# A SHIELDING MODEL FOR AN INFLATABLE VEHICLE, TRANSHAB, AND THE ASSOCIATED ASTRONAUT SPACE RADIATION RISK ASSESSMENT

William Atwell[1] and Gautam Badhwar[2]

[1]Boeing North American, Houston, Texas 77058 USA
[2]NASA Johnson Space Center, Houston, Texas 77058 USA

February 2000

# A SHIELDING MODEL FOR AN INFLATABLE VEHICLE, TRANSHAB, AND THE ASSOCIATED ASTRONAUT SPACE RADIATION RISK ASSESSMENT

William Atwell[1] and Gautam Badhwar[2]

[1]Boeing North American, Houston, Texas 77058 USA
[2]NASA Johnson Space Center, Houston, Texas 77058 USA

## Abstract

TransHab, a habitable inflatable structure, has been proposed as a possible module for the International Space Station that provides significant increase in the available volume compared with the US Hab module and for a human Mars mission. A study was undertaken to understand and provide design inputs for crew radiation exposures. The results show that the current design provides sufficient shielding to assure that the crew exposures are below the crew exposure limits currently adopted for the ISS. In addition, the shielding provides adequate protection from the largest solar particle events (SPEs) observed during the last 40 years.

## Introduction

A new design concept of a habitable inflatable structure has been proposed as a possible replacement for the International Space Station (ISS) HAB module and as a precursor for a human mission to Mars. Besides the advantage in launch weight, the concept provides for a large habitable volume, micrometeoroid protection, and a "storm shelter" for mitigation of SPEs. The present study was performed to ascertain the level of radiation protection offered by the latest design and to assure a conservative design for missions in low-Earth orbit. Space radiation in low earth orbit consists of trapped protons and electrons, galactic cosmic rays (GCR), and SPEs. ISS will be in a $51.65°$ inclination orbit with a nominal altitude of 400 km. For the purpose of this study, the worst-case free space radiation environment was considered to ensure a conservative shield design. The trapped proton and GCR fluxes and spectra were taken at the time of solar minimum when their fluxes are the highest.

## Radiation Environment

The trapped AP-8MIN (Sawyer and Vette, 1976) proton energy spectrum was calculated using SPENVIS (Heynderickx, *et al*, 1996) for a nominal $51.65°$ x 400 km orbit. As an initial check between model calculations and Tissue Equivalent Proportional Counter (TEPC) flight data for STS-91, a comparison was first made using the AP-8MIN model, the BRYNTRN radiation transport code (Wilson, *et al*, 1989), and the STS-91 Shuttle/SpaceHab shielding distribution at the TEPC location. The calculated dose and dose equivalent rates, over the LET range of 0.3 to 220 keV $\mu m^{-1}$, are 336 $\mu Gy$ day$^{-1}$ and 500 $\mu Sv$ day$^{-1}$, respectively. The TEPC measured dose and dose equivalent rates were 310 $\mu Gy$/day and 585 $\mu Sv$/day, suggesting that the model calculations are accurate to about 20%. The galactic cosmic ray spectra used the epoch 1976-77 solar minimum spectra from the Badhwar and O'Neill (1996) model.

Solar particle events (SPEs) occur in about a seven-year period centered near the time of solar maximum. During the last 40 years of observations, four very large fluence events (February 1956, November 1960, August 1972, and October 1989) have been observed.

## TransHab Space Radiation Shielding Model

A shielding model of the TransHab structure was constructed that took careful account of the material properties especially the inflatable bladder layer buildup. For the purpose of this conservative design study, the material thicknesses were all converted to equivalent aluminum thicknesses. Using a ray-tracing technique, 512 rays (material thicknesses) were generated over a $4\pi$ steradian solid angle for 9 locations (discussed below) in the TransHab to produce shielding distributions for these locations. The minimum thickness is 3.26 g cm$^{-2}$ and is sufficient to exclude almost all the dose from trapped electrons. In order to calculate the organ level space radiation exposure to an astronaut inside a space vehicle, the TransHab

shielding was augmented by shielding distributions using the Computerized Anatomical Male (CAM) model (Billings and Yucker, 1973).

## Trapped Dose and Radiation Transport Model

PDOSE (Hardy, 1980) is a simple proton transport/dose code that does not take the secondary particle production into account. It has been used extensively since the early days of the U.S. space program. BRYNTRN was developed at NASA Langley Research Center and takes into account almost all-secondary particle production, including target and projectile production. Comparison of absorbed dose rate calculations show that the two codes give absorbed dose rate within 5% of each other. However, dose equivalent values calculated by BRYNTRN are always higher, as expected, by about 15%. The PDOSE dose equivalent values were adjusted upwards by 15% to account for secondary particle production.

## Galactic Cosmic Radiation

The GCR dose and dose equivalent at various locations in the TransHab can also be calculated using the GCR spectra described in the environment section and a radiation transport code such as HZETRN (Wilson, *et al*, 1995). For the purpose of this design study, a much more *conservative* approach was adopted. Badhwar, *et al* (1998) measured the GCR dose and dose equivalent rate on the *Mir* orbital station around the last solar minimum using a TEPC. These measurements have been made in various *Mir* modules and show small variations due to differences in mass shielding distribution of these modules. TransHab structure is more akin to polyethylene than aluminum used in the *Mir* structure. Direct comparison of shielding properties of aluminum and polyethylene for GCR particles (Badhwar and Cucinotta, 2000) show that polyethylene attenuates the dose and dose equivalent more effectively and at a higher rate per unit g cm$^{-2}$ of shielding thickness than aluminum. Thus, the *Mir* observations provide an upper bound to GCR dose and dose equivalent. The actual values are expected to be smaller. Based on these measurements, a GCR BFO exposure of 18.84 rem/yr was adopted (Badhwar, *et al*, 1998) for this study.

## Results

Figure 1 shows the 9 selected dose point locations in the TransHab; Table 1 shows total BFO exposure from the combined AP-8MIN trapped proton and GCR environments. There is only about a 20% variation in dose equivalent between these locations with the maximum dose equivalent being about 30 rem/year, which is well below the ISS BFO limit of 50 rem/yr. These results show that the current TransHab design provides sufficient radiation protection for the crew during the time of maximum exposure, i.e., at solar minimum. It is worth noting that the calculations presented in this paper are *conservative* and the actual exposures would be smaller. During the times of solar maximum, the radiation exposure rate from the combined trapped and GCR environments would be about a factor 2 to 2.5 lower. However, during these times, the probability of a solar particle event increases, and such an event or events can increase the exposure considerably.

## Solar Particle Events

One of the design considerations of the TransHab was to incorporate a "storm shelter," an area of increased shielding (5.74 cm water jacket) to ameliorate astronaut radiation exposures. In keeping with design philosophy, the worst case exposure will be when the geomagnetic field was "turned-off"; that is, the full flux of solar particles can reach the TransHab. These particles have an isotropic distribution (except early into the event), and as such the solid earth provides an effective shielding. This purely geometric effect reduces the flux of particles by nearly 1/3 at all energies. Thus, the maximum exposure seen at a point in the TransHab is about 2/3 of the free space exposure. Table 1 also shows these exposures at the 9 points in the TransHab for the August 1972 event. As can be seen, the maximum exposures can reach as high as 41 rem. However, in the storm shelter, which for this case included a top and bottom water shield to make a complete 5.74 cm thick water enclosure, the exposure is only about 5.3 rem. Calculations for the February 1956, November 1960, and October 1989 SPEs give exposures of 12.5, 14.9, and 16 rem, respectively. Considering the fact that the total trapped plus GCR dose equivalent rate during solar maximum would be

less than 15 rem/year, the absolute worst case exposures are still within the ISS crew limits. In a real situation the lower bound to these exposures can be obtained by assuming that the geomagnetic field is "quiet" ($Kp = 0$). Thus, the storm shelter provides a safe area during even the worst SPE.

### Dose Comparisons for the TransHab and ISS Hab & Lab Modules

There was some consideration of replacing the ISS Hab module with the TransHab module. Armstrong, *et al* (1995) report "skin" (surface of a tissue sphere) and "BFO" (5-cm depth) dose and dose equivalent calculations taken at locations (3 each) in the ISS US Hab and Lab modules for an orbit of 470 km x 51.6 deg at solar maximum (AP-8MAX proton model). Using the same input parameters as Armstrong, *et al* (1995), dose and dose equivalent skin and BFO values were computed using the CAM model. Similar computations were made using several of the TransHab shielding distributions. These two sets of computations are then compared with calculations for the TransHab. The results show that the BFO dose equivalent exposures in the ISS Lab and Hab modules are fairly consistent ranging from about 8 to slightly over 14 rem/yr. For the TransHab, there is approximately a factor of two variation (7.5-11 rem/yr for the more heavily shielded areas to over 16 rem/yr in the less shielded locations [treadmill and wardroom]).

### Conclusions

1.) There is approximately a 20% variation in BFO dose equivalent between the 9 locations in the TransHab with the maximum value being about 30 rem/yr, which is well below the 50 rem/yr crew limit.
2.) Crew exposures vary by about a factor of 2-2.5 from solar minimum and solar maximum.
3.) The TransHab module provides sufficient shielding to protect the crew during the largest solar particle events on record.
4.) Except for the less shielded locations in the wardroom and at the treadmill, the TransHab is slightly better shielded than the ISS Lab and Hab modules.

### Acknowledgements

### References

Armstrong, T. W., Colborn, B. L., and Ringler, S. J., "Ionizing Radiation Dose Estimates for International Space Station Alpha Using the CADrays 3-D Mass Model," Science Applications International Corporation Report No. SAIC-TN-9550, October 1995.

Badhwar, G. D., and O'Neill, P. M., "Galactic Cosmic Radiation and Its Application," *Adv. Space Res.*, vol. 17, 7-17, 1996.

Badhwar, G. D., Atwell, W., Cash, B., Petrov, V. M., Akatov, Yu. A., Tchernykh, I. V., Shurshakov, V. A., and Arkhangelsky, V. A., "Radiation Environment on the Mir Orbital Station During Solar Minimum," *Adv. Space Res.*, Vol. 22, 501-510, 1998.

Badhwar, G. D., and Cucinotta, F. A., "A Comparison of Depth Dependence of Dose and Linear Energy Transfer Spectra in Aluminum and Polyethylene," *Rad. Res.*, Vol. 153, 1-8, 2000.

Billings, M. P., and Yucker, W. R., "The Computerized Anatomical Male (CAM) Model, Report NASA CR-134043, 1973.

Hardy, A. C., NASA Johnson Space Center, private communication, 1980.

Heynderickx, D., Lemaire, J., Daly, E. J., and Evans, H. D. R., "Calculating Low-Altitude Trapped Particle Fluxes With the NASA Models AP-8 and AE-8," *Radiat. Meas.,* Vol., 26, 947-952, 1996.

Sawyer, Donald M., and Vette, James I., "AP-8 Trapped Proton Environment for Solar Maximum and Solar Minimum," National Space Science Data Center, NASA Goddard Space Flight Center, Greenbelt, MD 20771, Report NSSDC/WDC-A-R&S 76-06, December 1976.

Wilson, John W., Townsend, Lawrence W., Nealy, John E., Chun, Sang Y., Hong, B. S., Buck, Warren W., Lamkin, S. L., Ganapol, Barry D., Khan, Ferdous, and Cucinotta, Francis A., "BRYNTRN: A Baryon Transport Model," NASA TP-2887, 1989.

Wilson, John W., Badavi, Francis F., Cucinotta, Francis A., Shinn, Judy L., Badhwar, Gautam D., Silberberg, R., Tsao, C. H., Townsend, Lawrence W., and Tripathi, Ram K., "HZETRN: Description of a Free-Space Ion and Nucleon Transport and Shielding Computer Program," NASA TP 3495, 1995.

Yucker, W. R., and Huston, S. L., "Computerized Anatomical Female. Final Report," McDonnell Douglas Corporation Report MDC H 6107, Huntington Beach, CA 92647, 1990.
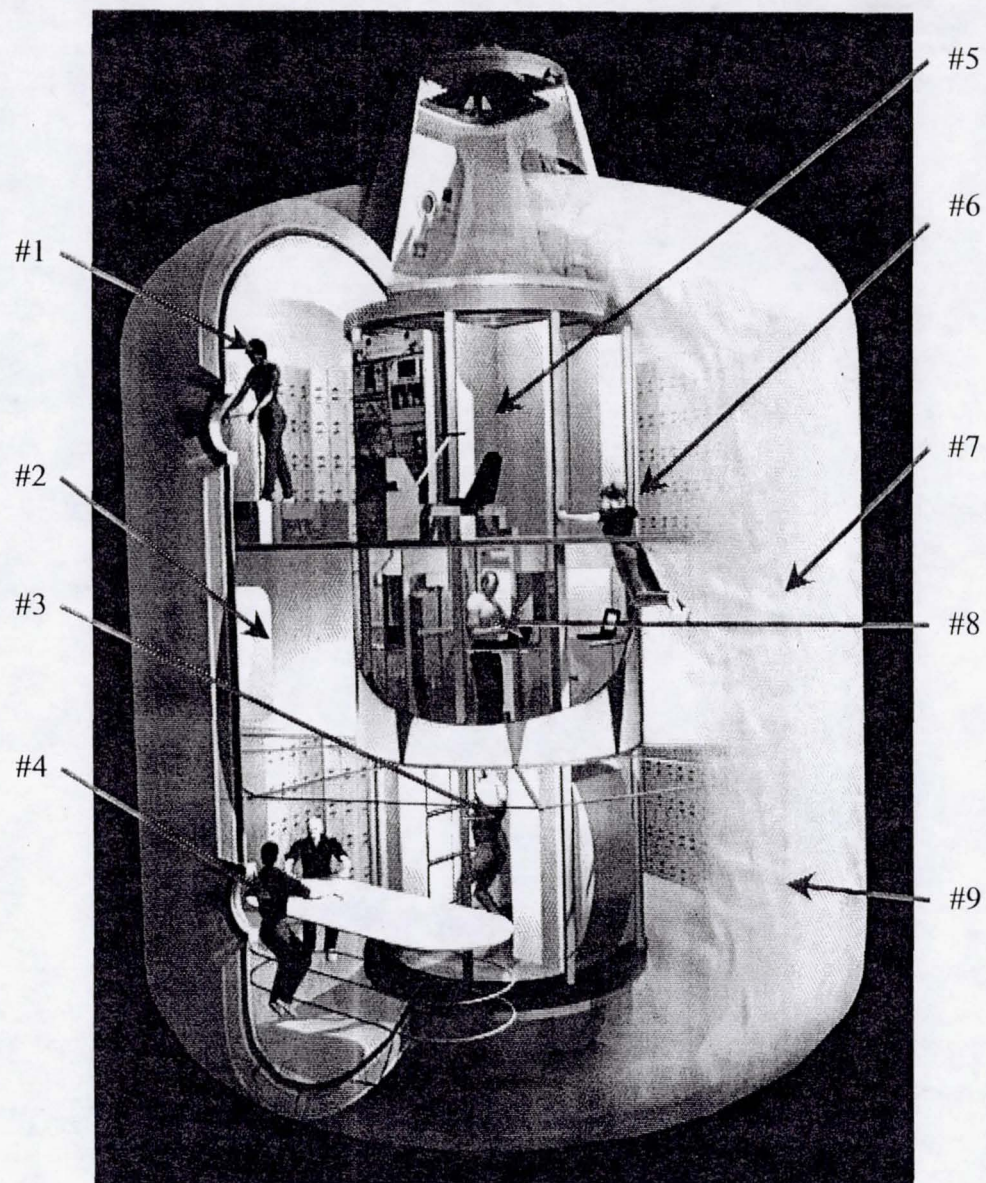
Fig. 1 TransHab pictorial showing dose point locations.

Table 1. TransHAB CAM BFO Exposures

| Location | Trapped Proton + GCR (rem/year) | August 1972 SPE | |
| --- | --- | --- | --- |
| | | Free Space (rem) | Earth Shadowing (rem) |
| 1 | 29.1 | 54.1 | 37.3 |
| 2 | 28.9 | 46.7 | 32.2 |
| 3 | 23.5 | 21.0 | 14.5 |
| 4 | 29.2 | 59.7 | 41.2 |
| 5 | 23.2 | 15.2 | 10.5 |
| 6 | 28.2 | 40.2 | 27.7 |
| 7 | 27.7 | 35.3 | 24.3 |
| 8 | 25.3 | 23.2 | 16.0 |
| 9 | 28.8 | 42.0 | 29.0 |