Space Radiation Transport Codes: Comparisons & Model Sensitivities to Nuclear Data

Zi-Wei Lin
Department of Physics
East Carolina University
Greenville, NC
Compare Space Radiation Transport Codes

We have compared dose, dose equiv. & spectra of

- **4 transport codes:**
  - 1-d deterministic: HZETRN (1995), UPROP,
  - 3-d Monte Carlo: FLUKA, Geant4.
- **3 space radiation environments:**
  - Oct. 1989 SPE, Jan. 20 2005 SPE,
  - 1977 solar minimum GCR.
- **2 shielding materials:**
  - aluminum (Al), polyethylene (CH₂).
- **2 geometries:**
  - slab, spherical shell (10g/cm², r=1.5m)

Other comparison studies include

- …
Comparing transport codes: slab geometry

Oct. 1989 SPE

- Dose values from HZETRN, FLUKA and Geant4 are ~ consistent,
- Dose from UPROP is lower behind thick shielding.
- Dose equivalent from Geant4 are often higher than HZETRN.
- Dose equivalent from UPROP behind shielding are much lower (*UPROP has no neutrons*).
Comparing transport codes: ion spectra

1977 solar minimum GCR

Behind 10g/cm\(^2\) Al slab:

HZETRN and Geant4 are consistent.

At inner wall of a spherical 10g/cm\(^2\) Al shell (average thickness 27.3g/cm\(^2\)):

HZETRN and Geant4 are consistent.
Comparing transport codes: shell geometry

- Dose values from HZETRN and Geant4 agree.
- Dose equivalent from HZETRN & Geant4 are close for aluminum, but Geant4 are higher than HZETRN for CH₂.

A key goal of comparison studies is to identify the physics models/components, which cause the differences in the transport model results, for future improvements.
Model Sensitivities to Nuclear Data

1d propagation equation ($\Lambda_{kj}=1/n\sigma_{kj}$): 

$$\frac{\partial J_k(E,x)}{\partial x} = -\frac{J_k(E,x)}{\Lambda_k(E)} + \sum_j \frac{J_j(E,x)}{\Lambda_{kj}(E)} + \frac{\partial[\omega_k(E)]J_k(E,x)}{\partial E}$$

→ Sensitivity matrix $S_{jk}$ (for dose equiv. $H$):

$$\delta H(x) \equiv \rho x \sum_{j,k} S_{jk} \frac{\delta \sigma_{kj}}{\sigma_{kj}},$$

$$S_{jk} = \frac{n}{\rho \Gamma \rho} \int J_j \left[ -Z_j^2 Q(Z_j^2 L_1) \frac{A_k}{A_j} + Z_k^2 Q(Z_k^2 L_1) \right] L_1 \sigma_{kj} dE.$$

→1-d projections

Partial cross section to light fragments (e.g. nucleons & $\alpha$) are by far the most important.
Several projectiles are important (e.g. O, Mg, Si, Fe).

Zi-Wei Lin (ECU)      Workshop on Applied Nuclear Data Activities (WANDA) 2/28-3/04/2022 6
Model Sensitivities to Nuclear Data

Sensitivity function in energy $S(E)$ (for dose equiv. $H$):

$$H = \sum_k \int J_k(E)L_k(E)Q[L_k(E)] \, dE,$$

$$\delta H = \int S(E) \frac{\delta \sigma(E)}{\sigma(E)} \, d(\ln E).$$


Cross sections in a wide energy range $\sim(0.1, 10)$ GeV/u are all important, with the radiation risk being most sensitive to cross sections at (lab-frame) energy of $\sim(0.3, 0.85)$ GeV/u in solar minimum GCR environments, $\sim(0.85, 1.2)$ GeV/u in solar maximum GCR environments.
Further Studies Helpful for Space Radiation Transport

**Nuclear cross section data:**
Results from sensitivity studies need to be combined with available cross section data to identify:
- what important cross sections are missing or need to be better measured.

**Space radiation transport codes:**
- Transport codes in general need to use theoretical nuclear physics models for fragmentation as well as secondary particle productions (*pions, kaons, anti-nucleons, …*) that are tuned to double-differential experimental data.

- → Synergy with relativistic heavy ion collisions:
  especially because of the recent/future focus of relativistic heavy ion physics on high net-baryon density physics (*at energies that overlap with space radiation physics*) & renewed interests in light nuclei productions (\(^2\)H, \(^3\)H, \(^3\)He, \(^4\)He, …).

- It could also be useful to develop “fast Monte Carlo” codes (*faster than normal Monte Carlo & more accurate than deterministic*), this can benefit from such works in radiation therapy research.