COG11.1 Code Features for Shielding and Criticality Safety Analyses

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ABSTRACT

The performance of a shipping package in satisfying the regulatory requirements of the Code of Federal Regulations (CFR) is normally documented in the Safety Analysis Report for Packaging (SARP). In Chapter 5, shielding evaluations for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) are documented to meet 10 CFR 71 requirements. In Chapter 6, nuclear criticality safety evaluations for NCT and HAC are documented to show that the package is subcritical. The COG code developed by LLNL, is a Monte Carlo radiation transportation code, which has been heavily used in the areas of radiation detection and nuclear criticality safety. Unique features of COG include specifications for rotational surfaces, use of the perspective 3-D graphics, input of multiple cross section libraries, and repeated structure modeling capability. Furthermore, the time dependent gamma ray source term can be automatically generated for direct radiation dose calculations. This paper presents some of these COG code features for solving shielding and criticality safety problems for the 9975 shipping container. Comparison of COG results against SARP and MCNP results indicates that COG can be a powerful tool for preparation of the Chapters 5 and 6. COG is distributed through the Radiation Safety Information Computational Center (RSICC) of ORNL.

INTRODUCTION

The performance of a shipping package for meeting the regulatory requirements of the Code of Federal Regulations (CFR) is normally documented in the Safety Analysis Report for Packaging (SARP). In Chapter 5 [1], shielding evaluations for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) are documented to meet 10 CFR 71 requirements. In Chapter 6, nuclear criticality safety evaluations for NCT and HAC are documented to show that the package is subcritical. COG [2,3,4] is a modern Monte Carlo radiation transport code developed by LLNL. It provides accurate answers to complex three-dimensional shielding, criticality safety, and activation problems. Using COG, a complex curved solid can be modeled by rotating a curve made of straight line segments. A three-dimensional perspective picture can be generated. Multiple cross section libraries can be input to a single problem. Multiple cells of the same shapes can be modeled using repeated structure capability. The time dependent gamma ray source can be automatically calculated by solving the Bateman equations for problem dependent decay chains.

COG MODELING OF THE 9975 PACKAGE

The 9975 shipping package [1] was selected for demonstration of these COG features. Figure 1 shows COG model of the 9975 container. In the model, two concentric stainless steel cylindrical containment vessels, a 35-gallon steel drum, Celotex, lead shielding, aluminum impact absorbers, and aluminum bearing plates are included. The primary containment vessel, primary vessel plug, the secondary containment vessel, and the secondary containment vessel plug are modeled using the "revolution" option in COG to accurately model the hardware contours. In all COG calculations, ENDF/B-VII.1 cross section data were used.

NUCLEAR CRITICALITY SAFETY EVALUATION

The criticality safety evaluation in Chapter 6 includes the single package and array analyses for NCT and HAC. Figures 1 and 2 show a NCT single container, and a HAC 5 × 5 × 2 array for the 9975 containers, respectively. The 5 × 5 × 2 array was generated using the "lattice" and "unit" repeated structure modeling options in COG.

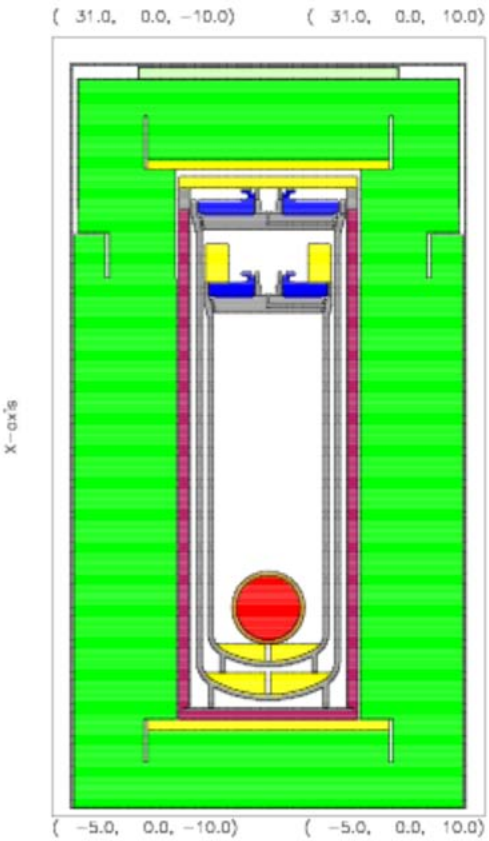

Figure 1. COG Single 9975 Container Model.

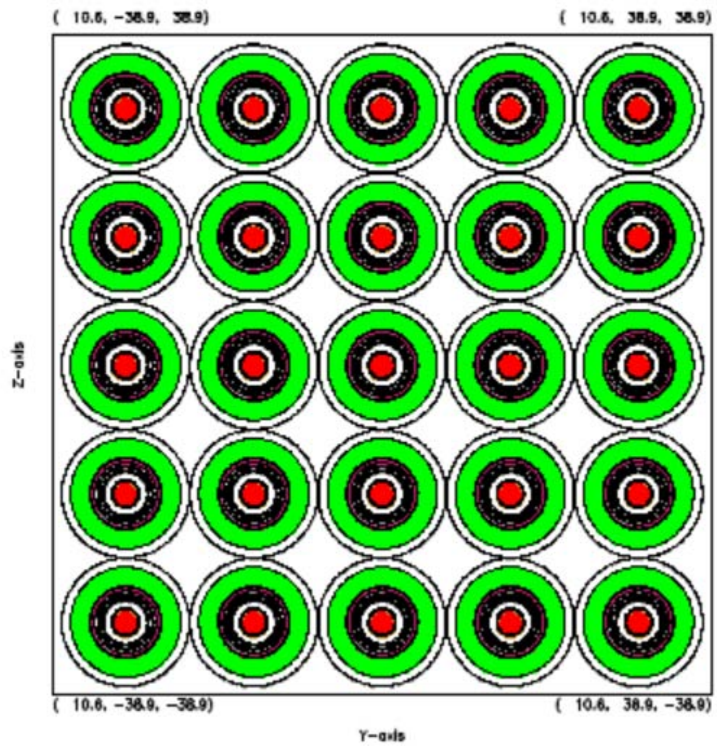

Figure 2. COG 5 × 5 × 2 Array Model.

To test COG, three cases from the 9975 SARP are selected. These are 1) an infinite array of dry 9975 containers (Case 1), 2) a single flooded package with infinite water reflection (Case 2), and 3) a 5 × 5 × 2 array of the 9975 containers for the HAC. The content for the package evaluated is 4.4 kg Pu-239 with 100 g polyethylene. Table 1 compares $k_{eff} \pm 1\sigma$ for the three selected cases. Note that the SARP $k_{eff} \pm 1\sigma$ values are calculated by SCALE [5]. COG and SCALE results compare well with each other indicating that COG can be used as a high fidelity criticality safety analysis tool for SARP preparation. The minor differences in the results are due to differences in a geometry modeling approximation.

Table 1. $k_{eff} \pm 1\sigma$ Comparison.

Case No.	Description	9975 SARP	COG
1	Dry, Infinite Array, NCT	0.8734 ± 0.0015	0.8780 ± 0.0015
2	Flooded, Single, Infinite Water Reflection, NCT	0.9311 ± 0.0016	0.9302 ± 0.0015
3	5 × 5 × 2 Array, HAC	0.8605 ± 0.0014	0.8602 ± 0.0016

RADIATION SHIEDING EVALUATION

The shielding evaluation for the package must show that the requirements of 10 CFR 71 for radiation dose limits are met for the NCT and HAC. Radiation dose calculation for the 9975 container (see Figure 1) under NCT, loaded with 4.4 kg plutonium oxide was calculated for comparison with MCNP [6] results. Fixed source calculations were performed to calculate neutron and gamma ray dose rates at the top, bottom, and the side of the 9975 container. Table 2 compares COG results with MCNP results. Relative errors of the results are less than 5%.

Table 2. Radiation Dose Rate Comparison (mrem/hr)

Detector		MCNP	COG
Top	Neutron	8.97	9.19
	Photon	0.09	0.04
Bottom	Neutron	146.9	170.0
	Photon	2.75	1.77
Side	Neutron	151.9	146.7
	Photon	3.11	2.75

Comparison in Table 2 shows relatively good agreement between COG and MCNP, indicating that COG can be applied to any type of package radiation dose calculations.

RADIATION SOURCE SPECTRUM GENERATION

One of the unique features of COG is automatic generation of the gamma ray source spectrum from alpha decay using the “RadSrc” option. The user specifies the parent isotopes of the source at time zero and COG determines the decay chains for all originating isotopes, and solves the Bateman equations to get the amplitudes of all daughters in all chains at a time specified by user. The discrete photons for each daughter isotope are weighted appropriately to yield the resulting photon source. To test this feature, one gram of Am-241 is positioned at the bottom of the 9975 container, and the photon dose rates at the top, bottom, and the side are calculated. As an example, the photon source after a 1000-day decay was calculated using ORIGEN [5], and input to MCNP to compare with COG results. As indicated in Table 3, good agreement is observed between MCNP and COG. Note that dose rate at the top is not given because the calculated value was insignificant.

Table 3. Photon Dose Rate Comparison (mrem/hr)

Detector	MCNP	COG
Bottom	3.76E-5	2.85E-5
Side	2.79E-5	2.01E-5

CONCLUSION

This study demonstrated that COG can be applied to shielding and criticality safety analyses required for SARP preparation. Users can utilize the unique "revolution" feature of COG to model geometry contours more accurately. Multiple cross section libraries can be utilized. Multiple cells can be modeled using "lattice" and "unit" repeated structures. The time dependent gamma ray source spectrum can be automatically generated enabling a one-step shielding calculation. COG11.1 is now available for SARP applications. It is distributed through the Radiation Safety Information Computational Center (RSICC) of the Oak Ridge National Laboratory (ORNL).

ACKNOWLEDGEMENT

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REFERENCES

1. Safety Analysis Report for Packaging Model 9975, S-SARP-G-00003, Savannah River Laboratory, January 2008.

2. R. M. Buck, E. M. Lent, "COG User's Manual: A Multiparticle Monte Carlo Transport Code," UCRL-TM-202590, Lawrence Livermore National Laboratory, September 2002.

3. R. M. Buck, E. M. Lent, "COG11 Manual Supplement," LLNL-SM-461824, Lawrence Livermore National Laboratory, November 2010.

4. R. M. Buck, E. M. Lent, "COG11.1 Manual Supplement," LLNL-SM-635621, Lawrence Livermore National Laboratory, April 15, 2013.

5. "SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations," ORNL/TM-2005/39, Version 5, Oak Ridge National Laboratory, April 2005.

6. "MCNP- A General Monte Carlo N-Particle Transport Code, Version 5," LA-UR-03-1987, Los Alamos National Laboratory, February 2008.