# WORKING WITH 150-MeV EVALUATIONS: NJOY AND KERMA

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**Abstract**

New evaluations of neutron and proton data to 150 MeV will allow the accurate determination of radiation heating for several important applications. The NJOY Nuclear Data Processing System has been extended to convert these data into kerma factors for easy calculations of neutron heating. The results compare well with experimental kerma measurements.

## Introduction

As new evaluations of neutron and proton data to 150 MeV become available from Los Alamos in support of accelerator-driven applications[1], it has been necessary to extend the NJOY Nuclear Data Processing System[2] in a number of ways. One set of extensions is designed to provide accurate kerma factors for the determination of radiation heating from neutrons. Heating is important in a variety of applications, including accelerator technologies and radiation therapy.

The kerma factor is proportional to the total energy emitted with secondary charged particles, including the residual nuclei. A full calculation of radiation heating would have to follow the slowing down of each particle in the medium, but when particle mean paths are fairly short, folding the kerma factor with the neutron fluence can provide a reasonably good approximation to the energy deposition (or "absorbed dose") by neutrons in matter. In addition, if total kerma factors derived from evaluated cross section data agree well with measurements, it helps to build confidence in the prediction of energy deposition by a transport code that uses these same data.

## Kerma Factors From ENDF Below 20 MeV

Following the introduction of the ENDF-6 format, a number of evaluated nuclear data files that contain explicit information on the energies of emitted charged particles have become available. A processing code like NJOY can easily integrate these distributions, thus obtaining kerma factors that are directly traceable to the best judgment of the evaluator and that satisfy conservation of energy for all emitted radiations. However, even now, explicit charged-particle distributions are not available for many important materials. Thus, it is necessary to attempt to estimate emitted energies by using kinematics, rough estimates for reaction dynamics, or energy balance. The energy-balance approach takes advantage of the fact that many ENDF-format evaluations give explicit distributions for the emitted neutrons and photons. The energies needed for the kerma factor can be obtained by subtracting the average emitted energies for the neutrons and photons from the available energy (E+Q). This approach is used by the HEATR module of NJOY. Unfortunately, this requires that extreme care be taken in assuring energy balance in evaluations, and many current materials violate reasonable limits on the kerma factor (for example, negative values are found). Negative kerma factors may look absurd, but they serve to just cancel out the errors in the photon heating for a large system.

## Kerma Factors From ENDF Above 20 MeV

The new high-energy Los Alamos evaluated data libraries use GNASH model calculations, along with measured data, to extend existing ENDF/B-VI neutron libraries from 20 MeV up to 150 MeV. Proton ENDF libraries from zero to 150 MeV have also been generated with the GNASH code. These new evaluations use the File-6 format, in which secondary inclusive emission spectra are represented. The evaluations allow total neutron kerma factors to be determined unambiguously, because the emission spectra of all secondary charged particles, including heavy recoils ($A>4$), are represented.

The light-particle ejectile ($A\leq4$) angle-integrated spectra are represented in the center-of-mass frame, as this is the natural frame from which the Kalbach angular distribution systematics can be applied to determine angle-energy correlated emission spectra. NJOY then performs a transformation into the lab frame to obtain the partial kerma factors for the light particles. Lab-frame angle-integrated spectra are provided for the heavy recoils by making use of a model recently developed for GNASH[3] that facilitates the calculation of nonelastic recoil kerma factors. Finally, elastic recoil partial kerma factors are determined from the neutron elastic scattering angular distributions after having determined the $P_1$ component of a Legendre coefficient fit to the highly forward-peaked distributions.

## Results and Comparison with Experiments

In recent years, total kerma factors have been measured for a number of elements (particularly those of importance in medical applications), allowing a test of evaluated nuclear data and the NJOY processing methods. The measurements have been made in two ways: direct determination of the ionization produced by the secondary charged particles, and measurements of secondary charged-particle differential cross sections. Both methods involve significant uncertainties; the latter, in particular, require extrapolations for data at unmeasured angles, energies (below detector thresholds), and for elastic and nonelastic recoils, to determine the total kerma factor.

Figure 1 shows the total kerma factors determined by NJOY from the evaluated ENDF data compared with measurements. The discontinuities seen at 20 MeV arise because of the different evaluation methods used in the new high-energy evaluations compared with the older <20 MeV evaluations. In general, the agreement is seen to be good. For C and O, there is a tendency for the ENDF evaluations to overpredict kerma factors in the 15-20 MeV range. The LAHET results shown were generated with a special version using elastic cross sections from the new ENDF evaluation, and they show reasonable agreement with the full calculation.

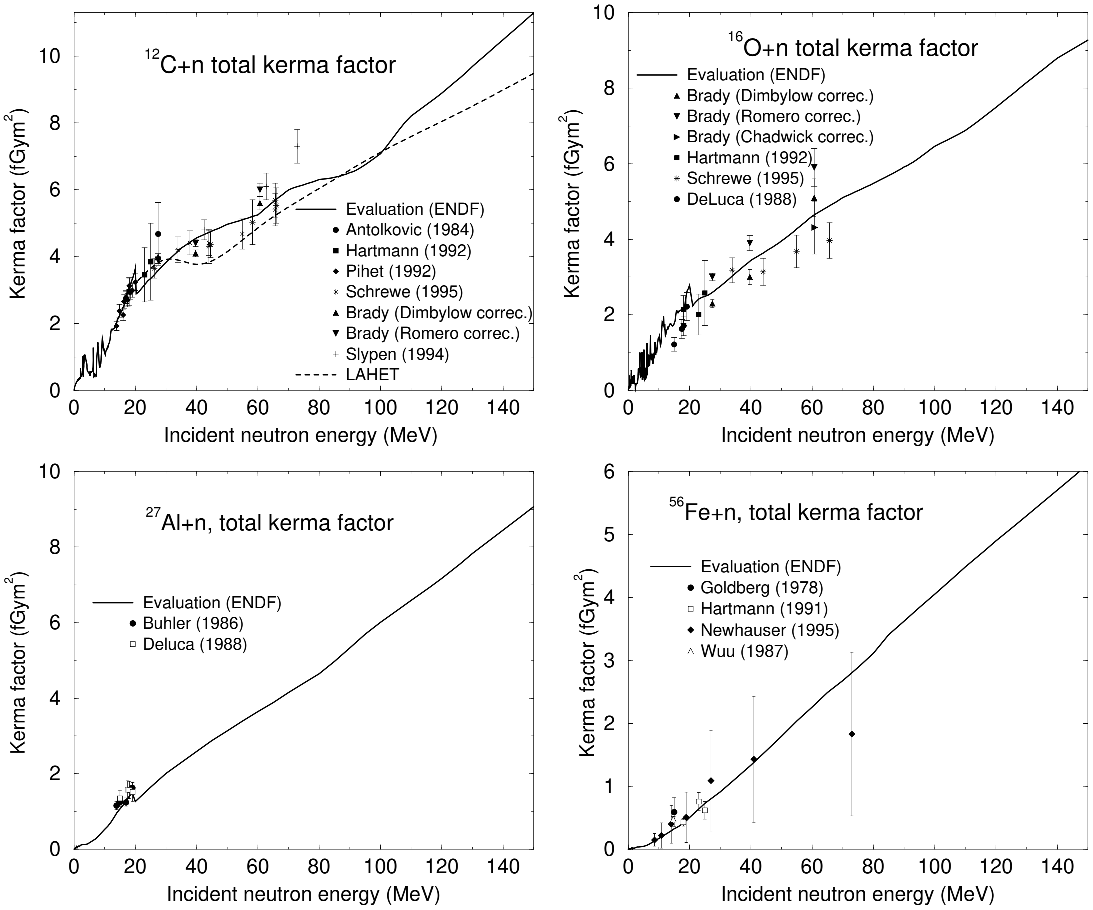


Figure 1: NJOY kerma factors compared with measurements[4]

# References


[1] P.G. Young and M.B. Chadwick, "Neutron- and Proton-Induced Nuclear Data Libraries to 150 MeV for Accelerator-Driven Applications", this conference.

[2] R.E. MacFarlane and D.W. Muir, "The NJOY Nuclear Data Processing System, Version 91," Los Alamos National Laboratory report LA-12740-M (Oct. 94).

[3] M.B. Chadwick, P.G. Young, R.E. MacFarlane, and A.J. Koning, "High-Energy Nuclear Data Libraries for Accelerator-Driven Technologies: Calculational method for Heavy Recoils", paper at the *2nd. Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications*, 3-7 June 1996, Kalmar, Sweden.

[4] For citations to C and O experimental kerma factors, see M.B. Chadwick *et al.*, Nucl. Sci. Eng. **123**, 17 (1996); **123**, 1 (1996); For Al citations, see G. Buhler *et al.*, Phys. Med. Biol. **31**, 601 (1986), and P.M. DeLuca *et al.*, Radiat. Prot. Dos. **23**, 27 (1988); For Fe citations, see E. Goldberg *et al.*, Lawrence Livermore National Laboratory report UCID-17789 (1978), C.L. Hartmann, PhD thesis, University of Wisconsin (1991), W.D. Newhauser *et al.*, At. Data and Nucl. Data Tables (in press), and C. Wuu *et al.*, Medical Physics **14** 6 1007 (1987).