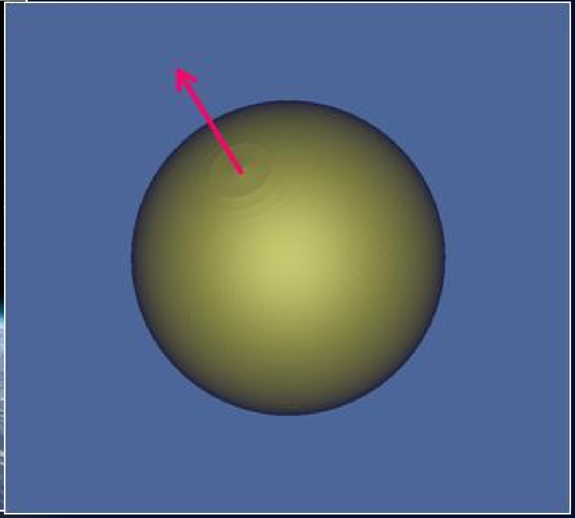
Neutron Production in the Spherical Phantom on Board the International Space Station

R. Machrafi , A. Tasbaz, V. Kovaltchouk
University of Ontario Institute of Technology, Oshawa Ontario, Canada

V. Shurshakov, N. Khoshooniy
State Scientific Center of Russian Federation Institute of Biomedical Problems, Russian Academy of Sciences (IMBP-RAN), Moscow Russia



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1. Background

- For last few years, with the intent to characterize the neutron component of the radiation field onboard ISS, more than 12 experiments (cessions) have been carried out during 8 expeditions, namely ISS-13-21.

- The detectors were positioned on/in the spherical phantom in order to establish the relationship between the neutron dose measured externally and internally.

- The phantom was located at various places throughout the ISS to evaluate the influence of its shielding (docking module and service module).

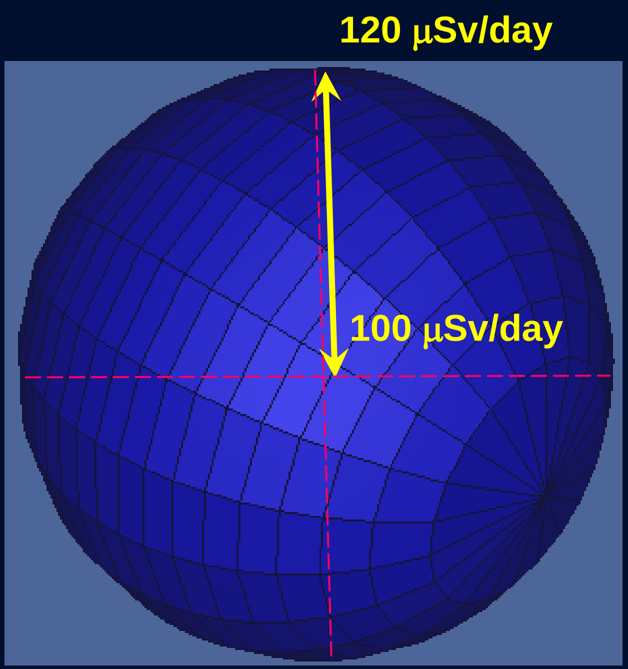
2. Some Data from Literature

2.1. Phantom data

- The dose rate inside the phantom is consistent in all measurements done in the docking module and is about 100 μSv/day [(1-3)]

- The comparison of the value of 100 μSv/day in inside and 120 μSv/day on the surface is within about 20% uncertainty.

- Another measurement on PIRS module gives a surface dose of 131 μSv/day and inside dose of 114 μSv/day, consequently a the difference of about 13% which is comparable with the data in Docking module [(2)]



Internal/external doses

Module	surface	inside	Ratio
SM	118±33	91±27	0.77
PIRS	131±35	114±31	0.66

[(3)] B. J. Lewis[1], et al., Review of Bubble Detector Response Characteristics and Results from Space, Radiation Protection Dosimetry , September, 2011, pp 1-21

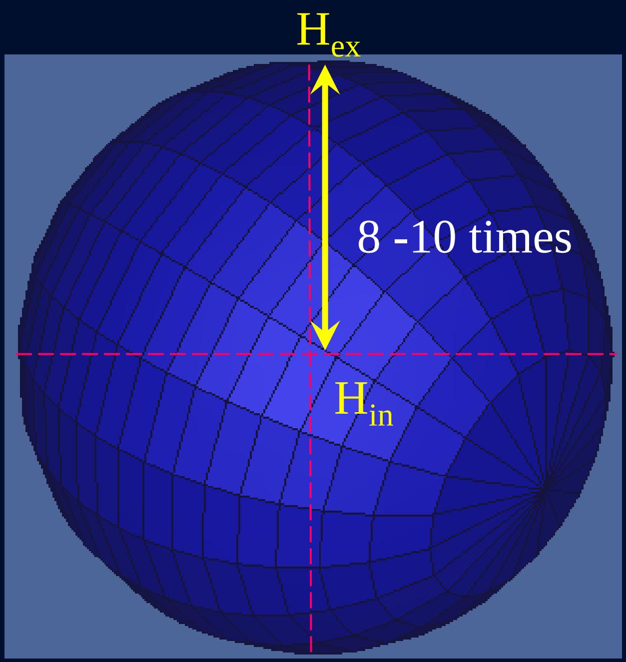
[(4)] M.B. Smith et al., Measurements of the neutron dose and energy spectrum on the international space station during expeditions ISS-16 to iss-21, Radiation Protection Dosimetry (submitted, 2011)

[(1)] *R. Machrafi et al., Radiation Protection Dosimetry, 2009*

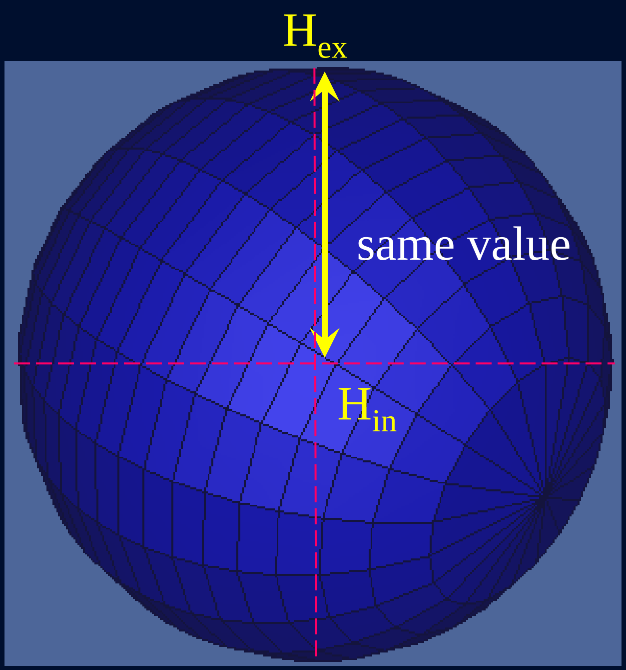
2. Some Data from Literature

2.2. Main findings

Phantom on Earth



Phantom in space



- The internal dose is 10 times less than its external value (with ^{252}Cf source shielded by 15cm of tissue with (NCRP 38).

- The internal and external dose are the same within uncertaintity even in different module

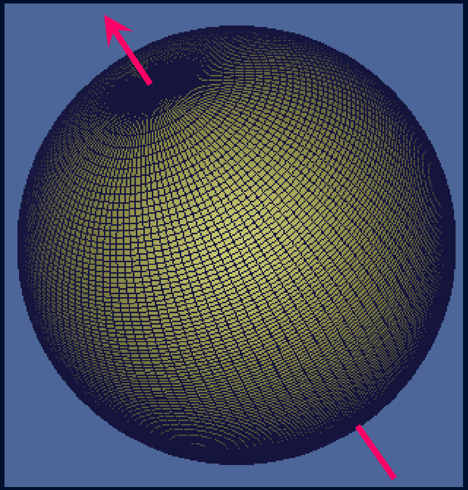
2. Some Data from Literature _ continue

- The difference of the dose value in different locations is expected as the neutron production increases with the thickness of the shielding, however, the equal value obtained for doses at the center and on the surface is surprising.

- This difference has a major impact on the way of using a dosimeters and therefore on the safety of the space crew:

To anticipate some of the ongoing measurements, a preliminary simulation of the phantom has been performed to clarify the neutron compensation.

3. Monte Carlo Model of the Phantom

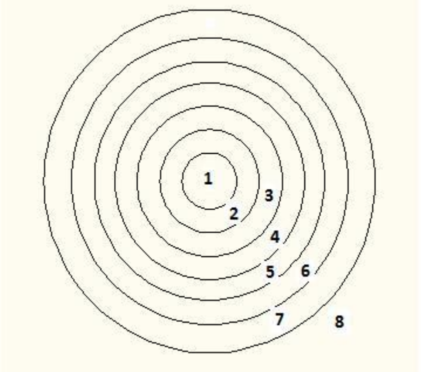


3.1. Spherical phantom Model

The spherical phantom has been simulated as follow:

- 8 equidistant Concentric spheres with an increase of 2.5 cm in between has been modeled .
- The phantom then has been exposed to different spectra: neutrons and to high energy protons
- An average neutron flux has been tallied in different cells (spheres)

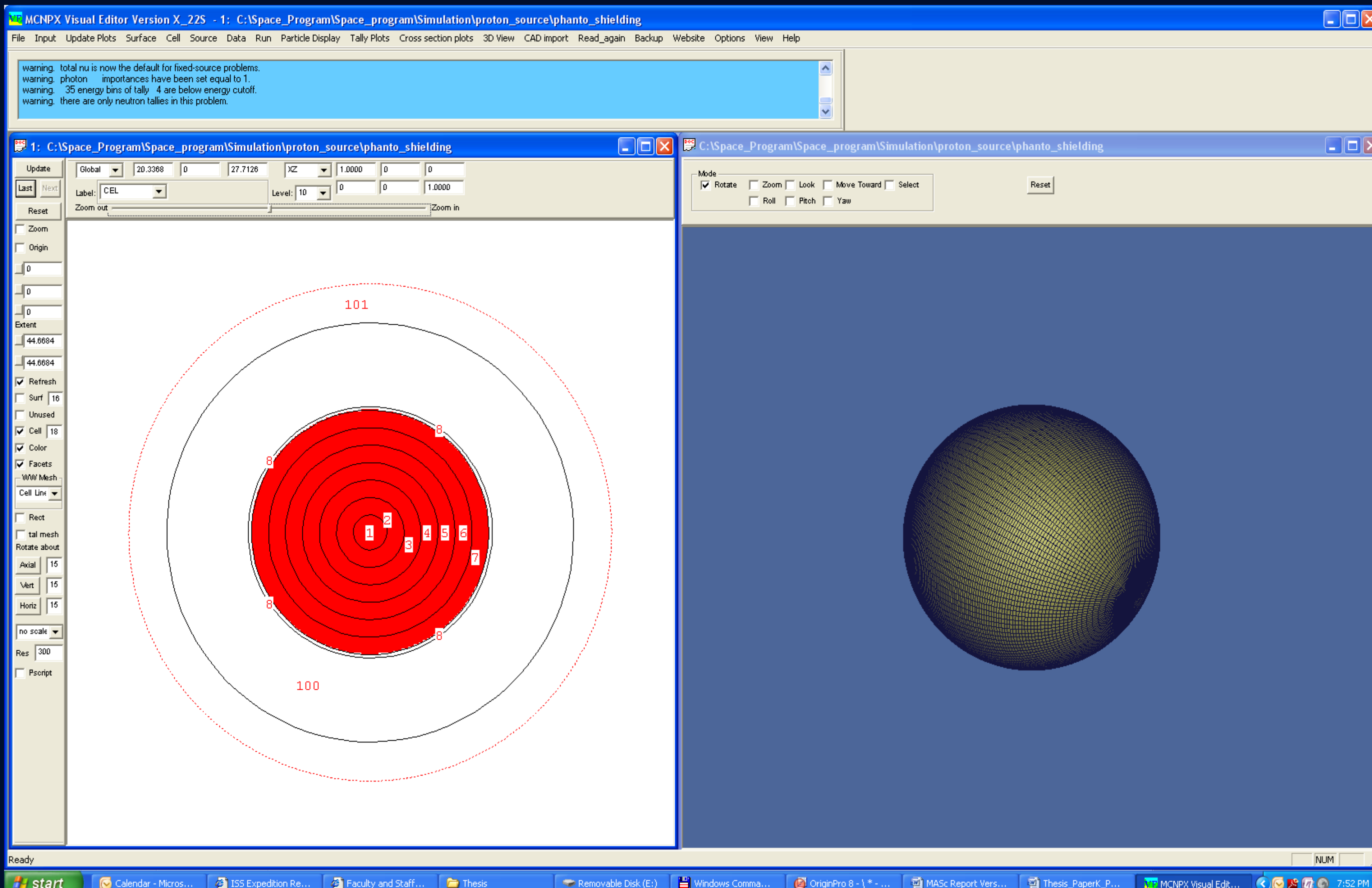
Cell Num	Radius of Cell (cm)
1	2.5
2	5
3	7.5
4	10
5	12.5
6	15
7	17.5
8	18



Monte Carlo Model of the Phantom

3. Monte Carlo Model of the Phantom

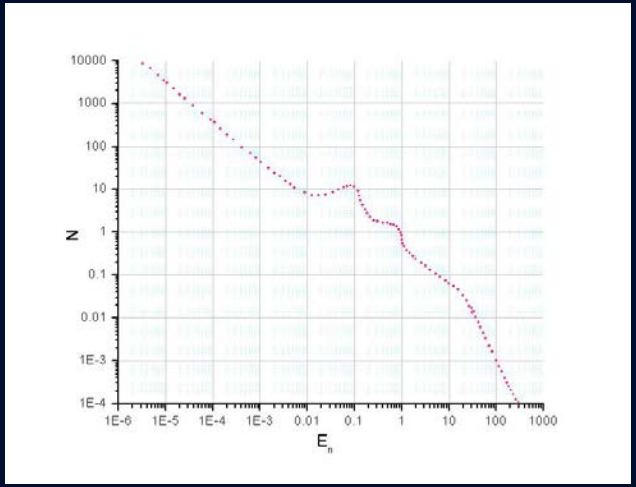
3.1. Spherical phantom Model



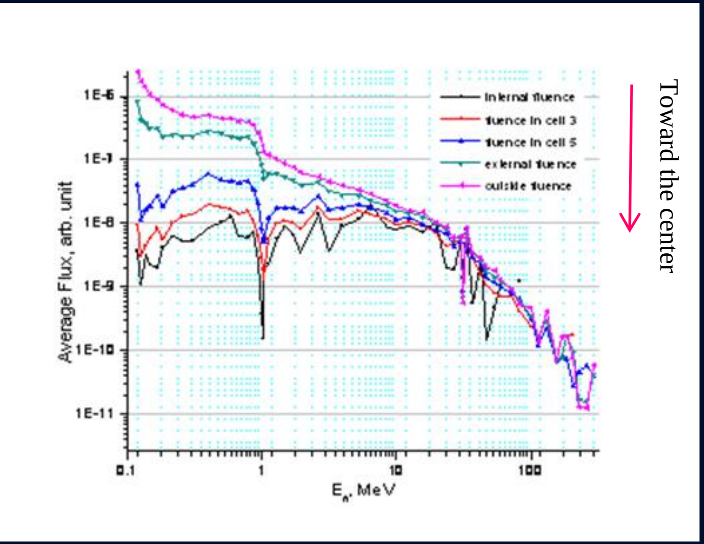
3. Monte Carlo Model of the Phantom _continued

3.2. Irradiation with Neutron Spectra

- The phantom has been exposed to the neutron spectra measured [(3)]
- An average integral neutron flux has been tallied in different cells (sphere) of the phantom.
- Also the neutron spectra in different cells has been tallied.
- Figure 1 and 2 show the resulted data



Mir Station Neutron Spectra



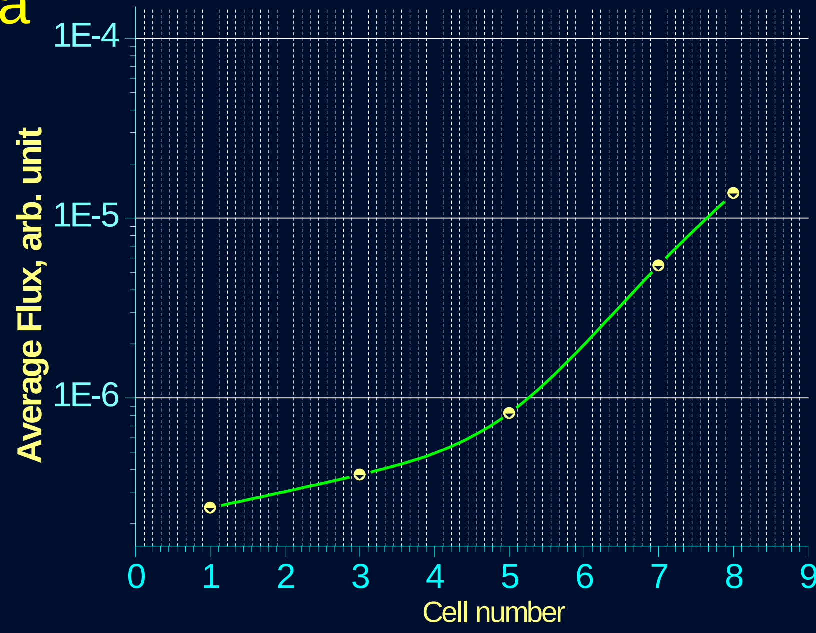
Average flux in different phantom cells

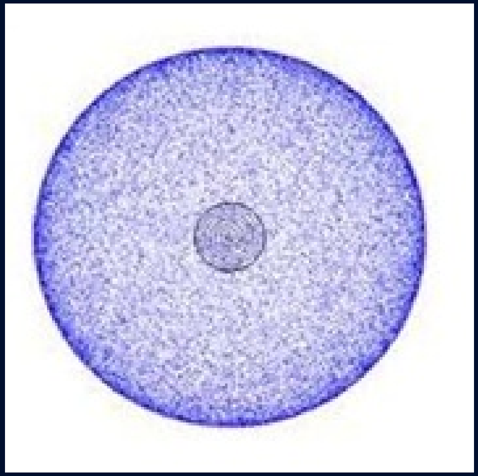
(3). *V. Lyagoshin et al……*

3. Monte Carlo Model of the Phantom _continued

3.2. Irradiation with Neutron Spectra

- The integrated flux in each cell has been determined to evaluate the population of neutron along the radius of the phantom
- The calculated data suggest that neutron population is decreasing toward the phantom center due to absorption in the slowing down process.
- Also the neutron spectra in different cells has been tallied.





Attenuation of neutron from the surface to the center

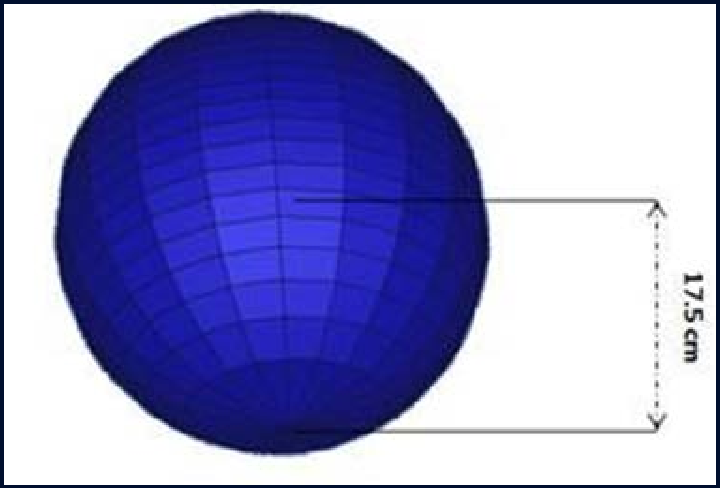
3. Monte Carlo Model of the Phantom _continued

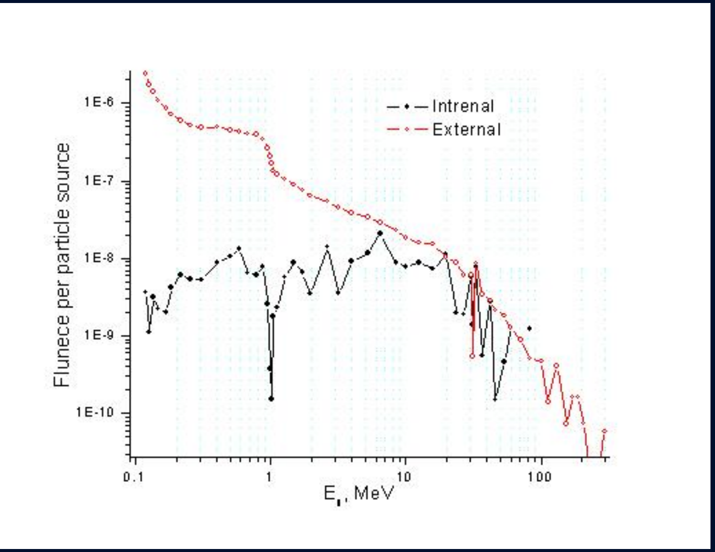
3.3.Irradiation with High energy protons

- ❖ Before doing any MCNP calculation, the SRIM code (The Stopping and Range of Ions in Matter) code was used to calculate the range of proton penetration inside the phantom.

- ❖ Proton with less than 300 MeV will deposit energy in the phantom at the end of their track (Brag peak)

- ❖ The phantom has irradiated with different protons energy in 4π geometry



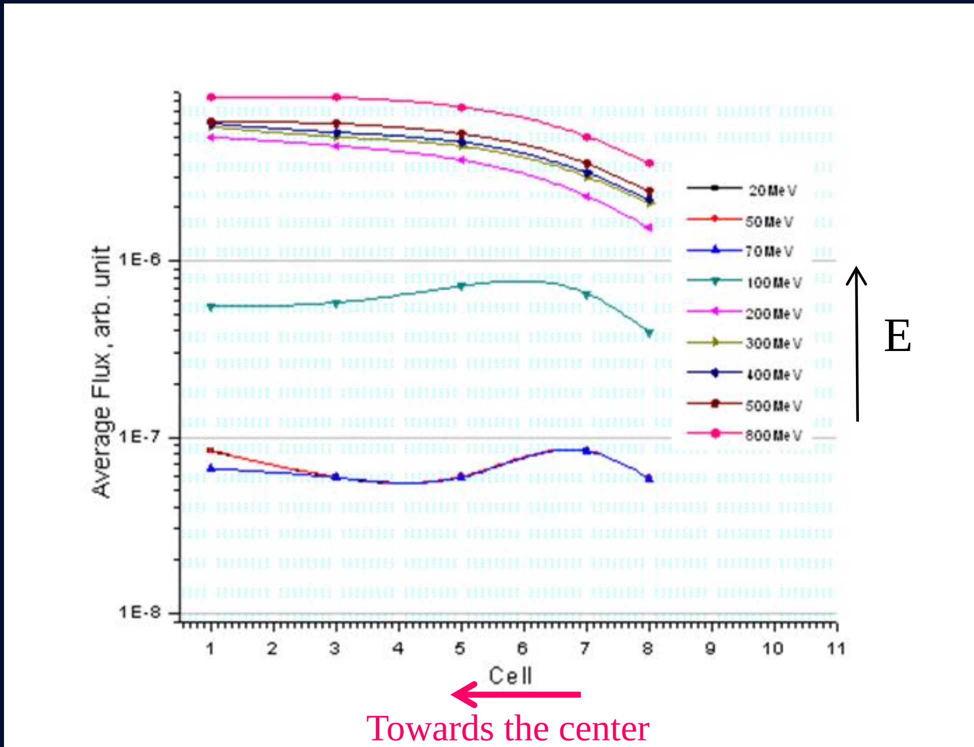


3. Monte Carlo Model of the Phantom _continued

3.4. Over all neutron production

- proton of low energy 10 MeV has a short range of penetration, therefore, they will not reach the inner cell of the phantom and cannot contribute that much to secondary neutron production inside the phantom.

- On the other hand, the protons of other energies have a longer range and their contribution can be significant to secondary neutron production



Neutron Production inside the Phantom as a Function of Proton Energies

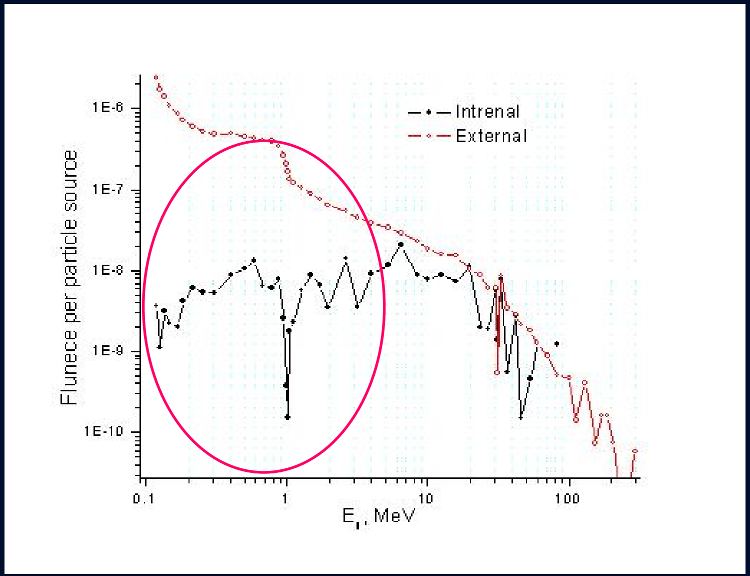
Discussion

- There are two processes that compete when interactions with the phantom occur.

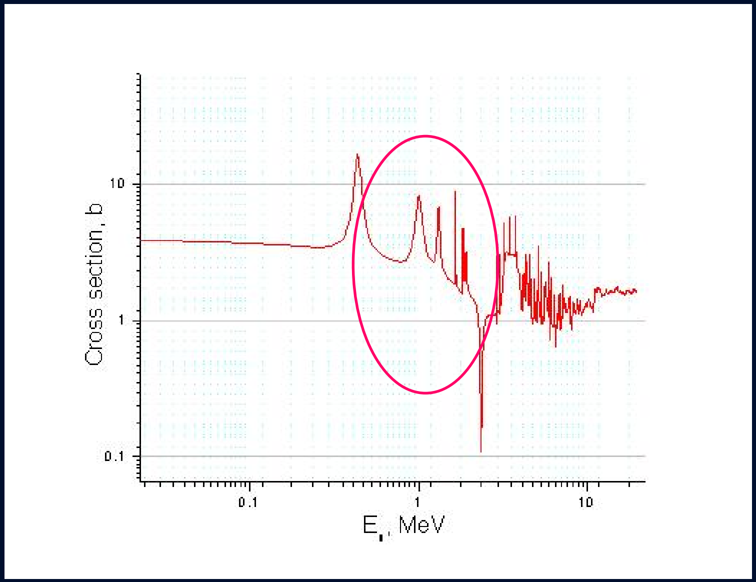
  - The first one is the absorption process due to the attenuation of neutrons in the phantom media (in this case low energy neutrons are more concerned due to their high cross section).

  - The second process is the production of secondary neutrons through threshold reaction (n,xn).

- The absorption process is an additive process and the total absorption cross at one energy such as thermal is around few barns, but in the resonance region, especially, for the Oxygen, Nitrogen and Carbon it presents more than tens of barns. Therefore, the rate of absorption of neutrons in the phantom may change the neutron spectrum from one cell to another.



Neutron attenuation in the phantom



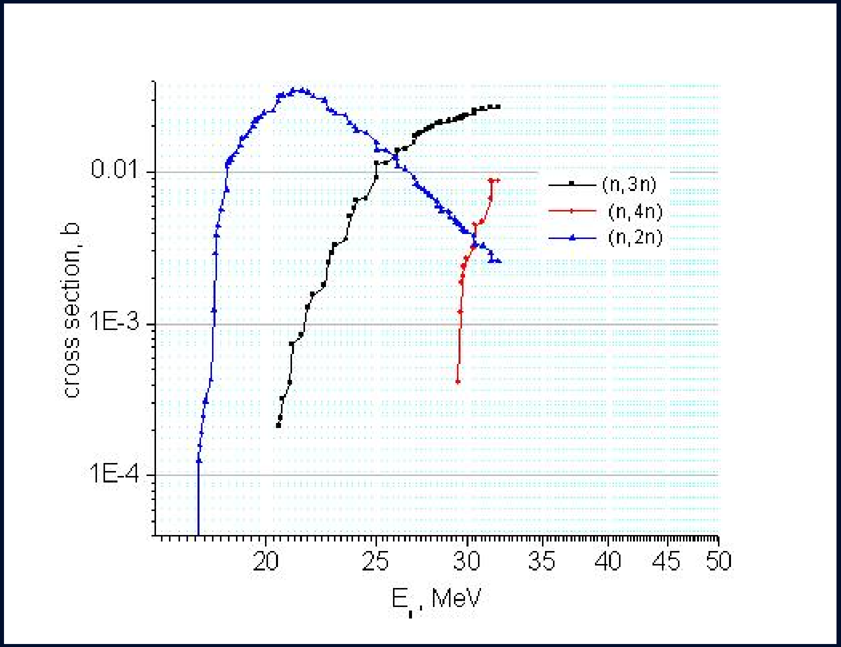
Neutron Cross Section of Oxygen

Discussion _ continued

- In the second process, when neutrons have enough energy to create secondary neutrons through different threshold reactions. Even their reaction cross sections are not that high enough, but in additive manner they create enough secondary neutrons.

- The cross sections for (n,2n), (n,3n) and (n,4n) for C are presented in.

- The comparison between the absorption and the production cross section are clearly different in the favour of absorption which is mostly a dominating process.



Threshold neutron Cross Section on Oxygen

Discussion _ continued

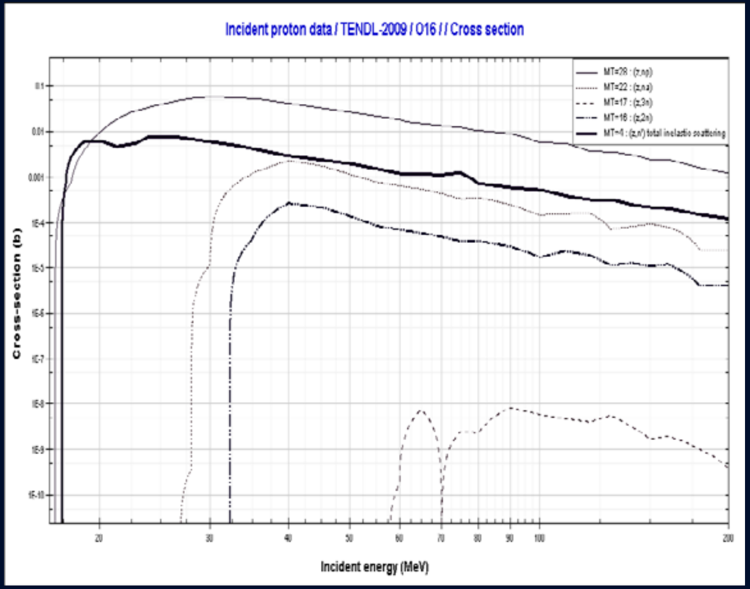
Regarding charged particle irradiation:

- Not all charged particles from cosmic radiation interact with the shielding material of the station and get absorbed.
- Since protons presents more than 85% of the charged particle flux hitting the space craft external material, some of them escape the absorption process.

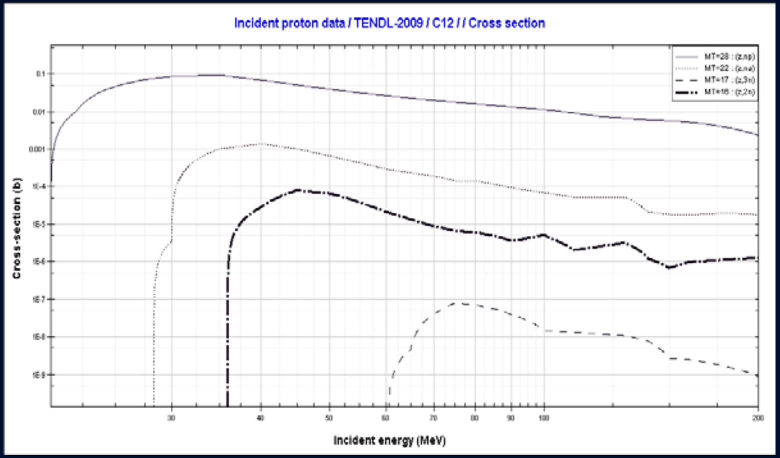
- In the literature, there is no precise data on the fluence of the charged particle field inside the space station; however some estimation has be done

- These protons interact with the phantom media through different high energy reactions among them, one can cite neutrons as secondary products.

- The rate of such production depends mainly on the cross section of the interaction with the constituents of the phantom such Oxygen, Carbon and Nitrogen.



Proton Cross Section on Oxygen



Proton Cross Section on Carbon

Discussion _ continued

- As a result of interaction with the fast part of the neutron spectra and high energy protons with the constituents of the phantom, a large number of neutrons are created at different depths.
- The overall contribution from different components is a sum from the fast neutron part as well as from the proton part.
- The results of the 2 competing processes absorption against production gives and an overall neutron flux in each cell.
- the ratio of external to internal neutron flux was found to be 0.72 when summing the result from all processes.
- The measured ratio of the dose rate is about 1.2. however no comparison can be made since the spectra of neutron and charged particle are not precise from one side and from another side the dose fluence to dose conversion factor depends on the energy spectra and a good comparison have to take this into account.

	Overall Neutron Flux per particle source
In internal cell	3.24E-05
In external cell	2.34E-05
Ratio	0.72

Ratio of External to Internal Neutron Flux

Conclusion

- Monte Carlo simulation code MCNPX has been used to estimate secondary neutron production on the surface and inside the phantom.

- The Russian spherical phantom has been used in the simulation and was first bombarded with a measured neutron spectra and the neutron flux resulted from the neutron produced by fast neutrons was calculated.

- The phantom has been also bombarded with different proton energies and secondary neutrons produced in different layers of the phantom have been calculated.

- Neutrons produced from proton interaction was added to the number of neutrons that were produced using the neutron spectrum and the external to internal neutron flux ratio was calculated

- The ratio of external to internal neutron flux was found to be 0.72.

The lack of data and information not only on the charged particle spectra but also on the neutron spectra inside the ISS makes the comparison with the experiment difficult.

Some Ideas for the Future

From previous calculations and experiments, the major issue to be investigated is an accurate measurement of the neutron and charged particle spectra to clarify the between the internal and external doses.

To do so, one needs to:

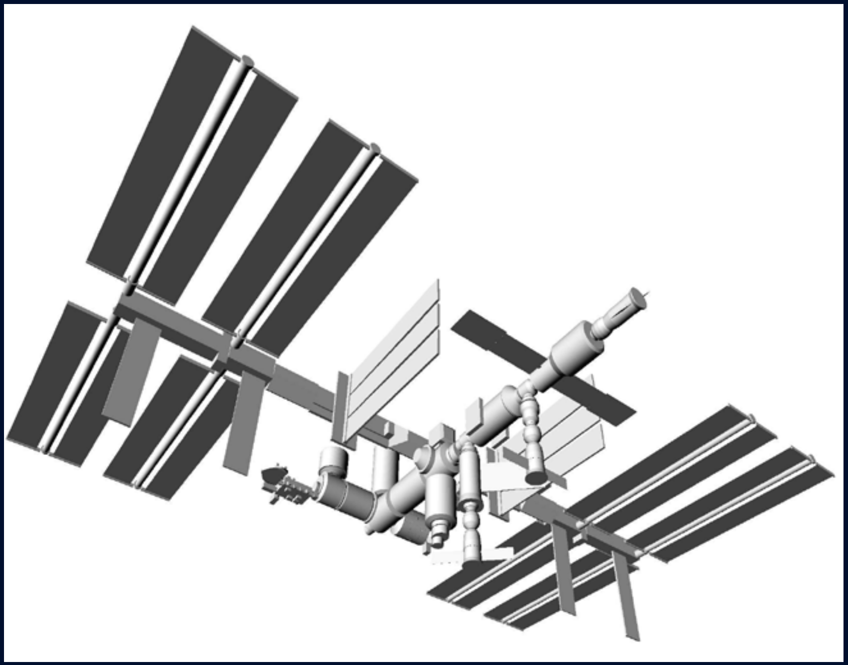
1. Neutron spectra

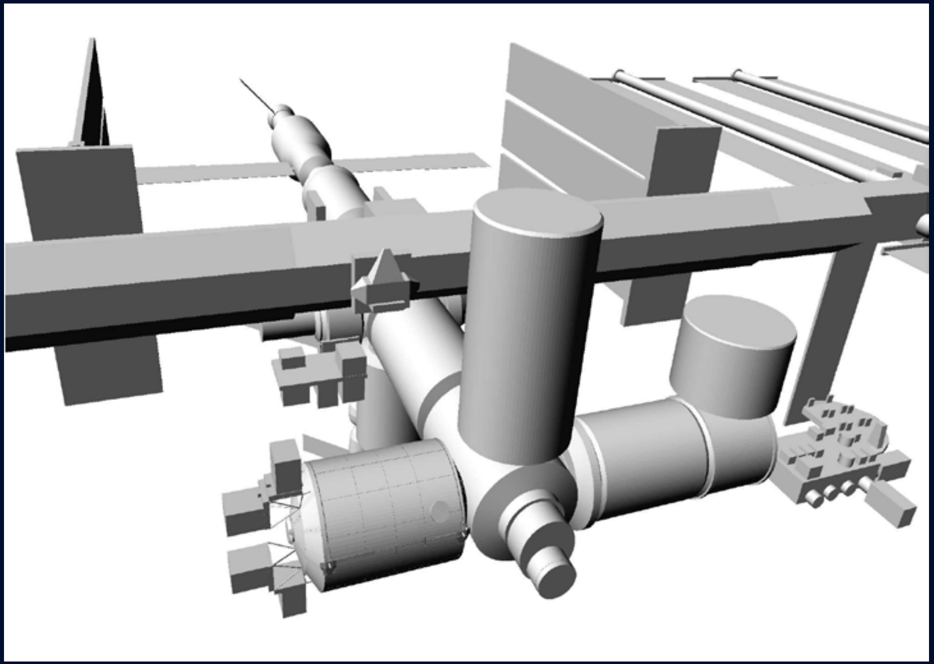
- Measure the neutron spectra on the surface of the phantom and simulate this spectra with MCNP through the phantom
- Measure the spectra inside the phantom and compare it with the simulated one
- If the measured spectra inside is the same as the simulated one, one needs to find an alternative explanation for the low attenuation of neutrons incident on the phantom.
- But if the spectrum is different, that means there is a contribution from other process (es) that contribute to neutron production inside the phantom and compensate for the decrease of the dose due to the attenuation of the neutron spectra observed on the surface.

2. Build a 3D mass distribution model to estimate:

- Charged particle spectra inside the station
- Spectra of secondary neutrons behind different shielding

Two simplified models of the ISS to start with





Thank you for your attention