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# Background-Source Cosmic-Photon Elevation Scaling and Cosmic-Neutron/Photon Date Scaling in MCNP6

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## INTRODUCTION

The Earth is continuously being bombarded by cosmic radiation consisting of various particles, such as protons, alpha particles, and heavier nuclei. Many such particles are deflected by the Earth's magnetic field. However, those particles with sufficient momentum to overcome deflection and penetrate the Earth's shielding magnetic field go on to propagate through the atmosphere colliding with atmospheric molecules.

These collisions produce secondary particles such as neutrons, protons, photons, muons, pions, and other exotic particles that carry enough energy to undergo additional nuclear interactions, and so on, forming a cascade shower. Particles in the cascade shower constantly lose energy through interactions as they propagate through the atmosphere. These atmospheric energy losses make the integral cosmic background flux at ground level highly dependent on the atmospheric depth traveled by the incident particle and subsequent progeny and therefore the elevation of the ground where a cascades deposits its energy.

Previous work has been done using the galactic cosmic-ray (GCR) source option, in the all-energy, all-particle radiation transport code MCNP6 [1] in 2010, to simulate GCR interactions and their cascades to produce an increasingly accurate global cosmic and terrestrial background flux data file (background.dat) [2]. The latest version of this data file (Release 4) contains neutron and photon background data for a 2054 grid locations around the world [3] and is used as the basis of the background source option in MCNP6. When a user invokes the background-source option (PAR=BG, BN, BP) and provides a longitude and latitude on the location keyword (LOC), the nearest background.dat grid point is used to sample the background flux at that location.

In this paper, two scaling techniques are discussed which are automatically applied to provide better accuracy when using the background-source option at a specific location, altitude, and date. Examples of each scaling method are presented and discussed.

## DESCRIPTION OF ACTUAL WORK

While the simulation of GCR backgrounds can provide an accurate description of the neutron and photon background fluxes at a certain location, it is impossible to tabulate the background particle fluxes for every point on earth and at every point in time. For this reason, two scaling methods have been implemented to account for location (i.e., elevation) and temporal influences on the magnitude of background fluxes in order to better tailor the MCNP sampled source particles derived from flux distributions provided in the background.dat file.

### Elevation Scaling of the Cosmic-Photon Background-Source

Due to the dependence of cosmic-ray backgrounds on atmospheric depth, cosmic-neutron elevation scaling was implemented shortly after the background-source option was introduced in MCNP, whereby the neutron flux weight factor was adjusted by an exponential elevation scaling factor as described by McMath et al. [4]. In this reference, a similar exponential elevation scaling factor was also proposed for the cosmic-photon flux, however, cosmic-photon elevation scaling is complicated by the fact that photon backgrounds consist of two distinct sources: GCR interactions in the atmosphere (cosmic) and naturally occurring radioactive material (NORM) in the soil (terrestrial).

Previous versions of the background.dat file did not provide any way to separate the cosmic and terrestrial components of the photon background-source, instead simply providing the total background-photon flux. With Rel. 4 of this file in 2014 [3] two new columns were added that provide the energy grid and differential cosmic-photon flux separate from the total-photon flux. Using this information, the cosmic background component can now be scaled independently of the terrestrial background component and then recombined to form the elevation scaled total background-photon flux at a given elevation.

Cosmic-photon elevation scaling of the background flux is invoked when the user provides a value for the elevation (ALT) entry on the LOC keyword that differs from the value for that location in the background.dat file. For example, the Albuquerque International Airport is located at roughly 35°N, 107°W with an elevation of 1,632 meters. The background-photon source definition for this location would then take the form:

```
SDEF PAR=BP LOC=35 -107 1.632
```

MCNP will then take the user provided coordinates and match them with the closest available grid point in the background.dat data file. In this case the closest location in the background data file is 36°N, 110°W with an elevation of 1,997 meters. The difference in elevation between the user-specified location and the closest background location is then used to calculate the exponential scaling factor to be applied to the integral cosmic-photon flux.

If one wishes to eliminate elevation scaling, the value of the ALT entry can be set to -1, forcing the elevation of the evaluated background.dat grid point to be used. Comments are written to the MCNP output file that indicate to the user the latitude, longitude, and elevation of the background.dat location spectrum being used as well as the elevation scaling factor that has been generated. If one has an alternate background spectrum for a specific location of interest (e.g., measured data), it can be added to the background.dat file with a small amount of editing and sampled with the background-source option.

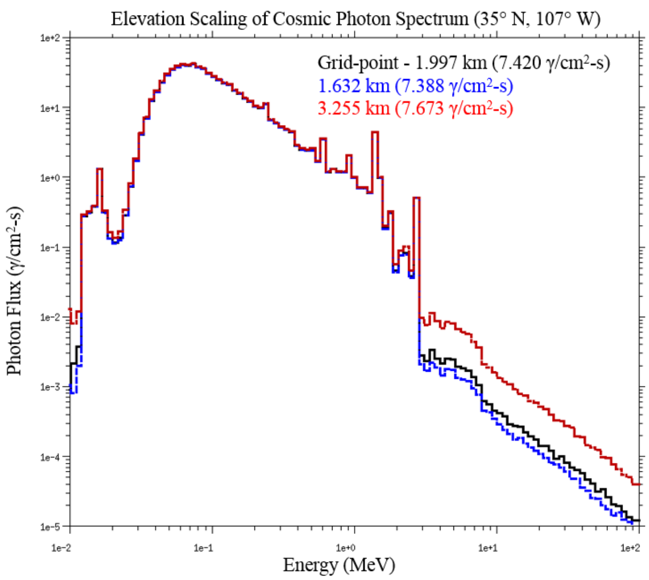


**Fig. 1.** Elevation scaling of the cosmic-photon background near the Albuquerque International Airport.

Extending the example from before, a simple MCNP input file was created to simulate the photon background near the Albuquerque International airport. In this example, a 10 cm radius sphere centered about the origin was created and a background-photon source was placed on its surface, directed inward. Photons emitted from this sphere were weighted by a factor of $\pi R^2$ such that a central tally cell has a unit flux. Finally, a 1 cm radius sphere, centered at the origin, was used to tally the background-photon flux.

Figure 1 shows the effect of elevation scaling on the MCNP cosmic-photon background-source spectrum near the Albuquerque International Airport. The default spectrum for the nearest grid point (35°N, 107°W) in the background.dat file is shown in black, while the spectrum scaled to the elevation of the location of interest is shown in blue. Additionally, the photon spectrum that would be encountered at the peak of the nearby Sandia Mountain range (3.255 km) is shown in red. The effect of cosmic-photon elevation scaling is most noticeable at photon energies greater than 3 MeV due to the nature of the photon background, which is dominated by NORM gamma rays up to ~3 MeV and dominated by GCR-produced photons beyond 3 MeV. The figure shows that the magnitude of background-photon spectrum has been scaled down by a factor of 0.70 in the Albuquerque Airport case due to the decrease in elevation from the background.dat grid point location. Conversely, in the Sandia Mountain peak case, the magnitude of the cosmic-photon flux is scaled up by a factor of 3.37 due to the decrease in atmospheric depth traveled by GCR particle showers.

### Date Scaling of the Cosmic-Neutron/Photon Background-Sources

Cosmic-particle fluxes are also known to be dependent on the solar cycle, due to solar modulation. Variations in solar magnetic activity over time cause modulation of GCRs in the region of space known as the heliosphere [5]. The solar modulation potential is a parameter used to measure the magnetic field effects on the GCR flux and has been reconstructed from ground based measurements from 1936 to present by Usokin et al [5]. This modulation is seen to be nearly sinusoidal over time, ranging from ~200 MV to over 1200 MV, with an inverse effect – increased modulation leads to a decrease in the magnitude of cosmic-particle fluxes.

Knowledge of solar modulation potentials has already been implemented in MCNP6 to allow date scaling of the cosmic-source option [6] and has now been extended for use with the background-source option when: (1) the date is specified in the background.dat file, and (2) when the user specifies a date on the source definition card.

Date scaling of the background-source option is automatically applied when the user specifies a particular date with the DAT keyword on the SDEF card. This date is used to select a solar modulation potential from the MCNP built-in table of solar modulation potential values from 1936 to 2014 [6]. If the user-specified date is before 1936, then the solar modulation potential value for 1936 is used. Whereas, if the date falls within the range for which tabulated data is available, linear interpolation is used to select the appropriate solar modulation value. Finally, if the specified date is after 2014 (or the latest date for which data is available), a sinusoidal fit is used to predict the solar modulation potential of future years as described in Liegey et al. [6].

An MCNP input file was created in the same fashion as the previous example, this time employing the background-neutron source option (PAR=BN) with date scaling. The location, 37°N, 120°W, 196 m, was selected to match measured data taken from Sandia National Laboratory – Livermore (SNLL) on November 6th 2006 by Goldhagen et al. [7]. This measurement date was specified in the MCNP simulation with the DAT keyword (DAT=11 6 2006) to allow date scaling of the background-neutron flux.

Figure 2 shows a comparison between the measured background-neutron spectrum at SNLL and the MCNP-generated spectrum for the same location. In this case, the nearest background.dat grid-point location is 38°N, 120°W, with an elevation of 1,695 m (labelled Unscaled). It is obvious that significant elevation scaling is required to match the location of the measurement, however it is also important to note that the background-neutron spectrum for the nearest grid-point in the background.dat file was evaluated for September 1, 2013. According to the Usokin data, this date corresponds to a solar modulation potential of 610 MV while the input date from 2006 corresponds to a potential of 422 MV. The difference in solar modulation potentials indicates a higher GCR flux during 2006 than in 2013, and therefore the neutron background should be scaled accordingly. Elevation scaling from 1,695 m down to 196 m results in a scaling factor of 0.28, bringing the background spectrum below the measured value, while the difference in solar modulation potential results in a scaling factor 1.48, increasing the magnitude of the neutron background spectrum. While the elevation+date scaled spectrum is somewhat higher than the measured spectrum, detailed modeling of the SNLL building and experimental container has verified that the cosmic-neutron flux is attenuated by the surrounding structure, leading to a ~15% reduction in the measured flux.

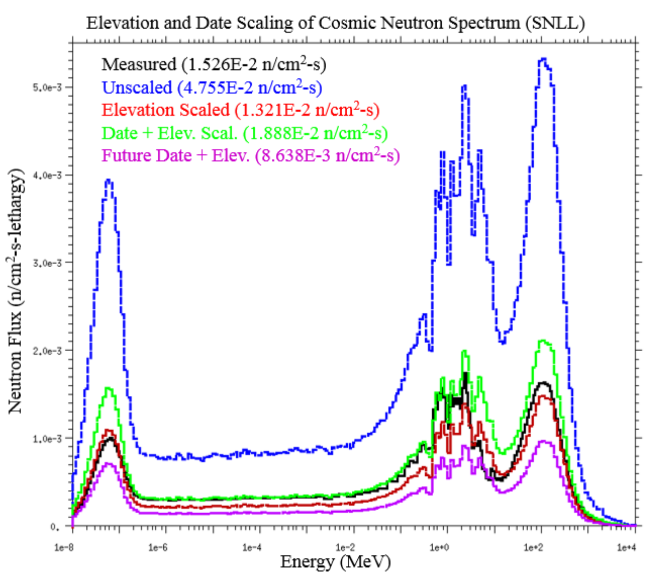


**Fig. 2.** Neutron background spectrum at SNLL location 37° N, 120° W, 196 m with the effects of scaling.

While date scaling, combined with elevation scaling, shows good agreement with measurements taken in the past, for many applications it is desirable to use the background-source option to predict the effects of background fluxes on a scenario that will occur in the future. In these cases, a sinusoidal fit based on the most recent solar modulation potential values can be used to predict the effect of solar modulation in the future. To demonstrate this capability, the date of the SNLL example was changed to November 6, 2016, and a solar modulation potential of 890 MV was predicted by MCNP. This result is also shown in Figure 2.

## CONCLUSION

Cosmic ray background fluxes scale with elevation as GCRs go through atmospheric interactions, and with date due to solar modulation. The newest version of the background.dat data file now allows for elevation scaling of the cosmic-photon background-source, while knowledge of the solar modulation potentials over time enables date scaling of cosmic-photon and neutron background-sources for both past and future dates. Implementation of these scaling methods provide a means by which more accurate background-sources can be created for specific locations and dates with MCNP6.


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