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Estimation of the Secondary Neutrons Production at the Proton Irradiation Test Facility

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1. Introduction

TR102 is the one of the 100 MeV proton irradiation facility at the KOMAC (Korea Multi-purpose Accelerator Complex) in the Republic of Korea, which is specialized in use the radiation effect testing of the electronics. The TR102 facility can provide the 100 MeV proton beam to the DUT (Device Under Test) with proton flux of 10^6 ~ 10^8 [#/cm^2-sec]. The unique feature of TR102 facility is the capability of providing the sufficient large beam area appropriate for various size DUT's, the area of square-like proton beam is up to the maximum 150 mm × 150 mm in limited condition, is normally 100 mm × 100 mm with 10% spatial uniformity. Figure 1 and 2 introduce the TR102 facility and the typical beam profile of the incident proton beam at DUT position.

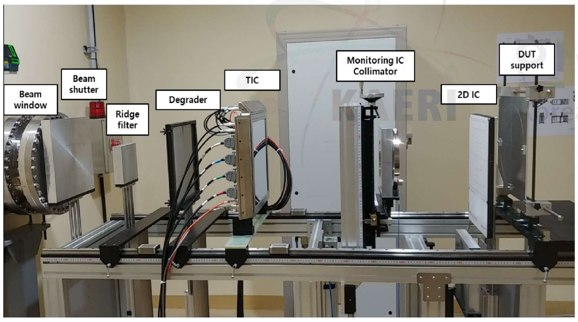

Fig. 1. TR102 radiation effect test facility at KOMAC

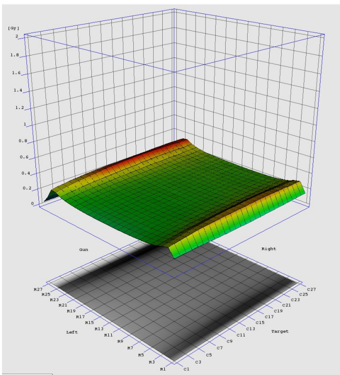

Fig. 2. The typical beam profile of proton beam at TR102 facility.

During the radiation effect testing of electronics use in the proton beam, the contamination of secondary neutrons is inevitable. Because secondary neutrons are the byproduct of the proton beam interacting with matter. During the radiation effect test of electronics, the beam irradiation apparatus become the source of secondary neutron production, such as collimating aperture, the energy degrader, the DUT fixture, the DUT itself and the final beam stop [1].

The secondary neutron produced by 100 MeV proton beam have a spectrum which its energy is from thermal to 100 MeV as below mentioned in figure 3, neutrons of several MeV are dominant. Neutrons in two energy ranges are of particular concern, Neutrons with energies above 20 MeV have a similar SEE cross-section as protons of the same energy [2]. Therefore, these energy of neutrons can cause the SEE in the DUT directly and then, contributed the unexpected soft error data.

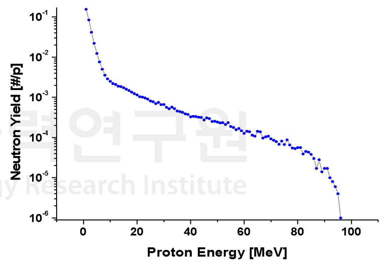

Fig. 3. the energy spectrum of the neutron induced by 100 MeV proton.

The other concerned neutron is those with energies ranging from 0.025 eV to 10 eV, can interact with ^{10}B, which have a huge absorption cross-section with thermal neutron and an isotope of boron used inter fabrication of some chips. This nuclear reaction produces the secondary products with sufficient energy to cause SEE effects in these chips [3].

In this paper, the spatial distribution of secondary neutrons in the TR102 facility and the average flux of secondary neutrons can effect on the DUT are estimated by the monte-carlo method. The calculation investigated with two cases:

1) Total area irradiation of DUT

There is no irradiation apparatus between the proton beam window and DUT. In this case, the proton beam window, the DUT itself and the final beam stop are the source of the secondary neutrons. .

2) Defined area irradiation of DUT

There is the collimating aperture in front of the DUT, which is used to define the beam area for the irradiation of the concerned chips and block the proton beam for the protecting the local part of DUT. In this case, the another source of secondary neutron is added, the contamination of secondary neutrons will be increase more than case 1.

2. Methods and Results

To estimate the spatial flux distribution of the secondary neutron induced by interaction between proton and the apparatus in TR102 facility, the simplified calculation model was established. The proton beam irradiation apparatus consists of the proton beam window, collimating aperture, DUT and final beam stop. And then, they are enclosed the 1 m thick concrete wall which the size of the inner space was 4 m(W) × 4 m(L) × 3 m(H). the simplified calculation model constructed by MCNPX code, is shown as figure 4.

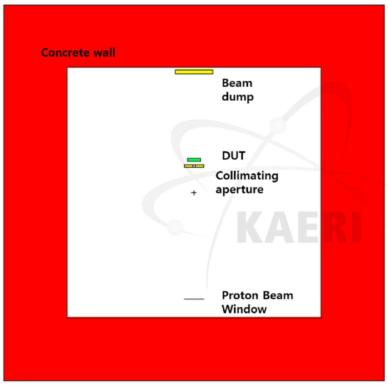

Fig. 4. the calculation model of MCNPX code

100 MeV Proton is extracted from the AlBeMet beam window, propagated the opposite side of the target room. The proton beam is finally dumped at the beam stop which located at the end of wall, after pass through the collimator and DUT. The materials and dimensions of the apparatus which is used in MCNP modeling are summarized as Table 1.

Table 1. Modelling parameters of TR102 facility

Component	Materials	Thickness
Beam window	AlBeMet (Al: 38wt%, Be: 62 wt%)	0.5 mm
Collimator	Aluminum	50 mm
DUT	Si	5 mm
Beam stop	Aluminum	60 mm
Enclosure	Concrete	1000 mn
Inner space (Air)	Void	-

For the calculation, the incident proton energy was assumed with 100 MeV, the average current was 10 nA. the uniform distribution and dia. 20 cm of the beam profile was assumed.

The total neutron flux at the DUT cell calculated by using the f4 tally card of MCNPX, so the flux of neutrons calculated with averaged over DUT volume with two case of with and without collimating aperture. And then, total flux of neutron at the DUT cell was separated into the 5 energy bins by E card of MCNPX. The contribution of the thermal neutron and neutrons with above 20 MeV were investigated.

For the calculation of the spatial distribution of secondary neutrons, the inner space of TR102 target room was divided by 5 cm cubic cell. The neutron flux was scored with a track averaged over unit cell by TMESH card of MCNPX in two case of the with and without the collimating apertures.

2.1 Secondary Neutron flux at the DUT

The neutrons in range from 0.025 eV to 10 eV and above 20 MeV can cause the additional SEE effect on the DUT. Therefore, the averaged neutron flux was calculated during the proton beam with 10nA average current. The calculation results are shown as Table 2.

In the case of the total area irradiation of DUT, which there is no the collimator in front of DUT, the total neutron flux over all energy was estimated by 4.92 ×10^6 [#/cm^2-sec]. at that time, the flux of primary proton beam was 1.99 × 10^8 [#/cm^2-sec]. the flux of the neutrons with energies from 0.025 eV to 10 eV was 2.32× 10^4 [#/cm^2-sec]. Very low Energy or thermal neutrons have the small portion compare to the flux of primary proton beam.

Table 2. The calculated secondary neutron flux at the DUT

Energy bin	Neutron flux with collimator [#/cm2-sec]	Neutron flux without collimator [#/cm2-sec]
< 0.025eV	6.32E+03	5.37E+03
0.025 ~ 10 eV	2.61E+04	2.32E+04
10 eV ~ 1 MeV	1.63E+06	1.37E+06
1 ~ 20 MeV	2.69E+06	2.45E+06
20 ~ 100 MeV	1.60E+06	1.07E+06
Total	5.96E+06	4.92E+06

But the flux of the neutrons with above 20 MeV was 1.07× 10^6 [#/cm^2-sec]. this flux of neutrons is about 1/200 amount compare to the flux of primary proton beam. That means, in this case secondary neutron can cause the about 0.53% of additional error at the total soft error which is induced by proton in the device under test.

Another case of calculation shows the effect of collimating aperture. the total neutron flux over all energy was estimated by 5.96 ×10^6 [#/cm^2-sec] which is increased about 21% compare to the first case. the flux of the neutrons with energies from 0.025 eV to 10 eV was 2.61×10^4 [#/cm^2-sec]. this increment is considered to be not essential. But the flux of neutrons with energies above 20 MeV was estimated by 1.6×10^6 [#/cm^2-sec] which is increased about 49.5% compare to the first case. This neutron flux can add the 0.8% of additional error at the total soft error which is induced by proton in the device under test.

2.2 Spatial distribution of secondary neutrons

The spatial neutron flux was estimated by track averaged mesh tally card of MCNPX to obtain the guidance for minimizing the effects of the secondary neutrons. Figure 5 shows the spatial distribution of secondary neutrons in the TR102 facility in case of the without the collimator. The most of neutrons are distributed in the between the DUT and the final beam stop. this results imply that the main source of the secondary neutron is the DUT itself and the final beam stop. therefore, to reduce the contamination induced by secondary neutron, it is recommended that the location of DUT have to be far from the final beam stop.

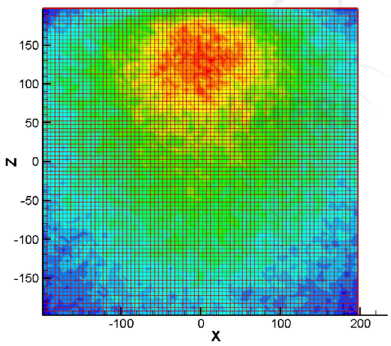

Fig. 5. the spatial distribution of secondary neutrons in the TR102 facility without the collimator

Figure 5 shows the spatial distribution of secondary neutrons in the TR102 facility in the case of the defined area irradiation of the DUT (with the collimator). One more hot spot of the secondary neutrons was created which neutrons are distributed in the between the collimator and DUT. As mentioned above, the collimator become the another secondary neutron source. Therefore, the insertion of the collimator in front of DUT cause the contamination of secondary neutrons to be increased.

But during the radiation effect testing of electronics, the use of the collimator is essential for screening the other components on the DUT circuit board against proton beam. If the collimator can be located far from the DUT, the alignment between DUT and the collimating aperture will be difficult. Therefore, in this case it is proposed that use the new material of collimator and beam stop which have the lower neutron yield than the aluminum such as graphite, HDPE (high density polyethylene). For reducing the secondary neutron contamination, another option is the insertion of the additional neutron absorber at the behind the proton beam scraping apparatus. The neutron absorber can be consisted of the combination of neutron attenuator such as the HDPE and thermal neutron absorber such as the cadmium. Through the further study, the optimization of the proposed options to minimize the neutron contamination will be reported.

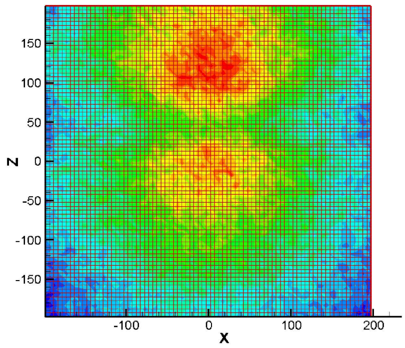

Fig. 6. the spatial distribution of secondary neutrons in the TR102 facility with the collimator

3. Conclusions

The neutron flux in the DUT and spatial distribution of the secondary neutron in the TR102 facility was investigated during the proton beam irradiation. In the case of the defined area irradiation of DUT, it is revealed that about <1 % of the additional soft error can be contributed by the secondary neutron. To minimize the contamination of secondary neutron during the radiation effect testing of electronics, the location of DUT have to be modified with far from the final beam stop. and the lower neutron yield material have to be used in collimator.

Acknowledgement

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