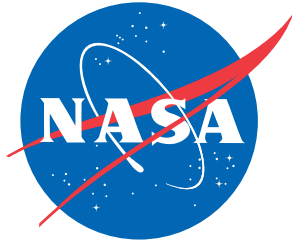


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Vehicle Design Data Format and Process for a Complete TARIS and OLTARIS Radiation Analysis for Designers and Engineers

*Robert C. Singleterry, Howard L. Abston, Charles J. Wittkopp, Martha S. Cloudsley, Kandyce E. Goodliff, and Julie L. Fowler
Langley Research Center, Hampton, Virginia*

*Nicholas A. Vitullo and Dustin R. Whitlow
Analytical Mechanical Associates, Hampton, Virginia*

April 2018

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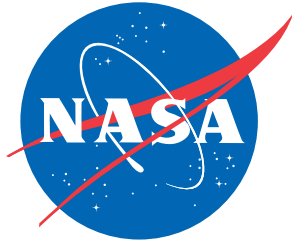
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National Aeronautics and
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Langley Research Center
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Abstract

Protecting astronauts from space radiation is a complex task when it comes to modeling and simulation. This document shows what information is needed from a spacecraft designer using CAD at each phase of the design to enable the engineers to evaluate the design phase against space radiation limits to determine the suitability of the design for spaceflight. The current personal exposure limits are listed in NASA STD-3001. A proxy to determine the REID (Radiation Exposure Induced Death) in NASA STD-3001 is the whole body effective dose equivalent (E or effective dose). For short-term tissue effects, organ averaged gray equivalent (G_T) is used. The TARIS (for LaRC engineers) and OLTARIS (for designers) systems are used to generate these response functions. The E can use ICRP60 or NASA Q-values. A possible space radiation design basis environment for short-term tissue effects is described and used in all analyses. A single space vehicle was designed with three astronaut configurations and two of those configurations were used in a storm shelter thickness perturbation analysis. Conversion of the data from the CAD model to input necessary for TARIS and OLTARIS is also discussed in detail with relevant examples.

1 Introduction and Background

Performing space radiation analyses on complex vehicles is a non-trivial task. The data needed are complex and depend on the solution method chosen. This document will focus exclusively on the TARIS^[1] (Tool for the Assessment of Radiation In Space) solution method which is the NASA Langley Research Center's space radiation analysis tool. An example will be shown and will include the data and their formats. As a by-product of this analysis, an appropriate input file for OLTARIS (On-Line TARIS) is generated and can be used by the designer to perform the analysis.

In the past, these types of analyses have been performed, but data has been manipulated on a case-by-case basis. This document and the corresponding software is the first attempt at defining a clear path from the design to the analysis results for any arbitrary analysis. To that end, a procedure is described that will allow any space vehicle designer to supply the information needed for a space radiation analysis using TARIS. At the current time, TARIS can only be executed by the space radiation engineers at NASA Langley. OLTARIS,^[2,3] the on-line version of TARIS, is open to any person from a non-designated country. While an OLTARIS ready file is also generated by the software described here, that path will not be described because of the hands-on nature of that path. The TARIS path, once properly defined in this document, is automatic.

This document will describe the necessary information that the designers must give the engineers to complete the analysis. It is assumed that the designers will have a CAD (Computer Aided Design) representation of their vehicle. While the approved CAD package for NASA is CREO,^[4] this document will not use CREO specific (or any other specific CAD package) terminology, processes, or procedures. If any CREO specific items are used as an example, they will be noted. Of course, it is assumed that the CAD model is free from defect and will be referenced in this document as a well-formed CAD model. Any deviation from this type of CAD model will be deemed an ill-formed CAD model and will be returned to the designer unanalyzed.

A well-formed CAD model is a model that only has water tight solids and no surfaces. It can be ray traced directly in the CAD package or a faceted or tessellated version can be ray traced. All materials and their isotopic makeup must be tracked. Anything deviating from this is an ill-formed CAD model. The fidelity of the CAD model drives the fidelity of the response function. A low fidelity model will have a higher uncertainty associated with the response. A high fidelity model will have a lower uncertainty. The uncertainty must be tracked by the designers and engineers. The software described here does not calculate uncertainty.

Design Basis Exposure Limits Currently, for stochastic and long-term tissue effects, design requirements have not been established for exploratory habitats to ensure that the permissible exposure limit of no more than 3% REID (Radiation Exposure Induced Death) with a 95% CI (Confidence Interval)^[5] is not exceeded. The whole body effective dose equivalent (effective dose - E ^[6,7]) will be used as a limiting response function^[5] through OLTARIS. For short term tissue effects, the current personnel exposure limits stated in NASA-STD-3001^[5] call for the response function to be organ averaged gray equivalent (G_T ^[6,7]). Because of the nature of the G_T response function algorithm, the response is based on the average orientation of an astronaut at a point in the vehicle and not an exact orientation. The boundary condition is transported

through the vehicle to the astronaut's body surface. Relative Biological Effectiveness (RBE) factors scale the flux to reflect risk which, as a consequence, decouples the astronaut's orientation from the vehicle's orientation. That RBE weighted flux is then transported through the astronaut and the dose to various organs is calculated.

Effective Dose Effective Dose or E is the weighted sum of organ and tissue dose equivalents throughout the body and represents the stochastic health effect risks of radiation to the whole body. The organs and tissues are weighted by their relative radiation sensitivity. This is implemented in TARIS by determining the mass averaged dose equivalents to all the organs that have non-zero weights (and some zero weighted organs and tissues) and then performing the weighted sum. The units of E are Sv (Sievert).

Organ Averaged Gray Equivalent Organ averaged gray equivalent or G_T is a weighted organ dose calculation depending on the importance of the particles and represents the deterministic health effect risks of the radiation to specific organs and is being used for short-term tissue effects. This is implemented in TARIS by determining the flux through all habitat items except the body, weighting the flux at the body's surface, and then continuing the particle transport through the body to find the mass averaged dose for the organs of interest. The separation of the transport runs decouples the body from the CAD model and hence generates a direction averaged response. The organs of interest are: lens of the eye, skin, blood forming organs (BFO), heart, central nervous system (CNS), and CNS with $Z > 10$ particles (where Z is the atomic number) to better represent the exposure from those types of particles. The units of G_T are GyE (Gray-Equivalent), except for the CNS exposures which are in Gy (Gray).

Ray-by-Ray Algorithm The ray-by-ray algorithm transports the space radiation boundary condition from the outside of the vehicle to the point of the ray trace origin along each ray. The flux from each ray can be converted to dose equivalent at the ray trace origin and used in the E response function. Currently, no ray-by-ray analysis exists for G_T response function.

Interpolation Algorithm The interpolation algorithm creates an interpolation database of dose or dose equivalent at preset material depths for up to three materials. The ray trace is then interpolated over this database and the response functions determined. An approximation is made with respect to the ray trace in that the materials in the ray trace are reordered to match the material order in the database's creation.

Design Basis Environment The preliminary design basis space radiation environment requirement that the vehicle must be evaluated against is a SPE (Solar Particle Event) which is the summation of the three October 1989 events as modeled by Tylka^[8] using a Band^[9] fit modified with ground level effects and is shown in Figure 1. For comparison, this figure also plots two other historical SPEs used in analyses of this type. The fitting parameters for the three October 1989 SPEs are shown in Table 1. $\Psi_{DB}(E)$ is the integral flux of the design basis SPE as a function of energy (E)

$$\Psi_{DB}(E) = \sum_{i=1}^4 \frac{d}{dE} J(R(E), J_0^i, \gamma_1^i, \gamma_2^i, R_0^i) \frac{d}{dE} R(E), \quad (1)$$

where $J(R(E), J_0, \gamma_1, \gamma_2, R_0)$ is the integrated flux as a function of the fit parameters J_0 , γ_1 , γ_2 , and R_0 , and of the earth's magnetic field rigidity $R(E)$. This function is defined using a Band fit as

$$J(R(E), J_0, \gamma_1, \gamma_2, R_0) = \begin{cases} J_0 R(E)^{-\gamma_1} e^{-\frac{R(E)}{R_0}} & \text{if } R(E) \leq (\gamma_2 - \gamma_1) R_0 \\ J_0 R(E)^{-\gamma_2} [(\gamma_2 - \gamma_1) R_0]^{\gamma_2 - \gamma_1} e^{-(\gamma_2 - \gamma_1)} & \text{if } R(E) > (\gamma_2 - \gamma_1) R_0. \end{cases}$$

To get the differential fluence needed by TARIS, $\phi(E, J_0, \gamma_1, \gamma_2, R_0)$ is $\frac{d}{dE} J(R(E), J_0, \gamma_1, \gamma_2, R_0)$ and is

$$\phi(E, J_0, \gamma_1, \gamma_2, R_0) = \begin{cases} J_0 e^{-\frac{R(E)}{R_0}} \left[\gamma_1 R(E)^{-\gamma_1 - 1} + \frac{R(E)^{-\gamma_1}}{R_0} \right] \frac{dR(E)}{dE} & \text{if } R(E) \leq (\gamma_2 - \gamma_1) R_0 \\ J_0 \gamma_2 R(E)^{-\gamma_2 - 1} [(\gamma_2 - \gamma_1) R_0]^{\gamma_2 - \gamma_1} e^{-(\gamma_2 - \gamma_1)} \frac{dR(E)}{dE} & \text{if } R(E) > (\gamma_2 - \gamma_1) R_0, \end{cases}$$

where $R(E)$ is defined as

$$R(E) = \sqrt{E^2 + 2m_0E},$$

with

$$\frac{dR(E)}{dE} = \frac{E + m_0}{R(E)}.$$

Example Analysis The example used to illustrate the data and its format is a simple habitat fitted with 30 days worth of provisions, a propulsion unit, and a crew vehicle, as shown in Figure 2. While this is a simple or low fidelity model, considerations for space radiation protection have been included, leading to inclusion of a deployable storm shelter. The example analysis will be a single female phantom (FAX05^[10]) floating near the center of the vehicle’s habitat. All the input and output is shown in this document. A second analysis is included that shows perturbations with the storm shelter. For this second analysis, only the results and some of the heuristic files that generated those results are shown. All input and output data for both analyses are available electronically from the authors.

Paper Outline Section 2 will detail the data file interfaces needed between the CAD model and the TARIS analysis. Section 3 describes what is needed by the CAD model to fulfill the data needs in this analysis. Section 4 describes the specific example used by this document to illustrate the data and processes to obtain space radiation analysis results. A summary of the process is given in Section 5

2 Interface Between the CAD Model and the TARIS Analysis

TARIS is a flat data file driven analysis where numerous pieces of information are needed to fully model the situation to be analyzed. This section enumerates those pieces of information, places them in a flat file format, and describes the process to generate the proper data formats. As stated in the introduction, this is a complex analysis of a complex vehicle. Ultimately, if the data format and process in this document are strictly adhered to, then a viable analysis results that can be used to characterize a vehicle for space radiation suitability.

Interaction with the CAD model is a multi-step process. The first step, of course, is the creation of the vehicle to analyze. Once the designer is finished with the design, information inherent in the CAD model must be extracted and be used as input to the analysis. The TARIS method and associated response functions rely on inserting a human phantom into the CAD model before extracting information. The most complex aspect of this extraction is the ray trace.

The ray trace is the key element between the CAD model and the TARIS analysis. First and foremost, it is not the responsibility of the designer to ray trace the detailed phantom being used in the analysis. There are over 1000 points in the phantom that are used to generate the mass averaged data. It is also imperative that the phantom’s ray trace and the vehicle’s ray trace be aligned or oriented properly so that they can be combined. Since the analysis method fixes the phantom’s ray direction, the ray trace in the vehicle must be manipulated to ensure this alignment.

As with all radiation transport algorithms, the materials at an isotopic level must be identified and quantified, along with a bulk material density. In the CAD model, it is assumed that the volumes of each CAD part are determined by the CAD package and at the creation of that part. Then, either the density of the part or the total mass of the part can be input by the designer and the remaining quantity calculated. The units of the various quantities are also very important as the total CAD model can contain numerous different unit systems. This information must all be tracked, understood, and consolidated. Usually a Bill of Materials or BOM can be generated for the CAD model and this can, with other information, be used to complete the materials information. As an example, a CAD part is labeled as *alum* in the design and this is implicitly understood by the designer to be 100% ²⁷Al. The designer is not worried about this detail. The engineer, however, must define the BOM material *alum* as 100% ²⁷Al in TARIS in order to complete the analysis. However, the designer and the engineer must agree that the part labeled *alum* is that isotopic composition.

Once the designer-produced data exists and is in the proper format, then an algorithm operates on that data and produces the data in the correct format to enable TARIS. This process can change the designer-produced data where the CAD model is deficient or needs to be manipulated. These data are usually in the form of heuristic rules and not algorithms.

Once all of the CAD data has been processed, the TARIS analysis can proceed. The sections below describe the data coming from the CAD model and the data coming out of the process ready to be used in the TARIS analysis. Section 2.1 describes how to generate properly oriented rays for a ray trace. Section 2.2 describes what is needed from a ray trace using the oriented rays from Section 2.1. Section 2.3 describes the data needed from a BOM. Section 2.4 shows how to define materials isotopically. To manipulate the data that isn't fully modeled in the CAD's BOM, Section 2.5 describes the heuristics to perform this task. The last section then describes the input, output, and check files generated.

2.1 Oriented Rays

In CAD, coordinate systems are needed and used everywhere. In science and engineering, only one coordinate system is used to link all parts of the problem together. While this is ultimately true in CAD, as only one coordinate system is used at the top layer, each part can have its own coordinate system or even multiple coordinate systems to describe it. These part-based coordinate systems are linked to the top level coordinate system and this drives the TARIS analysis.

The human phantom used in the E and G_T response functions already has been ray traced for use in TARIS. It is a complex phantom and contains too much data to put into a CAD model for a ray trace. A shadow phantom is placed in the designer's CAD model to obtain the data that is needed. Figure 3 shows this phantom.^[11] It has two distinct sets of points: the three points in the chest (labeled A, B, and C in Figure 3), and another set of points which will be described in the next section.

Points A, B, and C are used by the engineers to orient the CAD model's ray trace so it matches the phantom's ray trace. After the shadow phantom is placed in the CAD model, the (x,y,z) coordinates of all three points, in reference to the top level coordinate system, are gathered. The OLTARIS website can be used by the designer to convert the standard ray distribution into a distribution that matches the already ray traced phantom to the CAD model. Of course, these points can be given to the engineers, who can generate the oriented ray files and send them to the designers.

Ultimately, these ray files are just the direction cosines of the ray distribution chosen. There are two types of distributions to choose from: an evenly spaced latitude and longitude, or a geodesic distribution. While research is still on-going about which is better or how many rays to use, the geodesic distribution with 1002 rays has been shown to be a good starting distribution.^[12] Therefore, the file contains the transformed or oriented direction cosines of the rays to use in the CAD model to create the ray traces. Currently, there is no standard manner to generate the ray traces. For the engineers, a CREO ray trace module was developed and is used. This ray tracer is only available to NASA engineers. As long as the ray trace algorithm used by the designer generates data in the proper format (or can be converted to the proper format), then any ray trace algorithm will suffice.

To use the OLTARIS website for the generation of the oriented ray distributions, log into the OLTARIS website (oltaris.nasa.gov) and click on the Uploads menu item and click on the Thickness Distributions item. At the bottom right of page, follow the link label Download Rotated Ray Distribution. Here you can input the A, B, and C point locations and choose which ray distribution to modify. The default ray distribution is the 1002 geodesic distribution. Input the (x,y,z) triplets for each point and then click the Download Rotated Ray Distribution button. An ASCII text file will be downloaded that contains the rotated ray distribution. Data Snippet 1 shows the format of the file.

2.2 Ray Trace

The TARIS analysis algorithm can use two different methods: the interpolation method, or the ray-by-ray method. Once the shadow phantom is in the CAD model and the oriented rays are generated, a ray trace is necessary to continue the analysis for either method. As seen in Figure 3, there is a second set of points that are oriented through the middle of the body from the head to the feet. These points are key to the understanding of the analysis and the response functions. For the E response, all five points or zones can be

used. For the G_T response, only the center, or third point, can be used. Of course, for E , using the center point only is also acceptable.

If only the center point is used to generate a ray trace, the astronaut's orientation is decoupled from the CAD model and this has been called the "spinning astronaut" analysis in the past. The astronaut's radiation response function is just averaged over all directions or orientations. If all five points are used to generate five ray traces, then the astronaut's orientation is fixed in space and coupled to the CAD model. For a SPE storm shelter analysis, the use of all five points is the superior method as the astronaut's orientation to the rest of the vehicle is critical. The coordinate system of the ray trace is the same coordinate system used to generate the oriented ray distribution in Section 2.1, and is usually the top level coordinate system. Data Snippet 17 shows the format of the file.

2.3 Bill of Materials (BOM)

The BOM data links the part names to material data. The data just describes the CAD part name, the number of these parts, the OLTARIS material name (optional), the part density, the part volume, the part mass, the part length unit and the part mass unit. A label then defines whether the item is a part or some other CAD construct (assembly or sub-assembly as an example). Only parts are read and used.

In a well-formed CAD model, the parts are water tight. Each CAD part has a defined volume and should have a material associated with it. The part has a single density and therefore a defined mass. Its name should be unique. If the part name is descriptive of the part, that would be helpful, but of course is not necessary. The material name associated with the part name is important and is called in this document the OLTARIS material name. The OLTARIS material name should be defined in the BOM but usually is not defined. The associated heuristics file can assign an OLTARIS material name to a part, or change the OLTARIS material name associated with a part in the BOM.

To explain this "OLTARIS material" naming convention, a description of the TARIS and OLTARIS computational environments is necessary. The coding exists in a repository and the on-line version (OLTARIS) is a tag of a particular TARIS set of routines that have passed rigorous tests. The TARIS coding is the computational core of OLTARIS which also includes algorithms to read in the data from the website and process the results back to the website, among other tasks. Part of OLTARIS website is the generation of material cross sections. Behind the scenes, a database is established that contains the materials created by an OLTARIS user. The names are unique and descriptive of the material. A basic user account comes with a few relevant, preset names like aluminum and polyethylene. New materials can be generated of course. Because of the secure network, TARIS cannot use materials defined in OLTARIS. Therefore, a mechanism has been established that defines the needed materials, just like in OLTARIS, and generates the cross sections for use in TARIS.

Another detail about the BOM data and its creation needs to be explained. While the volume of a part is determined by the CAD package knowing the shape of a part, the mass and density are related by

$$\rho = \frac{m}{V} \quad (2)$$

where m is mass, V is volume, and ρ is density. The designer can input the part's mass or the density and the other is calculated by Equation 2. However, when printed in the BOM, the number of significant figures can be insufficient for the three values and when read in and compared, can violate Equation 2. This can also happen because computers represent real numbers as floating point numbers. For IEEE 64-bit floating point numbers, between 14 and 15 significant figures can be represented. If the BOM contains less than 14 significant figures for the mass, volume, and/or density, then errors in Equation 2 will occur. Therefore, it is assumed by this analysis that the volume and density are accurate to 14 significant figures in the BOM and the part mass is calculated using Equation 2. The calculated mass is then compared to the read mass from the BOM and large differences are noted in the check files.

In order for the interpolation method to work, tissue must be the last material defined in the BOM. Therefore, it is necessary to place all the tissue parts at the end of the BOM. This might have to be done manually and an error is created during the analysis if this data movement is necessary.

The BOM describes the parts and materials needed by the analysis along with its volume and density (the mass will be calculated and a check will be performed). Data Snippet 18 shows the format of the file.

2.4 Materials Definition

Materials must be defined isotopically in order to be used in any particle transport algorithm. This is where the physics of the particle interactions are held. To that end, from the BOM, a material called *alum* was identified. The proper atomic and nuclear cross sections must be created. The collection of isotopes that the designer wants to represent the material *alum* can be defined in three different ways:

1. elemental mass percentage
2. chemical formula
3. molecular mass percentage

These are the same methods and data used to define materials in OLTARIS and not unique to this process. To illustrate the meaning of these methods, examples will be shown.

These material definitions can be carried one of two ways. First, every analysis generates the material database by defining every material being used. Ultimately, that database gets created and used to define the inputs to the cross section generation codes. Second, the materials database can be carried from analysis to analysis. The database is interrogated for the needed materials and extra materials in the database are not a burden on analysis performance. If the second method is used, just the materials database needs to be in place. If the first method is used, then a materials database input file needs to be created by the designer or engineer and agreed upon by both.

For this material database input file, lumped tissue will be used as an example of how to use elemental mass percentage (Item 1 above) . For TARIS, lumped tissue is defined with four isotopes: ^1H , ^{12}C , ^{14}N , and ^{16}O . Their mass percentages are 9.993, 14.901, 3.5, and 71.606, respectively. Lumped tissue has a bulk density of 1.1 g/cm^2 . Therefore, the general format is:

```
<method tag>
<number of isotopes N>
<bulk density in g/cm^2>
<A of isotope 1> <Z of isotope 1> <mass percent of isotope 1>
.
.
.
<A of isotope N> <Z of isotope N> <mass percent of isotope N>
```

This translates for lumped tissue as:

```
elemental mass percentage
4
1.1
1 1 9.993
12 6 14.901
14 7 3.500
16 8 71.606
```

The chemical formula definition is similar to the elemental mass percentage except that the percentage is substituted for the number of isotopes in the material. Polyethylene will be the example. The general form is:

```
<method tag>
<number of isotopes N>
<bulk density in g/cm^2>
<A of isotope 1> <Z of isotope 1> <number of atoms 1>
.
.
.
<A of isotope N> <Z of isotope N> <number of atoms N>
```

Since polyethylene has 2 atoms of ^1H and 1 atom of ^{12}C , and has a bulk density of 1.0 g/cm^2 , this translates to

```
chemical formula
2
1.0
  1 1  2
12 6  1
```

The molecular mass percentage is a combination of the two previous methods. Mars regolith will be used as the example for this method. It consists of SiO_2 , Fe_2O_3 , H_2O , and an amalgam of minerals represented as $\text{Al}_2\text{CaK}_2\text{MgNa}_2\text{O}_7$. The mass percentages are 51.2, 9.3, 7.4, and 32.1 respectively. The bulk density is 1.7 g/cm^2 . The general form is:

```
<method tag>
<number of molecules N>
<bulk density in g/cm^2>
<number of isotopes in molecule 1 M>
<mass percent of molecule 1>
<A molecule 1 isotope 1> <Z molecule 1 isotope 1> <number of atoms molecule 1 isotope 1>
.
.
.
<A molecule 1 isotope M> <Z molecule 1 isotope M> <number of atoms molecule 1 isotope M>
.
.
.
<number of isotopes in molecule N M>
<mass percent of molecule N>
<A molecule N isotope 1> <Z molecule N isotope 1> <number of atoms molecule N isotope 1>
.
.
.
<A molecule N isotope M> <Z molecule N isotope M> <number of atoms molecule N isotope M>
```

For mars regolith, this gives

```
molecular mass percentage
4
1.7
2
51.2
28 14 1
16  8  2
2
9.3
56 26  2
16  8  3
2
7.4
  1  1  2
16  8  1
6
32.1
27 13  2
40 20  1
30 19  2
```

24 12 1
23 11 2
16 8 7

Data Snippet 2 shows the format of this file for aluminum, polyethylene, and lumped tissue (or tissue).

2.5 Heuristics

The BOM data can be incomplete or can be perturbed for an analysis. The TARIS analysis needs the units of length and density to be cm and g/cm³ respectively. No other units are allowed. Therefore, the units in the BOM must be defined so they can be converted. An OLTARIS material must also be associated with each CAD part. The designers may not have had these rules in mind when the CAD model was created and therefore this information is carried separately from the CAD model.

The heuristics file contains data that either defines or redefines the data in the BOM necessary to complete the analysis. The heuristics file can also be used to move material from one CAD part to another. This allows for a generic storm shelter to be modeled and then perturbed without creating a separate CAD model for each perturbation. The storm shelter wall thickness can be varied by manipulating the density to ensure that the radiation risk is met. Of course, the mass moved to the storm shelters must be moved from some other identified CAD part in order to have the overall mass of the vehicle not change. This allows for items like food and water to supplement other materials to create a storm shelter.

The current heuristic file contains 4 sections, which are described below. Each section begins with these labels

- 1) bom_material oltaris_material
- 2) part_unit density_unit
- 3) part oltaris_material
- 4) part_density density_gpcc from_part_name

and ends with these labels

- 1) end end
- 2) end end
- 3) end end
- 4) end 0.0 end

A single horizontal tab (ASCII Character 9) must exist between these keywords and between the data following the keywords. The sections can be in any order and do not have to exist. All sections can be as long as necessary. For the bom_material and part_unit sections, default values can be defined. Currently the process can only handle these density units: g/cm³, lbm/in³, lbm/ft³, tonne/mm³, kg/mm³, and kg/m³, but other units can be easily added. Data Snippet 6 shows the format of the file.

Section bom_material/oltaris_material This section facilitates the association of a part name with an OLTARIS material name. When the initial CAD model example used in this document was created, no OLTARIS materials were assigned to new parts and hence were left “UNDEFINED” or “UNASSIGNED” in the BOM. Some parts that came from other CAD models had OLTARIS material names already assigned. Only three OLTARIS materials can be used in the interpolation method. Since a human phantom is necessary for the response function, the last material must be tissue. This leaves only two other materials that can be used in the model. The ray-by-ray algorithm can have as many OLTARIS material names as needed. For the example used in this document, three other material names existed in parts and hence are listed in the BOM. This section allows the substitution of the existing names for the wanted names. For the OLTARIS material names that are undefined, a default name can be given to those materials.

Section part_unit/density_unit Each part has units associated with it, which are printed in the BOM. That does not mean that they are the correct units. From Equation 2, if the density unit is defined, then the mass and volume units are also defined. Therefore, a default density unit can be defined for all parts. Then, part names can be associated with the appropriate density units. This aids in tracking parts created in other CAD models with other units. As long as the units are noted by the designer and placed in this section, then they are easily tracked and properly converted.

Section part/oltaris_material This section, in conjunction with the bom_material/oltaris_material section, facilitates the association of OLTARIS materials with CAD parts. For this section, the CAD part name is associated with an OLTARIS material name. This allows for CAD part material changes. This section can also be used to perturb the CAD model for comparison runs. In this way, the designer can change an aluminum pressure vessel to a graphite epoxy pressure vessel without a redesign of the CAD model.

Section part_density/density_gpcc/from_part_name A SPE storm shelter will be mandatory for a well designed space vehicle. This section facilitates the creation of a storm shelter by moving mass from part to part throughout the vehicle. CAD parts with volume but no mass/density can be created where the storm shelter is suppose to be. The crew, minus the astronaut being analyzed, can be placed within the storm shelter (real tissue phantoms exist for this purpose and can be downloaded from the OLTARIS website). The shadow phantom is placed in the storm shelter. The areal density (g/cm^2) of the storm shelter can be manipulated to vary the shelter's thickness and hence mass. This of course affects the ray trace of the shadow phantom and hence the final response function value of the modeled astronaut. To keep the mass of the vehicle constant, the part where the mass comes from must be identified. Ultimately, the wanted density in g/cm^3 of the storm shelter CAD part is listed as the middle value. All masses, and hence densities, are recalculated to keep the vehicle's mass the same as the part's volume is assumed to not change. This is a complex section and its use will be illustrated in the second example.

2.6 Data Inputs, Outputs, and Checks

This section describes the data input and output from the conversion process. However, because various data manipulations have occurred with the CAD generated data, check files are also written that correlate BOM information to the ray trace data and vice-versa. This section shows the input data and how it was manipulated to arrive at the data needed by TARIS^a. The section also describes the performed checks on the design to help determine what changes need to be made to the design if it fails to meet the exposure requirements.

It is assumed that well-formed ray trace files, a BOM file, a materials database file, and a ray distribution file exist. The heuristic file is optional but usually needed. There can be one or five ray trace files as outlined in Section 2.2. If only two OLTARIS materials exist besides tissue, then all the files necessary for the interpolation and ray-by-ray method are created. If more than three OLTARIS materials exist, then only the files necessary for the ray-by-ray method are created. Currently, if only ray-by-ray analysis files are created, then only the E response function can be generated.

Sections 2.6.1.1 through 2.6.1.3 describe and show the input decks needed and how to execute the scripts to run the three response functions for this analysis. A standard OLTARIS boundary condition input file is needed or a standard OLTARIS boundary condition file can be supplied. The standard `energy.dat` and `isotope.dat` files must exist. The scripts will error if they do not exist. The engineers know where the files exist or how to generate them if necessary. Sections 2.6.2.1 through 2.6.2.14 describe and show the output files from the conversion process.

2.6.1 Inputs

These are the inputs for the TARIS process scripts.

2.6.1.1 Interpolation E Input Deck To execute the perl script to generate the results for this response function, an appropriate input deck must be created. Table 2 shows the ordered inputs. Once these values are in a file called, for this example, `int_script.dat`, then to execute the script that generates the response function, the user enters

```
perl -I <path> <path>/int_ed_script.pl int_script.dat
```

where `<path>` is the directory path of the executables and scripts. It is assumed that the TARIS build command placed all the executables and scripts into a single sub-directory. The official OLTARIS build

^aThe conversion program that creates the TARIS input data is not available outside of NASA civil servants and direct contractors.

directory is `/data/raadtool_Exe` and the data directory is `/data/raadtool_Static_Data`. The response function output is in the `effective_dose_reduced.dat` file. This script uses a single thread to perform the analysis. Wall clock times can exceed 60 minutes for typical vehicles with a GCR environment.

2.6.1.2 Interpolation G_T Input Deck To execute the perl script to generate the results for this response function, an appropriate input deck must be created. Table 3 shows the ordered inputs. Once these values are in a file called, for this example, `int_script.dat`, then to execute the script that generates the response function, the user enters

```
perl -I <path> <path>/int_ge_script.pl int_script.dat
```

where `<path>` is as described above. The response function output is in the `PEL_cGy-eq.dat` file. This script uses a single thread to perform the analysis. Wall clock times can exceed 30 minutes for typical vehicles with a GCR environment.

2.6.1.3 Ray-by-Ray E Input Deck To execute the perl script to generate the results for this response function, an appropriate input deck must be created. Table 4 shows the ordered inputs. Once these values are in a file called, for this example, `rbr_script.dat`, then to execute the script that generates the response function, the user enters

```
perl -I <path> <path>/rbr_ed_script.pl rbr_script.dat
```

where `<path>` is as described above. The response function output is in the `effective_dose_reduced.dat` file.

This script uses multiple threads to perform the analysis and must be submitted to a queuing system. The default queuing system for the HZE Cluster is GE (originally called the Sun grid engine but now just GE). For 250 threads on the HZE Cluster, wall clock times can exceed 5 hours for typical vehicles with a GCR environment and can exceed 1 hour for a SPE environment. Two files are necessary that identify the nodes and the cores per node that GE has assigned to the batch job. These files are created with this `csH` code^b:

```
touch nodes.dat
touch cores.dat
foreach line ("cat ${PE_HOSTFILE}" )
    set argv = ($line)
    echo "${1}" >> nodes.dat
    echo "${2}" >> cores.dat
end
```

where `${PE_HOSTFILE}` is a GE created file and environment variable. This coding is already in the `rbr_ed_script.pl` script but assumes that `${PE_HOSTFILE}` exists.

2.6.2 Outputs

These are the output files for the TARIS process scripts and OLTARIS XML upload files.

2.6.2.1 Density Output File The density file for an interpolation run maps the CAD part name to a unique material number (100+), an OLTARIS material number (1, 2, 3, etc), and the part's density in g/cm^3 . For example, a CAD part is assigned a unique material number of 100 and is linked to OLTARIS material polyethylene which has an OLTARIS number of 2 with a density of $0.20973 \text{ g}/\text{cm}^3$. This is repeated for every CAD part. For the ray-by-ray density file, the CAD part name and number are mapped to the same OLTARIS number as the CAD part and a density. For the ray-by-ray method, a material map file (see Section 2.6.2.2) maps the rest of the data. All analyses need this file. Data Snippet 3 and 4 show the format of the files for the interpolation and ray-by-ray method respectively.

^bThis generic code has been adapted from the unix cshell forum: <https://www.unix.com/unix-for-dummies-questions-and-answers/84750-reading-file-c-shell.html> and is not unique to any NASA process.

2.6.2.2 Materials Map Output File The materials map file maps the CAD part unique material number (100+) to the OLTARIS material name. The OLTARIS material names are typically aluminum, polyethylene and tissue, but more materials are possible and must match a material name that already has cross section files. This file is only used for the ray-by-ray method. Data Snippet 5 shows the format of the file.

2.6.2.3 Spatial Output File The spatial file is only used for the interpolation method and is the grid where the interpolation values are generated. To ensure that the grid is never extrapolated, the grid must always be larger than the thickest ray. Since the interpolation method can have up to three materials, there could be up to three grids in the file. Data Snippet 7 and 8 show the format of the files for both the SPE and GCR environment, respectively, as there should be different grids due to the nature and computational time of the SPE and GCR runs.

2.6.2.4 Transport Input (trninput.dat) Output File The transport input file (TRaNsport INPUT) lists the OLTARIS materials used for the interpolation method. There are up to three materials that can be enumerated in this file. If more than three materials are needed, then the ray-by-ray method must be used and this file is unnecessary. Data Snippet 9 shows the format of the file.

2.6.2.5 Body Spatial Output File The body spatial file is only for the G_T analysis and is the same as in Section 2.6.2.3 but only for one material: tissue. Data Snippet 10 and 11 show the format of the files.

2.6.2.6 Body Transport Input (trninput.dat) Output File The body transport input file is only for the G_T analysis and is the same as in Section 2.6.2.4 but only for tissue. Data Snippet 12 shows the format of the file.

2.6.2.7 RadICal Output Files The RadICal^c file is the file format that lists each ray and what the thickness of each material is for that ray. This is a complex format but well understood by the engineers.

The first two lines of the file are informational. The third line is three-point coordinate of the ray trace origin. The remaining lines are grouped by rays. The first line for each ray lists the three direction cosines for the ray direction and the number of thicknesses to follow. The next set of lines list the thicknesses from the outside of the vehicle to the origin of the ray trace. These lines contain the material number and the thickness of the material in centimeters. Data Snippet 13 shows the format of the file. There can be 1 or 5 of these files depending on the response function wanted.

2.6.2.8 OLTARIS XML Output File An XML file is produced for the interpolation method, assuming that the number of OLTARIS materials is three or less, and for the ray-by-ray method. These can be directly uploaded into OLTARIS and used in computations that can be executed there. These are complex file formats that incorporate all the data listed above into one file format that OLTARIS can parse and generate the data files above. Data Snippet 21 and 22 show the format of the files.

2.6.2.9 Material Definition Files Material definition files are produced for each OLTARIS material used in the analysis. The data come from the materials database file called `material_database.dat`. This file can be carried from analysis to analysis or created for the specific analysis being performed. If created for each analysis, then an input file needs to be created called `material_database_input.dat`. All materials necessary for the current analysis must be defined in the database. Extra materials do not slow the performance of the analysis.

The database created is a FORTRAN direct access unformatted file to keep the full significant digits of a 64-bit floating point number. Therefore, no examples of this file format are shown here. The resultant output files are of the form `<material name>.matdef`. Data Snippet 14 shows the `tissue.matdef` output format as an example.

^cIt has been lost to history what RadICal stands for.

2.6.2.10 Thickness Distribution Output Files This file outputs the total ray thicknesses in g/cm^2 sorted from thinnest to thickest. Then, the cumulative thickness is generated. These data can be plotted and can give a sense of how the vehicle is protecting the astronauts at that point in the vehicle. The plot can illuminate whether holes or thin sections exist in the vehicle, or other anomalies that directly affect the exposure of an astronaut. An example plot is shown in Figure 4. If holes or thin rays exist in the vehicle, then the smallest thickness would be at or near $0 \text{ g}/\text{cm}^2$. Figure 4 shows that the thinnest rays are at about $1 \text{ g}/\text{cm}^2$ and that is sufficient. The Figure also shows that there are very few of those thin rays because the curves rise rapidly. The Figure also shows the median thickness for each point ray traced. In this case, a value around $14 \text{ g}/\text{cm}^2$ is sufficient. Data Snippet 15 shows the format of the file.

2.6.2.11 Statistics Output Files For each of the ray traces, a set of statistics are produced based on total ray thickness in g/cm^2 . Table 5 shows the example data in g/cm^2 . The median, mean, standard deviation, variance, skewness, and kurtosis are generated. While this data set is not like a normal data set, the mean and standard deviation are biased by the outliers so the median is the best measure of the average thickness of the vehicle; however, all are calculated. Data Snippet 16 shows the format of the file.

2.6.2.12 BOM Check Files The BOM check files are a set of files that describes all the read and computed information part by part. This includes the density in the units read and the density in the TARIS units of g/cm^3 , the volume, and the mass. Each ray that crosses the part is also listed in the read thickness units and the TARIS thickness units of cm plus the thickness units of g/cm^2 . If the OLTARIS material name changes through the heuristic file, this is noted. The number of rays with a thickness below a minimum thickness in cm and g/cm^2 is also listed along with the thicknesses tagged. The number of zero thickness rays is listed along with the thicknesses tagged. Data Snippet 19 shows the format of the file.

2.6.2.13 Ray Trace Check Files The ray trace check files are a set of files that describes all the read and computed information ray by ray. This includes the number of thicknesses per ray, the density and thickness of the part for that ray in the read units and the TARIS units of g/cm^3 and cm and also the thickness in g/cm^2 . If the ray trace had to be reordered, then that ray is tagged. If the total ray thickness is less than a minimum value in cm and g/cm^2 , then that ray is tagged. If a part thickness is below a minimum value in cm and g/cm^2 , then that thickness is tagged. The total number of thicknesses below the minimum thickness is reported. Other error conditions in the ray trace file are also reported, such as overlapped parts and parts where the ray entrance is farther from the ray origin than the exit. Data Snippet 20 shows the format of the file.

2.6.2.14 Log File of Conversion Execution When the data conversion is executing, a log file is generated to help determine where errors occurred, what phase of data conversion has finished, and what the overall outcome of that phase is. Details of the data conversion are written to the check files described in Sections 2.6.2.12 and 2.6.2.13. If a phase has been threaded to speed-up execution, then the thread number is also printed. The phase of the data conversion process are

1. Get the number of ray trace files to convert from the user
2. Get the base ray trace file name from the user and create all the output file names
3. Get a flag from the user that signals whether to produce the check files
4. Read the ray trace file(s) (Section 2.2)
5. For 5 ray trace files, make sure all have the same number of rays
6. Reorder the thicknesses in the ray trace from outside to inside
7. Check for part overlaps and other anomalies
8. Calculate the void and part thicknesses for all ray traces
9. Remove duplicate part names and sort by ray trace for later binary searches of parts

10. Read the BOM file (Section 2.3)
11. Apply the heuristics data (Section 2.5)
12. Calculate the ray trace thicknesses in length units of cm and areal density units of g/cm^2
13. Read the direction cosine file (Section 2.1)
14. Create the OLTARIS material data
15. Write the RadICal file(s) (Section 2.6.2.7)
16. Write the density files (Section 2.6.2.1)
17. Write the material map file (Section 2.6.2.2)
18. If the number of OLTARIS materials is less than four
 - (a) Write the TRNINPUT files (Section 2.6.2.4 and 2.6.2.6)
 - (b) Write the spatial grid files (Section 2.6.2.3 and 2.6.2.5)
19. Write the ray distribution file(s) (Section 2.6.2.10)
20. Write the overall statistics file (Section 2.6.2.11)
21. Write the XML OLTARIS input files (Section 2.6.2.8)
22. Write the .matdef input files (Section 2.6.2.9)
23. If check files are to be written
 - (a) Write the BOM check files (Section 2.6.2.12)
 - (b) Write the ray trace check files (Section 2.6.2.13)

If a total ray thickness in cm or g/cm^2 is longer than preset maximums, the `Check_Error.dat` file is appended with the zone (or number of the ray trace file), the ray number, and the total ray length. This is to ensure that some unit error has not occurred in the conversion process that can produce rays long enough to crash the computers being used in the analysis.

3 Inherent Problems in CAD Models and Ray Tracing and What is Checked

Creating a well formed CAD model seems simple, but has inherent problems and traps. Even if the designers took extra care to ensure that no parts overlapped, all parts have suitable dimensions, no parts are duplicated, all extraneous items are deleted, all parts are modeled as air-tight (meaning that all their edges meet), etc. . . . , that does not guarantee that a ray trace will be perfect. Therefore, this process, in the check files `<base>.thkchk` and `<base>.bomchk`, tries to enumerate potential problems with the ray trace and BOM data. Besides the standard units check on all data, ray trace entrance and exit values are checked to ensure that the entrance occurs closer to the ray trace origin than the exit. If this is not found, then the entrance and exit values are swapped and the analysis continues with a warning message printed in the check files. If any overlaps occur, *i.e.*, the exit of part i is farther than the entrance of part $i + 1$, that is noted in the check files and the analysis continues. If the thickness starts at the ray trace origin, then that thickness is ignored as that would mean the part is inside the body. Other checks will be added as they are encountered.

In the CAD creation process, many problems can occur in which a seemingly well formed CAD model yields an ill-formed CAD model either by translation or by unintentional design/analysis. Some background information:

1. Each time a CAD model is translated there is potential for a loss in model fidelity and precision due to rounding errors in the conversion process. In addition to rounding errors there are sometimes other errors introduced in the translation. To further compound the issue there can also be a loss in fidelity when a converted model is opened as the importing algorithms can often introduce error.
2. There is an inherent benefit when the same CAD tool that was used to generate the geometries is later used to process the models. This is because the same geometry kernel that is used to create the geometry is used to interrogate the model. This minimizes the potential for error when analyzing a model.
3. It should be noted that PTC CREO is the current CAD tool NASA is using (native)^d. As such, this tool will most likely be used to interrogate and analyze the CAD geometries as delivered. Given this and the factors mentioned above, the models that use the native CAD tool clearly have several specific advantages.
4. Metadata, like material information, can be embedded simply in the native tool. Other tools support this as well; however, this metadata can be lost during a translation/conversion process.
5. Although metadata can be captured by other mechanisms such as external files and by introducing additional steps to parse the CAD model, processing and linking the external data to the CAD parts opens up the possibility for additional errors.
6. Overly complex geometries, such as models that include small fasteners, can often be a drain on computer resources and are not necessary for a radiation analysis. It is suggested that models be de-featured to a degree; however, close attention to detail is also needed during this process to fill any voids created during this process.

Therefore, to reduce the number of problems encountered in an analysis, the preferred data delivery format to the engineers for analysis is the flat files described in Section 2. With this method, no inadvertent design changes can be introduced by the engineers. If this is not an available option, then native CAD files that contain the model plus any metadata needed outside of the CAD model can be delivered. There is added risk that the NASA ray tracing software can introduce anomalies not detected or corrected for. Human error in metadata incorporation can also produce unintended design errors. The check files produced by the analysis can be used to verify the analyzed design with the intended design. If the native CAD files are produced through a conversion process from the designer's CAD tool, then it is incumbent on the designer to ensure that the resultant native CAD files are the intended design and that a well-formed CAD model is delivered.

4 30 Day, Deep Space Habitat Example

To enable the radiation analysis process from the CAD model to the radiation response function that meets the radiation risk, a low fidelity, generic, 30 day, deep space habitat was designed at NASA Langley. A sample analysis with a female astronaut placed at the center of the vehicle was performed and is described in the next section. Another analysis was performed with this CAD model to investigate the storm shelter configuration and is described in Section 4.2. Figure 2 shows the configuration of the storm shelter analyzed where the female astronaut is on the inside (option 1) and the outside bottom (option 2) of a 4 by 1 stack of astronauts in a storm shelter in the corridor of the vehicle. This is one of many designs that can be used to configure a storm shelter in this generic habitat. Section 4.3 shows how an analysis is set up and executed.

4.1 Sample Analysis: Female Astronaut in Center of the Habitat

A well-formed CAD file was produced by designers that enabled a 30 day mission in deep space and the female shadow phantom was placed at the center of the vehicle looking at the crew capsule. The designers then created

- BOM file

^dNASA cannot endorse a particular CAD application.

- Five ray trace files

A materials definition file was created and called `material_database_input.dat` to create the isotopic definitions of the materials used in the model. The file for this model is:

```
aluminum
chemical formula
1
2.7
27 13 1
polyethylene
chemical formula
2
1.0
  1 1 2
12 6 1
tissue
elemental mass percentage
4
1.1
  1 1 9.993
12 6 14.901
14 7 3.500
16 8 71.606
```

A heuristics file was created by the engineers to assign the correct OLTARIS materials to the parts. The model was made from parts that had existing OLTARIS material names associated with other projects. Those material names have been all changed to aluminum in this heuristics file. The default units for all parts was lbm/in^3 . The food items and water were modeled as polyethylene. The heuristics file for this model is:

```
bom_material      oltaris_material
blank             aluminum
AES_ALUMINUM     aluminum
TEMPSTA_SPANG    aluminum
AMG6             aluminum
TISSUE           tissue
end              end
part             oltaris_material
DSH_CONSUMABLES_1 polyethylene
DSH_CONSUMABLES_2 polyethylene
DSH_WATER_AND_TANK polyethylene
end              end
```

TARIS and OLTARIS results were compared and were accurate to four significant figures. Runs were generated for three SPE environments and three GCR environments. Response functions for E and G_T were generated. The E response functions were run for the dose equivalent using the new NASA Q values for the average US population^[13] and the ICRP60 Q values^[14] with the interpolation and ray-by-ray methods. G_T can only be used with the interpolation method and the reported value is to the Blood Forming Organs or BFO.

The ray trace software that was used produced one duplicate record in the pelvis. It also produced two part intersections where the exit and entrance were reversed. No part overlaps were detected. Of course, this was a well controlled and formed CAD model and as a consequence, the fidelity of the model is low. This means that the racks are solid objects that have the same mass as the equipment they represent. Most were modeled as aluminum, but the food and water racks were modeled as polyethylene. The racks and their contents have no form. The 1002 geodesic ray configuration was used to generate the ray traces at the five

points of interest in the FAX05 phantom. Data Snippets from 1 to 23 show the abbreviated output from this generic model conversion.

4.2 Female Astronaut in SPE Storm Shelter Perturbation Analysis

To the well formed CAD file described above, a storm shelter was added as shown in Figure 2. The astronauts are stacked one over the other in a 4 by 1 configuration with the astronaut of interest on the inside (option 1) and the outside (option 2) of the stack. These analyses were different from the above analysis as the storm shelter thickness was perturbed. The mass used for the storm shelter came from the food and water along with parasitic shielding in a ballast part. The amount of parasitic shielding in the ballast was zeroed once used.

For a zero thickness storm shelter, the heuristic file section `part/oltaris_material` is changed from the above analysis and a `part_density/density_gpcc/from_part_name` section is added to make

```

part                                oltaris_material
DSH_CONSUMABLES_1                  polyethylene
DSH_CONSUMABLES_2                  polyethylene
DSH_WATER_AND_TANK                 polyethylene
DSH_STORM_SHELTER_PANEL_1          polyethylene
DSH_STORM_SHELTER_PANEL_2          polyethylene
DSH_STORM_SHELTER_PANEL_3          polyethylene
DSH_STORM_SHELTER_PANEL_4          polyethylene
DSH_STORM_SHELTER_PANEL_5          polyethylene
DSH_STORM_SHELTER_PANEL_6          polyethylene
DSH_STORM_SHELTER_BALLIST          polyethylene
end                                  end
part_density                        density_gpcc      from_part_name
DSH_STORM_SHELTER_BALLIST          0.0             DSH_STORM_SHELTER_BALLIST
end                                  0.0             end

```

The `DSH_STORM_SHELTER_PANEL_*` panels have densities in the model of zero. Table 6 shows the material make up of the storm shelter perturbations. As an example of how the heuristic file is configured, the last section for the 25 cm thick panel is now

```

part_density                        density_gpcc      from_part_name
DSH_STORM_SHELTER_PANEL_1          1.968503937     DSH_WATER_AND_TANK
DSH_STORM_SHELTER_PANEL_2          1.968503937     DSH_WATER_AND_TANK
DSH_STORM_SHELTER_PANEL_3          1.968503937     DSH_WATER_AND_TANK
DSH_STORM_SHELTER_PANEL_4          1.968503937     DSH_CONSUMABLES_1
DSH_STORM_SHELTER_PANEL_5          1.968503937     DSH_CONSUMABLES_1
DSH_STORM_SHELTER_PANEL_6          1.968503937     DSH_CONSUMABLES_2
DSH_STORM_SHELTER_PANEL_1          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_PANEL_2          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_PANEL_3          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_PANEL_4          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_PANEL_5          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_PANEL_6          9.842519685     DSH_STORM_SHELTER_BALLIST
DSH_STORM_SHELTER_BALLIST          0.0             DSH_STORM_SHELTER_BALLIST
end                                  0.0             end

```

The volume for panels `DSH_STORM_SHELTER_PANEL_1` and `DSH_STORM_SHELTER_PANEL_2` is 6930 cm³ each. The volume for panels `DSH_STORM_SHELTER_PANEL_3` and `DSH_STORM_SHELTER_PANEL_4` is 3738 cm³ each. The volume for panels `DSH_STORM_SHELTER_PANEL_5` and `DSH_STORM_SHELTER_PANEL_6` is 3760.25 cm³ each.

Figure 5 shows E versus storm shelter depth for both astronaut positions. Figure 6 shows the G_T in BFO versus storm shelter depth for both astronaut positions.

4.3 Engineer's Process

The engineer's process is quite precise and is enumerated here. From the OLTARIS repository location `trunk_script_examples/Response_Functions/AES_Examples/Examples`, copy the `analysis_scripts` directory to the same level as `<top>` (see Step 1 below). Execute

```
source go.sge_init.csh <email address>
```

in `analysis_scripts` to initialize the `go.sge` script with your correct email address. From the OLTARIS repository location `trunk_script_examples/Response_Functions/AES_Examples/Examples`, copy `progs` directory to the same level as `<top>`. Execute

```
source compile.csh
```

in `progs` after pointing to the Intel compiler or

```
source pgi_compile.csh
```

after pointing to the PGI compiler^e. The GNU Fortran compiler has not been tested. If a default materials database input file, `material_database_input.dat`, is wanted, then create a `materials` directory at the same level as `<top>` and place your default file there.

To create and run an analysis, perform these steps^f:

Step 1: Create the top level directory for the analysis: `% mkdir <top>`. It should be at the same directory level as `analysis_scripts` and `progs`.

Step 2: Create where the original CAD data will exist: `% mkdir Original`.

Step 3: Copy the CAD data to `<top>/Original`.

1. BOM file.
2. Ray trace file(s) (1 or 5).
3. Rotated ray distribution file.

Step 4: Create or copy the `material_database_input.dat` file in or copy the `material_database.dat` file to `<top>/Original`.

Step 5: Create the heuristic file(s) which is/are a function of the analysis being performed.

Step 6: Create the directory control files in `<top>`:

1. Top level directories or the perturbed vehicles to analyze: `direcs.dat`. Names in the file depend on the analysis being performed. If `none`, then no directories are created and only a single vehicle configuration is analyzed.
2. Boundary conditions: `bcnds.dat`. Values can be `<spe|hze>-<flag>^<value>`.

spe: Create/read a SPE boundary condition.

<flag>

db: The design basis SPE.

king: The August 1972 SPE modeled by King.

oct: The October 1989 SPE as modeled by Sauer/Badavi.

<filename>: The file name of a file the contains a TARIS ready boundary condition in `[1:100,1:6]` array format.

<value>: The multiplication constant used to modify the preset SPEs. Not used for the input file name.

^ecurrently, no version of the PGI compiler can compile the code due to a compiler bug that has been turned into PGROUP - last version tested at PGROUP is 18.4

^fThe commands below are standard unix commands and not unique to any NASA process.

hze: Create/read a GCR boundary condition.

<**flag**>

2014: 2014 Badhwar-O'Neill model as implemented on OLTARIS.

2010: 2010 Badhwar-O'Neill model as implemented on OLTARIS.

matthia: 2013 Matthia model

<**filename**>: The file name of a file the contains an TARIS ready boundary condition in [1:100,1:59] array format.

<**value**>: Parameters used to define the 2014/2010 models (ϕ the Solar Modulation Parameter (MV) with a range from 397 to 2526) or the Matthia W value with a range from 0 to 200.

3. Analysis types: **types.dat**

int_ge: The G_T analysis using the interpolation method with 1 phantom point.

int_ed: The E analysis using the interpolation method with NASA Q values.

int_60: The E analysis using the interpolation method with ICRP60 Q values.

rbr_ed: The E analysis using the ray-by-ray method with NASA Q values.

rbr_60: The E analysis using the ray-by-ray method with ICRP60 Q values.

Step 7: Create the analysis specifics file **files.csh**. These values must be set:

ccnt The number of cores to use for a ray-by-ray job (usually 250)

que The queue name (usually 10g)

version The version of OLTARIS (null string or `_test`)

email The email address of the user

rays The number of rays in the ray trace (usually 1002)

phan The phantom name (MAX or FAX)

phan_rbr The Ray-by-Ray phantom name (MAX, FAX, MAX_simple, or usually FAX_simple)

base The base name of all files

base1 The name used in the SGE scripts as the job name

mveh The name of the vehicle definition directory (usually vehicle)

vehc The relative/absolute pathname of the `$mveh` directory (if relative, then from the analysis directory)

orig The relative/absolute pathname of the Original directory (if relative, then from the analysis directory)

ray_file The file name of the rotated rays in LINUX format (not DOS)

bom_file The file name of the BOM file

heur_file The name of the heuristics file

hzetf A flag to determine if the DSTAR/HSTAR routines are used or the HZETrgFrg code is used in the dose and dose equivalent calculations

numrt The number of ray traces (1 or 5)

If numrt = 5

rt1_file The name of the head ray trace file

rt2_file The name of the chest ray trace file

rt3_file The name of the pelvis ray trace file

rt4_file The name of the thighs ray trace file

rt5_file The name of the shins ray trace file

If numrt = 1

rt_file The name of the pelvis or only raytrace file

Step 8: Create the directory structure from <top>: `$ source ../analysis_scripts/setup.csh.`

Step 9: Test that everything is defined from <top>: `$ source ../analysis_scripts/go.csh test.`

Step 10: Analyze the vehicle from <top>: `$ source ../analysis_scripts/go.csh vehicle.` Ensure that the vehicle analysis is satisfactory.

Step 11: Generate the response functions: `$ source ../analysis_scripts/go.csh analysis`

Step 12: Create the single execution file <top>/go.csh that contains:

```
#!/bin/csh
#
source ../analysis_scripts/setup.csh
source ../analysis_scripts/submit.csh
#
```

Step 13: Re-run the analysis all in one step by queuing a job that executes: `$ source go.csh`

Step 14: All response function data can be put into a plottable form by executing `$../progs/post` from the <top> directory

5 Summary

A complete and well defined process is described that will analyze a well formed CAD model for potential space radiation requirements. Once this process is setup, the process is automatic and repeatable. The potential for the introduction of unintentional design errors by the engineers has been minimized, but due to the nature of the information supplied by the designers, is not zero. Guidelines for the production of the input data from the CAD model are enumerated to reduce the risk of unintentional design errors; however, the closer the production of the flat files necessary for the analysis (ray traces, BOM, and heuristics) is to the designer, the potential for unintentional design errors by the analysis is reduced. A perturbation capability to allow for trade-study type analyses is available and can be used to produce an exposure limit versus storm shelter thickness plot. A vehicle thickness distribution plot with statistical information is also produced. A feedback loop has been created to allow the design to not only have a response function value associated with it, but detailed data to help make the design better in the next cycle.

Ultimately, radiation analysis is a collaboration between the designer of the vehicle and the engineer performing the analysis. This process defines that interface as detailed data must be used to perform the analysis. The chance for introduction of unintentional design errors through the analysis process has been acknowledged and steps have been taken to mitigate them. This complete and well defined process will reduce the uncertainty in the analysis and any results derived.

Any Fortran, Perl, or C-shell source code associated with this process, except for the generic items in this document, are not available for distribution.

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Table 1: Fitting Parameters for Equation 1.

Index	October 1989	J_0 ($\frac{\text{protons}}{\text{cm}^2}$)	γ_1	γ_2	R_0 (GV)
1	19 th first 23 hours	1.220e9	0.528	5.81	0.1621
2	19 th next 54 hours	9.090e9	0.911	4.43	0.08435
3	22 nd	1.090e9	1.226	7.25	0.1352
4	24 th	4.420e7	2.176	5.65	0.3850

Table 2: The input deck for the interpolation E response function.

Item Number	Value	Description
0	/data/raadtool_Static_Data	the absolute or relative location of the static data directory
1	/data/raadtool_Exe	the absolute or relative location of the executable and perl directory
2	vehicle	the absolute or relative location of the vehicle model directory - should be on the local node's scratch directory
3	0 1 2 3 - 1 - 2 - 3	the Whole Body Effective Dose Equivalent flag: ± 1 -Avg US Population, ± 2 -Never Smoker, ± 3 -ICRP60, + spheres. - no sphere
4	0 1	the dose flag
5	0 1 2 3 - 1 - 2 - 3	the dose equivalent flag: ± 1 -Avg US Population, ± 2 -Never Smoker, ± 3 -ICRP60, + spheres. - no sphere
6	0 1	the TLD flag
7	0 1	the LET flag
8	0 1	the TEPC flag
9	hze spe	the transport environment
10	none 2010 2014 matthia <filename>	the transport environment qualifier
11	42 492 1002 4002 9002	the number of rays
12	tissue silicon <material name>	the target material name
13	MAX FAX none	the phantom for WBEDE
14	hab.trn	the name of transport input file (in the vehicle model directory)
15	hab.den_int	the name of vehicle density file (in the vehicle model directory)
16	hab.spt_<spe hze>	the name of spatial input file (in the vehicle model directory)
17	1 5	the number of vehicle zone points
18	hab<1 1-5>.thk	the name of the vehicle thickness file(s) (in the vehicle model directory)

Table 3: The input deck for the interpolation G_T response function.

Item Number	Value	Description
0	/data/raadtool_Static_Data	the absolute or relative location of the static data directory
1	/data/raadtool_Exe	the absolute or relative location of the executable and perl directory
2	vehicle	the absolute or relative location of the vehicle model directory - should be on the local node's scratch directory
3	hze spe	the transport environment
4	none 2010 2014 matthia <filename>	the transport environment qualifier
5	42 492 1002 4002 9002	the number of rays
6	MAX FAX	the phantom for WBEDE
7	hab.trn	the name of transport input file (in the vehicle model directory)
8	hab.den_int	the name of vehicle density file (in the vehicle model directory)
9	hab.spt_<spe hze>	the name of spatial input file (in the vehicle model directory)
10	hab.thk	the name of the vehicle thickness file(s) (in the vehicle model directory)
11	hab.btrn	the name of transport input file (in the vehicle model directory)
12	hab.bspt_<spe hze>	the name of spatial input file (in the vehicle model directory)

Table 4: The input deck for the ray-by-ray E response function.

Item Number	Value	Description
0	$\${TMPDIR}$	the working directory (a SGE created directory on the local node's scratch directory)
1	/data/raadtool_Static_Data	the absolute or relative location of the static data directory
2	/data/raadtool_Exe	the absolute or relative location of the executable and perl directory
3	vehicle	the absolute or relative location of the vehicle model directory - should be on the local node's scratch directory
4	nodes.dat	a list of nodes that SGE has allocated the job
5	cores.dat	a list of the number of cores per node that SGE has allocated to the job
6	0 1 2 3 - 1 - 2 - 3	the Whole Body Effective Dose Equivalent flag: ± 1 -Avg US Population, ± 2 -Never Smoker, ± 3 -ICRP60, + spheres, - no sphere
7	0 1	the dose flag
8	0 1 2 3 - 1 - 2 - 3	the dose equivalent flag: ± 1 -Avg US Population, ± 2 -Never Smoker, ± 3 -ICRP60, + spheres, - no sphere
9	0 1	the TLD flag
10	0 1	the LET flag
11	0 1	the TEPC flag
12	hze spe	the transport environment
13	none 2010 2014 matthia <filename>	the transport environment qualifier
14	0 1	the NTRN value: 0-Forward only transport, 1-Forward/Backward neutron transport (diffusion-like)
15	42 492 1002 4002 9002	the number of rays
16	tissue silicon <material name>	the target material name
17	MAX FAX MAX_simple FAX_simple none	the phantom for WBEDE
18	hab.den_rbr	the name of vehicle density file (in the vehicle model directory)
19	hab.mmp	the name of the material map file (in the vehicle model directory)
20	1 5	the number of vehicle zone points
21	hab<1 1-5>.thk	the name of the vehicle thickness file(s) (in the vehicle model directory)

Table 5: Example statistics in g/cm^2 over all total ray thicknesses.

Median	Mean	Standard Dev	Variance	Skewness	Kurtosis
1.432378E+01	2.358931E+01	4.220190E+01	1.781001E+03	7.070574E+00	6.544471E+01
1.411482E+01	2.329099E+01	4.941269E+01	2.441614E+03	9.111864E+00	1.039084E+02
1.418256E+01	2.272045E+01	5.222046E+01	2.726977E+03	1.524924E+01	3.240577E+02
1.477744E+01	2.362711E+01	5.028831E+01	2.528914E+03	9.406076E+00	1.092828E+02
1.795938E+01	2.549778E+01	6.459141E+01	4.172050E+03	1.435564E+01	2.519735E+02

Table 6: Polyethylene storm shelter characteristics.

Material Makeup	Thickness ($\frac{g}{cm^2}$)	Density ($\frac{g}{cm^3}$)	Mass (kg)
Food and Water	0	0	0
	1	0.39370	186.167
	2	0.78740	372.335
	3	1.1811	558.502
	4	1.5748	744.669
	5	1.9685	930.837
Parasitic	10	3.9370	1861.67
	15	5.9055	2792.51
	20	7.8740	3723.35
	25	9.8425	4654.18

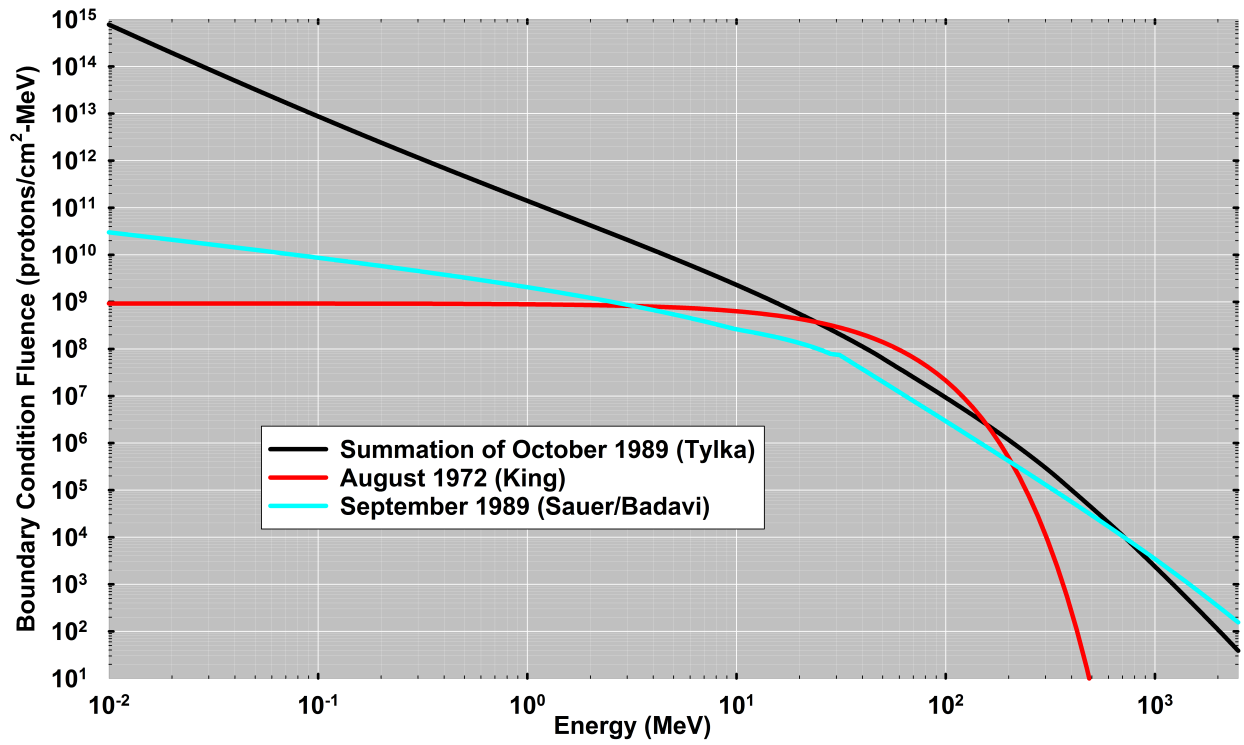
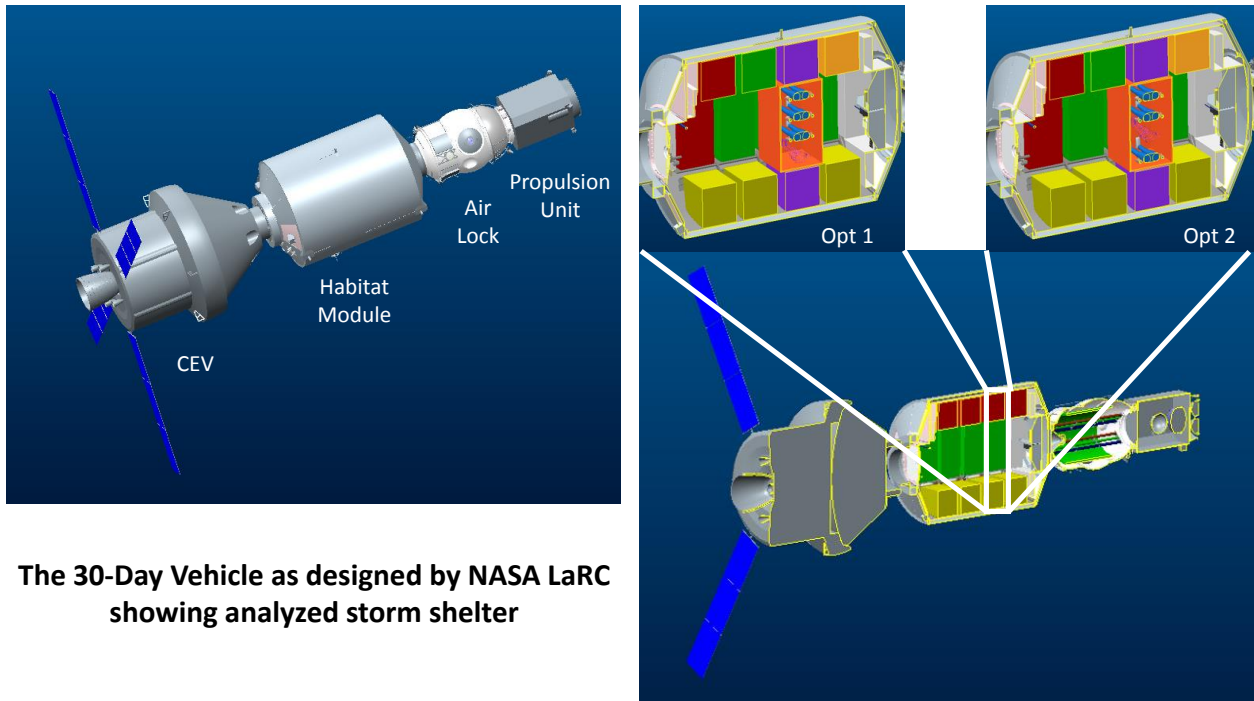


Figure 1: Design basis SPE based on all three October 1989 events as modeled by Tylka compared to two other SPEs used in this same type of analysis.



The 30-Day Vehicle as designed by NASA LaRC showing analyzed storm shelter

Figure 2: Overall CAD model for the 30 day provisioned vehicle used in the example with each storm shelter configuration.

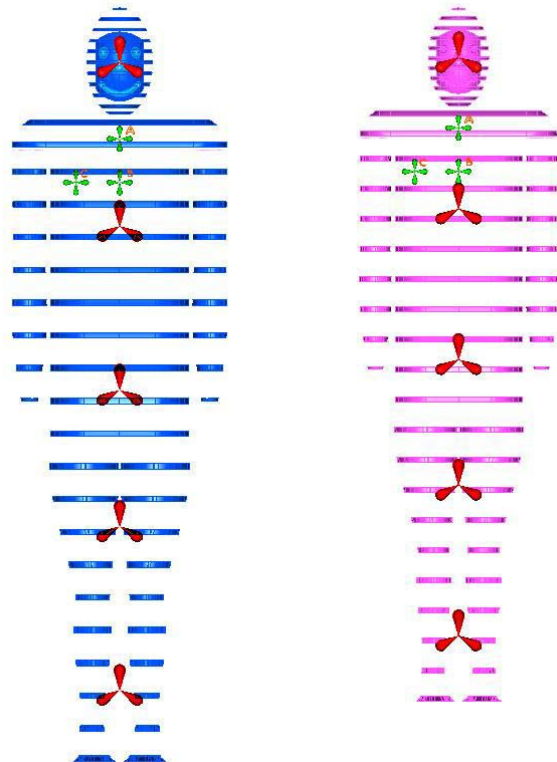


Figure 3: Shadow phantoms used in the CAD model to determine orientation values and ray trace origins.

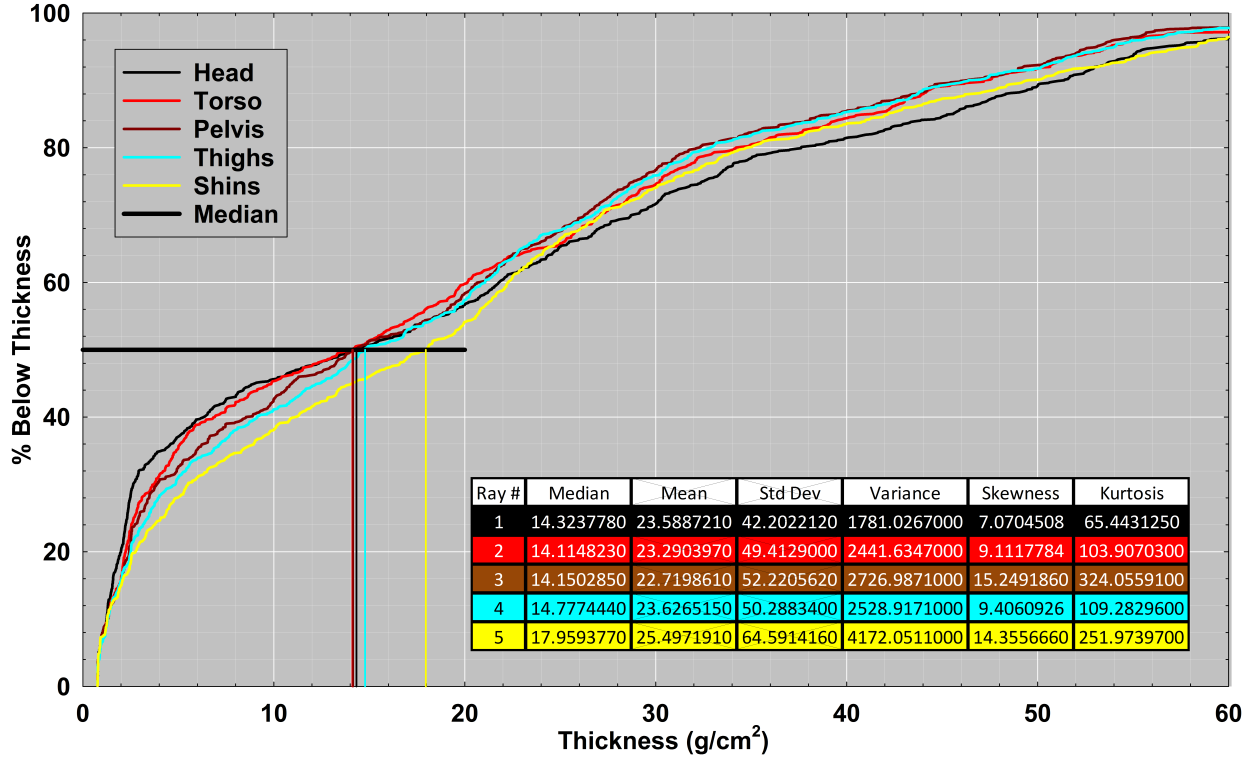


Figure 4: An example thickness distribution plot for the vehicle shown in Figure 2 at the center of the vehicle.

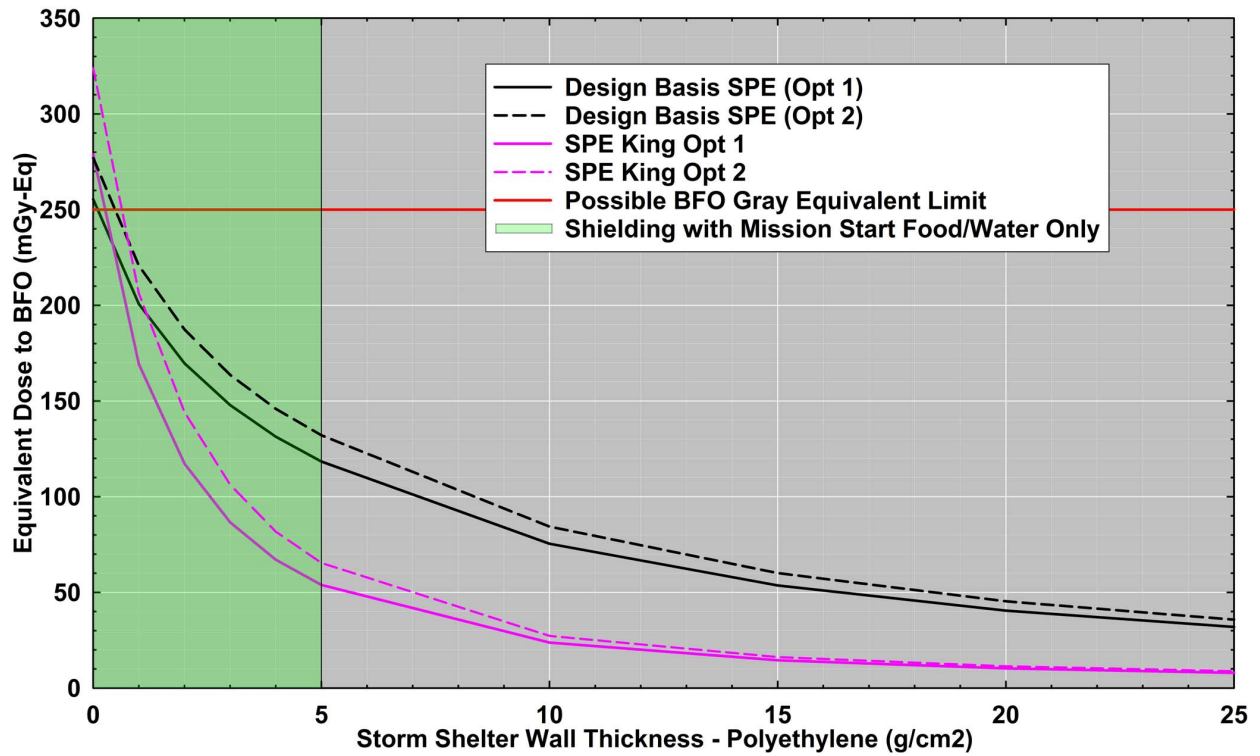


Figure 5: G_T to BFO versus storm shelter thickness (polyethylene) for both astronaut positions using interpolation with the design basis and the King modeled August 1972 SPE.

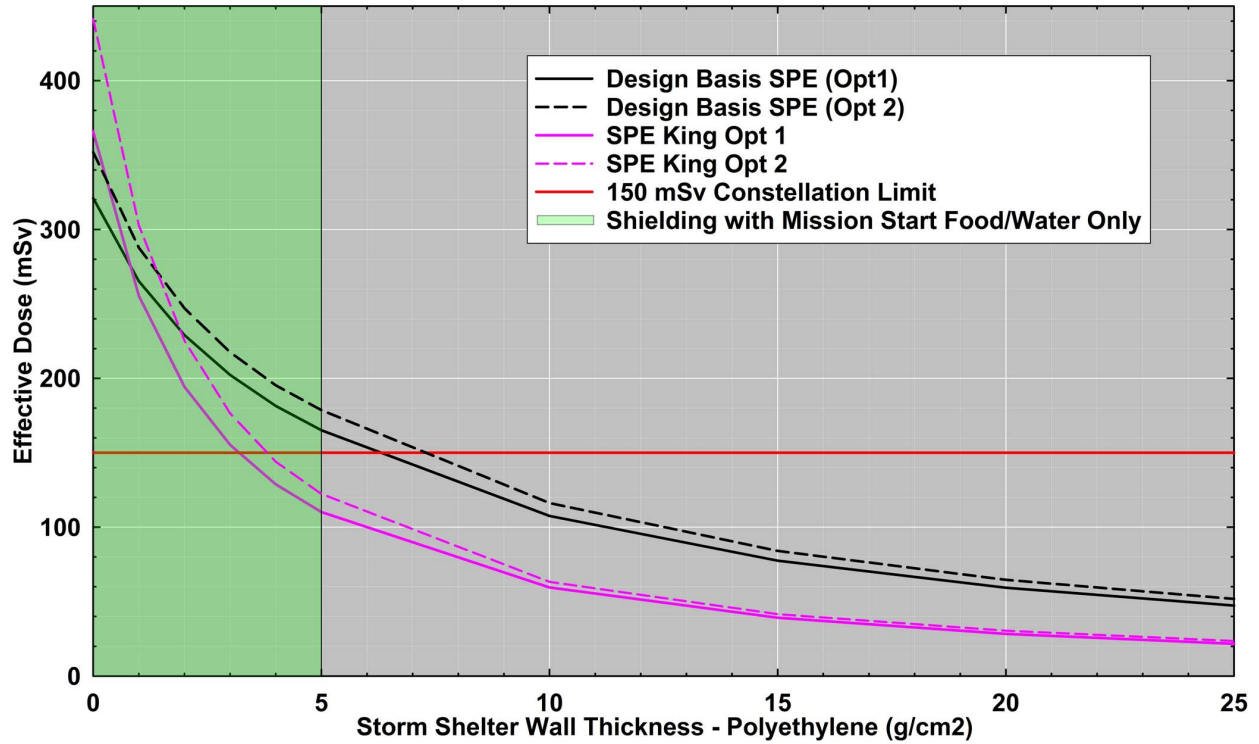


Figure 6: E versus storm shelter thickness (polyethylene) for both astronaut positions using interpolation with the design basis and the King modeled August 1972 SPE.

DATA Snippet 1: ORIENTED RAY DISTRIBUTION

0.5257310	0.0000000	0.8506510
0.4986140	-0.0896420	0.8621760
0.4432130	0.0000000	0.8964160
0.4635800	-0.1875220	0.8659840
0.4083850	-0.0943970	0.9079160
.		
.		
.		
0.7317290	0.3583360	-0.5798000
0.7711490	0.4221190	-0.4765960
0.7976920	0.4781830	-0.3674610
0.8113050	0.5246680	-0.2578930
0.8135190	0.5611230	-0.1527380

DATA Snippet 2: MATERIALS DATABASE INPUT

```

aluminum
chemical formula
1
2.7
27 13 1
polyethylene
chemical formula
2
1.0
1 1 2
12 6 1

```

```
tissue
elemental mass percentage
4
1.1
  1 1 9.993
12 6 14.901
14 7 3.500
16 8 71.606
```

DATA Snippet 3: DENSITY FILE FOR INTERPOLATION

```
100      1  3.9388504E-01 DSH
101      1  4.1519857E-01 DSH_INNER_SHELL
102      1  4.1519857E-01 DSH_ENDCONE_HATCH_GOREPANEL
103      1  4.1519857E-01 DSH_D4_STANDOFF_COF
104      1  4.1519857E-01 DSH_D4_SRG_SC_PANELS
.
.
.
321      1  0.0000000E+00 MANIFOLD_SOLID_BREP-401
322      1  0.0000000E+00 MANIFOLD_SOLID_BREP-113
323      1  0.0000000E+00 MANIFOLD_SOLID_BREP-75
324      1  0.0000000E+00 MANIFOLD_SOLID_BREP-37
326      3  1.1000000E+00 Fake Tissue Material needed if adding tissue to trninput
```

DATA Snippet 4: DENSITY FILE FOR RAY-BY-RAY

```
100    100  3.9388504E-01 DSH
101    101  4.1519857E-01 DSH_INNER_SHELL
102    102  4.1519857E-01 DSH_ENDCONE_HATCH_GOREPANEL
103    103  4.1519857E-01 DSH_D4_STANDOFF_COF
104    104  4.1519857E-01 DSH_D4_SRG_SC_PANELS
.
.
.
321    321  0.0000000E+00 MANIFOLD_SOLID_BREP-401
322    322  0.0000000E+00 MANIFOLD_SOLID_BREP-113
323    323  0.0000000E+00 MANIFOLD_SOLID_BREP-75
324    324  0.0000000E+00 MANIFOLD_SOLID_BREP-37
326    326  1.1000000E+00 Fake Tissue Material needed if adding tissue to trninput
```

DATA Snippet 5: MATERIAL MAP FILE

```
100 aluminum
101 aluminum
102 aluminum
103 aluminum
104 aluminum
.
.
.
321 aluminum
322 aluminum
323 aluminum
324 aluminum
326 tissue
```

DATA Snippet 6: HEURISTICS

```

bom_material      oltaris_material
blank            aluminum
AES_ALUMINUM     aluminum
TEMPSTA_SPANG    aluminum
AMG6             aluminum
TISSUE          tissue
end              end

part              oltaris_material
DSH_CONSUMABLES_1 polyethylene
DSH_CONSUMABLES_2 polyethylene
DSH_WATER_AND_TANK polyethylene
end              end
    
```

DATA Snippet 7: SPATIAL FILE FOR SPE

```

      0      39      0      21      0      24
0.000000E+00  5.000000E-02  1.000000E-01  2.000000E-01  3.000000E-01
4.000000E-01  5.000000E-01  7.500000E-01  1.000000E+00  2.000000E+00
3.000000E+00  4.000000E+00  5.000000E+00  7.500000E+00  1.000000E+01
2.000000E+01  3.000000E+01  4.000000E+01  5.000000E+01  7.500000E+01
1.000000E+02  1.500000E+02  2.000000E+02  2.500000E+02  3.000000E+02
3.500000E+02  4.000000E+02  4.500000E+02  5.000000E+02  5.500000E+02
6.000000E+02  6.500000E+02  7.000000E+02  7.500000E+02  8.000000E+02
8.500000E+02  9.000000E+02  9.500000E+02  1.000000E+03  1.500000E+03
0.000000E+00  5.000000E-02  1.000000E-01  2.000000E-01  3.000000E-01
4.000000E-01  5.000000E-01  7.500000E-01  1.000000E+00  2.000000E+00
3.000000E+00  4.000000E+00  5.000000E+00  7.500000E+00  1.000000E+01
2.000000E+01  3.000000E+01  4.000000E+01  5.000000E+01  7.500000E+01
1.000000E+02  1.500000E+02
0.000000E+00  5.000000E-02  1.000000E-01  2.000000E-01  3.000000E-01
4.000000E-01  5.000000E-01  7.500000E-01  1.000000E+00  2.000000E+00
3.000000E+00  4.000000E+00  5.000000E+00  7.500000E+00  1.000000E+01
2.000000E+01  3.000000E+01  4.000000E+01  5.000000E+01  7.500000E+01
1.000000E+02  1.500000E+02  2.000000E+02  2.500000E+02  3.000000E+02
    
```

DATA Snippet 8: SPATIAL FILE FOR GCR

```

      0      29      0      11      0      14
0.000000E+00  1.000000E-01  3.000000E-01  5.000000E-01  1.000000E+00
3.000000E+00  5.000000E+00  1.000000E+01  3.000000E+01  5.000000E+01
1.000000E+02  1.500000E+02  2.000000E+02  2.500000E+02  3.000000E+02
3.500000E+02  4.000000E+02  4.500000E+02  5.000000E+02  5.500000E+02
6.000000E+02  6.500000E+02  7.000000E+02  7.500000E+02  8.000000E+02
8.500000E+02  9.000000E+02  9.500000E+02  1.000000E+03  1.500000E+03
0.000000E+00  1.000000E-01  3.000000E-01  5.000000E-01  1.000000E+00
3.000000E+00  5.000000E+00  1.000000E+01  3.000000E+01  5.000000E+01
1.000000E+02  1.500000E+02
0.000000E+00  1.000000E-01  3.000000E-01  5.000000E-01  1.000000E+00
3.000000E+00  5.000000E+00  1.000000E+01  3.000000E+01  5.000000E+01
1.000000E+02  1.500000E+02  2.000000E+02  2.500000E+02  3.000000E+02
    
```

DATA Snippet 9: TRNINPUT FILE

```

3
aluminum
    
```

polyethylene
tissue

DATA Snippet 10: BODY SPATIAL FILE FOR SPE

```
      0      24      0      0      0      0
0.000000E+00 5.000000E-02 1.000000E-01 2.000000E-01 3.000000E-01
4.000000E-01 5.000000E-01 7.500000E-01 1.000000E+00 2.000000E+00
3.000000E+00 4.000000E+00 5.000000E+00 7.500000E+00 1.000000E+01
2.000000E+01 3.000000E+01 4.000000E+01 5.000000E+01 7.500000E+01
1.000000E+02 1.500000E+02 2.000000E+02 2.500000E+02 3.000000E+02
```

DATA Snippet 11: BODY SPATIAL FILE FOR GCR

```
      0      14      0      0      0      0
0.000000E+00 1.000000E-01 3.000000E-01 5.000000E-01 1.000000E+00
3.000000E+00 5.000000E+00 1.000000E+01 3.000000E+01 5.000000E+01
1.000000E+02 1.500000E+02 2.000000E+02 2.500000E+02 3.000000E+02
```

DATA Snippet 12: BODY TRNINPUT FILE

1
tissue

DATA Snippet 13: RADICAL FILE FOR POINT 1

RadICAL Thickness File 1.0

```
0 0
3.6855000E+01 -2.6117500E+02 1.6301700E+02
5.2573100E-01 0.0000000E+00 8.5065100E-01 00003
00100 1.5082883E+00
00101 7.4648661E-01
00182 1.0210457E+02
4.9861400E-01 -8.9642000E-02 8.6217600E-01 00003
00100 1.4822176E+00
00101 7.3299120E-01
00182 8.3453424E+01
4.4321300E-01 0.0000000E+00 8.9641600E-01 00004
00100 1.4312858E+00
00101 7.0837631E-01
00182 4.3395414E+01
00181 2.6312861E+01
4.6358000E-01 -1.8752200E-01 8.6598400E-01 00004
00100 1.4536980E+00
00101 7.1843811E-01
00182 5.7042448E+01
00181 9.2529510E+00
4.0838500E-01 -9.4397000E-02 9.0791600E-01 00004
00100 1.4075506E+00
00101 6.9606473E-01
00182 1.4739165E+01
00181 4.8256556E+01
.
.
.
7.3172900E-01 3.5833600E-01 -5.7980000E-01 00004
00100 1.8917517E+00
```

```

00101 9.4619340E-01
00178 5.2609325E+01
00177 6.8629574E+01
7.7114900E-01 4.2211900E-01 -4.7659600E-01 00004
00100 2.0407038E+00
00101 1.0225465E+00
00178 5.6922846E+01
00177 4.6617967E+01
7.9769200E-01 4.7818300E-01 -3.6746100E-01 00004
00100 2.1740913E+00
00101 1.0915605E+00
00178 4.8182841E+01
00177 1.7291247E+01
8.1130500E-01 5.2466800E-01 -2.5789300E-01 00005
00100 4.4600660E+00
00101 7.8269154E-01
00101 1.1380065E+00
00103 4.3543495E-01
00178 3.2355218E+01
8.1351900E-01 5.6112300E-01 -1.5273800E-01 00008
00100 4.3205074E+00
00101 1.0479743E+00
00101 7.8055982E-01
00101 8.5350515E-01
00103 4.5266491E-01
00103 6.2651245E-01
00103 6.0922708E-01
00103 6.1525644E-01

```

DATA Snippet 14: TISSUE.MATDEF FILE

elemental mass percentage

```

4
1.1000000000000000
1 1 9.993000000000000
12 6 14.901000000000000
14 7 3.500000000000000
16 8 71.606000000000000

```

DATA Snippet 15: THICKNESS DISTRIBUTION FILE FOR POINT 1

```

1 9.9800399E-02 7.6716314E-01
2 1.9960080E-01 7.6767929E-01
3 2.9940120E-01 7.6825500E-01
4 3.9920160E-01 7.6833975E-01
5 4.9900200E-01 7.6901650E-01
.
.
.
998 9.9600798E+01 3.4536404E+02
999 9.9700599E+01 4.5390707E+02
1000 9.9800399E+01 4.5934572E+02
1001 9.9900200E+01 5.0244020E+02
1002 1.0000000E+02 5.0600058E+02

```

DATA Snippet 16: STATISTICS FILE

1.4323778E+01	2.3589314E+01	4.2201905E+01	1.7810008E+03	7.0705741E+00	6.5444709E+01
1.4114823E+01	2.3290989E+01	4.9412689E+01	2.4416138E+03	9.1118637E+00	1.0390842E+02
1.4182565E+01	2.2720454E+01	5.2220461E+01	2.7269766E+03	1.5249241E+01	3.2405773E+02
1.4777444E+01	2.3627108E+01	5.0288307E+01	2.5289138E+03	9.4060756E+00	1.0928280E+02
1.7959377E+01	2.5497784E+01	6.4591411E+01	4.1720503E+03	1.4355642E+01	2.5197353E+02

DATA Snippet 17: RAY TRACE FOR POINT 1

Origin Point XYZ									
	36.855	-261.175	163.017						
Unit System (Default is in-lbm-sec):				DEFAULT					
Ray#	Phi (rad)	Theta(rad)	Part_Name	Xin	Yin	Zin	Xout	Yout	Zout
1		DSH	108.450692	-261.175	278.861313	108.762878	-261.175	279.366442	
1		DSH_INNER_SHELL	105.135365	-261.175	273.497	105.289873	-261.175	273.747	
1		DSH_EVA	83.529094	-261.175	238.537304	104.662768	-261.175	272.732321	
2		DSH	103.389731	-273.136771	278.065211	103.680698	-273.189081	278.568334	
2		DSH_INNER_SHELL	100.292425	-272.57993	272.709519	100.436315	-272.605799	272.958325	
2		DSH_EVA	83.529094	-269.566179	243.723286	99.911403	-272.511429	272.050677	
3		DSH	94.131648	-261.175	278.861309	94.381398	-261.175	279.366438	
3		DSH_INNER_SHELL	91.479384	-261.175	273.497	91.602991	-261.175	273.747	
3		DSH_CONSUMABLES_1	71.949486	-261.175	233.997	76.540906	-261.175	243.283329	
3		DSH_EVA	83.529094	-261.175	257.417221	91.101306	-261.175	272.732321	
4		DSH	97.055521	-285.526616	275.473724	97.320838	-285.633939	275.969346	
4		DSH_INNER_SHELL	94.223771	-284.381149	270.183914	94.354895	-284.43419	270.428857	
4		DSH_CONSUMABLES_1	74.852132	-276.545159	233.997	76.540906	-277.228282	237.151689	
4		DSH_EVA	83.529094	-280.055063	250.205876	93.940019	-284.266369	269.653855	
5		DSH	88.604423	-273.136728	278.065615	88.830731	-273.189038	278.56874	
5		DSH_INNER_SHELL	86.195229	-272.57985	272.70953	86.307144	-272.605719	272.958336	
5		DSH_CONSUMABLES_1	68.782147	-268.554867	233.997	76.540906	-270.348281	251.246168	
5		DSH_EVA	83.529094	-271.963581	266.782215	85.898879	-272.511349	272.050687	
.									
.									
.									
998		DSH	105.040381	-227.783845	108.98896	105.585361	-227.516962	108.557134	
998		DSH_LIFE_SUPPORT	56.769942	-251.422427	147.237	76.540906	-241.740361	131.571085	
998		DSH_WATER_AND_TANK	83.529094	-238.318166	126.033855	98.684908	-230.896192	114.024845	
998		DSH_INNER_SHELL	99.249189	-230.619857	113.577725	99.521771	-230.486371	113.36174	
999		DSH	116.311244	-217.681473	113.910371	116.930806	-217.342331	113.527461	
999		DSH_LIFE_SUPPORT	62.387592	-247.198723	147.237	76.540906	-239.451345	138.489777	
999		DSH_WATER_AND_TANK	83.529094	-235.626083	134.170841	100.810991	-226.166151	123.490048	
999		DSH_INNER_SHELL	109.735911	-221.280742	117.974148	110.046358	-221.110806	117.782281	
1000		DSH	127.578195	-206.790238	121.224885	128.260973	-206.380941	120.91036	
1000		DSH_LIFE_SUPPORT	71.110553	-240.640228	147.237	76.540906	-237.384959	144.73548	
1000		DSH_WATER_AND_TANK	83.529094	-233.195832	141.516334	98.661017	-224.124877	134.545734	
1000		DSH_INNER_SHELL	120.341503	-211.128332	124.558505	120.68431	-210.922834	124.400589	
1001		DSH	134.748658	-197.867527	131.899123	136.173253	-196.946246	131.446281	
1001		DSH_WATER_AND_TANK	86.497266	-229.071527	147.237	96.831886	-222.388165	143.95189	
1001		DSH_D4_STANDOFF_COF	104.398963	-217.494564	141.546511	104.538046	-217.40462	141.5023	
1001		DSH_INNER_SHELL	129.710965	-201.125384	133.500476	130.074457	-200.890315	133.384931	
1001		DSH_INNER_SHELL	133.004	-198.995791	132.453705	133.254	-198.834116	132.374236	
1002		DSH	136.691722	-192.312833	144.272679	138.075507	-191.358371	144.012874	
1002		DSH_D4_STANDOFF_COF	112.650362	-208.89531	148.786439	112.847418	-208.759391	148.749441	
1002		DSH_D4_STANDOFF_COF	113.807549	-208.097143	148.569177	114.002674	-207.962556	148.532542	
1002		DSH_D4_STANDOFF_COF	118.6462	-204.759694	147.660721	118.846861	-204.621288	147.623047	
1002		DSH_D4_STANDOFF_COF	122.244623	-202.277689	146.985118	122.389604	-202.177689	146.957898	
1002		DSH_INNER_SHELL	132.674	-195.084049	145.027005	132.947363	-194.895497	144.975682	
1002		DSH_INNER_SHELL	133.004	-194.856432	144.965048	133.254	-194.683995	144.918111	
1002		DSH_INNER_SHELL	133.907698	-194.233108	144.795379	134.243346	-194.001595	144.732361	

DATA Snippet 18: BILL OF MATERIALS

```

| PROGRAM: AES CUSTOM COMPONENT BOM |
| PROGRAM PROTECTED                 |
| AUTHOR: DUSTIN WHITLOW             |
| VERSION: -                         |
| RELEASE DATE: 10/12/2017          |
|-----|

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- NOTES: 1. THIS IS A CUSTOM RECURSIVE UNIQUE COMPONENT REPORT BASED ON PROJECT SPECIFIC NEEDS AND SHOULD NOT BE USED FOR ANY OTHER PURPOSES!
2. The information contained in this BOM is for REFERENCE and INFORMATIONAL PURPOSES ONLY! THE UTILITY, THE RESULTS, AND THIS REPORT ARE NOT WARRANTIED and SHALL NOT be relied upon for accuracy!
3. This list is not an exhausted list of warnings but rather is a list of warnings known at the time of development. Other potential issues could exist.
4. The first item listed will ALWAYS BE the Top Level Assembly that was used to generate the report.
5. The ONLY assembly reported by this tool will be the Top Level Assembly (TLA). NO OTHER ASSEMBLIES ARE REPORTED!
6. SUPPRESSED objects WILL NOT be reported. However components that are hidden WILL be reported (unlike the ray trace function that does not report hidden components). Hidden components are displayed because they exist in the assembly structure and have only been removed for visual purposes. As a result reported mass property values will also include hidden parts.
7. REPORTS that are generated on the same TLA more than once in the same day WILL OVERWRITE previously saved reports IF saved to the SAME directory.
8. IPS Units do not have a MASS UNIT, therefore components with IPS will have the term UNDEFINED listed for its mass unit parameter.
9. You must be mindful of the state (Suppressed Objects, Active Simplified Rep, Models Open In Session, etc..) of the assemblies (and their contained components) that are used to run a report against as the output results can vary based on these and possibly other criteria.
10. If desired, model session cleanup (Erase Not Displayed or Erase Current) must be performed manually after report generation.

UNIT CONVENTIONS:

Centimeter Gram Second (CGS)
Foot Pound Second (FPS)
Inch lbm Second (DEFAULT)
Inch Pound Second (IPS)
Meter Kilogram Second (MKS)
Millimeter Kilogram Second (MMKS)
Millimeter Newton Second (MMNS)

DSH1_LARC_MASTER, Simplified Rep Used For Report: ORIGINAL_CONFIGURATION, AES RADWORKS CUSTOM BOM REPORT
Report Generated On Nov 29, 2017 08:56:24

OBJECT NAME:	OBJECT QTY:	OBJECT TYPE:	UNIT SYSTEM:	MATERIAL:	DENSITY:	VOLUME:	UNIT LENGTH:	MASS:	UNIT MASS:				
DSH1_LARC_MASTER	N/A	ASSEMBLY	DEFAULT	DEFAULT	N/A	N/A		5698490.788904	INCH		97030.589487	LBM	
DSH1_SEP_RING	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.098		6006.387678	INCH		588.625992	LBM	
DSH	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.014231		136727.177322	INCH		1945.746686	LBM	
DSH_TOP_LEVEL_SKEL	1	PART	DEFAULT	DEFAULT	UNDEFINED	1		0	INCH	0	LBM		
DSH_INNER_SHELL	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.015		30448.83154	INCH		456.732473	LBM	
DSH_ENDCONE_HATCH_GOREPANEL	1	PART	PART	DEFAULT	DEFAULT	UNDEFINED	0.015	0.015		4574.097878	INCH	68.611468	LBM
DSH_D4_STANDDFC_COF	16	PART	DEFAULT	DEFAULT	UNDEFINED	0.015		197.038524	INCH		2.955578	LBM	
DSH_D4_ENDCONE_AFT_GOREPANEL	1	PART	PART	DEFAULT	DEFAULT	UNDEFINED	0.015	0.015		2754.097454	INCH	41.311462	LBM
MANIFOLD_SOLID_BREP-515	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.110002	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-477	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.110002	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-439	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.110002	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-401	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.011628	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-113	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.880015	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-75	1	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000		0.880015	INCH		0.000000	LBM	
MANIFOLD_SOLID_BREP-37	1	PART	PART	DEFAULT	DEFAULT	UNDEFINED	0.000000	0.000000	INCH		0.000000	LBM	
_CAF_PHANTOM	1	PART	DEFAULT	DEFAULT	UNDEFINED	1		0	INCH	0	LBM		

DATA Snippet 19: BOM CHECK FILE FOR POINT 1

Part Names Used
 DSH
 DSH_INNER_SHELL
 DSH_ENDCONE_HATCH_GOREPANEL
 DSH_D4_STANDOFF_COF
 DSH_D4_SRG_SC_PANELS

MANIFOLD_SOLID_BREP-515
 MANIFOLD_SOLID_BREP-439
 MANIFOLD_SOLID_BREP-113
 MANIFOLD_SOLID_BREP-75
 MANIFOLD_SOLID_BREP-37

Fake Tissue Material needed if adding tissue to trinput
 Used Part Count: 94

Part Names NOT Used
 DSH_D4_SRG_HANDRAIL_SUPPORT
 DSH_D4_SRG_SHORT_BANISTER_SHAFT
 DSH_D4_SRG_HANDRAIL_CLAMPBUSH
 DSH_D4_SRG_HANDRAIL_KNOB
 DSH_D4_SRG_MIR1

MANIFOLD_SOLID_BREP-893
 MANIFOLD_SOLID_BREP-553
 MANIFOLD_SOLID_BREP-477
 MANIFOLD_SOLID_BREP-401
 _CAF_PHANTOM

Unused Part Count: 133
 Used Part Count: 94
 Total Part Count: 227

Mat #	Part Name	OLTARIS Material Name		Part Density	Units	Part Density	Units	
100	DSH	aluminum		1.4230000E-02	lbm/inch	3.9388504E-01	g/cm ³	
				Part Volume	Units	Part Volume	Units	
				1.3672718E+05	inch ³	2.2405570E+06	cm ³	
				Part Mass	Units	Part Mass	Units	
				1.9456277E+03	lbm	8.8252190E+05	g	
						Number of Rays Intersecting:		1101
Ray #	Intersec #	Thickness	Units	Thickness	Units	Thickness	Units	
1	1	5.9381429E-01	in	1.5082883E+00	cm	5.9409220E-01	g/cm ²	
2	1	5.8355024E-01	in	1.4822176E+00	cm	5.8382335E-01	g/cm ²	
3	1	5.6349833E-01	in	1.4312858E+00	cm	5.6376206E-01	g/cm ²	
4	1	5.7232203E-01	in	1.4536980E+00	cm	5.7258988E-01	g/cm ²	
5	1	5.5415378E-01	in	1.4075506E+00	cm	5.5441313E-01	g/cm ²	
...								
998	1	7.4478415E-01	in	1.8917517E+00	cm	7.4513272E-01	g/cm ²	
999	1	8.0342668E-01	in	2.0407038E+00	cm	8.0380270E-01	g/cm ²	
1000	1	8.5594147E-01	in	2.1740913E+00	cm	8.5634207E-01	g/cm ²	
1001	1	1.7559315E+00	in	4.4600660E+00	cm	1.7567533E+00	g/cm ²	
1002	1	1.7009871E+00	in	4.3205074E+00	cm	1.7017832E+00	g/cm ²	

OLTARIS material changed from blank to aluminum
 The number of thicknesses below 1.0000000E-01 g/cm² is 68
 The number of thicknesses below 2.5400000E-01 cm is 68

Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in cm = 1101 1.4455609E+00 1.9453997E+00 1.4793707E+00 2.1885376E+00 2.2278105E+00 6.0523917E+00
Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in g/cm^2 = 1101 5.6938481E-01 7.6626386E-01 5.8270199E-01 3.3954161E-01 2.2278105E+00 6.0523917E+00

Mat # Part Name OL TARIS Material Name Part Density Units Part Density Units
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 4.1519857E-01 g/cm^3
Part Volume Units Part Volume Units
3.0448832E+04 inch^3 4.9896695E+05 cm^3
Part Mass Units Part Mass Units
4.5673247E+02 lbm 2.0717037E+05 g

Ray # Intersec # Thickness Units Thickness Units Thickness Units Number of Rays Intersecting: 834
1 2 2.9389236E-01 in 7.4648661E-01 cm 3.0994017E-01 g/cm^2
2 2 2.8857921E-01 in 7.3299120E-01 cm 3.0433690E-01 g/cm^2
3 2 2.7888831E-01 in 7.0837631E-01 cm 2.9411683E-01 g/cm^2
4 2 2.8284965E-01 in 7.1843811E-01 cm 2.9829448E-01 g/cm^2
5 2 2.7404123E-01 in 6.9606473E-01 cm 2.8900508E-01 g/cm^2

276 2 3.0922754E-01 in 7.8543796E-01 cm 3.2611272E-01 g/cm^2
321 2 0.0000000E+00 in 0.0000000E+00 cm 0.0000000E+00 g/cm^2 ***** Zero Thickness *****
321 3 3.8137725E-01 in 9.6869822E-01 cm 4.0220212E-01 g/cm^2
321 4 6.4960766E-02 in 1.6500035E-01 cm 6.8507908E-02 g/cm^2 ***** Thickness Below 1.0000000E-01 g/cm^2 and 2.5400000E-01 cm *****
321 5 3.3104754E-01 in 8.4086075E-01 cm 3.4912418E-01 g/cm^2
330 2 4.6168692E-01 in 1.1726848E+00 cm 4.8689704E-01 g/cm^2

1001 2 3.0814628E-01 in 7.8269154E-01 cm 3.2497241E-01 g/cm^2
1001 3 4.4803406E-01 in 1.1380065E+00 cm 4.7249867E-01 g/cm^2
1002 2 4.1258831E-01 in 1.0479743E+00 cm 4.3511744E-01 g/cm^2
1002 3 3.0730701E-01 in 7.8055982E-01 cm 3.2408732E-01 g/cm^2
1002 4 3.3602565E-01 in 8.5350515E-01 cm 3.5437412E-01 g/cm^2

OLTARIS material changed from blank to aluminum
The number of thicknesses below 1.0000000E-01 g/cm^2 is 1
The number of thicknesses below 2.5400000E-01 cm is 1
***** Ray 321 had zero thickness *****
***** Ray 868 had zero thickness *****
***** Ray 931 had zero thickness *****

Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in cm = 834 7.1358774E-01 7.8460162E-01 2.2164733E-01 4.9127540E-02 4.0797557E+00 2.7993410E+01
Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in g/cm^2 = 834 2.9628061E-01 3.2576547E-01 9.2027656E-02 8.4690894E-03 4.0797557E+00 2.7993410E+01

Mat # Part Name OL TARIS Material Name Part Density Units Part Density Units
326 Fake Tissue Material needed if addi tissue 1.1000000E+00 g/cm^3 1.1000000E+00 g/cm^3
Part Volume Units Part Volume Units
0.0000000E+00 cm^3 0.0000000E+00 cm^3
Part Mass Units Part Mass Units
0.0000000E+00 g 0.0000000E+00 g

Ray # Intersec # Thickness Units Thickness Units Thickness Units Number of Rays Intersecting: 0
The number of thicknesses below 1.0000000E-01 g/cm^2 is 0
The number of thicknesses below 2.5400000E-01 cm is 0
Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in cm = 0 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308
Number, Median, Mean +/- Std Dev, Variance, Skewness, Kurtosis in g/cm^2 = 0 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308 1.7976931+308

BOM ZONE TOTALS

The total volume for this zone is: 9.2073191E+07 cm^3 with the actual volume being 9.2589308E+07 cm^3 with a difference of 5.5742659E-01 %
The total mass for this zone is: 3.8289082E+07 g with the actual mass being 4.1701251E+07 g with a difference of 8.1824145E+00 %

The total read mass for this zone is: 3.8289082E+07 g with the actual read mass being 4.1697891E+07 g with a difference of 8.1750174E+00 %
This part has zero thicknesses at ray 321: DSH_INNER_SHELL
This part has zero thicknesses at ray 868: DSH_INNER_SHELL
This part has zero thicknesses at ray 931: DSH_INNER_SHELL
This part has zero thicknesses at ray 290: DSH_ENDCONE_HATCH_GOREPANEL
This part has zero thicknesses at ray 308: DSH_ENDCONE_HATCH_GOREPANEL
. .
This part has zero thicknesses at ray 501: MANIFOLD_SOLID_BREP-37
This part has zero thicknesses at ray 506: MANIFOLD_SOLID_BREP-37
This part has zero thicknesses at ray 507: MANIFOLD_SOLID_BREP-37
This part has zero thicknesses at ray 513: MANIFOLD_SOLID_BREP-37
This part has zero thicknesses at ray 514: MANIFOLD_SOLID_BREP-37

DATA Snippet 20: RAY TRACE CHECK FILE FOR POINT 1

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Ray # Intersection Number Direction Cosines l, m, n
  1          3          5.2573100E-01 0.0000000E+00 8.5065100E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name      OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
  100 DSH            aluminum      1.4230000E-02 lbm/inch 5.9381429E-01 in 3.9388504E-01 g/cm^3 1.5082883E+00 cm 5.9409220E-01 g/cm^2
  101 DSH_INNER_SHELL aluminum      1.5000000E-02 lbm/inch 2.9389236E-01 in 4.1519857E-01 g/cm^3 7.4648661E-01 cm 3.0994017E-01 g/cm^2
  182 DSH_EVA        aluminum      4.1000000E-04 lbm/inch 4.0198649E+01 in 1.1348761E-02 g/cm^3 1.0210457E+02 cm 1.1587603E+00 g/cm^2
      Total
No duplicate intersections found
No BAD intersections found
OLTARIS Material aluminum      has a thickness of 2.0627927E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 0.0000000E+00 g/cm^2
OLTARIS Material tissue        has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 1.5082883E+00 3.4786448E+01 4.7602115E+01 2.2659614E+03 7.0697096E-01 -1.5000000E+00
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 5.9409220E-01 6.8759757E-01 3.5278072E-01 1.2445424E-01 3.7895791E-01 -1.5000000E+00

Ray # Intersection Number Direction Cosines l, m, n
  2          3          4.9861400E-01 -8.9642000E-02 8.6217600E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name      OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
  100 DSH            aluminum      1.4230000E-02 lbm/inch 5.8355024E-01 in 3.9388504E-01 g/cm^3 1.4822176E+00 cm 5.8382335E-01 g/cm^2
  101 DSH_INNER_SHELL aluminum      1.5000000E-02 lbm/inch 2.8857921E-01 in 4.1519857E-01 g/cm^3 7.3299120E-01 cm 3.0433690E-01 g/cm^2
  182 DSH_EVA        aluminum      4.1000000E-04 lbm/inch 3.2855679E+01 in 1.1348761E-02 g/cm^3 8.3453424E+01 cm 9.4709296E-01 g/cm^2
      Total
No duplicate intersections found
No BAD intersections found
OLTARIS Material aluminum      has a thickness of 1.8352532E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 0.0000000E+00 g/cm^2
OLTARIS Material tissue        has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 1.4822176E+00 2.8556211E+01 3.8819397E+01 1.5069456E+03 7.0690924E-01 -1.5000000E+00
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 5.8382335E-01 6.1175107E-01 2.6314610E-01 6.9245871E-02 1.5799973E-01 -1.5000000E+00

Ray # Intersection Number Direction Cosines l, m, n
  3          4          4.4321300E-01 0.0000000E+00 8.9641600E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name      OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
  100 DSH            aluminum      1.4230000E-02 lbm/inch 5.6349833E-01 in 3.9388504E-01 g/cm^3 1.4312858E+00 cm 5.6376206E-01 g/cm^2
  101 DSH_INNER_SHELL aluminum      1.5000000E-02 lbm/inch 2.7888831E-01 in 4.1519857E-01 g/cm^3 7.0837631E-01 cm 2.9411683E-01 g/cm^2
  182 DSH_EVA        aluminum      4.1000000E-04 lbm/inch 1.7084809E+01 in 1.1348761E-02 g/cm^3 4.3395414E+01 cm 4.9248418E-01 g/cm^2
  181 DSH_CONSUMABLES_1 polyethylene 7.5800000E-03 lbm/inch 1.0359394E+01 in 2.0981368E-01 g/cm^3 2.6312861E+01 cm 5.5207981E+00 g/cm^2
      Total
No duplicate intersections found
No BAD intersections found
***** This ray was reordered from outside to inside *****
OLTARIS Material aluminum      has a thickness of 1.3503631E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 5.5207981E+00 g/cm^2
OLTARIS Material tissue        has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 1.3872073E+01 1.7961984E+01 1.7941206E+01 3.2188686E+02 3.1951297E-01 -1.5846576E+00
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 5.2812312E-01 1.7177903E+00 2.1978894E+00 4.8307177E+00 1.1476528E+00 -6.7192335E-01

Ray # Intersection Number Direction Cosines l, m, n
  4          4          4.6358000E-01 -1.8752200E-01 8.6598400E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name      OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
  100 DSH            aluminum      1.4230000E-02 lbm/inch 5.7232203E-01 in 3.9388504E-01 g/cm^3 1.4536980E+00 cm 5.7258988E-01 g/cm^2
  101 DSH_INNER_SHELL aluminum      1.5000000E-02 lbm/inch 2.8284965E-01 in 4.1519857E-01 g/cm^3 7.1843811E-01 cm 2.9829448E-01 g/cm^2
  182 DSH_EVA        aluminum      4.1000000E-04 lbm/inch 2.2457657E+01 in 1.1348761E-02 g/cm^3 5.7042448E+01 cm 6.4736111E-01 g/cm^2
  181 DSH_CONSUMABLES_1 polyethylene 7.5800000E-03 lbm/inch 3.6428941E+00 in 2.0981368E-01 g/cm^3 9.2529510E+00 cm 1.9413957E+00 g/cm^2
      Total
  
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No duplicate intersections found

No BAD intersections found

***** This ray was reordered from outside to inside *****

OLTARIS Material aluminum has a thickness of 1.5182455E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 1.9413957E+00 g/cm^2
OLTARIS Material tissue has a thickness of 0.000000E+00 g/cm^2

Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 5.3533245E+00 1.7116884E+01 2.3292362E+01 5.4253413E+02 1.0861965E+00 -7.2601959E-01
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 6.0997549E-01 8.6491029E-01 6.3495140E-01 4.0316328E-01 1.0061605E+00 -7.6135548E-01

Ray # Intersection Number Direction Cosines l, m, n
5 4 4.0838500E-01 -9.4397000E-02 9.0791600E-01

PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)

Mat # Part Name OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
100 DSH aluminum 1.4230000E-02 lbm/inch 5.5415378E-01 in 3.9388504E-01 g/cm^3 1.4075506E+00 cm 5.5441313E-01 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 2.7404123E-01 in 4.1519857E-01 g/cm^3 6.9606473E-01 cm 2.8900508E-01 g/cm^2
182 DSH_EVA aluminum 4.1000000E-04 lbm/inch 5.8028207E+00 in 1.1348761E-02 g/cm^3 1.4739165E+01 cm 1.6727125E-01 g/cm^2
181 DSH_CONSUMABLES_1 polyethylene 7.5800000E-03 lbm/inch 1.8998644E+01 in 2.0981368E-01 g/cm^3 4.8256556E+01 cm 1.0124885E+01 g/cm^2
Total 6.5099336E+01 cm 1.1135575E+01 g/cm^2

No duplicate intersections found

No BAD intersections found

***** This ray was reordered from outside to inside *****

OLTARIS Material aluminum has a thickness of 1.0106895E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 1.0124885E+01 g/cm^2
OLTARIS Material tissue has a thickness of 0.000000E+00 g/cm^2

Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 8.0733576E+00 1.6274834E+01 1.9293282E+01 3.7223074E+02 8.9260349E-01 -9.1790063E-01
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 4.2170911E-01 2.7838937E+00 4.2406345E+00 1.7982981E+01 1.1509448E+00 -6.6960971E-01

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Ray # Intersection Number Direction Cosines l, m, n
21 10 0.0000000E+00 0.0000000E+00 1.0000000E+00

PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)

Mat # Part Name OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
100 DSH aluminum 1.4230000E-02 lbm/inch 5.0512900E-01 in 3.9388504E-01 g/cm^3 1.2830277E+00 cm 5.0536541E-01 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 2.5000000E-01 in 4.1519857E-01 g/cm^3 6.3500000E-01 cm 2.6365109E-01 g/cm^2
297 MANIFOLD_SOLID_BREP-1693 aluminum 0.0000000E+00 lbm/inch 2.3749020E+00 in 0.0000000E+00 g/cm^3 6.0322511E+00 cm 0.0000000E+00 g/cm^2
300 MANIFOLD_SOLID_BREP-1579 aluminum 0.0000000E+00 lbm/inch 2.3749020E+00 in 0.0000000E+00 g/cm^3 6.0322511E+00 cm 0.0000000E+00 g/cm^2
303 MANIFOLD_SOLID_BREP-1465 aluminum 0.0000000E+00 lbm/inch 2.3749020E+00 in 0.0000000E+00 g/cm^3 6.0322511E+00 cm 0.0000000E+00 g/cm^2
306 MANIFOLD_SOLID_BREP-1351 aluminum 0.0000000E+00 lbm/inch 2.3749020E+00 in 0.0000000E+00 g/cm^3 6.0322511E+00 cm 0.0000000E+00 g/cm^2
313 MANIFOLD_SOLID_BREP-1007 aluminum 0.0000000E+00 lbm/inch 1.1874510E+00 in 0.0000000E+00 g/cm^3 3.0161255E+00 cm 0.0000000E+00 g/cm^2
315 MANIFOLD_SOLID_BREP-931 aluminum 0.0000000E+00 lbm/inch 1.1874510E+00 in 0.0000000E+00 g/cm^3 3.0161255E+00 cm 0.0000000E+00 g/cm^2
318 MANIFOLD_SOLID_BREP-515 aluminum 0.0000000E+00 lbm/inch 1.1874510E+00 in 0.0000000E+00 g/cm^3 3.0161255E+00 cm 0.0000000E+00 g/cm^2
320 MANIFOLD_SOLID_BREP-439 aluminum 0.0000000E+00 lbm/inch 1.1874510E+00 in 0.0000000E+00 g/cm^3 3.0161255E+00 cm 0.0000000E+00 g/cm^2
Total 3.8111534E+01 cm 7.6901650E-01 g/cm^2

No duplicate intersections found

This ray contains 1 BAD which are not printed above with a thickness of 0.0000000E+00 g/cm^2

***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-1693 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-1579 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-1465 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-1351 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-1007 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-931 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-515 *****
***** The ray has a part with zero thickness: MANIFOLD_SOLID_BREP-439 *****

***** This ray has a total thickness in g/cm^2 less than 1.0000000E+00 at 7.6901650E-01 g/cm^2 *****

***** This ray was reordered from outside to inside *****

OLTARIS Material aluminum has a thickness of 7.6901650E-01 g/cm^2

OLTARIS Material polyethylene has a thickness of 0.000000E+00 g/cm²
 OLTARIS Material tissue has a thickness of 0.000000E+00 g/cm²
 Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 3.0161255E+00 3.4646849E+00 2.1730831E+00 4.7222903E+00 -6.4555260E-02 -1.3495099E+00
 Ray thickness distribution in g/cm² median, mean+/-sd, variance, skewness, kurtosis = 0.000000E+00 6.9910591E-02 1.5700136E-01 2.4649427E-02 2.0382527E+00 2.6227682E+00

Ray # Intersection Number Direction Cosines l, m, n
 998 4 7.3172900E-01 3.5833600E-01 -5.7980000E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)

Mat #	Part Name	OLTARIS Material	Density	Units	Thickness	Units	Density	Units	Thickness	Units	Thickness	Units	
100	DSH	aluminum	1.4230000E-02	lbm/inch	7.4478415E-01	in	3.9388504E-01	g/cm ³	1.8917517E+00	cm	7.4513272E-01	g/cm ²	
101	DSH_INNER_SHELL	aluminum	1.5000000E-02	lbm/inch	3.7251709E-01	in	4.1519857E-01	g/cm ³	9.4619340E-01	cm	3.9285815E-01	g/cm ²	
178	DSH_WATER_AND_TANK	polyethylene	4.4870000E-02	lbm/inch	2.0712332E+01	in	1.2419973E+00	g/cm ³	5.2609325E+01	cm	6.5340640E+01	g/cm ²	
177	DSH_LIFE_SUPPORT	aluminum	1.8060000E-02	lbm/inch	2.7019517E+01	in	4.9989908E-01	g/cm ³	6.8629574E+01	cm	3.4307861E+01	g/cm ²	
Total										1.2407684E+02	cm	1.0078649E+02	g/cm ²

No duplicate intersections found
 No BAD intersections found
 ***** This ray was reordered from outside to inside *****
 ***** The ray will be reordered if any interpolation method is used *****
 OLTARIS Material aluminum has a thickness of 3.5445852E+01 g/cm²
 OLTARIS Material polyethylene has a thickness of 6.5340640E+01 g/cm²
 OLTARIS Material tissue has a thickness of 0.000000E+00 g/cm²
 Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 2.7250538E+01 3.1019211E+01 3.0139126E+01 9.0836692E+02 1.0369492E-01 -1.8620242E+00
 Ray thickness distribution in g/cm² median, mean+/-sd, variance, skewness, kurtosis = 1.7526497E+01 2.5196623E+01 2.6961356E+01 7.2691473E+02 4.5374727E-01 -1.4198114E+00

Ray # Intersection Number Direction Cosines l, m, n
 999 4 7.7114900E-01 4.2211900E-01 -4.7659600E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)

Mat #	Part Name	OLTARIS Material	Density	Units	Thickness	Units	Density	Units	Thickness	Units	Thickness	Units	
100	DSH	aluminum	1.4230000E-02	lbm/inch	8.0342668E-01	in	3.9388504E-01	g/cm ³	2.0407038E+00	cm	8.0380270E-01	g/cm ²	
101	DSH_INNER_SHELL	aluminum	1.5000000E-02	lbm/inch	4.0257736E-01	in	4.1519857E-01	g/cm ³	1.0225465E+00	cm	4.2455984E-01	g/cm ²	
178	DSH_WATER_AND_TANK	polyethylene	4.4870000E-02	lbm/inch	2.2410569E+01	in	1.2419973E+00	g/cm ³	5.6922846E+01	cm	7.0698023E+01	g/cm ²	
177	DSH_LIFE_SUPPORT	aluminum	1.8060000E-02	lbm/inch	1.8353530E+01	in	4.9989908E-01	g/cm ³	4.6617967E+01	cm	2.3304279E+01	g/cm ²	
Total										1.0660406E+02	cm	9.5230664E+01	g/cm ²

No duplicate intersections found
 No BAD intersections found
 ***** This ray was reordered from outside to inside *****
 ***** The ray will be reordered if any interpolation method is used *****
 OLTARIS Material aluminum has a thickness of 2.4532641E+01 g/cm²
 OLTARIS Material polyethylene has a thickness of 7.0698023E+01 g/cm²
 OLTARIS Material tissue has a thickness of 0.000000E+00 g/cm²
 Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 2.4329335E+01 2.6651016E+01 2.5384783E+01 6.4438718E+02 6.0554353E-02 -1.9181136E+00
 Ray thickness distribution in g/cm² median, mean+/-sd, variance, skewness, kurtosis = 1.2054041E+01 2.3807666E+01 2.8613399E+01 8.1872658E+02 8.3387924E-01 -9.8105865E-01

Ray # Intersection Number Direction Cosines l, m, n
 1000 4 7.9769200E-01 4.7818300E-01 -3.6746100E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)

Mat #	Part Name	OLTARIS Material	Density	Units	Thickness	Units	Density	Units	Thickness	Units	Thickness	Units	
100	DSH	aluminum	1.4230000E-02	lbm/inch	8.5594147E-01	in	3.9388504E-01	g/cm ³	2.1740913E+00	cm	8.5634207E-01	g/cm ²	
101	DSH_INNER_SHELL	aluminum	1.5000000E-02	lbm/inch	4.2974822E-01	in	4.1519857E-01	g/cm ³	1.0915605E+00	cm	4.5321435E-01	g/cm ²	
178	DSH_WATER_AND_TANK	polyethylene	4.4870000E-02	lbm/inch	1.8969623E+01	in	1.2419973E+00	g/cm ³	4.8182841E+01	cm	5.9842960E+01	g/cm ²	
177	DSH_LIFE_SUPPORT	aluminum	1.8060000E-02	lbm/inch	6.8075776E+00	in	4.9989908E-01	g/cm ³	1.7291247E+01	cm	8.6438785E+00	g/cm ²	
Total										6.8739740E+01	cm	6.9796395E+01	g/cm ²

No duplicate intersections found
 No BAD intersections found
 ***** This ray was reordered from outside to inside *****

***** The ray will be reordered if any interpolation method is used *****

OLTARIS Material aluminum has a thickness of 9.9534349E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 5.9842960E+01 g/cm^2
OLTARIS Material tissue has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 9.7326692E+00 1.7184935E+01 1.9007917E+01 3.6130091E+02 8.0940147E-01 -1.0060986E+00
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 4.7501103E+00 1.7449099E+01 2.4692869E+01 6.0973776E+02 1.0964188E+00 -7.1684820E-01

Ray # Intersection Number Direction Cosines l, m, n
1001 5 8.1130500E-01 5.2466800E-01 -2.5789300E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
100 DSH aluminum 1.4230000E-02 lbm/inch 1.7559315E+00 in 3.9388504E-01 g/cm^3 4.4600660E+00 cm 1.7567533E+00 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 3.0814628E-01 in 4.1519857E-01 g/cm^3 7.8269154E-01 cm 3.2497241E-01 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 4.4803406E-01 in 4.1519857E-01 g/cm^3 1.1380065E+00 cm 4.7249867E-01 g/cm^2
103 DSH_D4_STANDOFF_COF aluminum 1.5000000E-02 lbm/inch 1.7143108E-01 in 4.1519857E-01 g/cm^3 4.3543495E-01 cm 1.8079197E-01 g/cm^2
178 DSH_WATER_AND_TANK polyethylene 4.4877000E-02 lbm/inch 1.2738275E+01 in 1.2419973E+00 g/cm^3 3.2355218E+01 cm 4.0185094E+01 g/cm^2
Total 3.9171417E+01 cm 4.2920111E+01 g/cm^2

No duplicate intersections found

No BAD intersections found

***** This ray was reordered from outside to inside *****

OLTARIS Material aluminum has a thickness of 2.7350164E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 4.0185094E+01 g/cm^2
OLTARIS Material tissue has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 1.1380065E+00 7.8342834E+00 1.2344793E+01 1.5239392E+02 1.4510933E+00 1.7898904E-01
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 4.7249867E-01 8.5840221E+00 1.5810518E+01 2.4997247E+02 1.4953219E+00 2.4358954E-01

Ray # Intersection Number Direction Cosines l, m, n
1002 8 8.1351900E-01 5.6112300E-01 -1.5273800E-01 PARTS ORDERED OUTSIDE (TOP) TO INSIDE (BOTTOM)
Mat # Part Name OLTARIS Material Density Units Thickness Units Density Units Thickness Units Thickness Units
100 DSH aluminum 1.4230000E-02 lbm/inch 1.7009871E+00 in 3.9388504E-01 g/cm^3 4.3205074E+00 cm 1.7017832E+00 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 4.1258831E-01 in 4.1519857E-01 g/cm^3 1.0479743E+00 cm 4.3511744E-01 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 3.0730701E-01 in 4.1519857E-01 g/cm^3 7.8055982E-01 cm 3.2408732E-01 g/cm^2
101 DSH_INNER_SHELL aluminum 1.5000000E-02 lbm/inch 3.3602565E-01 in 4.1519857E-01 g/cm^3 8.5350515E-01 cm 3.5437412E-01 g/cm^2
103 DSH_D4_STANDOFF_COF aluminum 1.5000000E-02 lbm/inch 1.7821453E-01 in 4.1519857E-01 g/cm^3 4.5266491E-01 cm 1.8794582E-01 g/cm^2
103 DSH_D4_STANDOFF_COF aluminum 1.5000000E-02 lbm/inch 2.4665844E-01 in 4.1519857E-01 g/cm^3 6.2651245E-01 cm 2.6012707E-01 g/cm^2
103 DSH_D4_STANDOFF_COF aluminum 1.5000000E-02 lbm/inch 2.3985318E-01 in 4.1519857E-01 g/cm^3 6.0922708E-01 cm 2.5295022E-01 g/cm^2
103 DSH_D4_STANDOFF_COF aluminum 1.5000000E-02 lbm/inch 2.4222695E-01 in 4.1519857E-01 g/cm^3 6.1525644E-01 cm 2.5545360E-01 g/cm^2
Total 9.3062075E+00 cm 3.7718388E+00 g/cm^2

No duplicate intersections found

No BAD intersections found

***** This ray was reordered from outside to inside *****

OLTARIS Material aluminum has a thickness of 3.7718388E+00 g/cm^2
OLTARIS Material polyethylene has a thickness of 0.0000000E+00 g/cm^2
OLTARIS Material tissue has a thickness of 0.0000000E+00 g/cm^2
Ray thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 7.0353613E-01 1.1632759E+00 1.2054155E+00 1.4530266E+00 2.1792860E+00 2.9156169E+00
Ray thickness distribution in g/cm^2 median, mean+/-sd, variance, skewness, kurtosis = 2.9210720E-01 4.7147985E-01 4.7035771E-01 2.2123638E-01 2.1677781E+00 2.8858888E+00

RAY TRACE ZONE TOTALS

The total number of rays with a thickness below 2.5400000E+00 cm is 76
The total number of rays with a thickness below 1.0000000E+00 g/cm^2 is 75
The total number of rays with a thickness above 2.5400000E+03 cm is 0
The total number of rays with a thickness above 1.0000000E+03 g/cm^2 is 0
The number of rays reordered is 539
If an interpolation method is used, 54 rays will be reordered by material
The number of overlaps is: 0 with a combined thickness of 0.0000000E+00 cm
The total duplicate thickness is: 0.0000000E+00 g/cm^2
The total BAD thickness is: 0.0000000E+00 g/cm^2
Thickness distribution in cm median, mean+/-sd, variance, skewness, kurtosis = 8.2468403E+01 7.3205281E+01 5.5909487E+01 3.1258707E+03 1.5557134E+00 6.9684437E+00

```

Thickness distribution in g/cm^2  median, mean+/-sd, variance, skewness, kurtosis = 1.4323778E+01 2.3589314E+01 4.2201905E+01 1.7810008E+03 7.0705741E+00 6.5444709E+01
Ray      21 has a part with zero thickness: MANIFOLD_SOLID_BREP-1693
Ray      21 has a part with zero thickness: MANIFOLD_SOLID_BREP-1579
Ray      21 has a part with zero thickness: MANIFOLD_SOLID_BREP-1465
Ray      21 has a part with zero thickness: MANIFOLD_SOLID_BREP-1351
Ray      21 has a part with zero thickness: MANIFOLD_SOLID_BREP-1007
.
.
Ray      839 has a part with zero thickness: DSH1_CORPUS_MIM2
Ray      841 has a part with zero thickness: DSH_STORM_SHELTER_BALLIST
Ray      844 has a part with zero thickness: DSH_STA-PASS_KORPUS
Ray      848 has a part with zero thickness: DSH_D4_SRG_VMN_STBDCONE
Ray      868 has a part with zero thickness: DSH_INNER_SHELL
OLTARIS Material aluminum          has a maximum thickness of 5.0600058E+02 g/cm^2
OLTARIS Material polyethylene     has a maximum thickness of 1.2812696E+02 g/cm^2
OLTARIS Material tissue           has a maximum thickness of 0.0000000E+00 g/cm^2

```


DATA Snippet 21: XML FILE FOR INTERPOLATION

```
<?xml version="1.0"?>
<thickness_metafile version_number="1.0">
  <creator_creator_name="Automated Process Convert" creator_organization="NASA Langley Research Center" creator_email="none" creator_phone="none" creator_time="12:05:52" creator_date="2017-Oct-16" />
  <job_bundle job_id=" 1" job_label="Ray Traced Vehicle" >
    <analysis_description number_of_zones=" 5">
      <material_table name="generic" type="volumetric density" units="g/cm3" >
        <material name="DSH" material_id=" 100" type_id=" 1" density=" 3.9388504E-01" />
        <material name="DSH_INNER_SHELL" material_id=" 101" type_id=" 1" density=" 4.1519857E-01" />
        <material name="DSH_ENDCONE_HATCH_GOREPANEL" material_id=" 102" type_id=" 1" density=" 4.1519857E-01" />
        <material name="DSH_D4_STANDOFF_COF" material_id=" 103" type_id=" 1" density=" 4.1519857E-01" />
        <material name="DSH_D4_SRG_SC_PANELS" material_id=" 104" type_id=" 1" density=" 4.1519857E-01" />
        .
        .
        .
        <material name="DSH1_MPCV_CAPSULE_TOP" material_id=" 290" type_id=" 1" density=" 2.9534458E-01" />
        <material name="DSH1_ESA_SERVICE_MODULE" material_id=" 291" type_id=" 1" density=" 9.9094059E-02" />
        <material name="ESA_SERVICE_MOD_SOLAR_PAN_RADWX" material_id=" 292" type_id=" 1" density=" 2.6998979E+00" />
        <material name="DSH1_MAIN_THRUSTER_ESA_SERV" material_id=" 293" type_id=" 1" density=" 2.6998979E+00" />
        <material name="Fake Tissue Material needed if adding tissue to trminput" material_id=" 326" type_id=" 3" density=" 1.1000000E+00" />
        <material_type_define id=" 1" user_material_name="aluminum" />
        <material_type_define id=" 2" user_material_name="polyethylene" />
        <material_type_define id=" 3" user_material_name="tissue" />
      </material_table>
      <thickness_set type="length" units="cm" material_table="generic" cad_model="Input CAD model" target_x=" 3.6855000E+01" target_y="-2.6117500E+02" target_z=" 1.6301700E+02" order="outside_in" >
        <ray number=" 1" thk_count=" 3" xdir=" 5.25731E-01" ydir=" 0.00000E+00" zdir=" 8.50651E-01" >
          <thk material_id=" 100" thickness=" 1.5082883E+00" />
          <thk material_id=" 101" thickness=" 7.4648661E-01" />
          <thk material_id=" 182" thickness=" 1.0210457E+02" />
        </ray>
        <ray number=" 2" thk_count=" 3" xdir=" 4.98614E-01" ydir="-8.96420E-02" zdir=" 8.62176E-01" >
          <thk material_id=" 100" thickness=" 1.4822176E+00" />
          <thk material_id=" 101" thickness=" 7.3299120E-01" />
          <thk material_id=" 182" thickness=" 8.3453424E+01" />
        </ray>
        <ray number=" 3" thk_count=" 4" xdir=" 4.43213E-01" ydir=" 0.00000E+00" zdir=" 8.96416E-01" >
          <thk material_id=" 100" thickness=" 1.4312858E+00" />
          <thk material_id=" 101" thickness=" 7.0837631E-01" />
          <thk material_id=" 182" thickness=" 4.3395414E+01" />
          <thk material_id=" 181" thickness=" 2.6312861E+01" />
        </ray>
        <ray number=" 4" thk_count=" 4" xdir=" 4.63580E-01" ydir="-1.87522E-01" zdir=" 8.65984E-01" >
          <thk material_id=" 100" thickness=" 1.4536980E+00" />
          <thk material_id=" 101" thickness=" 7.1843811E-01" />
          <thk material_id=" 182" thickness=" 5.7042448E+01" />
          <thk material_id=" 181" thickness=" 9.2529510E+00" />
        </ray>
        <ray number=" 5" thk_count=" 4" xdir=" 4.08385E-01" ydir="-9.43970E-02" zdir=" 9.07916E-01" >
          <thk material_id=" 100" thickness=" 1.4075506E+00" />
          <thk material_id=" 101" thickness=" 6.9606473E-01" />
          <thk material_id=" 182" thickness=" 1.4739165E+01" />
          <thk material_id=" 181" thickness=" 4.8256556E+01" />
        </ray>
        .
        .
        .
        <ray number=" 998" thk_count=" 2" xdir=" 7.31729E-01" ydir=" 3.58336E-01" zdir="-5.79800E-01" >
          <thk material_id=" 100" thickness=" 5.3630035E+00" />
          <thk material_id=" 130" thickness=" 6.7091685E-01" />
        </ray>
        <ray number=" 999" thk_count=" 5" xdir=" 7.71149E-01" ydir=" 4.22119E-01" zdir="-4.76596E-01" >
          <thk material_id=" 100" thickness=" 5.2879516E+00" />
          <thk material_id=" 130" thickness=" 6.6165526E-01" />
          <thk material_id=" 165" thickness=" 2.0586278E-01" />
          <thk material_id=" 165" thickness=" 2.0586278E-01" />
          <thk material_id=" 170" thickness=" 9.7161633E+00" />
        </ray>
        <ray number=" 1000" thk_count=" 5" xdir=" 7.97692E-01" ydir=" 4.78183E-01" zdir="-3.67461E-01" >
          <thk material_id=" 100" thickness=" 5.2531786E+00" />
          <thk material_id=" 130" thickness=" 6.5742665E-01" />
        </ray>
      </thickness_set>
    </analysis_description>
  </job_bundle>
</thickness_metafile>
```

```
<thk material_id=" 165" thickness=" 1.9901144E-01" />
<thk material_id=" 165" thickness=" 1.9901144E-01" />
<thk material_id=" 170" thickness=" 3.1307657E+01" />
</ray>
<ray number=" 1001" thk_count=" 5" xdir=" 8.11305E-01" ydir=" 5.24668E-01" zdir="-2.57893E-01" >
  <thk material_id=" 100" thickness=" 5.2417338E+00" />
  <thk material_id=" 130" thickness=" 6.5604468E-01" />
  <thk material_id=" 165" thickness=" 1.9567305E-01" />
  <thk material_id=" 165" thickness=" 1.9567172E-01" />
  <thk material_id=" 170" thickness=" 4.7328757E+01" />
</ray>
<ray number=" 1002" thk_count=" 5" xdir=" 8.13519E-01" ydir=" 5.61123E-01" zdir="-1.52738E-01" >
  <thk material_id=" 100" thickness=" 5.2418994E+00" />
  <thk material_id=" 130" thickness=" 6.5603972E-01" />
  <thk material_id=" 165" thickness=" 1.9513989E-01" />
  <thk material_id=" 165" thickness=" 1.9513950E-01" />
  <thk material_id=" 170" thickness=" 6.0270181E+01" />
</ray>
</thickness_set>
</analysis_description>
</job_bundle>
</thickness_metafile>
```

DATA Snippet 22: XML FILE FOR RAY-BY-RAY

```
<?xml version="1.0"?>
<thickness_metafile version_number="1.0">
  <creator creator_name="Automated Process Convert" creator_organization="NASA Langley Research Center" creator_email="none" creator_phone="none" creator_time="12:05:52" creator_date="2017-Oct-16" />
  <job_bundle job_id=" 1" job_label="Ray Traced Vehicle" >
    <analysis_description number_of_zones=" 5">
      <material_table name="generic" type="volumetric density" units="g/cm3" >
        <material name="DSH" material_id=" 100" type_id=" 100" density=" 3.9388504E-01" />
        <material_type_define id=" 100" user_material_name="aluminum" />
        <material name="DSH_INNER_SHELL" material_id=" 101" type_id=" 101" density=" 4.1519857E-01" />
        <material_type_define id=" 101" user_material_name="aluminum" />
        <material name="DSH_ENDCONE_HATCH_GOREPANEL" material_id=" 102" type_id=" 102" density=" 4.1519857E-01" />
        <material_type_define id=" 102" user_material_name="aluminum" />
        <material name="DSH_D4_STANDOFF_COF" material_id=" 103" type_id=" 103" density=" 4.1519857E-01" />
        <material_type_define id=" 103" user_material_name="aluminum" />
        <material name="DSH_D4_SRG_SC_PANELS" material_id=" 104" type_id=" 104" density=" 4.1519857E-01" />
        <material_type_define id=" 104" user_material_name="aluminum" />
        .
        .
        .
        <material_type_define id=" 289" user_material_name="aluminum" />
        <material name="DSH1_MPCV_CAPSULE_TOP" material_id=" 290" type_id=" 290" density=" 2.9534458E-01" />
        <material_type_define id=" 290" user_material_name="aluminum" />
        <material name="DSH1_ESA_SERVICE_MODULE" material_id=" 291" type_id=" 291" density=" 9.9094059E-02" />
        <material_type_define id=" 291" user_material_name="aluminum" />
        <material name="ESA_SERVICE_MOD_SOLAR_PAN_RADWX" material_id=" 292" type_id=" 292" density=" 2.6998979E+00" />
        <material_type_define id=" 292" user_material_name="aluminum" />
        <material name="DSH1_MAIN_THRUSTER_ESA_SERV" material_id=" 293" type_id=" 293" density=" 2.6998979E+00" />
        <material_type_define id=" 293" user_material_name="aluminum" />
        <material name="Fake Tissue Material needed if adding tissue to trninput" material_id=" 326" type_id=" 326" density=" 1.1000000E+00" />
        <material_type_define id=" 326" user_material_name="tissue" />
      </material_table>
      <thickness_set type="length" units="cm" material_table="generic" cad_model="Input CAD model" target_x=" 3.6855000E+01" target_y=" -2.6117500E+02" target_z=" 1.6301700E+02" order="outside_in" >
        <ray number=" 1" thk_count=" 3" xdir=" 5.25731E-01" ydir=" 0.00000E+00" zdir=" 8.50651E-01" >
          <thk material_id=" 100" thickness=" 1.5082883E+00" />
          <thk material_id=" 101" thickness=" 7.4648661E-01" />
          <thk material_id=" 182" thickness=" 1.0210457E+02" />
        </ray>
        <ray number=" 2" thk_count=" 3" xdir=" 4.98614E-01" ydir=" -8.96420E-02" zdir=" 8.62176E-01" >
          <thk material_id=" 100" thickness=" 1.4822176E+00" />
          <thk material_id=" 101" thickness=" 7.3299120E-01" />
          <thk material_id=" 182" thickness=" 8.3453424E+01" />
        </ray>
        <ray number=" 3" thk_count=" 4" xdir=" 4.43213E-01" ydir=" 0.00000E+00" zdir=" 8.96416E-01" >
          <thk material_id=" 100" thickness=" 1.4312858E+00" />
          <thk material_id=" 101" thickness=" 7.0837631E-01" />
          <thk material_id=" 182" thickness=" 4.3395414E+01" />
          <thk material_id=" 181" thickness=" 2.6312861E+01" />
        </ray>
        <ray number=" 4" thk_count=" 4" xdir=" 4.63580E-01" ydir=" -1.87522E-01" zdir=" 8.65984E-01" >
          <thk material_id=" 100" thickness=" 1.4536980E+00" />
          <thk material_id=" 101" thickness=" 7.1843811E-01" />
          <thk material_id=" 182" thickness=" 5.7042448E+01" />
          <thk material_id=" 181" thickness=" 9.2529510E+00" />
        </ray>
        <ray number=" 5" thk_count=" 4" xdir=" 4.08385E-01" ydir=" -9.43970E-02" zdir=" 9.07916E-01" >
          <thk material_id=" 100" thickness=" 1.4075506E+00" />
          <thk material_id=" 101" thickness=" 6.9606473E-01" />
          <thk material_id=" 182" thickness=" 1.4739165E+01" />
          <thk material_id=" 181" thickness=" 4.8256556E+01" />
        </ray>
        .
        .
        .
        <ray number=" 998" thk_count=" 2" xdir=" 7.31729E-01" ydir=" 3.58336E-01" zdir=" -5.79800E-01" >
          <thk material_id=" 100" thickness=" 5.3630035E+00" />
          <thk material_id=" 130" thickness=" 6.7091685E-01" />
        </ray>
        <ray number=" 999" thk_count=" 5" xdir=" 7.71149E-01" ydir=" 4.22119E-01" zdir=" -4.76596E-01" >
          <thk material_id=" 100" thickness=" 5.2879516E+00" />

```

```
<thk material_id=" 130" thickness=" 6.6165526E-01" />
<thk material_id=" 165" thickness=" 2.0586278E-01" />
<thk material_id=" 165" thickness=" 2.0586278E-01" />
<thk material_id=" 170" thickness=" 9.7161633E+00" />
</ray>
<ray number=" 1000" thk_count=" 5" xdir=" 7.97692E-01" ydir=" 4.78183E-01" zdir="-3.67461E-01" >
  <thk material_id=" 100" thickness=" 5.2531786E+00" />
  <thk material_id=" 130" thickness=" 6.5742566E-01" />
  <thk material_id=" 165" thickness=" 1.9901144E-01" />
  <thk material_id=" 165" thickness=" 1.9901144E-01" />
  <thk material_id=" 170" thickness=" 3.1307657E+01" />
</ray>
<ray number=" 1001" thk_count=" 5" xdir=" 8.11305E-01" ydir=" 5.24668E-01" zdir="-2.57893E-01" >
  <thk material_id=" 100" thickness=" 5.2417338E+00" />
  <thk material_id=" 130" thickness=" 6.5604468E-01" />
  <thk material_id=" 165" thickness=" 1.9567305E-01" />
  <thk material_id=" 165" thickness=" 1.9567172E-01" />
  <thk material_id=" 170" thickness=" 4.7328757E+01" />
</ray>
<ray number=" 1002" thk_count=" 5" xdir=" 8.13519E-01" ydir=" 5.61123E-01" zdir="-1.52738E-01" >
  <thk material_id=" 100" thickness=" 5.2418994E+00" />
  <thk material_id=" 130" thickness=" 6.5603972E-01" />
  <thk material_id=" 165" thickness=" 1.9513989E-01" />
  <thk material_id=" 165" thickness=" 1.9513950E-01" />
  <thk material_id=" 170" thickness=" 6.0270181E+01" />
</ray>
</thickness_set>
</analysis_description>
</job_bundle>
</thickness_metafile>
```

DATA Snippet 23: LOG FILE

```

Starting at 20171203 045526.630
The number of threads assigned to this process is 5
Finished Initialization and starting Read and manipulate ray trace. Time: 0.0000527833 20171203 045526.633
Read the Ray Trace file hab1.txt
Ray Trace Origin : 36.8550 -261.1750 163.0170
Units of length : in
Read the Ray Trace file hab2.txt
Ray Trace Origin : 36.8550 -261.1750 176.8170
Units of length : in
Read the Ray Trace file hab3.txt
Ray Trace Origin : 36.8550 -261.1750 190.6170
Units of length : in
Read the Ray Trace file hab4.txt
Ray Trace Origin : 36.8550 -261.1750 202.1170
Units of length : in
Read the Ray Trace file hab5.txt
Ray Trace Origin : 36.8550 -261.1750 215.9170
Units of length : in
The number of rays in each ray trace are consistent
For ray trace 5 the number of ray reordered are: 517 on thread number 4
Ray Voids and Thicknesses Calculated (Unit: in) for ray trace 5 on thread number 4
For ray trace 1 the number of ray reordered are: 539 on thread number 0
For ray trace 2 the number of ray reordered are: 564 on thread number 1
Ray Voids and Thicknesses Calculated (Unit: in) for ray trace 1 on thread number 0
For ray trace 4 the number of ray reordered are: 532 on thread number 3
Ray Voids and Thicknesses Calculated (Unit: in) for ray trace 2 on thread number 1
Ray Voids and Thicknesses Calculated (Unit: in) for ray trace 4 on thread number 3
For ray trace 3 the number of ray reordered are: 522 on thread number 2
Ray Voids and Thicknesses Calculated (Unit: in) for ray trace 3 on thread number 2
Created a unique part name list from the RT data for ray trace 1 on thread number 0
Created a unique part name list from the RT data for ray trace 5 on thread number 4
Created a unique part name list from the RT data for ray trace 2 on thread number 1
Created a unique part name list from the RT data for ray trace 3 on thread number 2
Created a unique part name list from the RT data for ray trace 4 on thread number 3
Finished Read and manipulate ray trace and starting Read and manipulate BOM. Time: 0.0129858500 20171203 045527.409
Read the NEW FORMAT BOM file hab.bom and the number of parts read: 229
Applied the Heuristics rules
Finished Read and manipulate BOM and starting Create ray trace thicknesses. Time: 0.0132536167 20171203 045527.425
Calculated the thicknesses in cm and g/cm^2 for ray trace 5 on thread number 4
Calculated the thicknesses in cm and g/cm^2 for ray trace 4 on thread number 3
Calculated the thicknesses in cm and g/cm^2 for ray trace 1 on thread number 0
Calculated the thicknesses in cm and g/cm^2 for ray trace 2 on thread number 1
Calculated the thicknesses in cm and g/cm^2 for ray trace 3 on thread number 2
Finished Create ray trace thicknesses and starting Read direction cosines. Time: 0.0141668167 20171203 045527.480
Read the Direction Cosine Data from gd_1002_rays.dat
Finished Read direction cosines and starting Create OLTARIS materials. Time: 0.0146438167 20171203 045527.508
Creating OLTARIS Material Map
Part Number 1 and like BOM materials are mapped to OLTARIS material 1 aluminum
Part Number 64 and like BOM materials are mapped to OLTARIS material 2 polyethylene
Tissue was not found and is now mapped to OLTARIS material 3 and the BOM data updated with a fake tissue material for thk_combine.pl
Number of OLTARIS materials created: 3
Finished Create OLTARIS materials and starting Create and write RadICal data. Time: 0.0180975167 20171203 045527.715
Wrote the RadICal file hab1.thk on thread number 0
Wrote the RadICal file hab5.thk on thread number 4
Wrote the RadICal file hab3.thk on thread number 2
Wrote the RadICal file hab2.thk on thread number 1

```

```

Wrote the RadICal file hab4.thk on thread number      3
Finished Create and write RadICal data and starting Create and write AUX files. Time:      0.0193396500 20171203 045527.790
0.05 <= Part Density (g/cm^3) => 15: DSH_C_T 2.1285847E-02
0.05 <= Part Density (g/cm^3) => 15: DSH_IMAGERY_GN_C 1.2954195E-02
0.05 <= Part Density (g/cm^3) => 15: DSH_FIRE_DET_SUPPRESSION 1.5030188E-02
0.05 <= Part Density (g/cm^3) => 15: DSH_EVA 1.1321081E-02
0.05 <= Part Density (g/cm^3) => 15: DSH_STORM_SHELTER_BALLIST 3.2495904E+01
0.05 <= Part Density (g/cm^3) => 15: DSH-PROP-BASE-RING_1 8.0161392E+01
Wrote the density files hab.den_int and hab.den_rbr
Wrote the material map file hab.mmp
  61.0000000 B written to hab.trn
Wrote the trninput.dat file hab.trn
  31.0000000 B written to hab.btrn
Wrote the body trninput.dat file hab.btrn
The maxthick for Material Number 3 is smaller than 5.0000000E-02
Assume it is tissue and add up to 300 g/cm^2 of tissue
  Wrote hab.spt_spe - no size data available
  Wrote hab.spt_hze - no size data available
Wrote the spatial.dat file hab.spt
  Wrote hab.bspt_spe - no size data available
  Wrote hab.bspt_hze - no size data available
Wrote the body spatial.dat file hab.bspt
Finished Create and write AUX files and starting Create and write thickness distribution. Time: 0.0197713000 20171203 045527.816
Wrote Ray Thickness Distribution file hab1.prn
Wrote Ray Thickness Distribution file hab2.prn
Wrote Ray Thickness Distribution file hab3.prn
Wrote Ray Thickness Distribution file hab4.prn
Wrote Ray Thickness Distribution file hab5.prn
Finished Create and write thickness distribution and starting Create and write XML. Time:      0.0201382667 20171203 045527.838
Finished Create and write XML and starting Write the .matdef files. Time:      0.0239512167 20171203 045528.067
Finished Write the .matdef files and starting Write ray trace check files. Time:      0.0239563500 20171203 045528.067
Wrote RT Check file hab1.thkchk on thread number      0
Wrote RT Check file hab5.thkchk on thread number      4
Wrote RT Check file hab2.thkchk on thread number      1
Wrote RT Check file hab4.thkchk on thread number      3
Wrote RT Check file hab3.thkchk on thread number      2
Finished Write ray trace check files and starting Write BOM check files. Time:      0.0676508500 20171203 045530.689
Wrote BOM Check file hab2.bomchk on thread number      1
Wrote BOM Check file hab1.bomchk on thread number      0
Wrote BOM Check file hab5.bomchk on thread number      4
Wrote BOM Check file hab4.bomchk on thread number      3
Wrote BOM Check file hab3.bomchk on thread number      2
Finished Write BOM check files and starting Write Timing Data. Time:      0.0948298500
  PHASE          Phase Time (sec)  Phase Time (min)  Cumul Time (sec)  Cumul Time (min)  with assigned thread = 5
Initialization    0.0031670000      0.0000527833      0.0031670000      0.0000527833
Read and manipulate ray trace  0.7759840000      0.0129330667      0.7791510000      0.0129858500
Read and manipulate BOM      0.0160660000      0.0002677667      0.7952170000      0.0132536167
Create ray trace thicknesses  0.0547920000      0.0009132000      0.8500900000      0.0141668167
Read direction cosines      0.0286200000      0.0004770000      0.8786290000      0.0146438167
Create OLTARIS materials    0.2072220000      0.0034537000      1.0858510000      0.0180975167
Create and write RadICal data  0.0745280000      0.0012421333      1.1603790000      0.0193396500
Create and write AUX files    0.0258990000      0.0004316500      1.1862780000      0.0197713000
Create and write thickness dis  0.0220180000      0.0003669667      1.2082960000      0.0201382667
Create and write XML          0.2287770000      0.0038129500      1.4370730000      0.0239512167
Write the .matdef files      0.0003080000      0.0000051333      1.4373810000      0.0239563500
Write ray trace check files    2.6216700000      0.0436945000      4.0590510000      0.0676508500
Write BOM check files        1.6307400000      0.0271790000      5.6897910000      0.0948298500

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14. ABSTRACT Protecting astronauts from space radiation is a complex task when it comes to modeling and simulation. This document shows what information is needed from a spacecraft designer using CAD at each phase of the design to enable the engineers to evaluate the design phase against space radiation limits to determine the suitability of the design for spaceflight. The current personal exposure limits are listed in NASA STD-3001. A proxy to determine the REID (Radiation Exposure Induced Death) in NASA STD-3001 is the whole body effective dose equivalent (E or effective dose). For short-term tissue effects, organ averaged gray equivalent (GT) is used. The TARIS (for LaRC engineers) and OLTARIS (for designers) systems are used to generate these response functions. The E can use ICRP60 or NASA Q-values. A possible space radiation design basis environment for short-term tissue effects is described and used in all analyses. A single space vehicle was designed with three astronaut configurations and two of those configurations were used in a storm shelter thickness perturbation analysis. Conversion of the data from the CAD model to input necessary for TARIS and OLTARIS is also discussed in detail with relevant examples.					
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