4 - 9 Modified Simulation Method for Delayed Gamma Spectra from Proton Irradiated W Target

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In the study of accelerator driven systems (ADS), which are capable of transmutation of minor actinides and long-lived fission products[1], activation and radiation exposure analyses are among the most important aspects for radiation safety and protection of ADS, especially for the spallation targets.

When spallation targets are irradiated by protons, hundreds of radioactive residues are produced. To estimate the possible radiation exposure, one common way is to simulate photon fluence at a given position using Monte Carlo simulation code, then calculate the effective does by applying fluence-to-dose conversion coefficient provided by the International Commission on Radiological Protection publications[2]. In order to verify the feasibility of simulation method in terms of the delayed gamma spectra and measured exposures, a natural tungsten target was irradiated experimentally and simulated by 250 MeV protons in this study, the parameters related to the experimental measurements as shown in Table 1.

Table 1 Parameters related to the experimental measurements.

Energy/MeV	Proton number	Irradiation time/s	Cooling time/t_c/h	Time of measurement/t_d/s
250	1.296×10^{12}	82547	4.7	3211

There is a big difference between the measured and the simulated with common way. Then a more accurate method was developed for the simulation of delayed photons and estimation of exposures caused by spallation residues. The modified method was validated by the experimental results and was conducive to improve radiation safety and protection of ADS.

I Experiment and calculational methods

Irradiation experiment was conducted with 250 MeV proton beam at the HIRFL - CSR in China. In the experiment, a natural tungsten target with 100 mm in diameter and 0.15 mm in thickness was bombarded by the proton beam. The irradiation time was lasted about 23 h to get sufficient statistics. The protons number of the beam was determined to be about 1.296×10^{12}[3]. In the measured γ-spectra, the photon count rates were provided for gamma rays at different energy bins.

The gamma spectra simulation was conducted by Monte Carlo program FLUKA and MCNPX. Firstly, a model, shown in Fig. 1, was built first using the FLUKA 2011.2C.3 code to simulate the spallation process of the tungsten target[4]. In the FLUKA model, the time evolution of spallation products in the region defined by the geometry of the object was recorded. Then, a model for the HPGe probe was built by using the MCNPX 2.7.0 code[5] to score the gamma spectrum from the activated foil, in which the unstable isotopes were obtained from the FLUKA simulation results.

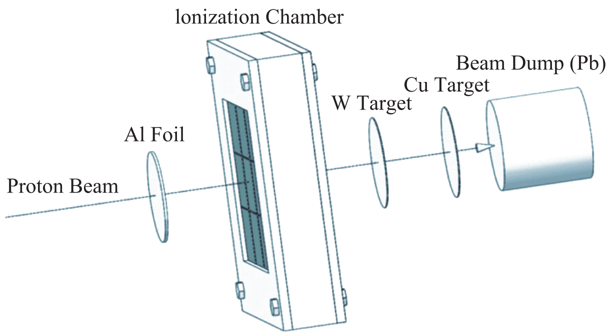

Fig. 1 (color online) The schematic diagram of the experimental setup.

II Results and discussion

Activities of induced radionuclides in tungsten foil were calculated by FLUKA2011.2c.3 as shown in Fig. 2. Then delayed gamma spectra were simulated by MCNPX2.7.0 with CINDER90 database (the gamma delayed data of MCNPX). The results are shown in Fig. 3. Obviously, there is a big difference between the measured and the simulated delayed gamma spectra.

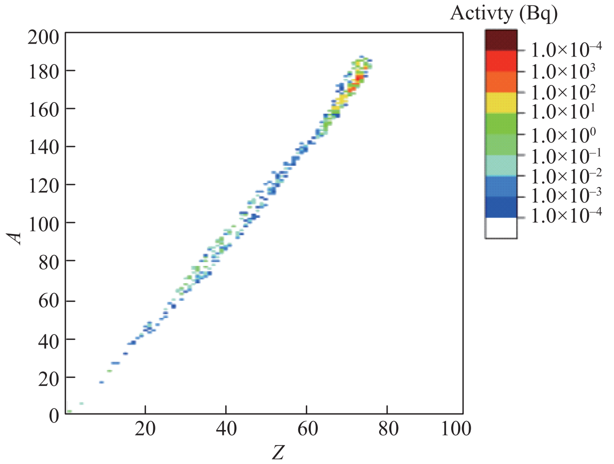

Fig. 2 (color online) The activities of induced radionuclides in tungsten foil.

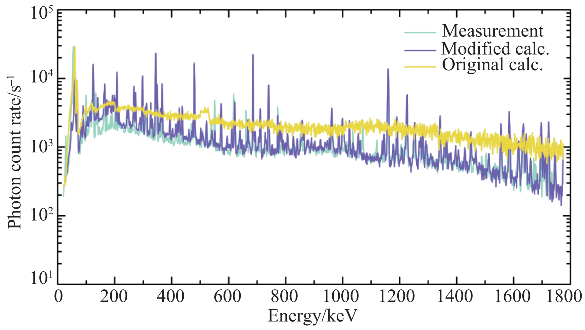

Fig. 3 (color online) Calculated results of gamma-spectra of 250 MeV proton beams on tungsten target.

It is found that most of the residual nuclides were processed based on the 25-group data in the simulation rather than gamma peaks information from CINDER90 database. This is the main reason for the difference between the measured and calculated results. Since the line emission is useful for studies which require high fidelity, detailed amplitude emission signatures, the database for gamma peaks should be modified to give more accurate simulation results.

In order to improve the database, delayed photon information of missing nuclides, such as half-life, emission photon energy, branching ratio, and average decay energy, that are provided by Nuclear Data Services were written into CINDER90 database. With this modified database, the delayed gamma spectra from the irradiated tungsten target were recalculated and shown in Fig. 3. Compared to the estimations based on the default CINDER90 database and the experimental observations, the modified delayed gamma spectra are improved to a great extent and well consistent with the measured spectra.

To study precisely the radiation safety and protection problems for these different targets, the database for MCNPX modeling should be modified accordingly. With the default database, the ADS shielding design would be more conservative than that with modified database. This could provide an effective way to improve and optimize the shielding design of ADS facilities.

References

[1] H. Nifenecker, O. Meplan, S. David, Accelerator Driven Subcritical Reactors. UK: Institute of Physics Publishing Bristol And Philadelphia, (2003).

[2] International Commission on Radiological Protection. ICRP Publication 74: Conversion Coefficients for use in Radiological Protection against External Radiation. Ann ICRP Volume 26(3/4); 1996.ISSN 0146-6453.

[3] Y. Q. Ju, X. Y. Zhang, F. Ma, et al., Journal of Physics G: Nuclear and Particle Physics, 42(2015)125.

[4] A. Ferrari, P. R. Sala. FLUKA: a multi-particle transport code, European Organization for Nuclear Research (2014) CERN-2005-010.

[5] D. B. Pelowitz, MCNPX User's Manual, Version 2.7.0. Los Alamos National Laboratory; 2011. LA-CP-11-00438.