Space Radiation: Opportunities for Tactical Collaboration

National Aeronautics and Space Administration

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Introduction

- **Space is a radiation environment**
- **NASA was given the authority by congress *"to make, promulgate, issue, rescind, and amend rules and regulations governing the manner of its operations and the exercise of the powers vested in it by law*"**
  - National Aeronautics and Space Act –1958 § 203(b)(1)
  - Astronauts considered radiation workers
    - NASA limits excessive space radiation exposure (and has been since the 60s)
    - NCRP 132 (2000) recommendations are the basis for current supplementary OSHA radiation standards in accordance with 29 CFR 1960.18
- **The Space Radiation Analysis Group (SRAG): operational astronaut radiation protection**
- **The Space Radiation Element (SRE): executing research to characterize and mitigate the health risks due to space radiation exposure**

Three Major Questions

- **What’s Out There?**

  The Space Radiation Environment

- **What’s the Big Deal?**

  Space Radiation Health Risks

- **What Do We Do?**

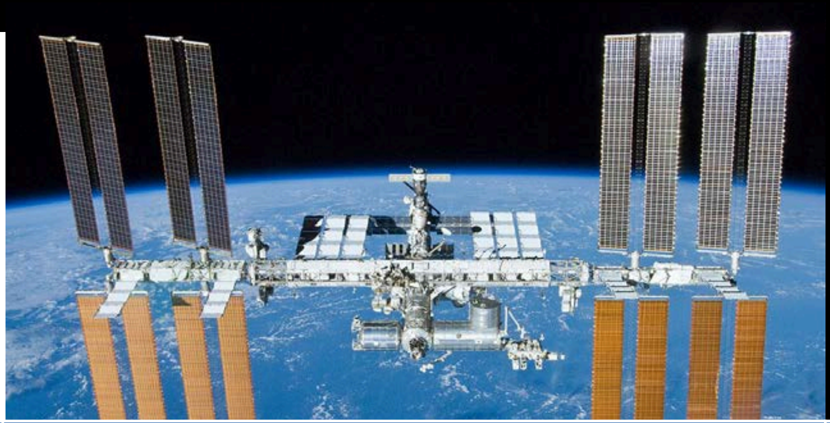
  Space Radiation Element Research

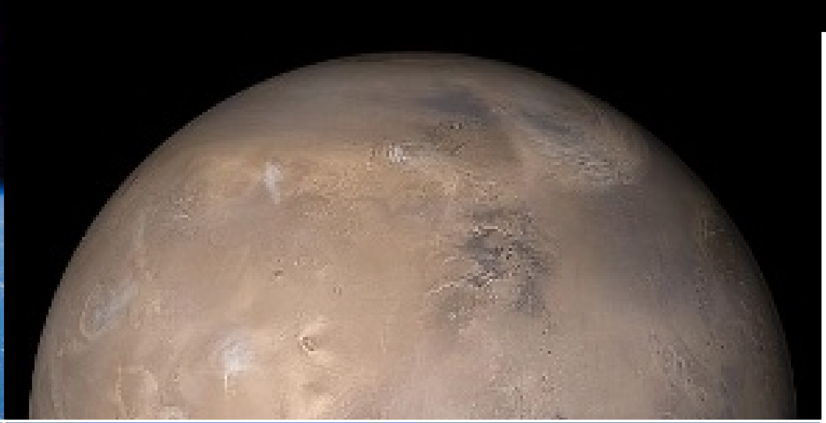
What’s Out There? The Space Radiation Environment

- **Range of dose profiles**
  - Individual mission doses can be **<100 mSv**
    - Shuttle, ISS, Short Lunar, Short Deep Space
  - Solar particle event doses may **exceed 100 mSv**
  - Accumulated career doses can **exceed 100 mSv**
  - Long-durations missions are anticipated **exceed 1,000 mSv**

- **Range of dose rates**
  - Protracted
  - Fractionated
  - Quasi-acute
- **Mixed-field environment**
  - Charged particles
  - Neutrons
  - Low-LET
  - High-LET

What's Out There? The Space Radiation Environment





Exposure Type	ISS (51.6° inclination)	Beyond Leo Earth Orbit
Galactic Cosmic Rays (GCR)	• **Limited to polar regions** • Fractionated low dose-rate • ~ 87% protons, 12% Helium, 1% HZE	• **Continuous** • Chronic low dose-rate • ~ 87% protons, 12% Helium, 1% HZE
Trapped Radiation	• **South Atlantic Anomaly (SAA)** • Fractionated low dose-rate • Protons	• **Transit through Van Allen Belts** • Low to moderate dose-rate • Protons
Solar Particle Events (SPEs)	• **Limited to polar regions** • Fractionated low dose-rate • Protons	• **Full Event** • Fluctuating dose-rate • Protons
Neutrons, Secondary Radiation	• Shielding • Chronic low dose-rate	• Shielding • **Planetary (albedo)** • Chronic low dose-rate

What's Out There? The Space Radiation Environment

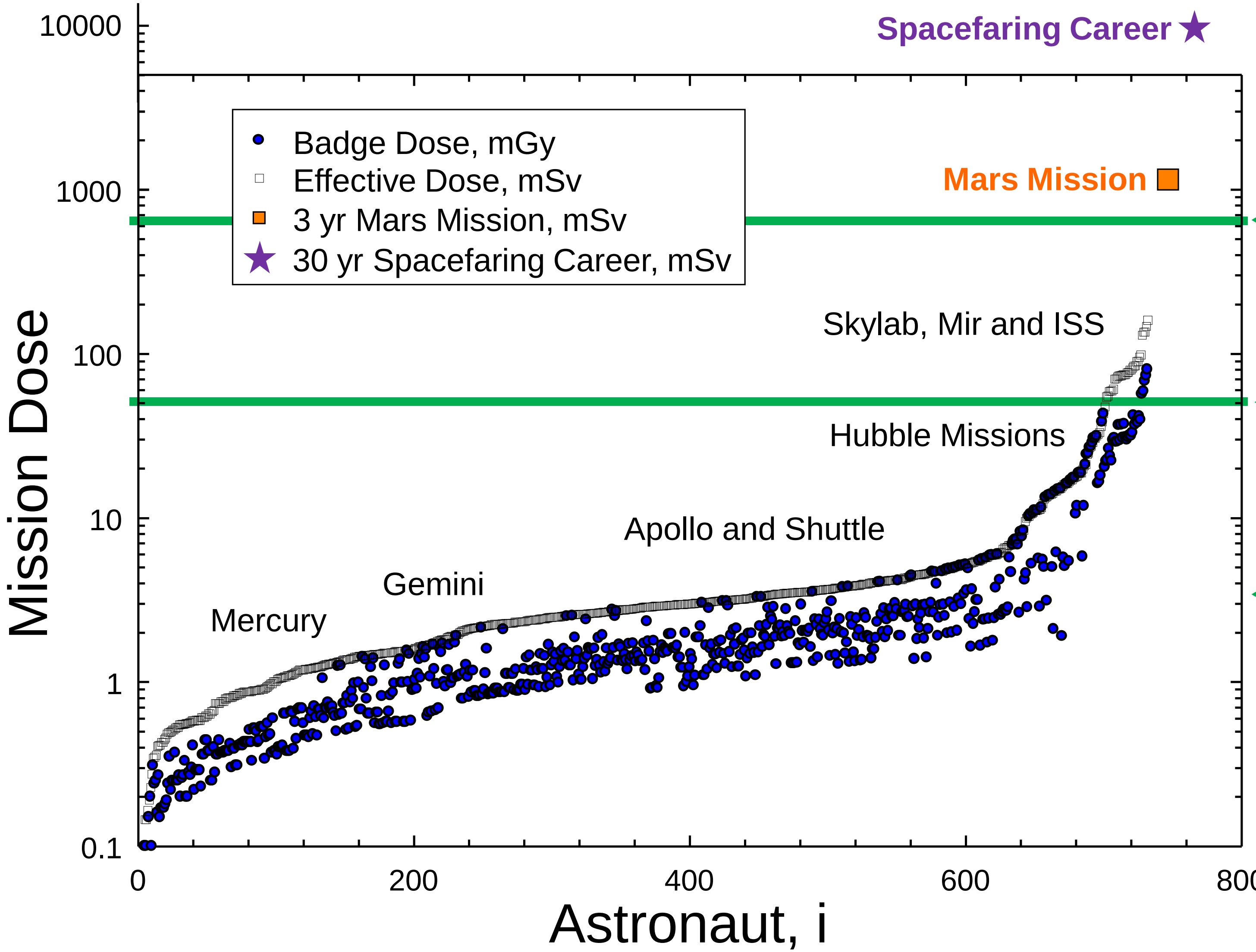
- **Doses depend on mission and solar parameters**
  - – Duration
  - – Trajectory and shielding
    - Determine source exposure
      - – Effects "quality factor"
    - EVAs
  - – Solar cycle
    - 11-year cycle
    - Modulates GCR and trapped radiation <u>fluence</u>, as well as SPE <u>likelihood</u>
- **Each crew member is badged**
- **Active radiation area monitoring**

Exposure Type	Dose Rate or Dose
ISS – IV: 51.6° @ 400 km	**300 – 450 μGy/day**
ISS Trapped – IV***	<0.1 – 20 μGy/min
GCR in "free space" in water CRaTER (2009 to present)	**250 – 550 μGy/day**
1972 event – IV "free space"	200 – 400 mSv
Sheltered 1972 event	~ 80 mSv

*** Passes are at most ~20 min and only see peak dose rates for a fraction of the pass

KEY POINT: Space radiation is *<u>different</u>* than terrestrial radiation

Historical and Projected NASA Mission Doses



650 mSv
NCRP Recommended Terrestrial Radiation Worker *Lifetime* Limit for 65 yo

50 mSv/yr
Terrestrial Radiation Worker *Annual* Limit

3.6 mSv
Average US *Annual* Dose

Modified from Cucinotta et al. Radiat Res (2008)

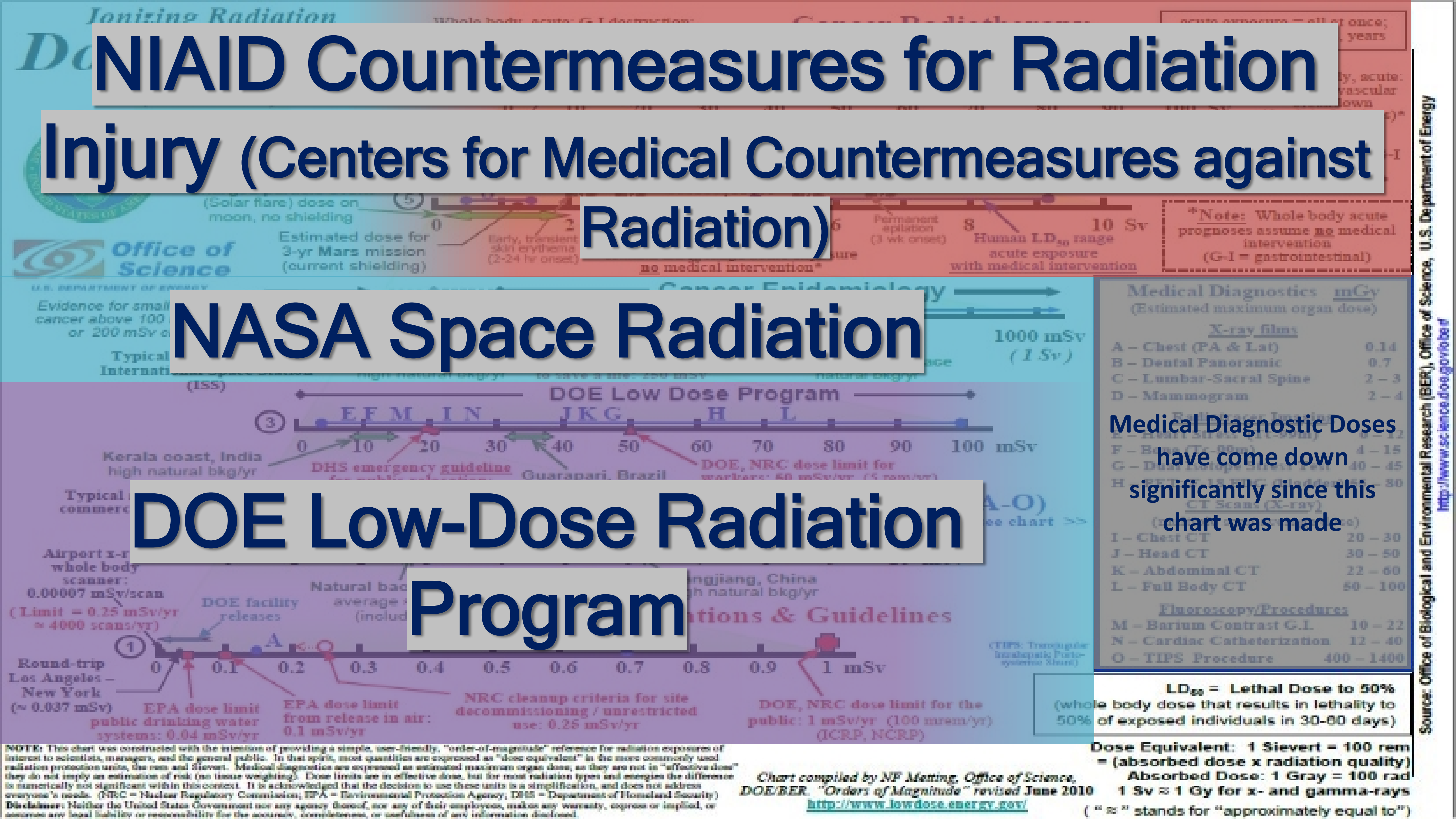
KEY POINT: *Moderate* career doses at low dose-rates

NIAID Countermeasures for Radiation Injury (Centers for Medical Countermeasures against Radiation)

NASA Space Radiation

DOE Low-Dose Radiation Program

Medical Diagnostic Doses have come down significantly since this chart was made



What's the Big Deal? Space Radiation Health Risks

- **Mission Success**
  - Acute effects
    - Very large high-energy solar events
      - Estimate ~ 200 – 400 mSv (unsheltered) for 1972 Event
      - MILD symptoms IF they occur at all given doses
  - Potential early neurological effects
    - Behavior or memory decrements
    - Observed only in animal models

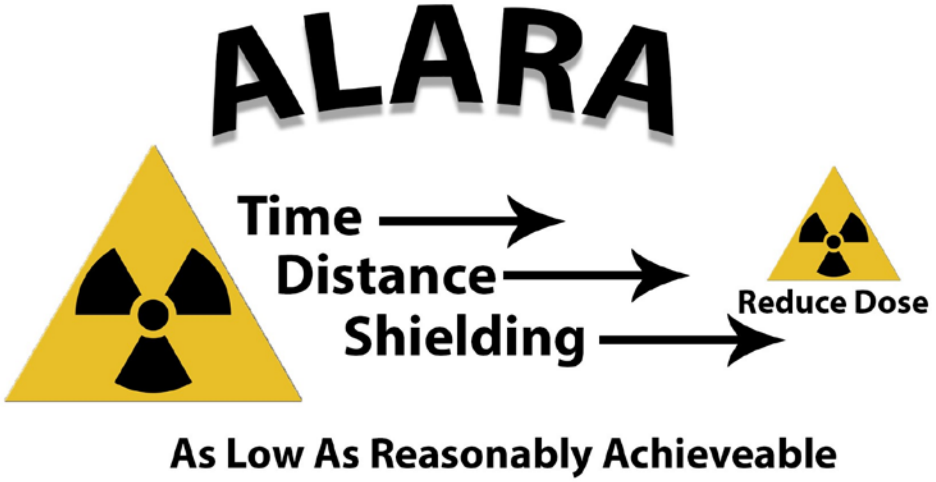
Risks beyond the "low-dose" region

- **Long Term Health**
  - Cancer
    - Space radiation may cause unique impacts
  - Degenerative
    - Cardiovascular disease
    - Cataracts
  - Potential late neurological decrements
    - Behavior or memory decrements
    - Neurodegenerative disease
    - Observed only in animal models

KEY POINT: Space radiation impacts in-mission and long-term health risks

The Space Radiation Protection Challenge

- **Traditional terrestrial protection strategies fall short in space**
  - Time
    - At some point you will always reach a limit
  - Distance
    - There is no point source to move away from
  - Shielding
    - Energetic particles are penetrating
    - Secondary particles
- **NASA is exploring other countermeasure strategies**
  - Health surveillance including early disease detection
  - Compound-based countermeasures



https://www.lsu.edu/camd/safety/training/radiationsafetytraining.php

What Do we Do? Space Radiation Element Research

Mission: Characterize and facilitate the management of the human health outcomes associated with space radiation exposure to protect astronaut health and wellbeing, and enable human spaceflight

Three primary health risks:

1. Carcinogenesis
2. Cardiovascular & Immune
3. Central Nervous System

Formally Degenerative Tissues now listed under the Cardiovascular (CVD) or Immune (IM) Risks

Integrated into the Behavioral Medicine (BMed) Risk

Characterization	⟷	Mitigation
Dose and Dose Rate Effects	Biomarkers	Countermeasure Identification
Radiation Quality	Individual Susceptibility	Countermeasure Validation
Species Translation	Combined Stressors	

https://humanresearchroadmap.nasa.gov/

Unique Challenges for NASA and Risk Assessment

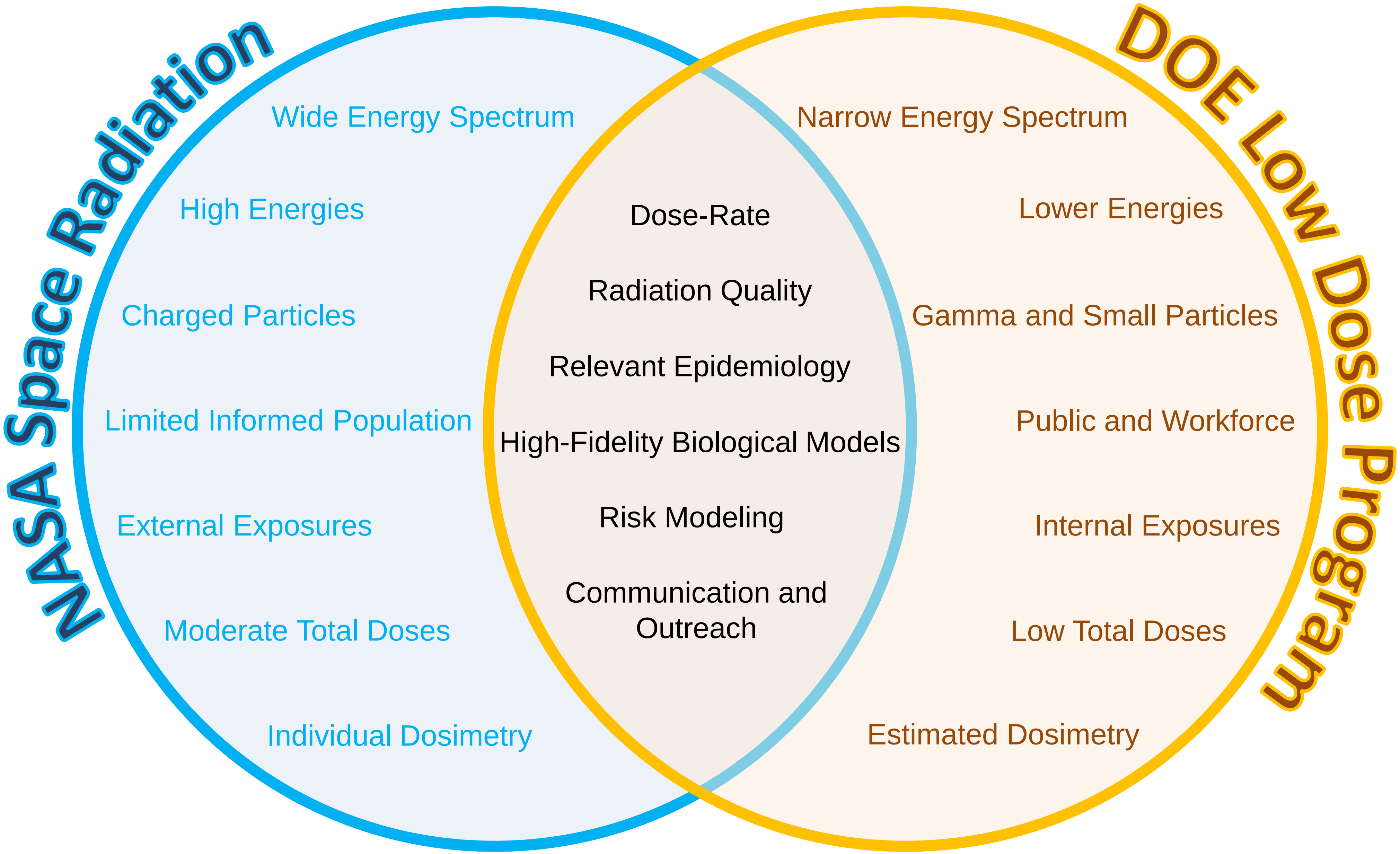
- **Limited observed outcomes in astronauts**
- **VERY small, unique cohort**
  - Approximately 500 total
  - Relatively young cohort
  - Changing demographics
- **Generally small accumulated exposures to date**
- **Healthy worker and generally healthy**
  - Recent study indicates ***lower risk*** of all-cause mortality and other expected outcomes in early NASA astronauts (Elgart et al. 2018)
- **MANY competing risks**

https://humanresearchroadmap.nasa.gov/

The Big Picture

- **Space radiation is *<u>different</u>* from terrestrial radiation**
  - Exposure is *<u>unavoidable</u>* in space
  - Doses depend on mission
- **NASA's space radiation research is *<u>NOT</u>* a low-dose program**
  - Focuses on *<u>moderate total doses at low-dose rates</u>*
- **Space radiation impacts *<u>in-mission</u>* and *<u>long-term health risks</u>***
  - Risks beyond those in the low-dose range: Acute, CVD, CNS
- **Astronaut radiation exposures are regulated via *<u>supplementary</u>* OSHA standards**
  - Enable human spaceflight
  - Exceed annual terrestrial limits
- **Understanding of space radiation risks is *<u>incomplete and still evolving</u>***
- **Key cross-functional areas for collaboration between NASA and DOE**
  - Many areas outside DOE mission

Key Cross-Functional Topics



Thank You for Your Attention