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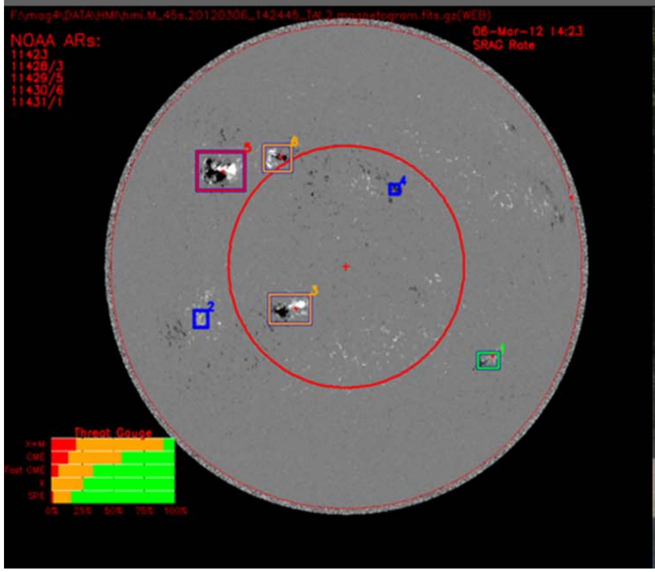

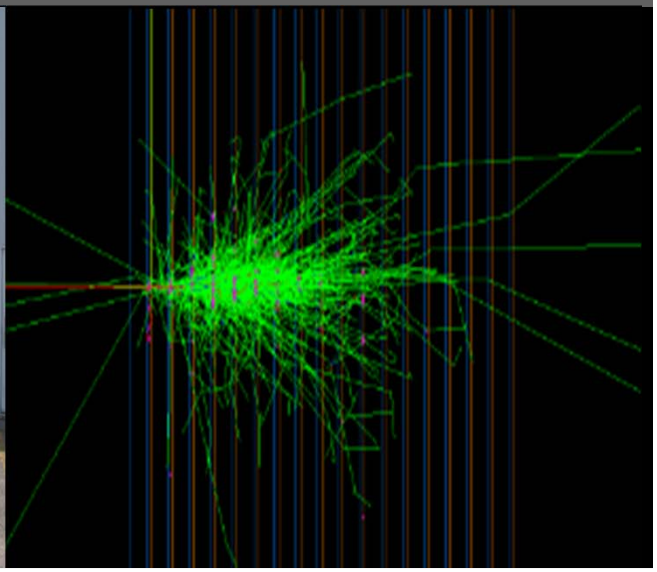

Toward Radiation-Smart Structures and Designs

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Space Radiation: The Drive & The Challenges

The Drive

A NASA strategic radiation protection guideline is the:

"*Demonstration of shielding concepts providing radiation protection focusing on light-weight multi-functional structure-capable materials that can provide GCR/SPE protection while providing other functionalities such as thermal insulation, structural integrity, and/or MMOD protection*."

The Challenges

Effective shielding against the combined effects of GCRs and SEPs can be mass prohibitive

Shielding effectiveness of new, potential shielding materials (or combinations thereof) is not well characterized

Little data to guide dose and risk assessment models

Known, large uncertainties and variabilities in radiobiological effects

Other uncertainties and variabilities? (e.g., in generalization and scale-up of shielding or protection solutions)

Space Radiation: The Path Forward

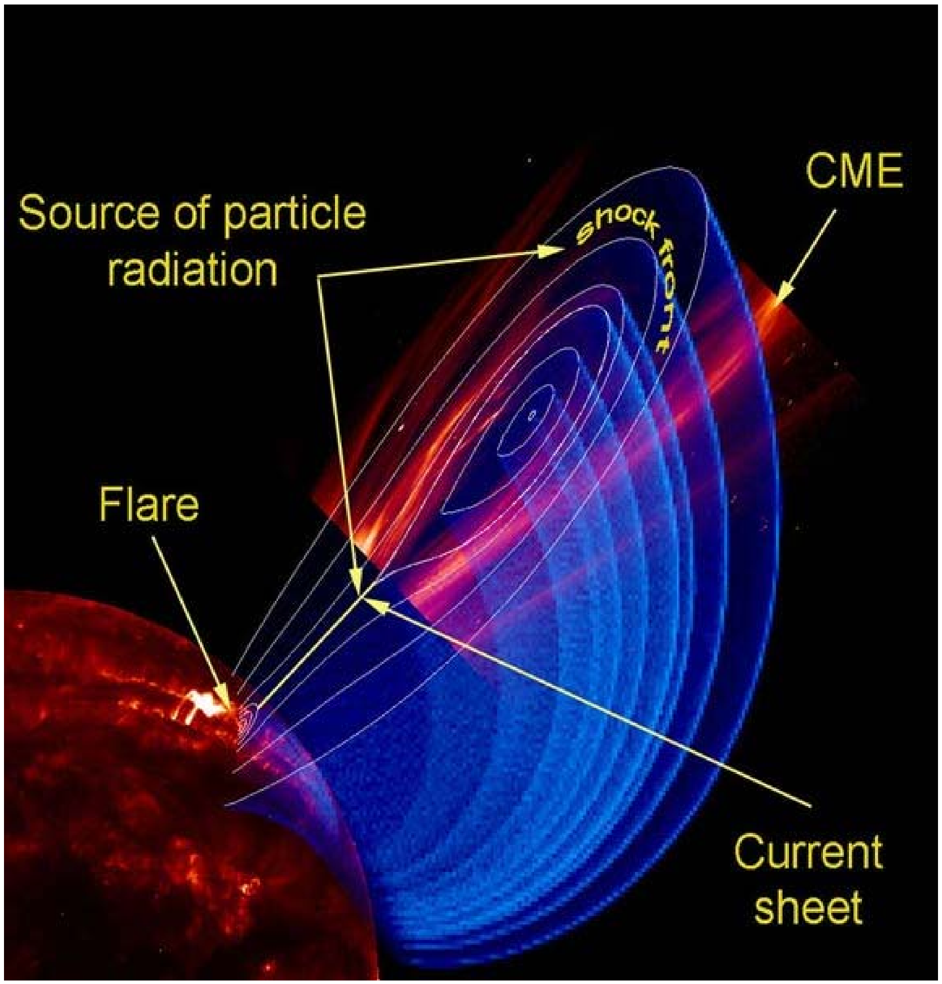
NASA's technology roadmaps call for an integrated approach in radiation protection

- **TA02 and TA03**: coordination with radiation protection measures for nuclear propulsion and power systems;
- **TA03**: survivability of solar power cells and other power system components in extreme radiation environments;
- **TA06**: astronaut health;
- **TA08**: instrumentation for particles, fields, and waves;
- **TA10**: use of boron nitride nanotubes for protection against radiation; and
- **TA12**: materials and structures for radiation shielding.

No one center or group (in academia or in the private sector) can realistically implement this integrated approach on its own!

Space Radiation: Natural Sources

Two main sources of ionizing radiation:



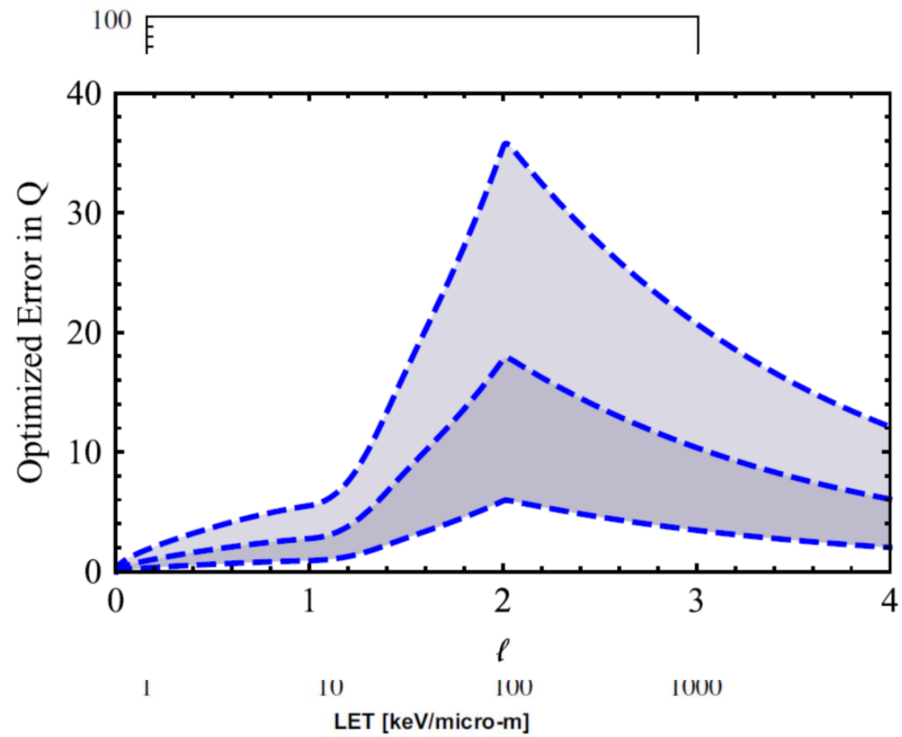
Space Radiation: Uncertainties in radiobiological effects

Large uncertainties -and variabilities- in the radiation quality factor is seen as a main hindrance toward reliable dose and risk estimates

These can be captured mathematically If we model the quality factor an as Ornstein-Uhlenbeck process,

$$dQ = C(\ell)Q\,d\ell + \sqrt{D(\ell)}\,dW$$

with a corresponding PDF of the form,



$$f_Q(Q,\ell;Q_0,0) = \frac{1}{\sqrt{4\pi q_1(\ell)}} \exp\left\{ -\frac{[Q\exp(q_2(\ell)) - Q_0]^2}{4q_1(\ell)} + q_2(\ell) \right\}$$

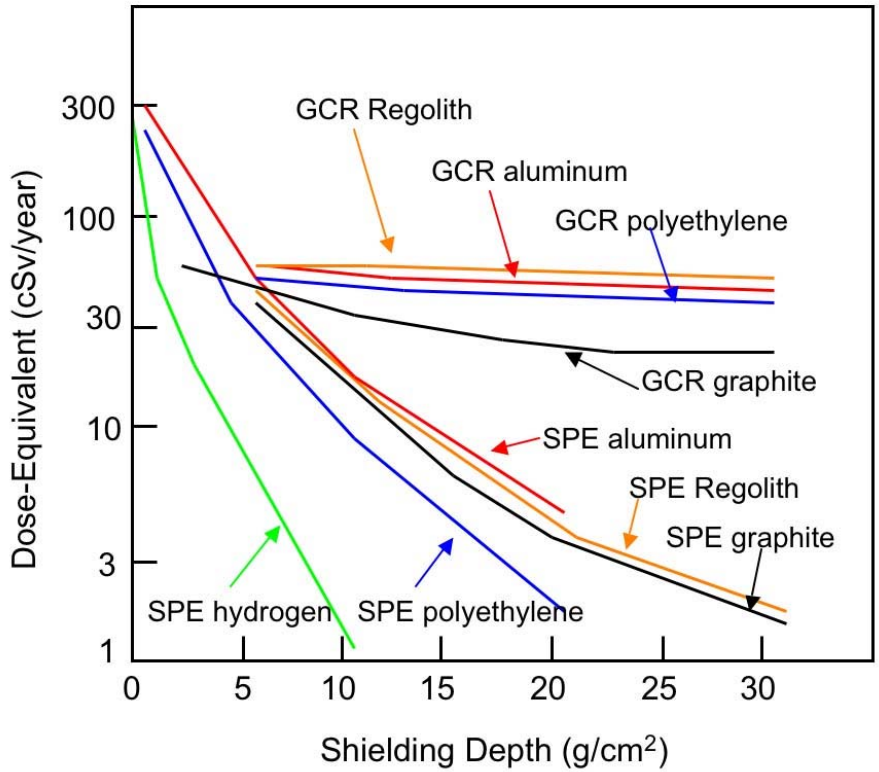
Space Radiation: Shielding effectiveness (how certain?)

Materials vary in their ability to shield against GCR nuclei

Polymeric based materials tend to be most effective - but their structural and safety properties remain poor or poorly known

Aluminum, like all metals, is **a poor GCR shield**

Regolith is not that much better either!



Space Radiation: Regolith as a shield material

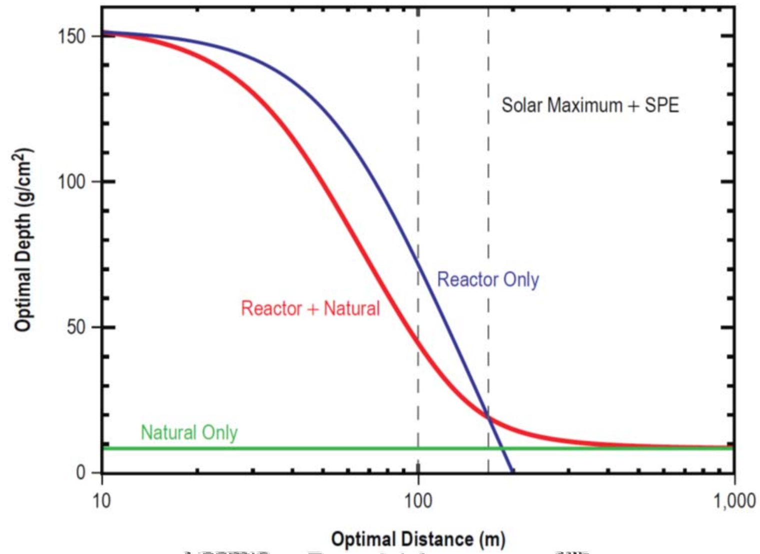
TABLE I: 1999 NCRP-recommended dose limits by organ and exposure duration.

Limit (cSv)	Bone Morrow	Eye	Skin
30-day Exposure	25	100	150
Annual	50	200	300
Career	50-300	400	600

TABLE II: Expected doses on the lunar surface with and without shielding (no nuclear power source assumed).

Duration (days)	GCR (cSv)	SEP (cSv)	Mission (cSv)
10	0.3/0.8	7.5/20.5	7.8/21.3
30	1.0/2.5	7.5/20.5	8.5/23.0
180	6.0/15.0	7.5/20.5	13.5/35.5
360	12.0/30.0	7.5/20.5	19.5/50.5

In-Space expected levels and limits



Use of regolith as a shield material in the presence of a small nuclear-power source exposure of few cSv/yr

Space Radiation at Marshall

- Monitoring & Detection

  protons- TaSEPS

  neutrons- ANS

- Forecasting

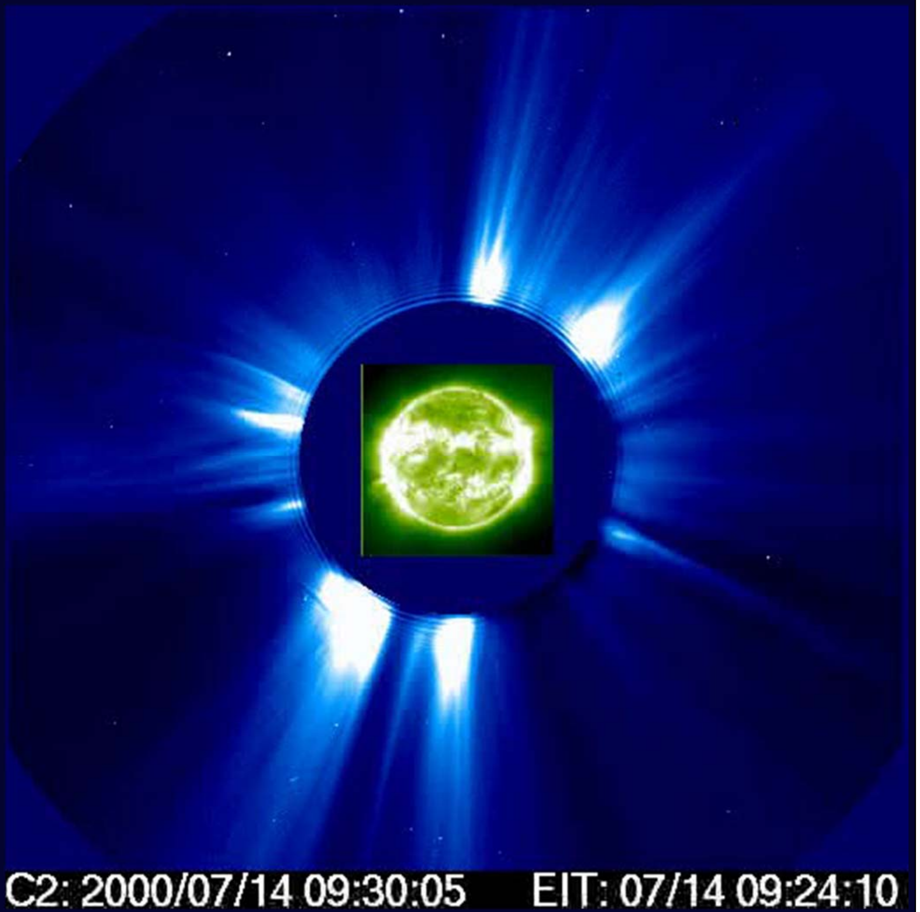
  Mag4

- Modeling & Simulation

  Geant4-based

- Radiation-Smart Structures

  Geant4-informed



Bastille Day (2000 July 14) Flare, Coronal Mass Ejection and Solar Energetic Particle Event

Science & Technology Office

Space Radiation: Monitoring & Detection

- Marshall scientists and engineers develop state-of-the-art charged particle and neutral particle detectors suitable for the harsh environments of space

-*Trapped and Solar Energetic Particle Spectrometer (TaSEPS)*: *TaSEPS is a compact wide dynamic range charged particle spectrometer for measuring trapped and solar energetic protons by combing scintillation and Cherenkov techniques in a single CsI crystal that extends the dynamic range and reduces the mass and power requirements*

Planned for a balloon flight

Space Radiation: Monitoring & Detection

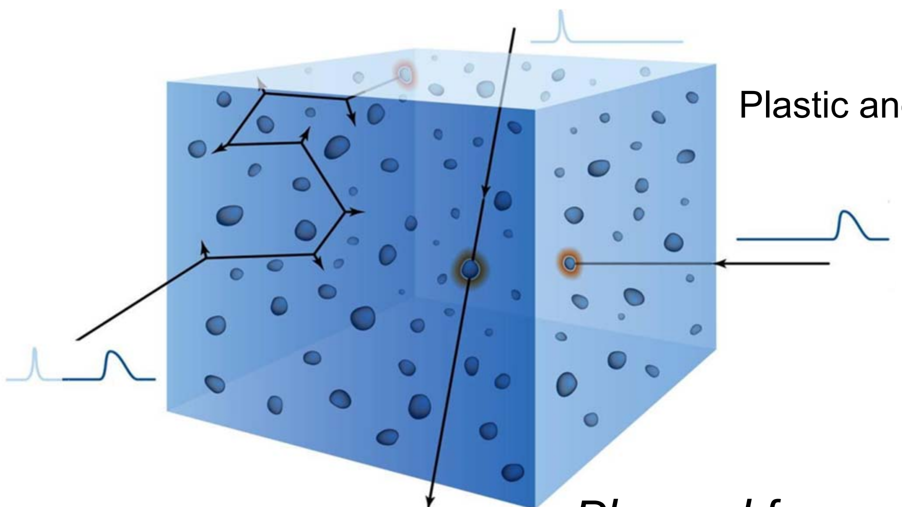
- Marshall scientists and engineers develop state-of-the-art charged particle and neutral particle detectors suitable for the harsh environments of space:

-Advanced Neutron Spectrometer (ANS): *is a new instrument technique being developed to meet NASA's requirements to monitor the radiation exposure due to <u>secondary neutrons</u> for future crewed missions. New instrument designs are needed to achieve the measurement performance requirements that fit within the resource limits of exploration missions beyond Earth's protective magnetic field*

$n + {}^{6}Li \rightarrow {}^{3}H + {}^{4}He$
Q = 4.78

$n + Gd \rightarrow Gd^{*} + \gamma$
Q = [0,2]

$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$
Q = 2.73 (93%)
or 2.25 (7%)



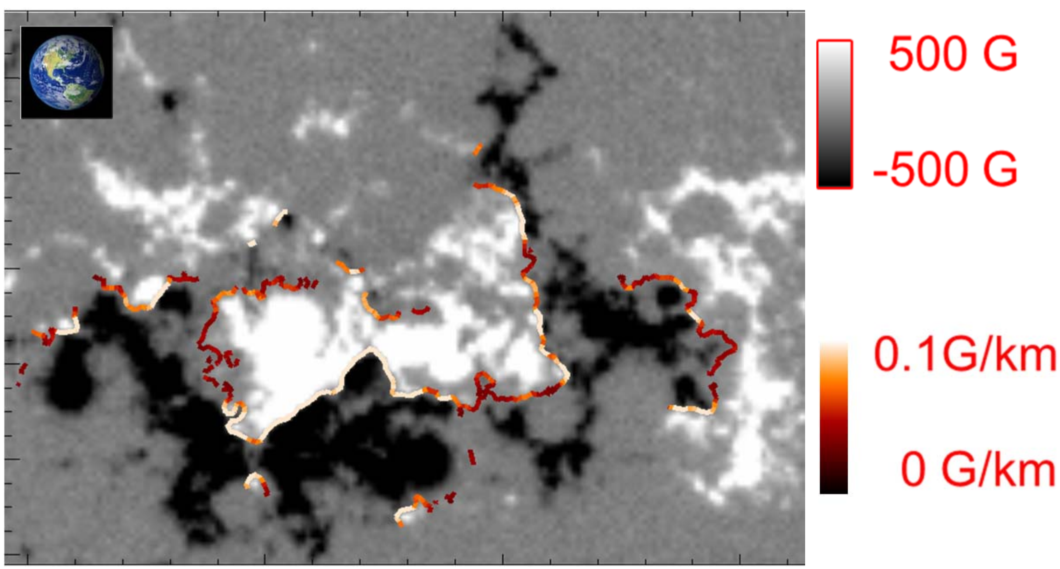
Plastic and Li-Gd-B scintillator

Planned for an ISS flight demonstration

Space Radiation: Magnetic-based Forecasting (Mag4)

- Marshall scientists and engineers developed an automated prediction system that downloads and analyzes magnetograms from the HMI (Helioseismic and Magnetic Imager) instrument on NASA SDO (Solar Dynamics Observatory), and then automatically converts the rate (or probability) of major flares (M- and X-class), Coronal Mass Ejections (CMEs), and Solar Energetic Particle Events

[Present cadence of new forecasts: **96 min**; Vector magnetogram actual cadence: **12 min**]



A magnetogram of an active region on the Sun

When the transverse gradient of the vertical (or line-of-sight) magnetic field is large, there is more free-energy stored in the magnetic field

For each Active Region: The integral of the gradient along the neutral line is the free-energy proxy

Mag4: A Comparison of Safe and Not Safe Days

June 26, 2013

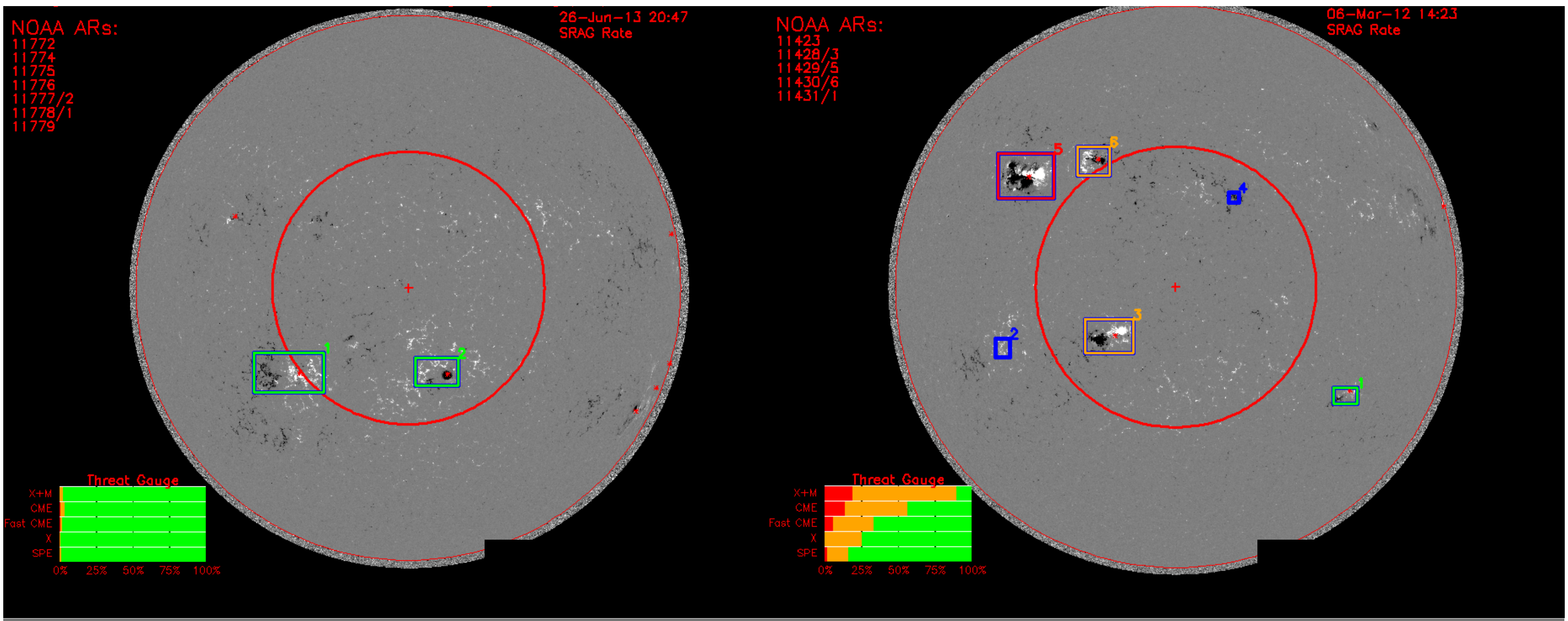
C1, C1.5 flares

March 7, 2012

X5.4, X1.3, C1.6

CME 2684, 1825 km/sec,

Solar Energetic Proton Event reaches 6530 'particle flux unit' >10 MeV



Space Radiation: Modeling & Simulation

- Marshall scientists and engineers use Geant4 for the design, analysis, and development of

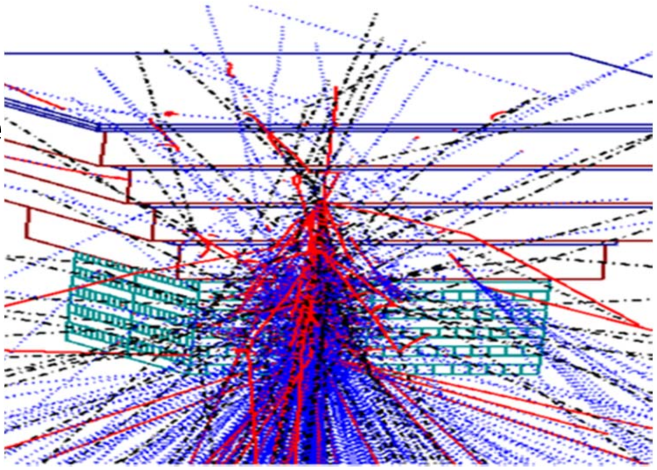
  particle detector systems

  exposures at accelerators and in-situ

  dose estimates

  shielding solutions

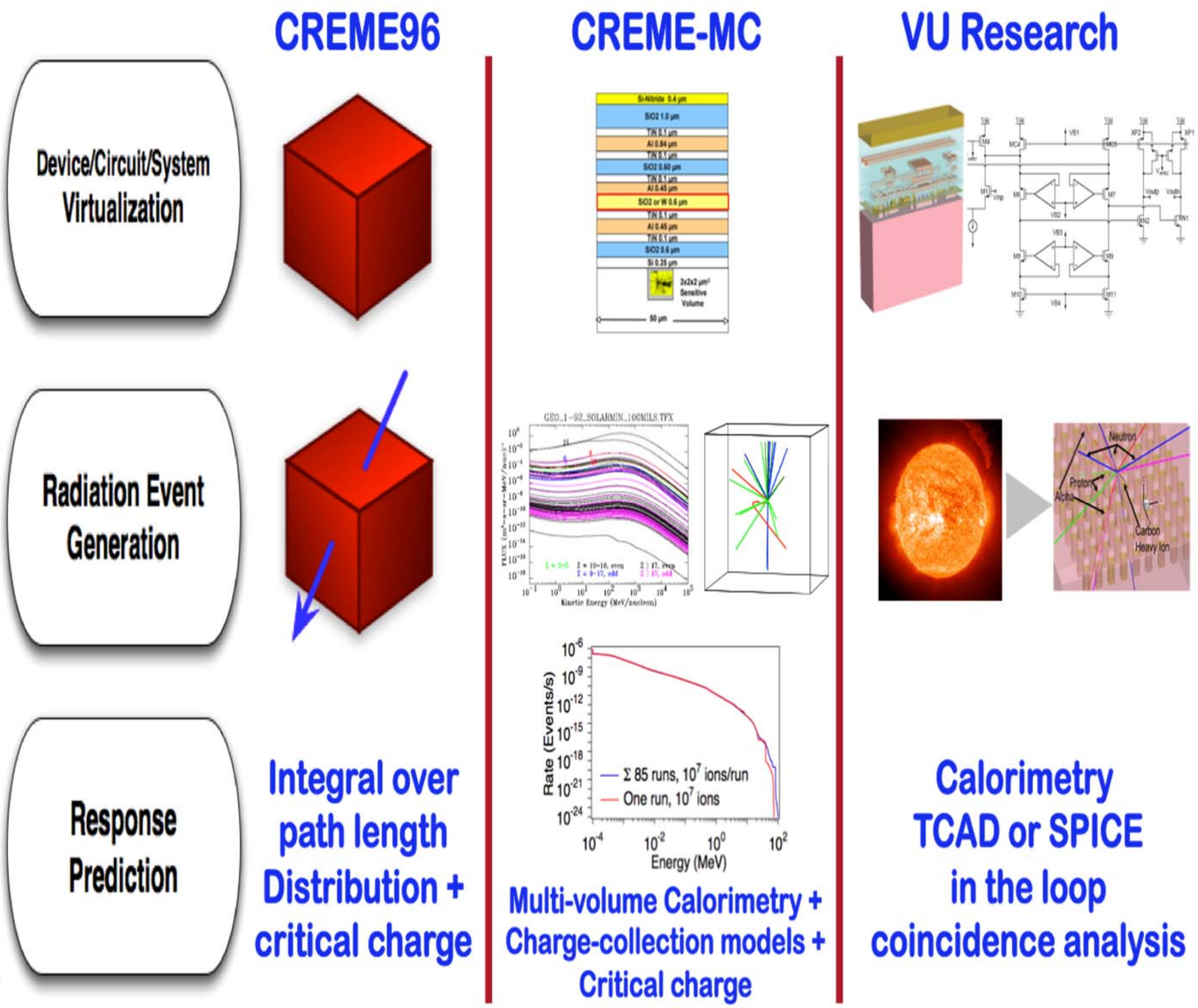
- Marshall scientists and engineers collaborate with experimental and theoretical and computational groups at Oak Ridge National Laboratory, Berkeley's Lawrence National Laboratory, Brookhaven National Laboratory, Indiana University's Cyclotron Facility, Japan's HIMAC facility, and others for basic and applied nuclear modeling, simulation, and exposure and shielding studies



Space Radiation: Modeling & Simulation

Marshall managed HEDS' Space Radiation Shielding Project (SRSP) and ETDP's Advanced Avionics and Processor Systems (AAPS) Project. Under these two radiation projects:

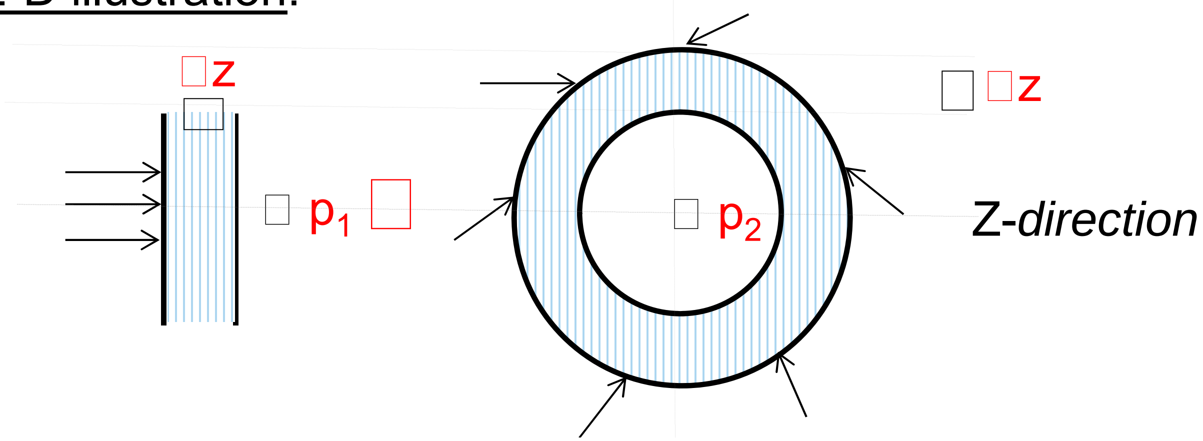
- Marshall developed the first generation of multi-functional shielding materials
- Marshall managed all accelerator-based testing of shielding materials
- Marshall managed the acquiring of basic nuclear-physics data needed for shielding and exposure risk assessment studies
- Marshall also developed a unique, sophisticated online simulation tools to reliably gauge the radiation effects on electronics (Crème-MC)

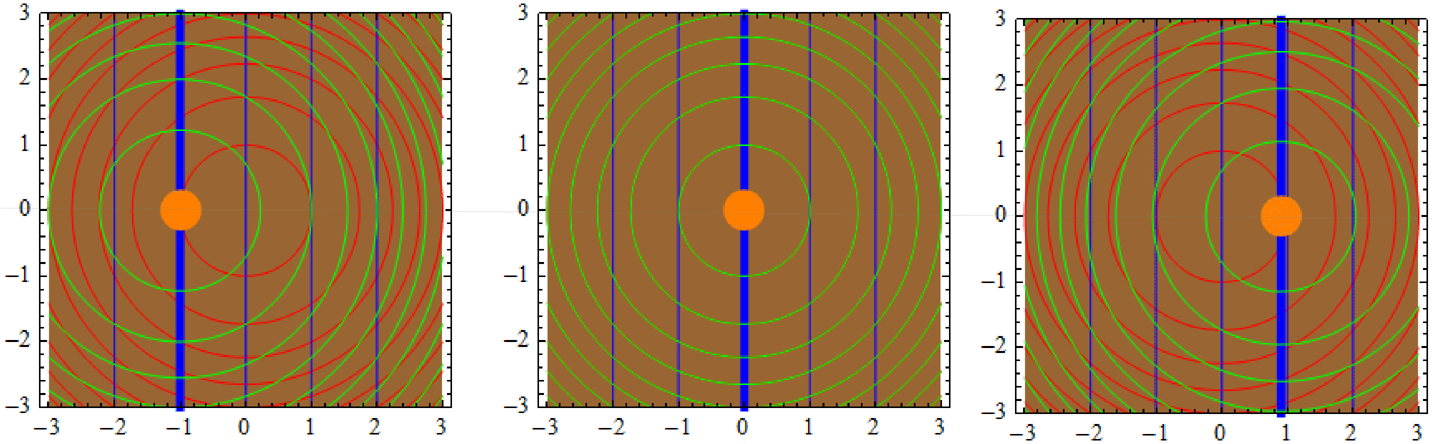


Virtual Irradiation Capabilities of Crème-MC

Complex geometry and material composition -in the presence of known physical uncertainties- are expected to produce large errors in any radiation protection solution.

A 2-D illustration:

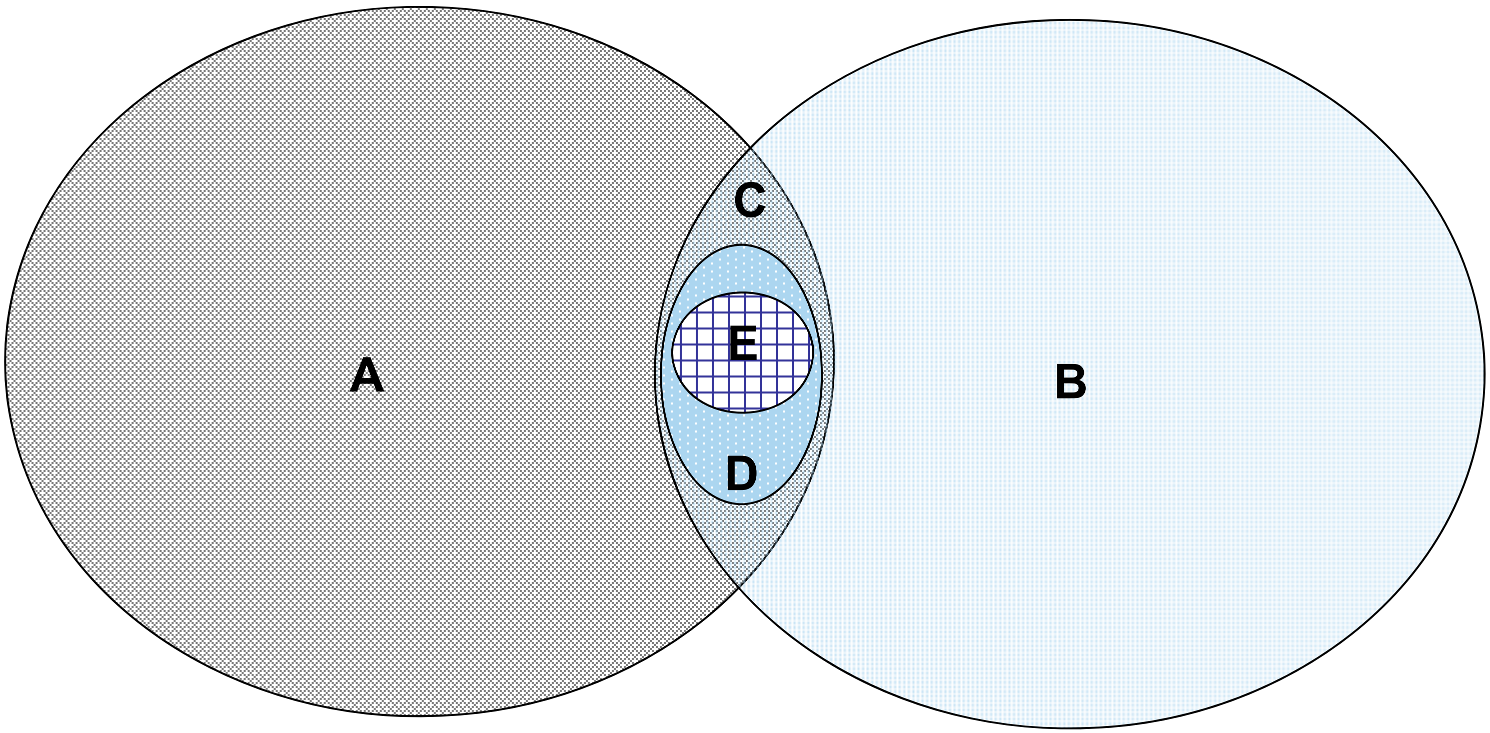




Space Radiation: Modeling & Simulation

A 3-D illustration:

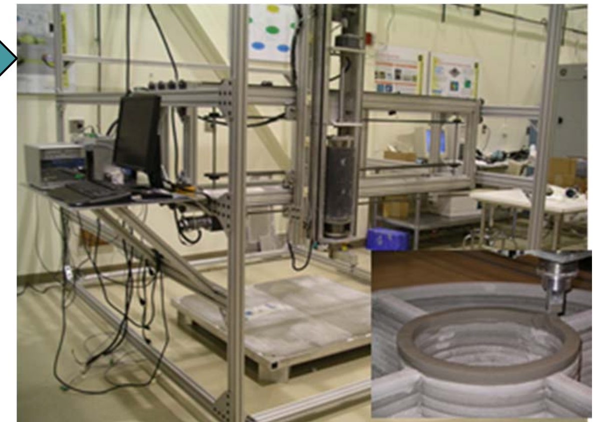
Radiation-Smart Structures and Designs?

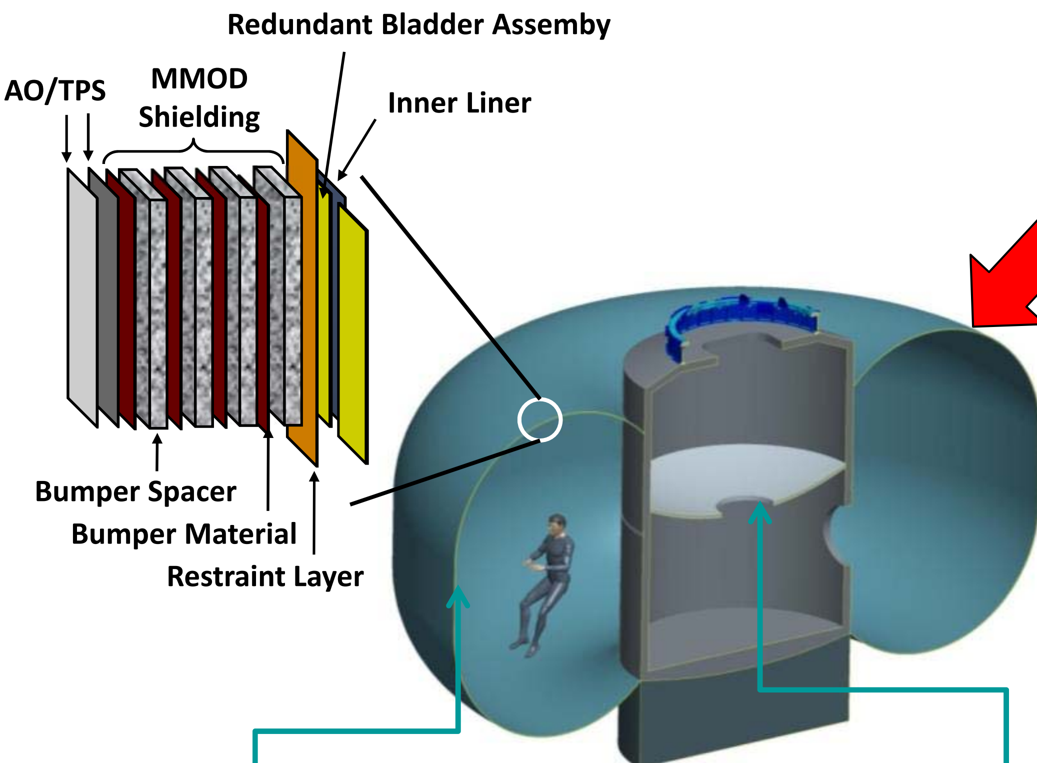


A: Adaptive Structures
B: Sensory Structures
C: Controlled Structures
D: Active Structures
E: Intelligent Structures

Space Radiation: Radiation-Smart Structures and Designs

Smart Materials: Multi-functional





Smart Designs: Optimized

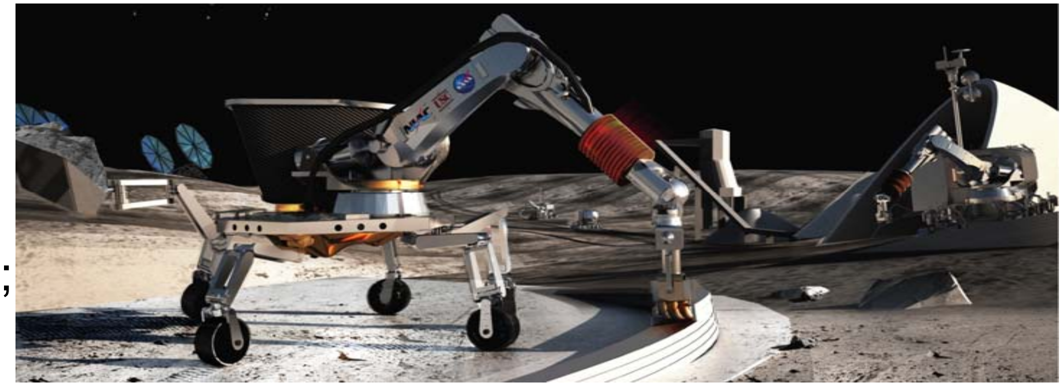
radiation shielding will most likely focus on MMOD shielding materials and core

Space Radiation: Contour-crafting technology

- A new technology (developed at the University of Southern California) for robotic and autonomous construction; allows for versatile design options & construction materials
- Current capabilities (at USC and MSFC) are for small structures only
- Current R&T efforts to improve TRL and space and terrestrial applicability (NIAC)
- Large-scale demonstration of the new technology just started
- Space applications focusing on remote lunar base construction, MMOD and radiation protection solutions
- Terrestrial applications for forward construction capability for military and for rapid, disaster relief efforts (FEMA)

Space Radiation: Built-In Protection (A New Paradigm)

-NASA in collaboration with DoD, academia, and the private sector is embarking on a new and radical way in looking at the challenges and solutions of space-radiation exposure; from the ‘grounds’ up!



-Marshall is at the heart of this new paradigm making

-Space-radiation protection solutions and strategies have evolved…