



3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

Space Radiation and Exploration

Francis A. Cucinotta, Ph.D.

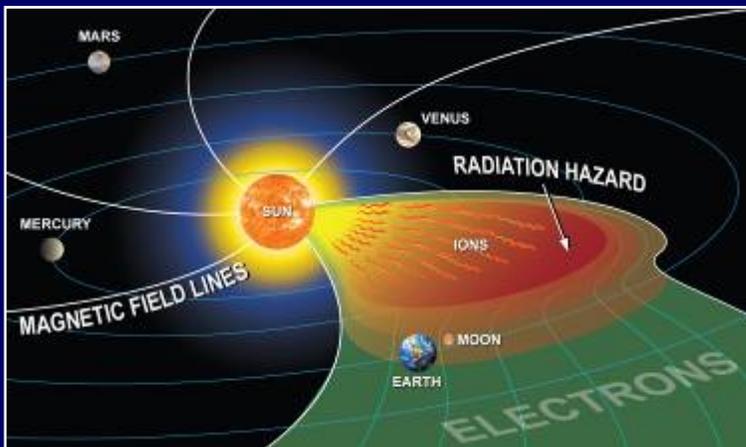
**Chief Scientist, NASA Space Radiation Program
Element**

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Executive Summary

- Estimating space radiation risks carries large uncertainties that preclude setting exposure limits and evaluating many mitigation measures
- NASA needs to close the knowledge gap on a broad-range of biological questions before radiation protection goals can be met for exploration
- The Human Research Program (HRP), Space Radiation Program Element (SRP) led by JSC is committed to solving the space radiation problem for exploration





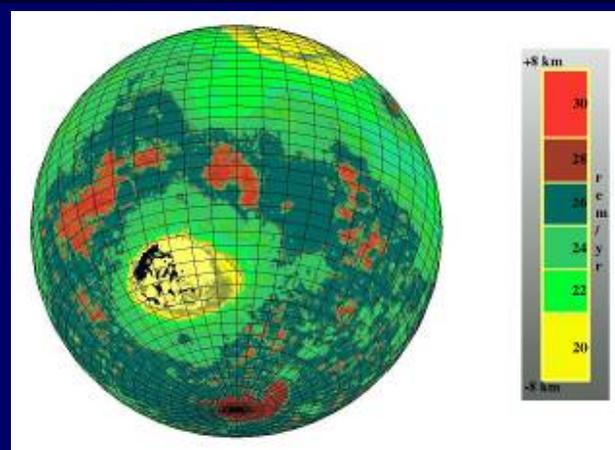
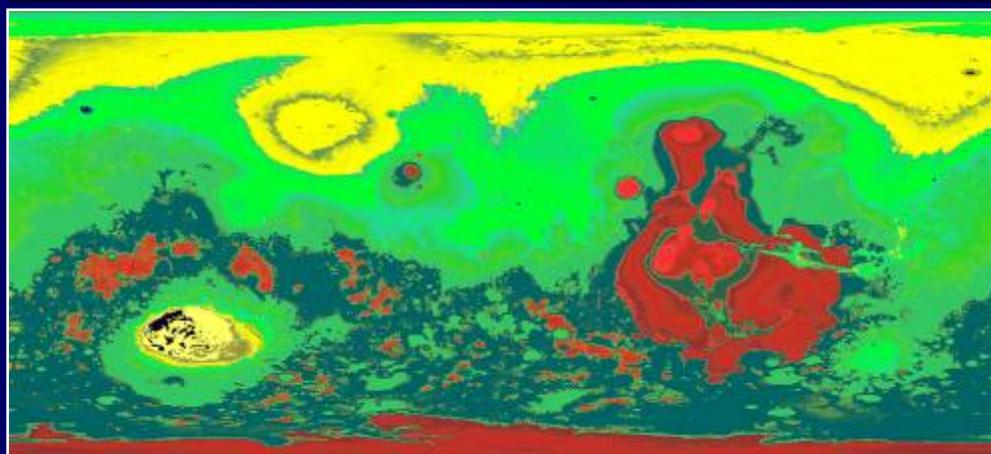
Space Radiation Environments

Galactic cosmic rays (GCR) penetrating protons and heavy nuclei—*a biological science challenge*

- shielding is not effective
- large biological uncertainties limits ability to evaluate risks and effectiveness of mitigations

Solar Particle Events (SPE) largely medium energy protons—*a shielding and operational challenge*

- shielding is effective; optimization needed to reduce weight
- optimized event alert and responses required on risks must be obtained



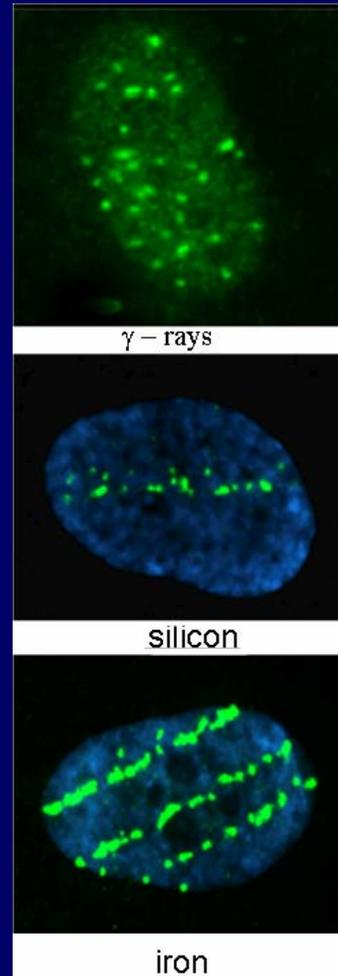
GCR doses on Mars



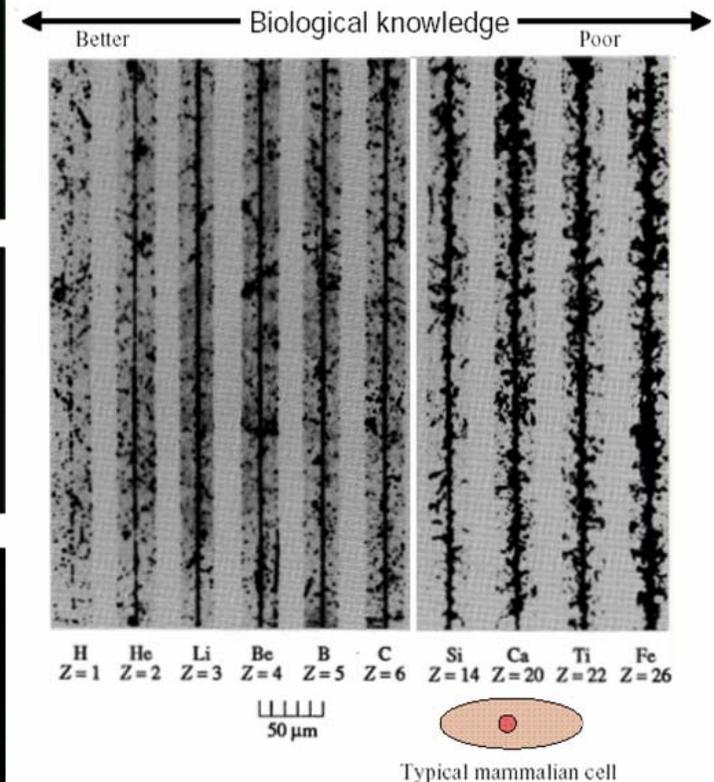
The Space Radiation Problem

Space radiation is comprised of high-energy protons and heavy ions (HZE's) and secondary protons, neutrons, and heavy ions produced in shielding

- Unique damage to biomolecules, cells, and tissues occurs from HZE ions
- No human data to estimate risk
- Animal models must be applied or developed to estimate cancer, and other risks
- Shielding has excessive costs and will not eliminate galactic cosmic rays (GCR)



Single HZE ions in cells
And DNA breaks



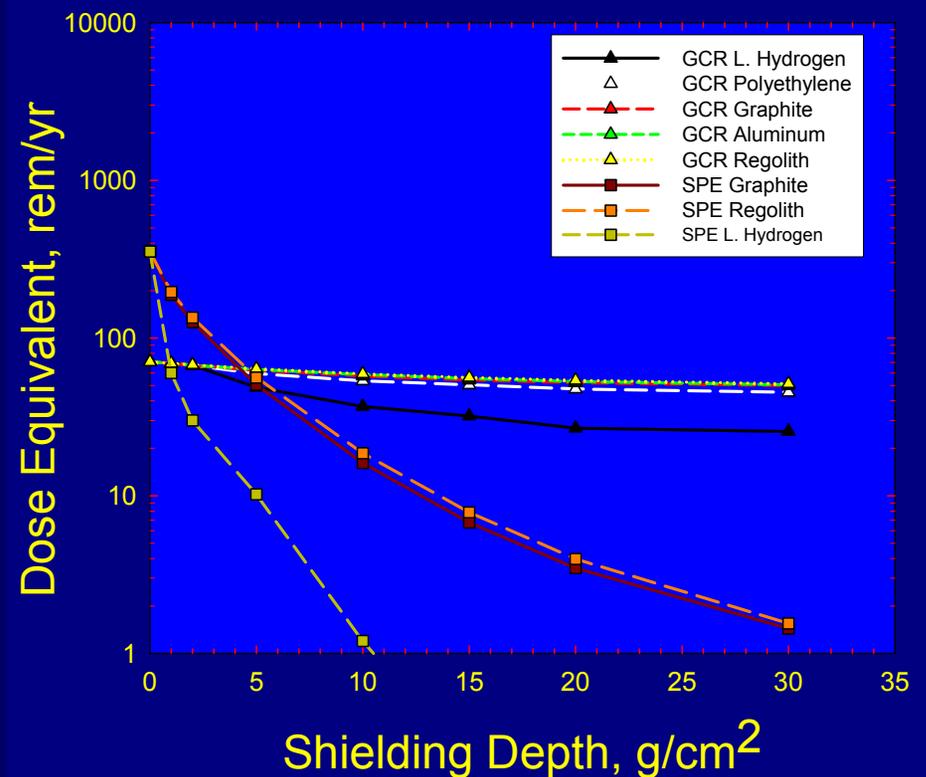
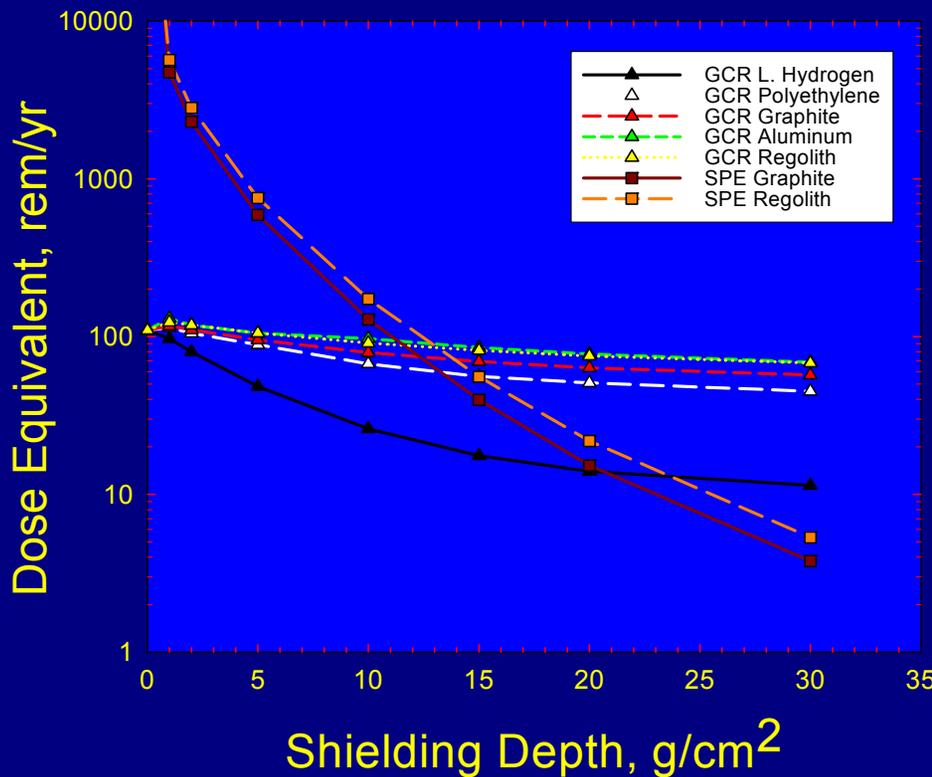
Single HZE ions in photo-emulsions
Leaving visible images

GCR and SPE Doses: Materials & Tissue

- GCR much higher energy producing secondary radiation

No Tissue Shielding

With Tissue Shielding



August 1972 SPE and GCR Solar Min



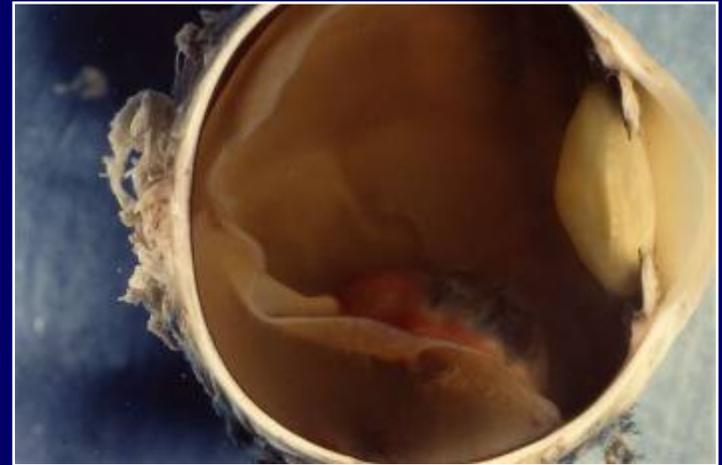
Categories of Radiation Risk

Four categories of risk of concern to NASA:

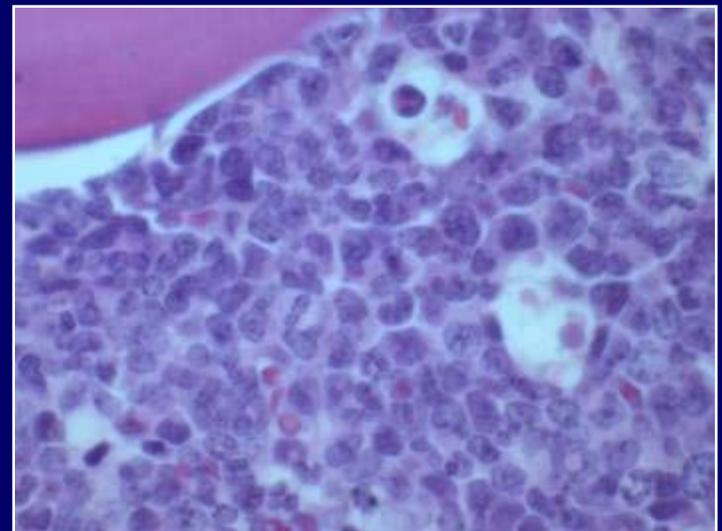
- ***Carcinogenesis (morbidity and mortality risk)***
- ***Acute and Late Central Nervous System (CNS) risks***
- ***Chronic & Degenerative Tissue Risks***
 - ✓ cataracts, heart-disease, etc.
- ***Acute Radiation Risks***

Differences in biological damage of heavy nuclei in space with x-rays, limits Earth-based data on health effects for space applications

- **New knowledge on risks must be obtained**



Lens changes in cataracts



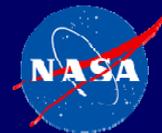
1st experiments for leukemia induction with GCR



Foundations of SRP Research Plans

- External review by NCRP, National Academy of Sciences, and standing Radiation Discipline Working Group (RDWG)
- Simulate space radiation at the NASA Space Radiation Laboratory (NSRL)
 - Located at DoE's Brookhaven National Lab (Long Island NY)
- Five NASA Specialized Centers of Research (NSCOR's) studying the biology of space radiation risks
- Broad program of directed research including collaborative research with DoE
- NSBRI research on acute risks and EVA dosimetry
- Collaborate with SMD on advanced SPE alert & Mars robotic missions
- Long-term goal to improve knowledge to develop individual risk assessments, countermeasures





Radiation and Risk Uncertainties

What could we do about risk?

- Optimize Mission Operations & Shielding
- Biological countermeasures (C.M.)
- Limit mission parameters

What are impacts of uncertainties?

- Increase costs due to excessive safety margins
- Limits ability to judge mitigation approaches
- Inadequate information to advise Astronauts on risks

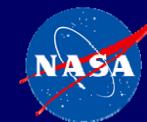
What could we do about uncertainties?

- Probabilistic risk assessment
 - Approved by NASA Medical Policy Board
- Narrow the knowledge gap on biological effects to achieve uncertainty reduction



Major Sources of Uncertainty

- Radiation quality effects on biological damage
 - Qualitative and quantitative differences of Space Radiation compared to x-rays
- Dependence of risk on dose-rates in space
 - Biology of DNA repair, cell regulation
- Predicting solar events
 - Temporal and size predictions
- Extrapolation from experimental data to humans
- Individual radiation-sensitivity
 - Genetic, dietary and “healthy worker” effects



Minor Sources of Uncertainty

- Data on space environments
 - Knowledge of GCR and SPE environments for mission design
- Physics of shielding assessments
 - Transmission properties of radiation through materials and tissue
- Microgravity effects
 - Possible alteration in radiation effects due to microgravity or space stressors
- Errors in human data
 - Statistical, dosimetry or recording inaccuracies

Long Island, NY

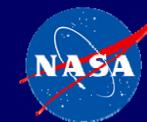
NASA Space Radiation Laboratory
(NSRL)
Brookhaven National Lab
Upton, NY



Collider Accelerator Div.
RHIC-AGS Complex



NSRL



Estimates of “Safe Days” in Space for GCR

Research progress shows significant increase in “Safe Days” to be within acceptable risks for a Mars mission

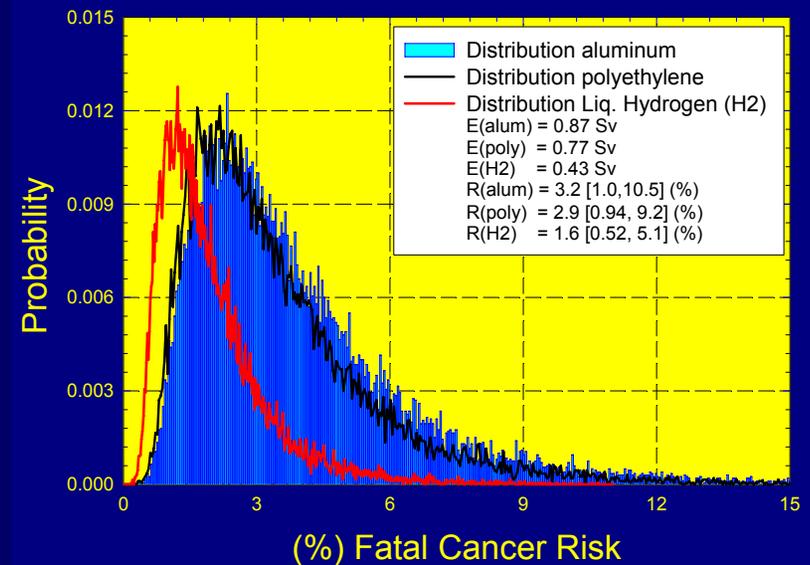
- Uncertainties are being reduced through NSRL research

Table: Estimates of “Safe Days” in deep space under heavy shielding

Age, yr	Females		Males	
	Previous (2001)	Current (2006)	Previous (2001)	Current (2006)
30	54	112	91	142
35	62	132	104	166
40	73	150	122	186
45	89	182	148	224
50	115	224	191	273

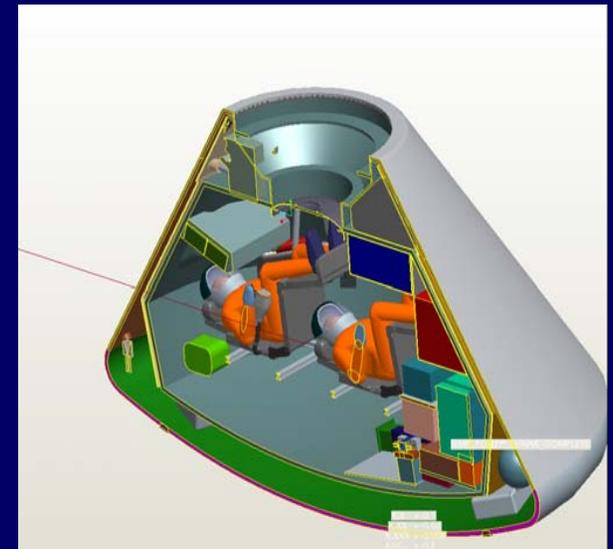
Significance Tests of Shielding

- Physics of Space Environments and Radiation Transport is well understood
- Radiobiology of GCR limits our ability to judge merits of Radiation shielding



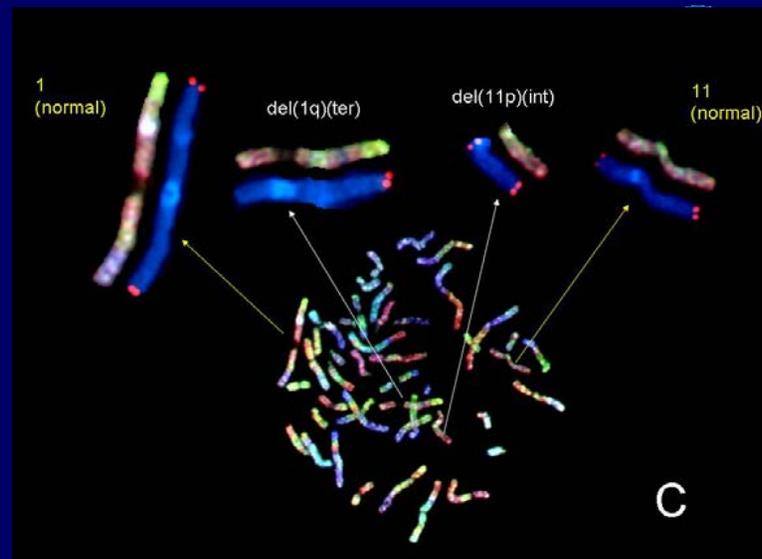
Statistical Test in Deep Space:

Test Material	E, Sv	Risk(%)	95% CL	χ^2/n	$P(n, \chi^2)$
<u>Solar Minimum</u>					
Aluminum	0.87	3.2	[1.9, 8.7]	-	-
Poly.	0.78	2.9	[1.8, 7.5]	0.08	>0.99
Hydrogen	0.43	1.6	[1.0, 4.2]	1.1	<0.15
<u>Solar Max with 1972 SPE</u>					
Aluminum	1.21	4.4	[3.0, 11.]	-	-
Poly.	0.94	3.5	[2.3, 8.8]	0.32	>0.99
Hydrogen	0.52	2.1	[1.2, 5.2]	1.38	<0.001

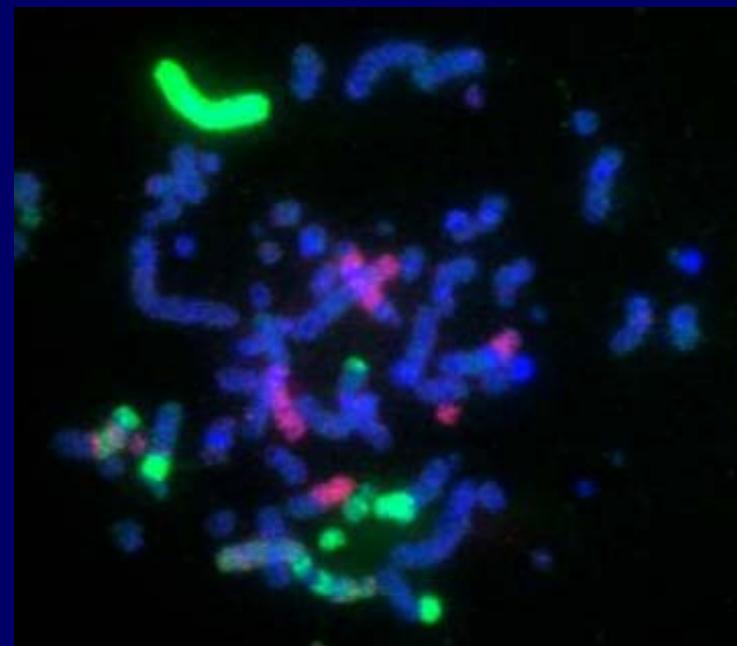


Flight Science Goals

- RAD detector on MSL will measure Mars surface environment
- Crew samples
 - Advanced bio-monitoring of crew
 - For GCR need individual cell based assays
 - New cytogenetic techniques
 - DNA damage protein markers
 - Telomere length changes (ends of chromosomes)
 - Intra-cellular communication



Iron nuclei at NSRL and Rx-FISH

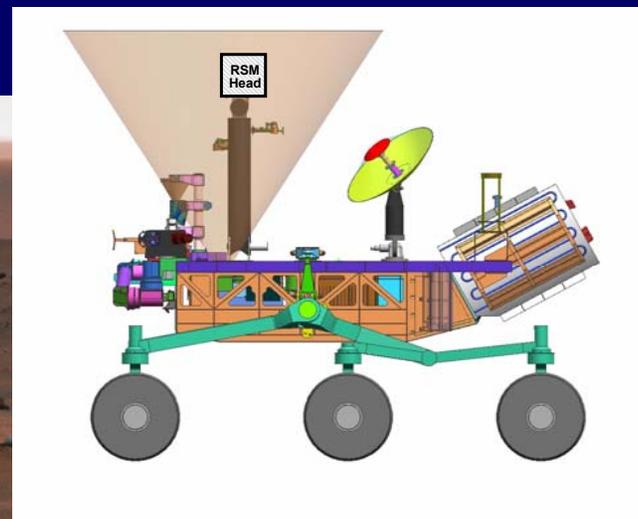
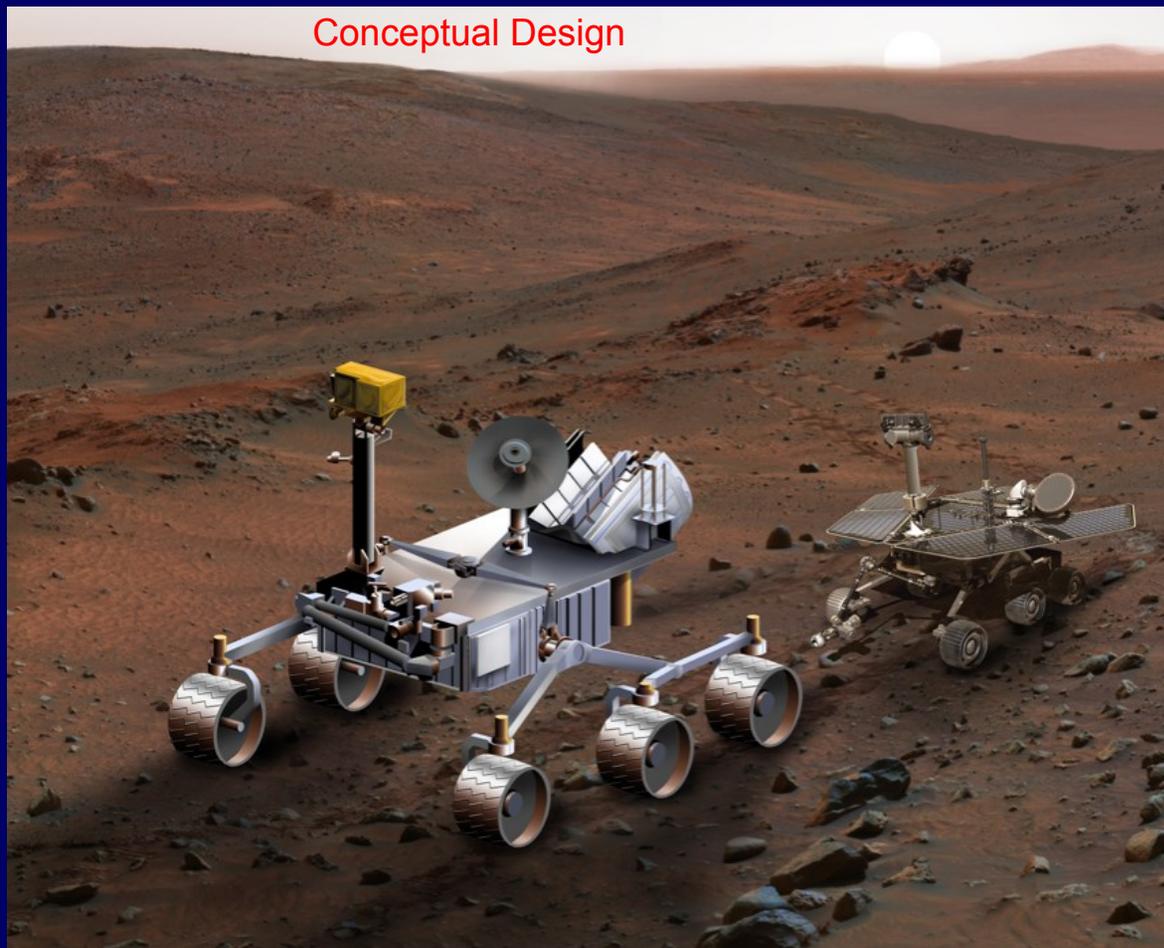


Rogue cell from ISS Crew

RAD experiment on MSL (Mars 2009)

- Principle Investigator Don Hassler, SWRI
- Measure Neutron and Charged particles on Mars

Conceptual Design

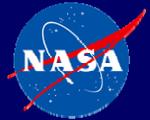


FOV ~ 75 deg.

(full angle)

Geometric factor

~ 198 mm² * sr



SRPE Major Deliverables

Develop the Knowledge to Accurately Estimate and Reduce Risk:

- Knowledge base on radiation effects on health and performance through ground-based research
- Achieve accuracy required for cost effective risk prediction
- Develop approaches to prevent acute risks and reduce chronic risks
- Evaluate mitigation approaches (shielding/biological)
- Data from precursor robotic missions to characterize crew exposure
- Operate and maintain the NSRL to facilitate this research

Develop Recommendations and Requirements for:

- Risk projection models for NASA programs
- Acceptable levels of risk (acute & chronic dose limits)
- Crew constraints, mission length and operations

Provide Capabilities:

- Crew risk projection and analysis
- Concept evaluation
- Architectural and mission assessment



Summary

Space radiation is a major challenge to exploration:

- Risks are high limiting mission length or crew selection
- Large mission cost to protect against risks and uncertainties

NASA approach to solve these problems:

- Probabilistic risk assessment framework for ISS and Exploration Trade Studies
- Ground-based research at NSRL
- Five Specialized Centers of Research (NSCOR's)
- Collaborative research with DoE, NSBRI, and ESA
- Ongoing external reviews by authoritative bodies
- Well defined deliverables to Cx, ISS, and CHMO





Backup Charts



Solar Particle Event Risks

Research studies show that the risks of acute death from large solar particle events has been over-estimated:

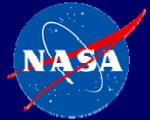
- New knowledge of dose-rates, tissue shielding, and proton biological effectiveness show risk is very small

SPE risk remain large for lunar EVA

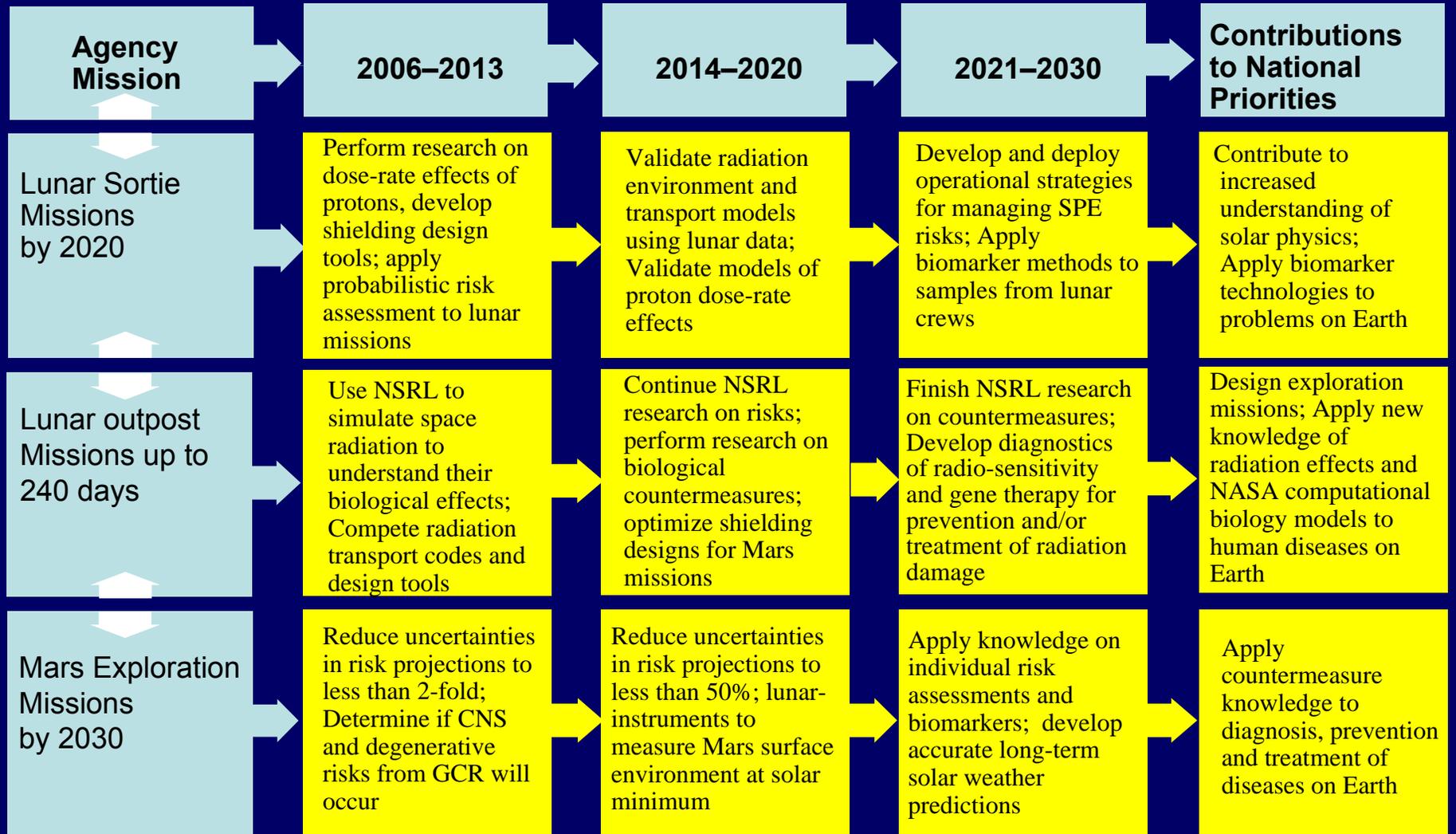
- Radiation sickness if unprotected for longer than 2 hours EVA
- Additional cancer risk both EVA and IVA

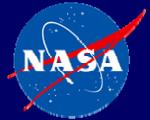
Proper resource management through research:

- Probabilistic risk assessment tools for Lunar and Mars Architecture studies
- Optimize shielding requirements through improved understanding of proton biological effects and shielding design tools
- ESMD and SMD collaborations on research to improve SPE alert, monitoring and forecasting
- Biological countermeasure development for acute sickness and proton cancer risks



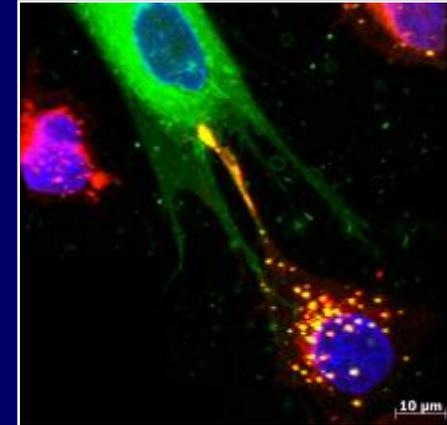
Space Radiation Research



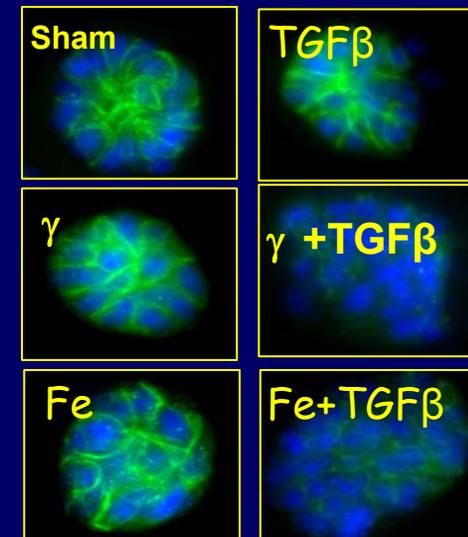


Space Safety Requirements

- Congress has chartered the National Council on Radiation Protection (NCRP) to guide Federal agencies on radiation limits and procedures
 - NCRP guides NASA on astronaut dose limits
- Crew safety
 - limit of 3% fatal cancer risk
 - prevent radiation sickness during mission
 - new exploration requirements limit Central nervous system (CNS) and heart disease risks from space radiation
- Mission and Vehicle Requirements
 - shielding, dosimetry, and countermeasures
- NASA programs must follow the ALARA principle to ensure astronauts do not approach dose limits



Cell fusion caused by radiation



Space Radiation in breast cancer formation



NASA Space Radiation Laboratory

The NASA Space Radiation Laboratory (NSRL), a \$34-million facility, is located at DOE's Brookhaven National Laboratory is managed by NASA's Johnson Space Center. It is one of the few places in the world that can simulate heavy ions in space. New joint DoE-NASA Electron beam injector source (EBIS) for 2009 increases space simulation capability

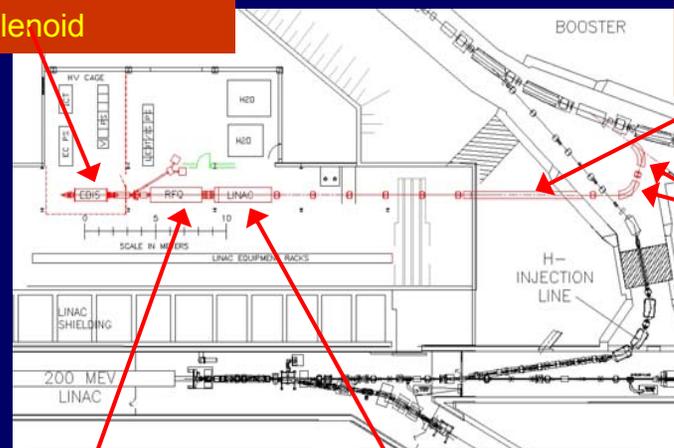


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EBIS SC solenoid



Beam port

Dipoles - preparing

RFQ

Linac

EBIS Construction