



Astronaut Dose Calculations

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ISS Exploration TIM #4 - Radiation Environment and Risk Analysis At and
Near the Lunar Surface: Cis-lunar Vehicle Requirements

ESA Permanent Mission in the Russian Federation
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- Goals
- Protocol Actions and Results
 - Dose in Concentric Spheres
 - Astronaut in an Aluminum Sphere
 - Astronaut in Realistic Spacecraft Geometry
- Background Information about Calculation Methods
 - OLTARIS
 - Ray-Tracing and Transport Calculation Options
 - Astronaut Body Models

- The Protocol Actions for Astronaut Dose Calculations were developed to provide participating agencies an opportunity to compare results best on their best practices.
- The results presented here were calculated using the HZETRN space radiation transport code and human response models developed for the On-Line Tool for the Assessment of Radiation in Space (OLTARIS).
- Two sets of results are presented:
 - The first set, labelled TARIS 4.0, were calculated using the latest version of the space radiation analysis tools developed for OLTARIS, but not yet incorporated into OLTARIS.
 - The second set, labelled OLTARIS (TARIS version 3.5), were calculated with the current version of OLTARIS and TIM participants should be able to reproduce these results.

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 1 – Dose in Concentric Spheres



Calculate absorbed dose and dose equivalent (or equivalent dose) in a 30 cm diameter water sphere at the center of a 400 cm diameter aluminum sphere with a wall thickness of 27 g/cm² (similar to calculations presented by JAXA).

- Use a free space GCR environment corresponding to the 1997 solar minimum – use Agency-specified GCR model
- Use Agency-specified transport code
- Use Agency-specified quality factor or radiation weighting factors

Due 1 October, 2017

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 1 - Dose in Concentric Spheres - Results



	Dose in Silicon (mGy/day)	Dose in Tissue (mGy/day)	Dose Equivalent (ICRP 60) (mSv/day)	Dose Equivalent (NASA Q – Solid Cancer) (mSv/Day)	Dose Equivalent (NASA Q – Leukemia) (mSv/Day)
Best Result (TARIS version 4.0)	0.26	0.32	0.83	0.53	0.90
Best OLTARIS Result (TARIS version 3.5)	0.25	0.31	0.77		

Best Results (TARIS version 4.0):

- Dose calculated at the center of the water sphere.
- The latest versions of codes developed for OLTARIS but not yet implemented in OLTARIS (TARIS version 4.0) were used.
- The 2014 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

Best OLTARIS Results (TARIS version 3.5):

- Dose calculated at the center of the water sphere.
- OLTARIS (TARIS version 3.5) was used.
- The 2010 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

Note: The difference between the TARIS 4.0 ICRP 60 dose equivalent and the TARIS 3.5 ICRP 60 dose equivalent is mostly due to the addition of a neutron-hydrogen elastic recoil production channel in the light ion cross section routines. Switching between the 2010 and 2014 versions of the Badhwar-O'Neill environment only changes the ICRP 60 dose equivalent by ~1% for this geometry.

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 2 – Astronaut in an Aluminum Sphere



Calculate absorbed dose and dose equivalent (or equivalent dose) in the skin and Blood Forming Organs (BFO) in a realistic human phantom at the center of a 400 cm diameter aluminum sphere with a wall thickness of 27 g/cm².

- Identify and use Agency-specified phantom

Due 1 April, 2017

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 2 – Astronaut in an Aluminum Sphere – Results



Dose	Dose in Skin (mGy/day)	Dose in BFO (mGy/day)
TARIS version 4.0 - Male	0.35	0.33
TARIS version 4.0 - Female	0.35	0.34

Dose Equivalent	Dose Eq in Skin (ICRP 60) (mSy/day)	Dose Eq in BFO (ICRP 60) (mSy/day)	Dose Eq in Skin (NASA Q – Solid Cancer) (mSv/day)	Dose Eq in BFO (NASA Q – Leukemia) (mSv/Day)
TARIS version 4.0 - Male	0.99	0.84	1.04	0.53
TARIS version 4.0 - Female	0.99	0.85	1.04	0.54
OLTARIS (TARIS version 3.5) – Male	0.96	0.79		
OLTARIS (TARIS version 3.5) – Female	0.96	0.81		

TARIS version 4.0:

- TARIS version 4.0 codes were used
- The 2014 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

OLTARIS (TARIS version 3.5):

- OLTARIS (TARIS version 3.5) was used
- The 2010 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 3 – Astronaut in Realistic Spacecraft Geometry



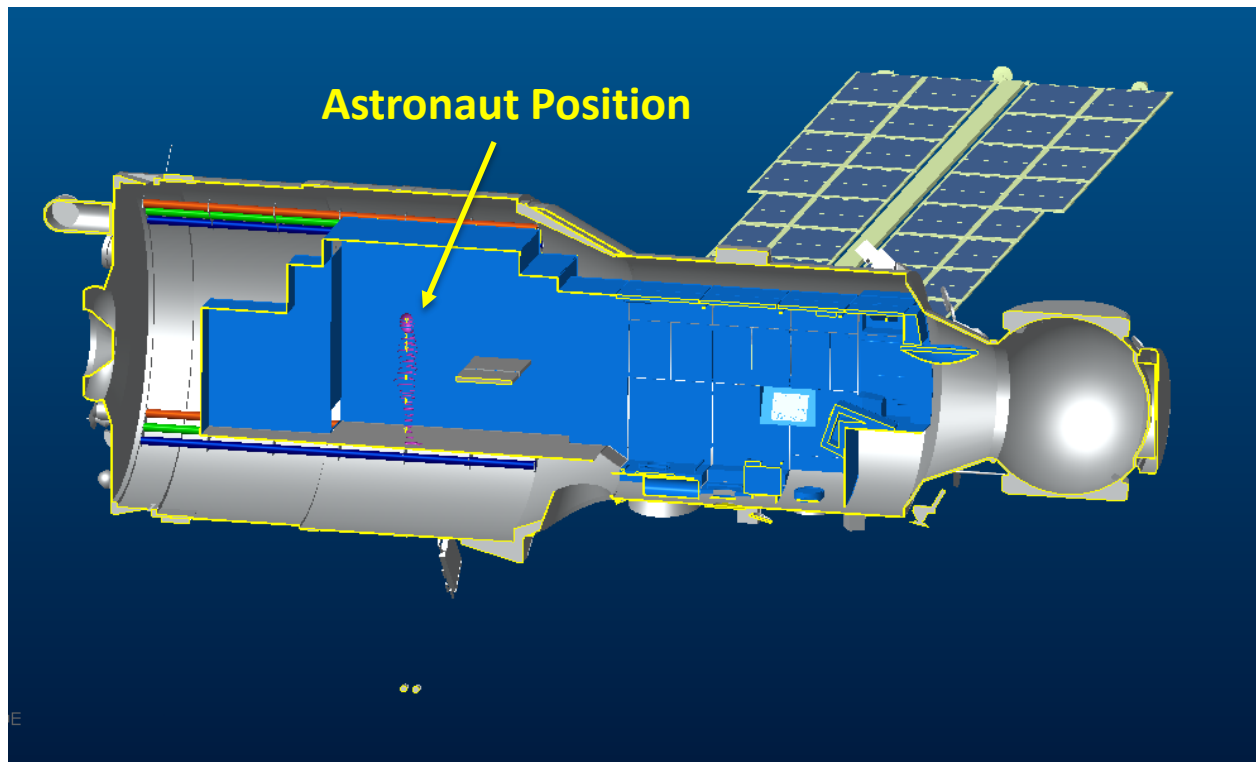
Calculate absorbed dose and dose equivalent (or equivalent dose) in the skin and BFO in a realistic human phantom inside a realistic space habitat to represent the space habitat. CAD models will be exchanged as necessary.

- Use the same free space GCR environment as used for previous calculations.

Due 1 October, 2017

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 2 – Astronaut in Realistic Spacecraft Geometry – **Habitat Model**



- A CAD model of the ISS Russian Service Module was used for this analysis
- Calculations were performed for free space GCR environments

TIM #3 Protocol Actions for Astronaut Dose Calculations

Part 2 – Astronaut in Realistic Spacecraft Geometry – Results



Dose	Dose in Skin (mGy/day)	Dose in BFO (mGy/day)
TARIS version 4.0 - Male	0.36	0.34
TARIS version 4.0 - Female	0.36	0.34

Dose Equivalent	Dose Eq in Skin (ICRP 60) (mSy/day)	Dose Eq in BFO (ICRP 60) (mSy/day)	Dose Eq in Skin (NASA Q – Solid Cancer) (mSv/day)	Dose Eq in BFO (NASA Q – Leukemia) (mSv/Day)
TARIS version 4.0 - Male	1.24	0.93	1.25	0.55
TARIS version 4.0 - Female	1.24	0.96	1.26	0.56
OLTARIS (TARIS version 3.5) – Male	1.18	0.88		
OLTARIS (TARIS version 3.5) – Female	1.18	0.91		

TARIS version 4.0:

- TARIS version 4.0 codes were used
- The 2014 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

OLTARIS (TARIS version 3.5):

- OLTARIS (TARIS version 3.5) was used
- The 2010 version of the Badhwar-O'Neill free space (1 AU) GCR environment was used.

Background Information about Calculation Methods

To access OLTARIS, go to <http://oltaris.nasa.gov> and request an account.

National Aeronautics & Space Administration

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Type:

Comments:

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Response Functions

☒ Differential Fluence: Differential Fluence after Transport (Function of Depth, Energy and Isotope)

☒ Dose: Dose in

☒ Dose Equivalent: Uses ICRP 60 quality factor

☒ Effective Dose Equivalent: Whole body quantity, uses anatomical model and ICRP 60 quality factor, also computes Avg. Dose Equivalent to BFO, skin, and lens. Use the drop down list below to select the anatomical model:

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☐ TLD-100: TLD = Thermo-Luminescent Dosimeter

☐ TEPC: TEPC = Tissue Equivalent Proportional Counter

☐ LET: LET in

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Project Summary

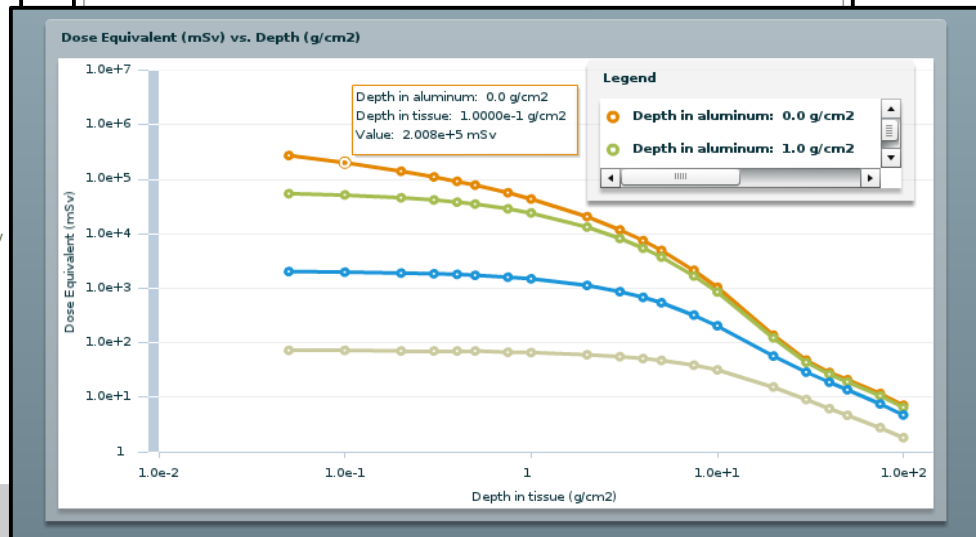
Project Name: SPE_sample
Project Description: [No Comment]
SPE defined by Historic Event: August 1972 (King) multiplier=1.0
Thickness Distribution Name: STS_dloc2 (968 rays)
Grid Engine Id: 2089108

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Event Totals

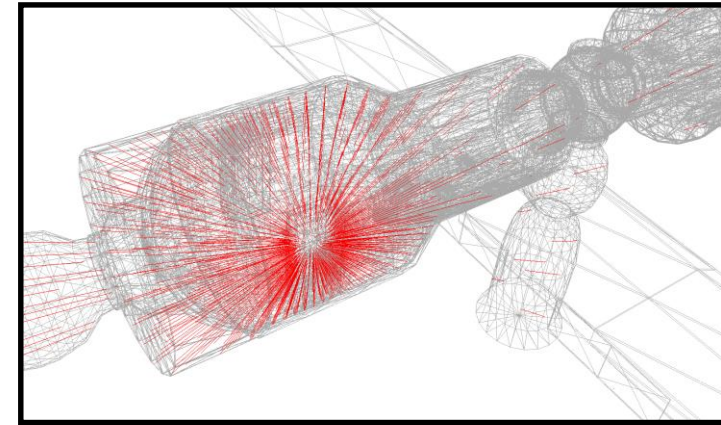
Data	Value	
Dose at point 1	8.690E+03 mGy	+ Sphere Viewer
Dose Equivalent at point 1	1.561E+04 mSv	+ Sphere Viewer

Whole Body Effective Dose Equivalent & Average Organ Dose Equivalent Values



Ray-Tracing and Transport Calculation Options

- Ray-tracing is the first step in NASA's radiation analysis process:
 - The thickness of each type of material is evaluated along each of a large number of evenly distributed rays emanating from the dose point.
- OLTARIS offers two transport options:
 - Ray-by-ray calculations:
 - The transport of the external environment is calculated along each ray, for the material thicknesses in the ray-trace.
 - A “forward-backward” approximation is used in which the direction of motion of both the primary and secondary particles is either the same as the direction of the incident particle or directly opposite (180°) the direction of the incident particle.
 - Interpolation calculations:
 - The transport of the external environment is pre-run through a variety of combinations of aluminum, polyethylene, and human tissue, and a dose versus shield thickness matrix is created.
 - For these calculations, a “straight-ahead” approximation is used which assumes that all primary and secondary particles move in the same direction as the incident primary particle.
 - The dose calculated for each ray by interpolating over the dose versus shield thickness matrix.
 - This method is much faster!
- A new 3D version of HZETRN has been developed and is currently being tested for complex vehicle and human body geometry.

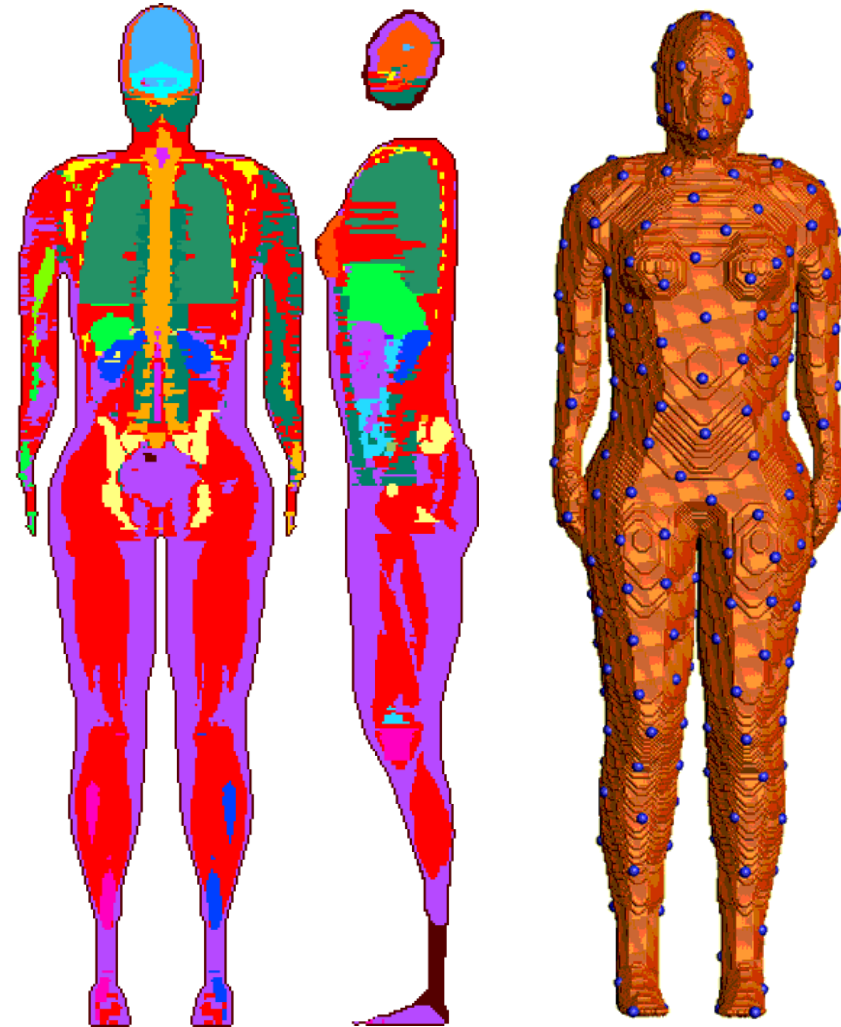


Example of Spacecraft Ray-Trace

Note: The error introduced by using the faster interpolation method varies depending on space environment and vehicle geometry. For the calculations presented here, differences were $< 1\%$ for spherical geometry and $< 5\%$ for the service module calculations.

Astronaut Body Models

- Astronaut exposure calculations utilize the Male and Female Adult voxel models (MAX/FAX)^{1,2}.
 - Developed in 2005 to match ICRP reference humans
- HZETRN calculates dose or dose equivalent at a point.
- Organ doses are calculated by calculating dose or dose equivalent at a large number of points and averaging.
- Organ/tissue dose points have been identified^{3,4} and ray-traced.
 - ~200 BFO points and ~200 skin points
- OLTARIS users can choose to combine these body ray-traces with their spacecraft geometry to calculate organ averaged dose equivalent and whole body effective dose.



FAX Cutaway Views

229 Skin Points in FAX

¹Kramer, R., et al., Physics in Medicine and Biology, Vol. 48, pp. 1239-1262, 2003.

²Kramer, R., et al., Physics in Medicine and Biology, Vol. 49, pp. 5203-5216, 2004.

³Slaba, T.C., et al., NASA Technical Paper 215562, 2009.

⁴Slaba, T.C., et al., Advances in Space Research, Vol. 45, , pp. 866-883, 2010.

Quality Factors

ICRP 60 Quality Factor:

$$Q(L) = \begin{cases} 1 & L > 10 \text{ keV}/\mu\text{m} \\ 0.32L - 2.2 & 10 - 100 \\ 300/\sqrt{L} & L > 100 \end{cases}$$



The ICRP 60 quality factor is a function of Linear Energy Transfer (LET or L).

NASA Quality Factor⁺:

$$Q_{NASA} = (1 - P(Z, E)) + \frac{6.24(\Sigma_0 / \alpha_\gamma)}{LET} P(Z, E)$$



The new NASA direction has distinct quality factors for solid cancer and leukemia and the LET dependence is replaced with a dependence on $(Z^*/\beta)^2$.

where:

$$P(Z, E) = (1 - \exp(-Z^{*2} / \kappa\beta^2))^m \quad \text{and}$$

Table 6.3. Cancer risk cross section or QF parameters for solid cancer and leukemia risks.*.

Parameter	Solid Cancer	Leukemia
m	3	3
κ	550 (1000)	550 (1000)
$\Sigma_0/\alpha_\gamma, \mu\text{m}^2 \text{ Gy}$	7000/(6.24)	1750/6.24
E_{TD}	0.2 MeV/u	0.2 MeV/u

*Values in parenthesis for when distinct values for light ions ($Z \leq 4$) are to be used.



We look forward to seeing how these calculation results compare with your results!