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# Visual Assessment of the Radiation Distribution in the ISS Lab Module: Visualization in the Human Body

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## *Abstract*

The US Lab module of the International Space Station (ISS) is a primary working area where the crewmembers are expected to spend majority of their time. Because of the directionality of radiation fields caused by the Earth shadow, trapped radiation pitch angle distribution, and inherent variations in the ISS shielding, a model is needed to account for these local variations in the radiation distribution. We present the calculated radiation dose (rem/yr) values for over 3,000 different points in the working area of the Lab module and estimated radiation dose values for over 25,000 different points in the human body for a given ambient radiation environment. These estimated radiation dose values are presented in a three dimensional animated interactive visualization format. Such interactive animated visualization of the radiation distribution can be generated in near real-time to track changes in the radiation environment during the orbit precession of the ISS.

KEYWORDS: Space radiation, international space station and destiny module, radiation transport, 3D-visualization.

## 1. Introduction

Visualizing the radiation dose distribution in the habitable volume of any module of the ISS or visualizing the radiation dose distribution inside of a human being is a challenging task. In this paper, we present our approach to quantify the total shielding offered by the module for several dose points in the habitable area of the Lab module (Figure 1) and the self-shielding at various locations inside of the human body. Utilizing these integrated shield values, we calculated and presented the radiation dose distribution for a given GCR (Galactic Cosmic Ray) environment [1].

Structural design and variations in the distribution of material composition layers increases the complexity in quantifying the total shielding offered for a specific dose point location in the habitable volume of the module (Fig. 2). Also, in the case of the Lab module, integrated shielding offered by the ISPRs (International Standard Payload Racks) will be varied as a function of time depending on the experimental set-up and contents on the ISPR. As a base line approach, we considered the optimal

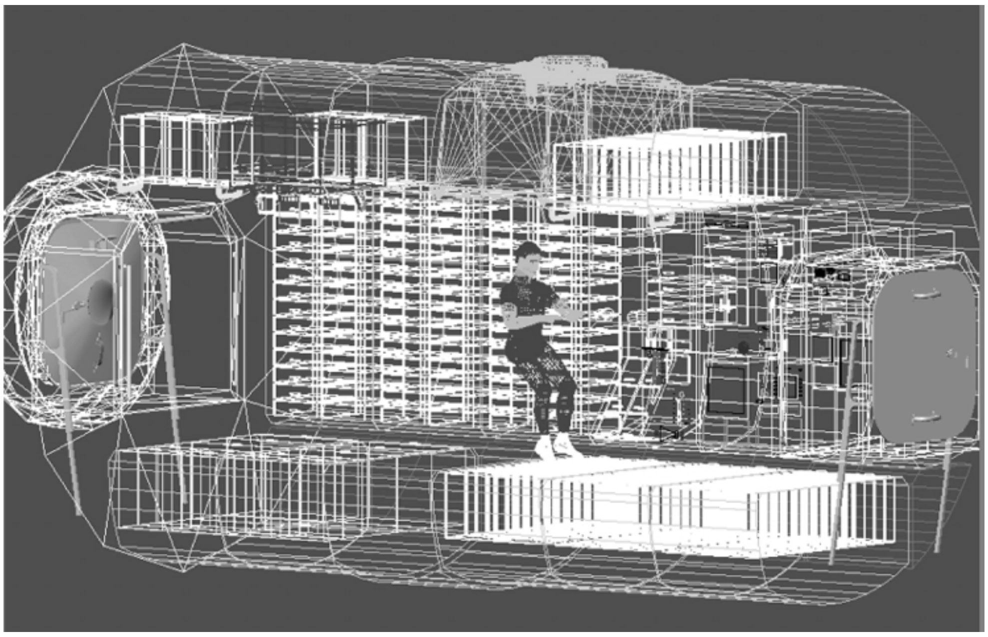


Fig. 1 – US Lab module line drawing that shows various racks and other components that offers shielding to the crewmembers. Picture generated for this study by the GRAF Laboratory/SP3 at NASA Johnson Space Center.

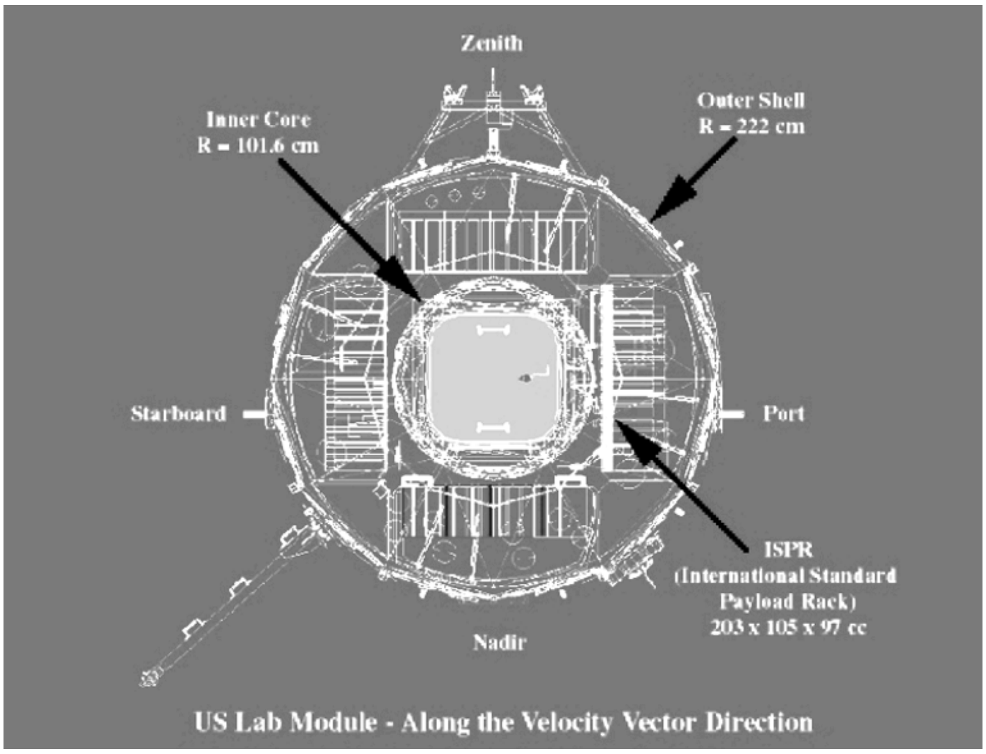


Fig. 2 – US Lab module as seen in the velocity vector direction. In this cross sectional view, four different arrays of rack systems are seen. In each array there are six different racks in the orthogonal plane. A total of 24 racks are in the module, 13 of these racks are identified as the ISPRs. Picture generated for this study by the GRAF Laboratory /SP3 at NASA Johnson Space Center.

shielding provided by the Lab module structure, the ISPR, and other rack system configurations for estimating the total shielding provided at a specific dose point location. For each dose point location, a total of 512 different and independent rays in the $4\pi$ solid angle are considered for evaluating the total shielding offered at that point of interest in the 3D space (see Figure 2). These integrated shield values are used for evaluating the radiation transport of a given ambient radiation.

Similarly, in the case of the human body data, different anatomical structures offer different shielding based on their variations in the density and variations in the elemental composition. A complete and more realistic human model three-dimensional data is not readily available for our calculations at this time. However, the CAM (computerized anatomical male) model that has been used for several calculations in the past has been available at the NASA Johnson Space Center [2-4]. The CAM model is limited to 11 different tissue/organ types in the body. Based on its ability to provide more realistic organ-tissue-bone interface contours, we have used the CAM model data in our calculations to estimate the self-shielding offered at different locations inside of the human body.

## 2. Methodology

By considering the integrated shielding provided by the rack systems, outer shell and inner shell material composition, an estimated total shielding for several locations in the working area are calculated. Shield data for about 3,888 different points that are about 10 cm apart in the working area of the Lab module were calculated utilizing the CAMERA ray-tracing algorithm. Considering these shield values, dose equivalent and fluence data were calculated utilizing the BRYNTRN [5] and HZETRN [6] transport code for a given ambient radiation environment. The estimated dose and fluence values in the working area are then translated to a 3-D lattice with an interpolated color scheme to visualize the radiation estimates at various locations of the working area of the Lab module utilizing MATLAB-5 software [7]. Several perspective views of the Lab module's working area with the radiation dose visualization are presented in this paper. Also, by calculating the shielding provided by various anatomical zones, radiation dose estimations inside of a human being are calculated for about 25,631 different points that are about 2.5 cm apart. These estimated dose values are presented in three different planes and several perspective views for a simulated ambient radiation environment.

In both the cases (calculations for the Lab module and the calculations for the CAM model), we have implemented the same procedures. The only difference is the number of individual data points for estimating the total shield values. For the Lab module we calculated for more than 3,000 points (about 10 cm apart for the entire habitable volume) and for the human body data we calculated for more than 25,000 data points (about 2.5 cm apart inside of the human body). The following are the detailed steps in obtaining the dose calculations for visualization:

*Step-1*: Total shield values for 512 different and independent rays in the $4\pi$ solid angle are determined using the CAMERA ray-tracing algorithm. In the case of the Lab module data, for each of the 3,888 data points, 512 different shield values are generated. Also, in the case of the CAM model, for each of the 25,631 data points, 512 different shield values are generated. These shield values are utilized to calculate the radiation transport in the second step.

*Step-2*: By utilizing the extended BRYNTRN (baryon transport) code [5] and the HZETRN (high Z, atomic number and high energy transport) code of [6], the selected GCR environment data is transported through the shielding calculated in Step-1 to determine the dose distribution values.

*Step-3*: By utilizing the SUMCAM (summation of the CAM shield data) code [8], all the transport calculated dose values for the 512 different rays translated in to average representation of the dose for each of the data points. After this calculation, we have one dose value for each of the data point (3,888 for lab module and 25,631 for the human body data).

*Step-4*: By utilizing the visualization algorithms developed [9], dose values of all the data points were plotted in a 3D-lattice with the interactive capability and visualization options. Independent image planes can be selected and viewed at any desired perspective orientation.

### 2.1. *Description of the US Lab Module*

The US Lab module of the ISS can accommodate up to four sets of six racks along the length of the module. Each rack has the dimensions of 203 cm high, 105 cm wide and 97 cm deep. A total of 24 of these racks will provide the closed envelope for the inner core habitable volume in the Lab module. Of these 24 racks, 13 are identified as ISPRs (International Standard Payload Racks), with the ability to interchange between the JEM (Japanese Experimental Module) racks and the Columbus Module racks. The remaining 11 racks in the Lab module are identified as System racks. Each ISPR will can be fitted with eight Mid-Deck Lockers (MDLs) and two Standard Interface Racks (SIRs). The configuration of the equipment and orientation of the objects in these MDLs are expected to change sporadically. In the forward section of the Lab module, an earth observation window is also located facing the nadir orientation. In our visualization, we have considered a 3D-latice of 80”x 80”x240” (203x203x609 $\text{cm}^3$) to represent the data of the habitable volume of the Lab module [10].

### 2.2. *Description of the CAM Model*

Human body shield values are calculated utilizing the CAM (Computerized Anatomical Male) model originally developed by Paul Kase in the 70s [2]. The CAM model consists of about 1500 quadratic surfaces that result in about 2500 closed volumes [11]. Current resolution of the model is about 0.1 inch and is represented within 5% of organ size and body weight Anatomical composition is modeled for 11 different tissue types. Typically, the CAM model represents a 50th percentile U.S. Air Force cohort of about 5’ 9.25” (~ 176 cm) height and 155 lbs (70 kg) weight. In our current visualization, we have used a 19” × 19” × 71” (~ 48 × 48 × 180 $\text{cm}^3$) 3D-lattice to represent all the data for dose distribution visualization. Though at this time, the CAF (computerized anatomical female) model is available at the NASA Johnson Space Center, we have not used for our calculations [12]. We intend to present our results for the CAF model in future publications.

## 3. Results

The GCR (Galactic Cosmic Ray) environment considered for the present analysis is of representative spectra for the ISS altitude (450 km) and inclination (51.6°). The data used was the validated environ-

**Table I** - Description of the Computing systems and the computer codes used to calculate the dose distribution values. These data are compared for US Lab module and the human body data from the CAM model.

| | Computing Systems | Calculation Procedure | Computer Code Software | Data for US Lab Module | Data for CAM Human body |
|---|---|---|---|---|---|
| Step-1 | SGI/NT | Shield Data (Lab/CAM) | CAMERA/ BRYNTRN | ~ 16 Mb | ~ 120 Mb |
| Step-2 | PC/Win-98 | Spectra (GCR/Proton) | BRYNTRN/ HZETRN | ~ 50 kb | ~ 50 kb |
| Step-3 | DEC/UNIX | Dose Calculations (Dose Eq.) | HZETRN/ SUMCAM | ~ 1 Mb | ~ 6 Mb |
| Step-4 | SGI/NT | Visualization (Interactive) | «MATLAB» | > 3,000 (x,y,z,v) data points | > 25,000 (x,y,z,v) data points |

ment for the 8th docking Space Shuttle mission to the Mir Station, STS-89.

Figure 3, illustrates the radiation dose distribution among the 3,888 dose points in the habitable volume of the Lab module. In this figure, cut-away view of the habitable volume of the Lab module is shown with superimposed view of the radiation dose distribution contours.

Figure 4, illustrates the decrease in dose by the augmentation of additional shielding (5 g/cm$^2$, polyethylene) as local shielding in the Lab module. This additional shielding provided up to 33% decrease in the radiation dose over a one-year time [13].

Figures 5 and 6, illustrate the visualization inside of the human model in three different image planes (transverse, sagittal, and coronal). These three image planes can be interactively viewed or animated in any desired perspective view.

Figure 5, illustrates the cross-sectional view of the head at the eye level with various contours depicting the radiation dose distribution and decrease of the dose towards the center of the brain. These results are comparable with earlier estimated calculations of GCR transport in the brain [14]. Figure 6 is an illustration of the cross-sectional view of the pelvis region.

Figure 7, illustrate the image views of major sagittal and major coronal planes are also shown. These illustrations depict the human body self-shielding that offers a minimum dose decrease of 22% to a maximum decrease of 55% at the deep organ level.

## 4. Conclusions

In this paper we presented an approach and a model to calculate the integrated shielding offered by the structure and the rack systems of the Lab module. We also presented the three dimensional visualization of radiation dose distribution in the habitable volume of the Lab module. All our calculations are presented for the GCR radiation environment only. In our future publications we intend to present other radiation environments such as proton spectra.

Similarly, for the human body data, we presented

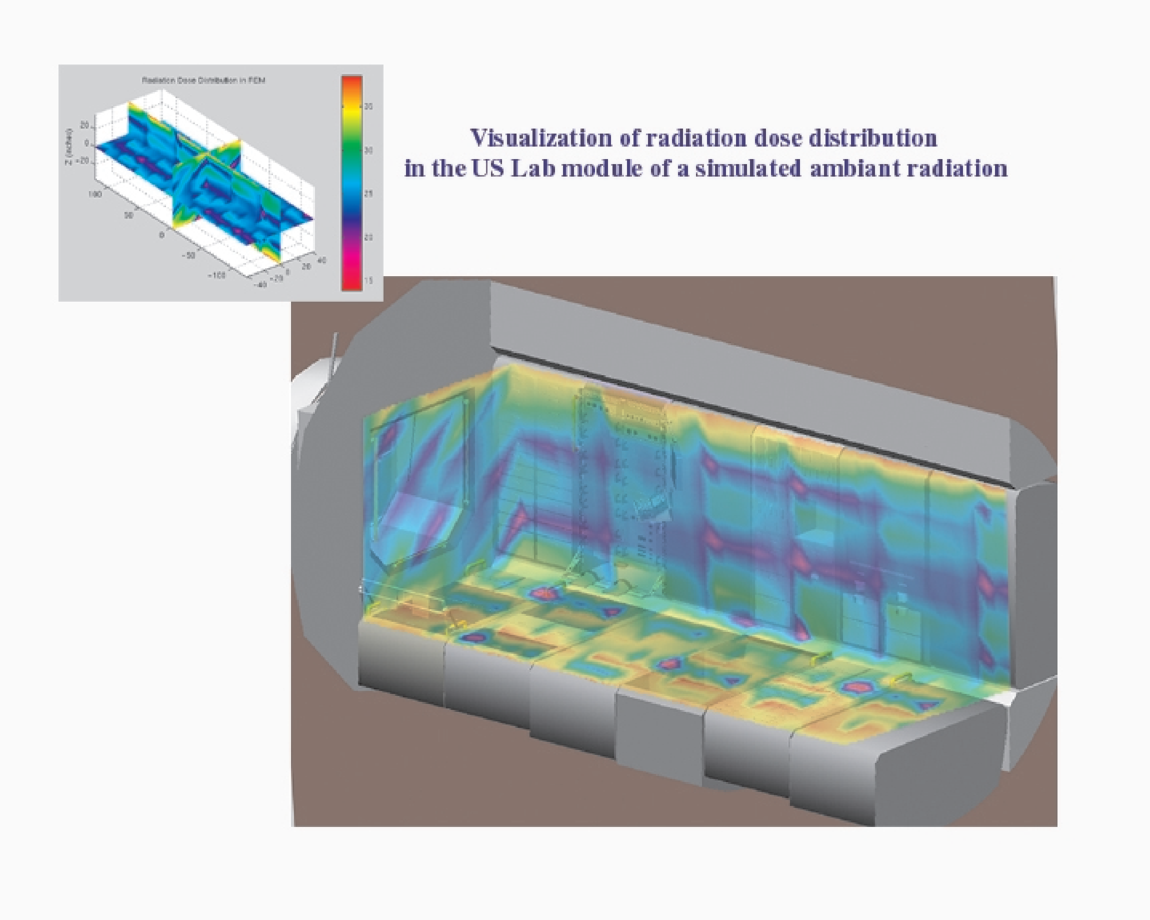
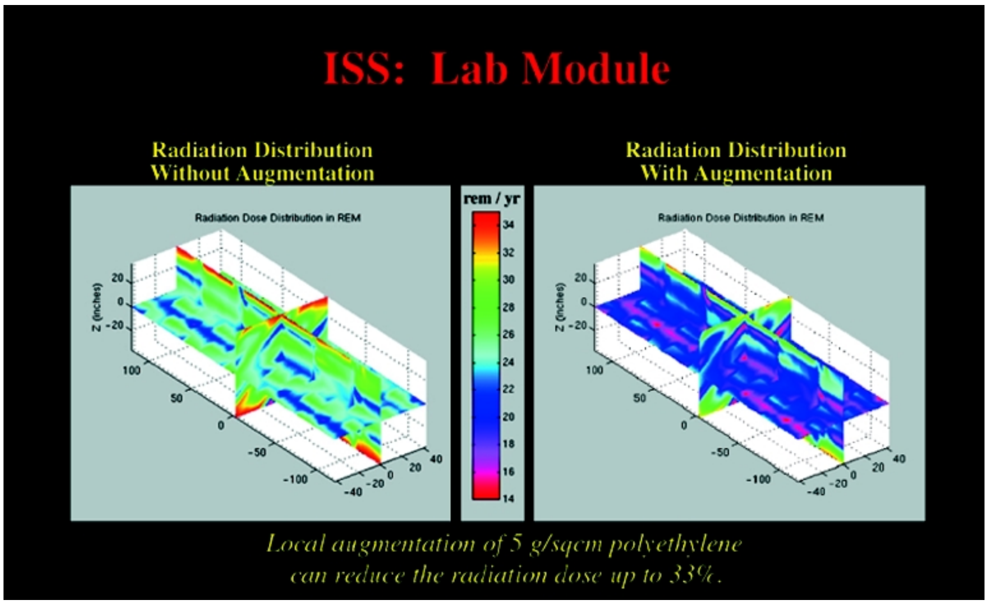


Fig. 3 – Radiation dose distribution contours along the port side, nadir, and aft walls of the habitable volume in the lab module are show in this cut-away illustration. Inset is the visualization of the three image planes that can be interactively selected to view in the desired perspective view of the habitable volume. Estimated radiation dose distribution scale (rem/yr) is shown in the inset diagram. The GRAF Laboratory/SP3 at NASA Johnson Space Center generated this cut-away view of the Lab module.



ISS: Lab Module

Radiation Distribution Without Augmentation

Radiation Distribution With Augmentation

*Local augmentation of 5 g/sqcm polyethylene can reduce the radiation dose up to 33%.*

Fig. 4 – Illustration of the advantages with additional shielding in the habitable volume of the Lab module. Estimated radiation dose measurements (rem/yr) with current shielding and the proposed additional shielding augmentation are shown. In the left image, radiation dose visualization with current optimal shielding is shown. In the right image, radiation dose visualization with additional augmentation of polyethylene (5 g/cm$^2$) is shown. With this additional shielding augmentation, radiation dose is estimated to be 33% lower (Cucinotta-1999).

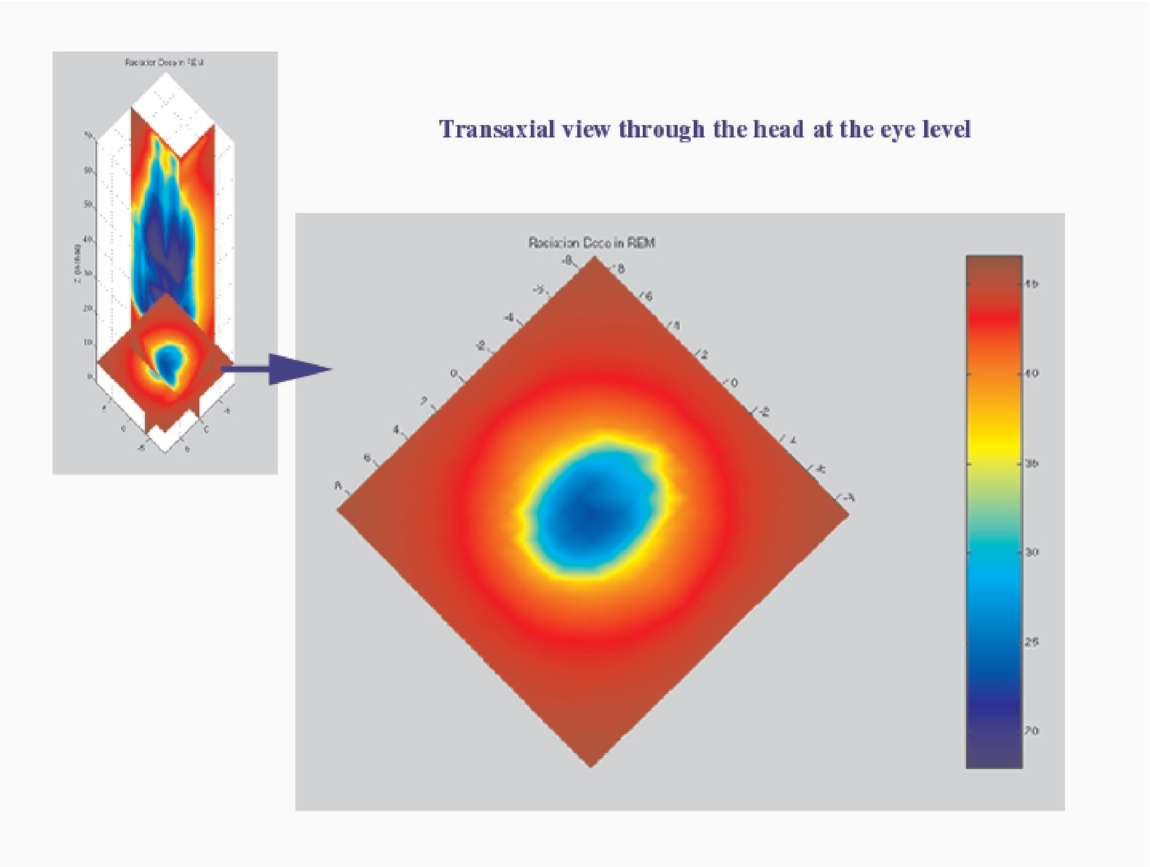


Fig. 5 – A transverse plane through the head at the eye level is shown in this diagram. In-set image illustrates the orientation of the image plane in the three dimensional perspective. Yellow (bright oval shape) represents the cross-sectional boundary of the skin bone interface of the skull with the nose facing the north east corner of the image. Light blue and dark blue shades (faint and darker shades) represent the brain matter boundary. CAM model assumes uniform density for the brain matter. From these calculations, based on the estimated dose distribution, it is estimated that the radiation dose reduction is about 22% at the skull boundary, 44% at the brain matter outer boundary and about 55% near the brain stem area.

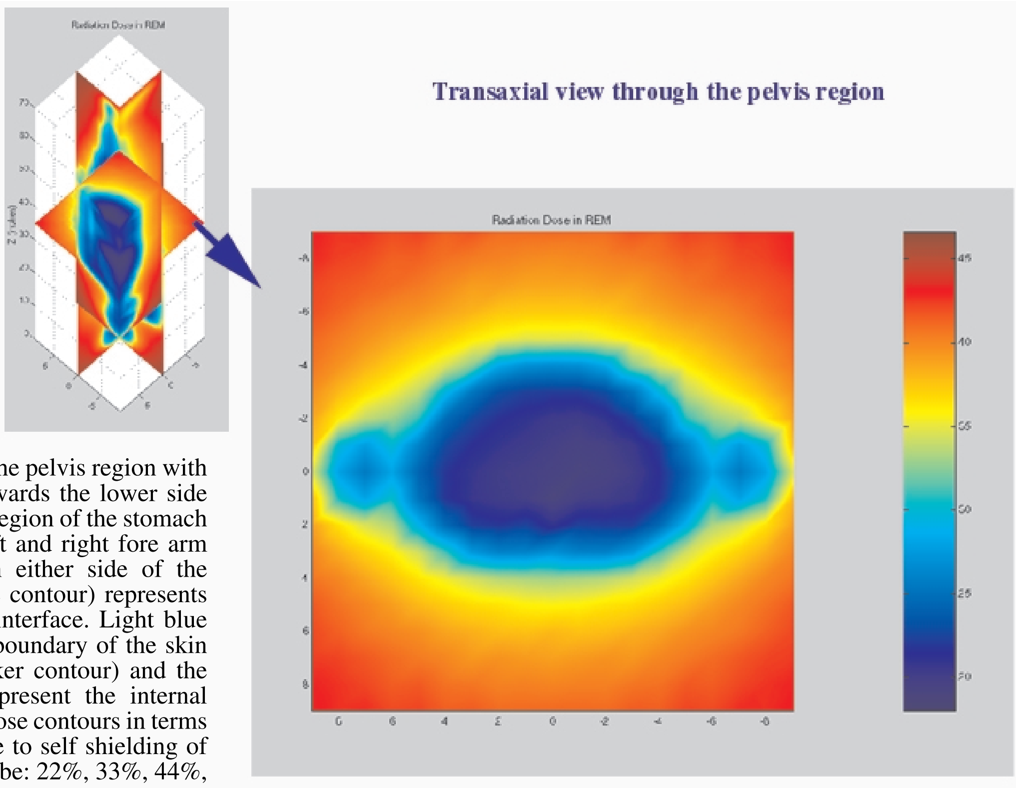


Fig. 6 – A transverse plane near the pelvis region with the tip of the spine (coccyx) towards the lower side of the image and the suprapubic region of the stomach facing the top of the image. Left and right fore arm cross-sections are also seen on either side of the image. Yellow (brightest outline contour) represents the envelope of the skin tissue interface. Light blue (brighter contour) indicates the boundary of the skin tissue interface. Dark blue (darker contour) and the deep blue (darkest contour) represent the internal organs. The gradations of these dose contours in terms of dose distribution decrease due to self shielding of the human body are estimated to be: 22%, 33%, 44%, and 55%.

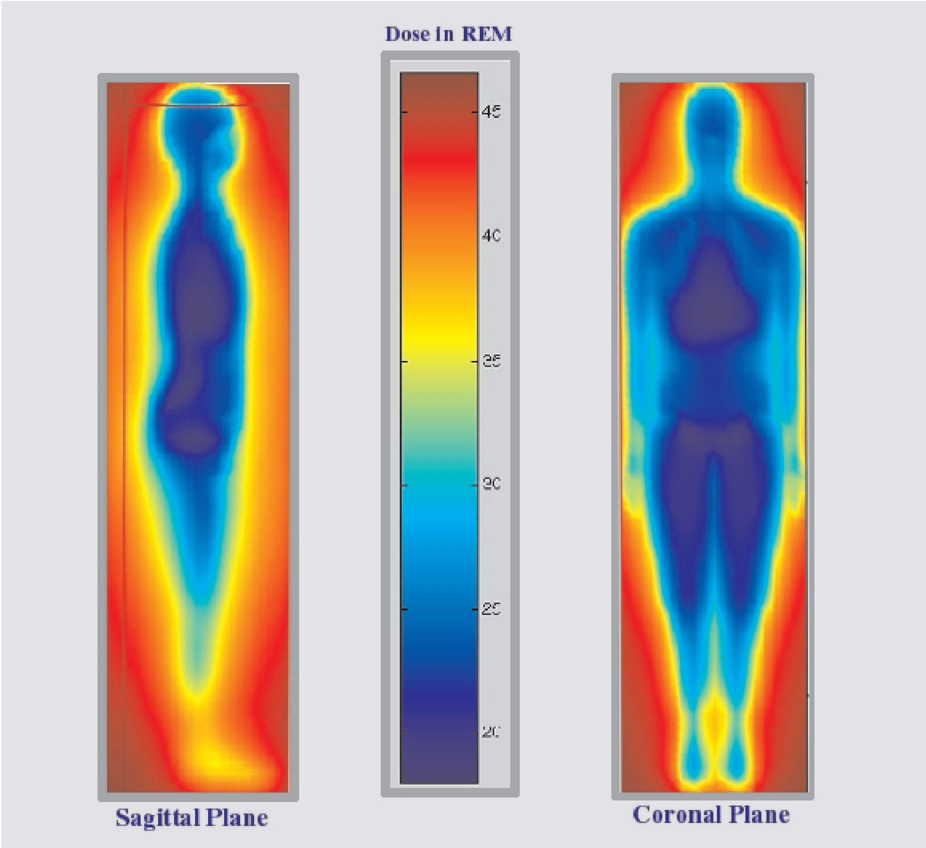


Fig. 7 – Representative views of major sagittal and coronal planes. Note the outer envelope (yellow) and the skin tissue interface (light blue) contours. Dark blue and deep blue contours represent the internal organs. These image planes can be interactively selected and viewed at 1” (~ 2.5 cm) increments. The resolution of these estimated dose values are true to 1” (~ 2.5 cm resolution). These image planes can be interactively selected and viewed in the desired perspective view as well as independent image planes can be displayed. Visualization data is represented as 1” × 1” × 1” (~ 2.5 × 2.5 × 2.5 cm$^3$) voxel size.

our approach and the calculation procedures for estimating the self-shielding offered by the human body and the radiation transport for a given GCR environment. In our future publications we intend to incorporate the proton spectra as well.

The algorithms and model developed for visualization and animation of the calculated radiation dose distribution proved to be very useful and easier to implement with the MATLAB software routines. However, the calculation steps involved in collecting the integrated shielding for specific dose points and radiation transport require significant computing power time at this stage. Because of the complexity in the calculation procedures (few hundred subroutines of calculation procedures) and large data sets (few hundred megabytes of data of output) for estimating the integrated shielding and radiation transport, our computing time turned out to be more than 10 hours. In the near future we intend to optimize our calculation procedures to increase the efficiency for updating the visualization data.

Also, we recommend a more realistic on-orbit configuration of the rack systems (both ISPRs and SPRs) for evaluating the integrated shielding. Based on the changes in the configuration, shield data needs to be recalculated and updated as required. For the human body data, we recommend a more realistic representation of internal organs and anatomical composition as opposed to the 11 tissue types of the CAM model presented in this paper.

In the near future, our model calculations of the human body data need to be verified and checked with experimental data. During the Space Shuttle mission, STS-91, using a phantom, NASA measured the radiation dose distribution inside of the upper human torso. Data from these first such experiments are to be presented during the later part of this year by Badhwar-00. These results will help us to verify our model calculations [15].

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