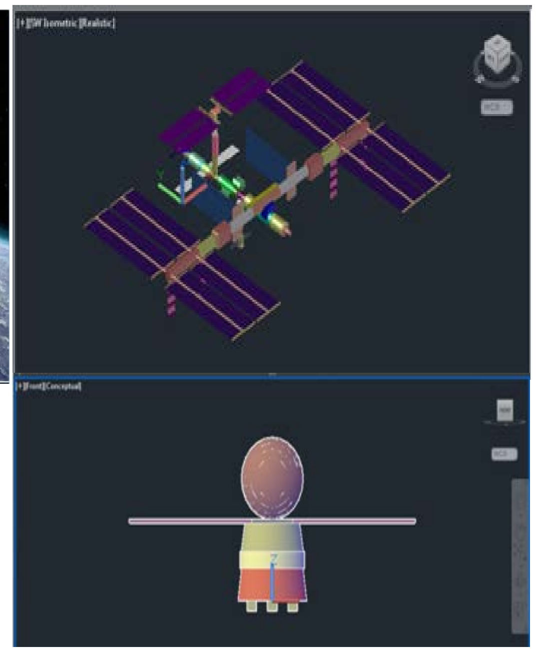
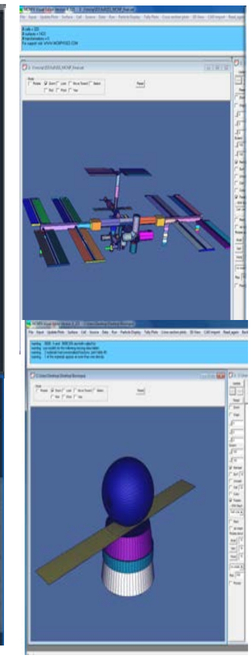
Preliminary attempt of implementing a full-scale geometrical input file of the International Space Station (ISS) and BION-M #1 (ENERGIA RSC) Biosatellite in MCNPX using AutoCAD solid modelling





Patrick Dolloso[1], Rachid Machrafi[1], Alexander Miller[1], Sergey Khulapko[2]

[1]Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada

[2]Institute of Biomedical Problems, Moscow, Russian Federation

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Introduction

- This work outlines the first successful attempt of a full-scale model of the International Space Station (ISS) in MCNPX using a simplified AutoCAD model.
- The methods used is analogous in the conversion of the Russian recoverable satellite BION-M #1.
- This work focuses on the **modeling and conversion** of the geometric input file into MCNPX which can be used for dose measurement simulations and compared with measurements taken from radiation detectors on the ISS.

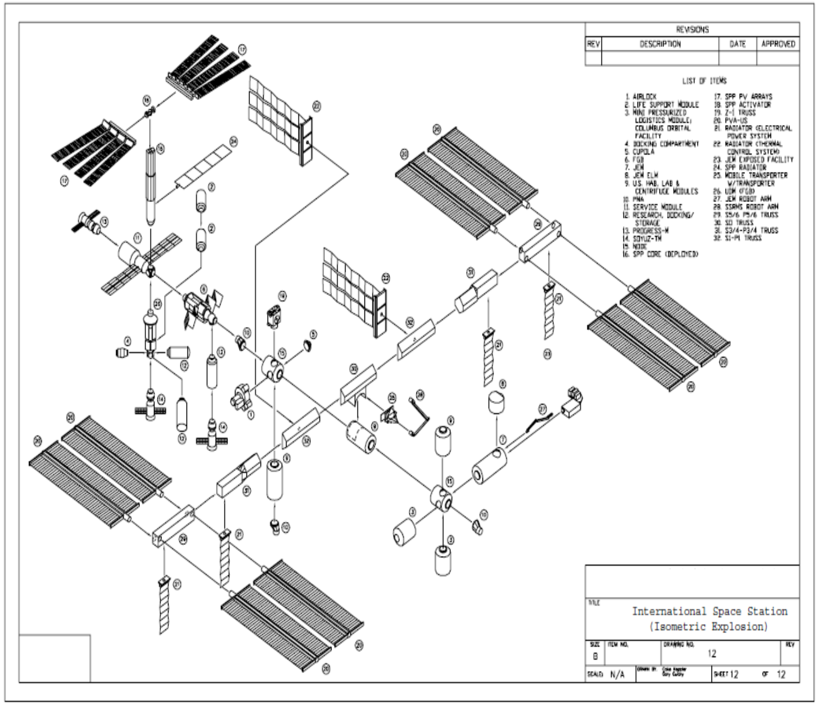

Figure 1: Exploded view of the ISS. (source: NASA http://www.nasa.gov/mission_pages/station/multimedia/scalemodel/index.html)

Overview

1. Introduction	a. Previous WRMISS Background b. Scope
2. MCNPX	a. Benefits of MCNP in Space Radiation Monitoring b. Assumptions and limitations
3. BION-M #1	a. Mission Overview b. Key components of Spacecraft c. MCNPX model: - Simplification of key components in AutoCAD - .SAT Conversion to .inp input file - Material Composition, Source, and detector declaration
4. International Space Station (ISS)	a. Key components of ISS b. MCNPX Model: - Simplification of Key Components in AutoCAD - .SAT conversion into .inp input file
5. Discussion & Conclusion	
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Introduction - Previous WRMISS background

- An interest to attempt to model the ISS in MCNP was expressed in WRMISS-16 in 2011 from the presentation: *Neutron Production in the Spherical Phantom on Board the International Space Station (R. Machrafi et. al)*
- A model of the ISS was attempted, but not successfully converted into MCNP.
- Furthermore, limitations on geometrical complexities and solid model-conversion algorithms on MCNP were major obstacles in modeling the ISS.
- The MCNP model presented in this work is the first successful conversion from an AutoCAD model into an (.inp) input file which is capable of material and source declaration in MCNP for simulation purposes.

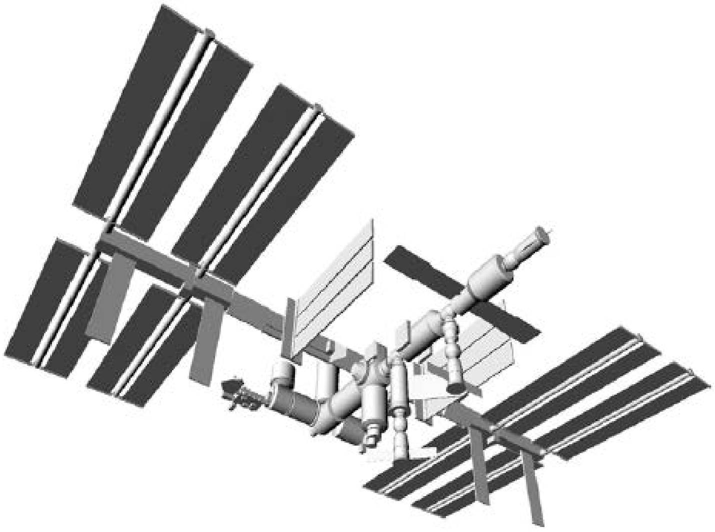


Figure 2: Simplified ISS model attempt in WRMISS-16, 2011 (source: Neutron Production in the Spherical Phantom on Board the International Space Station, R. Machrafi et. al)

Introduction - Scope

- This work is a first step in accurately modelling the ISS geometry using a simplified MCNP-compatible CAD model conversion.
- No simulations or material/source declarations have been performed in this work, however further work is ongoing to receive radiation measurement data, schematics, and detector locations to accurately model individual modules in the ISS.
- This work serves as a call for any schematics or resources from WRMISS members and various space organizations regarding component dimensions of the ISS

MCNPX - Benefits of MCNPX in Space Radiation Monitoring

used primarily for the simulation of nuclear processes but has the capability to simulate particle interactions. [1]

- Able to determine and compare doses from simulations by differentiating sources such as high energy particles, protons, neutrons, or electrons for simulating different radiation environments in earth orbit
- Capability of creating geometrically accurate spacecraft models via AutoCAD
- Capability of geometrical modification such as wall thicknesses and component positioning for differing scenarios in space
- Capability of declaring material compositions and densities of various spacecraft components
- Capable of placing detectors at differing measurement points

[1] MCNP - A General Monte Carlo N-Particle Transport Code - Version 5 Monte Carlo Codes Group - Los Alamos National Laboratory

MCNPX - Assumptions and Limitations

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

- MCNPX limits each CAD surface as a general second-order geometry with no splines. Many minor geometrical parts of the ISS were omitted from the CAD model in order to satisfy this constraint. [2]
- MCNPX limits a CAD region not to exceed the limits of an MCNPX cell. To avoid splitting complex cells, geometries which were too complex were omitted from this model. [2]
- Available MCNPX cross section data for high energy particles have been used.

[2] A.L. Schwarz , R.A. Schwarz, and L.L. Carter, MCNP/MCNPX Visual Editor Computer Code Manual, For Vised Version 22S Released February, 2008

BION-M #1 – Mission Overview

- On April 19, 2013, the Russian recoverable biosatellite BION-M #1 launched for a 30 day mission; orbit parameters were 560 km altitude and 62^{o} inclination. [3]
- Four space bubble detectors were placed inside the recoverable capsule of the vehicle to measure the neutron dose component inside the satellite. [3]
- 10 ml active volume with approximately 104 microscopic droplets giving a low sensitivity from 37 to 57 bubbles /mSv for each detector. Bubble counting was done automatically using a lightweight mini-reader after vehicle landing. [4]
- MCNPX modelling and conversion was performed successfully on July 1 2015 [5]

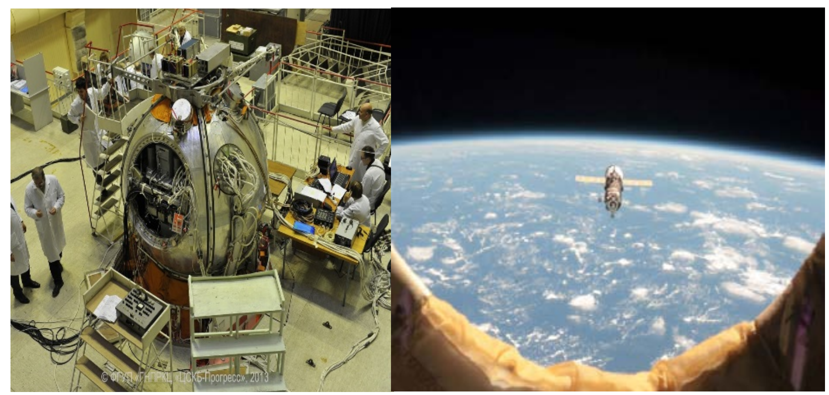


Figure 3 and 4: BION-M #1 Preparations before launch and photo of spacecraft above earth (source: Zarya, Russian and International Spaceflight)

[3] C. Robert, "Bion M1 - Return to Earth". Zarya - Soviet, Russian and International Spaceflight. Retrieved 19 May 2013.

[4] R. Machrafi et al. “Neutron dose study with bubble detectors aboard the International Space Station as part of the Matroshka-R experiment.” Radiat. Prot. Dosim. 133(4), 200–207 (2009)

[5] P. Dolloso, A. Miller, R. Machrafi, V. Shurshakov, S. Khulapko, O. Ivanova “Dose Measurement aboard Biosatellite BION-M #1 (AutoCAD implementation into MCNPX)” Canadian Nuclear Society, Student Conference 2015, June 1 2015

BION-M #1 - Key components of spacecraft

Module name	Thickness and material of the shielding, mm	Shielding density, g/cm^3
Агрегатный отсек (АО) – Instrument module	ЭВТИ-ВВ 30 слоев 1,5 мм – стеклотекстолит АФ-10ВО ОСТ 92-0956-74 9 мм – стеклосотопанель СПП-Iэ ТУ7554-477-05761784-2005, 1,5 мм - стеклотекстолит АФ-10ВО ОСТ 92-0956-74	1,55÷1,8 0,1
Приборный отсек (ПО) Payload module	3 mm, АМГ6 ЭВТИ-ВВ 30 слоев	2,64
Спускаемый аппарат (СА) Return capsule	3 mm АМГ6 (special composition), ТЗП: КТАН 50 КИФ ТИМ-1 ЭВТИ-ВВ 30 слоев 40 мм - Пенополиуретан ППУ-35-0,8 ТУ6-55-45-90	2,64 1,1÷1,35 0,2÷0,25 0,035

Table 1: Key parameters of the BION-M #1spacecraft (RSC Energia)

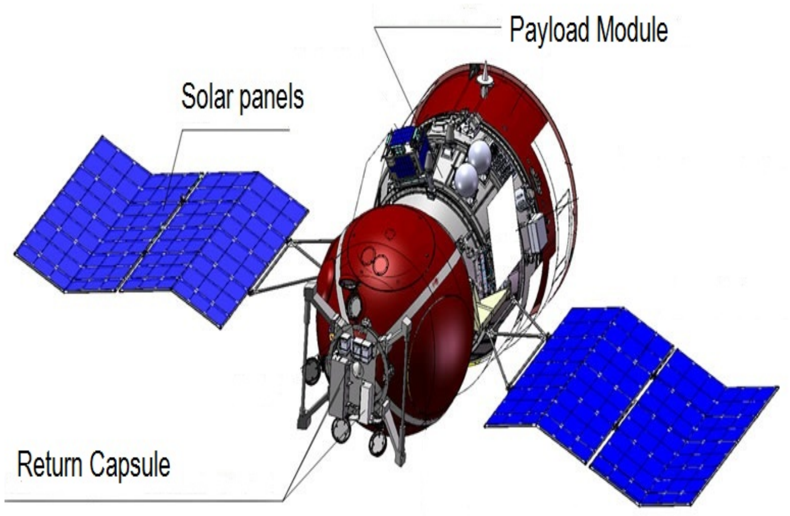


Figure 5: Key components of the BION-M #1 spacecraft (RSC Energia)

BION-M #1 – MCNPX Model: Simplification of key components in AutoCAD

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 2: BION-M #1 Component simplification summary

BION-M #1 – MCNPX Model: Simplification of key components in AutoCAD

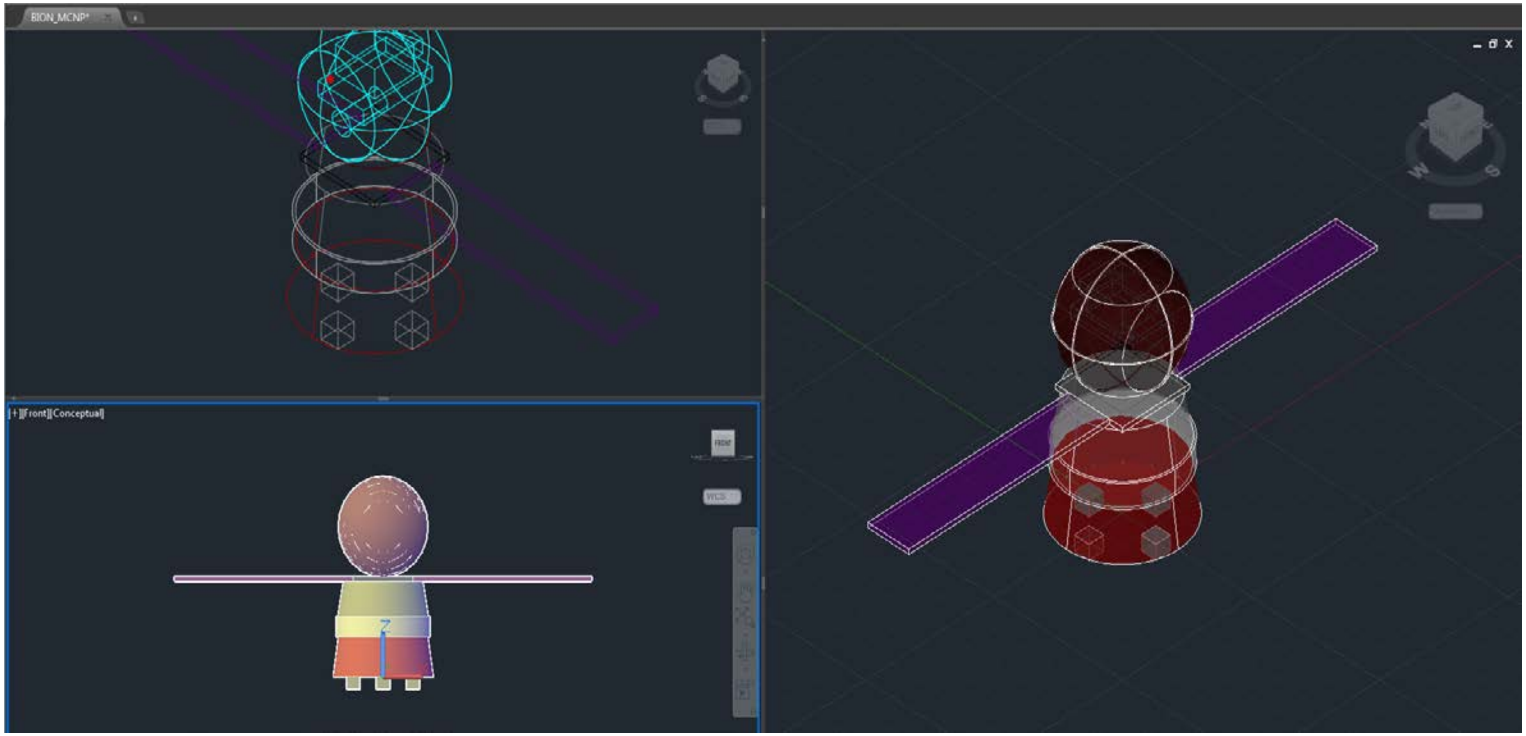


Figure 6: AutoCAD model of the BION-M #1 spacecraft

BION-M #1 – MCNPX Model: .SAT Conversion to .inp input file

- The conversion from the .SAT file format into an MCNPX input file proved successful with no omissions from the AutoCAD model.

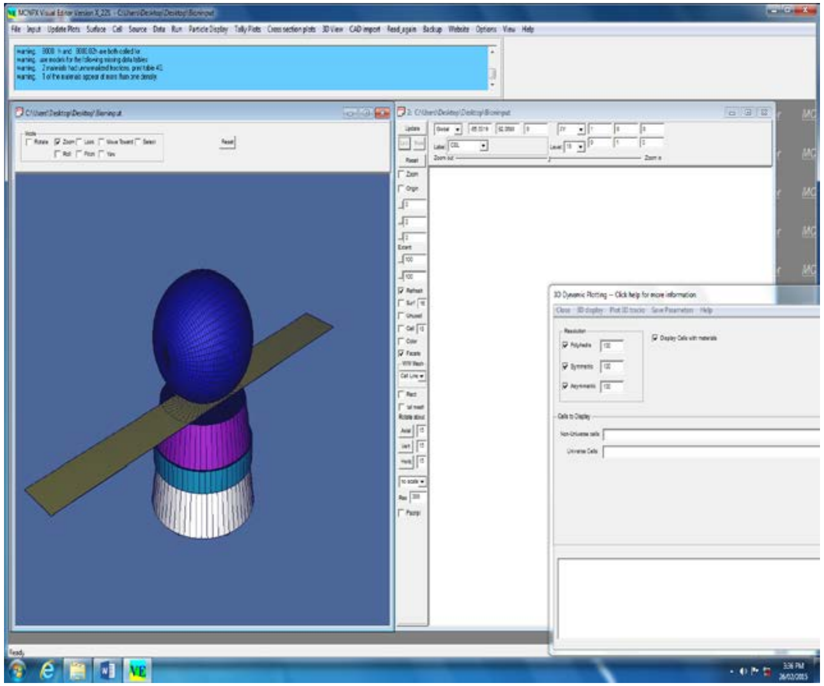


Figure 7: BION-M #1 in MCNPX

BION-M #1 – MCNPX Model: Material Composition declaration

Component	#	Defined Material	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 3: Material composition declaration summary

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 3

BION-M #1 – MCNPX Model: Source and Detector declaration

- 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 here

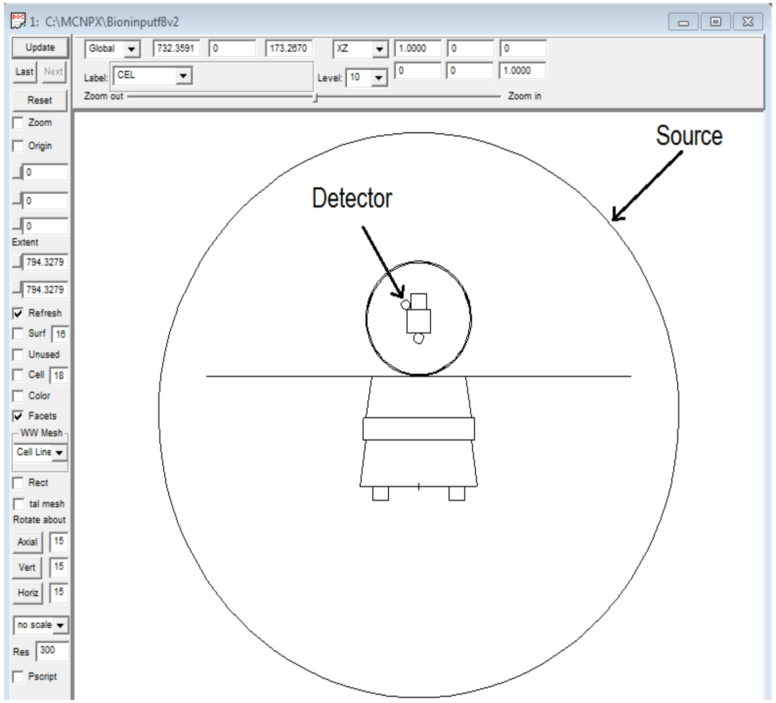


Figure 8: Source and detector declaration in MCNPX

International Space Station (ISS) - Simplification of key components

- The process shown was used to model the ISS into an (.inp) input file. This conversion process is similar to a previous MCNPX model of ENERGIA RSC's BION-M #1
- The primary reference used for dimensions is provided by the ISS Scale Model Drawing Package on the NASA database.
- Geometrical limits of MCNPX require simplifications to be made to the ISS blueprints provided by NASA scale drawings

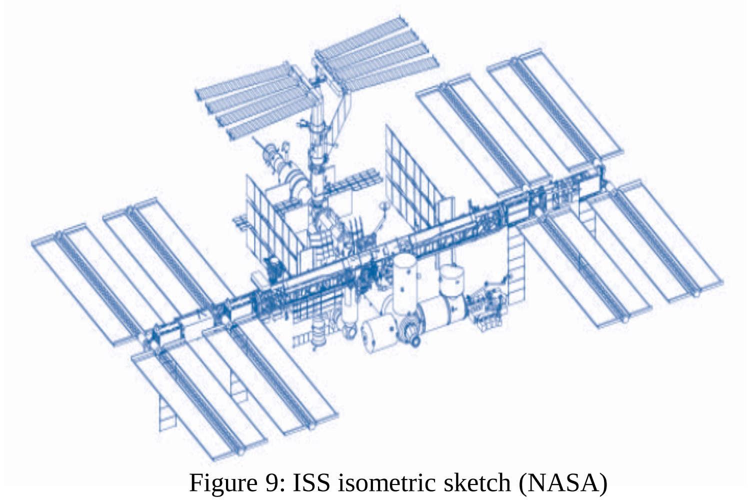


Figure 9: ISS isometric sketch (NASA)

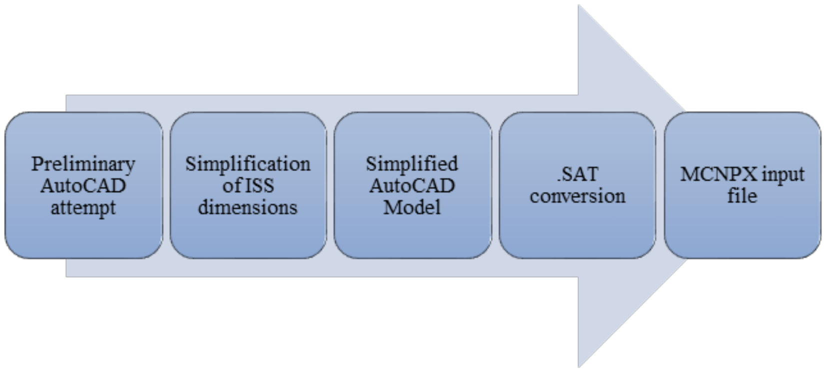
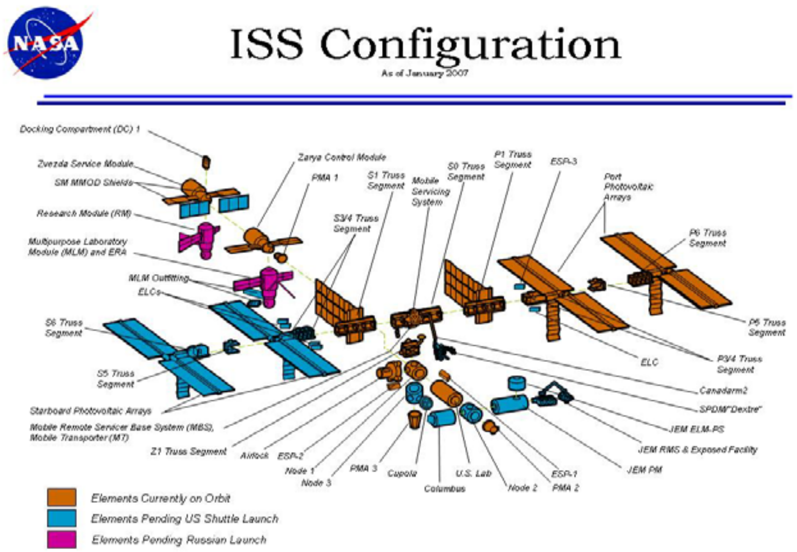


Figure 10: conversion process summary

International Space Station (ISS) - Simplification of key components



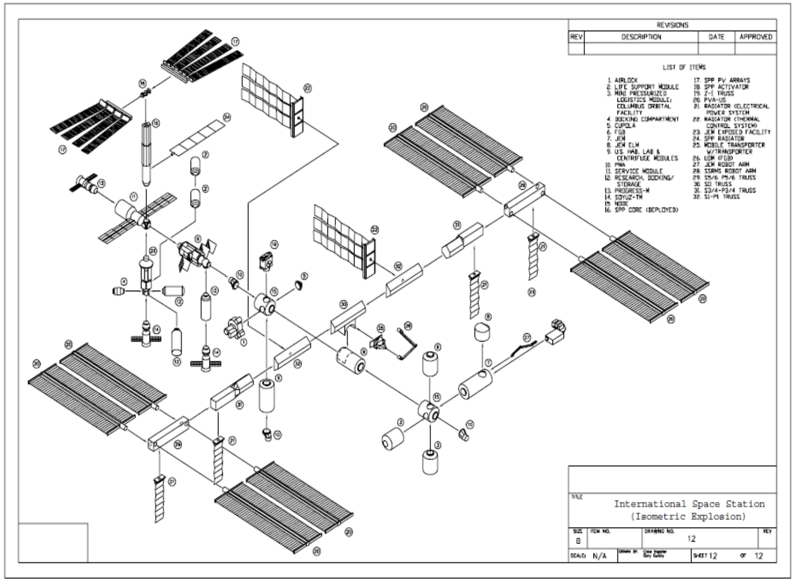


Figure 11 and 12: Isometric exploded view of major ISS components
(NASA, source: http://www.nasa.gov/mission_pages/station/multimedia/scalemodel/index.html)

International Space Station (ISS) - Simplification of key components in AutoCAD

#	Component Description	Second-order geometry used	Dimensions (total) [in]	Comments
1	Airlock	Cylinder, Cone	217x100x50	Omitted gas canisters due to complexity
2	Life Support Module	Cylinder	213x114x22	
3	Multi-Purpose Logistics Module, Columbus Orbital Facility	Cone, Cylinder	254x175x212	
4	Russian Docking Compartment	Cone, Sphere, Cylinder	160x100x223	
5	Cupula	Dodecahedron, cylinder	106x56x222	
6	Functional Control Block	Sphere, Cone, Cylinder, Parallelepiped	495x161x211	Simplified body to single cylinder due to complexity
7	Japanese Experimental Module (JEM)	Cylinder	419x175x175	
8	JEM ELM (Pressurized section)	Cylinder, Cone	175x156x156	
9	U.S. HAB & Lab Module	Cylinder	346x175x175	
10	Pressurized Mating Adapter	Pentagonal prism, Sphere	98x94x94	
11	Service Module	Cylinder, Sphere, Cone, Parallelepiped	517x161x161	1in. thickness was used for solar panels
12	Research, Docking and Storage Module	Cylinder, Cone	318x114x114	
13	Progress-M	Cylinder, Cone, Parallelepiped	285x436x285	1in. thickness was used for solar panels
14	Soyuz-TM	Cylinder, Sphere, Parallelepiped	434x87x87	1in. thickness was used for solar panels
15	Node	Cylinder	312x179x179	

Table 4: ISS Component simplification summary

International Space Station (ISS) - Simplification of key components in AutoCAD

16	SPP Core	Octagonal prism, cylinder	775x80x80	
17	Russian Science Power Platform Pholtovoltaic (SPP PV)	Parallelepiped	611x751x150	1in. thickness was used for solar panels
18	SPP Activator	Cylinder	138x50x50	
19	Z-1 Truss	Parallelepiped, Cylinder	177x116x116	
20	Photovoltaic Array (PVA) - US,	Cylinder, parallelepiped	460x1421x460	1in. thickness was used for solar panels
21	Radiator (Electrical)	Cylinder, Parallelepiped	539x134x539	1in. thickness was used for solar panels, truss simplified to solid body
22	Radiator (Thermal Control System)	Cylinder, Parallelepiped	454x907x454	1in. thickness was used for solar panels
23	JEM Exposed Facility	Cylinder, Parallelepiped	345x185x185	
24	SPP Radiator	Cylinder, Parallelepiped	785x148x148	
25	Mobile Transporter with Base	Triangular Prism, Parallelepiped	200x128x128	
26	Universal Docking Module	Sphere, Cylinder	495x161x161	Body simplified to single cylinder due to complexity
27	JEM Robotic Arm	N/A		Omitted due to complexity
28	SSRMS Robot Arm (Canadarm 2)	N/A		Omitted due to complexity
29	S-6/P-6 Trusses	Parallelepiped	592x89x128	Trusses simplified to solid body
30	S-0 Trusses	Trapezoidal Prizm	520x132x128	Trusses simplified to solid body
31	S-3&4 Trusses	Hexagonal Prism, Parallelepiped	593x132x111	Trusses simplified to solid body
32	P-3&4 Trusses	Trapezoidal Prizm	540x89x169	Trusses simplified to solid body

Table 4: ISS Component simplification summary (cont.)

International Space Station (ISS) - Simplification of key components in AutoCAD

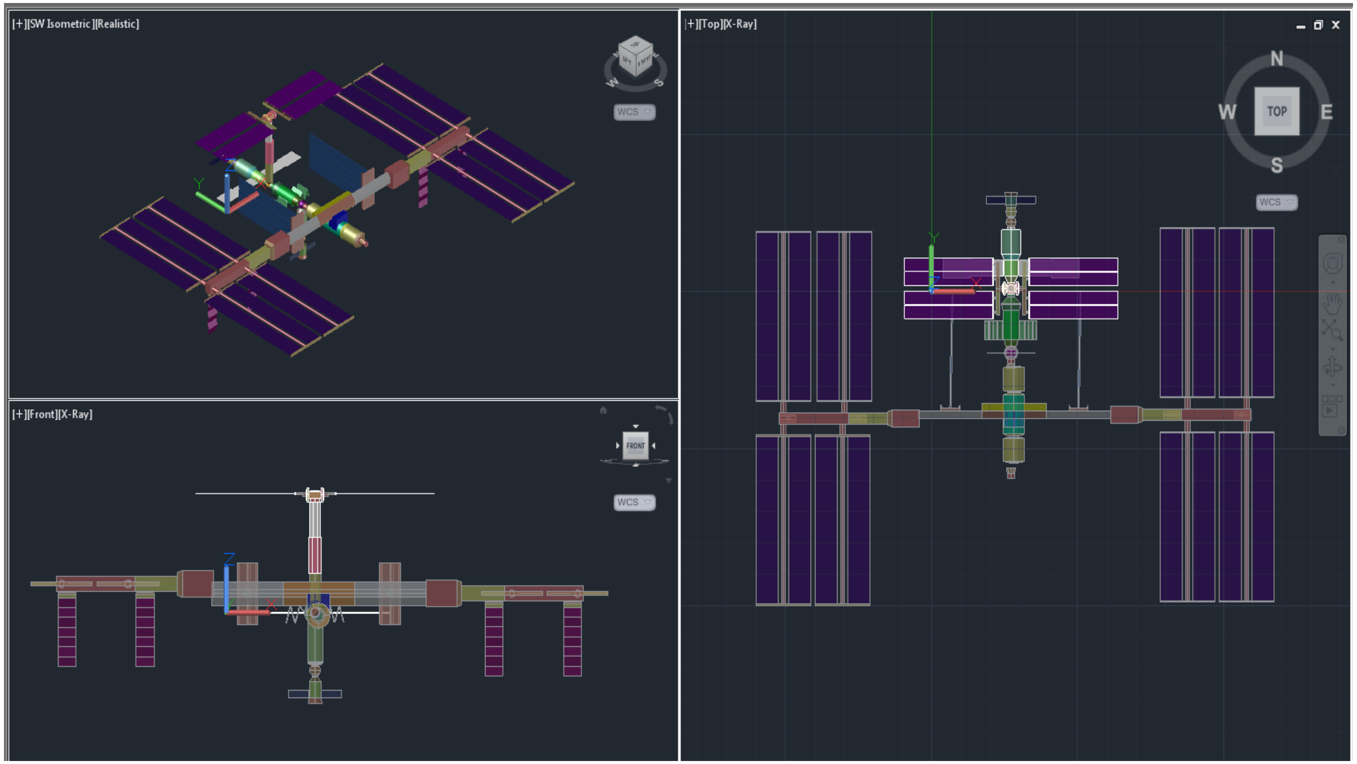


Figure 13: Simplified AutoCAD model of the ISS

International Space Station (ISS) - .SAT conversion into .inp input file

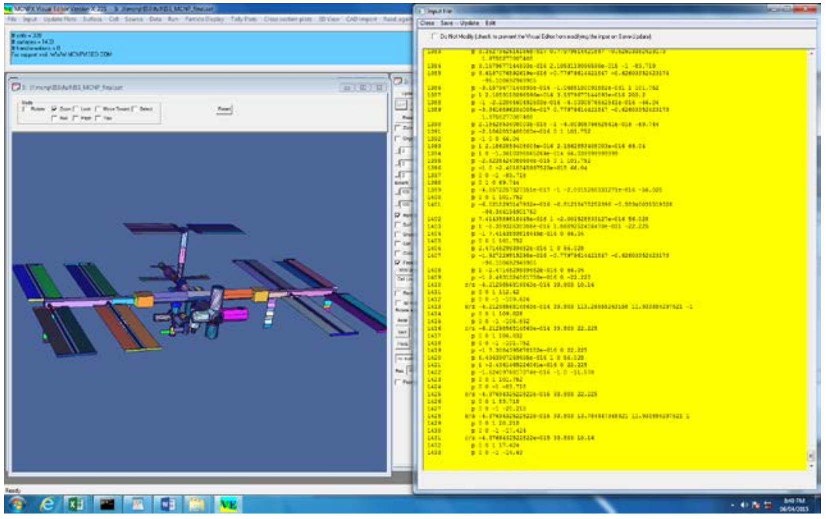


Figure 14: First successful conversion of a full scale ISS model in MCNP!

- A total of 1433 surfaces were converted in the first successful conversion of a full-scale ISS model.
- The .inp file is capable of material, source, and detector definitions in MCNPX
- Source and Detector declaration on the ISS was not performed, as locations and models of detectors are not known.
- Further work is ongoing to gather these resources which can be used for simulation purposes

Discussion & Summary

- The (.inp) files converted from a simplified AutoCAD proved successful in running in MCNPX.
- This milestone allows for source and detector definitions, as well as modifications to wall thicknesses and component positioning for simulation purposes to compare with data obtained from various radiation detectors on the ISS.
- Further work is ongoing to determine material compositions of various ISS components, detector types and locations in the ISS, and geometrical enhancements such as wall thicknesses and internal components.

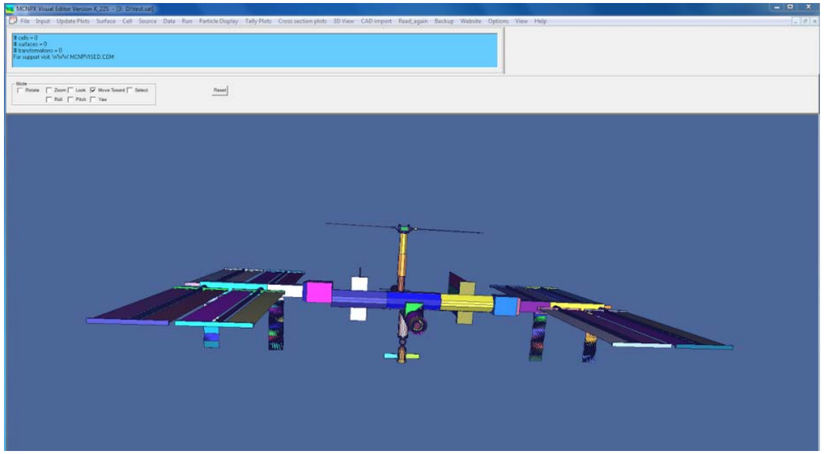


Figure 15: Front View of ISS model in MCNP

Concluding Remarks

- Resource gathering is the primary focus moving forward as parameters such as wall thicknesses and material compositions on ISS components directly affects simulation results.
- As mentioned previously, this work also serves as a call for any schematics or resources from WRMISS members and various space organizations regarding component dimensions of the ISS.
- Further work include: differing locations radiation detectors for multiple measurement points in the ISS, as well as detector models for accurately replicating measurement conditions.
- Source and material definitions for individual surfaces ongoing for currently known parameters.
- Full MCNP Simulations including radiation environments in earth orbit

Further Considerations

- Potential of new detector locations by placing detectors at different measurement points in the ISS model. Proving the successful conversion of a full scale model of the ISS shows potential of a new testing method for additional locations for new detectors.
- AutoCAD models of varying detectors, specifically space-grade bubble dosimeters to include in MCNPX simulations for accurately replicating measurement conditions.
- Dose calculations will be implemented in upcoming stages once additional resources and information become available such as:
- Supplementary libraries for high energy physics (MCNP6)
- AutoCAD implementation improvements for .SAT files to extend accepted surfaces

Figure 16 and 17: Bubble Dosimiters (BTI Bubble Technonogies Industries Inc.) and Canadian astronaut Chris Hadfield demonstrating its usage on the ISS (NASA)

End

Thank you for your attention.

Let’s end with a quote…

“Be glad for life, because it gives you the chance to love, to work, to play, and to look up at the stars”

- Henry Van Dyke, 1909