NEUTRON PRODUCTION IN A SPHERICAL PHANTOM ABOARD ISS

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Summary

As part of an ongoing research program on radiation monitoring on International Space Station (ISS) that was established to analyze the radiation exposure levels onboard the ISS using different radiation instruments and a spherical phantom to simulate human body. Monte Carlo transport code was used to simulate the interaction of high energy protons and neutrons with the spherical phantom currently onboard ISS. The phantom has been exposed to individual proton energies and to a spectrum of neutrons. The internal to external neutron flux ratio was calculated and compared to the experimental data, recently, measured on the ISS.

1. Introduction

The radiation field on earth is extremely different than space radiation. The radiation environment inside the International Space Station (ISS) is an extremely complex mixture of photons, charged and neutral particles. Other than the primary radiation sources, there are also secondary particles resulting from the interaction of the primary particles with the material of space-crafts (protons, neutrons and others). As secondary particles with high Linear Energy Transfer (LET), neutrons are very important component in any shielded space environment in terms of dose contribution. Currently, neutron contribution to the total dose equivalent of the astronaut is about 20 to 35% [1].

Although there are few groups conducting researches on space radiation and on neutron dose measurements in particular, up to now, there are no accurate measurement of the neutron spectra and neutron dose on the international space station. Previous studies show that the neutron dose received internally and externally in space environment is almost the same [2] whereas on earth, due to the attenuation of neutrons, the internal dose is much less than its external value. In fact the complexity of the space radiation field inside the space craft doesn't allow drawing clear conclusions on this big difference. It is also not clear why the experimental results are in variance with the theoretical results [3]. It is possible, that the difference is related to other secondary particles such as protons, which don't interact with the shielding material and go through to interact directly with the phantom itself. And from the interaction of these high energy protons, there will be additional secondary neutrons produced inside the phantom that compensate for the attenuation of the neutrons entering the phantom surface.

In this study the neutron production in a spherical phantom, currently flying aboard the international space station, has been carried to clarify the relationship between the internal and external doses measured on the surface and inside the phantom [2]. It includes the simulation of high energy protons and neutrons in different layer of the phantom. The simulation used the extended Monte Carlo Code MCNPX [4] to transport neutron spectra and individual energy protons through the phantom. The results from the calculations showed that the value of the neutron fluxes inside and outside the phantom is different from a recently measured data.

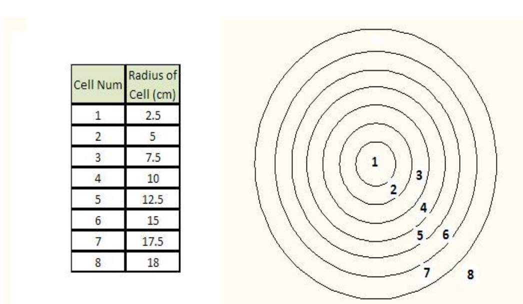
2. Methodology

To estimate the neutron production in tissue equivalent material, a 32 Kg spherical phantom, which is made of 8.6% Hydrogen, 2.6% Nitrogen, 32.3% Oxygen and 56.5% Carbon was used. To simulate the neutron field, two Monte Carlo models, using MCNPX, have been built: the first model has been used to transport a measured neutron space spectra through the phantom [5], while the second model has been built to transport high energy protons. In both models the phantom has been divided into 8 equidistant concentric cells (2.5 cm in between) Figure 1 (a) shows the 2D view of Phantom Model.

3. Simulation and Results

3.1 Neutron Production by Fast Secondary Neutrons

From interaction of high energy charged particles with the material shielding of the ISS, there is a wide neutron spectrum inside the ISS, shown in Figure 1 (b) , also from interaction of the exiting neutrons inside the ISS with the phantom itself, many secondary neutrons are created. The space neutron spectra measured by V. I. Lyagushin [5] was transmitted through the phantom.



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

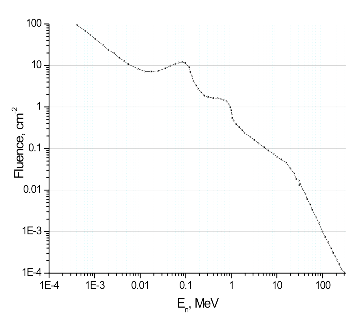


Figure 1 (a) 2D view of Phantom Model (b) Neutron Spectra used for Simulation

The neutron spectrum in different cells has been calculated. The two spectra of internal and external cells are presented in Figure 2 (a) and (b), respectively.

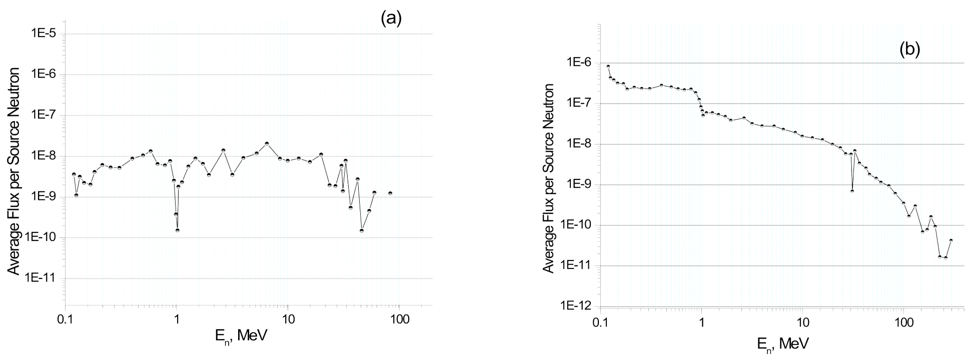


Figure 2 a) Neutron Flux in the Internal b) Neutron Flux in External Phantom Cell

3.2 Neutron Production by Different Proton Energies

The internal mixed field of different particles inside the space station contains not only secondary neutron created as a result of charged particle interaction with the shielding material of the station, but also high energy protons and other particles that escape the interaction and get through the shielding material. Theses protons interact with the phantom and generate additional secondary neutrons inside it. To estimate their contribution, protons of different energies were transmitted through the phantom and the neutron flux has been calculated in different cells. The range of proton penetration inside the phantom was calculated using the SRIM [6] code. Lower energy protons have a very short range of penetration; therefore, they are unable to significantly contribute to secondary neutron production inside the phantom. On the other hand, high energy protons contribution can be significant.

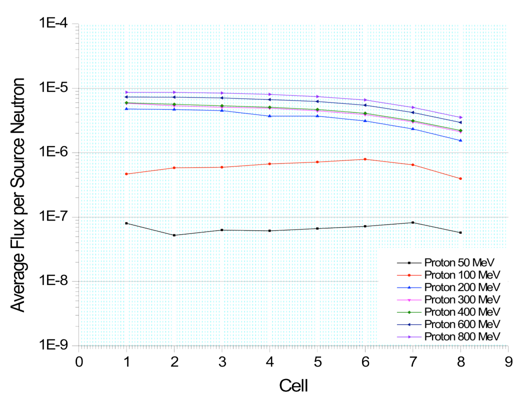


Figure 3 Neutron Productions inside the Spherical Phantom as a Function of Proton Energies

4. Discussion and Analysis

4.1 Neutrons Production inside the Phantom by External Neutron Spectra

When space neutrons are transmitted through the phantom, there are two processes that compete when the interaction with the phantom occur. The first one is the absorption process due to the attenuation of neutrons in the phantom media. In this process, low energy neutrons are more concerned because of their high absorption cross section.

The second process that competes with the absorption in the phantom is the production of neutrons as a result of interactions of the fast part of the energy spectrum with the phantom media. Theses neutrons have enough energy to create secondary neutrons through different threshold reactions. Even if the respective cross sections for these reaction are low, the resulting total contribution to secondary neutrons production can be relatively large

When analyzing the data obtained from MCNPX in different cells (Figure 1 (b), when the phantom has exposed to the neutron space spectra), one can see that neutrons are attenuated and their number decreases when going from the external cell to the internal one. This is explicitly clear when comparing the flux of neutrons in cell 1 against cell 8. The result is shown in Table 1.

Table 1 Neutron Flux in Internal and external Cells

Cell Num	Cell Radius, cm	Flux, cm^{-2}
1	2.5	2.45E-07
8	18	1.38E-05

4.2 Neutrons Production inside the Phantom by External Proton

Protons presents more than 86% of the charged particle flux hitting the space craft external material, some of them will pass through without any interactions. Up to now, there is no precise data on the fluence of the charged particle field inside the space station.These protons interact with the phantom media through different high energy reactions several of these leading to the production of neutrons as secondary products. The rate of such production depends mainly on the cross section of the interaction with the constituents of the phantom. In this section the phantom was exposed to different protons energy and the results for secondary neutron production from the proton interaction with phantom is presented in Table 2.

Table 2 Internal and external Neutron Flux when Bombarded with Different Proton Energies

Cell #	Radius(cm)	20 MeV	70 MeV	100 MeV	300 MeV	800 MeV
1	2.5	8.30E-08	6.64E-08	5.54E-07	5.72E-06	8.49E-06
8	18	5.82E-08	5.82E-08	3.94E-07	2.09E-06	3.54E-06

Protons inside the international space have an extended spectrum from few MeV to few hundred of MeV.The reactions that can take place with the phantom to produce neutrons have relatively small cross sections, but they can nonetheless generate a large contribution to the population of secondary neutrons inside

the phantom media. The contribution for all these proton reactions can compensate for the process of attenuation of external neutrons passing through the phantom.
The low energy protons do not contribute to the neutron production in the inner cell because of their short range. However, for high energy, protons can penetrate deeper in the phantom and consequently produce more neutrons in different cells, the neutron production reaches its maximum value (Bragg peak where protons deposit their maximum energy at the end of their range). After the maximum value, the number of neutrons decreases towards the center of the phantom because of the neutron absorption process (neutron attenuation). As the proton energy increases, the number of created neutrons increases accordantly in both cell external as well as the internal one.

4.3 Overall Neutrons Production inside the Phantom

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 production as well as from the proton interactions. The result of overall neutron flux and the ratio of external to internal neutron flux due to the absorption and production processes was calculated and presented in Table 3.

Table 3 Ratio of External Neutron Flux to Internal Neutron Flux per source particle

	Flux when the phantom was exposed to neutron space spectra	**Flux when the phantom was exposed to protons**	**Overall Neutron Flux**
Internal cell	2.45E-07	3.21E-05	$8.43.10^{-05}$
External cell	5.45E-06	1.80E-05	$5.29.10^{-05}$
Ratio	22.23	0.56	**0.63**

4.4 Comparison between Experimental Data and Simulation

The Matroshka-R experiments with space bubble detector have used the same spherical phantom used in this simulation [2]. The experimental data has shown that the dose received internally and externally is almost the same table 4 [2].

Table 4 Ratio of External to Internal Dose Measurement Obtained in 3 Different Experiments

Dose rate	Measurement #1	Measurement # 2	Measurement # 3
Ratio Internal to External	1.21 ± 0.35	1.43 ± 0.56	1.24 ± 0.38

5. Conclusion

This work has been conducted to investigate the relationship of the internal to external flux of neutrons of the Russian spherical phantom currently aboard the international space station and to clarify the large difference between the behaviour of the neutron dose internally and externally. Monte Carlo simulation code MCNPX has been used to estimate secondary neutron production on the surface and inside the phantom bombarded with the measured space neutron spectra and with proton energies from 20 to 800 MeV. The overall neutron flux was estimated and the ratio of external to internal neutron flux was calculated. Its value of 0.63 is two times less than the experimental ratio of the measured dose rate of 1.3. Finally, to clarify the difference between the phantom in space and the one on earth, experimental data on the cosmic ray spectra inside of the international space station are needed. There is a lack of data and information not only on the charged particle spectra but also on the neutron spectra inside the ISS.

6. References

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