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Radiation Measurements on the International Space Station

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Abstract

The International Space Station (ISS) is becoming a reality with the docking of the Russian Service module (Zarya) with the Unity module (Zaveda). ISS will be in a nominal 51.65-degree inclination by 400 km orbit. This paper reviews the currently planned radiation measurements, which are in many instances, based on experiments previously flown on the Space Shuttle. Results to be expected based on Shuttle measurements are presented.

KEYWORDS: Radiation, space station, anthropomorphic phantom, risk.

1. Introduction

The International Space Station is complex made of a series of modules provided by a consortium of nations. The station trusses provide a platform for mounting instrument on the outside of the station modules. The station will be in 51.65-degree inclination orbit with a nominal altitude of 400 km (370-430 km range). Space radiation is constant and significant hazard to the crew and equipment of the ISS. Recent movement to lower by a factor of two, the career limits of the crew from the currently accepted limits, increases the need for more accurate measurements.

In this paper, we review the planned physical measurements of external and internal radiation environment, measurements to quantify the radiation risk, and measurements to support operational requirements.

2. Measurements

Galactic cosmic rays have an energy spectrum extending in energy from few MeV to almost 10^{21} eV, flux that varies by 32 orders of magnitude, and charge extending from hydrogen to uranium. For radiation protection and upsets in electronic components, energies up to about 10 GeV/n, and ions of hydrogen, helium, carbon, oxygen, neon, silicon, and iron, are most important. A number of cosmic ray instruments are planned that are to be mounted on the station truss to cover the energy and charge range of the GCR ions. The Alpha Magnetic Spectrometer (AMS-II) is slated for launch in September 2003 (UF4 mission). This advanced version of the AMS-I spectrometer that flew on STS-91, will measure the energy spectrum from about 70 MeV/n to nearly 1400 GeV/n from ions between hydrogen and iron, with very high momentum resolution, and counting statistics. Figure 1 shows the proton energy spectrum and its comparison with model calculations of Badhwar and O'Neill (1996) and CRÈME 96 (Tylka et al., 1996). The orbit averaged transmission function was calculated using the IGRF 90 magnetic field (Smart and Shea, 1998). Figure 2 is the helium energy spectrum and its comparison with model calculations. In both cases the Badhwar and O'Neill model performs better than the CRÈME 96 model. The AMS-I measured the re-entrant proton energy spectrum. In the 70 to 2000 MeV-energy range, the spectrum agrees well with Armstrong and Colburn (1992) model in shape. AMS extended the energy range of albedo measurements from 2 to 12 GeV. With data from AMS-II expected to be available for nearly three years, the accuracy of GCR and geomagnetic transmission models can be substantially improved, significantly alleviating the need for other instruments, to provide life science needed data.

Other instruments under serious considerations, are the Advanced Cosmic-ray Composition Experiment (ACCESS), expected to extend the energy range to about 10^{16} eV, the Griesen-Zetsepin-Kuzmin (GZK) instrument to extend the energy to 10^{20} eV to look for the knee in the proton spectrum, the Extremely-Heavy Cosmic-Ray Composition Observer (ECCO) for trans-nickel nuclei, and the very high-energy electrons (ECAL) experiment. With the suite of these instruments, an accurate picture of the GCR environment external to the Space Station would become available.

3. Measurements to Quantify Radiation Risk

A second class of experiments is designed to measure quantities to help quantify the radiation risk. One of first such experiments is a joint NASA, ESA, and NASDA experiment to be flown on 5.A.1 mission in mid 200. It is based on the flight of a fully instrumented anthropomorphic phantom torso. Such an experiment was flown on STS-91 during the solar minimum, results of, which provides a

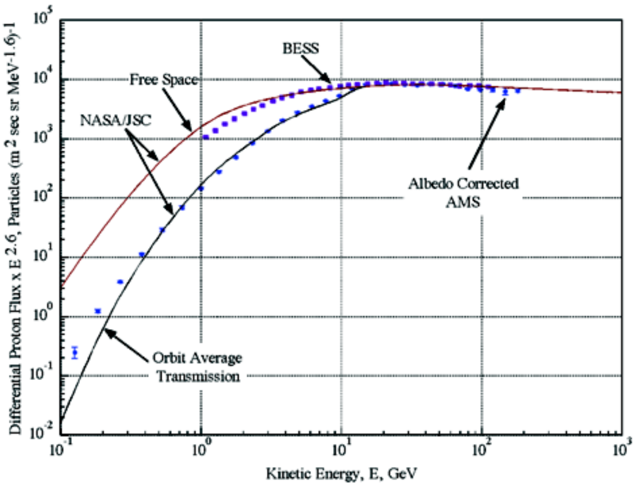

Fig. 1 – A comparison of orbit averaged AMS-I measured and calculated proton energy spectrum.

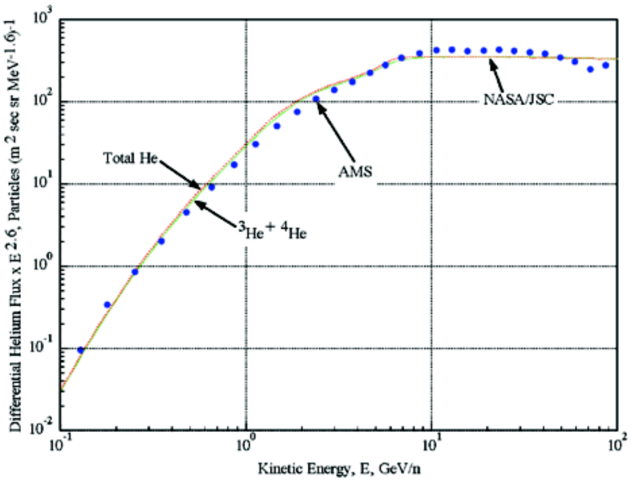

Fig. 2 – A comparison of the orbit averaged AMS-I measured and calculated proton energy spectrum.

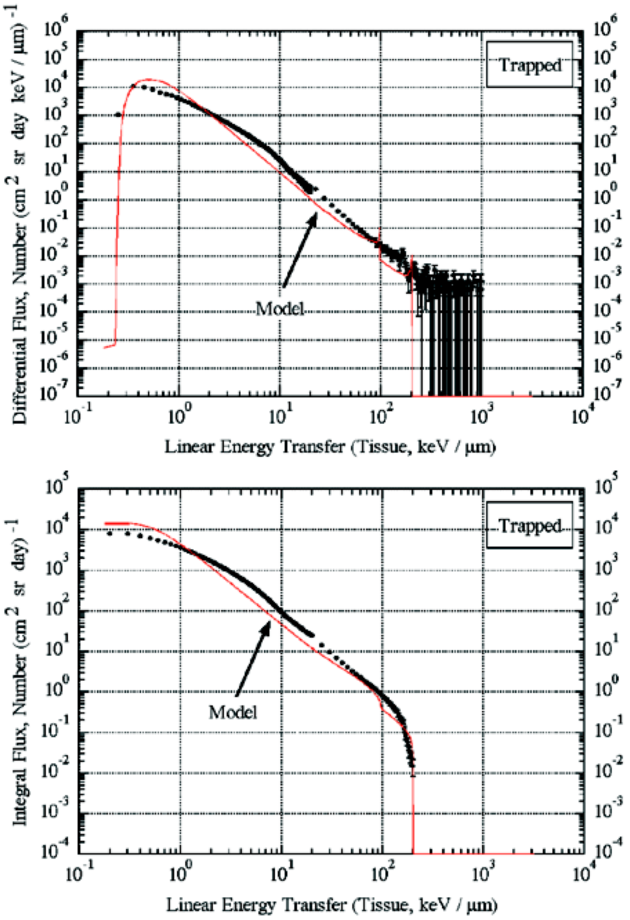

Fig. 3 – A comparison of the calculated linear energy transfer and measured lineal energy spectra of trapped particles on STS-91.

guide to the results to be expected on the ISS flight. The objectives of the experiment are (i) Determine particle flux, dose, and dose equivalent at key organ locations for both galactic and trapped particles; (ii) Develop a quantitative measure of the accuracy of the current radiation transport, and nuclear fragmentation models through body shielding; (iii) Relate skin dose measurements to organ level dose measurements; (iv) Quantitatively compare various techniques for measuring dose, ‘linear energy transfer’ spectrum, and dose equivalent; (v) Measure the neutron energy spectrum in 0.1 to 14 MeV energy range, and (vi) Provide directional measurements of the trapped proton flux inside the Human Research Facility. NASA would provide the fully instrumented phantom torso, a charged particle directional spectrometer, and a tissue equivalent proportional counter. ESA would provide two silicon detector based telescopes (DOSTEL), one pointed in the velocity and the other in the anti-velocity direction, to provide dose and energy deposition spectra, the Hungarian developed PILLE thermoluminscent detector reader, packages of TLD and PNTD, and the Bulgarian developed single silicon element detector, Liulin. NASDA would provide a set of Bonner spheres imbedded with ^{3}He proportional counters.

An idea of the results to be expected can gleaned from the flight of these instruments on different Shuttle flights. Figure 3 shows a comparison of the TEPC measured lineal energy spectra with the calculated LET spectrum using AP8MIN trapped proton model for external energy spectrum, and the BRYNTRN radiation transport models. The agreement is reasonably good. If the LET spectrum were smeared by the TEPC chord length distribution, the agreement would be even better. Table I presents a quantitative comparison of the measured dose and dose equivalent. The measured quality factor is higher than calculations because the calculations do not take into account the contribution spacecraft produced secondary neutrons that are detected by the TEPC. These measurements provide a strong constraint on the accuracy of models used to access the accuracy of transport through the phantom torso. Table II gives a comparison of the measured and

Table I – Comparison of the Calculated and the Measured Trapped Particle Dose Rates.

	Absorbed Dose Rate (mrad/day)	Dose Equivalent (mrem/day)	Quality Factor ICRP26
TEPC	30.1	58.5	1.89
AP8-MIN MODEL/BRYNTRN	33.6	50.0	1.49

Table II – Comparison of Calculated and Measured Quality Factors For Various Body Organs.

ORGAN	TRAPPED <Q> ICRP26	TRAPPED (mrem/day)	GCR <Q> ICRP26	GCR (mrem/day)	Calculated <Q> ICRP26	MEASURED Q(<LET>) ICRP26	MEASURED Q(<LET>) ICRP90	(<Q> - Q(<LET>))/ Q(<LET>) %
Brain	1.39	9.80	3.08	34.69	2.10	1.7±0.14	1.8±0.14	23.53
Colon	1.40	15.26	2.95	33.81	2.17	2.0±0.19	2.0±0.19	8.50
Heart	1.41	16.64	2.98	33.73	2.15	2.0±0.38	2.0±0.38	7.50
Stomach	1.40	12.18	2.86	32.44	2.20	1.7±0.29	1.7±0.29	29.41
Thyroid	1.39	27.18	3.20	36.36	1.89	1.7±0.18	1.7±0.18	11.18
Skin – Breast	1.46	31.68	3.32	39.26	2.10	1.7±0.15	1.8±0.15	23.53
Skin - Abdomen	1.45	28.56	3.27	38.83	2.11	1.9±0.17	1.9±0.17	11.05

calculated dose and dose equivalent at several organ locations. Although the agreement is good at some locations, the agreement at other locations is very poor. This clearly shows that even with accurate knowledge of the external GCR environment, and established accuracy of trapped belt/transport models, and knowledge of spacecraft shielding, it is still not possible to accurately predict the organ dose. These results also show that the ratio of blood-forming-organ (BFO) dose to skin dose is about 80%, and 90% for dose equivalent. What would the situation be during the solar maximum when the ISS experiment would be flown?

An idea of the DOSTEL results can inferred from its flight on STS-84. The results are given in Figure 4 along the results of a Monte Carlo model calculation. The agreement is very good. The model also shows that the requirement of a coincidence removes low energy (high LET) protons, leading to a lower estimate of quality factor than with a TEPC.

The Bonner Ball Neutron Detector (BBND) would provide the neutron dose equivalent and the neutron energy spectrum (0.1 to 14 MeV neutrons). It flew earlier on STS-89.

With knowledge of both neutrons, and charged particle spectra incident on the phantom, accurate estimates of the dose and dose equivalent at organ location should be possible. Comparisons with actual measurements should help to clarify the stated objective of such an experiment.

4. Operational Active Radiation Monitoring

A number of radiation monitoring instruments provide data for use in operational monitoring, such as warning for the radiation level during a solar particle event, will be flown in support of the Crew Health System. The suite of instruments consists of an External Charged Particle Directional Spectrometer (EVCPDS), and Internal Charged Particle Directional Spectrometer (IVCPDS), and an internal Tissue Equivalent Proportional Counter (TEPC).

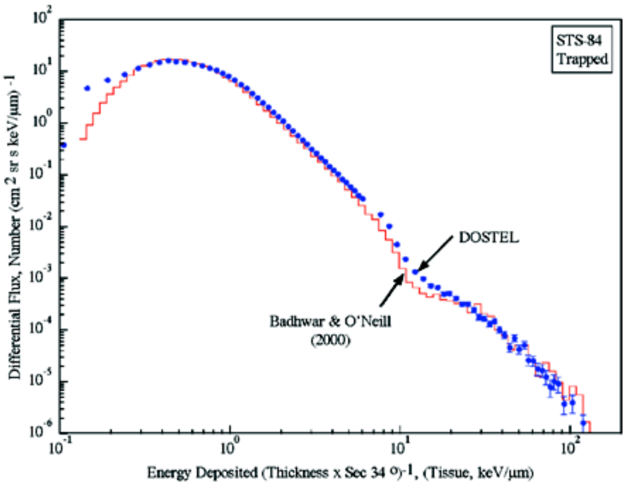

Fig. 4 – A comparison of the DOSTEL measured trapped linear energy transfer spectrum on STS-84 with a Monte-Carlo based calculations.

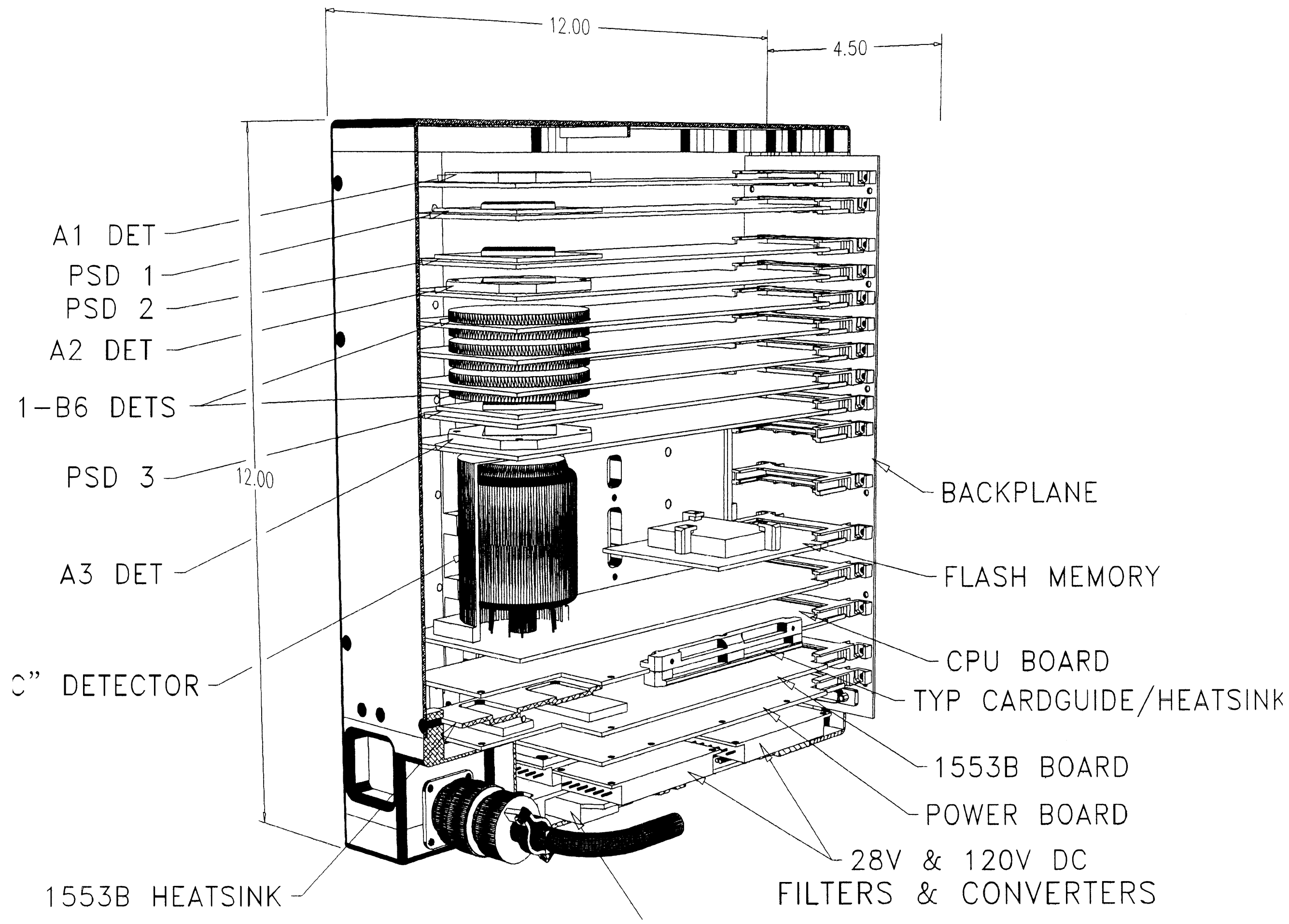

Fig. 5 – A schematic of one of the Directional Charged Particle Directional Spectrometer.

The EVCPDS consists of three identical charged particle spectrometers, housed in an avionics box mounted on to the S0 truss of the station. These mutually orthogonal spectrometers have their field of view in the velocity, anti-velocity, and nadir directions. Figure 5 is a schematic of one such spectrometer. It consists of a series of silicon solid- state detectors of varying thickness. Three of the detectors are 24 x 24 strip detectors that provide the (x, y) coordinates of the passage of the charged particle through the detector stack. The read of the detectors is initiated by a coincidence between the detectors A1A2 that define the geometrical field of view. Particles that stop in the detector stack provide the charge, energy, and mass of the particle. For particles with energy greater than 180 MeV/n threshold of the Cerenkov detector, the charge and energy are calculated from energy loss and signal in the Cerenkov counter. For particles that do not stop in the stack and have energy less than the Cerenkov threshold, are analyzed using the change in energy loss with detector thickness. Thus, by a combination of data from various detectors, the differential energy spectrum of protons in the energy range of 15 to 450 MeV, can be obtained. Because two detectors are pointed in opposite velocity directions, East-West asymmetry of trapped particles can be determined. The position sensitive detectors provide the arrival direction of each particle. Combined with pointing direction of the spectrometer to the local magnetic field direction, pitch angle distribution of trapped particles can be determined. Thus, with the knowledge of energy spectrum, East-West asymmetry, and pitch angle distribution, accurate model of the trapped belts, in low earth orbit can be made. This data also provides an accurate input to establish the radiation dose in various station modules. The nadir-pointing instrument can, similarly, provide data on solar particle events, and to a rather limited extent the spectra of galactic particles.

The internal IVCPDS is identical to one of the external spectrometers in functionality. It differs in its ability to be operated from any station module, and having a display to indicate the absorbed dose for the use of the crew. Combined with data from the external spectrometer, and station shielding distribution at the location of the internal spectrometer, the data can be used to help establish the accuracy of existing transport model(s), and hence aid in predicting the radiation levels at arbitrary locations inside the station modules. Using the two silicon coincidence detectors (A1A2), the spectrometer can also provide the linear energy transfer spectrum in silicon that can be converted to the spectrum in tissue. This provides a needed redundancy to the spectrum from TEPC.

The TEPC is based on a proven design of a unit flown on the *Mir* orbital station. It is a right cylindrical detector, 5 cm × 5 cm, filled with a low-pressure propane to simulate a 2 µm diameter tissue volume. The gas is surrounded by the A-150 tissue equivalent plastic. It measures the energy deposition spectrum of charged and neutral particles that with appropriate calibration, yields the time resolved lineal energy, y, spectrum of trapped and galactic particles. With the assumption that quality factor can be calculated by replacing y by LET, the dose equivalent can be calculated. Thus, the instrument provides, absorbed dose rate, dose equivalent rate, and y spectra in a time resolved manner. It has a display, an audio and visual alarm, and is wired into the caution and warning system of the station.

6. Conclusions

A review of the planned radiation measuring devices to be flown on the ISS shows that the instruments will provide a wealth of accurate data on both external and internal environment. These sets can be used to build improved radiation environment model(s), models of geomagnetic transmission, radiation transport through spacecraft structure and body, for operational monitoring, and radiation risk assessment.

REFERENCES

[1] Badhwar GD, O'Neill PM. GCR model and its applications. Adv Space Sci 1996: 17(2); 7-17.

[2] Tylka AJ, Adams JH, Jr, Boberg PR, Brownstein B, Dietrich WF, Fluechiger EO, Peterson EL, Shea MA, Smart DF, Smith EC. CRÈME96: A revision of the cosmic rays effects on microelectronics code. IEEE Trans In Nucl Sci 1997: 44(6); 2150-2160.

[3] AMS Collaboration, Protons in Near Earth Orbit Phys Lett 2000: B472; 215-226.

[4] Armstrong TW, Colburn BL. Predictions of induced radioactivity for spacecraft in low Earth Orbit, Nucl Tracks and Rad Meas 1992: 20; 101-130.

[5] Smart DF Shea MA and Fluckiger EG. Calculated vertical cutoff rigidities for the International Space Station during magnetically quiet times. In: Proceedings of 26th International Cosmic Ray Conference, Salt Lake City, Utah. 1999: Vol 3; SH3.6.28.