Neutron dose equivalent rate for heavy ion bombardment

Li Gui-Sheng, Zhang Tian-Mei, Li Zong-Wei, Su You-Wu and Zhang Shu-Min
(Institute of Modern Physics, the Chinese Academy of Sciences, Lanzhou 730000)

Abstract The fluence rate distribution of neutrons in the reactions of 50 MeV/u ^{18}O-ion on thick Be, Cu and Au targets have been measured with an activation method of threshold detectors and the neutron dose equivalent rate distributions at 1 m from the targets in intermediate energy heavy ion target area are obtained by using the conversion factors from neutron fluence rate to neutron dose equivalent rate.

Keywords Heavy ion reactions, ^{18}O-ion, Neutron dose equivalent rate

1 Introduction

The exact dose equivalent measurement of neutrons with energy greater than 14 MeV is a rather difficult problem in radiation protection. The energies of neutrons emitted from intermediate energy heavy ion reactions are rather high, the energy of most neutrons is over 20 MeV and the maximal neutron energy could reach twice incident ion energy per nucleon, most neutrons, particularly high energy neutrons, are emitted in the forward direction of 0° to 60° solid angles.[1~3]

Due to the existence of a vast amount of high energy neutrons the dose in intermediate energy heavy ion target area is quite high, which is produced mainly by neutrons. Therefore, exact measurement of the neutron dose equivalent rate in heavy ion target area is an important topic.

Neutron-Rem meter is a most useful instrument in routine dose survey, but these instruments are limited to energies from a few keV to about 15 MeV. The deviations of the sensitivity curves of Rem meters from the dose equivalent curves specified by the ICRP amount to as much as a factor of 5 or even more in the intermediate energy region, particularly in the high energy region[3~5] (see Fig.1). Therefore, the direct reading of Rem-meter must be corrected when measuring the intermediate and high energy neutron dose equivalent using a Rem-meter to obtain the real dose equivalent value.[3,6]

At present, the Rem-meter is calibrated by using an isotope neutron source for the low energy (E_P <20 MeV/u) heavy ion reactions in some heavy ion laboratories in the world, but the response of Rem-meter to E_n >20 MeV neutrons is not known and not calibrated too.[7~10] In the National Laboratory of Heavy Ion Accelerator, Lanzhou, we have used not only the correction factor method[3,6], but also used the activation method of threshold detectors to measure the neutron dose equivalent produced by the intermediate energy heavy ion reactions, the latter avoids the inconvenience caused by the Rem-meter energy response

2 Measurement principle

It is feasible that some suitable threshold detectors with suitable threshold energy is chosen to measure neutrons with different energies. The ^{27}Al. ^{19}F, ^{11}C and ^{27}Al could be used to measure neturons with energy over about 7, 11, 20 and 50 MeV as threshold detectors by threshold reactions of ^{27}Al(n, α)^{24}Na, ^{19}F(n, 2n)^{18}F, ^{12}C(n,2n)^{11}C and ^{27}Al(n, 4p6n)^{18}F, respectively. The parameters of detectors used in this study are the same as Ref.[11]

Neutron dose equivalent rate distributions in the intermediate energy heavy ion target area could be obtained approximately by using the conversion factors from measured neutron fluence rate to neutron dose equivalent rate.[12]

3 Experimental

The experiment was carried out in the rapid chemistry terminal area at HIRFL. A 50 MeV/u ^{18}O-ion beam passes through a hole in concrete shielding wall, then through a pair of quadrupole lenses and a collimating slit to a thick target, the thickness of which was slightly greater than the range of heavy ions in the target, and was completely stopped in the target and a copper beam stopper, and was collected and recorded by a beam integrator. The layout

*The Project Supported by National Natural Science Foundation of China with Contract No 19575053
Manuscript received date: 1998–01–01

of threshold detectors around the target is the same as shown in Fig.2 of Ref.[11].

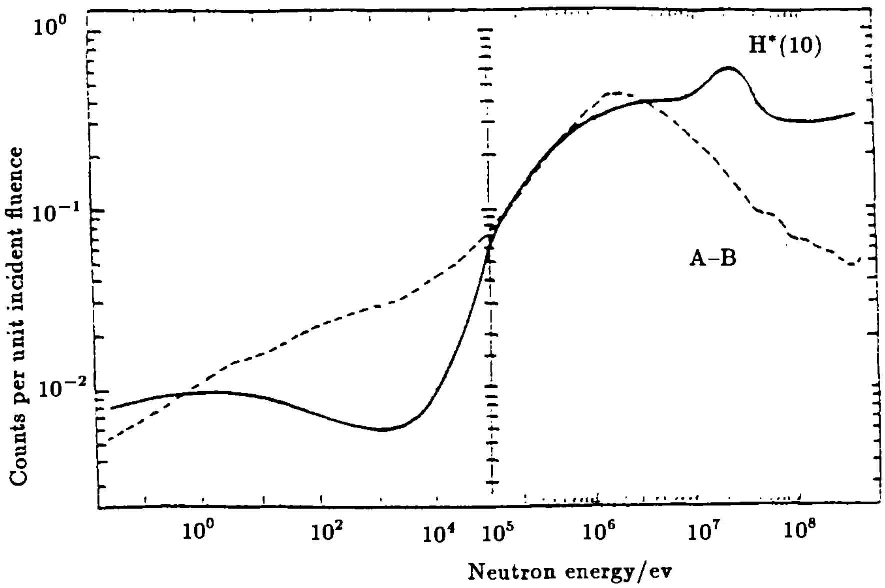

Fig.1 The H*(10) curve and the response curve of the standard A-B Rem-meter

All threshold detectors were disks shaped and previously cleaned with alcohol liquid and put into clean sample cells. The sample cells were located on a horizontal platform around the target and at 1 m from the target, and were irradiated in the radiation field of neutrons emitted from the reactions of 50 MeV/u ^{18}O-ion on thick Be, Cu and Au targets, respectively. The platform was at a side of the beam tube and its height was equal to that of the beam tube.

The irradiated activities of detectors were measured by an analysis system composed of a pc-multichannel analyser and a HPGe detector. The efficiency of the system was calibrated using a ^{152}Eu standard γ-source.

4 Results and discussion

Measured neutron fluence rate distribution at 1 m from the target with energies over 7, 11, 20 and 50 MeV, respectively, emitted from the reactions of 50 MeV ^{18}O-ion in thick Be, Cu and Au targets are shown in Table 1.

Table 1 Neutron distributions at 1 m from the target

Reactions	Neutron energy	$\overline{\varphi}$, $n \cdot cm^{-2} \cdot s^{-1} \cdot nA^{-1}$ 0°	30°	60°	90°	120°	150°
50 MeV/u ^{18}O + Be	>7 MeV	2.59×10^4	1.06×10^4	2.92×10^3	8.01×10^2	4.29×10^2	3.09×10^2
	>11 MeV	1.88×10^4	5.66×10^4	9.45×10^2	2.72×10^2	1.01×10^2	7.57×10^1
	>20 MeV	1.21×10^4	2.16×10^3	3.41×10^2	8.67×10^1	3.73×10^1	1.97×10^1
	>50 MeV	3.43×10^3	1.13×10^3	2.28×10^2	3.59×10^1	1.49×10^1	7.06×10^1
50 MeV/u ^{18}O + Cu	>7 MeV	8.74×10^3	4.42×10^3	1.89×10^3	6.81×10^2	4.60×10^2	3.23×10^2
	>11 MeV	6.41×10^3	2.06×10^3	5.60×10^2	1.79×10^2	6.67×10^1	5.07×10^1
	>20 MeV	2.62×10^3	6.49×10^2	1.76×10^2	4.67×10^1	2.82×10^1	1.97×10^1
	>50 MeV	1.63×10^3	3.75×10^2	9.77×10^1	3.27×10^1	1.44×10^1	9.41×10^0
50 MeV/u ^{18}O + Au	>7 MeV	6.09×10^3	2.67×10^3	1.55×10^3	8.81×10^2	3.63×10^2	2.43×10^2
	>11 MeV	4.32×10^3	1.29×10^3	5.16×10^2	2.10×10^2	7.33×10^1	4.87×10^1
	>20 MeV	2.70×10^3	6.36×10^2	1.47×10^2	9.44×10^1	4.99×10^1	3.09×10^1
	>50 MeV	1.11×10^3	3.71×10^2	8.27×10^1	4.90×10^1	1.99×10^1	1.01×10^1

In order to obtain neutron number between 0~7 MeV we have estimated the emitted neutron proportion in the same energy region for the reaction of 41.7 MeV/u $^{12}C + C$[2,3] and assumed that the proportions are approximately identical for the both reactions. Based on the measured neutron fluence rate data and the estimated neutron number of 0~ 7 MeV region, the neutron dose equivalent rate distributions in rapid chemistry terminal area were obtained approximately by using the conversion factors from neutron fluence rate to neutron dose equivalent rate listed in Table 2. The results are given in Fig.2.

It may be seen from Fig.2 that the neutron dose equivalent rates decrease exponentially

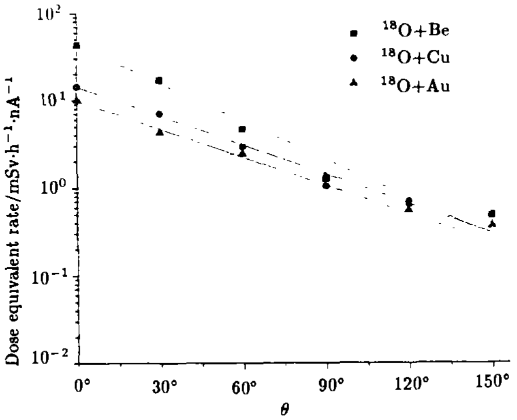

Fig.2 Neutron dose equivalent rate distribution curvers at 1 m from the target

Table 2 Conversion factor from neutron fluence rate to neutron dose equivalent rate

Neutron energy /MeV	Conversion factor $\times 10^{-2}$ /n·cm^{-2}·s^{-1}(mSv·h^{-1})$^{-1}$	Quality factor
2.5×10^{-8}	260	2.3
1×10^{-7}	240	2
1×10^{-6}	220	2
1×10^{-5}	230	2
1×10^{-4}	240	2
1×10^{-3}	270	2
1×10^{-2}	280	2
1×10^{-1}	48	7.4
5×10^{-1}	14	11
1	8.5	10.6
2	7.0	9.3
5	6.8	7.8
10	6.8	6.8
14	6.5	6.8
20	6.5	6.0
50	6.1	5.0
1×10^2	5.6	4.4

with the increase of angle between the threshold detector and the incident beam and its distributions are peaked remarkably in the heavy ion target area. The dose equivalent rate of neutrons emitted from 50 MeV/u ^{18}O + Be was greater than those of other reactions. Therefore, it can be concluded that the neutron dose equivalent rates produced by lighter targets are greater than those produced by heavier target when incident ion and its energy are identical. Because the ^{18}O and ^{9}Be are neutron-rich nuclei relatively and the excitation energy of resultant nucleus of $^{18}O + ^{9}Be$ (~625 MeV) is grater than those of ^{18}O + Cu(~209 MeV) and ^{18}O + Au(~42 MeV), the neutron yield and neutron dose equivalent rate produced by ^{18}O + Be were greater than those of others two reactions.

It is rougher to divide the neutron energy into only five energy region in this experiment. We would use some new suitable threshold detectors in next experiment to divide the emitted neutron energy into 9~10 energy region and it could be expected that the neutron dose equivalent rate values would be measured more exactly.

References

1 Cabriel T A *et al.* ORNL-TM-4334, 1975
2 Bertini H W, Santoro R T, Hermann O W. Phys Rev, 1976, C14:590
3 Li Gui-Sheng. Nuclear Science and Techniques, 1997, 8:117
4 Patterson H W, Thomas R H. Accelerator Health Physucs, New York and London: Academic Press, 1973
5 Birattari C, Ferrari A, Nuccetelli C *et al.* Nucl Instr and Meth, 1990, A297:250
6 Li Gui-Sheng. Nucl Intr and Meth, 1997, A394:381
7 Guo Z Y, Allen P T, Doucas G *et al.* Nucl Instr and Meth, 1987, B28:500
8 Clapier F, Zaidins C S. Nucl Instr and Meth, 1983, 217:489
9 Ohnesorge W F, Butler H M, Fulmer C B *et al.* Health Physics, 1980, 39:633
10 Festag J G, Dose rates during experimetns with heavy ions, 5th International Congress of IRPA, Jerusalem, (1980), 743
11 Li Gui-Sheng, Zhang Tian-Mei, Li Zong-Wei, Zhang Shu-Min. Nuclear Sciience and Techniques, 1997, 8:239
12 NBS of China. The rule for radiation protection of particle accelerators. Beijing: National Standard Press, 1986