Dose Rate Profile Surrounding a Waste Repository – 14281

Jenelle Parson *, Alexander Brandl *, Roman Koppitsch **, Norbert Zoeger **
* Colorado State University
** Nuclear Engineering Seibersdorf

ABSTRACT
The waste repository analyzed is an interim storage facility that houses low and intermediate level conditioned radioactive waste. In total, it contains 9996 200-L waste barrels. The barrels are arranged in a crate geometry to ensure easy access to each barrel. The repository walls are 0.2 m thick with extra shielding (0.7 m) present on the west, north, and east sides of the repository. Instead of extra shielding the south side of the repository has a 5.25 m gap from the crates to the wall, allowing for maneuverability of a crane. The dose rate profile was analyzed using Monte Carlo N-Particle Transport eXtended (MCNPX) for the south, west, and north sides. The east side was not explicitly analyzed, because of the symmetry between the west and east side. The dose rate was analyzed using f5 detector tallies and fluence rate to dose rate conversion factors from ICRP 21. Here, contributions due to skyshine and other wall effects are analyzed in detail. For the west and north side (where shielding was present), it was found that as distance from the source increases the dose rate initially increases logarithmically to a maximum and subsequently falls off following an exponential function. The initial increase in dose rate is significant with a peak dose rate as much as 300% of the dose rate at the wall and remaining elevated until around 60 m from the waste repository. A similar dose rate increase was not observed for the southern side of the repository; instead, the dose rate fell off with a power function corresponding to an infinite plane source. The dose rate was analyzed with and without repository structures, and the initial increase was only present with the repository structure. Skyshine and wall effects have been analyzed extensively for medical acceleratory facilities, but are generally not considered for a waste repository; the work suggests that skyshine and wall effects may be more significant than previously thought and should be considered in the construction of waste repositories.

INTRODUCTION
Skyshine refers to radiation that is directed upward and is scattered in the atmosphere and is reflected back to the ground, often at distances much further away from the source [1]. Skyshine radiation is of concern for workers onsite, as well as populations far from the source [1]. Fig. 1 displays an illustration of skyshine for a vertically orientated source [2].

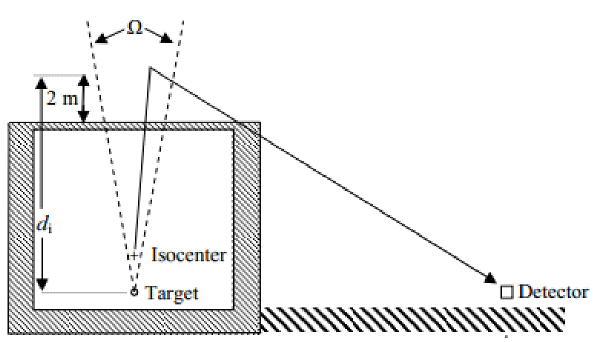

Fig. 1. Illustration of Skyshine [2]

Effects of skyshine on workers and the public were first observed at the Cosmotron and the Bevatron high-energy particle accelerators in the 1950s. Insufficient roof shielding was added at these facilities, resulting in increased worker and public dose due to low-energy neutrons scattered in the atmosphere [3]. More roof shielding was added above the facility and doses were decreased [3].

Accelerator skyshine has been further analyzed for the Varian Trilogy Linear Accelerator at the Colorado State University Veterinary Medical Center by Elder [2] and for Varian 2100 C treatment rooms by McGinley [4]. Both works found an initial increase in photon dose rate, peaking around 300% of the original dose rate, and returning to original dose rate at around 30 m (Fig. 2). Additionally, Elder found a similar, more pronounced increase when the gantry was not positioned vertically [2].

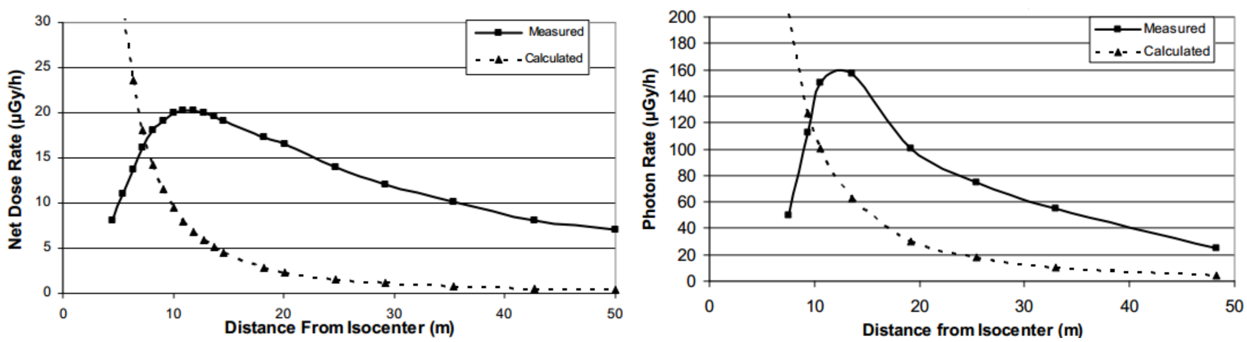

Fig. 2. Skyshine Dose Rates for the Varian Trilogy Linear Accelerator at the Colorado State University Veterinary Medical Center (L) [2] and for Varian 2100 C Treatment Rooms (R) [4]

Similar skyshine observations were observed in Monte Carlo simulations by Lagutina et. al [5]. The exposure rate around a collimated Co-60 source was determined experimentally, using DOT3.5, Monte Carlo Simulations, and using a single scattering method with allowance for subsequent scatterings [5]. A comparison of methods is shown in Fig. 3 for a Co-60 source with a collimation half angle of 75°.

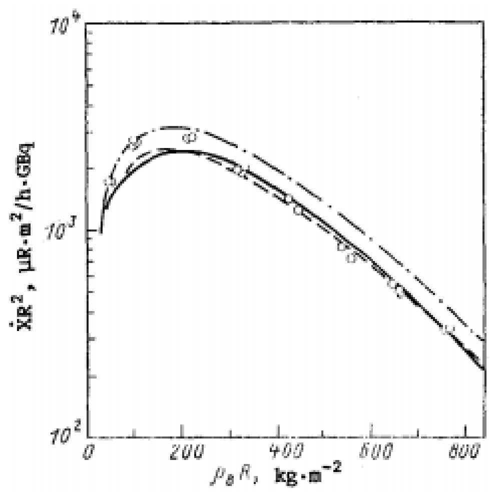

Fig. 3. Exposure Rate versus Distance Experimentally (o), DOT3.5 Calculation (- -), and Monte Carlo Methods (--), and Single Scattering with Allowance for Subsequent Scatterings (- · -) [5]

For each method, the exposure rate increases to a maximum and subsequently decreases, similar to the observations made by Elder and McGinley. The relationship between skyshine and detector position was also simulated by Lagutina et. al. For all detector positions, the skyshine reached a peak and subsequently decreased; the peak was reached at closer distances for lower detector positions, but the peak was less pronounced [5].

METHODS

The repository is an above ground interim waste storage facility that houses low and intermediate level conditioned waste. The facility houses a total of 9996 200-L waste barrels. The repository totals a length of 60.93 m, a width of 29.67 m, and height of 7.49 m. Fig. 4 shows a depiction of the waste repository analyzed, as created in Visual Editor (VISED) [6].

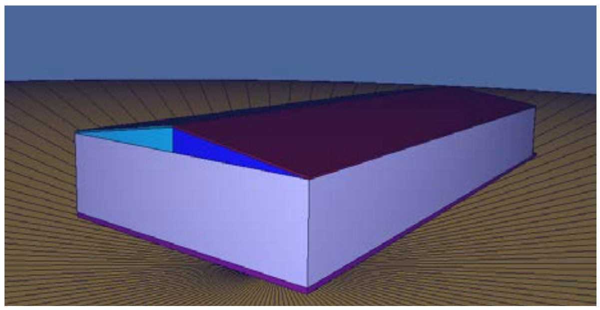

Fig. 4. Depiction of Waste Repository in VISED [6]

The waste is encased in concrete and stored in 200-L waste barrels composed of steel. A diagram of the 200-L waste barrel used for analysis is shown in Fig. 5.

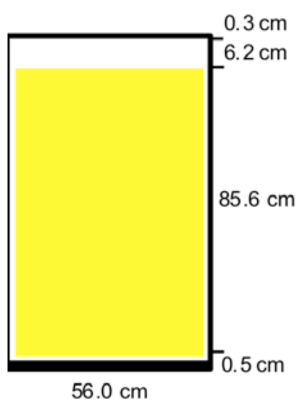

Fig. 5. 200-L Waste Barrel

The barrels are stored in a crate geometry, such that the tops of the individual barrels are accessible. There are a total of 21 stacking rows that contain 17 pallets of four drums, stacked seven high. The following is a bird's eye view of the waste repository (Fig. 6). The 21 stacking rows appear vertically on the figure, while the pallets of four appear horizontally.

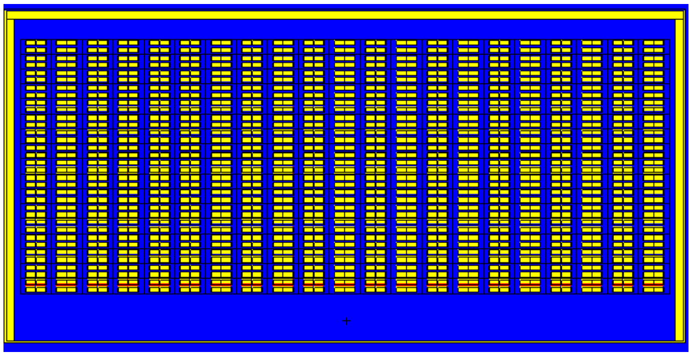

Fig. 6. Bird's Eye View of the Repository

The following nomenclature in Fig. 7 is based on the bird's eye view of the repository in Fig. 6 and will be used when discussing the repository.

Fig. 7. Nomenclature

The walls of the repository are 0.2 m thick and additional shielding is provided on the west, north, and east sides of the repository (0.7 m). There is a 1 m gap between the waste barrel structure and the walls on the west, north and east side; while there is a 5.25 m gap between the waste barrel structure and the south wall, allowing for maneuverability of a crane used to move waste barrels.

Monte Carlo N-Particle Transport eXtended (MCNPX) was used for the analysis [7]. The content of each barrel was modeled as homogeneous concrete; the waste barrel structure was created using a repeated source. The repository structures and ground below the repository were also modeled as concrete. The barrel contents and repository structure were modeled as nuclear grade concrete with a density of 2.3 g/cm^3, while the ground density corresponded to a typical soil density of 1.2 g/cm^3.

The source was created using a repeated source structure distributed through the contents of each barrel. The source radionuclide was chosen to be Co-60 with photon energies of 1.173 and 1.332 MeV. Co-60 was chosen due to its high photon energies and should provide a conservative estimate for the modeled dose rate.

The dose rate was determined using f5 detector tallies with ICRP 21 fluence to dose rate conversion factors [8]. The f5 detector tally is a deterministic estimator of photon fluence rate and uses a next event estimator procedure [9] [10]. By using a next event estimator, the photons don't actually have to make it to the detector to be counted; this tally is therefore useful when it is unlikely that particles will reach the tally location [9] [10]. An exclusion zone is used around the tally to exclude interactions that occur too close to the tally and cause an increase in variance of results, which is difficult to quantify. The radius of the spherical exclusion zone used was 1 cm.

RESULTS AND DISCUSSION

Dose rate profiles were developed for the north, west, and south walls with and without repository structures present to determine geometry effects. The dose rate profiles for the north and south walls are discussed here. For the west side of the repository, results were consistent with the north side and will not be discussed in detail.

The dose rate as a function of distance away from the waste barrel structure was developed at a detector height of 3.745 m for the north wall and is presented in Fig. 8. The dose rate values without the repository structure are corrected for attenuation. When the repository structure is present, the dose rate initially increases, reaches a maximum, and subsequently decreases. The peak dose rate in Fig. 8 is 250% of the original dose rate at the wall and falls to the original dose rate at around 60 m, consistent with dose rates due to skyshine developed by Elder and McGinley (Fig. 2) and by Lagutina et. al (Fig. 3) [2] [4] [5].

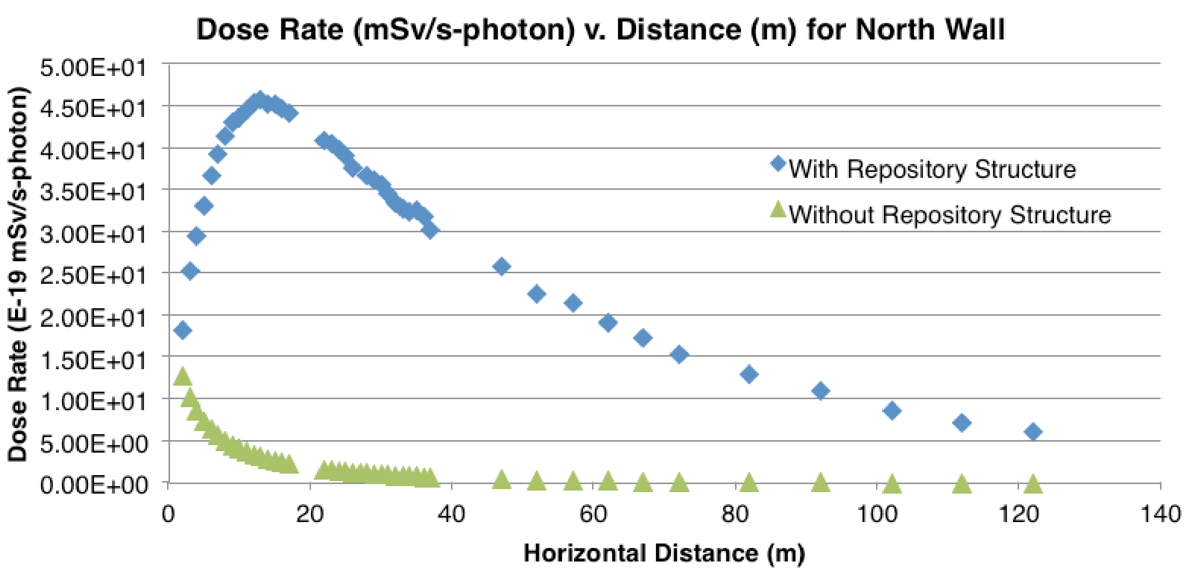

Fig. 8. Dose Rate versus Distance for North Wall with and without Repository Structure

The dose rate profile for the north wall at five heights: 1.465, 2.605, 3.745, 4.4775, and 5.21 m, was developed and is presented in Fig. 9. For higher detector locations, the dose rate increases more rapidly and reaches a larger peak dose rate. It is likely that at a higher height, more radiation is present at higher energy resulting in a higher peak dose rate. The presence of the peak at a different location could be resultant from the scattering angle, as seen in Fig. 1.

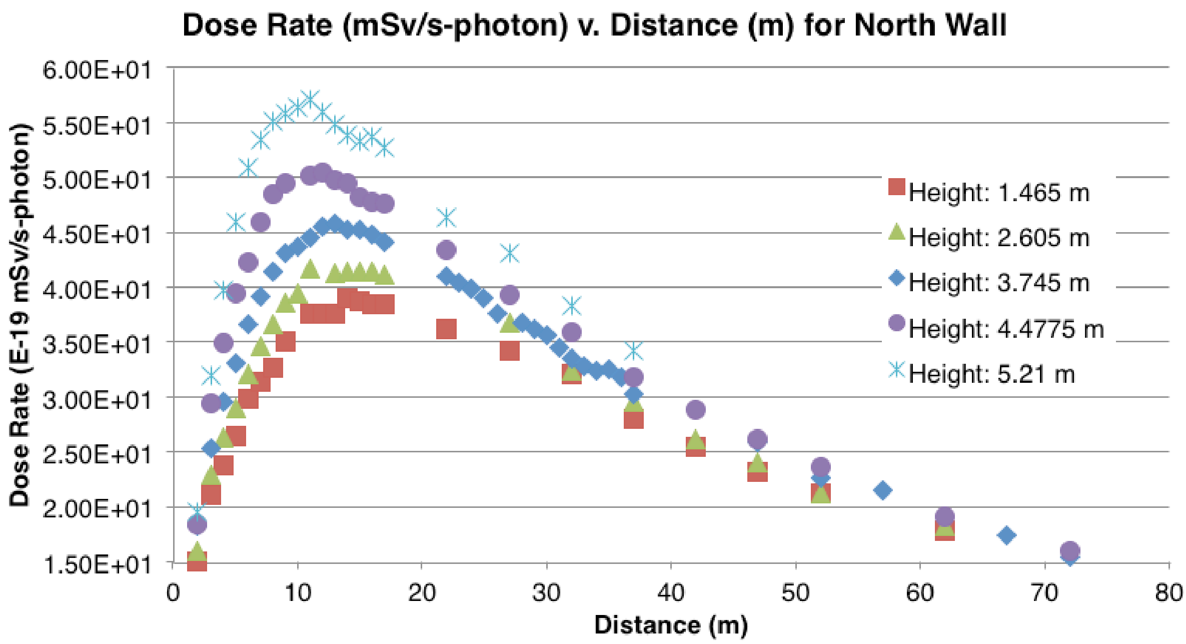

Fig. 9. Dose Rate versus Distance for North Wall for Various Heights

The dose rate as a function of distance with and without repository structures was also developed for the south wall at a detector height of 3.745 m (Fig. 10). The dose rate values without the repository structure are corrected for attenuation. No initial increase is present in Fig. 10.

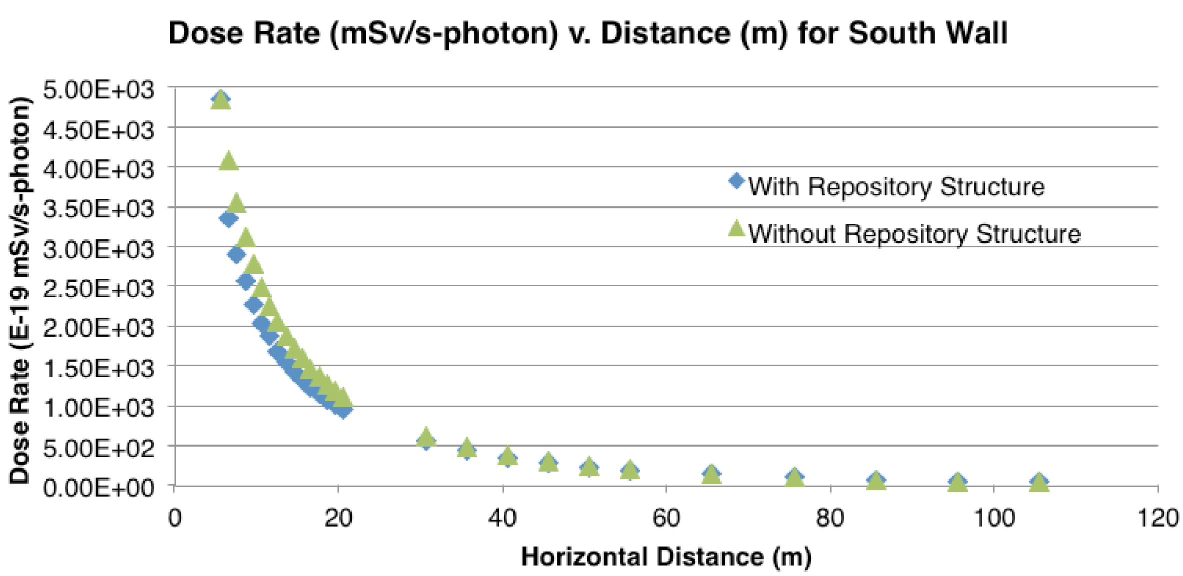

Fig. 10. Dose Rate versus Distance for South Wall with and without Repository Structures

The dose rate profile for the south side was also developed for five heights (1.465, 2.605, 3.745, 4.4775, and 5.21 m) and is presented in Fig. 11. For all five heights, the dose rate decreases without reaching a maximum. The dose rate appears to be largest for the height of 3.745 m (half way up the repository).

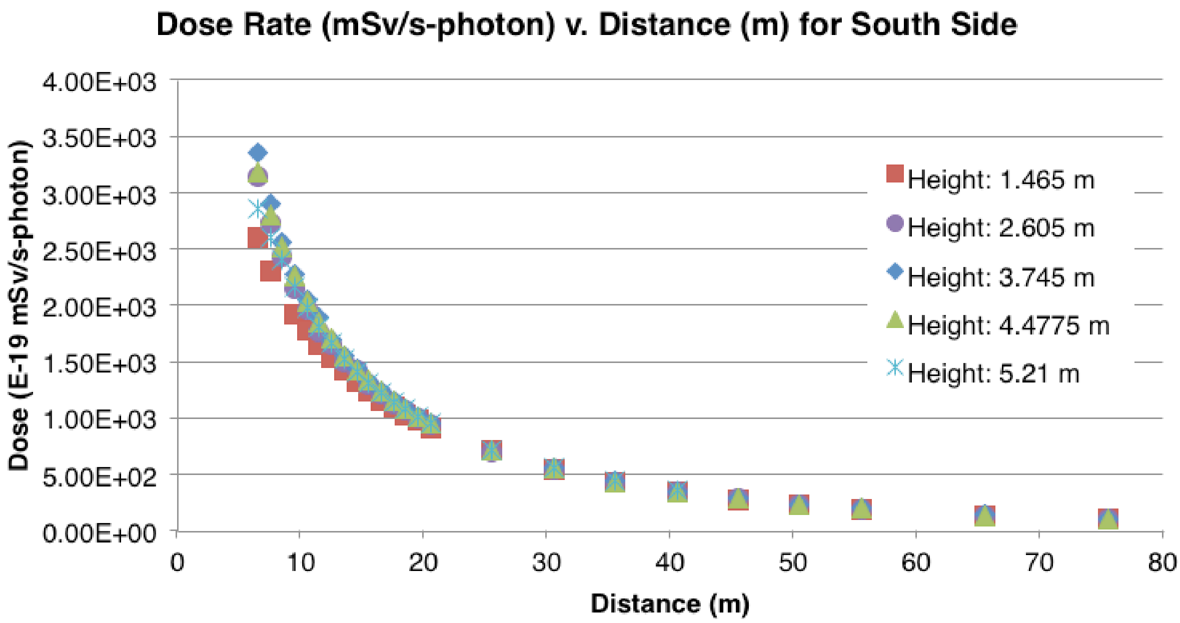

Fig. 11. Dose Rate versus Distance for South Wall for Various Heights

CONCLUSIONS

The dose rate profiles developed for the north side of the repository follow closely to dose rates due to skyshine developed by Elder and McGinley for medical accelerator facilities, and by Lagtina et. al for a collimated Co-60 source. As detector tally height increased, the dose rate increased more rapidly and reached a larger maximum. A larger maximum dose rate at higher heights could be due to increased abundance of radiation, more energetic radiation, or a combination of both, while the more rapid increase could be due to the angle of scattering by the skyshine to reach the detector position.

The lack of maxima in the south side profile, suggests that the larger air gap or smaller wall thickness affects skyshine, or rather the effects seen are due to wall effects. These effects need to be investigated further, possibly by computational source manipulation.

REFERENCES

[1] J. Shultis and R. Faw, Radiation Shielding, La Grange Park: American Nuclear Society, Inc., 2000.

[2] D. E. Elder, "Skyshine Radiation Resulting from 6 MV and 10 MV Photon Beams From a Medical Accelerator," Colorado State University, Fort Collins, 2008.

[3] R. H. Thomas, "The History and Future of Accelerator Radiological Protection," *Radiation Protection Dosimetry,* vol. 96, no. 4, pp. 441-457, 2001.

[4] P. H. McGinley, "Radiation Skyshine Produced by an 18 MeV Medical Accelerator," *Radiation Protection Management,* vol. 10, no. 5, pp. 59-64, 1993.

[5] I. Lagutina, V. P. Mashkovich, A. Stroganov and A. Chernyaev, "Skyshine From Photon Radiation," Plenum Publishing Corporation, 1989, pp. 118-124.

[6] A. Schwarz, R. Schwarz and L. Carter, "MCNP/MCNPX Visual Editor Computer Code," 2008.

[7] MCNPX Team, "Monte Carlo N-Particle eXtended," Los Alamos National Laboratory, Los Alamos, 2008.

[8] International Commission on Radiological Protection, "ICRP Publication 21," *Recommendations of the International Commission on Radiation Protection,* no. 21, 1973.

[9] X-5 Monte Carlo Team, "Volume I: Overview and Theory," in *MCNP - A General Monte Carlo N-Particle Transport Code*, Los Alamos, Los Alamos National Laboratory, 2008.

[10] J. K. Shultis and R. E. Faw, An MCNP Primer, Manhattan: Kansas State University, 2006.

ACKNOWLEDGEMENTS

In the development of this project, I would like to acknowledge Nuclear Engineering Seibersdorf for providing this project and repository drawings. I would also like to thank Rafe McBeth for running the MCNP files on the CSU cluster and assisting in debugging code. In addition, I want to thank Thomas McLean and Dave Seagraves at LANL for their help on developing a repeated source structure.

This publication was supported by Grant Number T42OH009229-06 from CDC NIOSH Mountain and Plains Education and Research Center. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC NIOSH and MAP ERC.