

TESTING MCNP-BRL FOR NUCLEAR VULNERABILITY ASSESSMENTS WITH THE M60A1 TANK

Kursat B. Bekar, John C. Wagner and Thomas M. Evans

*Oak Ridge National Laboratory, P.O. Box 2008 MS-6170, Oak Ridge, TN 37831, USA,
bekarkb@ornl.gov, wagnerjc@ornl.gov, evanstm@ornl.gov*

INTRODUCTION

The vulnerability of the crew and equipment of military vehicles in a nuclear environment has been of concern to U.S. defense agencies for many years. In order to address these issues, the Vehicle Code System (VCS) [1] and Monte Carlo Adjoint Shielding System (MASH) [2] were developed and used for these kinds of applications [3]. In the analysis, the problem geometry used was in GIFT5 format [1,3].

In order to use MCNP5 [4] and its powerful features such as variance reduction mechanisms for this kind of application, a time-consuming and error-prone geometry conversion process from CAD-based complex design to MCNP-style geometry is required.

Unlike standard MCNP, MCNP-BRL [5] can be directly used for this application. MCNP-BRL was developed for nuclear applications by integrating MCNP with the BRL-CAD geometry [6]. In addition to direct CAD geometry usage for particle transport, MCNP-BRL also enables most standard MCNP features, such as mesh-based weight windows, which is highly desirable in this application to obtain realistic results in a reasonable time.

In this summary, we present some preliminary testing results for MCNP-BRL for assessment of the vulnerability of the M60A1 tank in nuclear radiation environments. In addition, we discuss the performance of MCNP-BRL compared with standard MCNP and some challenges in these kinds of analyses.

OVERVIEW OF MCNP-BRL

MCNP-BRL, basically a CAD geometry-driven version of MCNP, was developed for nuclear applications in which complex CAD-based models are available and situations in which the complex geometry cannot easily be represented with standard MCNP5. With this code package, a powerful CAD code system, BRL-CAD [6], was physically linked to MCNP5 to enable Monte Carlo simulations directly on engineering designs without requiring any geometry conversion process from CAD geometry to MCNP-style geometry.

An extensive set of test problems was designed to comprehensively test the code package: (1) problems to test the functionality of MCNP-BRL compared with standard MCNP, (2) problems to evaluate the performance of MCNP-BRL, and (3) problems to test the code with unexpected conditions (e.g., errors in geometry or input files) and to determine code needs under these conditions.

The preliminary test results for MCNP-BRL demonstrate that it is operational with most MCNP features and that it is generally less efficient than MCNP in terms of execution time [5]. However, MCNP-BRL reduces total analysis time significantly, especially for complex geometries, because direct CAD geometry usage reduces input generation time and eliminates the possible human errors in the geometry conversion process.

Results also indicate that CAD geometries often have “null”, or undefined, spaces that are inconsequential to construction and design requirements but can cause problems for particle transport. To resolve this kind of problem, some minor modifications are essential in the CAD geometry/design. However, to eliminate this step, error detecting and handling algorithms were developed and implemented in the MCNP-BRL’s geometry interface. This feature enables MCNP-BRL to produce proper results for CAD designs with some insignificant geometry errors without performing any geometry conversion.

Error-Handling Mechanisms in MCNP-BRL

In CAD designs, geometry errors result in two common ways: (1) an undefined region (gap) between two objects, depicted in Fig.1.a, and (2) overlapping regions – two or more regions overlap, depicted in Fig.1.b.

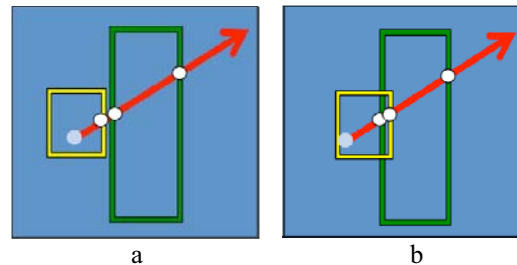


Fig. 1. Common geometry errors in CAD designs.

To handle these errors, MCNP-BRL first determines if these errors are significant for particle transport. For this purpose, it calculates the thickness of the overlap/gap region using BRL-CAD ray-tracing machinery. Later, it compares this thickness to the user-provided “minimum acceptable thickness for overlap/gap region,” which the user provides in the input file and evaluates the error as (1) significant if the calculated thickness is larger than the user-specified thickness (warns user and raises lost-particle flag) or (2) insignificant if the calculated

thickness is smaller than the user-specified thickness (continues particle transport as if there is no problem in geometry).

VULNERABILITY ANALYSIS WITH MCNP-BRL

The BRL-CAD model of the M60A1 tank, depicted in Fig.2, consists of many complicated regions with the following features:

1. More than 3500 primitive object definitions
2. More than 700 regions (some of them have very complicated cell definitions with more than 100-300 surfaces bound a region)
3. Includes Arbitrary Convex Polyhedron of N Vertices (ARBN), Triangular Surfaced Polyhedron (ARS), and Truncated General Cone (TGC) for some region definitions
4. Some minor overlaps in the model, especially for the definition of inner air regions
5. Some regions without any material declarations

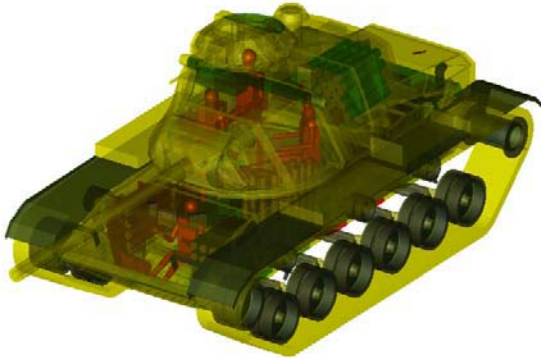


Fig. 2. BRL-CAD model of M60A1 tank with its crew.

After assigning materials to the regions, which did not have any material declarations (inner air regions and other undefined regions in the geometry), the model was tested with MCNP-BRL by defining a point source 1 m above the vehicle. This simple test demonstrates that MCNP-BRL can directly use this model for vulnerability analysis by setting accepted minimum thickness for gaps/overlaps to 0.5–2 mm. For comparison purposes, the CAD geometry has been converted to MCNP-style geometry to generate identical MCNP5 input for this problem. The conversion process is still in progress since the model has some complex region definitions with ARBN, ARS, and TGCs. After obtaining an identical MCNP model, the results of both codes and the performance of the codes will be compared.

A different version of the M60A1 model (simplified model) in the GIFT5 format that had been used in the previous analysis was also obtained [3]. This geometry was processed with MORITZ [7] to obtain an MCNP-style geometric model. After this process, the MORITZ-generated MCNP model was also modified since some

regions of the GIFT5 geometry were not uniquely defined in the conversion process. This model, depicted in Fig.3, consists of over 300 regions and some regions defined by over 100 surfaces.



Fig. 3. MCNP/BRL-CAD models of simplified M60A1 tank geometry.

For analysis with this model, a boosted fission source was defined 170 m away from the rear end of the armored vehicle at a 100 m elevation. In order to handle complicated cell definitions, MCNP was modified by increasing the “mlgc” parameter from 1000 to 9000 [4]. Dose values for the crew and a free-field dose box were computed by MCNP-BRL and MCNP5. These preliminary results and the MASH results from a previous study [3] are given in Table I.

Table I indicates that MCNP and MCNP-BRL produce comparable results, but there are 30% discrepancies between these values and the MASH results. The discrepancies result from poor statistics in the results and possibly due to the simplifications in geometry conversion process and we are currently investigating this. In order to improve statistics in these results, we will obtain mesh-based weight window parameters using ORNL’s ADVANTG/MCNP [8] code sequence and repeat these calculations for both MCNP5 and MCNP-BRL.

Table I. Dose Values Computed by Three Codes

Location	Dose (cGy)		
	MASH	MCNP5	MCNP-BRL
Commander’s head	2.69e5	1.63e5	1.62e5
Gunner’s head	1.51e5	1.24e5	1.24e5
Loader’s head	1.80e5	1.55e5	1.54e5
Driver’s head	6.88e4	5.46e4	5.48e4
Free-in-air	3.56e5	3.66e5	3.67e5

In this calculation, MCNP-BRL execution time (single processor) is almost 4 times longer than MCNP5 execution time (single processor), for 100 million source particles, 2820, and 790 min, respectively.

After obtaining identical MCNP5 geometry for the original M60A1 tank model, shown in Fig.2, MCNP5 and MCNP-BRL calculations will be performed and their

results will also be compared with the results of this simplified model. In this way, the effects of model simplification/modifications can be easily determined. In addition to this effort, parallel version of MCNP-BRL (MPI/OpenMP) will be extensively tested with these complex models and its performance will be reported.

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