Deep Space Habitat Project

Radiation Studies for a Long Duration Deep Space Transit Habitat

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10/31/2012

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Outline

Inside this package:

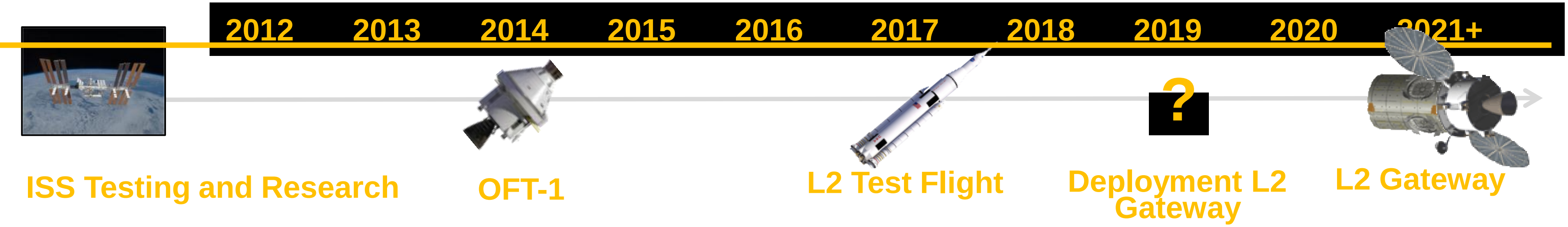
- ❑ **Introduction and Background**
- ❑ **Deep Space Habitat (DSH) Architectural /GCR Analysis**
- ❑ **DSH Conclusions on Galactic Cosmic Radiation**

Presentation Purpose and Background

- **The purpose of this presentation is to show data and conclusions from radiation analysis conducted of Deep Space Habitat Project architectures**

- **A new charter was initiated for the AES Deep Space Habitat Project at the beginning of FY2012 (October 2011)**
  - Initiate development effort for a deep space transit habitat that would be manned for a minimum of 365 consecutive days, without crew changeout or provisioning resupply during that period
  - Focus on the most pressing engineering challenges for a 1-year vehicle
  - Include a launch packaging option that could utilize ELVs (in addition to SLS)

- **The Human Exploration Architecture roadmap showed the first deep space facility launching in 2019, to be manned by 2021**



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Concept Architecture

- The intent would be to mature a deep space vehicle concept that could be produced in an accelerated, expeditious approach with minimal launch packages/weight/power/volume
  - ✓ Leverage off of ISS module capabilities/knowledge base (e.g. Hab, MPLM, node)
  - ✓ Address GCR as one of the key focuses of attention

- A concept architecture was evaluated during FY 2012 that was produced by MSFC in the previous fiscal year for our DSH project, referred to as the ISS-Derived Architecture for a Deep Space Habitat

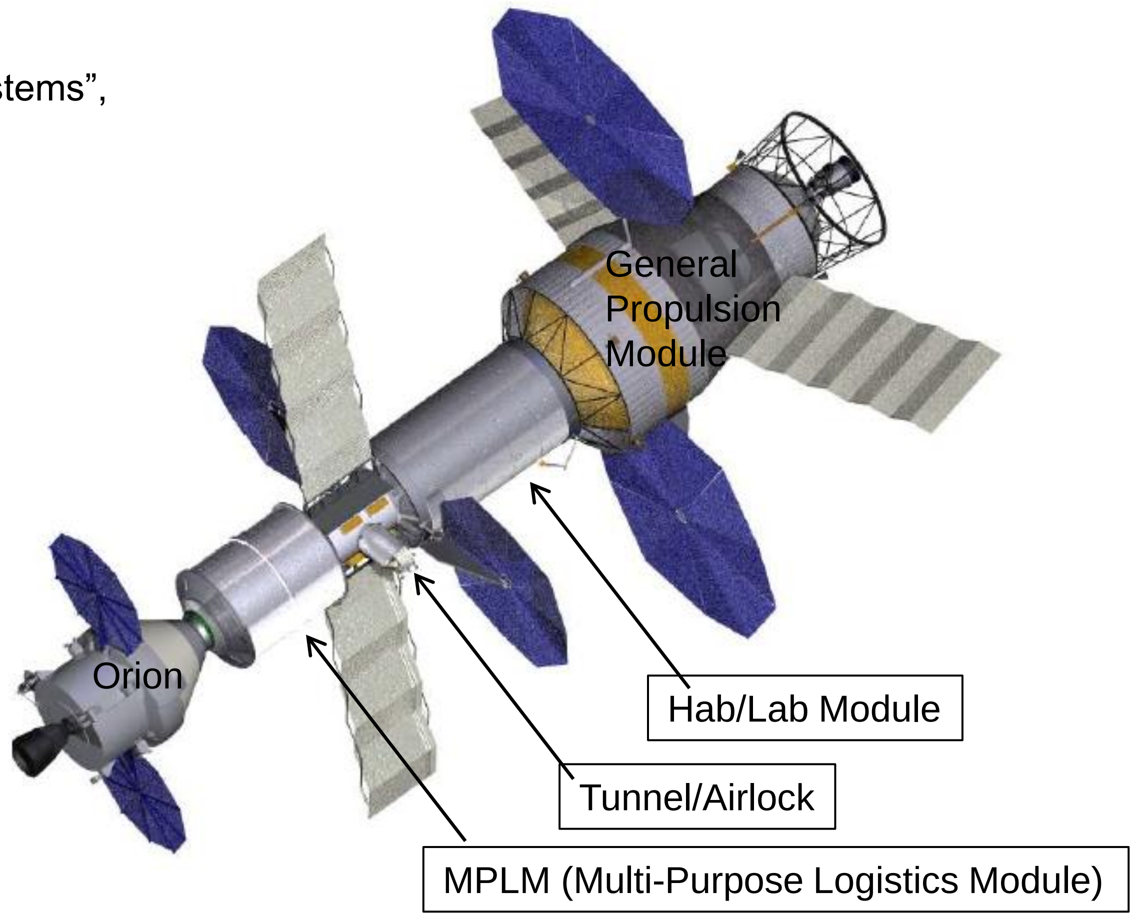
*MSFC study/ ISS-Derived Deep Space Facility

500-Day

*Reference chart from "DSH Configurations based on ISS Systems", D. Smitherman, et al, 12/2011.

This transit habitat consists of three basic elements:

1. an ISS Hab/Lab Module
2. a Tunnel/Airlock
3. an ISS MPLM



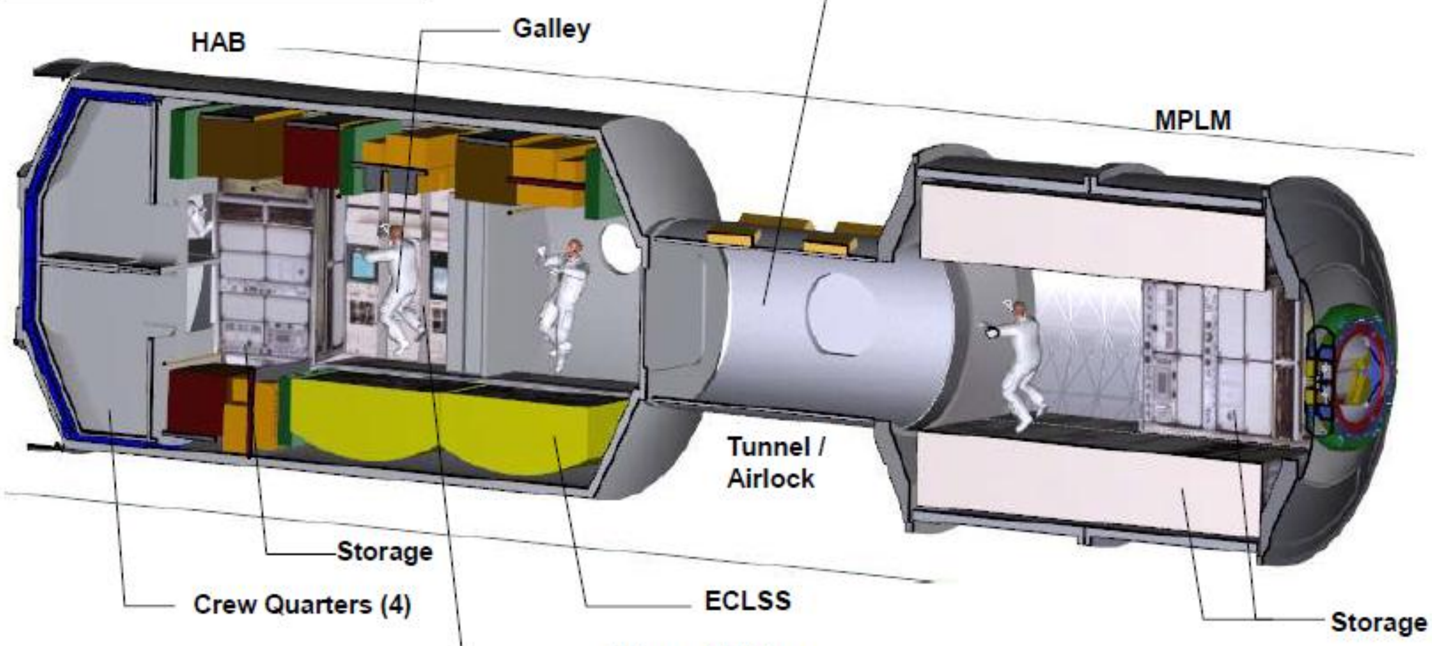
*MSFC study/ ISS-Derived Deep Space Facility

500-Day Configuration

500-day DSH: **45.5 mtons**
Pressurized volume = ~ 193 m^3
Habitable volume = ~ 90 m^3
Stowage volume = ~ 49 m^3

Habitation capability:
4 crewmembers

Service Tunnel / Airlock:
Pressurized volume = ~ 10 m^3
Habitable volume = ~ 9 m^3



HAB:
Pressurized volume = ~ 107 m^3
Habitable volume = ~ 56 m^3
Stowage volume = ~ 16 m^3

MPLM:
Pressurized volume = ~76 m^3
Habitable volume = ~ 25 m^3
Stowage volume = ~ 33 m^3

*Reference chart from “DSH Configurations based on ISS Systems”, D. Smitherman, et al, 12/2011.

Existing ground ISS Assets*

- N1-STA, MPLM, and Hab modules

Raffaello MPLM FM2 at KSC SSPF

US Hab shell at MSFC Building 4755

Node 1 STA at KSC SSPF

*Reference chart from "ISS-Derived DSH Testing", K. Kennedy, 01/2012.

SE&I Architectural/Galactic Cosmic Radiation Analysis

Addressing GCR

Focus on GCR:

- **It can be viewed as the sound barrier we must break through to achieve real space exploration**
    - **Without addressing this challenge, we cannot conduct space travel and exploration for durations beyond our ~180-day limit, using architectures that employ reasonable risk-reduction methods**

- **What we can do:**

Embark on pursuing a best-effort solution that implements a smart architecture (beginning with use of current ISS elements), incorporates little/no additional dead mass shielding, and meets requirements in the middle as best possible

DSH Results to Date

Galactic Cosmic Radiation (GCR)

- Will show a brief top-level primer on GCR
- Will show the substantive results and data from recent analysis steered by this effort
  - Crew lifetime exposure limits (example/approximation)
  - GCR analysis of the ISS-derived architecture for a one year exposure
  - Shield sizing for GCR using Aluminum, Polyethylene, water, and liquid hydrogen
  - GCR analysis of a “hub and spoke” architecture for a one year exposure

DSH Results to Date

❖ RADIATION PRIMER

❑ Radiation exposure in space is grouped into two general categories:

1) Solar Particle Events (SPE)

2) Galactic Cosmic Radiation (GCR)

Definition comparison

❑ Radiation Primer, continued

SPE	GCR
✓ Occasional, infrequent events occurring most often during solar cycle maximum (~11-year cycles)	✓ Occurs all day every day, varying in flux with solar cycle (lower GCR levels occur during solar maximum)
✓ Monitoring of SPE radiation events is performed, and can be reported in a timely manner to the crew to seek shelter in a specified area containing shielding for short periods if deemed necessary	✓ Is omni-directional in addition to being continuous, so having a small designated area as a temporary shelter that contains shielding is not a solution option (also, outside LEO, magnetic field not present to help protect against GCR)
✓ **High flux but lower energy and are only for brief periods**	✓ **Moderate flux but much higher energy -- all day, every day**

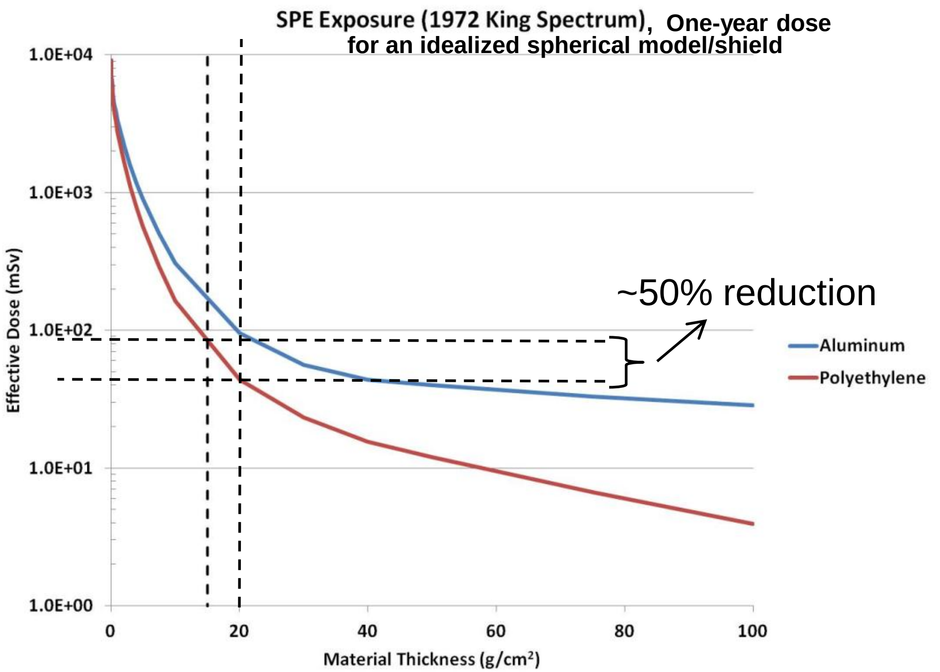
Shielding Effectiveness Comparison

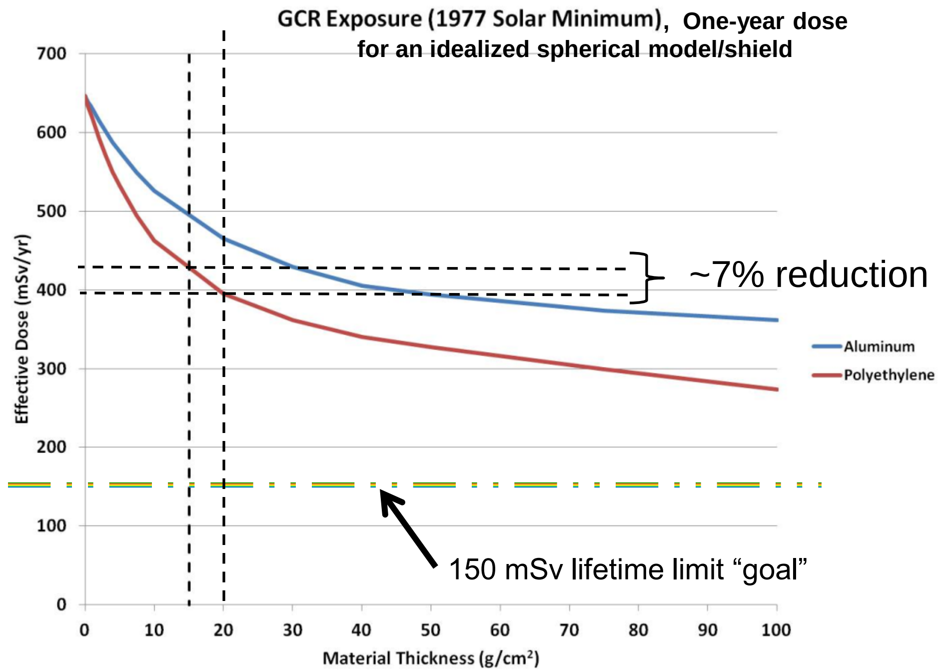
❑ Radiation Primer, continued

SPE

Shielding is not conducive for protecting against GCR.

GCR





SPE radiation is effectively curtailed by shielding.

GCR radiation does not respond very favorably to shielding. Shielding has much less effectiveness against GCR.

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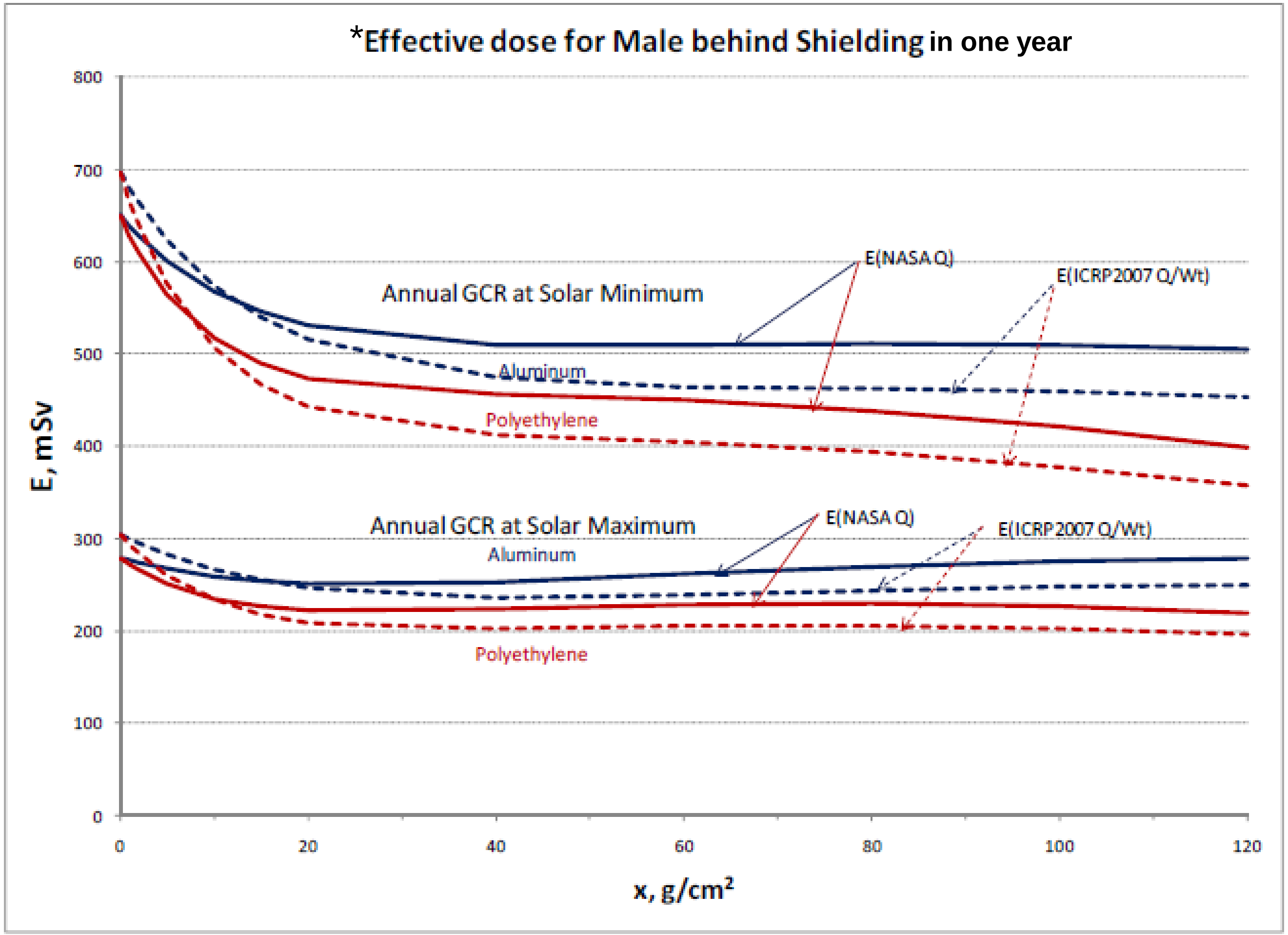
Effect of Solar Cycle on GCR Exposure



*Reference chart from "Space Radiation Risk Mission Analysis with the NASA 2012 Cancer Model", Dr. F. Cucinotta/NASA JSC

Permissible Exposure Limits (PEL), Stochastic Effects, and Risk of Exposure-Induced Death (REID)

- Predictive analysis results showing crew lifetime radiation exposure limit data and goals

*Permissible Exposure Limits
Stochastic Effects

Risk of Exposure Induced Death (REID)

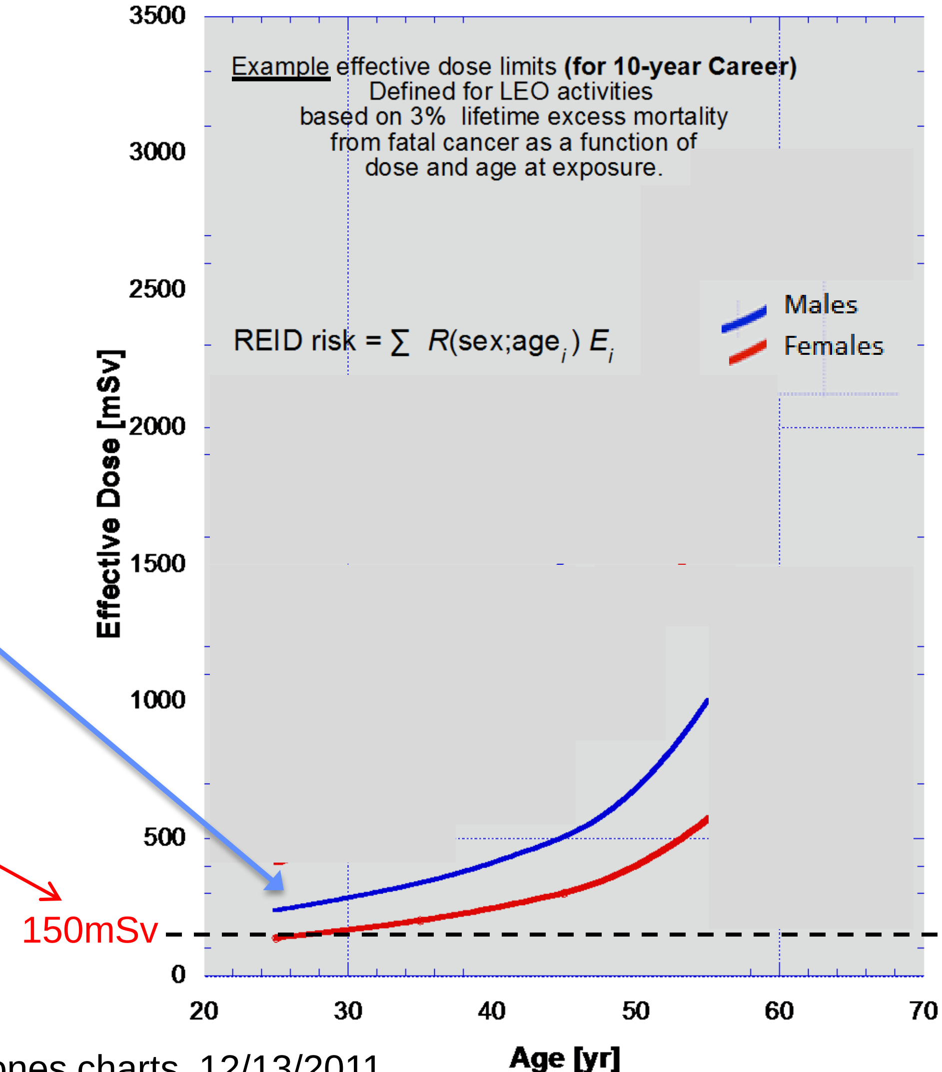
due to cancer is limited to

≤ 3% at a 95% confidence level

Cancer incidence is reported as well

and is usually ~1.5x higher than mortality

SRAG recommends 150 mSv as crew lifetime exposure limit goal



*Reference: Edward Semones charts, 12/13/2011

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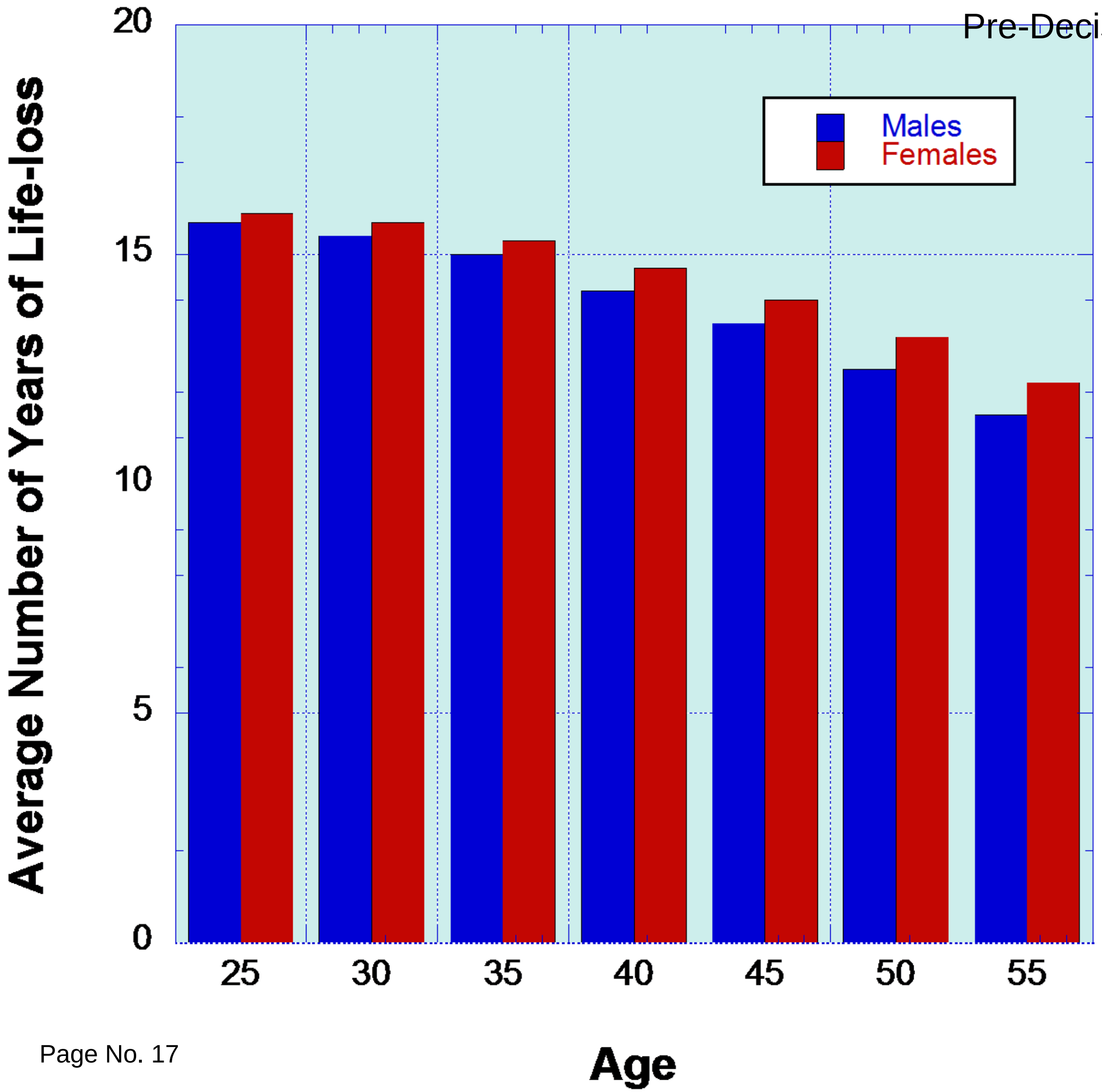
*Projected Average Years of Life Lost per Death for an Exposure-induced Cancer for Exposure Limit to 3% REID

*Reference: Edward Semones charts, 12/13/2011

Pre-Decisional, For Internal Use Only



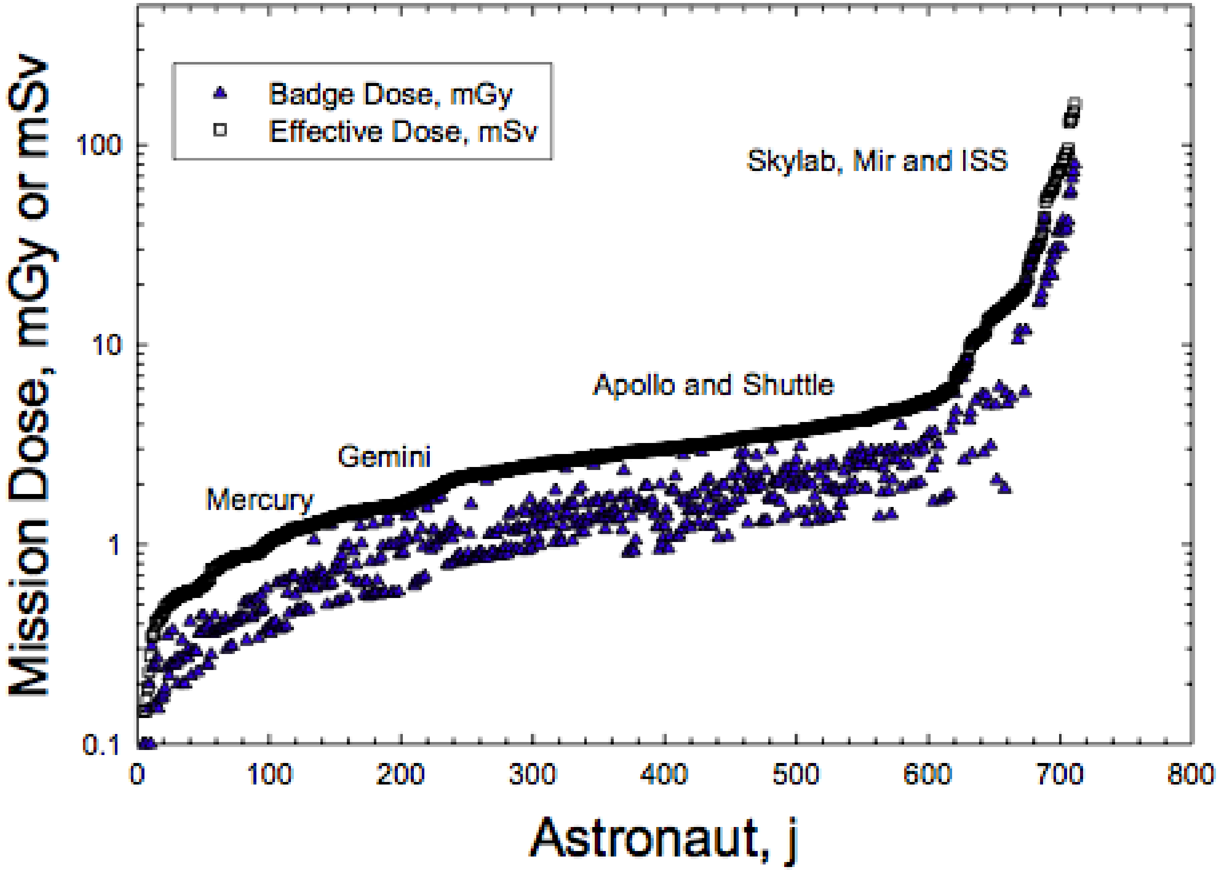
Astronaut exposures have not exceeded the REID limit estimate and thus they have lower “average” number of years of life-loss

NASA-STD-3001, Volume 1

Table 3—Example Career Effective Dose Limits in Units of Sievert (mSv) For 1-year Missions and Average Life-loss for an Exposure-induced Death for Rradiation Carcinogenesis (1 mSv= 0.1 rem)

	E(mSv) for 3% REID (Ave. Life Loss per Death, yr)	
Age, yr	Males	Females
25	520 (15.7)	370 (15.9)
30	620 (15.4)	470 (15.7)
35	720 (15.0)	550 (15.3)
40	800 (14.2)	620 (14.7)
45	950 (13.5)	750 (14.0)
50	1150 (12.5)	920 (13.2)
55	1470 (11.5)	1120 (12.2)

*Mission Doses



*Reference: Edward Semones charts, 12/13/2011

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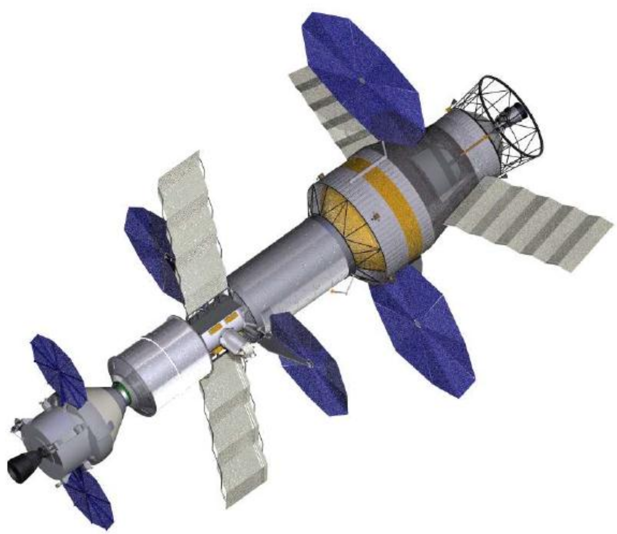
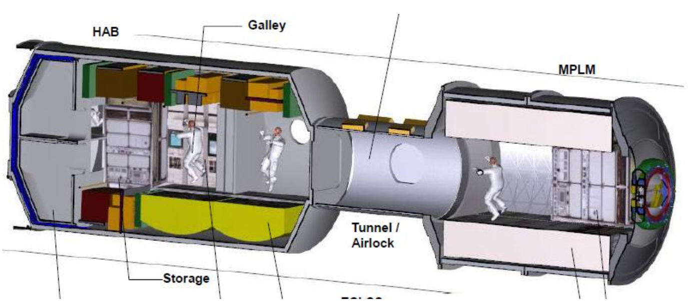
Analysis results of an ISS-derived architecture exposed to 365-days of GCR at EML1





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ISS-Derived Stack Example*

❑ Environment:

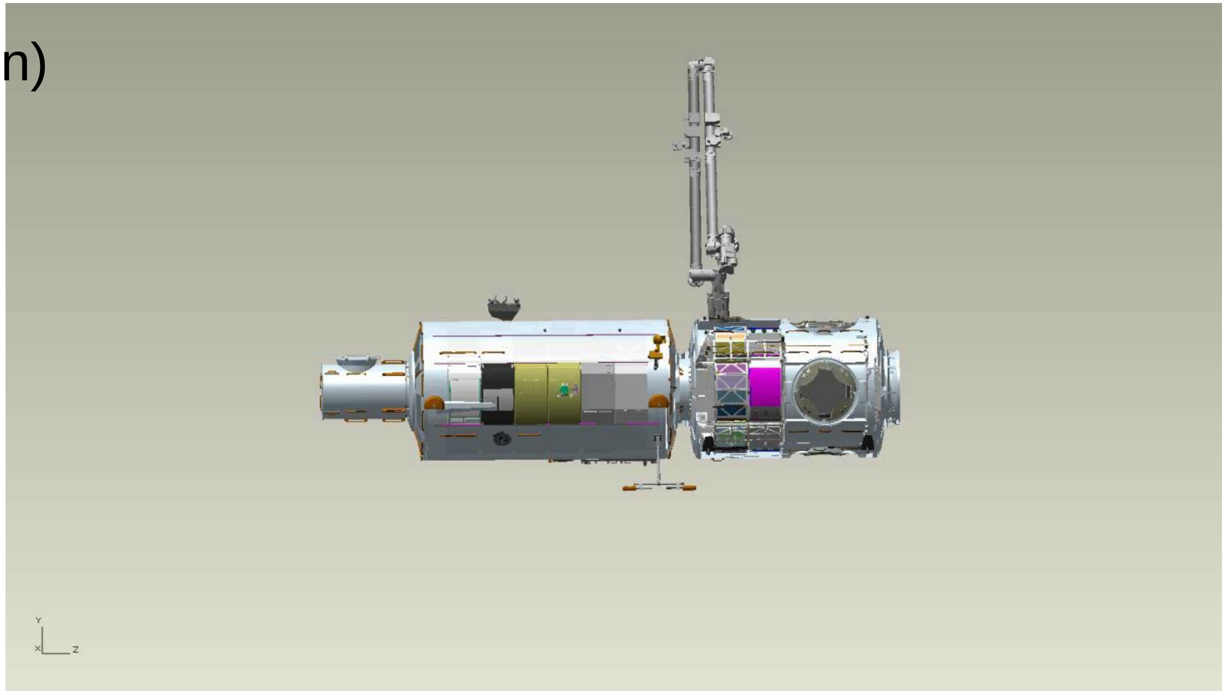
- GCR (1977 Solar Min)

❑ Vehicle Model:

- Crew Lock+Lab+Node

❑ Transport:

- HZETRN code
- Five dose locations examined

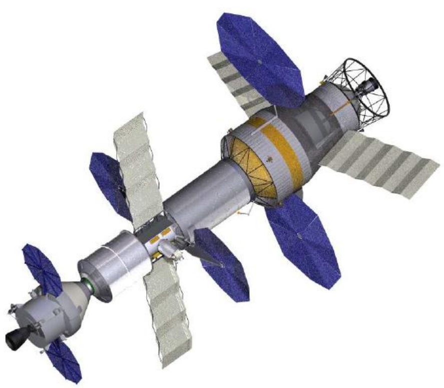


*Reference: Janet Barzilla charts, 04/30/2012

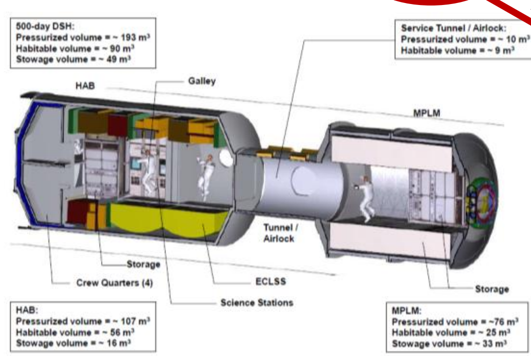
ISS-Derived, GCR Analysis Example

- **The DSH ISS-derived concept is an in-line architecture that was analyzed for GCR protection performance at EML1/L2 for 365 consecutive days of exposure**
  - Five "dose points"/locations inside this type architecture, using actual ISS module models, resulted in a range of internal dosage from **394 to 456 mSv**

Initial DSH Architecture/Point of Departure:
***MSFC study/ ISS-Derived Deep Space Facility**



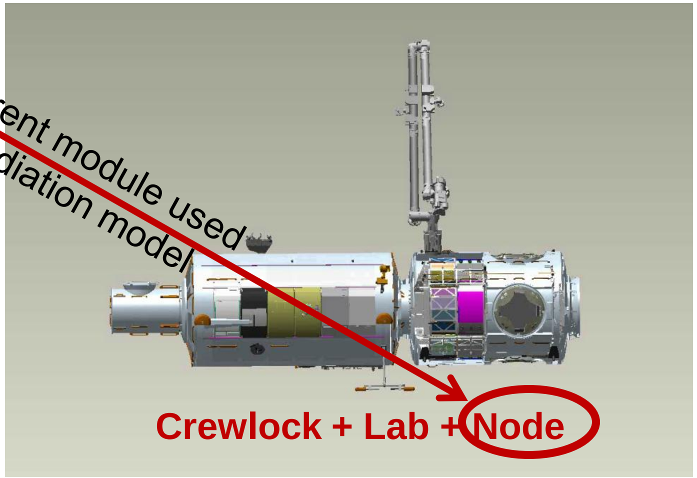
Lab + A/L tunnel + MPLM



Different module used in radiation model

*Reference from "DSH Configurations based on ISS Systems", D. Smitherman, et al, 12/2011.

Radiation Analysis Model of Similar ISS Elements



Crewlock + Lab + Node

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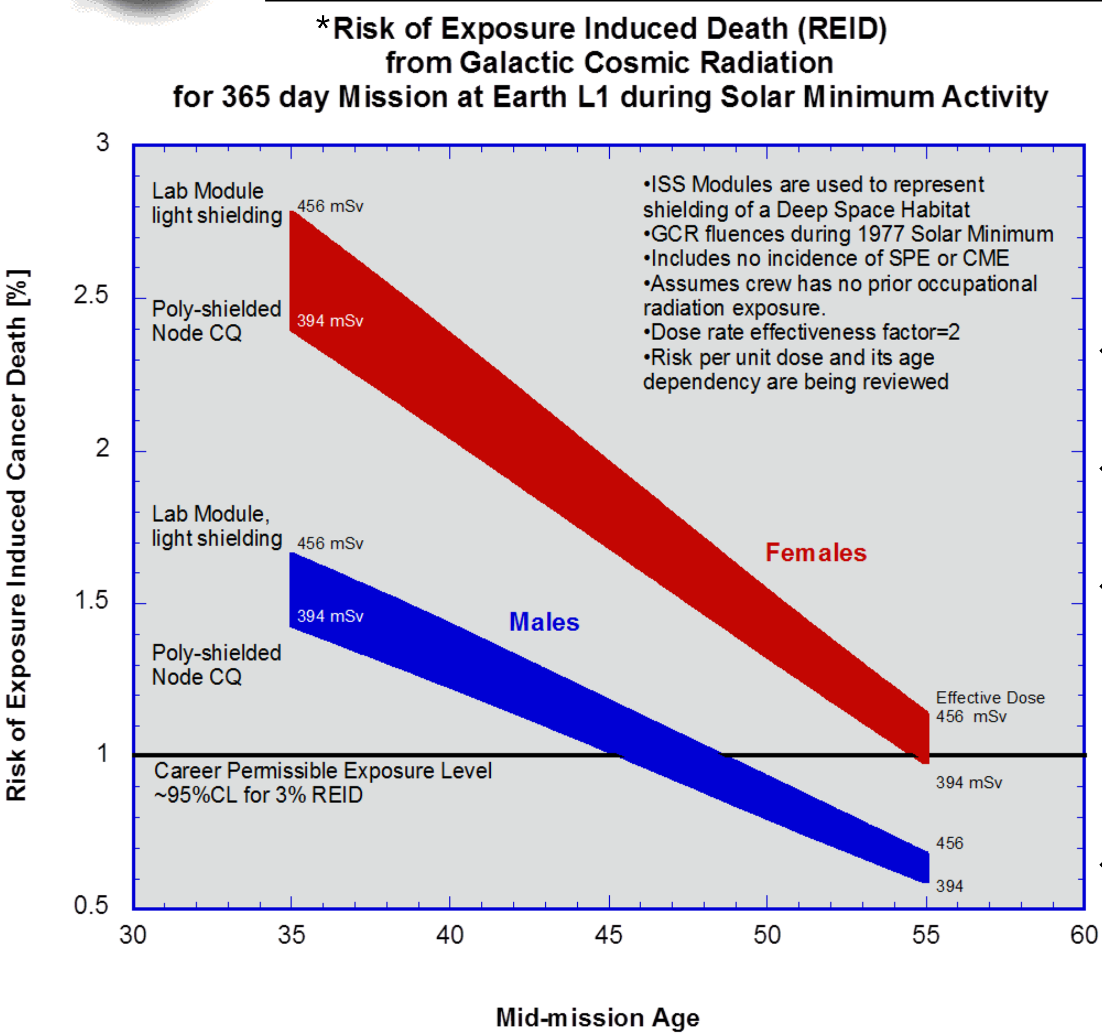
Risk of Exposure-Induced Death



*Analysis Reference: Janet Barzilla charts, 04/30/2012, Pre-Decisional

For illustration purposes only, not representative of formal exploration limits

Notionally, this suggests that for a typical ISS structure exposure to 1 year at EML1:

- **Males about 47 years old or older are in range**
- **Females about 57 years old or older are in range**
- **Recall: design target GCR exposure of 150 mSv Effective Dose --- these dose values are 2 – 3 times higher**
  - Far away from arriving at 150 mSv
- **Multiply these doses by 500+ days divided by 365 days for a short trip to Mars → these radiation values are a "broke" for Mars/NEA space travel meeting the 3%REID at 95%CL at solar minimum levels**

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Monolithic shield sizing for GCR: Aluminum, Polyethylene, water, liquid hydrogen

* GCR SHIELD SIZING

WHAT IS THE WEIGHT OF THE SHIELDING MASS NEEDED TO COMPLETELY ENCLOSE A CYLINDRICAL HABITAT AT DIFFERENT AREAL DENSITIES BETWEEN 10 AND 1000 G/CM^2?

INCLUDES BASELINE VEHICLE AND SUPPLEMENTARY SHIELDING MASS

EXAMPLE:

ONE ISS LAB MODULE IS APPROXIMATELY :

A CYLINDER 7 METERS LONG AND 5 METERS IN DIAMETER (A = 149 M^2; V = 137 M^3)

*Reference: Dr. S. Koontz charts, 01/31/2012

Shielding a small portion of the vehicle total habitable volume, say a cylinder 7 meters long and 5 meters in diameter (A = 149 m^2; V = 137 m^3) possibly feasible if launch costs and shielding mass requirements are low enough

Approximated shielding estimate for an ISS Lab Module

Shielding mass (g/cm^2)	Shielding mass (kg)	Shielding launch cost ($50,000/kg)	Shielding launch cost ($5,000/kg)
1000	1.49×10^6	\$9.7 $\times 10^{10}$	\$9.7 $\times 10^9$
500	7.4×10^5	\$1.9 $\times 10^{10}$	\$1.9 $\times 10^9$
100	1.5×10^5	\$9.6 $\times 10^9$	\$9.6 $\times 10^8$
50	7.5×10^4	\$4.8 $\times 10^9$	\$ 4.8 $\times 10^8$
10	1.5×10^4	\$9.6 $\times 10^8$	\$9.6 $\times 10^7$

Once again - The numbers used in the calculations are only estimates for the purpose of working the sample problem and do not represent any official NASA design or planning data

*Reference: Dr. S. Koontz charts, 01/31/2012

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* Physical thickness corresponding to areal densities

Areal density g/cm^2	Aluminum Density = 2.7 g/cm^3	Polyethylene or Water Density = 1.0 g/cm^3	Liquid Hydrogen Density = 0.07 g/cm^3 Boiling point = 20.28º K
1000	370 cm (146 in)	1,000 cm (394 in)	14, 285 cm (5624 in)
500	185 cm (72.8 in)	500 cm (197 in)	7,142 cm (2812 in)
100	37 cm (14.5 in)	100 cm (39.4 in)	1, 428 cm (562 in)
50	19 cm (7.5 in)	50 cm (20 in)	714 cm (281 in)
10	3.7 cm (1.5 in)	10 cm (4 in)	142 cm (56 in)

Thickness in cm = (areal density in g/cm^2)/(density in g/cm^3)

***Reference: Dr. S. Koontz charts, 01/31/2012**

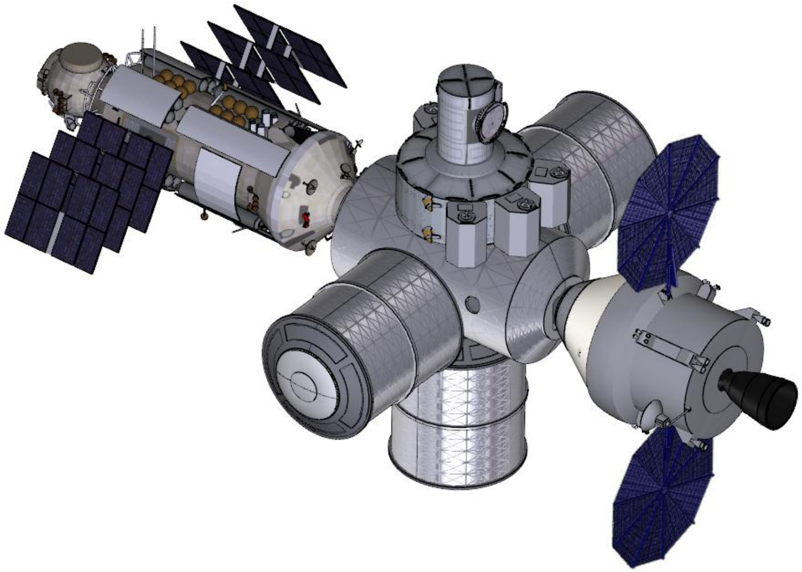
DSH SE&I Study, continued

❑ Radiation Remarks

- Although SPE shielding in the form of a specific storm shelter area will be incorporated into the DSH, we would not expect to generically use dead mass shielding as a primary go-forward solution for GCR

- Continued architecture pathfinding study by investigating and conducting radiation analysis of a “surrounded” architecture, the “hub and spoke”

Analysis results of a "surrounded" architecture exposed to 365-days of GCR at EML1



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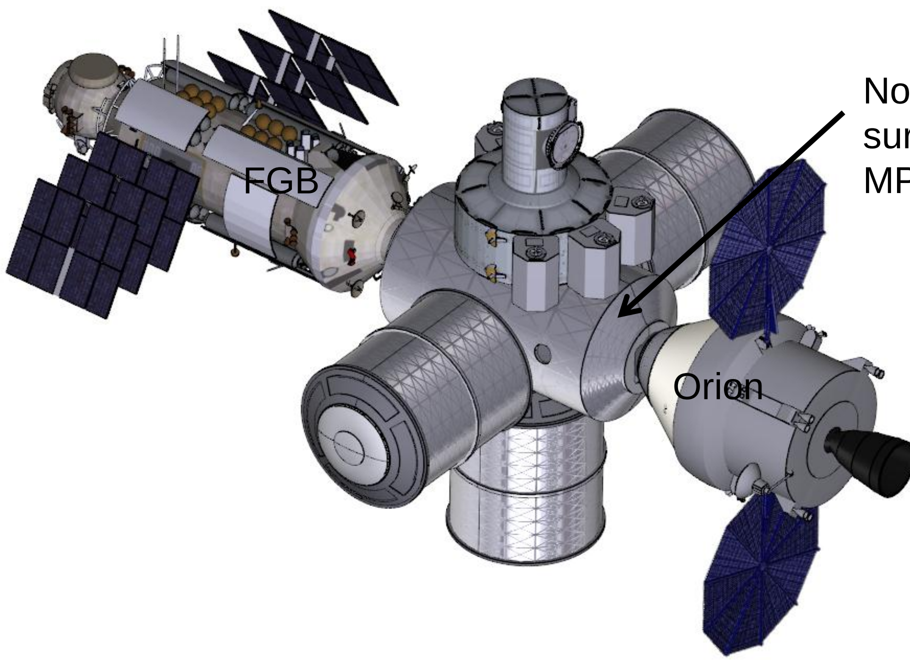
Hub and Spoke Architecture

- **Hub and Spoke: centralized Node module that acts as a "core/hub", which possesses an internal layout where most of the crew activity takes place most of the time**
  - Surround the core/hub with major structural elements that contain logistics, equipment, trash, prop, etc



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Comparison

The hopeful expectation would be that GCR analysis of the surrounded architecture would show a measurable shielding mass increase above the in-line version …

this in-line architecture <g/cm^2 **this surrounded architecture**

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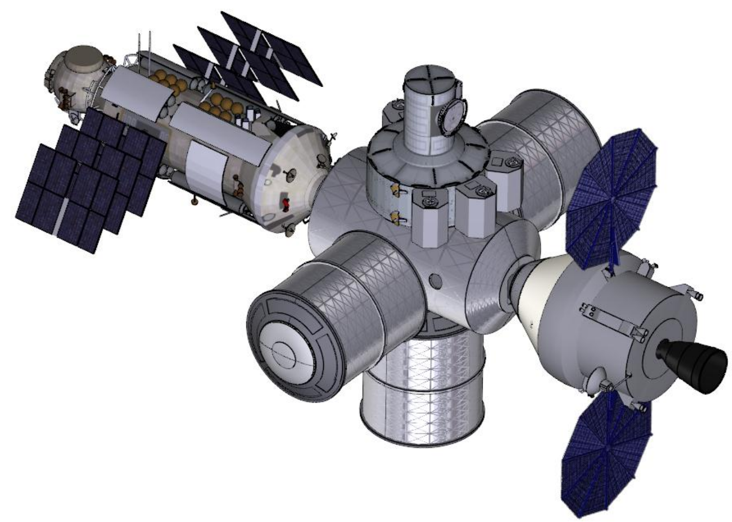
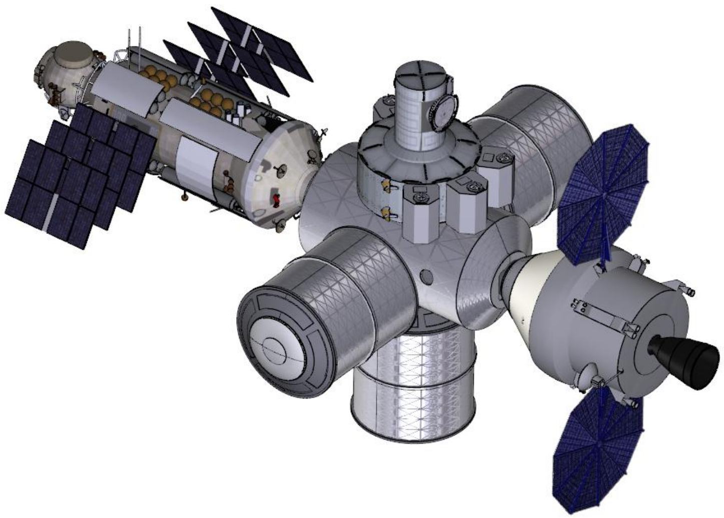


…so as to provide GCR reduction that is substantive enough to consider it as a smart architecture IF that much volume would be deemed necessary for the transit duration/application being considered.

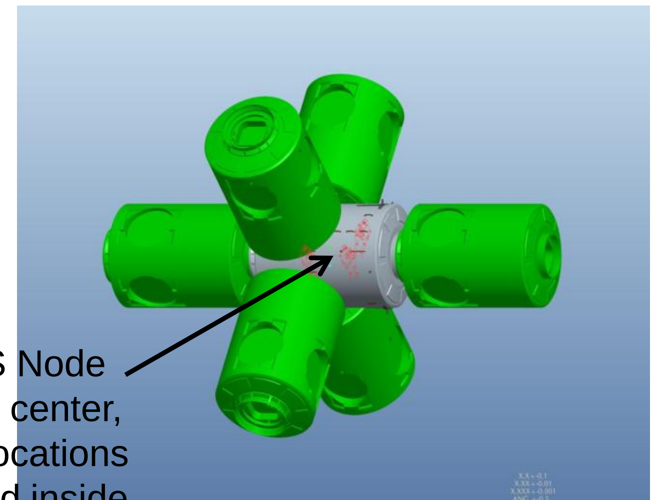
"Surrounded" Architecture Data/Results

- **The "surrounded" architecture was analyzed for GCR protection performance**

Hub and Spoke Architecture Concept



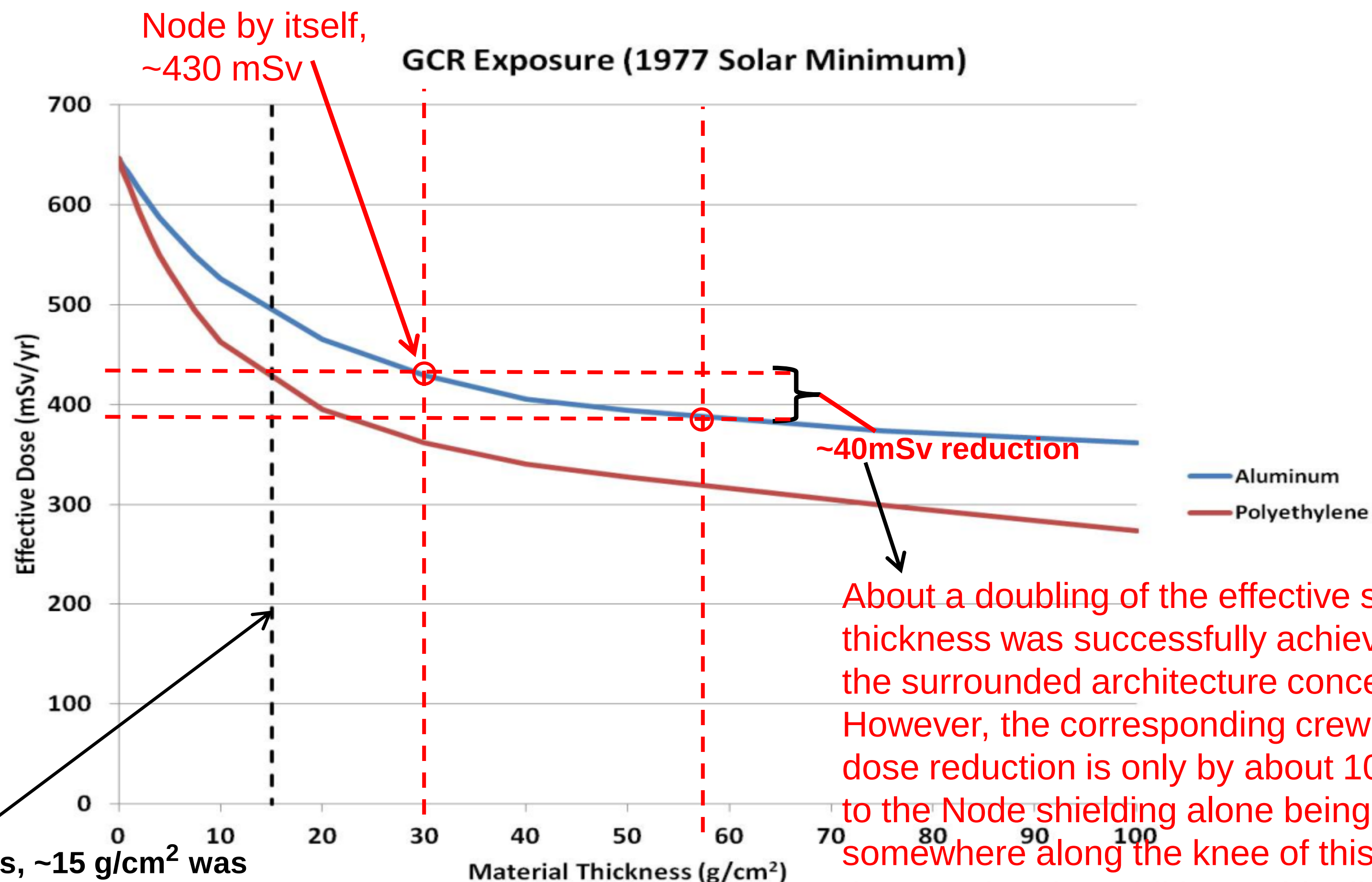
Radiation Analysis Model of Aluminum Weight-smeared Nodes



- Three "dose points"/locations examined inside the center Node showed a range of dosage from **~385 to 435 mSv for the surrounded architecture**
- This is essentially very little change from the ISS-derived results which were a range from **~394 to 456 mSv for the in-line architecture**

Results Interpretation/Discussion

Effective GCR Shielding



About a doubling of the effective shielding thickness was successfully achieved using the surrounded architecture concept. However, the corresponding crew radiation dose reduction is only by about 10%, due to the Node shielding alone being somewhere along the knee of this curve, thus placing the additional shielding provided on the flatter part of this curve.

Prior to this analysis, ~15 g/cm^2 was expected as an approx equivalent shielding provided by an ISS module, but the Node is actually showing closer to ~30 g/cm^2

"Surrounded" Architecture Conclusions

- The Hub-and-Spoke/Surrounded architecture shows a slight favorable GCR reduction over the in-line, but not by a significant amount
  - The general intent was/should be to aspire for a vehicle architecture that provides below ~400 mSv of dose in a best effort possible
  - The Aluminum curve won't let you get much lower/better than ~360 mSv out at 100 g/cm2, so getting as low as ~385 mSv is reasonable from just the vehicle architectural arrangement alone
  - It is of value to note that the dosage results from these studies are the "effective dose" for crew, which includes the additional protective effects of crew/human tissue and geometry in the analysis

- If the Node 2 by itself (or any other module), offers an inherit shielding such as was shown of approximately 30 g/cm^2, then the additional GCR protection provided by the "spokes" of a surrounded architecture will be limited to values along the flat part of the curve → ie, it already possesses an efficient amount of shielding that buys you the most bang for the buck, and beyond that, the shielding weight penalty buys you far less GCR protection

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DSH Conclusions on Galactic Cosmic Radiation

GCR: DSH Conclusions

Summary

- Two architectures were analyzed for crew radiation (GCR) protection capability
    1) The ISS-derived, baseline architecture
    2) A surrounded architecture, to evaluate the GCR protection benefit afforded by surrounding a core working/living module with logistics and less trafficked modules
- Results showed approximately a doubling of the effective shielding provided by the surrounded architecture over the simpler ISS-derived ("in-line"/exposed) architecture

    → **However the GCR reduction afforded by the surrounded structure, was minimal (~10%)**
- Note also, that the weight of the "surrounded" architecture is essentially twice the in-line architecture, and the large total volume of the surrounded architecture may not necessarily be needed

GCR: DSH Conclusions

Concluding remarks:

- ✓ The original ISS-derived baseline architecture provides a modest, but inherently efficient, amount of shielding (at knee of curve) which could be enhanced with small additions of discrete shielding to below ~400 mSv as best effort
  - ➢ However, for long transit cases of approximately a year or greater, neither architecture provides a reasonable solution for selecting crew within lifetime limits for meeting the 3% REID with a 95% confidence level at Solar Minimum level exposures
- ✓ It is expected that the GCR environment approximately doubles in range between the Solar Minimum and Solar Maximum levels

  → The possibility of GCR reduction for certain years of space travel is open to debate, and would need to be discussed carefully and carry margin
- ✓ Crew selection will have to play a significant role in controlling GCR risk
- ✓ A duration of several hundred days is a non-starter for in-transit space travel

  → A reduction in duration of transit to deep space destinations must be controlled to a value of approximately one year or less to as great an extent as possible, and will be dependent upon length of destination stays and GCR protection provided at that location.

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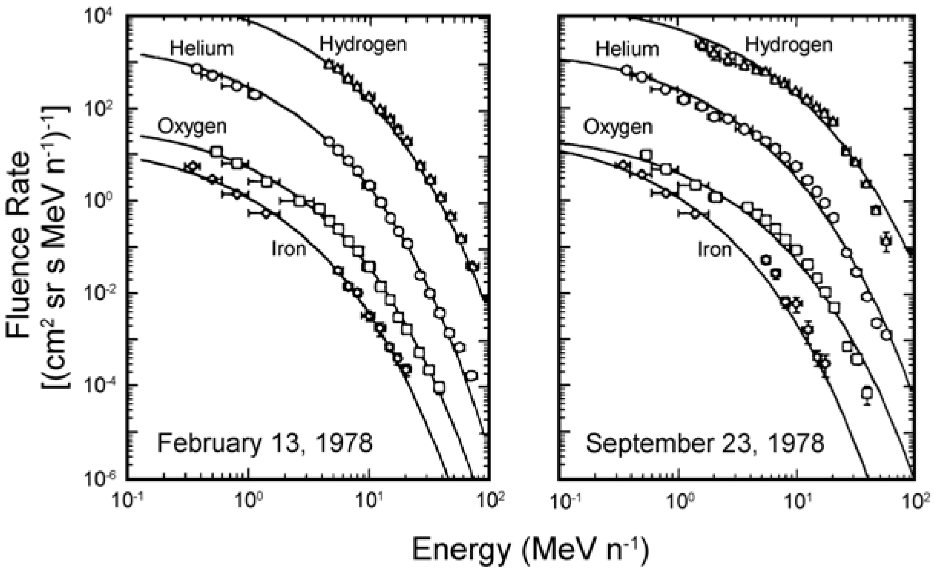
Back - up

Energy and Flux comparison

❑ Radiation Primer, continued

SPE

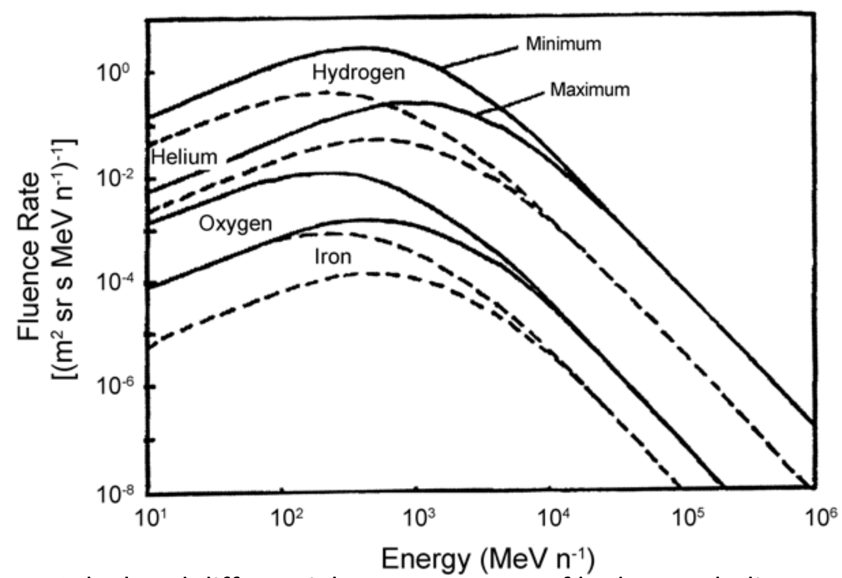
Higher Flux, Lower Energy



Combined hydrogen, helium, oxygen and iron energy spectra for two large SPEs. The solid curves are fits to a stochastic particle acceleration model (adapted from Mazur et al., 1992).

GCR

Lower Flux, Much Higher Energy



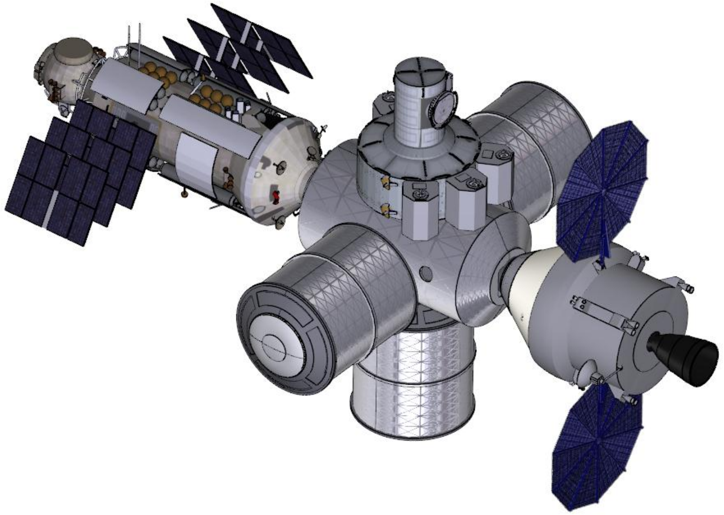
Calculated differential energy spectra of hydrogen, helium, oxygen and iron for the 1976 to 1977 solar minimum and the 1989 to 1990 solar maximum.

Images from National Council on Radiation Protection (NCRP) Report No. 153 (2006)

"Surrounded" Architecture Data/Results

- **The "surrounded" architecture was analyzed for GCR protection performance by smearing the total weight of one ISS Node over the volume of the ISS Node using Aluminum as the "cloud density material"**

Hub and Spoke Architecture Concept



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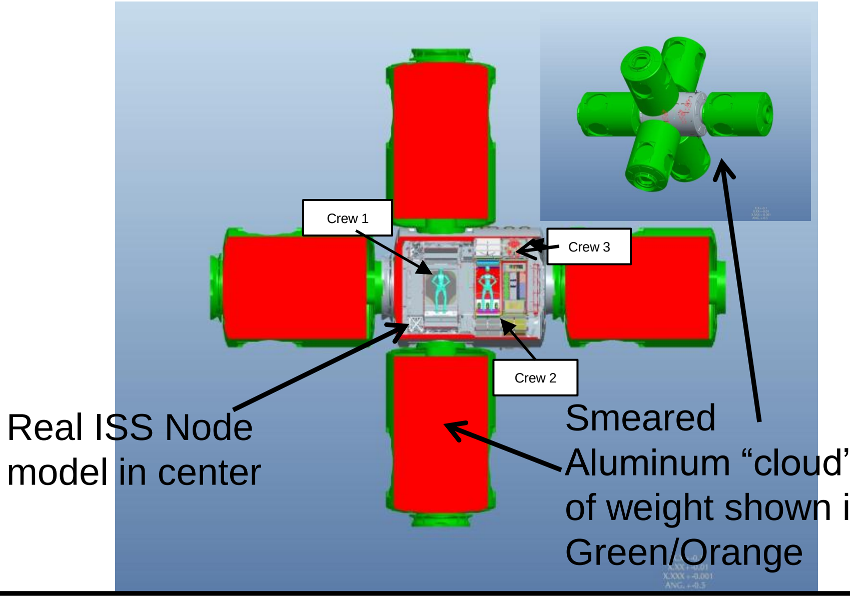

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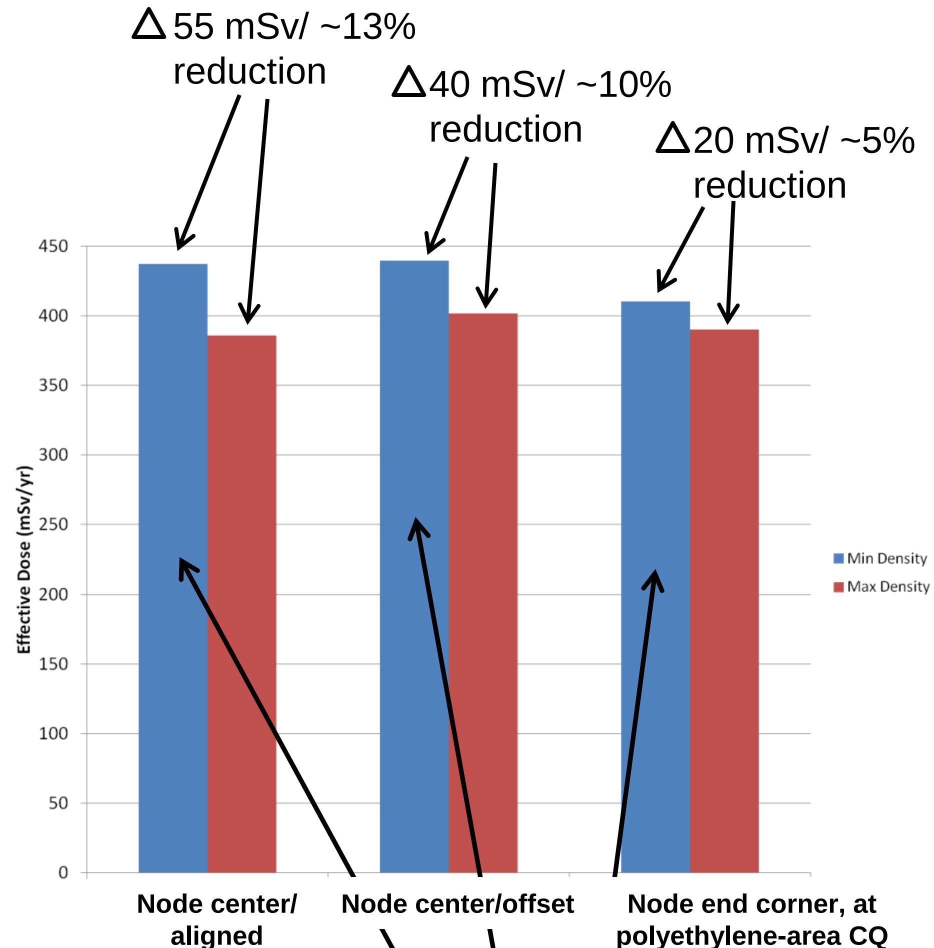
*Surrounded Architecture Analysis Parameters

- **GCR – 1977 Solar Minimum**
- **Central module = Node 2**
- **Varied outer module density**
  - Used average density of Node 2
  - Mass varied from minimum of 0 to maximum of 16800kg (equal to node weight)
  - Volume constant



The "naked" node results (node with zero surrounding it) shows ~430 mSv of shielding capability by itself

*Reference chart from Janet Barzilla/05-15-2012

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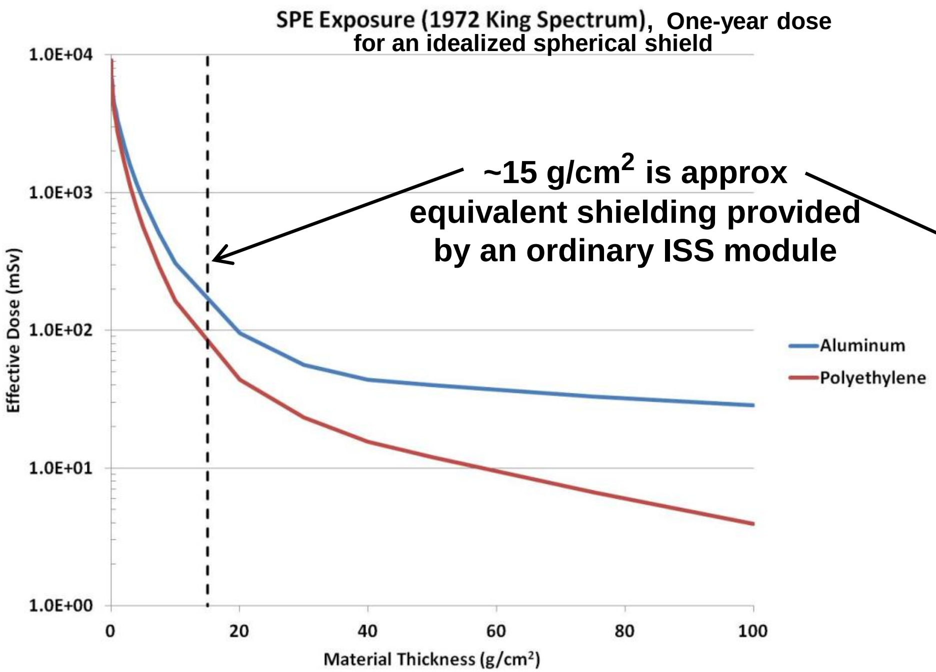
DSH SE&I Results to Date

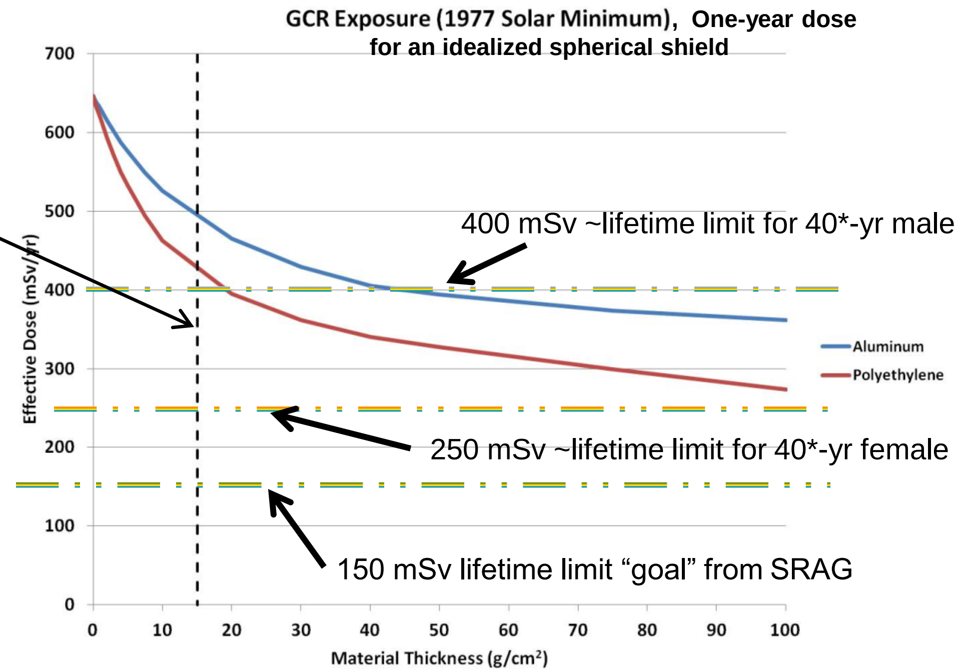
Radiation Primer, continued

SPE

Shielding is not conducive for protecting against GCR.

GCR





SPE radiation is effectively curtailed by shielding.

Shielding has profoundly less affect against GCR; lifetime limit goal is well below.

* Effective dose lifetime ceiling/limit is lower below this age.

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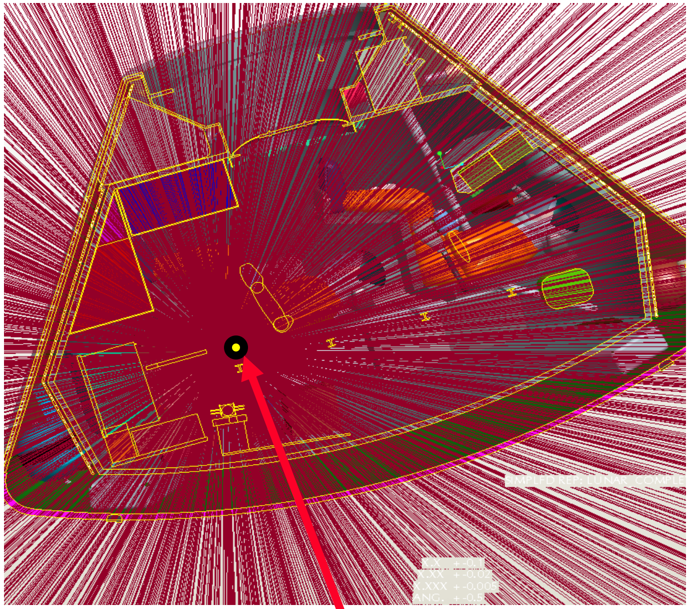
Shielding Assessment Technology

Software tool (*Pro/Engineer + Fishbowl tool kit*)

- **Ray Tracing technology**

  - Evenly distributed rays (up to 1 million rays) are created to start from dose point and end outside the vehicle.
  - Each Ray records distance and respective density of the parts it passes
  - Areal mass density is calculated.
  - Areal mass density is used in transport code that evaluates particle flux at dose point.



Dose point

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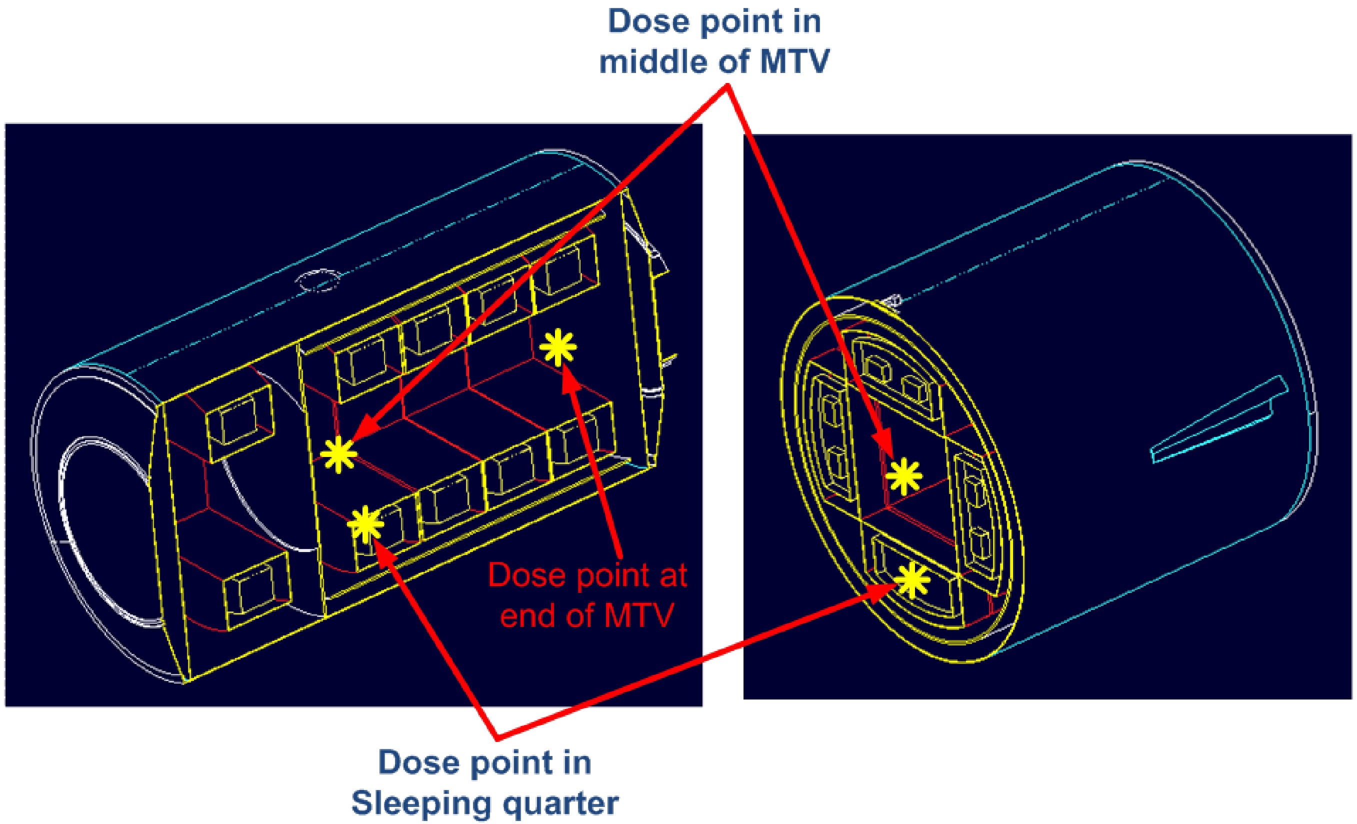
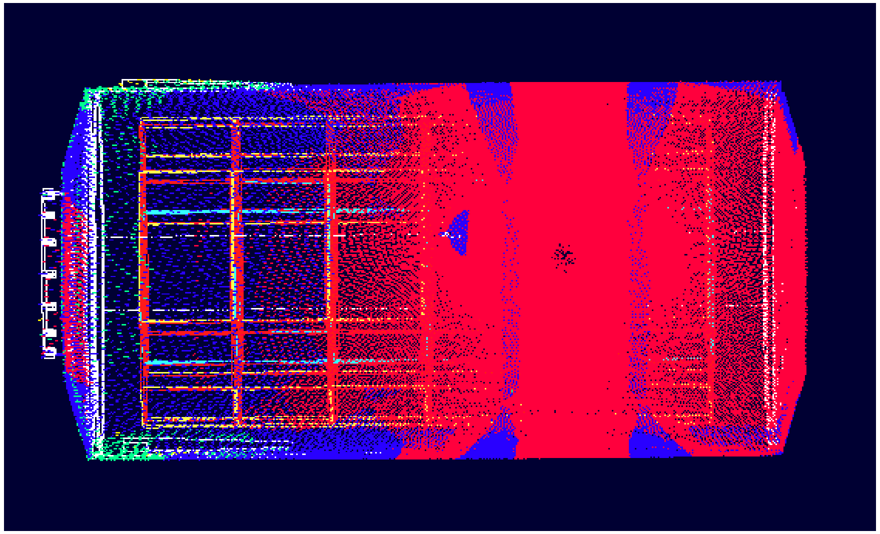
Ray Tracing (Dose Points)

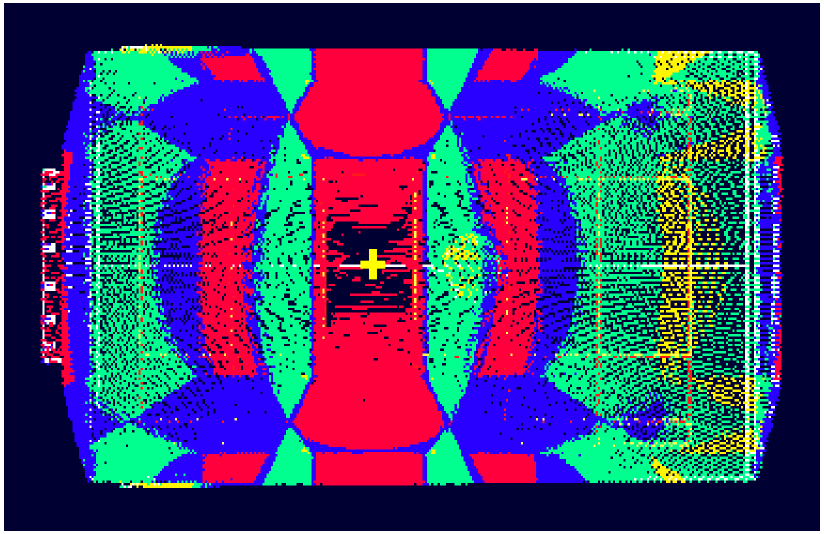


locations of dose points inside MTV that were used in ray tracing

Hot Spots Detection Capabilities

Single dose point Color Coding



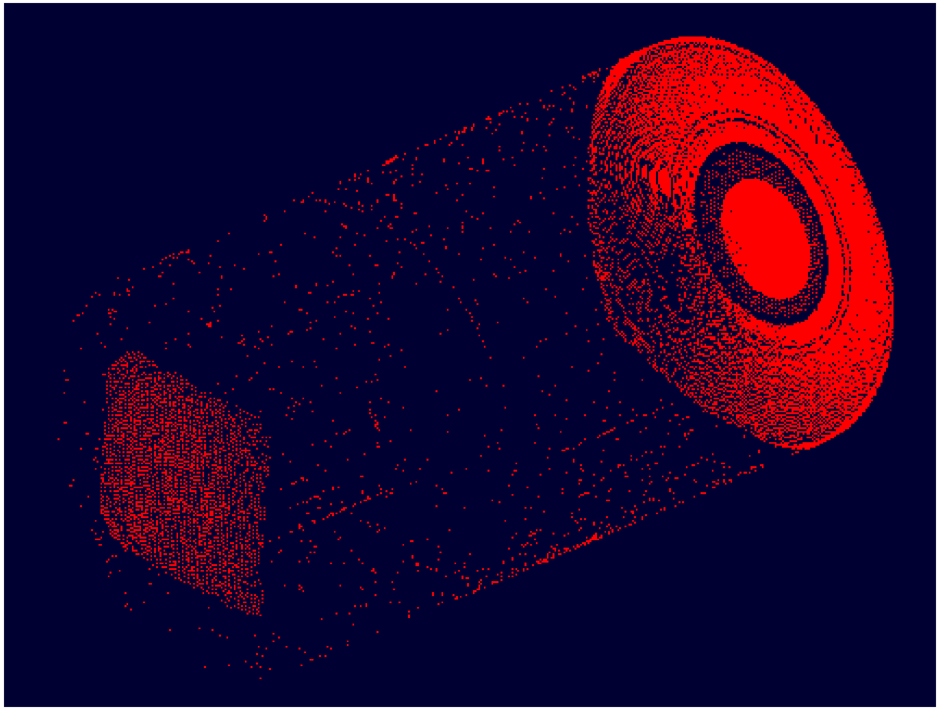


Every ray is color coded according to the areal density value-Shielding- it provides.

Only one dose point at a time-multiple colors

Hot Spots Detection Capabilities

Multiple dose point Hotspot detection



Every ray that provides less than 10 g/cm^2 shows up as a red pixel on the MTV surface.

Multiple dose points-single color

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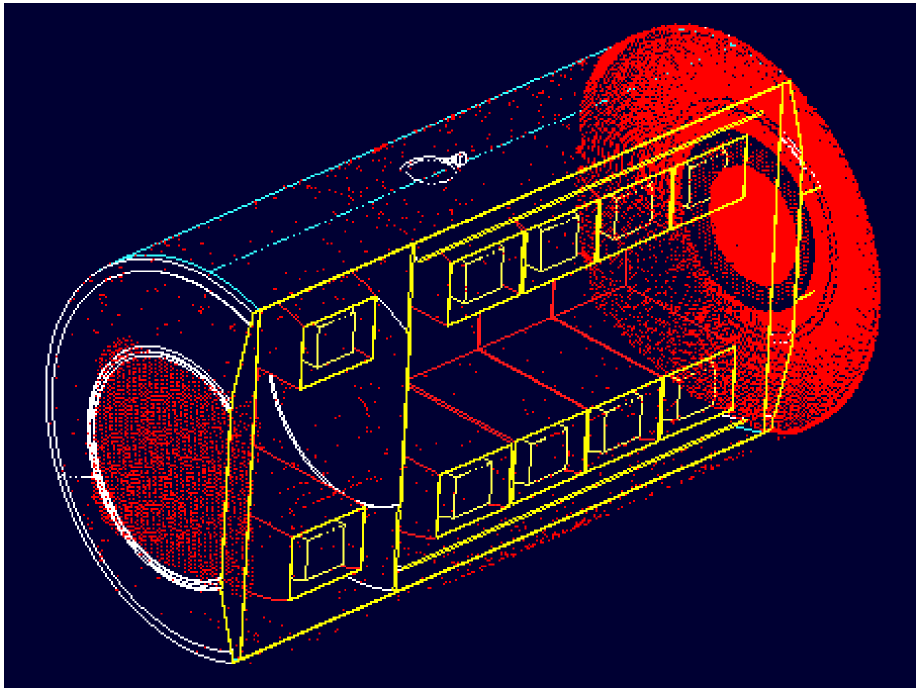
Hot Spots Detection Capability

Initial design



Initial Design:

Hotspots are shown on sides of habitat.

*ALARA
As Low As Reasonably Achievable

The ALARA principle is a legal requirement intended to ensure astronaut safety. An important function of ALARA is to ensure that astronauts **do not approach radiation limits** and that such limits are not considered as “tolerance values.” ALARA is especially important for space missions in view of the large uncertainties in cancer and other risk projection models. Mission programs and terrestrial occupational procedures resulting in radiation exposures to astronauts are required to find cost-effective approaches to implement ALARA.

Challenges: Uncertainties in biological response to the high-LET component of GCR make ALARA difficult to implement. ALARA is more easily performed for reducing SPE exposure using shielding and limiting exposures during EVAs

*Reference: Edward Semones charts, 12/13/2011

*Our Guidelines: NASA-STD-3001

4.2.2.2 Space Permissible Exposure Limits (SPEL) - Quantifiable limit of exposure to a space flight factor over a given length of time (e.g., lifetime radiation exposure). Physical/chemical agent measured.

4.2.10 Space Permissible Exposure Limit for Space Flight Radiation Exposure Standard

4.2.10.1 Planned career exposure for radiation shall not exceed 3 percent risk of exposure induced death (REID) for fatal cancer.

4.2.10.2 NASA shall assure that this risk limit is not exceeded at a 95 percent confidence level using a statistical assessment of the uncertainties in the risk projection calculations to limit the cumulative effective dose (in units of Sievert) received by an astronaut throughout his or her career.

4.2.10.3 Exploration Class Mission radiation exposure limits shall be defined by NASA based on National Council on Radiation Protection (NCRP) recommendations.

4.2.10.4 Planned radiation dose shall not exceed short-term limits as defined in table 4 in Appendix F supporting material for the radiation standard.

4.2.10.5 In-flight radiation exposures shall be maintained using the "as low as reasonably achievable (ALARA) principle.

*Reference: Janet Barzilla charts, 04/30/2012