RESIDUAL RADIATION STUDIES FOR MEDIUM ENERGY PROTON ACCELERATORS*

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Summary

Residual radiation levels to be encountered in medium energy proton accelerators at high beam intensity are evaluated. Excitation function data were obtained for the production of the most probable radionuclides. A computer code that takes into account the change of cross sections as the beam penetrates the target material was used to compute residual radiation dose rates for carbon, aluminum, iron, and copper as functions of bombardment time and cooling time.

Introduction

Operation of proton accelerators at high intensities will result in serious problems of induced radioactivity. These problems will be solved by a combination of shielding, remote handling, and waiting for the induced radioactivities to decay. The most practical approach to such radiation problems requires a realistic appraisal of residual radiation levels as a part of the accelerator development program.

Our approach to the problem is to compute the residual radiation levels from cross sections based on experimental data. The method of calculation takes into account each of the reaction products and sums the contributions to obtain gross residual radiation levels as a function of bombardment time and of cooling time. In earlier studies[1-3] such calculations were made for incident particle energies of several hundred MeV. The cross section data were obtained from the literature and the calculated gross activity decay curves were compared with experimentally measured ones. For a wide range of bombardment time and cooling time agreement within a factor of two or three was obtained.

In the present work residual radiation levels produced by proton beams of medium energy (~ 50 MeV) were investigated. A literature search yielded reasonably complete cross section data for aluminum but very little data for other materials of interest. It was thus necessary to obtain cross sections by other means. One alternative would have been to estimate the cross sections by calculations, such as those based on the nuclear evaporation model by Dostrovsky et al.,[4] or on the empirical formula of Rudstam et al.,[5] and use these to compute residual radiation levels. The results would be less tenuous, however, if experimentally determined cross sections were used. The Ge(Li) crystal spectrometer,[6] with its excellent γ-ray energy resolution, offers the possibility of determining the more important cross sections without the necessity of resorting to either chemical or mass-spectrometric separations.

Experimental

Excitation functions for the important reaction products produced by 0-60-MeV protons in carbon, aluminum, iron, and copper were measured. Stacks of target foils were bombarded with monitored proton beams at the Oak Ridge Isochronous Cyclotron. Gamma spectra of the residual radioactivity of each foil were measured with a high resolution Ge(Li) gamma spectrometer.

A sample spectrum is shown in Fig. 1. Individual radionuclides were identified by gamma energy and half life. Cross sections were determined from gamma peak intensities and

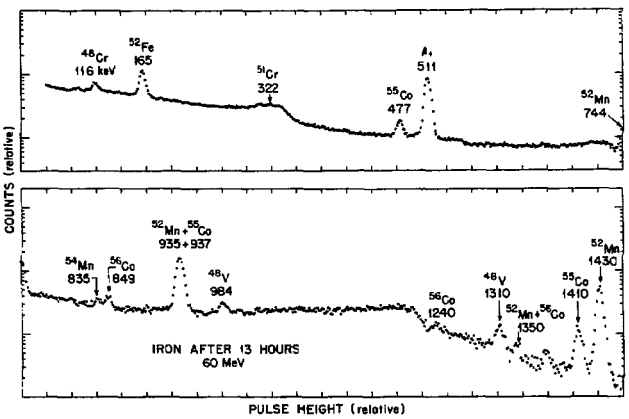

Fig. 1. Gamma-ray spectrum obtained from a 0.010 in. thick iron sample irradiated with 60-MeV protons.

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beam current measurements. Proton energies for individual foils were determined from range-energy tables. Proton energy uncertainties due to straggling were reduced by using different bombarding energies.

For residual radiation considerations ^{7}Be is the most important radionuclide produced in carbon. The excitation function for $^{12}C(p,x)^{7}Be$ is shown in Fig. 2. Data obtained at ORIC were extended to 160 MeV by a bombardment at the Harvard University Cyclotron.* Data from previous experiments[7,8] are shown for comparison. The agreement with previous data above 80 MeV serves as a check on the present work.

The measured excitation function for production of ^{58}Co by proton bombardment of copper is shown in Fig. 3; the scatter of data points is typical for this work. The dotted curve shows the excitation function predicted by the evaporation theory of Dostrovsky et al.[4] for one particular set of level density parameters. The agreement between the calculated and experimental excitation functions in Fig. 3 is typical for this work. Excitation functions for several other nuclides produced by proton bombardment of copper were also obtained.

The measured excitation functions for the important radionuclides produced by proton bombardment of iron are shown in Fig. 4. The curves represent the average of data obtained

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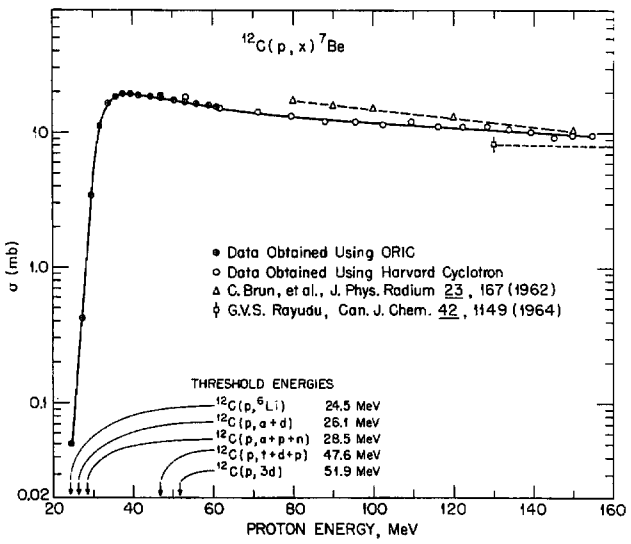

Fig. 2. Excitation function for the production of ^{7}Be by bombardment of carbon with protons.

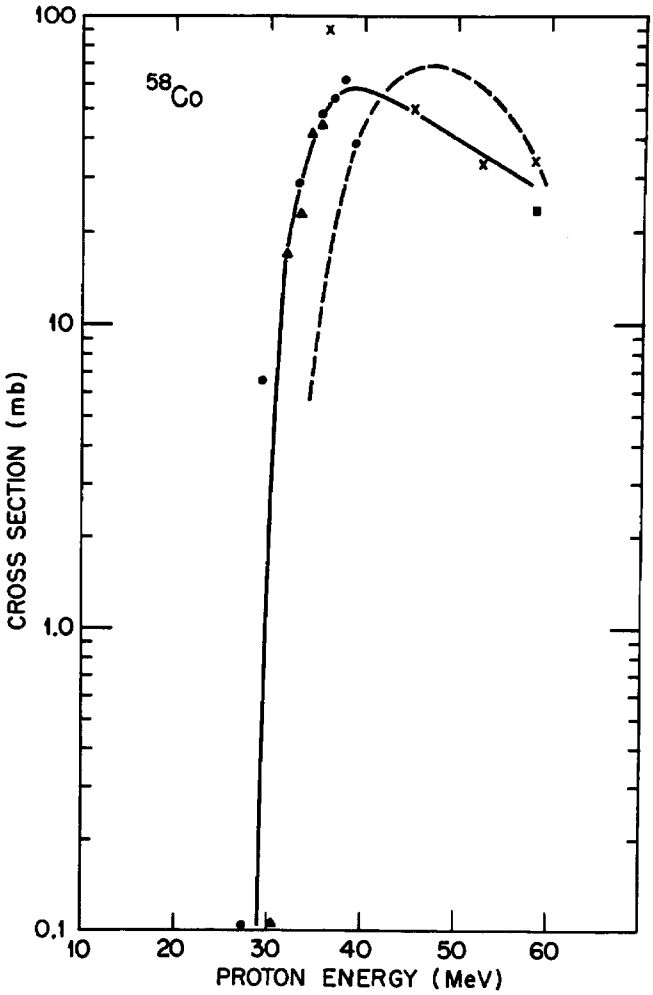

Fig. 3. Excitation function for the production of ^{58}Co by bombardment of copper with protons. The dotted curve is predicted from the evaporation theory of Dostrovsky et al. (Ref. 4).

from several measurements. The uncertainty in the cross sections is ± 30%.

Residual Radiation Calculations

A computer code was written for calculating residual radiation dose rates outside slabs of material irradiated by collimated beams of particles. The attenuation of the incident beam in the material as well as the absorption of the γ-rays in the material are taken into account.

The excitation functions and the gamma branching ratios for each of the radionuclides is included in the input data. The computer program divides the slab thickness into small slices and computes the beam energy at the middle of each slice. The excitation function data are interpolated to obtain the cross section for each radio-

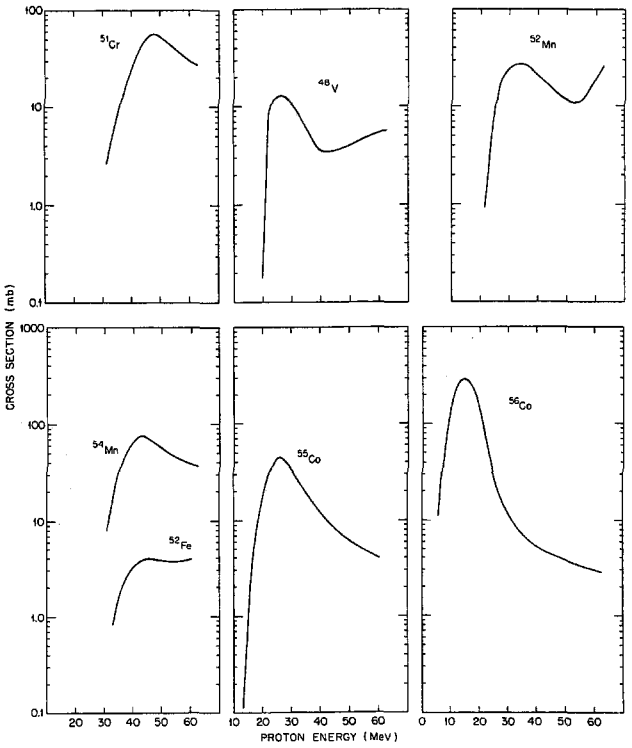

Fig. 4. Excitation functions for production of several radionuclides by proton bombardment of iron.

nuclide in each slice of the slab. The dose rate for each gamma is obtained by summing the contributions of all slices of the slab for specific bombardment and cooling times. The total dose rate is then obtained by summing the contributions of all the radioactive isotopes.

Decay curves for a particular set of bombardment conditions can be obtained by determining the total dose rate as a function of cooling time. Gross activity decay curves are shown in Fig. 5 for carbon, aluminum, iron, and copper for bombardment times of 1 day, 1 week, 1 month, and 1 year. These curves are for 50-MeV protons incident on stacks of material thick enough to stop the beam. The ordinate scale is the dose rate at 1 meter for a collimated beam of 1 mA. It is also the dose rate outside a large slab uniformly irradiated with a flux of 10^{11} particle/cm^2-sec.

Accelerator designers and operators are interested not only in the decay of residual radiation but also in the residual radiation level at some definite time after machine shutdown. In Fig. 6 are shown residual radiation dose rates as functions of bombardment time. The curves are for thick samples bombarded with 50-MeV protons. For irradiation times of a few years the buildup of ^{22}Na makes Al a poor choice of material from residual radiation considerations.

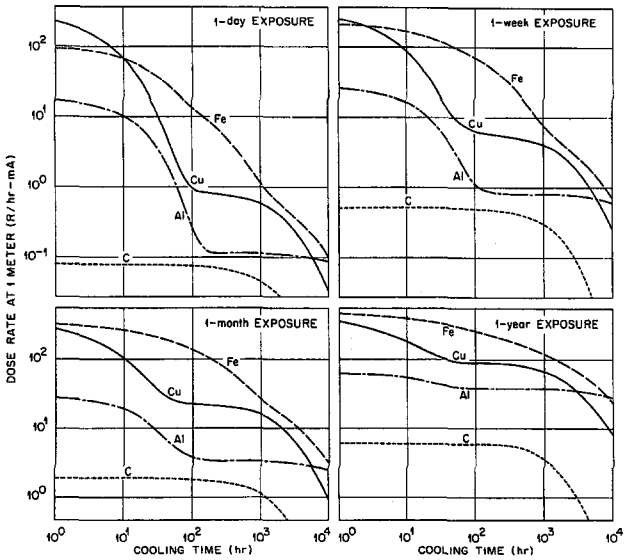

Fig. 5. Dose rate decay curves for thick targets of carbon, aluminum, iron, and copper after bombardment with 50-MeV protons.

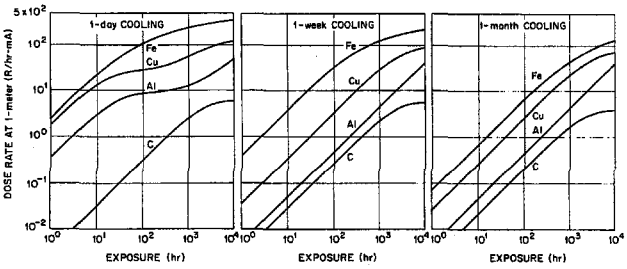

Fig. 6. Dose rates as functions of bombardment times for cooling times of 1 day, 1 week, and 1 month.

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