National Aeronautics and Space Administration

The Impact of Radiation on Human Space Exploration

-- General Considerations --

7th Space Weather & Robotic Mission Operations Workshop

September 30, 2015

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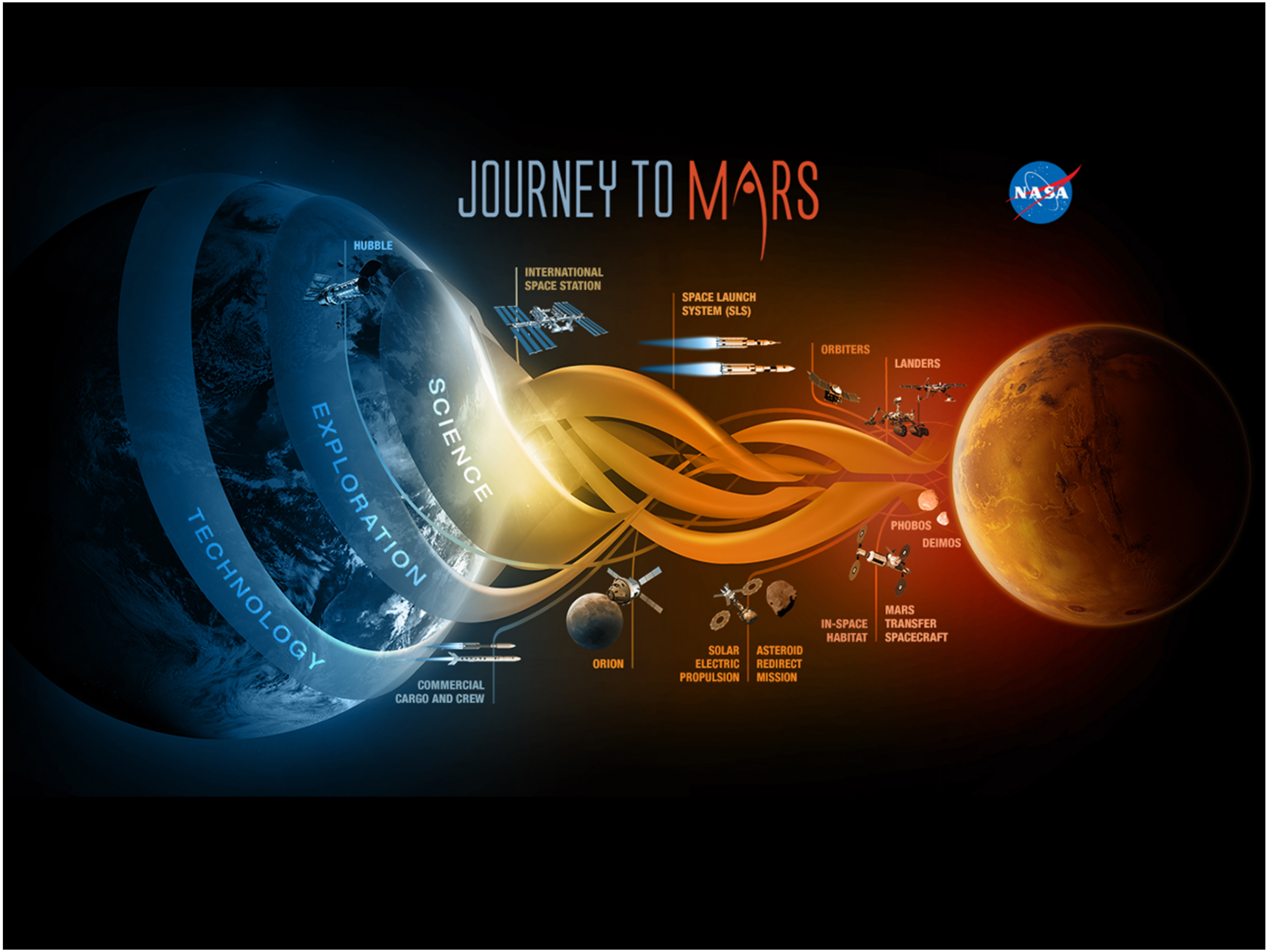
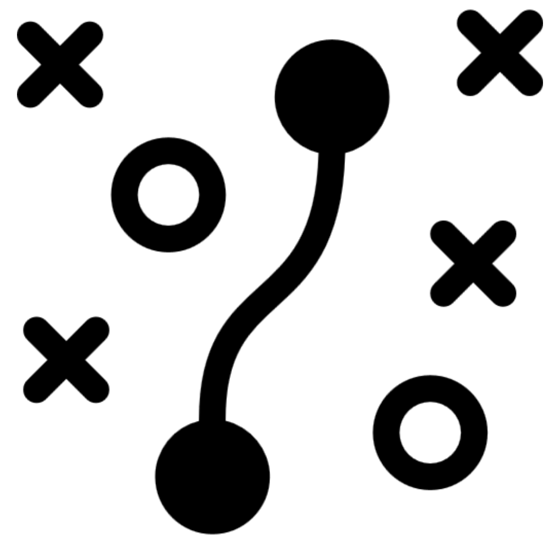
Topics

- The Human Exploration "Journey"
- Impacts of radiation
- Cross-cutting application of radiation knowledge
- Current activities
- What's needed for the future


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
MARS TRANSFER SPACECRAFT
IN-SPACE HABITAT
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
ORION
COMMERCIAL CARGO AND CREW

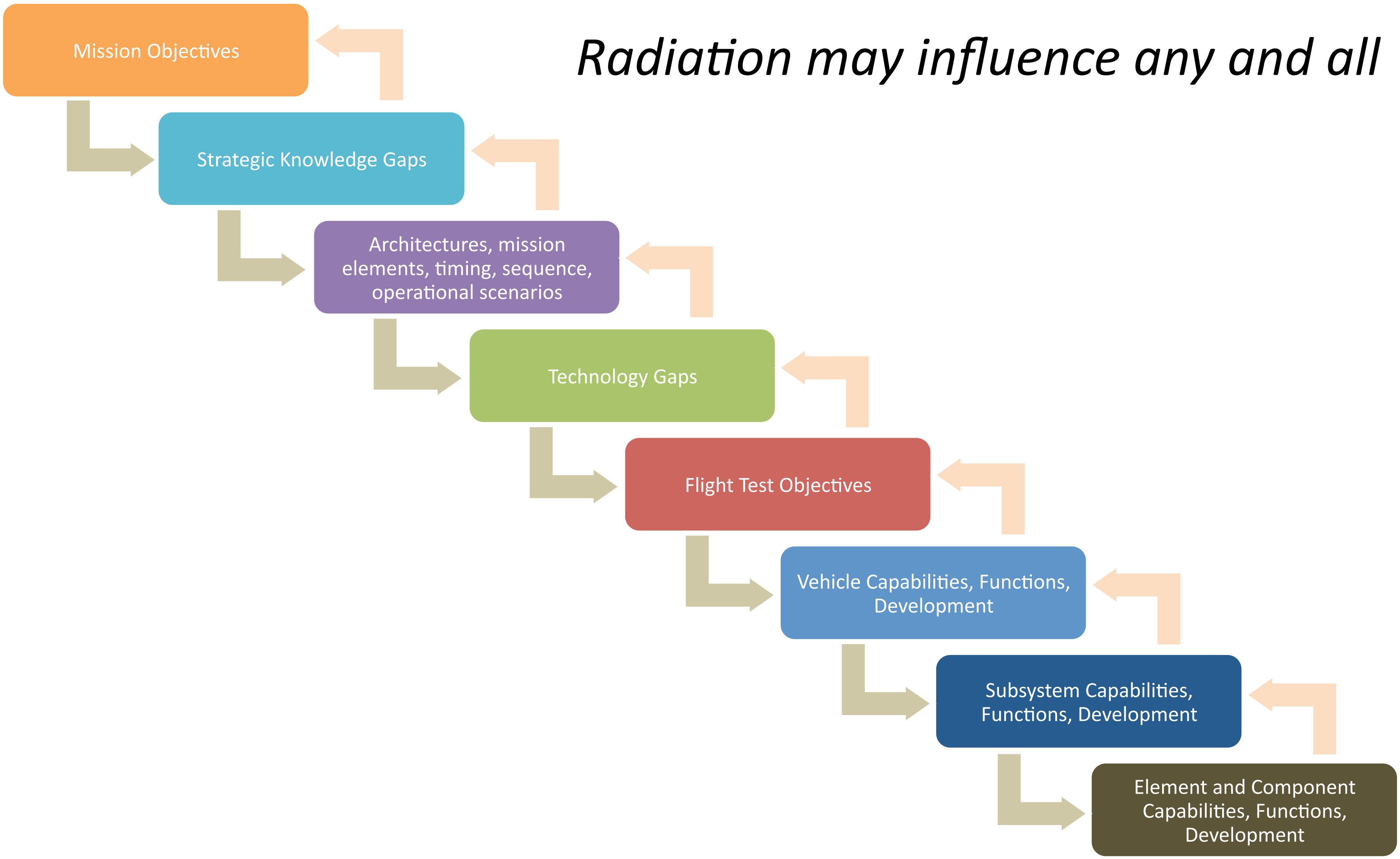
Premise

- Radiation is amongst the prime variables affecting performance and success of our human exploration ventures beyond Low Earth Orbit
- Impact of radiation is cross-cutting and significant
- An integrated, systematic, end-to-end approach to mitigation including detection, observation, synthesis, analysis, application, forecast, modeling, etc., is shared by all and strongly advised



"Decomposition" and "Recomposition"

Radiation may influence any and all



End-to-End Considerations

Identification

Observe
Alert
What

Characterization

When
Where
How
Magnitude
Effects

Mitigation

Risk
Deter
Avoid
Reduce

Protection

Forecast
Prevent
Block
Reduce

Radiation Effects are Cross-Cutting Examples: Crew Accommodations, Health

- Nutrient sustainability, stability, etc.
- Food preservation and storage
- Medication efficacy
- Passive flight crew radiation protection
- Nutritional factors to counteract oxidative damage
- Radiation carcinogenesis processes and models
- Cancer risk model application to reduce radiation quality effects uncertainties
- Cancer risk model application to reduce individual radiation sensitivity uncertainties
- Cancer risk model application to reduce age and gender dependence of cancer risk uncertainties
- Integrated multi-scale mechanisms of radiation damage
- Biological countermeasures, including side effects and mission risks, to reduce SPE and GCR cancer risks
- Synergistic effects on carcinogenic risk from space radiation
- Verification of carcinogenic and other health risks
- Level of accuracy of NASA's space environment, transport code and cross sections descriptions of radiation environments
- Integrated radiation shielding analysis codes with collaborative engineering design environments
- Biodosimetry methods and biomarker approaches for Lunar and Mars missions
- Research approaches on confounding effects of tobacco use on space radiation cancer risk estimates
- Biomedical or dietary countermeasures to mitigate Central Nervous System (CNS) risks
- Relationship, mechanisms, and thresholds of space radiation of immediate or acute functional changes in the CNS
- Probability and mechanisms of long-term or late degenerative CNS risks to space radiation exposure
- Individual susceptibility including hereditary pre-disposition and prior CNS injury to CNS risks and threshold doses
- Use of integrated multi-scale models of acute and late CNS risks to estimate radiation risks on CNS
- Synergy of shielding approaches for CNS and cancer risks
- Impact of combined spaceflight stressors on acute and late CNS risks from space radiation exposure
- Dose response for acute effects induced by SPE-like radiation, including synergistic effects from other spaceflight factors (microgravity, stress, immune status, bone loss, etc.)
- Quantitative procedures or theoretical models and use of epidemiology data to extrapolate molecular, cellular, or animal results to predict acute radiation risks
- Probabilities of hereditary, fertility, and sterility effects of space radiation
- Effective biomedical or dietary countermeasures to mitigate acute radiation risks
- Probabilistic risk assessment application to SPE risk evaluations for EVA, and combined EVA+IVA exposures

"NASA limits astronaut exposures to a 3% risk of exposure-induced death (REID) and protects against uncertainties in risks projections using an assessment of 95% confidence intervals in the projection model"

Cucinotta, F.A., Kim, M.Y., Chappell, L.J., NASA/TP-2013-217375

"Shielding thickness of 10 to 20 g/cm2 is sufficient to protect against most SPEs; however, thicknesses of several hundred g/cm2 are needed to significantly reduce organ doses from GCR..."

Cucinotta, F.A., Kim, M.Y., Chappell, L.J., NASA/TP-2013-217375

"...if 10% to 20% GCR dose reductions are possible and improve overall crew survivability, it is worth pursuing..."

NASA Human Research Program

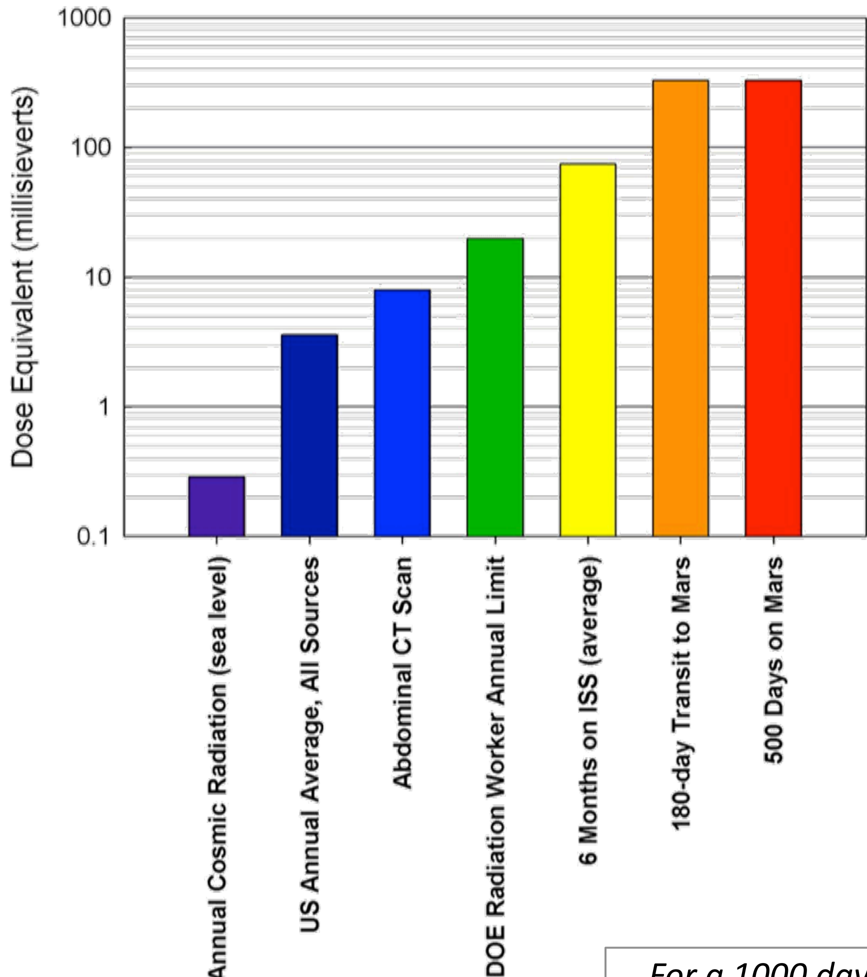
Radiation Effects are Cross-Cutting Additional Examples

- Avionics
  - Management of paired effects of more complex, current micro-processor designs and deep space radiation
- Extravehicular Activity
  - Affect on hardware and system performance
  - Operational limits, e.g. exposure
- Logistics
  - Management of spares and maintenance schedule, delivery, etc.
  - Use/reuse of trash and spent goods for added radiation shielding
- Research Payload Systems
  - Effects on internal and external environment systems that support research and payloads
- Vehicle and Structures
  - Materials
  - Mass

A Potential Systems View

Stimulus	Response at different scales to different exposure times, doses, repetition, etc.	Altering the Natural Response	Mitigating or Enhancing the Response; Altering the Degree of the Response
Origin	What changes and how?	Viability	Active shielding
Characteristics	What changes when?	Structure	Passive shielding
Environment / Space Wx	What changes for how long?	Chemistry	Mechanical shielding
Transfer / Transport	What changes and why?		Electronic / Electromechanical shielding
	Natural defense mechanisms		Pharmacological
	Combined environment effects		Pre-Disposition, Crew Selection
	Magnitudes that cause failure		Biological countermeasures
	Recovery after exposure		Time, Duration
	Degradation vs Performance		Prediction, modeling

Radiation Exposure Levels

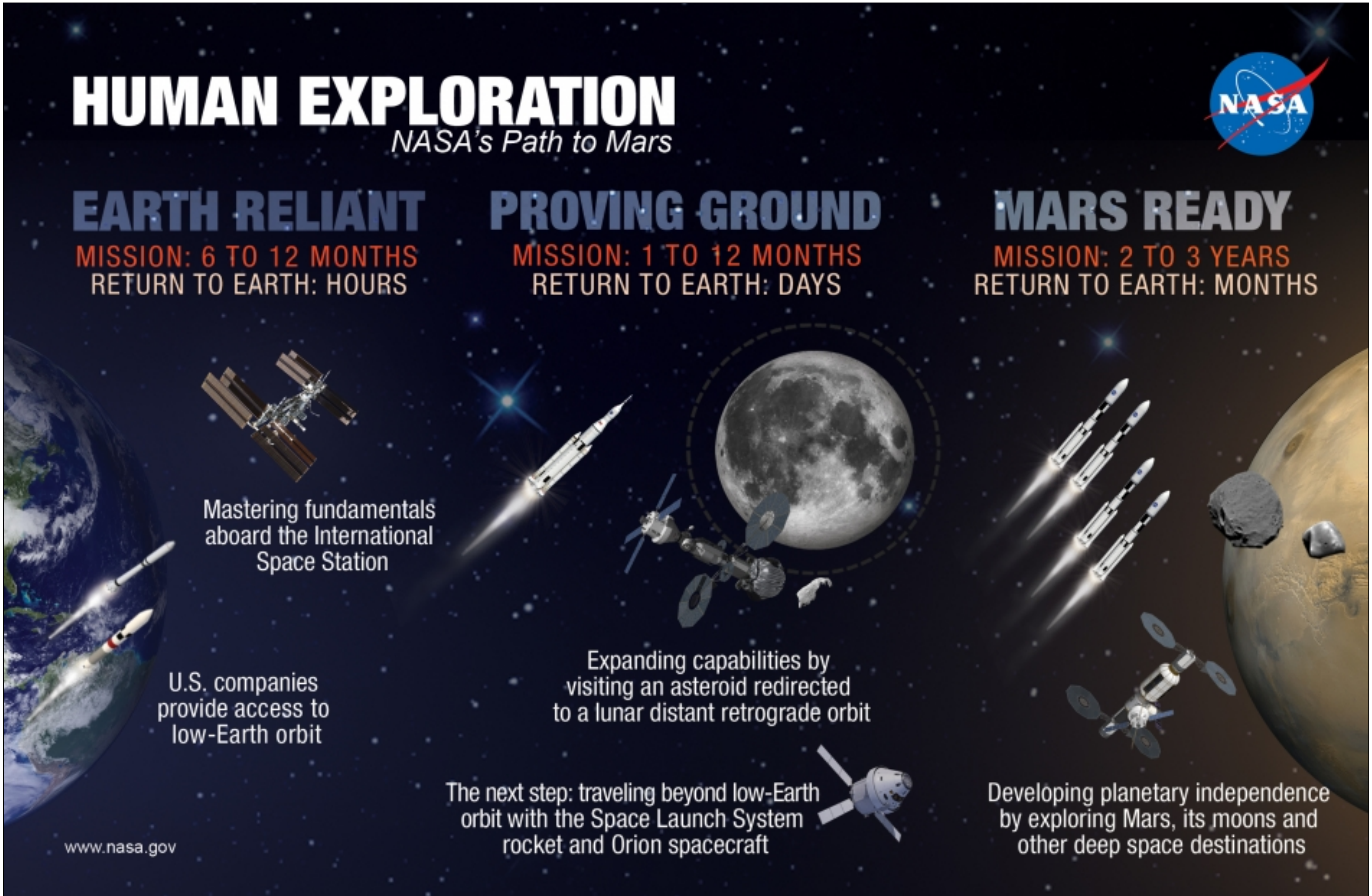


- Solar Proton Events (SPE) and Galactic Cosmic Rays (GCR) variances with solar cycles
- We have experience with SPEs
  - aluminum or polyethylene shielding could provide a 50% reduction in exposure*
  - Operations - warnings, storm shelter(s)
- "Obstinance" of GCRs
  - less affected by use of aluminum or polyethylene shielding
  - Shielding might only provide a 7% reduction in exposure*

For a 1000 day Mars mission (transit to/from + surface)

Dose equivalent = ~1000mSv

Reference: Hassler, E.M., et al, "Mars' Surface Radiation Environment Measured with the Mars Science Laboratory's Curiosity Rover", originally published in Science Express on 9 December 2013, doi: 10.1126/science.1244797 ***Science*** *24 January 2014:* ***vol. 343 no. 6169***



We must research and test radiation effects and mitigation techniques beyond the Earth's magnetosphere

Mitigation and Prevention Approaches

- Environment Characterization
  - LEO – ISS, robotic spacecraft
  - Cis-Lunar space – CRaTER, Exploration Augmentation Module, robotic spacecraft
  - Deep space - robotic spacecraft, human vehicles
  - Mars surface - Curiosity, MSL, Mars 2020, robotic spacecraft
- Shielding
  - Materials
  - Architectural configurations
    - Storm shields
    - Below surface
    - Habitation element arrangements – real-time alterations, preconfigured arrangements
  - Operational processes
- Timing
  - Mission and solar cycle coordination
  - Lessen exposure time – faster Mars transit, limited surface time
- Other Countermeasures
  - Crew Selection: predisposition, gender expectations, age expectations
  - Pharmacological intervention

Human Research Program Mitigation Strategies

Mission and Architecture Systems Analysis
- Near Earth Asteroid Systems
- Mars NTV
- ISRU
- Active Shielding Concepts

Innovative Multipurpose Shield Solutions
- Heavy Ion Testing of Inflatable Shield Prototype
- Water Filled Composite Shield Sections
- Reconfigurable Personal Shielding
- Hydrogen Storage BNNT

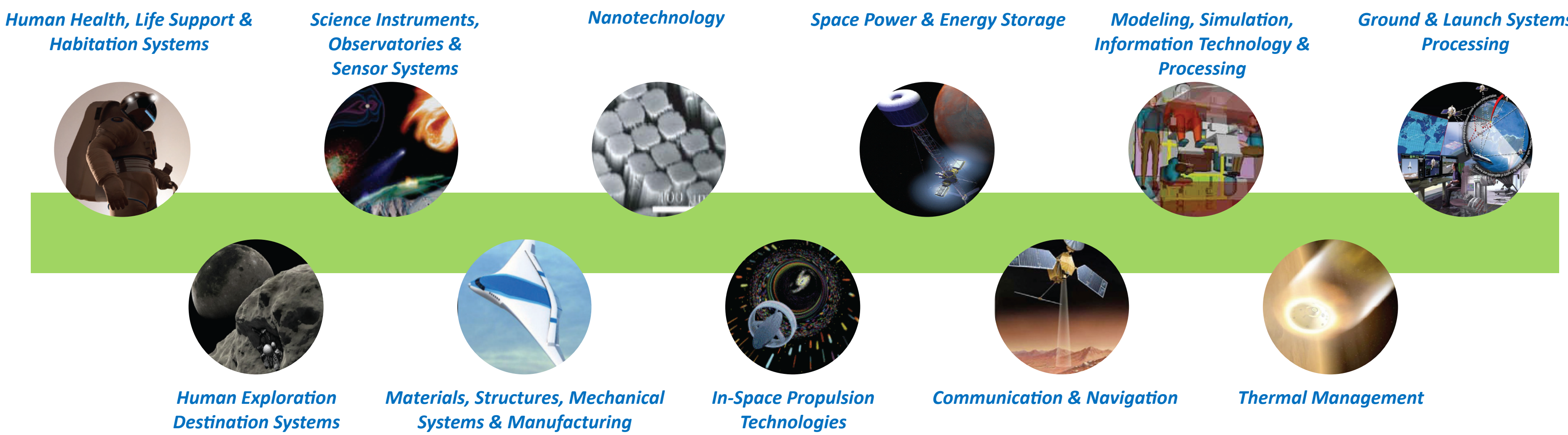
Environmental Monitoring, Modeling, and Prediction
- Predictive Models
- Precursor Data -- MSL RAD
- Onboard Dosimetry -- ISS TPEC

Radiobiology and Biological Countermeasures
- NASA Space Radiation Lab at Brookhaven
- X-ray vs Heavy Ion Track Damage to DNA
- X-ray vs Heavy Ion Track Damage to DNA
- Leukemia Induction with GCR – Mouse Model

Integrated Radiation Protection System Design and Analysis
- Design and Optimization Tools
- Crew Exploration Vehicle Shield Analysis
- High Energy Nuclear Physics and Transport

Crew Selection and Operations
- Human Digital Twin

Cross-cutting Radiation Technology Needs



- Transport and Nuclear Physics modeling
- Integrated Mortality Risk Projection Model Tool
- Cancer Risk Projection Model
- Degenerative Risk Projection Model
- Central Nervous System Risk Projection Model
- Central Nervous System Model piece
- Acute Model piece
- Performance Degradation Model Set
- Digital Twin
- Counter measures for inflight acute radiation
- Counter measures for inflight CNS effects

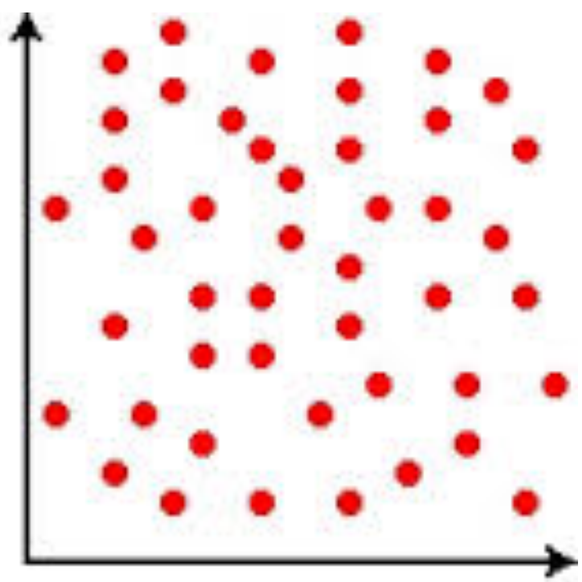
- Counter measures against degenerative effects
- Integrated design tool
- Uncertainty models for thick shielding
- Active Personal dosimetry for intravehicular and extravehicular activities
- Compact biological dosimetry (bio-dosimetry)
- In-situ active warning and monitoring dosimetry Proton event warning system
- In-situ active warning and monitoring dosimetry
- Miniaturized low power charged particle and neutron spectrometers with active warning
- Micro-imagers and analyzers
- In-space Thermal Protection System Repair
- Hydrazine or Hydrogen Peroxide Monopropellant

Reference: NASA Technology Roadmaps, 2014

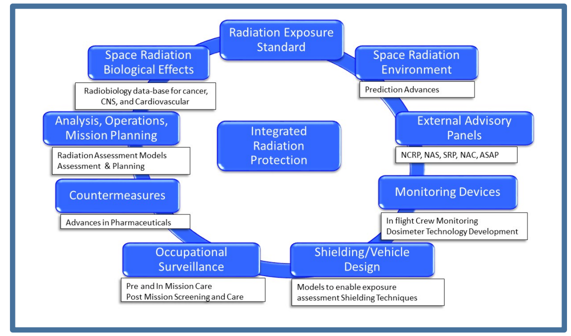
Are Our Radiation Mitigation Views Truly Integrated?

Yes, we have an extraordinary breadth of activities addressing radiation mitigation, but we should ask…

- *What is the relationship between contributing elements?*
- *How do each of the contributing elements relate to Strategic Knowledge and Risk Gaps?*
- *What is the strength of their interaction?*
- *Does the portfolio address an end-to-end view?*

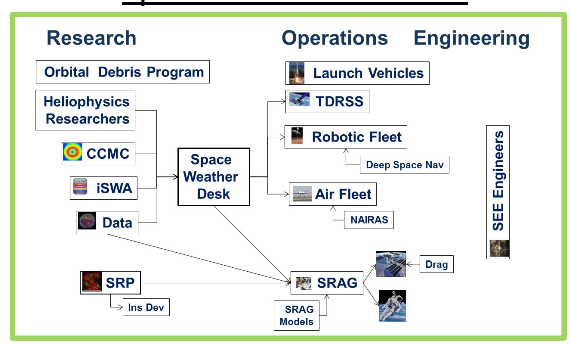


Office of the Chief Medical Officer

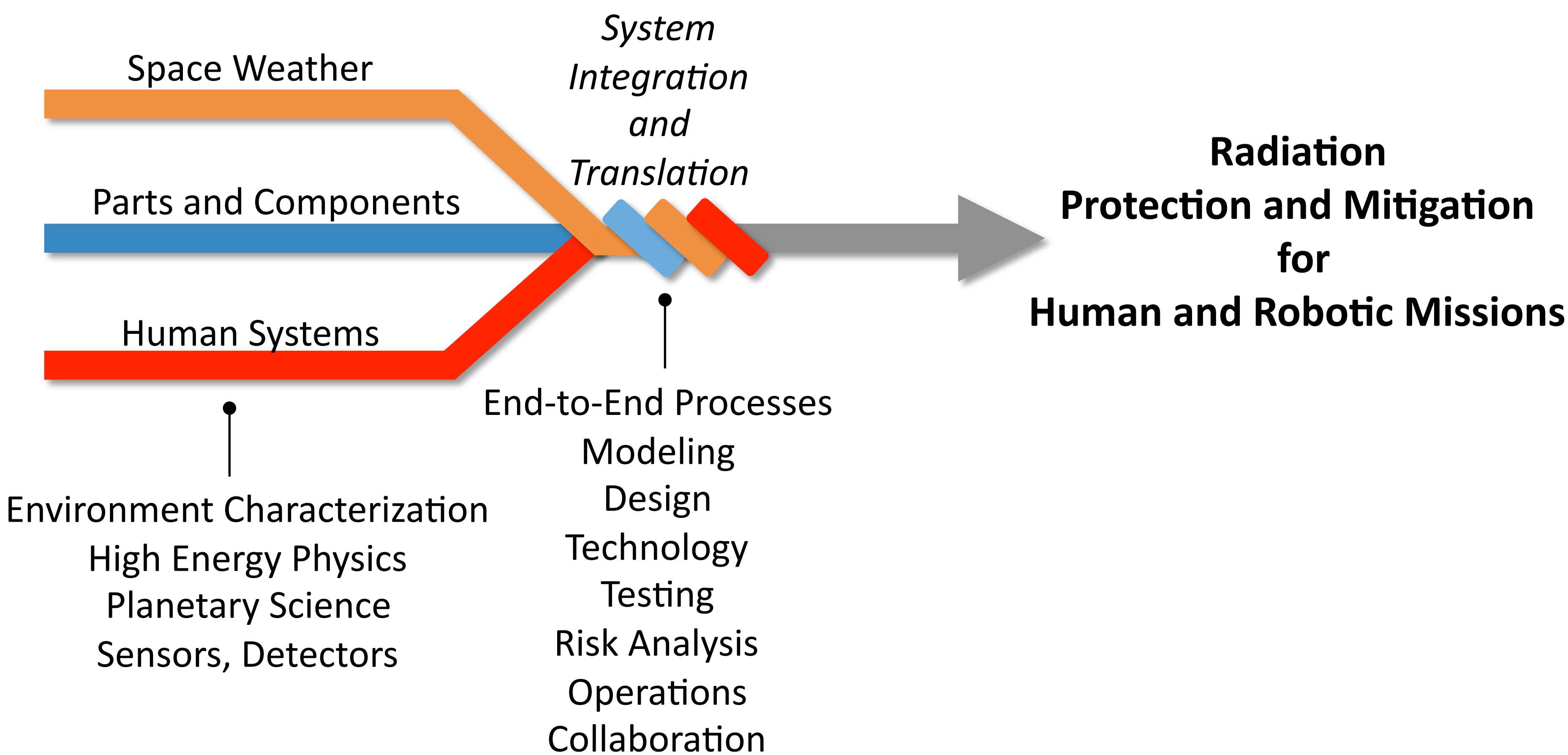


Human Research Program

Space Weather Entities



Influencing a Systems Approach to Radiation Mitigation



Closing

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