

SPENVIS-4 Technical Note

TN14 Review of Thiel's work.

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Purpose

This text gives a review of the work of ONERA and U. Köln that was presented by H. H. Fischer and K. Thiel at the SPENVIS & GEANT4 workshop held at the Faculty Club Leuven, 3-7 October 2005 (ESA contr. 15157). In their presentation they report on new NIEL data calculated inside GEANT4 with updates for calculating recoil energies due to high energy hadron interactions and with the inclusion of electrostatic screening. Further on they comment on how the extensions made in GEANT4 can be integrated in SPENVIS.

In this review we focus on the latest electron and proton NIEL calculations and available software tools. Additionally we discuss the current status and possible update of the NIEL module inside SPENVIS.

Introduction

NIEL calculations are a useful tool for approximating the expected particle-induced response of a device in a radiation environment. In many cases the damage factor varies linearly with the NIEL energy dependence and the displacement damage dose is obtained by multiplying the NIEL with the particle fluence. To account for deviations from a linear dependency, an equivalent dose can be defined at a particular reference energy (Warner et al., 2006).

The nonionizing energy loss rate can be calculated analytically from first principles based on differential cross sections and interaction kinematics. The basic equation is:

$$NIEL(E) = \frac{N_A}{A} \int_{T_{min}}^{T_{max}} Q(T) T \left(\frac{d\sigma}{dT} \right)_{T_0} dT$$

where,

- T_0 = the incident kinetic energy
- T_{min} = the threshold energy for displacement
- T_{max} = the maximum energy transfer in a collision
- N_A = Avogadro's number
- A = atomic mass of the lattice atom
- $Q(T)$ = the Lindhard partition factor that gives the fraction of energy consumed by the non-ionizing process
- $(d\sigma/dT)$ at T_0 = the differential cross section for the interaction that takes place at energy T_0 .

New data summary

New NIEL calculations have been performed using upgraded interaction models. We give a summary of published new NIEL data

Figure 1 and 2 give an overview of the available electron and proton NIEL data.

♦ Jun, W. Kim and R. Evans, 2009

In this work electron NIELs are computed analytically whereby using the modified Lindhard partition function from Akkerman et al. (2006) and the Mott differential cross section for elastic scattering in the relativistic case. The calculations are made for an energy range of 0.5 MeV – 1000 MeV and for 13 target elements (C, Al, Si, P, Cu, Ga, Ge, As, Se, Cd, In, Sb, Te, I and Hg). They also give a recipe to compute the NIELs for compounds composed of 2 or more of these elements.

♦ S. R. Messenger et al., 2007

NIEL calculated with the Monte Carlo ion transport code SRIM are given for electrons and protons incident upon InGaP₂, GaAs and Ge.

♦ Akkerman and Barak, 2006

NIEL curves for electrons and protons in Si are re-evaluated using a new partition factor for low energy (<500 keV) ions in silicon, based on the binary collision model for ion interactions in condensed matter. The new NIEL values are on average 15% larger compared to other published data. In an earlier paper by Akkerman et al. (2001), proton and electron NIEL data were performed for Si and GaAs devices, using the ENDF/B-VI library of differential cross sections .

♦ Xapsos et al., 2004

Accounting for relativistic Coulomb interaction and heavy ion fragmentation reactions, NIEL calculations are presented for the dominant heavy ions in space environments (H, He, C, Si, Fe) with energies from 200 MeV up to 2 GeV per nucleon. They also report that general methods recently developed for calculating NIEL for arbitrary ions, ion energies and materials will become available in a Windows compatible code to be distributed by the NASA SEE Program.

♦ S.R. Messenger et al., 2003

Using an analytical approach NIEL is calculated for heavy ions (including H, He, B, Si, Fe, Xe and Au) with energies from threshold up to 1 GeV incident upon Si, GaAs, InP and SiC target material. The main feature of their approach is the use of displacement cross sections based on screened Coulomb potentials. They conclude that their method give results similar to NIEL values obtained with SRIM for heavy ions at low energies and can be applied for any combination of target and incident ions.

♦ **Jun et al., 2003**

Proton induced NIEL data are presented for 10 materials (C, Al, Si, P, Ga, Ge, As, In, Cu and Se) for energies from 1 keV up to 1 GeV. Their calculations include all interaction mechanisms:

- Coulomb scattering: the Ziegler, Biersak, Littmark screened potential for $E < 50$ MeV and a relativistic scattering for $E \geq 50$ MeV
- Nuclear reactions are performed with the charged particle Monte Carlo transport code MCNPX .

The NIEL data are in good agreement with published data from previous studies, except at very low proton energies due to the inclusion of electrostatic screening.

NIEL software tools

Also several software tools have been developed to calculate NIEL values. We describe them briefly.

♦ **NEMO 2.0 code**

the Niel Evaluation Model of ONERA (Inguibert and Gigante, 2006)

The code calculates NIEL values for electron, proton, neutron and heavy ions ($Z > 2$) with energies from a few 100 eV up to a few 100 MeV in any material (for which the atomic number of each element is less than 84). NEMO 2.0 has been integrated in OMERE 3.0., the source code is not public available.

♦ **MULASSIS and GRAS**

Multi-LAYered Shielding Simulation Software & Geant4 Radiation Analysis for Space

MULASSIS and GRAS are both part of the GEANT 4 toolkit and allow to estimate the NIEL doses in 1D and 3D geometry respectively, due to different particle types (electrons, protons and neutrons) in a layer based on the calculated particle fluence entering the layer and tabulated NIEL coefficients (for Si, GaAs and InP).

♦ **MCNPX,**

Monte Carlo N-Particle eXtended,

MCNPX calculates the NIEL due to nuclear reactions. It allows tracking of primary and secondary particles from proton interactions.

♦ **SRIM**

Stopping and Range of Ions in Matter (<http://www.srim.org/>),

SRIM calculates the vacancy production rate per μm and per ion which can be converted to NIEL using the Kinchin-Pease approximation. SRIM does not include nuclear reaction analysis and the results are constrained to the lower energy range where Rutherford scattering dominates. The use of SRIM has been illustrated in Messenger et al., 1999.

NIEL inside SPENVIS

Currently in SPENVIS, damage calculations can be done inside the radiation dose package for simple geometries whereby using precalculated or user defined proton NIEL curves. SPENVIS provides also an interface to MULASSIS and GRAS to calculate NIEL doses behind shielding (in 1D and 3D) for electrons and protons.

For the implementation of electron NIEL in SPENVIS we suggest to update the MULASSIS and GRAS data files with recent electron NIEL calculations, presented in this review.

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