Energy loss of relativistic heavy ions in matter using dedx code

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Ref: Weaver & Westphal, Nucl. Instrum. Methods Phys. Res. B 187, 285-301 (2002)

Energy loss

- The overall form ($x' = \rho x$.)

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{Z_1^2 e^4 n_e}{4\pi \epsilon_0^2 m_e v^2} L.$$ or $$-\frac{\mathrm{d}E}{\mathrm{d}x'} = 4\pi N_A m_e c^2 r_e^2 \frac{Z_1^2 Z_2}{A_1 A_2} \frac{1}{\beta^2} L.$$

- Bethe form of dE/dx

L= $L_0 = \ln\left(\frac{2m_e c^2 \beta^2 \gamma^2}{I}\right) - \beta^2 - \frac{\delta}{2}$

- Density effect (Sternheimer & Peierls)

$$-\frac{\delta}{2} = -\frac{\delta_{\mathrm{high}}}{2} - \frac{a}{2}[X_1 - X]^m \quad (X_0 < X < X_1)$$

$$-\frac{\delta}{2} = -\frac{1}{2}\delta(X_0)10^{2(X-X_0)} \quad (X \leqslant X_0)$$

where $X \equiv \log_{10}(\beta\gamma)$

Further corrections

- $L = L_0 + \Delta L$
- BMA group

1. Bloch: similarities and differences between classical and quantum-mechanical range-energy calculations
2. Mott: order higher than Z^2 at high energies; origin is Dirac equation
3. Ahlen: relativistic Bloch correction; high charge and high energy

- BMA group are rendered obsolete by the Lindhard-Sorensen (LS) correction
  - Low-energy limit, LS -> Bloch correction
  - Using solutions to the Dirac equation, LS -> Mott scattering
- The finite nuclear size (FNS) correction
  - Converge at the Lorentz factor above 10/R, where R is the nuclear size divided by the electron Compton wavelength.
  - The most important modification at very high energies

- The ultrarelativistic limit

$$L = L_0 + \Delta L = \ln \frac{2c}{R\omega_p} - 0.2$$

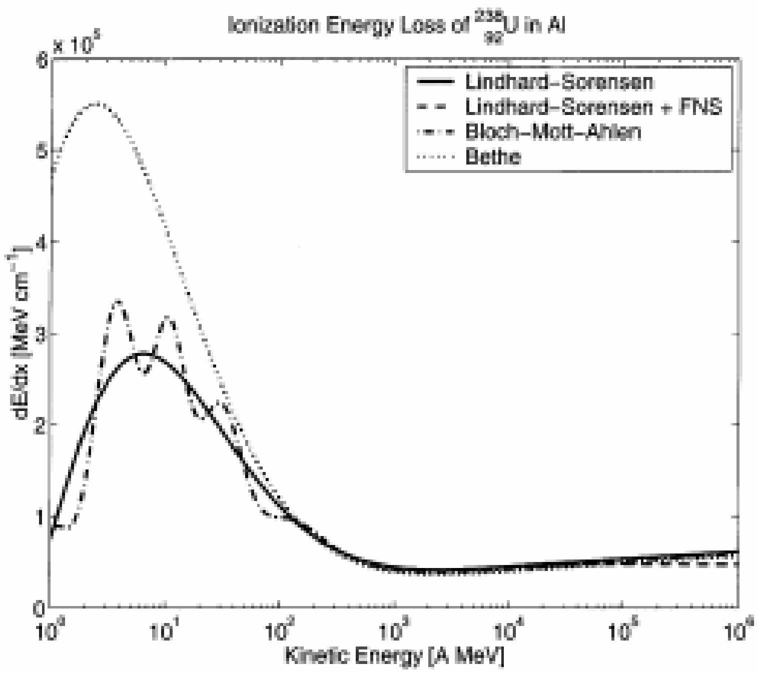


Fig. 1. dE/dx as calculated with several important corrections for uranium slowing in aluminum. All computations included the Sternheimer et al. density effect and the HBG electron capture correction.

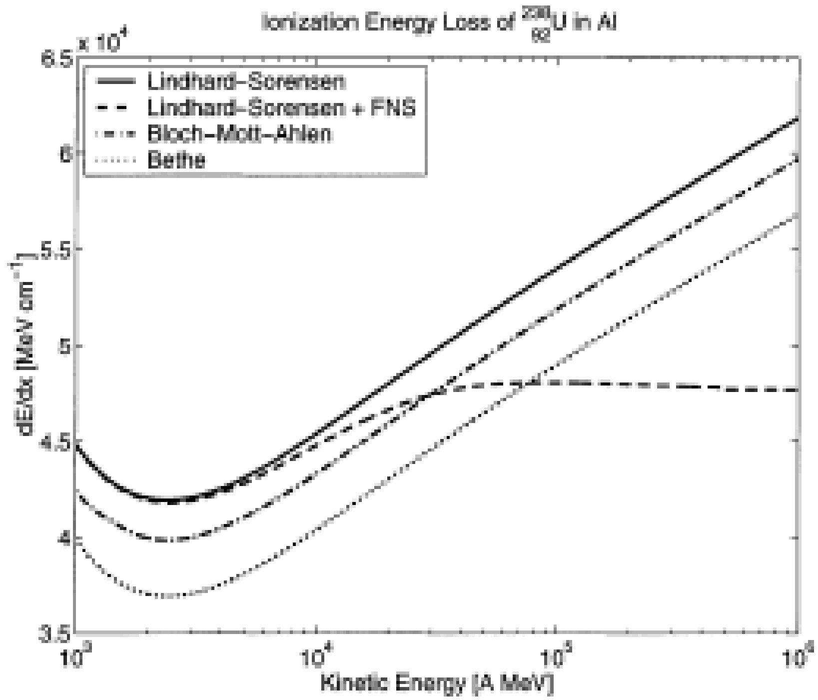


Fig. 2. The high-energy portion of Fig. 1.

- Additional ultrarelativistic effects
  1. QED or radiative correction: bremsstrahlung of scattered electrons during electron-projectile collisions
  2. Kinematic correction: finite mass of the nucleus in electron-projectile collisions
- Projectile bremsstrahlung (important for very highly charged ions at energies which are not “too” ultrarelativistic)
  – Emitted directly from the projectile in the effective field of the target nuclei
- Pair production

- Electron capture
  - The bare nuclear charge Z0 is replaced by the effective projectile charge Z1 in all expressions. For energies >>1 A GeV, Z1~Z0; for lower energies, empirical formula.
- The Barkas correction
  - Difference in energy loss between positive and negative pions -> the energy loss contains odd powers of Z1

- The shell corrections: when the velocity of the projectile is comparable to velocities of electrons in target atoms. (not fully understood, but small effects)

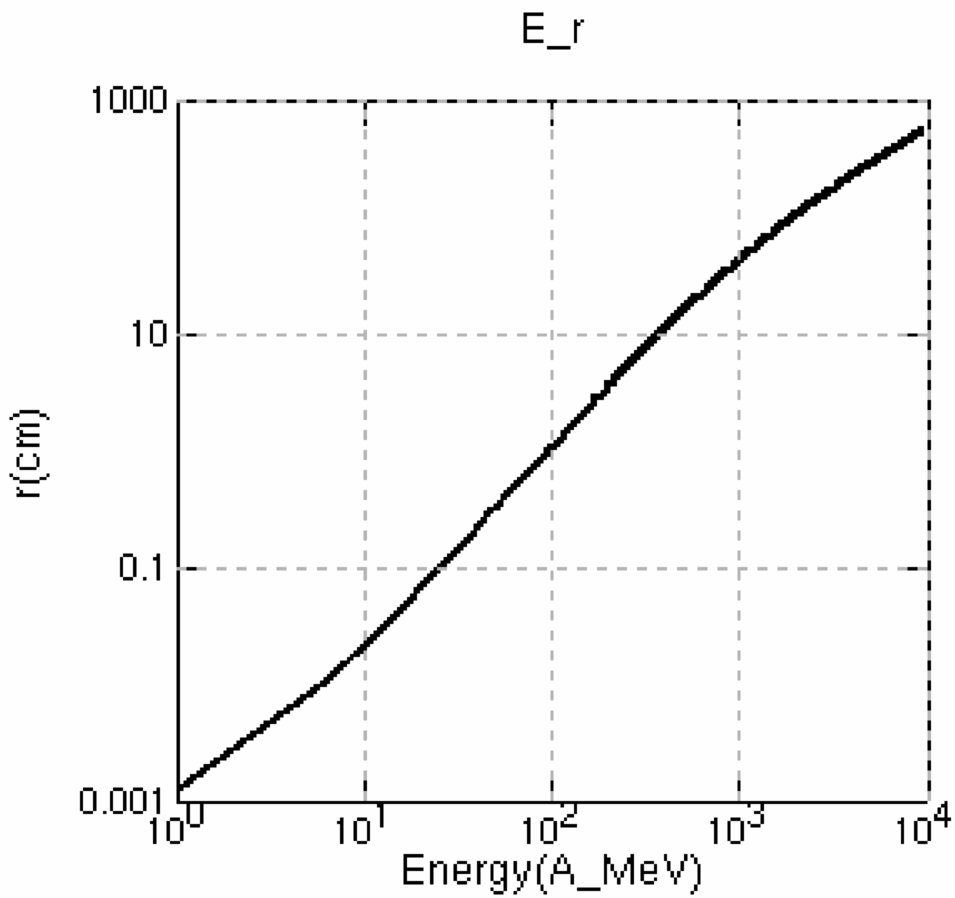
1. Inner shell correction: the velocity of the projectile may be low enough so that inner (K,L) shell electrons have velocities comparable to the projectile
2. Leung or relativistic shell correction: the inner shell electrons may actually have relativistic velocities for sufficiently heavy target atoms

Dedx code

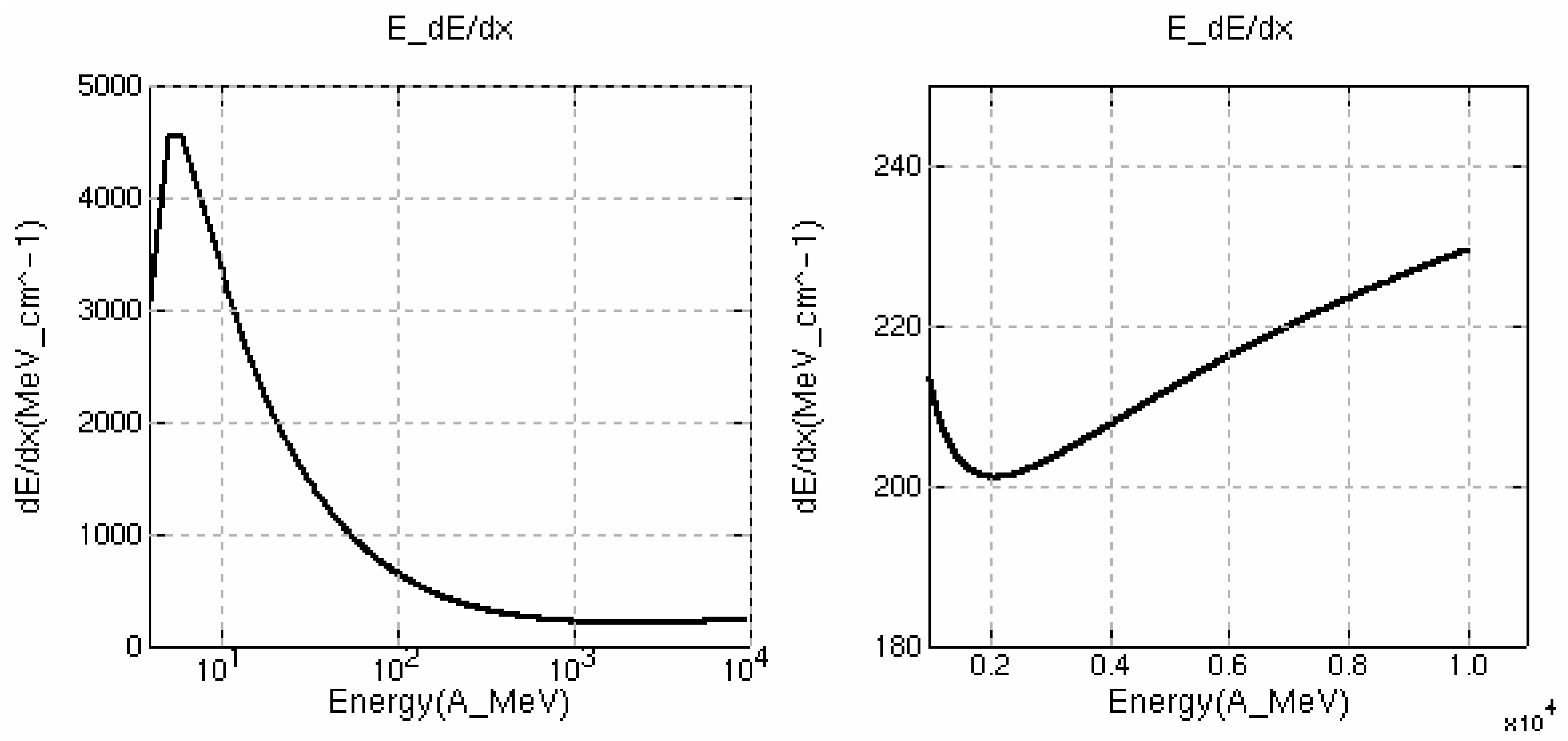
- Input task examples:

1. r 1200 0 92 238 Al
   - compute the range (in g cm^-2) of uranium (Z=92,A=238) at a kinetic energy of 1200 MeV per nucleon, in an aluminum target
2. e 0 9.2 79 197 CR-39
   - compute the initial kinetic energy (in A MeV) of gold (Z=79,A=197) whose range in the plastic track-etch detector CR-39 was 9.2 g cm^-2
3. e 10600 9.2 79 197 CR-39
   - compute the final kinetic energy after passing through 9.2 g cm^-2 of CR-39, given an initial energy of 10.6 A GeV
4. d 10600 0 79 197 Air
   - compute dE/dx (in A MeV g^-1 cm^2) for gold with kinetic energy 10.6 A GeV in air
5. d 10600 300 79 197 Air
   - compute REL instead of dE/dx with the REL cutoff set to 300 eV

Ranges of C in CsI using dedx code



dE/dx of C in CsI using dedx code



Further work

- Combine this code with the LAT geometry?