A Conceptual Framework for Utilization of Space Radiation Measurements

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Space Radiation Measurements: SOME QUESTIONS TO ADDRESS

- What is the purpose of space radiation measurements?
- What is a “dosimeter”?
- How does one take conflicting results of similar measurements into account for radiation protection?
- How are data communicated, shared, evaluated, and archived?
- What data are properly used in maintaining radiation exposure records?
- How much radiation monitoring is “enough”?

Space Radiation Measurements: 1. Relevant Critical Questions

- **Space Radiation Environment**
  - For a given mission, what are the fluxes of GCR in interplanetary space as a function of particle energy, LET, and solar cycle?
  - What is the solar cycle dependence of space radiation?
  - What is the trapped radiation flux as a function of time, magnetic field coordinates and geographical coordinates?
  - What are the doses related to heavy ions in deep space?
- **Nuclear Interactions**
  - What are the yields for nuclear interactions of HZE particles in tissue and space shielding materials?
  - How are radiation fields transformed as a function of depth in different space materials?
  - What are the optimal ways of shielding humans in space?
- **Atomic Interactions**
  - What is the precise energy deposition of heavy ions?
  - What are the yields and energy spectra of electrons?
- **Human Radiation Protection**
  - What should be the radiation dose limits for manned deep space missions?
  - What is the risk associated with each crew member at any time during a given mission?

Space Radiation Measurements:
2. Basis for Risk Assesment

What is risk?

- a priori vs. a posteriori probabilities
- probability of defined effect (e.g., excess leukemia)
- architecture-dependent (trip duration, spacecraft, EVA's, etc.)

Prospective risk assessment:

- radiation monitoring
  - identify radiation in sufficient detail to understand results, i.e., spectral information may be required in addition to ionization chambers; area monitors to define radiation field
- risk assessment vs. risk estimate
- architecture issues

Archival risk assessment:

- legal
  - evidence of causation (or lack of causation) of an effect by exposure to space radiation
- medical history
  - acute effects: treatment, record
  - late effects: how?
- epidemiological
  - evaluate effects of cumulative population exposures

What is a "dosimeter"? Instrument Specifications

Anything that measures φ(A,Z, LET, …), D(LET), QF(LET), …

- **Particle identification:**
  Positive charges vs. neutrons, electrons, γ-rays
  $(1,1) \leq (A,Z) \leq (56,26)$ [p to Fe]
  $\Delta Z/Z \leq 0.2$]; $\Delta A/A \leq 1$
- **Energies**:
  $10 \leq \varepsilon_{HZE} \leq 1000$ MeV/nucleon
  10 keV $\leq \varepsilon_n \leq$ 100 MeV
  700 keV $\leq \varepsilon_{x,\gamma,\beta} \leq$ 10 MeV
- **LET range**:
  $0.1 \leq$ LET ≤ 2000 keV/µm
- **Acceptance**
  - Solid angle (statistics) $\leq 2\pi$
  - detection efficiency $\geq 10\%$
  - $\Delta ø/ø$ (angular resolution) $\leq 3°$
- **Rate Dependence**
  $R \leq 10^5$ particles/sec; $N \leq 10^4$ particles/cm^2
  0.01 µGy/min $\leq \partial D/\partial t \leq$ 1 Gy/min
- **Localization**
  - Portability
    - » Personnel dosimetry
    - » Area monitoring
  - Shielding: traceable to mass distributions
- **Data acquisition and recording**
  - Telemetry and on-board readout
  - Coincidence and correlation w/other instruments
  - Autonomy > 90 days
  - Availability and distribution < 30 days
  - Stability: 50 yrs

Relevant Radiation Measurements

	PASSIVE	ACTIVE
INDIVIDUAL	• Emulsion • TLD • Nuclear track detectors • Internal Biodosimetry • Radioactivation of tissue • Other chemical or physical latency • Whole body/organ?	• Pocket ionization chamber • Portable silicon detectors • High dose or dose rate warning monitors • Whole body/organ?
AREA	• Emulsion • TLD • Nuclear track detectors • External Biodosimetry • Induced radioactivity • Other chemical or physical latency	• TEPC and similar ionization detectors • Scintillation counters • Particle spectrometers • (Moderated) neutron counters

Instrument Requirements

- **Accuracy**
  - Calibration, pre-experiment testing, intercomparisons
  - Timing and location
- **Precision**
  - Geometry factors and acceptance
  - Resolution in A ,Z, LET
- **Specificity**
  - No detection artifacts (e.g., response to unintended particles and/or energies, wall effects, kerma vs. dose)
  - Can the measurement be related to an individual exposure?
- **Sensitivity**
  - Signal-to-noise ratio
  - Dynamic range in particles, energies, LET
  - Doses, dose rates and flux
  - Sensitivity adequate for statistically significant results
- **Data quality**
  - Availability: space, ground, on-line, off-line, post-mission,
  - Stability of data, especially for integrating detectors
  - Can the data be interpreted in terms of individual risk?

Sources of Dosimetric Data

- **Reference dosimeters**
  - Output used to determine individual radiation exposure for the record
  - Basis for implementation of ALARA
- **Solicited, peer-reviewed experiments**
  - Yield radiation measurements of interest for radiation protection
- **Unsolicited, non-peer-reviewed measurements**
  - May yield radiation measurements of interest for radiation protection
- **Supporting, relevant data from measurements on other spacecraft**

Space Radiation Measurements: Reference Dosimeters

- **Design and reference**
  - on file and accessible to qualified researchers
  - standard data output format
- **Calibration**
  - according to an international protocol
  - at "accredited" ground facilities
    - » measured instrument specifications
    - » confirmed with calculated response
- **Intercomparison**
  - at ground facilities
  - in space
- **Certification as a "Reference Dosimeter"**
  - by TBD (Mission Control? NIST? MMOP?)

Space Radiation Measurements:
Data Certification

- **Defined data format**
  – original or converted from original format
- **Defined media on which data will be available**
  – e.g., web, server, disk, etc.
- **Procedures for data ownership**
  – copyright assignments, publication rights, etc.
  – adjudication of authorship of published data
- **Procedures for data storage**
  – how long? where?
- **Procedures for data access**
  – satisfy privacy concerns
  – provide appropriate public access

Space Radiation Measurements: Data Interpretation

- **Only certified data may be used for radiation protection**
- **Reference dosimeter data**
  - interpreted according to protocol(s) to be defined
  - are the only data that may be used for records
- **Data not obtained from reference dosimeters**
  - may be used to supplement reference dosimetry
  - may not be used independently of reference
- **The end-point of data interpretation is the assignment of a risk probability for a specified detrimental health effect and for a specified individual.**

Space Radiation Measurements: A Conceptual Framework for Utilization

- **Define reference dosimeter protocol(s)**
  - Accreditation of calibration facilities
  - Develop intercomparison protocols
  - Define access by proposed instruments
  - Define certification authority (-ies)
- **Define data certification process**
  - Incorporate into requirements for experiment approval?
  - Define certification authority (-ies)
  - Define formats, storage, access, etc.
- **Define data interpretation protocol**
  - Standardize calculations
  - Define sharing by appropriate international radiation protection officers

Objective:
ONE COMMON, UNIVERSALLY ACCEPTED RISK ASSESSMENT FOR EACH INDIVIDUAL CREW MEMBER AT ANY POINT IN TIME