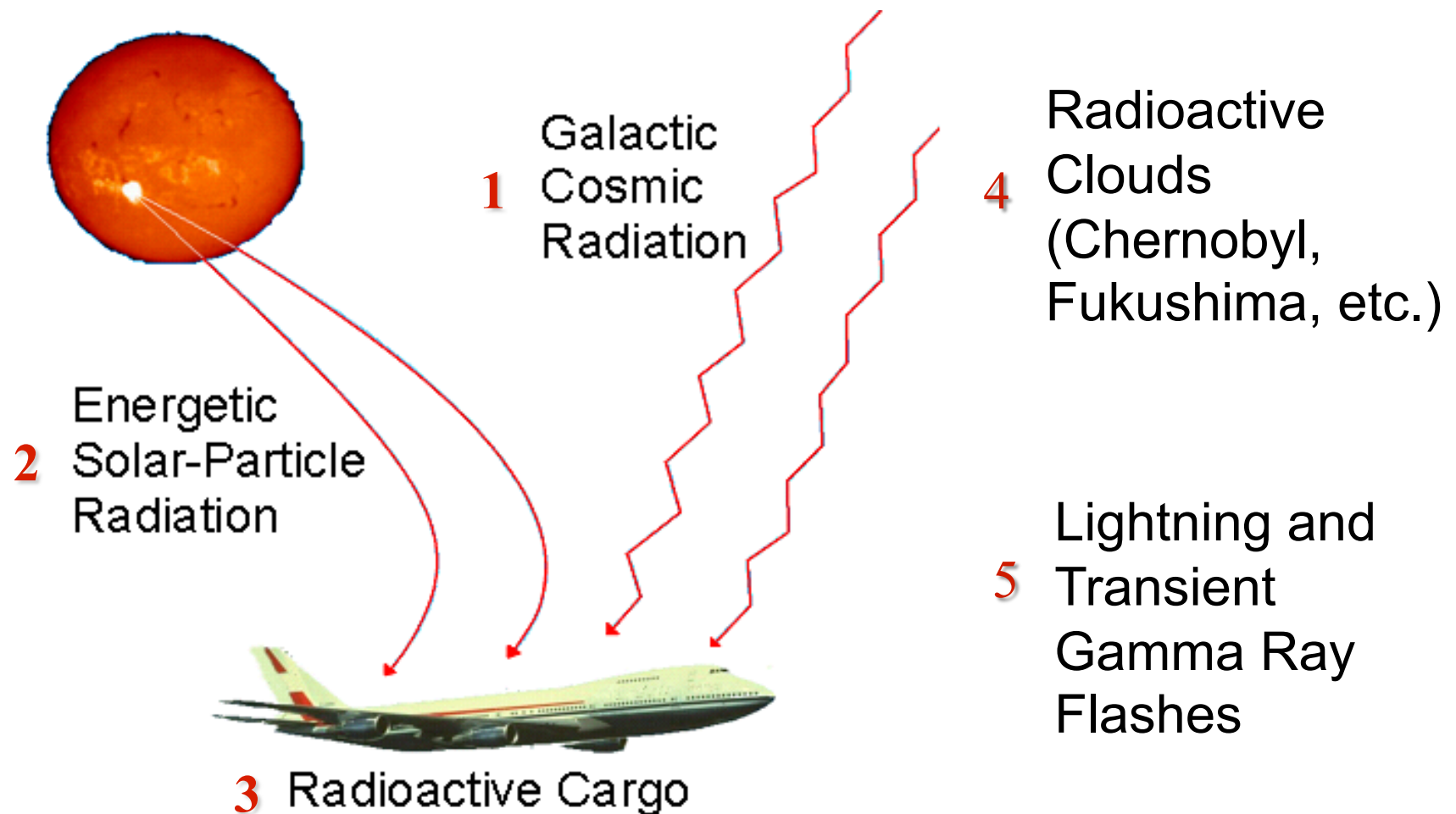


Sources of Occupational Exposure to Ionizing Radiation for Air and Space Travelers



FAA Models for Calculating Ionizing Radiation Exposure

Galactic Cosmic Radiation:

CARI

Solar Cosmic Radiation:

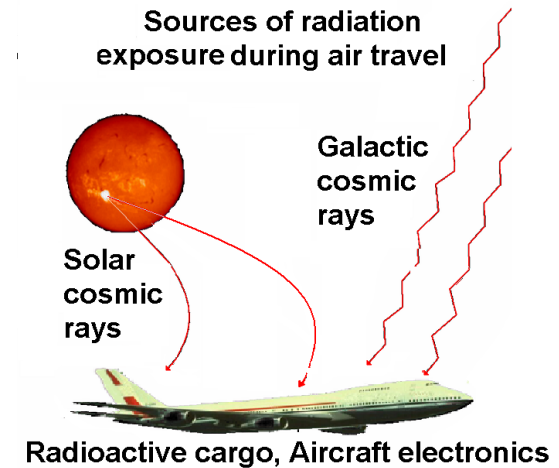
Solar Radiation Alert System for real time from GOES protons.

Ad hoc codes for after-the-fact add neutron data.



What is CARI?

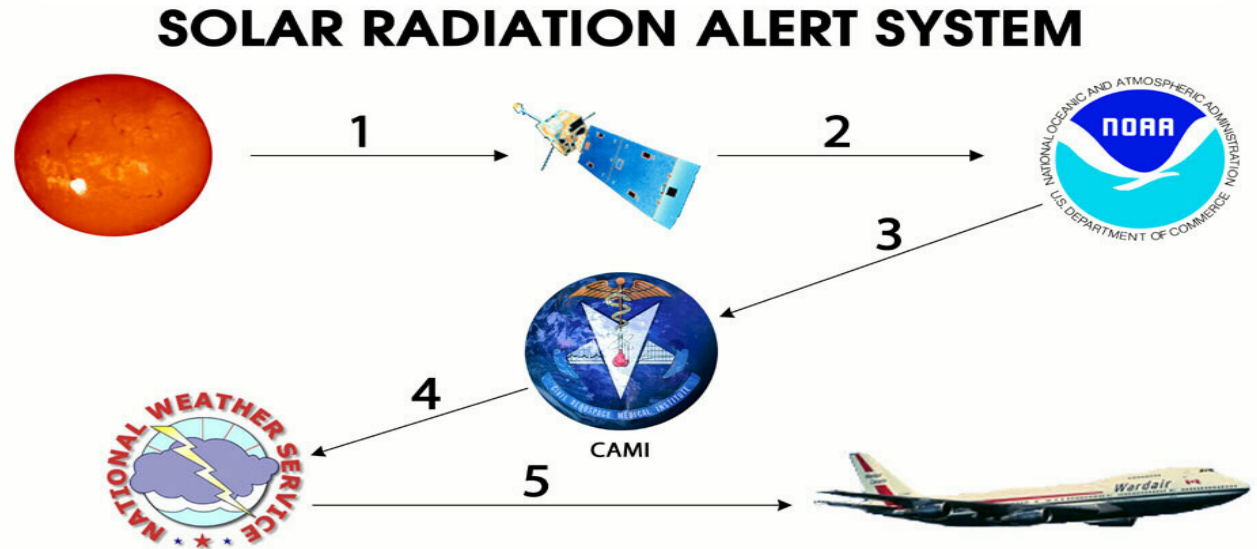
- The first CARI program was released in the early 1990s. Based on LUNN transport code.
- First called CARRIER, then shortened to CARI.
- Each series of PC computer programs has a base version and some variants, e.g., for NIOSH.
- Used by pilots and airlines worldwide to monitor career radiation doses.
- Used by epidemiologists to estimate past exposures for radiation effects studies.



CARI-7 Design

Up through CARI-6, altitude was limited to 60,000-87,000 feet. Based on LUN [O'Brien 1978].

CARI-7 is based on MCNPX2.7.0/ MCNP6v1.0.) and is an extension to GCR of the SPE dose calculation concepts used in the Solar Radiation Alert System.



1. An eruption on the Sun raises radiation levels in Earth's vicinity.
2. A GOES satellite measures the radiation and transmits the data to NOAA.
3. A CAMI computer obtains and analyzes the data from NOAA.
4. CAMI issues any needed alert or update to the National Weather Service.
5. The National Weather Service informs the aviation community.



MCNPX 2.7.0

(Monte Carlo N-Particle eXtended)

Where does it come from?

Los Alamos National Laboratory

Why use it for cosmic ray research?

It is capable of transporting all atomic species and dozens of subatomic particles and antiparticles at up to TeV energies.

What is it?

A general-purpose radiation transport code that uses Monte Carlo techniques. Last Stable version of MCNPX.

Same physics as MCNP6v1.0.



Particle Transport

MCNPX is used to simulate cosmic ray showers for neutrons and primary GCR ions H-Fe.

Flux tallies are made throughout the atmosphere approximately every 3 km through 33 km, then more sparsely up to 100 km.

Tallies include n, e, gamma, pi, mu, p, d($^2\text{H}^+$), t($^3\text{H}^+$), alpha, ^3He , and fully ionized Li-Fe.

Tally spectral energy range is 1MeV-1TeV for all particles, with additional lower-energy tallies for neutron and gamma spectra.

Using the superposition approximation is optional. Doses can be calculated all the way to the top of the atmosphere.



Transport Environment

The properties of the atmospheric model are based on the 1976 US Standard Atmosphere

| | |
|--|--|
| <i>Maximum altitude above sea level</i> | <i>100 km</i> |
| <i>Area of its uppermost surface</i> | <i>$5.262 \times 10^{18} \text{ cm}^2$</i> |
| <i>Total atmospheric depth</i> | <i>1035.08 g/cm²</i> |

100 1-km thick shells

Beneath the innermost shell, the Earth is modeled as a sphere of liquid water of radius 6371 km and density 1 g/cm³

Particles originate from the outer surface of the uppermost atmospheric shell

Empty space surrounds the uppermost atmospheric shell. Particles that leave the uppermost shell moving away from Earth escape

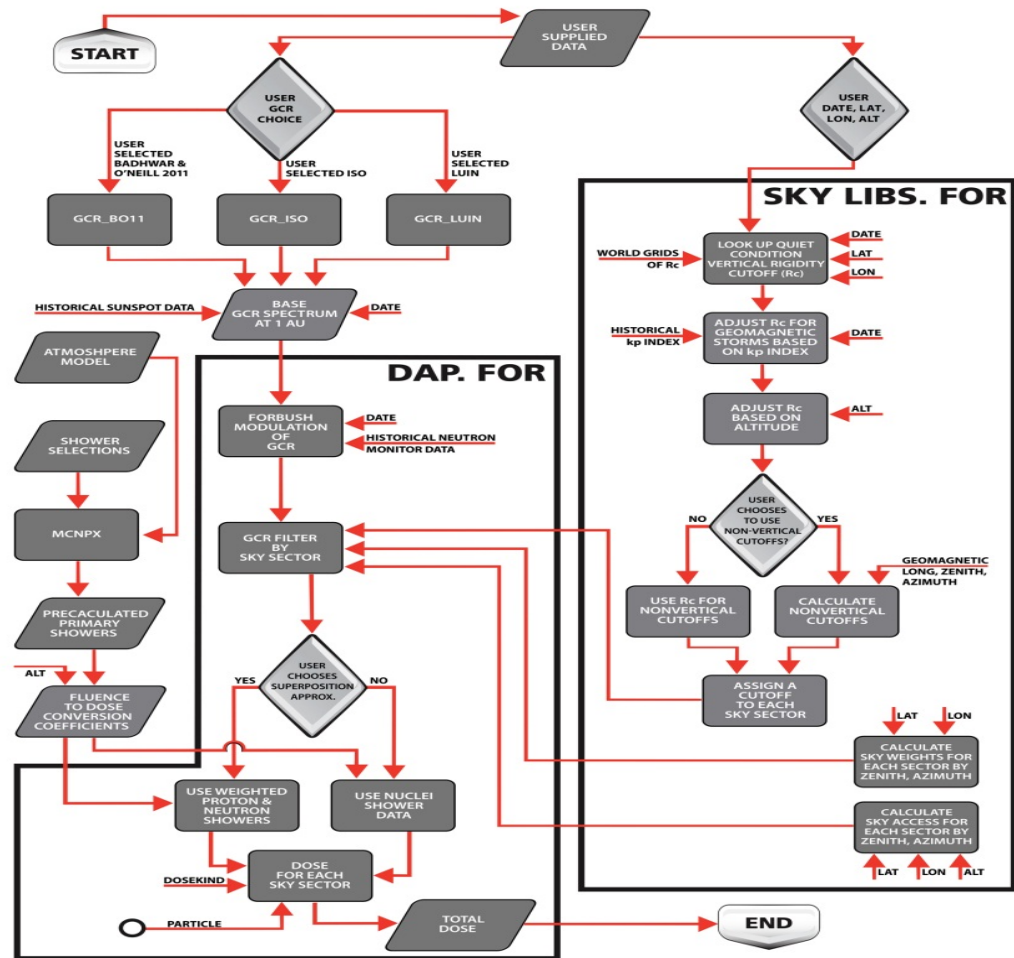


CARI-7 Process

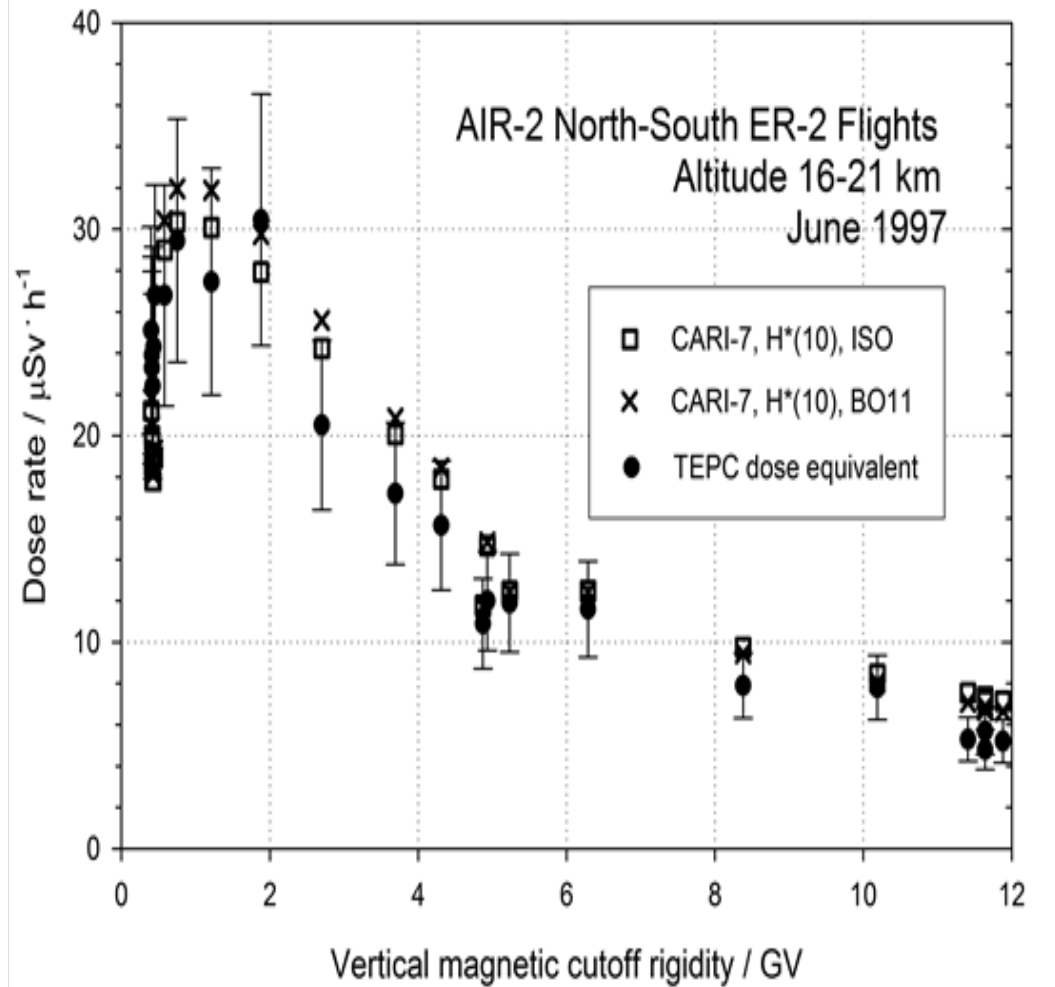
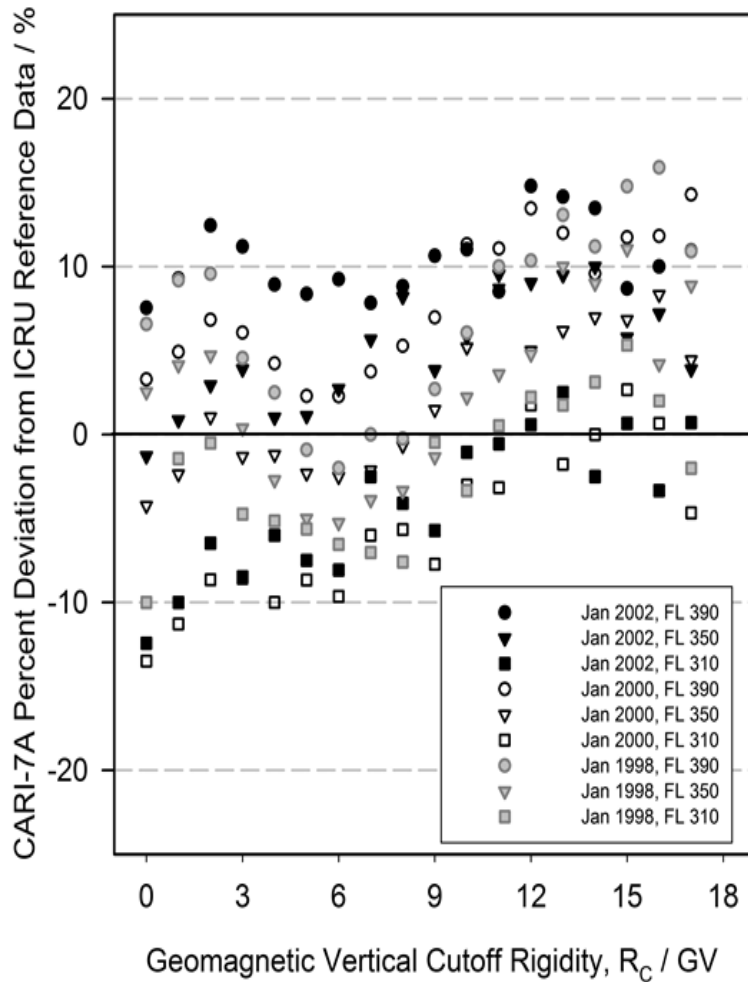
Shower data are reduced to dose rates at each tally altitude per unit fluence at the top of the atmosphere for each type and energy of primary particle.

Primary spectra at the top of the atmosphere are used to guide integration of doses at each altitude for the conditions of the time of the query

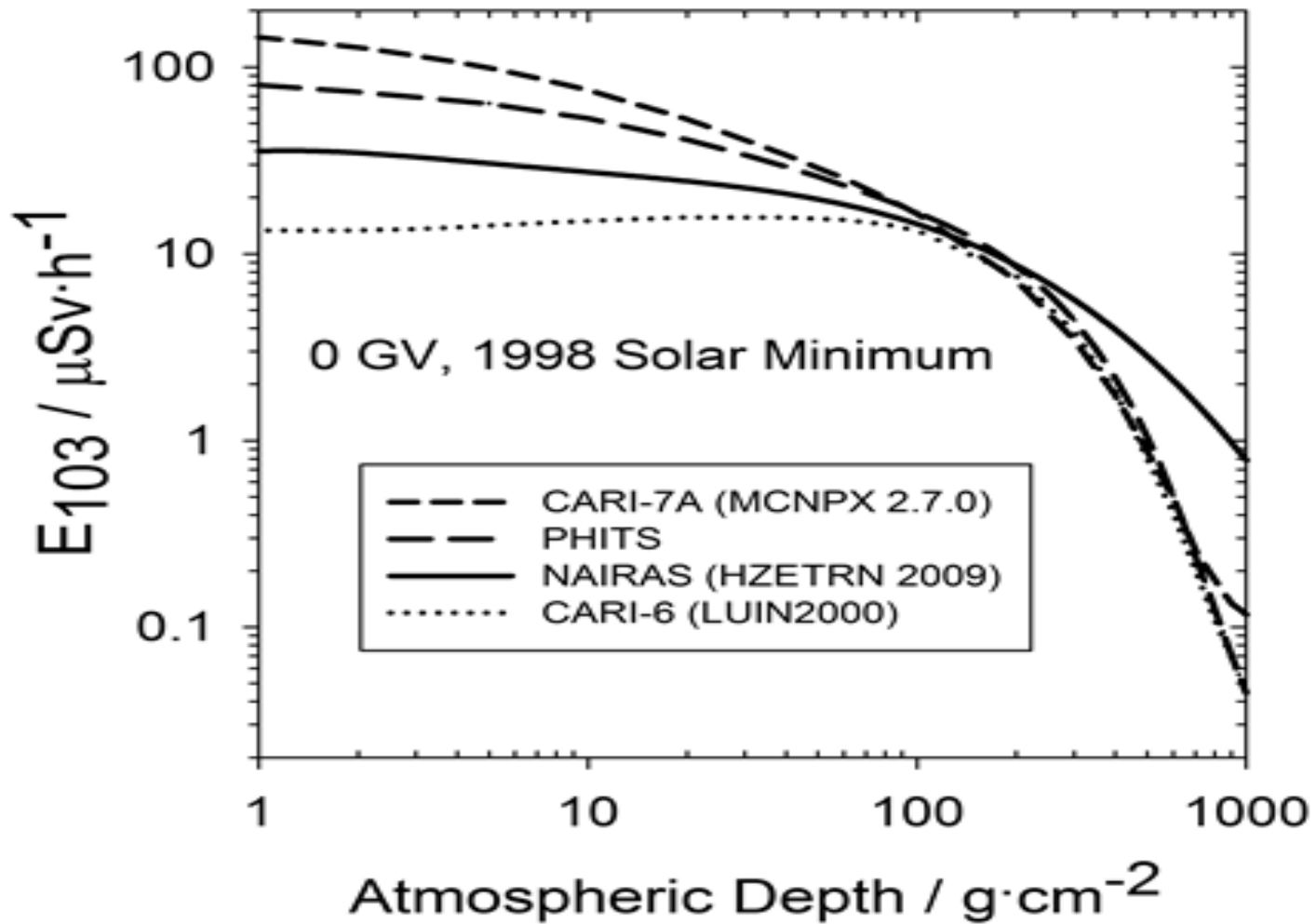
CARI-7 DOSE-AT-POINT PROCESS



CARI-7 vs Measurements



CARI-7 vs Other Codes



Some Weaknesses of the Approach

- Particles that escape cannot re-enter, even if they should.
- Shower data assume isotropic access to top of the atmosphere, which is an increasingly poor assumption at low geomagnetic latitudes.
- Simulation maximum depth limitations lead to high doses at lowest altitudes.
- For spacecraft it is difficult to include effects of structure.

Future Work

- Revise to generate particle spectra at altitude, then convert to dose. This would allow adding filters for effects of aircraft/ spacecraft structure rather than approximating effects, but slow down the calculations.
- Create a simplified version for distribution to laymen.
- Update the CARI online flight dose calculator.

