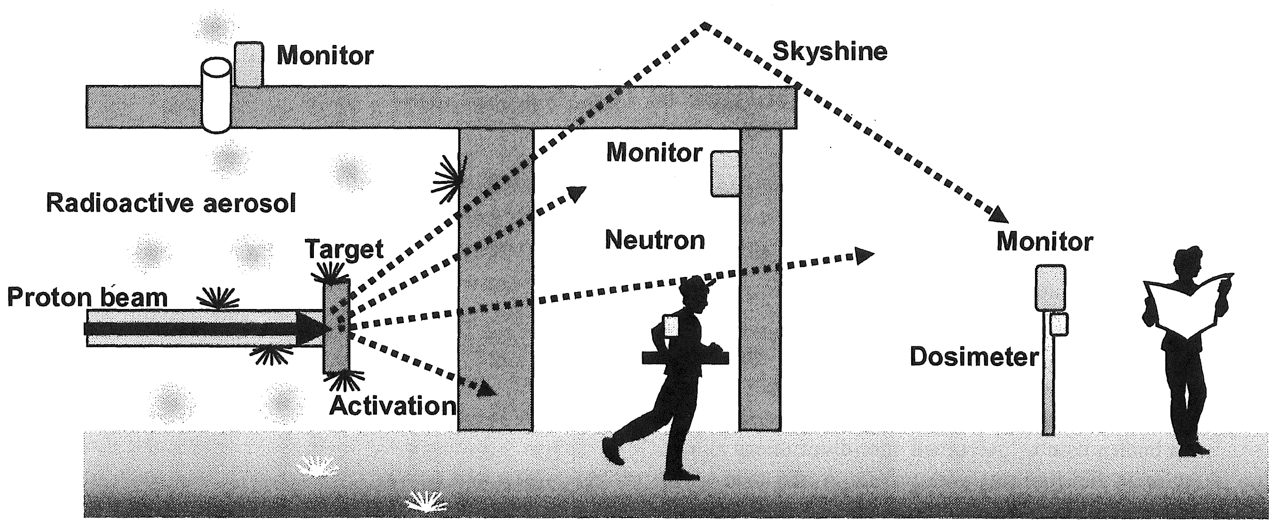

Fig.1 Major sources of exposure in high-energy proton accelerator facilities

other is the program to calculate both intranuclear cascade reactions and particle transport, such as the HETC-3STEP[7] and NMTC-JAM[8] codes. While the cross section data need to be verified in the former case, the applicability of the cascade calculation code to dose evaluation should be checked in the latter case.

2. Formation of Airborne Radionuclides and Dose Estimation

The air in the accelerator room and target room is exposed to primary proton beam and a variety of secondary particles in the high-energy proton accelerator facilities. As a consequence, various airborne radionuclides in aerosol and gaseous form are produced by nuclear spallation, which could cause internal exposure if they are inhaled into the human body. Physicochemical properties, such as particle size of the aerosol and chemical form of the gas, are key factors determining the internal dose because they influence significantly on transport, deposition and clearance in the respiratory and circulatory tracts in the body. Two important aspects should be pointed out; one is that the dose factor varies significantly with the particle size and chemical form, and the other is that smaller particles and more active gases are generated in the accelerator facilities than the reactor facilities. For this reason, it is quite important to obtain accurately these key data for realizing an economical design of ventilation system of the facilities as well as appropriate dose estimation for workers.

III. Outline of Joint Research Project

Considering the characteristics of exposure in the high-energy proton accelerator facilities, three major subjects were chosen for the joint research project. The followings outline the results of each research obtained in these three years from 2000 to 2002.

1. Dosimetry Studies for Neutrons of Several Tens MeV

The neutron dose calculation requires cross section data for charged particle production reactions in human tissues as well as neutron elastic scattering. Double differential cross sections were measured for neutrons of several tens MeV, incident to the principal tissue elements: carbon, oxygen and nitrogen[9-11]. The measurement was directed to the production of light charged particles: proton, deuteron, triton and α–particle. The results were compared with other experimental data and the LA-150 library[6]. It was found that the library does not represent the results for deuteron production reaction, while it does well for production of the other particles. A Bragg Curve Spectrometer (BCS) was developed to measure the production efficiency and energy of heavy particles or fragments due to neutron bombardment of several tens MeV[12].

Absorbed dose distributions in a PMMA phantom were measured for the incidence of 40 and 65 MeV quasi-monoenergetic neutrons and compared with the results calculated by some radiation transport codes such as MCNPX and NMTC/JAM. An agreement was observed between them within 20 %. It was concluded from this result that the method used here can be generally applied to dose calculation for neutron incidences of several tens MeV[13]. It was also found from another experiment[14] that the TEPC has a good sensitivity to measure the neutron absorbed dose and dose equivalent based on lineal-energy distribution in this energy region.

2. Development of Neutron Monitors and Dosimeters

The energy response of the conventional neutron rem monitor has been improved for energy region over 20 MeV by inserting a lead layer in its polyethylene moderator[15].

The lead layer works as a neutron breeder by multi-neutron production reaction in high-energy region. It was found from tests in some neutron fields that the improved monitor has a good energy response and performance over a wide energy range from thermal to 150 MeV. This neutron rem monitor will be installed in the facilities of the first term of the J-PARC Project.

A new method for neutron dose rate measurement has been developed using an organic liquid scintillator coupled with a spectrum weighted function (G-function)[16]. It was found from experiments in some neutron fields that the ambient dose equivalent can be evaluated directly by this method in the energy range from a few MeV to 100 MeV. Efforts have been made to get down the lower energy limit of the detector to the thermal energy region and two ideas were tested for this purpose. One is to load ^{10}B into the organic liquid scintillator, which is expected to have a role of moderator for intermediate energy neutrons and α production by ^{10}B $(n,\alpha)^{7}Li$ reaction of moderated neutrons[17]. The other is to combine the liquid scintillator with a ^{6}Li glass scintillator, which is also expected to detect moderated neutrons by ^{6}Li $(n,\alpha)^{3}He$ reaction[18]. Both of them are not definitive and another attempt is still being made.

The characteristics of plastic track detectors were investigated in some high-energy neutron fields. Three types of detectors: pure CR-39, TD-1 (CR-39 containing an antioxidant) and TNF-1 (co-polymer of CR-39 and NIPAAm), were examined and TD-1 was found to be the most promising element from viewpoints of detection efficiency and smoothness of post-etched surface[19]. Four materials: CH_2, CD_2 (deuterized hydrocarbon), LiF and C, were examined experimentally and theoretically as a radiator to improve the detection efficiency[20]. Based on this analysis, an idea of two-layer radiator has been proposed to adjust properly the energy dependence of the detector.

The response of superheated drop detectors or bubble detectors was measured in some neutron fields of 40-75 MeV[21]. It was found from the experiments that the detectors have about half as much sensitivity as nominal one even in this energy region. The experiment showed that a lead-breeder around the detector can improve the sensitivity up to the nominal.

3. Study on Physicochemical Properties of Airborne Radionuclides

The mechanism of radioactive aerosol formation was investigated by irradiating argon gas containing di-octyl phthalate (DOP) or NaCl aerosols by 45 or 65 MeV quasi-monoenergetic neutrons. The size distribution of ^{38}Cl and ^{39}Cl aerosols was analyzed[22, 23]. It was found from analyses that ^{38}Cl and ^{39}Cl aerosols are formed by attachment of the radioactive atoms generated by neutron irradiation to non-radioactive aerosol particles. No significant dependence of neutron energy was observed in the formation of the aerosol.

IV. Conclusion

Eight research groups from JAERI, KEK and five universities engaged themselves in research on radiation safety in proton accelerator facilities for three-year period of 2000-2002. They tackled three major subjects keeping a nice teamwork and obtained good results, which must be useful for dose estimation in and around the facilities. Industry groups are going to join the joint research activities and more practical progress is expected in the next phase of the project.

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