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MONTE CARLO ANALYSIS OF AN NE213 DETECTOR

S. N. Cramer

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MATHEMATICS DIVISION

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ABSTRACT

A Monte Carlo analysis of an NE213 detector has been performed using the ESP code. The investigation involved calculation of the alpha particle and proton spectra produced in the detector from neutron reactions with hydrogen and carbon. The sensitivity of these calculated spectra has been determined with respect to first collision only, hydrogen scatter only, and reaction Q value.

I. INTRODUCTION

A Monte Carlo analysis of a nominal 2 x 2 inch cylindrical NE213 detector has been performed using the ESP¹ code. The investigation involved calculation of the alpha particle spectrum due to the $(n,n')\alpha$ and the (n,α) reactions with carbon and the proton spectrum due to neutron collisions with hydrogen. The spectra are integrated over the volume of the detector. The neutron source consisted of a monoenergetic beam of neutrons incident on one end of the detector. The energy of the secondary particles was determined from an energy balance following each collision.

II. PHYSICAL CONSIDERATIONS

The purpose of this study was to determine the total energy of alpha particles and of protons produced per incident neutron over the entire volume of the detector so that pulse height spectra could be estimated using the light curve for the detector. In the calculation it was assumed that each neutron could produce no more than one secondary particle and that the energy of each particle produced was the sum of the energies of all particles of that type actually produced

by that neutron. That is, a neutron having two collisions with hydrogen produced only one proton with an energy equal to the sum of the two, had they been produced separately. Likewise, only one alpha particle was produced from a $(n,n')3\alpha$ reaction with carbon with an energy equal to the sum of the three individual alpha particle energies. In reality the detection equipment cannot distinguish between these individual particles of the same type, and it appears that only one higher energy particle has been detected. However, these assumptions assume a linear light output. Also, these alpha particles and protons give up their energy by ionization quickly in close vicinity of the reaction which produced them. In the calculation it has been assumed that this energy deposition takes place at the collision site, and there is no tracking of the charged particles. The energy contribution, in the laboratory system, to the alpha particle produced per neutron for each neutron-carbon collision is E_α , where:

$$E_\alpha = E_n' - E_n - |Q| \quad (1)$$

and E_n' = incident neutron energy,

E_n = exit neutron energy ($E_n = 0$ for the (n,α) reaction),

$$Q = \text{reaction } Q \text{ value } \begin{cases} Q = -7.27 \text{ MeV for } (n,n')3\alpha \\ Q = -5.695 \text{ MeV for } (n,\alpha) \end{cases} .$$

Although the correct energy of each alpha particle should be determined from multiple body collision mechanics, the above equation should suffice for the present purposes. The recoil proton energy is determined from a similar relationship with $Q = 0$.

III. SYSTEM DESCRIPTION

The detector investigated was an NE213 detector 2 inches in height and 2 inches in diameter. The carbon and hydrogen densities were 0.04023 atoms/barn-cm and 0.04871 atoms/barn-cm, respectively. The source was a monoenergetic beam of neutrons incident on and perpendicular to one base of the cylinder. Source energies used were 15 and 3.05 MeV.

IV. DATA AND CODE CHANGES

The data used in the calculation was ENDF/B material number 1165 for carbon and 1148 for hydrogen. However, in the 1165 data the $(n,n')3\alpha$ reaction (MT = 23) has been combined with the continuum inelastic scattering. In order to investigate the $(n,n')3\alpha$ reaction explicitly, the MT = 23 and MT = 91 (inelastic continuum) data from the version II ENDF/B data, MAT = 1140, was combined with the 1165 data.

The standard ESP code utilizes nonabsorption scattering; that is, all collisions are scattering collisions and the computational neutron weight is multiplied by Σ_S/Σ_T , the nonabsorption probability for the medium. In order to produce secondary particles and determine their energies, the code was modified to do analog scattering. At each collision if a random number $R \leq \Sigma_S/\Sigma_T$ ($0 \leq R \leq 1$), the neutron is scattered and the calculational weight remains unity; otherwise, the neutron is absorbed and the history is terminated. In this manner the secondary particle energy can be accurately determined from the energy loss of the scattered neutron. Also, since the (n,α) reaction with carbon represents the only appreciable absorption in the system, an alpha particle is produced when a neutron is absorbed.

V. SPECTRA CALCULATIONS

The proton spectra for the 15 MeV and 3.05 MeV source energies are given in Figs. 1 and 2, respectively. Figure 3 gives the alpha particle spectrum for the 15 MeV source. There is no alpha particle spectrum for the 3.05 MeV source since this energy is below the threshold values for $(n,n')\alpha$ and (n,α) reactions. The remaining curves will be used to explain the calculated spectra based on the calculational model. A 14 MeV source is used in these calculations. The error bars on all histograms represent one standard deviation of the mean.

Figure 4 shows a calculation resulting from first collisions with hydrogen. No carbon collisions are allowed and the neutron history is terminated following one collision with hydrogen. This curve can be determined analytically from

$$E = \frac{E'}{(A + 1)^2} (A^2 + 2\eta A + 1) \quad (2)$$

where E = neutron energy after collision (lab),

E' = neutron energy before collision (lab),

η = cm scattering angle cosine,

A = mass ration.

For hydrogen, η is also the lab scattering angle cosine and the equation reduces to

$$E = \frac{E'}{2} (\eta + 1) \quad (3)$$

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Fig. 1. Proton Spectrum for the 15 MeV Source.

Fig. 2. Proton Spectrum for the 3.05 MeV Source.

Fig. 3. Alpha Particle Spectrum for the 15 MeV Source.

Fig. 4. Proton Spectrum for a 14 MeV Source with no Collisions with Carbon and no Multiple Collisions Allowed.

For isotropic scattering, η is picked uniformly between ± 1 , and the final neutron energy is uniformly distributed between 0 and E' . Thus, the recoil proton energy is also uniformly distributed from 0 to E' ,* and the broad flat area of the spectra in Figs. 1 and 2 is due to single scattering with hydrogen.

Figure 5 shows proton spectrum calculated from hydrogen scattering only, but with multiple collisions allowed. The spike at the source energy is due to this multiple scattering effect. Recall that the calculational model allowed a maximum of only one proton produced per neutron and all hydrogen scattering energy loss for each neutron was combined into the energy of the single proton produced. In addition then to the flat spectrum in Fig. 4, additional hydrogen scatters tend to increase the energy of the one proton produced. The high energy portion of the spectrum in Fig. 5 results from collision sequences in which the neutron energy is decreased close to zero, all the energy going to the high energy proton. The low energy portion of the spectrum results from neutrons having only one small angle (and small energy loss) scatter with hydrogen at the source energy and escaping the system with no further collisions, producing a low energy

*The isotropic scattering for hydrogen had to be programmed directly into the code. Use of the standard Coveyou scattering technique² and the ENDF/B data for 1148 permitted scattering in discrete directions only, making the energy loss discrete, also. This effect would disappear if there were any significant multiple scatterings or if the source was a continuous spectrum over a wide energy range.

Fig. 5. Proton Spectrum for a 14 MeV Source with no Collisions with Carbon Allowed.

proton. This multiple collision effect with hydrogen is evident at high energies in Figs. 1 and 2. Since Fig. 2 is similar in shape to Fig. 5, it is apparent that the low energy spectrum in Fig. 1 is due to carbon scattering since the source for Fig. 2 is below the carbon reaction thresholds. First collisions with carbon produce a low energy neutron spectrum and subsequent neutron-hydrogen collisions produce lower energy recoil protons, which would add to the low energy spectrum of Fig. 5 if carbon collisions had been allowed.

Figure 6 shows an alpha particle spectrum calculated with the Q value equal to zero in Eq. (1). That is, all neutron energy loss from the $(n,n')3\alpha$ and (n,α) reactions with carbon was converted into alpha particle energy. Hydrogen scatter and multiple scattering were allowed in this calculation. The (n,α) reaction gives a large contribution to the alpha particle spectrum at the source since the neutron is absorbed and the entire energy loss goes into the alpha particle energy. The (n,α) reaction contribution after a scatter has occurred is reduced due to lower neutron energy at absorption. The $(n,n')3\alpha$ reaction contribution to the spectrum in Fig. 6 reflects the evaporation model used in calculating the secondary neutron energy from the $(n,n')3\alpha$ reaction. The neutron energy loss, and alpha particle energy gain, covers almost the entire spectrum. By inserting the appropriate Q values into the calculation, Fig. 3 is produced. That is, the (n,α) contribution is reduced by its Q value from that shown in Fig. 6 to that in Fig. 3. Likewise, the $(n,n')3\alpha$ contribution to the alpha particle spectrum is

Fig. 6. Alpha Particle Spectra for a 14 MeV Source with no Q Values Included in the Calculation.

reduced by its Q value from Fig. 6 to that in Fig. 3, and the two reaction contributions are separated in Fig. 3 relative to that in Fig. 6 due to the greater magnitude of the (n,n') Q value.

REFERENCES

1. S. N. Cramer, R. S. Carlsmith, G. W. Morrison, G. W. Perry, and J. L. Lucius, "ESP - A General Monte Carlo Reactor Analysis Code," ORNL-TM-3164 (1972).
2. D. C. Irving, R. M. Freestone, Jr., and F. B. K. Kam, "O5R, A General-Purpose Monte Carlo Neutron Transport Code," ORNL-3622 (1965).

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