Letters to the Editor

Comments on the *R*-Parameter Formalism for Neutron-Induced Gamma-Ray Production

In a recent Note,[1] it was observed that the R parameter determined from the experimental $(n,x\gamma)$ spectrum for 14-MeV neutrons incident on ^{93}Nb appeared to be a function of the gamma-ray energy. It was then proposed that the R parameter be considered both a function of the incident neutron energy and the outgoing gamma-ray energy. The consequences of this proposal are severalfold.

1. The $(n,x\gamma)$ spectrum would no longer be the simple R-parameter form, but would obey a new functional variation. The analog for an outgoing neutron evaporation spectrum would occur if the nuclear temperature were taken to be a function of the outgoing neutron energy rather than the excitation energy of the residual nucleus.

2. The spectral formulation has not been simplified. Rather than having an explicit and simple representation of the spectra $N(E_n,E_\gamma)$, one now has a continuous and unknown function for the R parameters, $R(E_n,E_\gamma)$.

The solution to the problems that inspired the proposed treatment has been given earlier[2] but will be repeated here.

In 1968, Howerton and Plechaty[3] noted that for incident neutron energies of 4 and 14 MeV, the experimental continuum $(n,x\gamma)$ spectra with $E_\gamma > 1$ MeV followed the simple evaporation form

$$N(E_n,E_\gamma) = E_\gamma \exp(-RE_\gamma) \ , \quad \text{for } A > 20 \ . \qquad (1)$$

From the experimental spectra, the R parameter was determined. Since, at that time, data were only available at 4 and 14 MeV, Howerton and Plechaty assumed a linear behavior of R on the incident neutron energy. By 1971, data had become available at intermediate energies, and from these results it became apparent that the energy dependence of the R parameter was not linear. In fact, the R parameter appeared to be an explicit function of the excitation energy in the residual nucleus. However, not enough information was yet available for a complete analysis.

In 1972, Morgan et al.[4] carried out an elegant $(n,x\gamma)$ experiment on ^{181}Ta for incident neutron energies between 0.007 and 20 MeV. These results showed quite clearly that for a given incident neutron energy the R parameter had different values over different ranges of gamma-ray energy (see Fig. 2 of Ref. 2). This could be directly related to the fact that each reaction type present, e.g., (n,γ) and $(n,n'\gamma)$, appeared to have its own photon spectrum with its own distinct R parameter. Thus for the first time, the functional dependence of the R parameter on excitation energy could be clearly defined (see Fig. 3 of Ref. 2). Furthermore, when the excitation energy for two different reactions was the same, the R values were equal, indicating essentially no dependence on the specific residual nucleus. These results, along with an extension of the basic formalism to include x-ray and electron production from internal conversion, were published[2] in 1975. Since that time, this extended technique has been used, all or in part, for some 70 elements and isotopes in the ENDL data file[5] and for some 18 materials in the ENDF/B-V file.[6] An added advantage is that since this formalism directly uses the neutronics data to calculate its results, average energy is conserved in both the neutron and gamma-ray fields over the entire range of incident energy.

The observation that the R parameter is apparently dependent on the emergent gamma-ray energy is satisfactorily explained when the R parameter is expressed as a function of the average excitation energy in the residual nucleus. If experimental spectra data are to be analyzed to determine the R parameters, a functional dependence on excitation energy should yield the most fruitful results.

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