QA: N/A

VALIDATION OF MCNP4A FOR REPOSITORY SCATTERED RADIATION ANALYSIS

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Abstract

Comparison is made between experimentally determined albedo (scattered) radiation and MCNP4A predictions in order to provide independent validation for repository shielding analysis. Both neutron and gamma scattered radiation fields from concrete ducts are compared in this paper. Satisfactory agreement is found between actual and calculated results with conservative values calculated by the MCNP4A code for all conditions.

Introduction

The purpose of the study that forms the basis of this paper was to perform comparison of scattered radiation calculations with experimental measurements to validate the MCNP4A computer code¹ in predicting albedo (scattered) radiation that may be encountered in the design of the potential Yucca Mountain repository.

A potential safety issue for the Yucca Mountain Site Characterization Project is the radiation field that workers may be exposed to from waste packages in the emplacement drifts. Once emplacement drifts have been filled, any direct radiation to workers in the accessible main drifts will be completely eliminated by the use of shadow shields after the last emplaced waste package. However, this arrangement does not preclude scattered neutron and photon radiation from influencing the occupied regions of the repository, namely the main drifts. Consequently, it is the scattered radiation field that is the major concern for worker safety.

Radiation shielding calculations have routinely been performed for the Yucca Mountain Repository using MCNP4A. This code has a long history of

documented comparisons of predicted calculations, particularly for criticality calculations². A less extensive history exists for comparisons in shielding and in particular for scattered radiation calculations³.⁴ Consequently, there is an interest and a need to perform benchmark calculations using this code against measured data which nearly approximate the scattered radiation conditions expected for the repository. Results of these calculations will serve to assist in the verification of repository shielding analyses involving scattered radiation.

Benchmark Calculations

For validation purposes, it is essential that the selected benchmark problems represent the repository geometry and conditions as closely as possible. The current repository design⁵ provides over 100 emplacement drifts spaced at 28 m apart for horizontal in-drift emplacement of waste packages. The typical usable emplacement drift length available for waste package emplacement is approximately 1000 m, which may contain over 60 large PWR waste packages per drift based on a center-to-center spacing of 15.2 m. The emplacement drift bored diameter is 5.5 m with a concrete lining of 0.2 m thick as part of the ground support structure. All the emplacement drifts are connected to the main drifts on both ends where personnel occupancy may be required during emplacement or retrieval operations. The main drifts are larger in diameter (7.62 m borehole) and may also be concrete lined. Radiation fields in the main drifts are entirely from scattered radiation from waste packages in the emplacement drifts, once emplacement is complete. An additional contribution will arise from the waste package transporter in transit in the main drifts.

The benchmark problems selected in this comparison are based upon work done in the 1960's in support of fallout shelter design. The geometry consists of square concrete shafts or ducts with one or more right angle bends. Direct radiation is the principal contributor to radiation fields in the first leg of the duct. Radiation fields in the second or third leg of the duct are from scattered radiation off the concrete walls only. The bend blocks direct radiation from the source and simulates the repository condition in which the concrete shadow shield eliminates the direct radiation contribution. Furthermore, the scattering medium is identical in material (concrete) and density (2.35 g/cc) for both experimental ducts and repository emplacement drift walls.

The benchmark experiments used in this study include the following (English units used to be consistent with the experiments):

1. A 2.5 MeV neutron source through a 3-ft-square (0.914 m) L-shaped concrete duct⁶
2. A Co-60 source through a 6-ft-square (1.83 m) L-shaped concrete duct⁷
3. A Cs-137 source through a 1-ft-square (0.305 m) U-shaped concrete duct⁷

The neutron energy of 2.5 MeV in Case 1 represents the approximate mean neutron energy for the neutron source spectrum associated with PWR spent fuel. The photon energies for Co-60 and Cs-137/Ba-137m in Cases 2 and 3 are characteristic of the photon source spectrum for PWR spent fuel.

The concrete ducts used in the experiments are considerably smaller in cross section than the repository emplacement drift. However, the L/D (length to diameter or equivalent) ratios which dictate the attenuation factor for scattered radiation are similar for the experimental and repository configurations.

For each experimental case, the concrete duct configuration was explicitly modeled in three-dimensional geometry. The source was placed on the axis at or near the duct entrance, consistent with the experimental mockup. Dose rate calculations were performed with MCNP4A at various points located along the duct axis, using the flux-to-dose-rate conversion factors in the ANSI/ANS-6.1.1-1977 Standard. The neutron dose conversion factors in this Standard are similar to the response function for the REM Ball counter⁸ used in the neutron measurements

for Case 1. For Cases 2 and 3, the experimental results are expressed in relative terms rather than absolute terms as for Case 1. Therefore, use of the photon dose conversion factors from the Standard is satisfactory.

Results

Figures 1 through 3 present the results of the MCNP4A calculations for Cases 1, 2, and 3, respectively, along with the experimental data for comparison. The agreement between the calculations and measurements is generally good or excellent in the first leg of the duct, since the contribution is mainly from direct radiation. Differences are noted in the second or third leg of the duct, as scattered radiation becomes dominant.

In all cases, the MCNP4A code consistently over-predicts the scattering contributions for both neutrons and photons by a factor of as much as 2. This factor is acceptable for shielding calculations involving a large dose reduction factor as encountered in the repository, and provides conservatism for the repository design.

Conclusions

The results of the shielding benchmark calculations against the relevant experiments validate the applicability of the MCNP4A code to repository scattered radiation analysis. This code will continue to serve as a primary calculational tool for the repository radiological safety design involving scattered radiation.

References

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FIG. 1 - 2.5 MeV NEUTRON SOURCE THROUGH A 3-FT-SQUARE L-SHAPED CONCRETE DUCT

FIG. 2 - GAMMAS FROM 3.67 Ci Co-60 SOURCE THROUGH A 6-FT-SQUARE L-SHAPED CONCRETE DUCT

FIG. 3 - GAMMAS FROM 80 Ci Cs-137 SOURCE THROUGH A 1-FT-SQUARE U-SHAPED CONCRETE DUCT