Radiation Measurements and Shielding Analysis for ISS

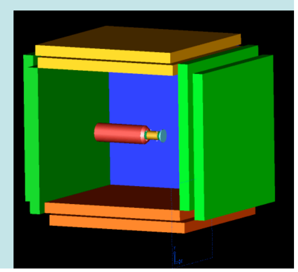
Mark Shavers
Wyle Laboratories, Life Sciences, Systems and Services
mshavers@ems.jsc.nasa.gov

Team USA
F. A. Cucinotta, M. Van Baalen, M. J. Golightly, N. Zapp, M. Weyland
NASA, Johnson Space Center
J. W. Wilson, J. E. Nealy, G. Qualls, B. Anderson
NASA, Langley Research Center

Team Russia
V. Petrov, S. Shurhakov
Institute of Biomedical Problems, Russian Academy of Sciences

Team Italy
M. Casolino, L. Narici
INFN, Tor Vergata, University of Rome

Acknowledgements: The authors are grateful to the NASA Space Radiation Analysis Group for their collaborative support, and to Eric Benton, Eril Research, for helpful discussions.

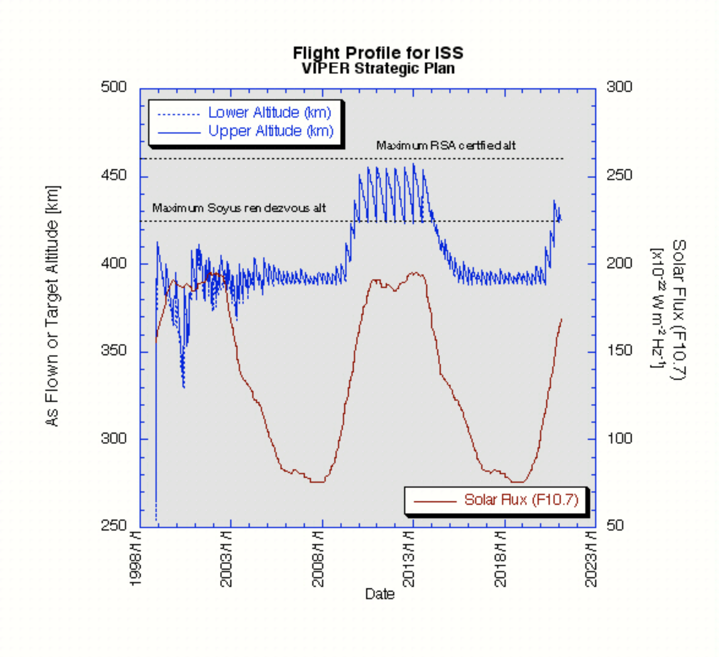


Low Earth Orbit and Exploratory Missions

Instrumentation and Analysis Parametersfor Ionizing Radiation Dosimetry

Exposure environment variables for a given Mission Segment

- Vehicle
  - vehicle assembly and staging, stowage reconfigurations
  - fuel, consumables
  - orientation
- Crewmembers
  - Phantom for all tissues
  - IVA location
  - orientation
  - risk analysis
- $\phi(\Omega x,y,z,t;\, Z,E)$ fully characterizes ion, n exposure
  - Location and orientation
  - solar activity, SPE



Objective and Approach for Future Experiment

Objective

- Characterize polyethylene-shielded radiation environment on International Space Station including the Service Module *Zvezda* crew quarters in order to optimize retro-fit shield design for ISS.

Approach

- Perform detailed modeling of ionizing radiation environment and measurements using *in situ* shielding material and radiation detectors.

Motivation

- Radiation exposure reduction ALARA
- Extend mission duration

Potential application of ALARA

- DB-8, TLDs, TEPC show relatively high dose rate in *Zvezda* Service Module crew quarters (CQs)
- Crew spends "off-duty" time in SM CQs
- Shielding distribution uncertain but significant solid angle thought to be relatively thin
- Thin area leaves questions about D gradient across shallow and deep tissues
- Retrofit is problematic due to volume constraints
- Reasons to think retrofit will be effective, even though massive shielding around large solid angle
  - DB-8 ~5% reduction in dose seen with only ~1.52 g cm^2 H2O-equiv Pb shield
  - TeSS polyethylene shielded, comparison with other crew
    - ~20% measured reduction Equivalent D in personal dosimeters
    - Up to 40% reduction in biodosimetry

BRADOS
TLD and CR-39 PNTD results–this workshop

~10% reduction in absorbed dose over ~1 g cm^{-2}
~50% for shielded/unshielded DB-8 Oct 03 SPE ~1.x g cm^{-2} shield

Summary
On-orbit Polyethylene Shield Evaluation

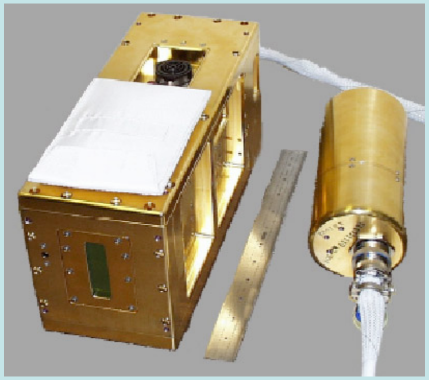
- Perform directional measurements in CQ's
  - Parallel to Proton distribution (so-called pitch angle or "East-West effect) during dominant ISS orientation
  - Perpendicular test
  - Establish any contribution of electrons/bremmstrahlung and trapped protons to CQ dose during stormy space weather
- Perform shielded measurements in *Zvezda* Service Module Crew Quarters and U.S. Segment
  - 0 vs ~5 and ~9.5 g cm^{-2} shielded detectors
- Collect ion and neutron E spectroscopy data in CQ's
- Post-installation: validate reduction gained by retrofits
- Improved Active Dosimetry: establish reliable LET_{tissue} spectral measurements with minimal crew-time and data downlink issues
- Temporary Sleep Station (Cucinotta)

Operational Radiation Monitoring Detectors

Active Instruments

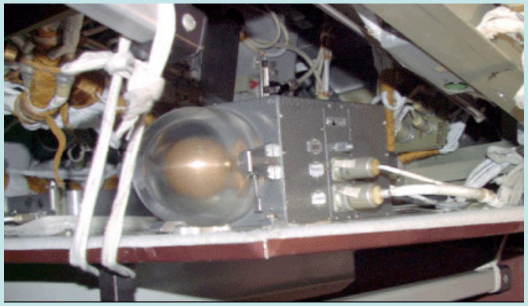
Issues

- May not be relocatable
- Limits on dynamic range of detection
- No single instrument is adequate
- Data storage and downlink/transfer requirements
- Volume and crew time constraints

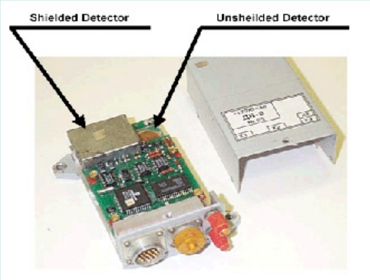


Tissue Equivalent Proportional Counter

R-16 ion chamber

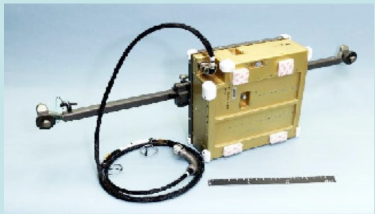


DB-8



Silicon Detectors

IVCPDS



Liulin

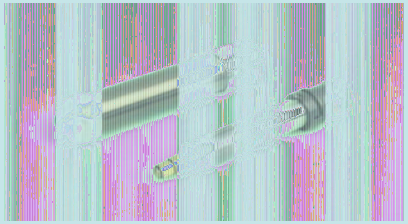
Passive Detectors

Thermoluminescence and Plastic Nuclear Track Detectors

Issues

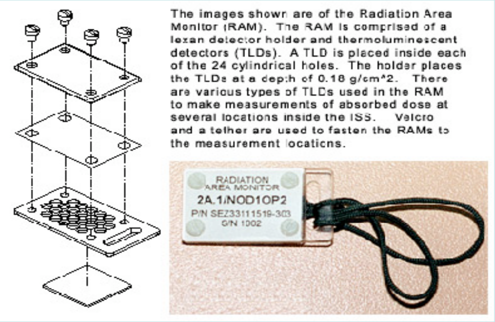
- Reliable
- On-orbit analysis not always possible
- Long turn-around on data collection
- Not capable of resolving GCR from trapped proton or e-,bremmstrahlung dose
- Not adequate for neutron spectroscopy
- No single instrument is adequate

Pille

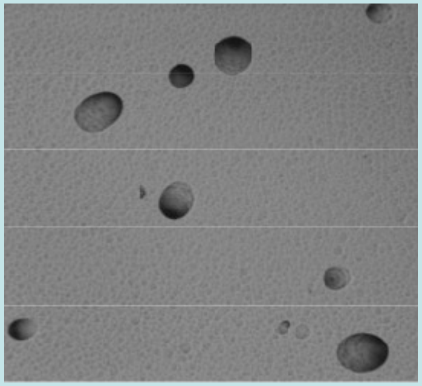


Brados

TLD

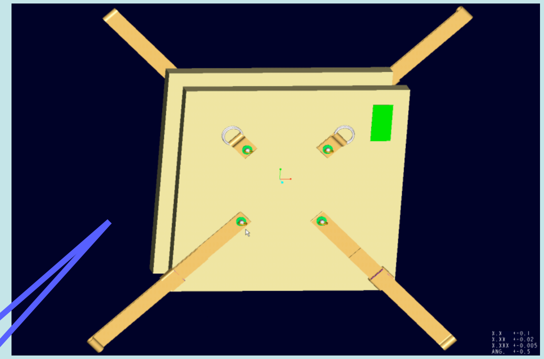


CR-39

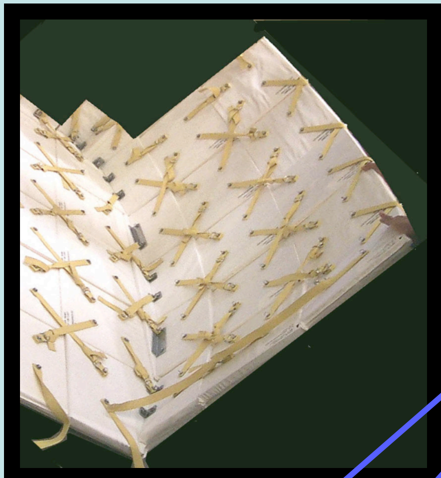


Images courtesy of NASA-SRAG and E. R. Benton

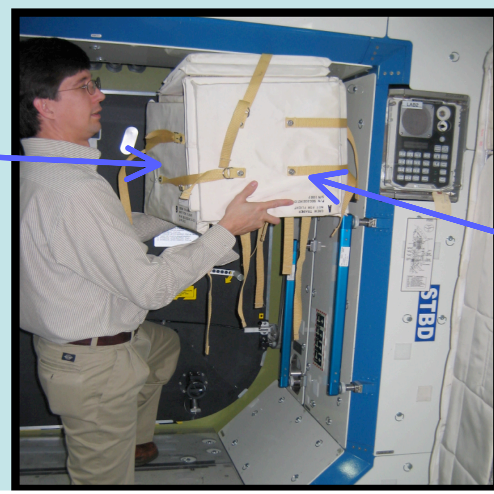
TeSS Polyethylene “Radiation Bricks”

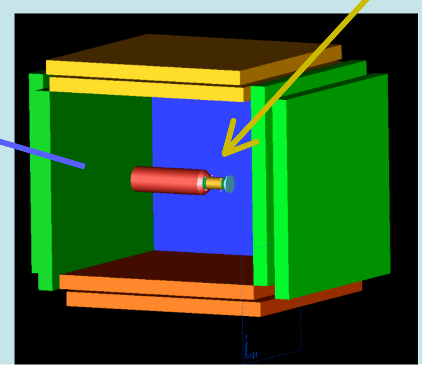


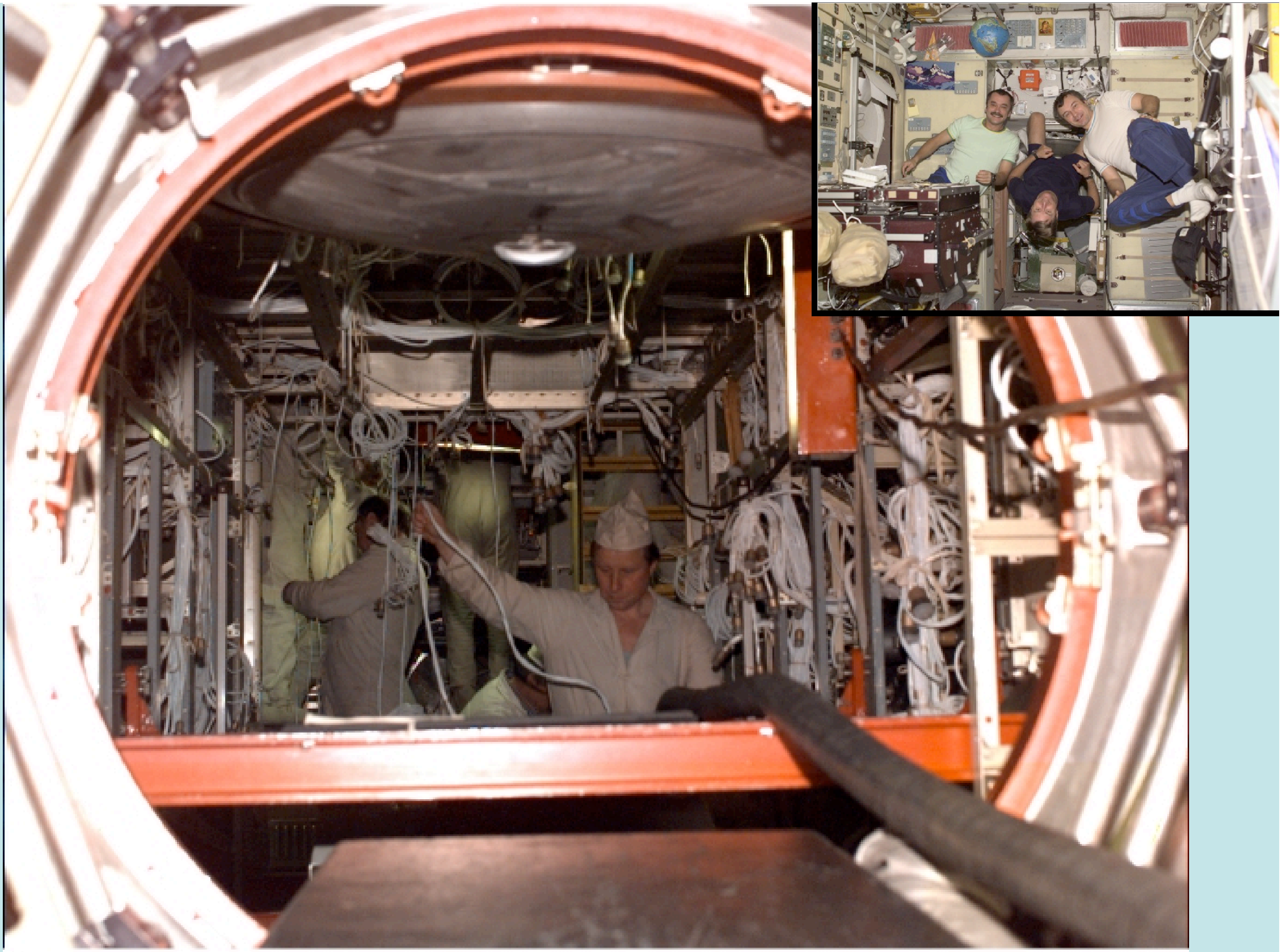
ρ=0.93 g cm-3
~14. % H by weight



Brick size: approx 35 cm x 35 cm x 2.5 cm

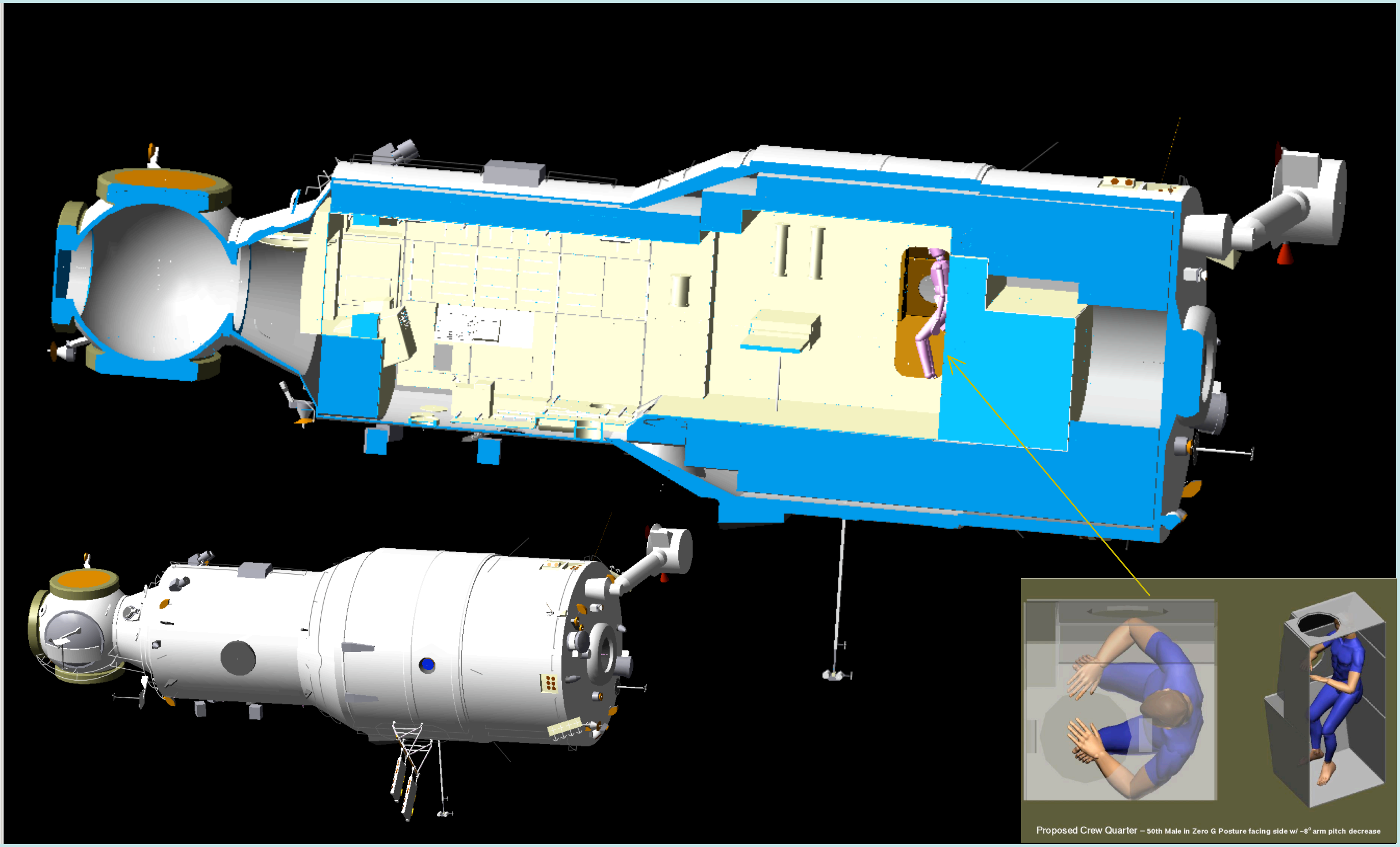





98E01365 1998.01.29 10:31:30
Serial : 4151184 Firmware : 031696
Frame : 22 Shtr : 60 Exp : P Exp Comp : -1.0 Dist : 2.6m
ISO : 200 Lens : 28 Prog : Po Mtr Area : Mtrx
Drv Mode : S F Sync : Norm F Mode : C F Area : Spot

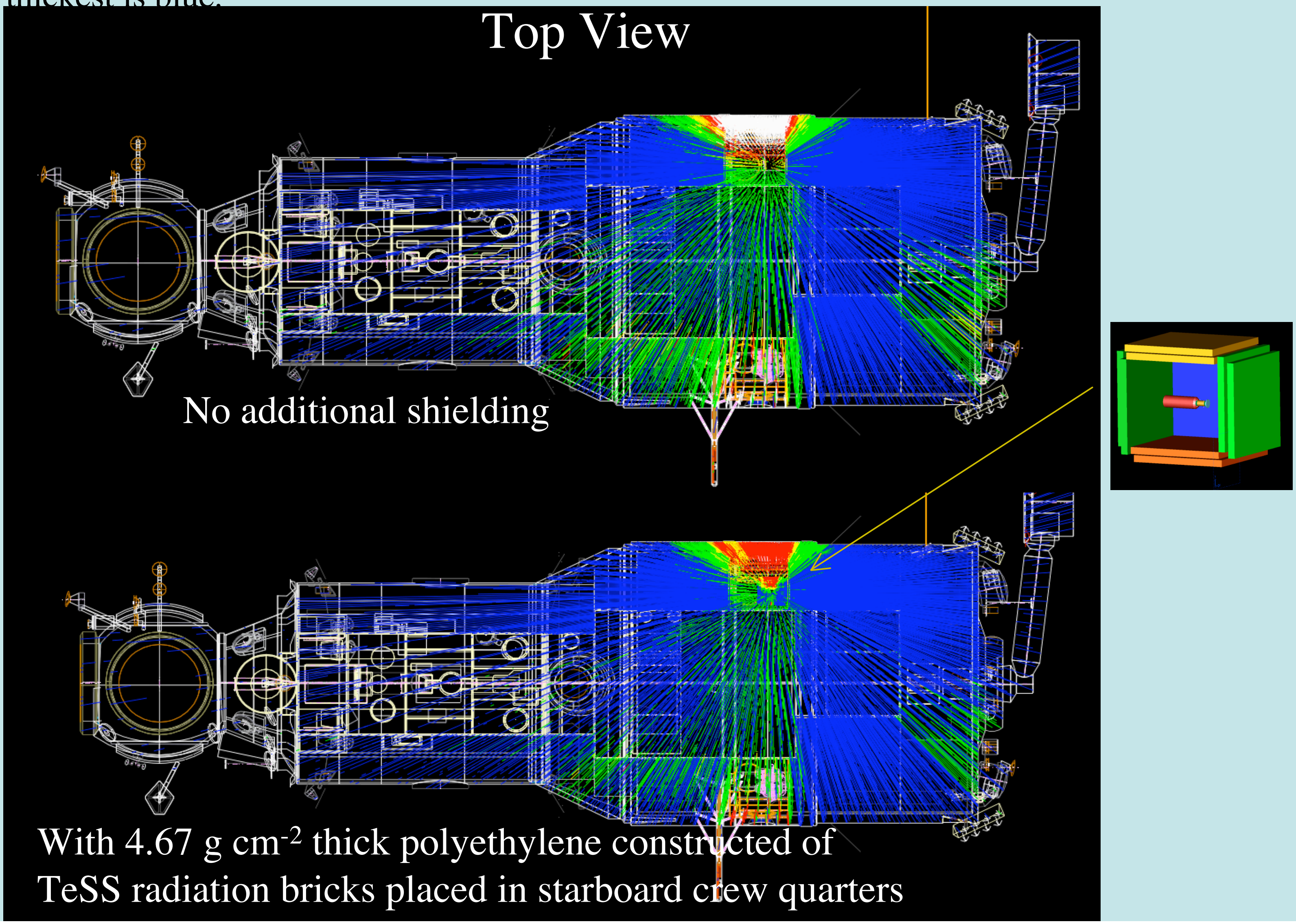
Zvezda Service Module

NASA-JSC CAD Model



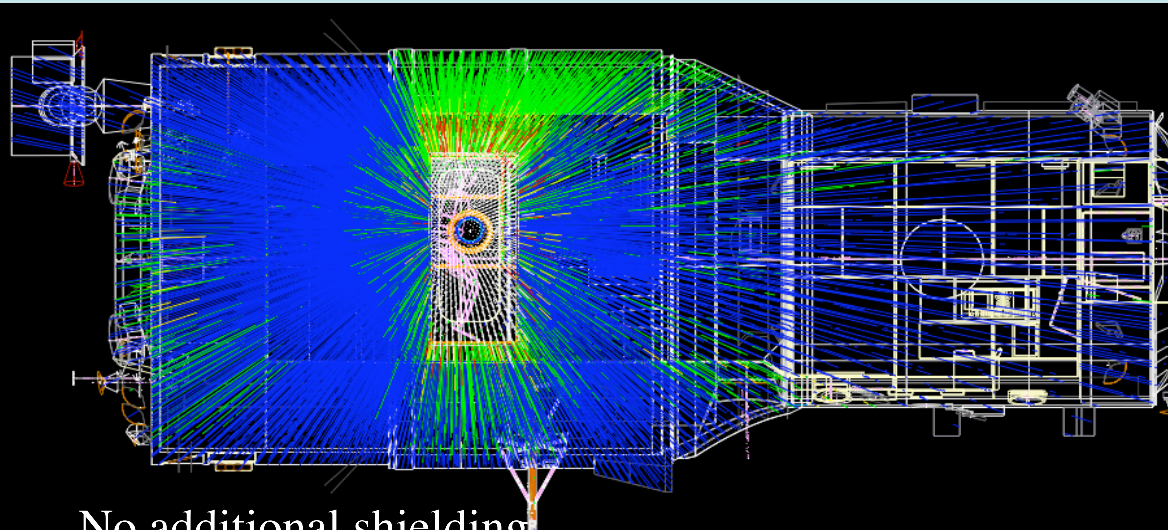
Ray Tracing Results

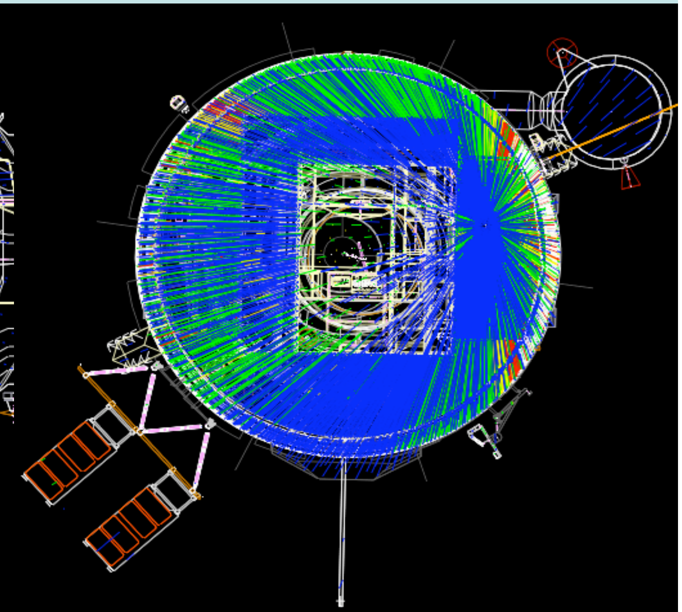
Shielding (pathlength in assigned material) along each of 5000 rays is color-coded to the total amount of shielding [g cm^{-2}]; thinnest shielding is white, thickest is blue.



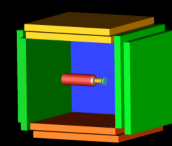
View from Starboard Side

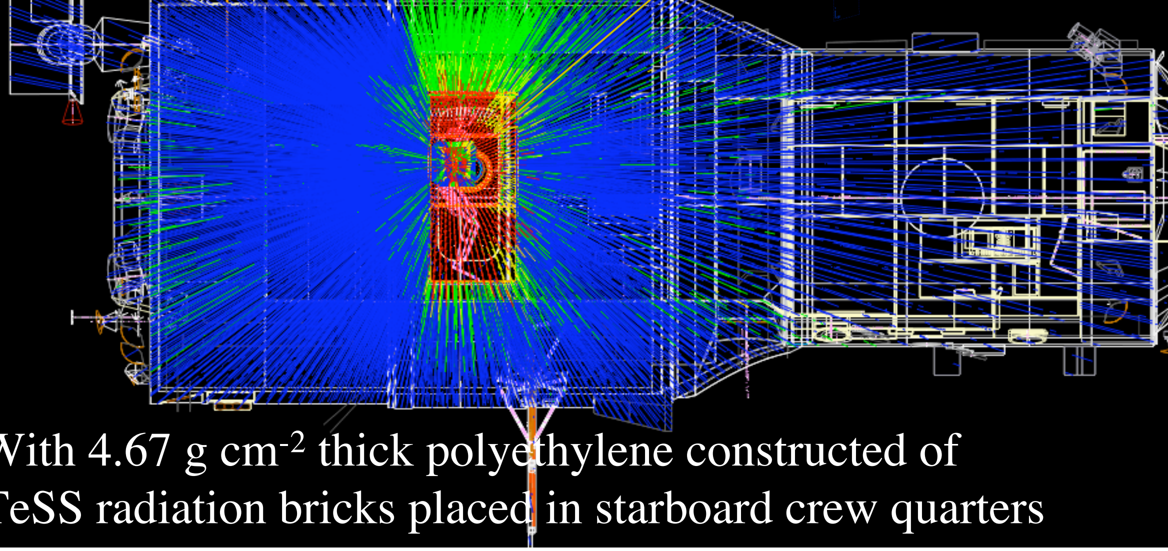
End View

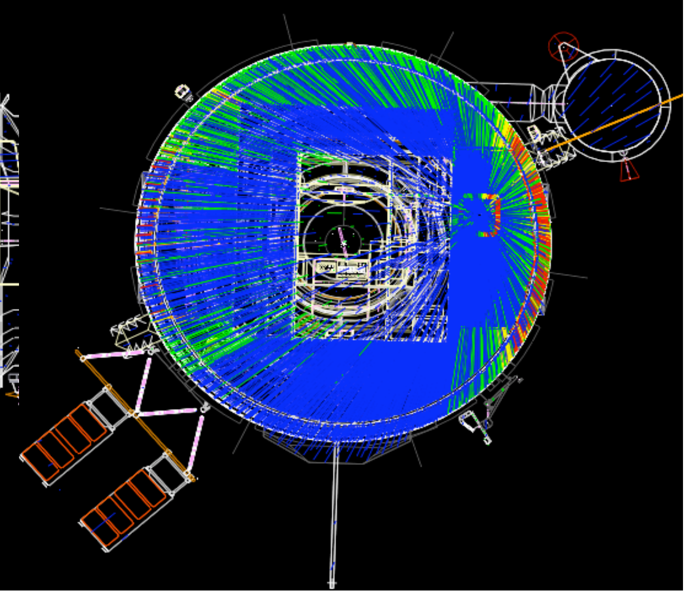




No additional shielding



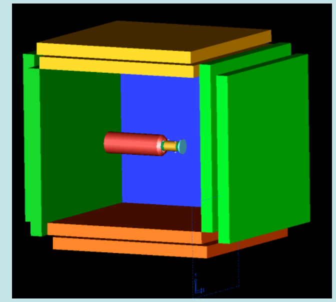




With 4.67 g cm^{-2} thick polyethylene constructed of TeSS radiation bricks placed in starboard crew quarters

Modeled Dosimetry

test shield: 4.7 g cm^{-2} polyethylene

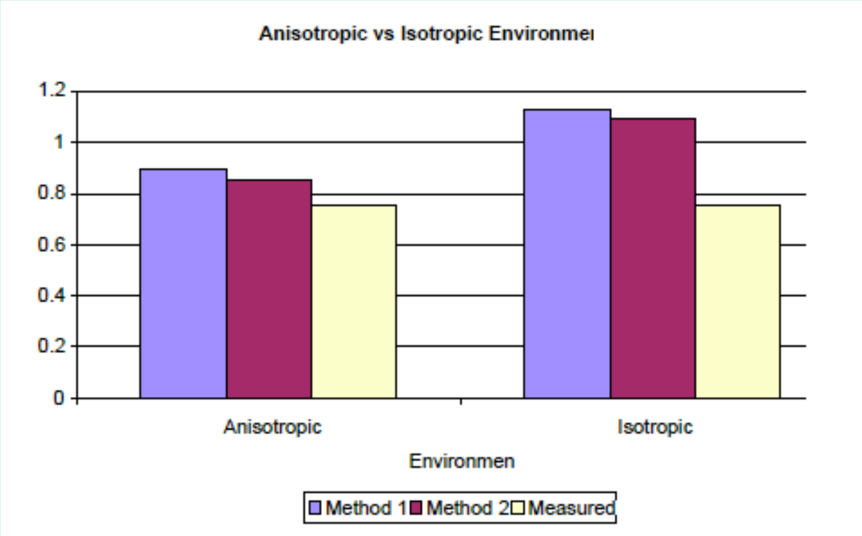


ISS orbit Solar Minimum Activity	Absorbed Dose mGy day^{-1}			Equivalent Dose mSv day^{-1}		
	Without Poly shield	**With Poly shield**	**% reduction**	**Without Poly shield**	**With Poly shield**	**% reduction**
Trapped protons						
SKIN-HIP	0.211	0.118	44.2	0.299	0.170	**42.9**
EYE	0.214	0.122	43.0	0.302	0.176	**41.7**
Avg. BFO	0.116	0.073	37.2	0.168	0.108	**35.7**
Galactic Cosmic Radiation						
SKIN-HIP	0.135	0.133	1.4	0.414	0.392	**5.2**
EYE	0.135	0.133	1.4	0.418	0.396	**5.3**
Avg. BFO	0.131	0.129	1.8	0.377	0.361	**4.2**
Combined Trapped Proton and GCR						
SKIN HIP	0.346	0.251	27.5	0.712	0.563	**21.0**
EYE	0.349	0.255	26.9	0.720	0.572	**20.6**
Avg. BFO	0.247	0.202	18.4	0.545	0.469	**13.9**

ISS orbit Solar Minimum Activity	Absorbed Dose mGy day^{-1}			Dose Equivalent mSv day^{-1}		
	Without Polyethylene shield	With Polyethylene shield	% reduction	Without Polyethylene shield	With Polyethylene shield	% reduction
Trapped protons						
CAM SKIN HIP	0.211	0.118	44.2	0.299	0.170	42.9
CAM EYE	0.214	0.122	43.0	0.302	0.176	41.7
CAM AVE BFO	0.116	0.073	37.2	0.168	0.108	35.7
CAM STOMACH	0.086	0.056	34.7	0.126	0.084	33.1
CAM COLON	0.112	0.071	36.7	0.162	0.105	35.2
CAM LIVER	0.094	0.061	35.7	0.138	0.091	34.1
CAM LUNG	0.105	0.067	36.2	0.152	0.100	34.7
CAM ESOPHAGUS	0.102	0.065	36.1	0.148	0.097	34.6
CAM BLADDER	0.083	0.054	34.8	0.121	0.081	33.2
CAM THYROID	0.124	0.078	37.5	0.179	0.115	36.0
CAM CHEST (fc)	0.195	0.113	42.3	0.277	0.163	41.0
CAM TESTES	0.132	0.079	39.9	0.189	0.116	38.5
CAM front BRAIN	0.155	0.095	38.8	0.221	0.138	37.5
CAM mid BRAIN	0.127	0.080	36.9	0.183	0.118	35.5
CAM rear BRAIN	0.154	0.094	38.8	0.220	0.138	37.4
point	0.366	0.190	48.0	0.557	0.259	53.5
Galactic Cosmic Radiation						
CAM SKIN HIP	0.135	0.133	1.4	0.414	0.392	5.2
CAM EYE	0.135	0.133	1.4	0.418	0.396	5.3
CAM AVE BFO	0.131	0.129	1.8	0.377	0.361	4.2
CAM STOMACH	0.130	0.127	2.0	0.361	0.348	3.8
CAM COLON	0.131	0.129	1.8	0.376	0.360	4.2
CAM LIVER	0.130	0.128	1.9	0.365	0.351	3.9
CAM LUNG	0.131	0.128	1.9	0.372	0.357	4.1
CAM ESOPHAGUS	0.131	0.128	1.9	0.370	0.355	4.0
CAM BLADDER	0.130	0.127	2.0	0.359	0.345	3.7
CAM THYROID	0.132	0.129	1.7	0.382	0.365	4.4
CAM CHEST (fc)	0.134	0.132	1.4	0.410	0.389	5.1
CAM TESTES	0.131	0.129	1.8	0.379	0.363	4.4
CAM front BRAIN	0.133	0.131	1.6	0.398	0.379	4.8
CAM mid BRAIN	0.132	0.130	1.7	0.386	0.369	4.4
CAM rear BRAIN	0.133	0.131	1.6	0.398	0.379	4.8
point	0.147	0.146	0.9	0.526	0.495	6.0
Combined Trapped Proton and GCR						
CAM SKIN HIP	0.346	0.251	27.5	0.712	0.563	21.0
CAM EYE	0.349	0.255	26.9	0.720	0.572	20.6
CAM AVE BFO	0.247	0.202	18.4	0.545	0.469	13.9
CAM STOMACH	0.216	0.183	15.0	0.487	0.431	11.3
CAM COLON	0.244	0.200	17.9	0.539	0.466	13.5
CAM LIVER	0.225	0.188	16.1	0.503	0.442	12.2

Anisotropicity of Trapped Protons

Transfer compartment, *Zvezda* Service Module



Validation of space radiation transport codes

J.W. Wilson, F.A. Cucinotta, M.J. Golightly, C. Hugger, J.E. Nealy, G.D.Qualls, F.F. Badavi, G. De Angelis, B.M. Anderson, M.S. Clowdsley, N. Luetke, N. Zapp, M.R.Shavers, E. Semones

100 MeV Proton Anisotropy in SAA

J. W. Wilson, J. Nealy, et al. unpublished

Preliminary results removed

International Space Station: A Testbed For Experimental And Computational Dosimetry, Presented at COSPAR 2004.
J.W. Wilson (1), F. A. Cucinotta (2), M.J. Golightly (2), J.E. Nealy (3), G.D. Qualls (1), F.F. Badavi (4), G. De Angelis (3), B.M. Anderson (1), M.S. Clowdsley (1), N. Luetke (5), N. Zapp (6), M.R. Shavers (7), E. Semones

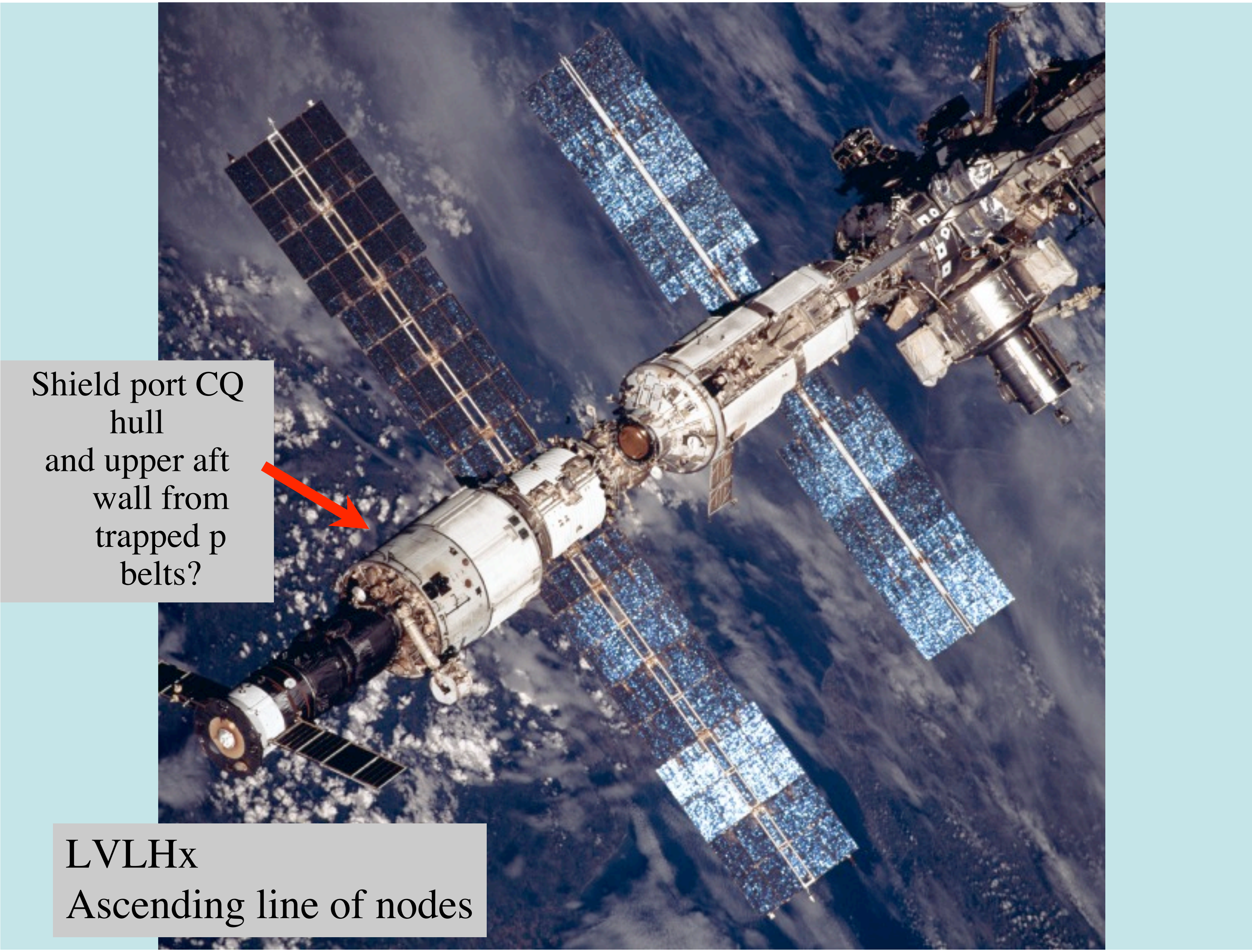
100 MeV Proton Anisotropy in SAA

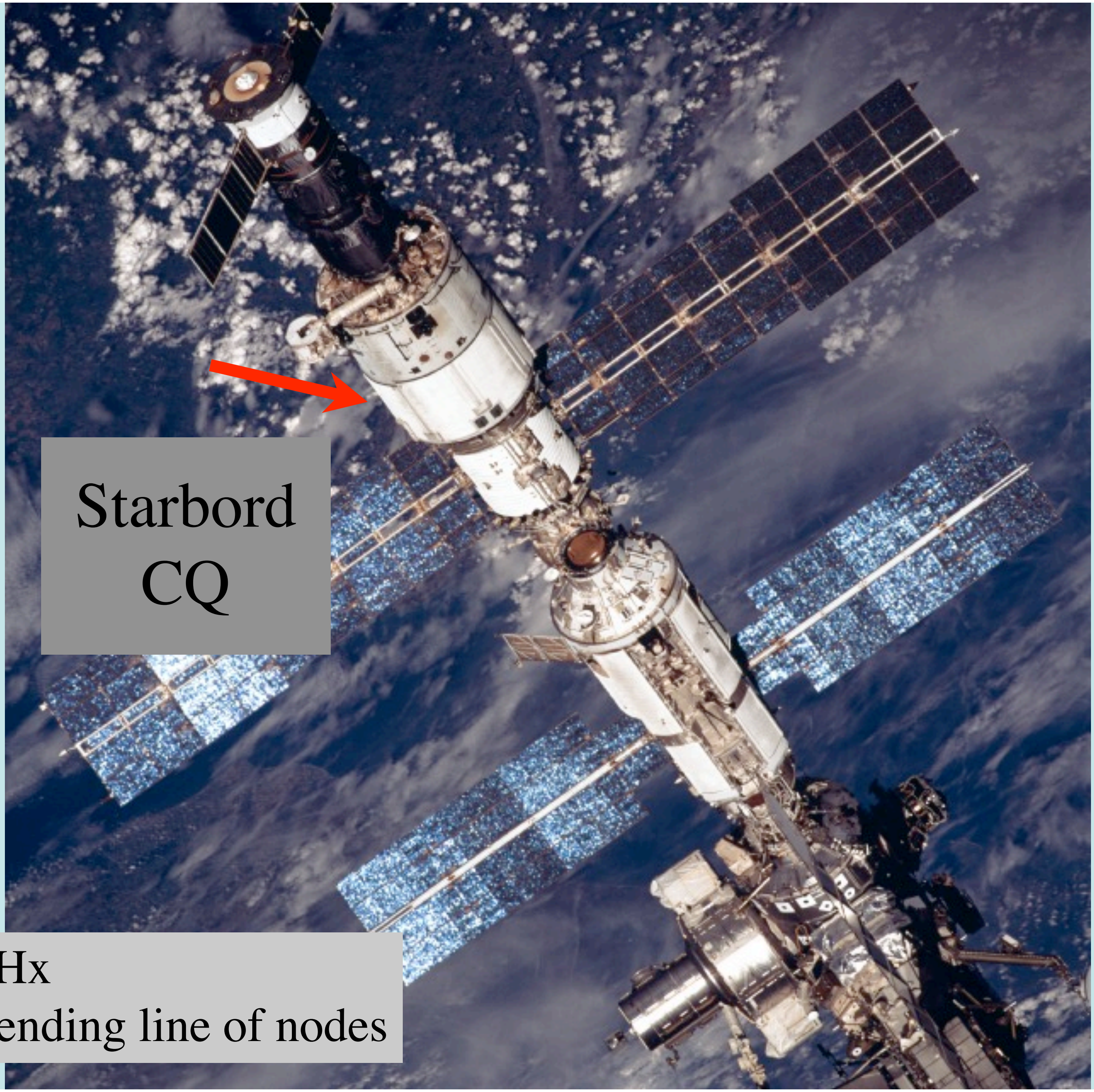
J. W. Wilson et al. unpublished

Preliminary results removed

For a common ISS orientation…

Preliminary results removed


Shield port CQ hull and upper aft wall from trapped p belts?
LVLHx
Ascending line of nodes

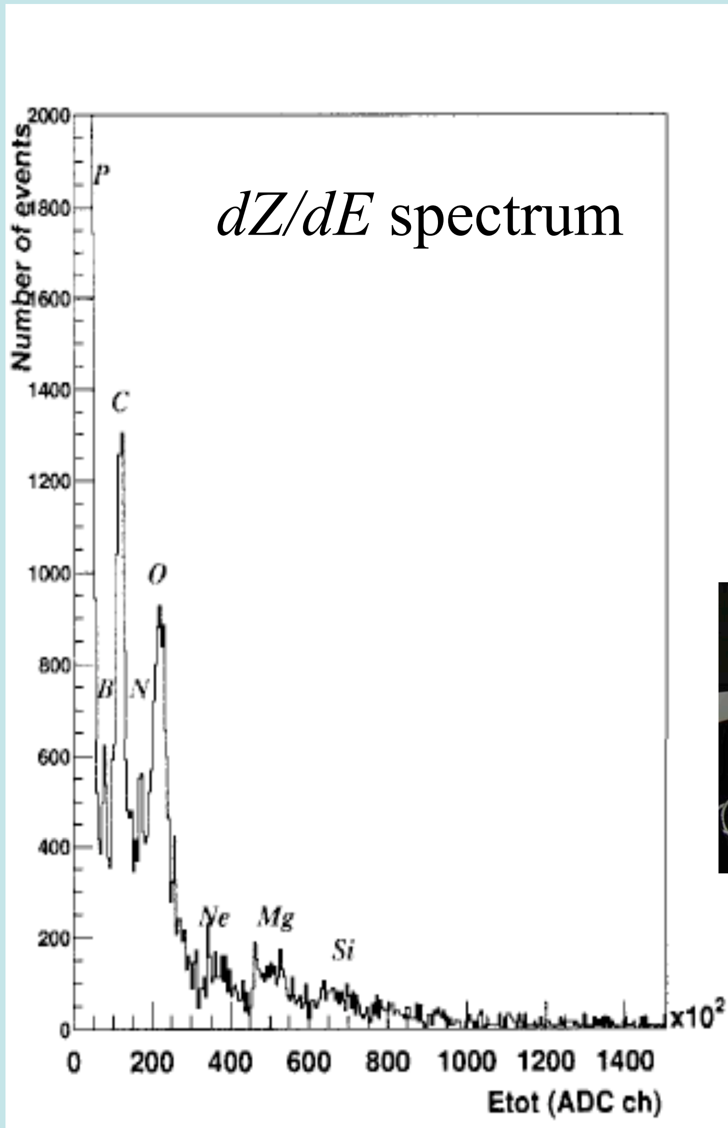


LVLHx
Descending line of nodes

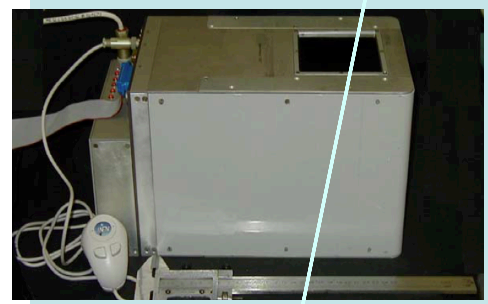
Shield more effective for trapped p than for GCR, therefore, optimize for trapped proton solid angle

The **Alteino** cosmic ion spectrometer (Casolino, et al. 2002) may be used to characterize the heavy ion flux and the effectiveness of radiation shielding materials.

Currently stowed in *Zarya* Functional Cargo Block



$\phi(,t;Z,E)$



Alteino evaluation of poly here?

Altea used elsewhere?

Matroshka-R

Photo provided by S. Shurshakov, IBMP


Electrons
IVA

Electrons

Are incident electrons an issue in LEO?

ISS Program Medical Operations Requirements Document

7.5 RADIATION HEALTH AND EXPOSURE MONITORING

...During the mission, the ionizing radiation environment is monitored to provide sufficiently comprehensive and timely data to:

1) maintain crew doses below legal limits and to practice ALARA actions to avoid unnecessary levels of exposure;

2) collect and record information to assess crewmembers' critical organ and tissue doses for an individual mission and cumulative career records;

3) initiate immediate countermeasures for transient radiation exposure events, e.g., during EVA, solar particle events, or electron belt enhancements.

Electrons

7.5.3.2.2 External Radiation Area Monitoring

External active radiation area monitoring shall monitor the time-resolved direction- and energy-dependent charged-particle spectra immediately exterior to the vehicle.

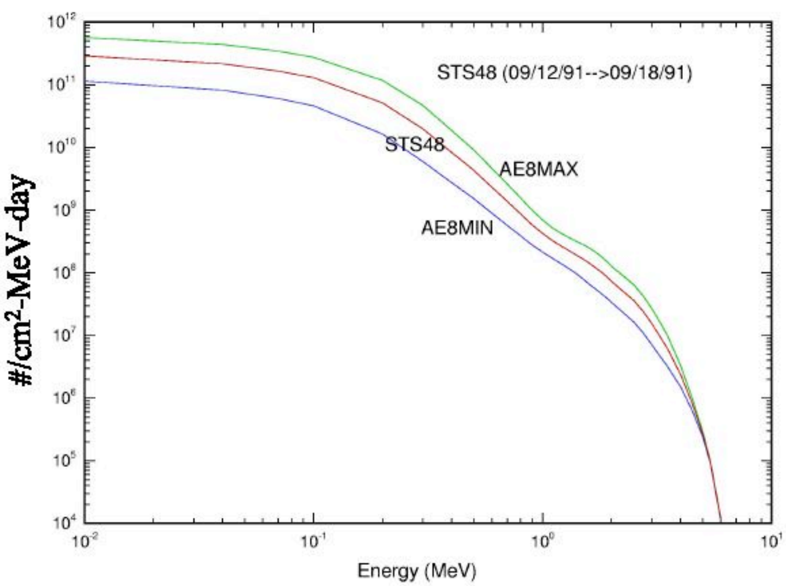
Rationale: …to calculate the radiation environment inside the vehicle as part of the crew health risk assessment process. …monitor a significant portion of the external radiation environment that is important to EVA crew exposures.

Consequences if not implemented: Increased uncertainty in estimated crew risks. Reliance on inaccurate characterization of the external electron and proton environment for EVA crew exposure predictions, which could lead to actual exposures that are significantly higher than estimated during the EVA go/no-go decision process.

Aluminum

ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	STOPPING POWER TOTAL	CSDA RANGE	RADIATION YIELD
MeV	MeV cm^2/g	MeV cm^2/g	MeV cm^2/g	g/cm^2	
5.0000	1.564E+00	1.263E-01	1.690E+00	3.092E+00	3.675E-02
10.0000	1.636E+00	2.858E-01	1.921E+00	5.861E+00	7.454E-02

Attix



10^4

Preliminary Shuttle Spacesuit Shielding Model
Brooke M. Anderson, J. Nealy, et al., NASA TP -2003-21205.

Electrons in LEO

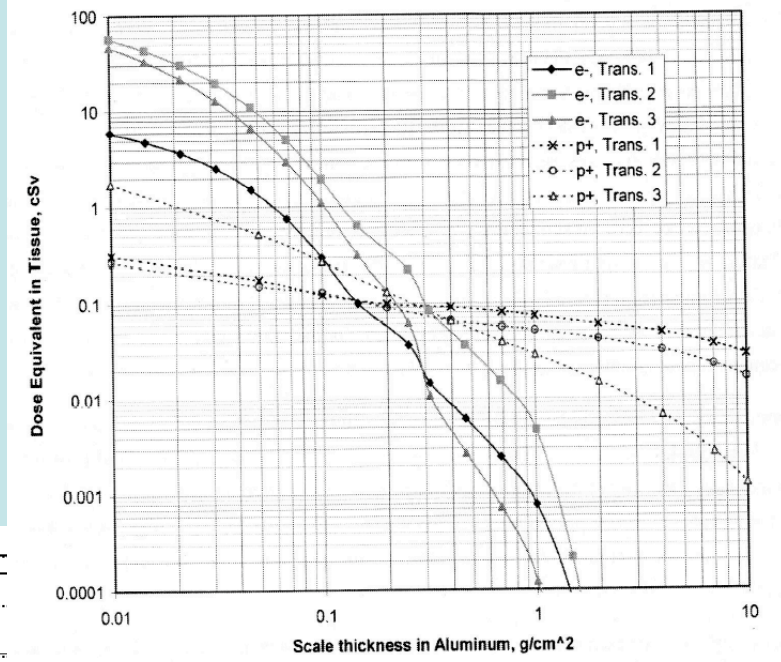
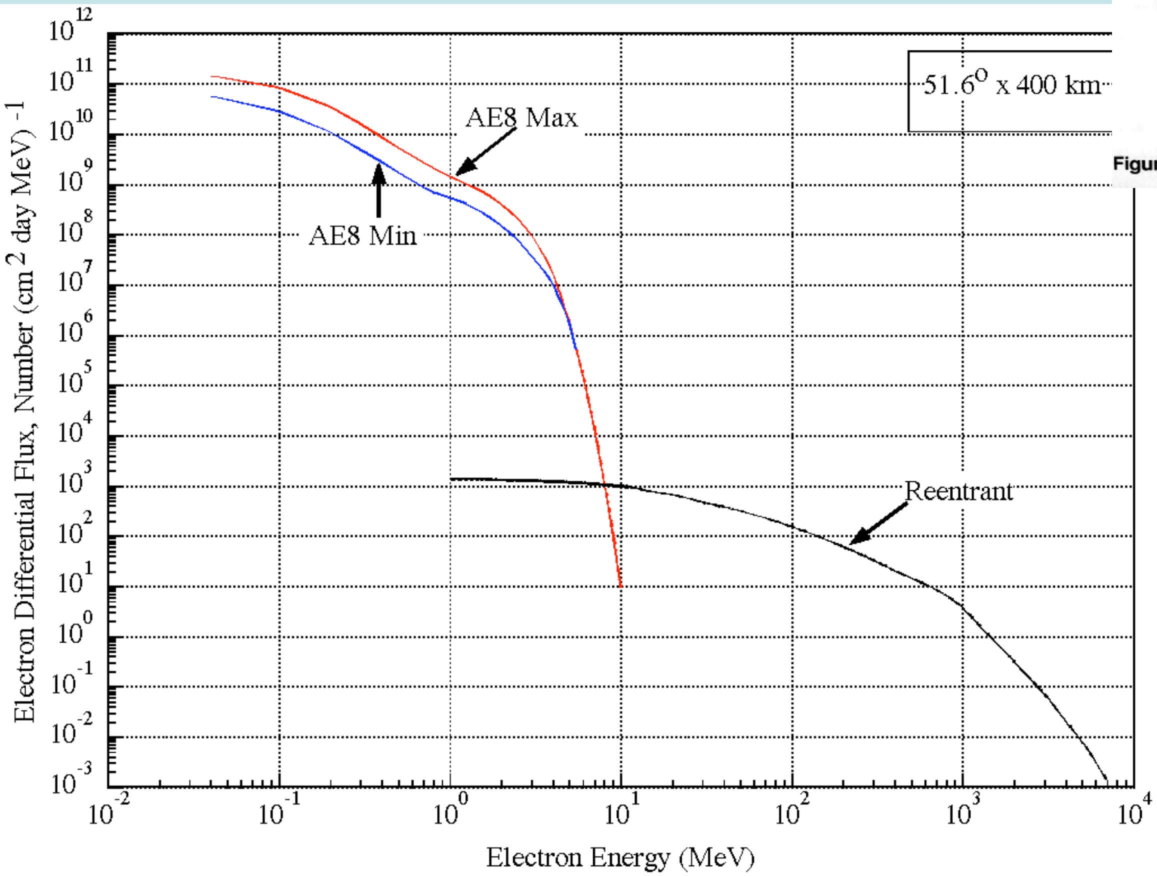


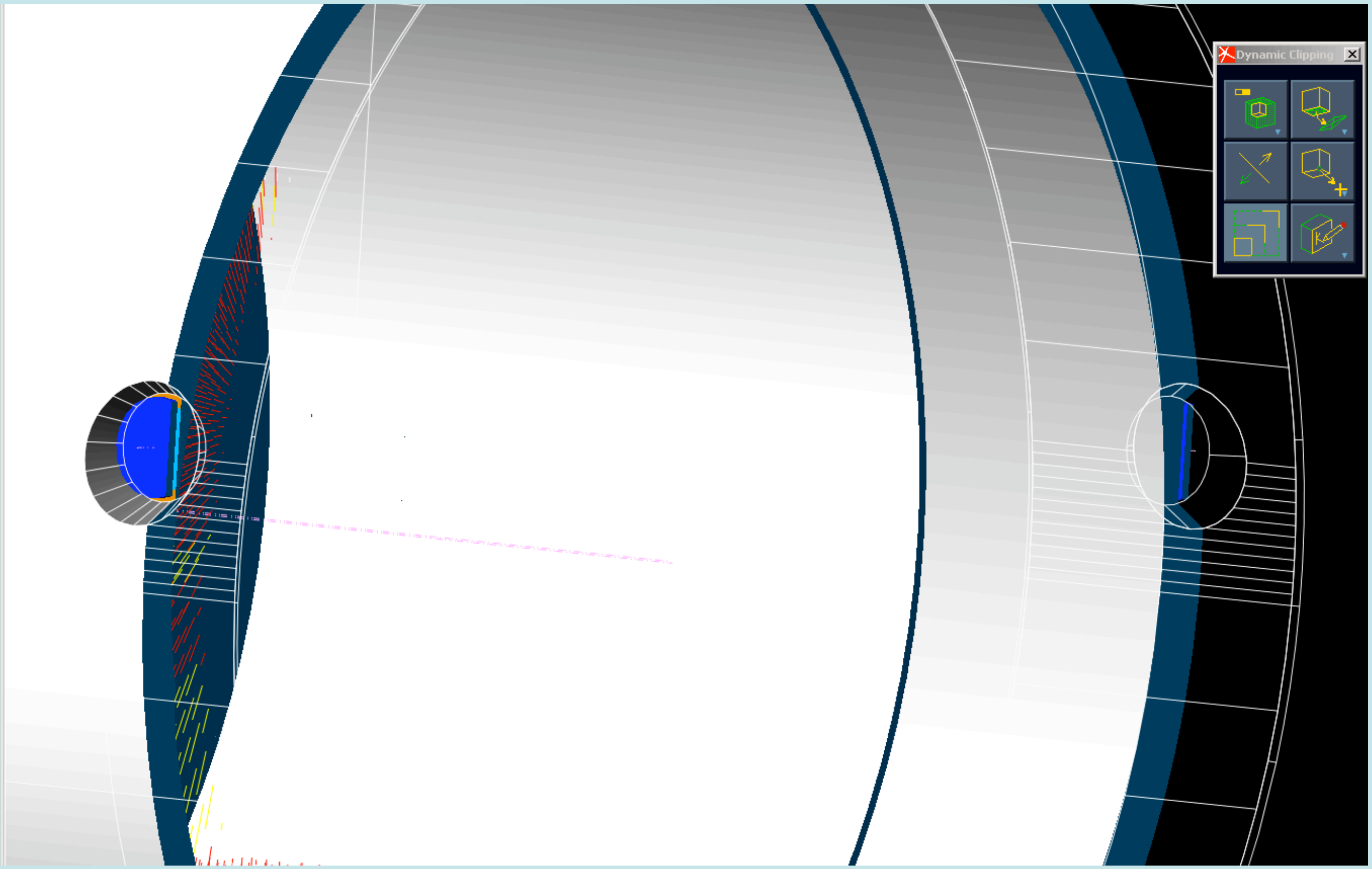
Figure 10-12. Sample dose-vs-depth functions for SAA trapped spectra in aluminum shield.



J.W.Wilson, et al. 2003

Badhwar, et al.; 2003

Hull thickness



Conclusions

- Vector flux models important for many LEO measurements, including shield design
  - Environmental parameters must be known
  - ISS orientation, detector orientation, location, time stamp necessary
- Non-operational measurements may be driving the need to document instrument and vehicle location and orientation

- Development of some tools needed for LEO analysis may not be driven by exploration needs

- Reminder: Q and $LET_{measured}$ not the only quantities need for risk analysis

Final Words

Thank you.

The NASA SRAG Manager retired… farewell M. Golightly
Long live the SRAG Manager!
Congrats and good luck Mark Weyland.

Zvezda launch