SOME RADIATION PROTECTION ASPECTS OF HEAVY ION ACCELERATION

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INTRODUCTION

The CERN Synchrocyclotron has been modified to accelerate heavy ions up to Ne. The present paper describes experiments performed with the most frequently used ^{12}C ions of 86 MeV/nucleon to assess some essential parameters for radiation protection, such as induced activity and secondary-particle production in various target materials. Moreover the attenuation of secondary neutrons in heavy concrete was studied. Finally it will be shown in this report that the experimental secondary-particle production is in good agreement with Monte Carlo calculations.

EXPERIMENTAL RESULTS

Fe and Al targets of 5 x 5 x 0.4 cm and 5 x 5 x 1.2 cm respectively were exposed to a beam of ^{12}C ions of 86 MeV/nucleon. The targets were thick enough to stop the primary ions. Various activation detectors were placed at 50 and 100 cm distance to measure the angular neutron distribution. The following reactions were employed: $^{12}C(n,2n)^{11}C$ for neutron >20 MeV, $^{32}S(n,p)^{32}P$ (E_n >3 MeV), $^{27}Al(n,\alpha)^{24}Na$ (E_n >7 MeV), and finally In foils inside 15 cm polyethylene spheres for neutrons between 0.4 and 10^7 eV.

The angular distributions were calculated using neutron spectra computed as a function of angle for ^{12}C ions of energy up to 900 MeV on iron by H.W. Bertini et al. (Ref. 1) using the HIC-1 code.

The calculated angular fast neutron distribution around the Fe target is presented in Fig. 1 and compared with the measured flux densities derived from the ^{24}Na and ^{32}P activities and In foils in moderator. The number of incident ^{12}C ions on the targets has been determined from the ^{24}Na activity of 0.1 mm thick Al foils placed in front of the target using a cross-section of 24.5 mb for the $^{27}Al(^{12}C,x)^{24}Na$ reaction. All flux densities have been normalized on 10^{11} ions/sec. As can be seen in Fig. 1 a very good agreement exists between the Al and S detector results. At large angles the indium-foil results are higher than the Al, S and theoretical predictions probably due to the contribution of room-scattered low-energy neutrons.

The results for the neutron flux density above 20 MeV are presented in Fig. 2. The ^{11}C-detector results are in good agreement with the calculated angular distribution except at small angles due to the ^{11}C activity produced by charged fragments. Using the ^{11}C data behind a 40 cm shielding block corrected for attenuation, the agreement at zero degrees becomes much better.

Some approximative data for the attenuation length in heavy concrete (density 3.4 g/cm^2) have been obtained from the detectors placed on 40 cm thick blocks under 0^o and 45^o. The attenuation length under 0^o derived from the S detectors is 78 ± 9 g/cm^2 while derived from the ^{11}C detectors an attenuation length of 104 ± 2 g/cm^2 is found as an average for all targets.

Under 45^o an attenuation length of 80 ± 4 g/cm^2 is found for the S detectors and 91 ± 12 g/cm^2 for the ^{11}C detectors. These values shall be considered as upper limits due to the unknown contribution of scattered neutrons.

The Fe target was exposed for 85 minutes with $3.7 \cdot 10^{11}$ ions/sec while the Al target was exposed for 45 minutes with $4.6 \cdot 10^{11}$ ions/sec.

The dose rate from induced radioactivity was measured at various distances from the target with tissue-equivalent ionization chambers. The dose rate a 1 metre from the Fe target versus decay time is presented in Fig. 3. An attempt was made to fit the experimental data with a relationship of the type

$$D = K\,\phi \log \left(\frac{T+t}{t}\right) ,$$

where:

ϕ is the flux density of ^{12}C-ions causing the activation,
K is a constant to be determined,
T is the irradiation time, and
t is the decay time.

This type of expression has shown to fit induced activity data in steel quite well for protons (see Ref. 2).

As can be seen the relation

$$D = \phi \cdot 10^{-15} \log \left(\frac{T+t}{t}\right) \text{ Gy/h} \qquad (1)$$

fits the experimental data between decay times from 1 to 10^4 h quite well with a maximum deviation of ~50% for the dose rate at 1 m from the target. The result can be compared with the constant $K = 3.6 \cdot 10^{-15}$ found for high-energy protons (Ref. 2). Therefore it can be concluded that the induced activity in thick steel targets by 86 MeV/n ^{12}C ions is lower by a factor 3.6 per incident ion.

The dose rate as measured at 1 m of the Al target is presented in Fig. 2 together with the dose rate calculated for an Fe target using the formula presented above for the same irradiation time (45 minutes) and beam intensity. It can be concluded that the dose rates are quite similar up to a decay time of ~70 hours, after which the Al target decays more rapidly as can be expected from the radionuclides produced in Al by ^{12}C ions due to target activation or projectile fragmentation (mainly ^{22}Na, ^{24}Na and ^{7}Be).

CONCLUSION

It can be concluded that the problem of induced activity around heavy ion accelerators is considerably smaller than for high-energy proton accelerators of equal intensity. It has also been shown in this report that the production of secondary neutrons is correctly predicted by the HIC-1 code (Ref. 1).

REFERENCES

1. H.W. Bertini, R.T. Santoro and O.W. Hermann, ORNL/TM-5161 (1976).
2. A.H. Sullivan and T.R. Overton, Health Physics, 11, 1101 (1971).

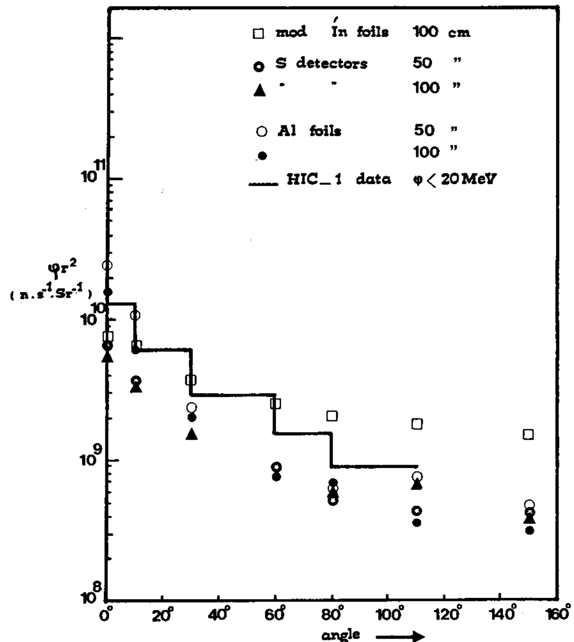

Fig. 1.

Comparison between measured data and HIC-1 calculations for the neutron flux density below 20 MeV around a thick Fe target.

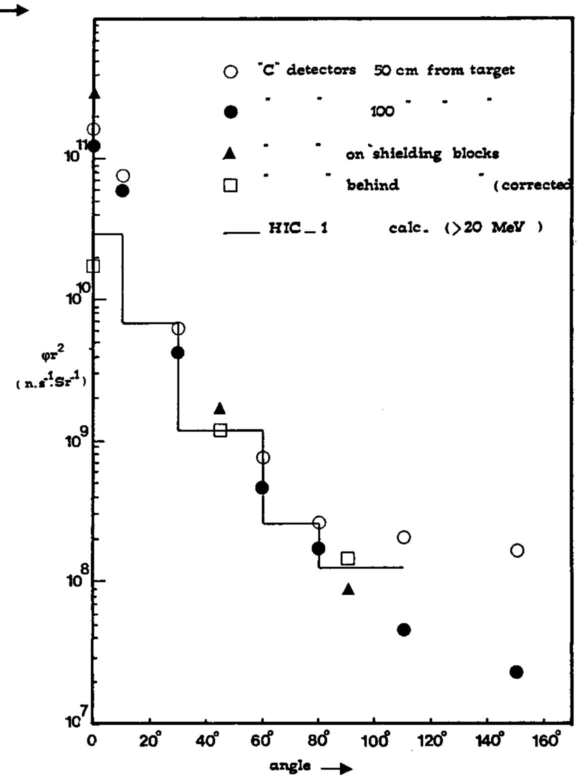

Fig. 2.

Comparison between measured data and HIC-1 calculations for the neutron flux density above 20 MeV around a thick Fe target.

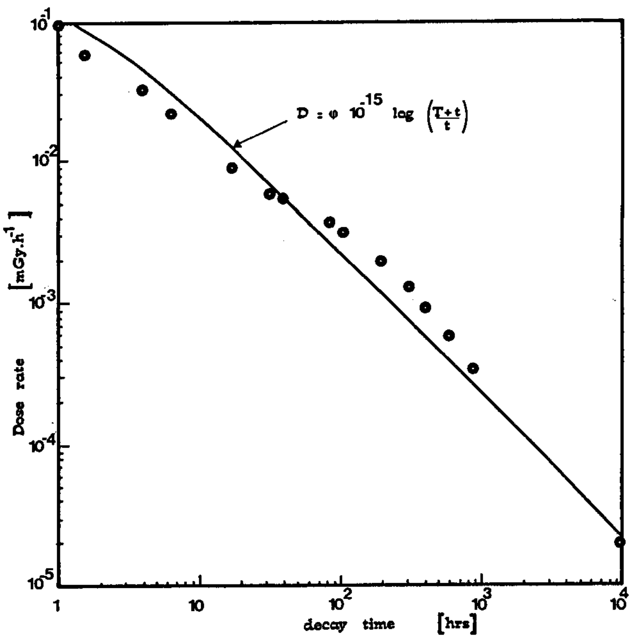

Fig. 3.

Measured decay of induced activity in a 4 mm thick Fe target irradiated with 86 MeV/n C ions for 85 minutes at $3.67 \cdot 10^{11}$ ions/sec.

Dose rates measured at 1 m from target with a TE ionization chamber.

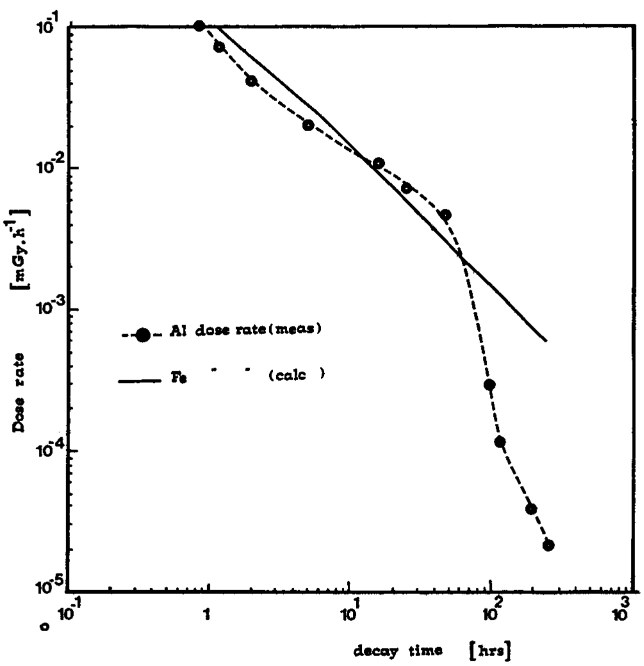

Fig. 4.

Measured decay of induced activity in a 12 mm thick Al target irradiated for 45 minutes at $4.62 \cdot 10^{11}$ ions/sec.

Dose rates measured at 1 m from target with a TE ionization chamber.