Dose Measurement aboard Biosatellite BION-M #1 (AutoCAD implementation into MCNPX)

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Summary

This work outlines the first AutoCAD implementation of the BION-M #1 space craft in MCNPX using a simplified model. The MCNPX data obtained from the simulation can be compared with measurements taken from different radiation detectors immediately after the vehicle landing.

1. Introduction

On April 19, 2013, the Russian recoverable biosatellite BION-M #1 was launched for a mission of 30 days; the orbit parameters were 560 km altitude and 62^{o} inclination. The vehicle was equipped with a set of detectors for dose measurement. For neutron detection, four space bubble detectors [1] were placed inside the recoverable capsule of the vehicle to measure the neutron dose component inside the satellite. Each detector has 10 ml active volume with approximately 10^4 microscopic droplets giving a low sensitivity from 37 to 57 bubbles /mSv. The bubble counting was done automatically using a lightweight mini-reader immediately after the vehicle landing. [2]

2. Scope

The objectives of this work are, evaluation of the neutron dose using a simplified MCNPX model and using space bubble detectors to measure the neutron dose inside the BION satellite.

3. Assumptions and Limitations

Significant MCNPX constraints and restrictions on 3D CAD are as follows:

- MCNPX limits each CAD surface as a general second-order geometry with no splines [3]. Many minor geometrical parts of the BION-M #1 were omitted from the CAD model in order to satisfy this constraint.
- MCNPX limits a CAD region not to exceed the limits of an MCNPX cell [3]. To avoid splitting complex cells, geometries which were too complex were omitted from this model.

- Available MCNPX cross section data for high energy particles have been used.

4. Conversion of AutoCAD to MCNPX

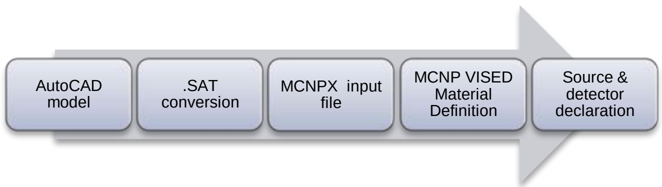

Figure 1 BION-M #1 conversion Process

The process in Figure 1 was used to convert the BION-M #1 CAD model into an MCNPX input file.

4.1 Simplified BION-M #1 AutoCAD Model

Components were used in the BION-M #1 model, which were all limited to second-order geometries with limited complexities. Dimensions used in the simplified model are listed intable 1 below:

Component Name	#	Second-order geometry used	Dimensions [cm]	Given/Inferred
"Legs" (Located at the bottom of the rocket)	1	Parallelepiped	27x27x27	Inferred
"Instrument Module" (Located in between the Legs and the cooler)	2	Chamfered Cylinder (funnel-shaped)	Diameter (bottom): 272 Height: 97 Diameter (top): 242.4	Given
"Cooler" (Located in between the Instrument module and the)	3	Cylinder	Diameter: 229.5 Height: 49	Given
"Payload Module" (Located in between the cooler and the solar panels)	4	Chamfered Cylinder (funnel-shaped)	Diameter (bottom): 229.5 Height: 86.5 Diameter: 250	Given
Solar Panels	5	Parallelepiped	Length: 1000 Width: 90 Thickness: 5	Inferred
Aluminum shield of return capsule (Outer sphere)	6	Hollow sphere	Thickness 2.75 Diameter (outer): 122 Diameter (inner): 119.25	Given
Return capsule (located inside aluminum shield)	7	Hollow sphere	Thickness: 2.00 Diameter (outer): 119.25 Diameter (inner): 119.05	Given
Oxygen tank (Inside return capsule)	8	Cylinder	Diameter: 36 Height: 72	Inferred
Organism container #1 (Bigger box located on top of the oxygen tube)	9	Parallelepiped	Height: 22.5 Length: 135 Width: 90	Inferred
Organism container #2 (smaller box located on top of the bigger box)	10	Parallelepiped	Height: 45 Length: 75 Width: 105	Inferred

Table 1 BION-M #1 Components & dimensions used in the AutoCAD model

A final version of the CAD model (before conversion into a .SAT file format) is shown in Figure 2. This AutoCAD model was converted to the .SAT file format.

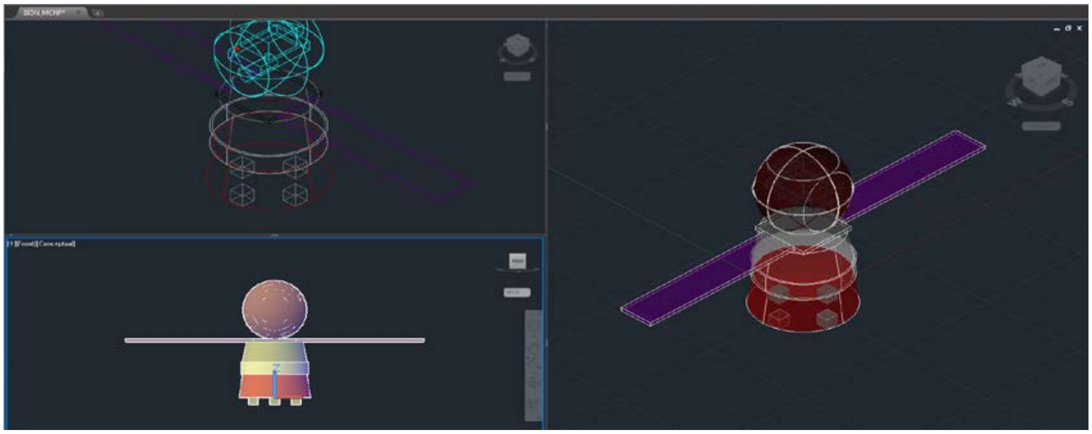

Figure 2Simplified BION-M #1 model in AutoCAD

4.2 MCNPXVisual Editor Model

The conversion from the .SAT file format into an MCNPX input file proved successful with no omissions from the AutoCAD model.The MCNPX model is shown in Figure 3.

Compositions of materials were also simplified since the material compositions of space-grade materials are complicated. Densities and cell material declarations can be seen in Table 2.

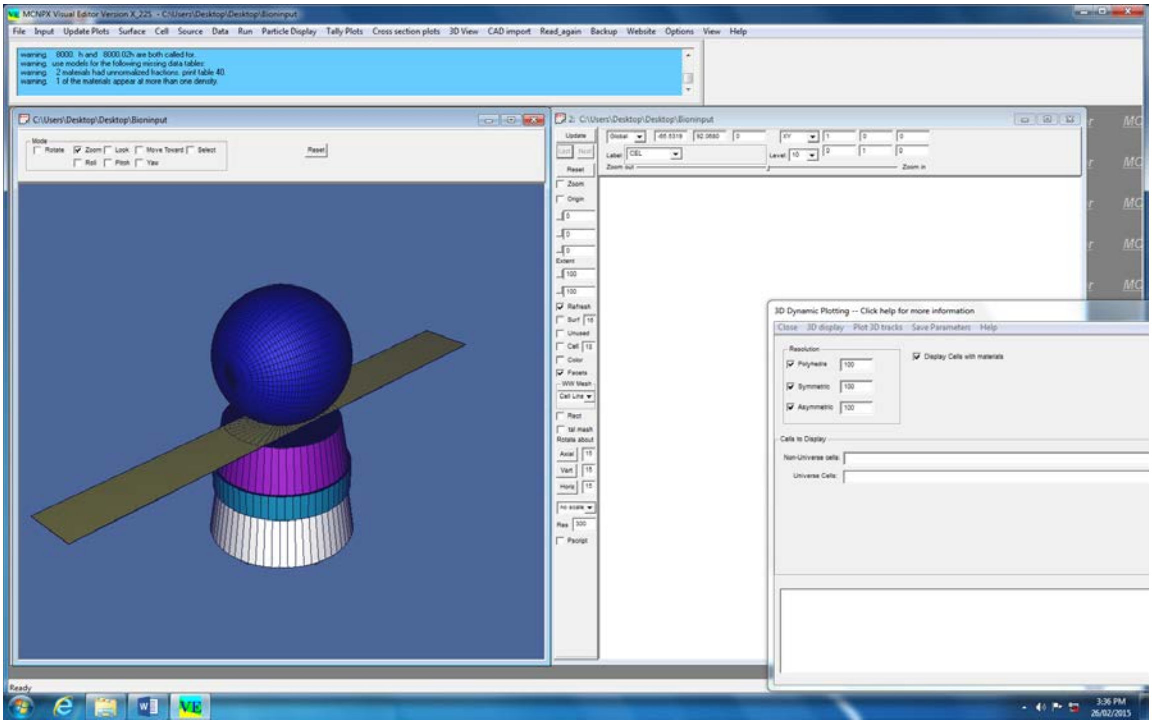

Figure 3 MCNPX BION-M #1 model

Component	#	Defined Material [4]	Densities [g/cm^3]
“Legs” (Located at the bottom of the rocket)	1	Aluminum	2.64
“Instrument Module” (Located in between the Legs and the cooler)	2	Aluminum	2.64
“Cooler” (Located in between the Instrument module and the)	3	Aluminum	2.64
“Payload Module” (Located in between the cooler and the solar panels)	4	Aluminum	2.64
Solar Panels	5	Silicon	2.33
Aluminum shield of return capsule (Outer sphere)	6	Aluminum	2.64
Return capsule (located inside aluminum shield)	7	AMT6 (special composition)	2.64
Oxygen tank (Inside return capsule)	8	Stainless Steel	7.85
Organism container #1 (Bigger box located on top of the oxygen tube)	9	Aluminum	2.64
Organism container #2 (smaller box located on top of the bigger box)	10	Aluminum	2.64
Inside return Capsule		Water (to simplify complicated space)	1

Table 2 BION-M #1 Component material definitions

4.3 Source & detector declaration in MCNPX code

The radiation source and detector were defined in MCNPX as spheres. The source was defined as an external sphere surrounding the satellite with a radius of 600cm in order to model omnidirectional isotropic radiation in space. The detector of interest was simplified to a sphere of 10cm in radius located in the center of the return capsule as seen in Figure 4.

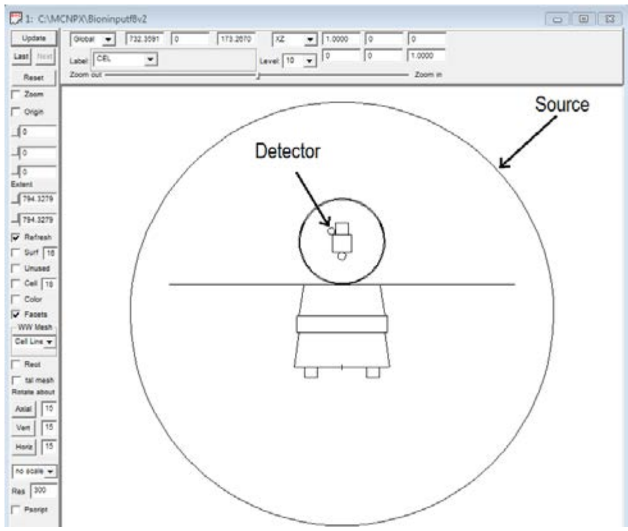

Figure 4 Source and detector declaration in MCNPX

5. Concluding remarks and Further Considerations

The AutoCAD model of the BION-M #1spacecraft proved successful running in MCNPX. This milestone allows for simulation data from MCNPX to be obtained and will be used to compare experimental data retrieved from the BION-M #1 space mission to simulation data from MCNPX. Further work is ongoing to model space radiation in general and to extract the neutron component in particular for the BION-M #1 spacecraft, as well as enhancing current geometries for further simulations. Current work ongoing include:

- A geometrically detailed AutoCAD model of the bubble detector's dimensions, material composition, and quantities for improved modelling
- Differing locations of the bubble detector for multiple measurement points in the return capsule
- Additional detailed material compositions in MCNPX model
- Full MCNP Simulations including radiation environments in earth orbit [5]

Neutron dose calculations will be implemented in upcoming stages once additional resources and information become available such as:

- Supplementary libraries for high-energy physics
- MCNP6 model
- Additional dimensions of components

- AutoCAD implementation improvements for .SAT files to extend accepted surfaces
- Bug fixes for MCNP VISED and .SAT conversion algorithms

6. References

[1] R. Machrafi et al. “Neutron dose study with bubble detectorsaboard the International Space Station as part of theMatroshka-R experiment.” Radiat. Prot. Dosim. 133(4),200–207 (2009).
[2] C. Robert, "Bion M1 - Return to Earth". Zarya - Soviet, Russian and International Spaceflight. Retrieved 19 May 2013.
[3] A.L. Schwarz , R.A. Schwarz, and L.L. Carter, MCNP/MCNPX Visual Editor Computer Code Manual, For Vised Version 22SReleased February, 2008
[4] "Biological space vehicle "Bion-M". Russian Academy of Sciences Institute of Biomedical Problems. Retrieved 19 April 2013.
[5] T.P. Dachev et al. “BION-M No. 1 spacecraft radiation environment as observed by the RD3-B3 radiometer-dosimeter in April-May 2013” Journal ofAtmosphericandSolar-TerrestrialPhysics123(2015)82–91