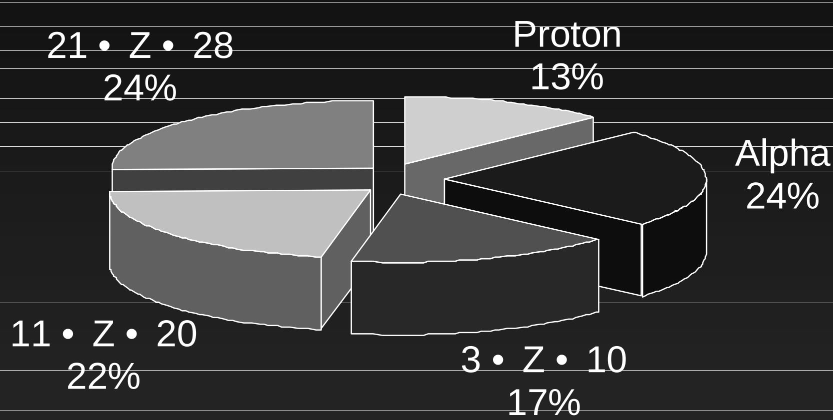
Requirements for Space Radiation Dosimetry

Walter Schimmerling, Francis A. Cucinotta, and John W. Wilson

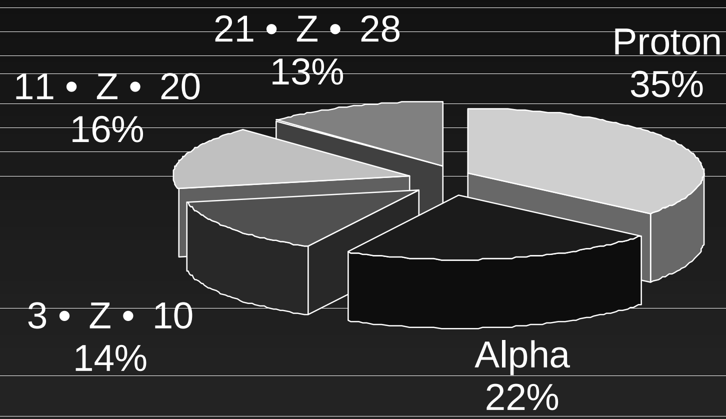
Workshop on Radiation Monitoring for the International Space Station
Farnborough, UK
3-5 November 1999

Primaries and Secondaries
Inside 5 g/cm^2 of Aluminum (all energies)

C3H10T1/2 Cell Death

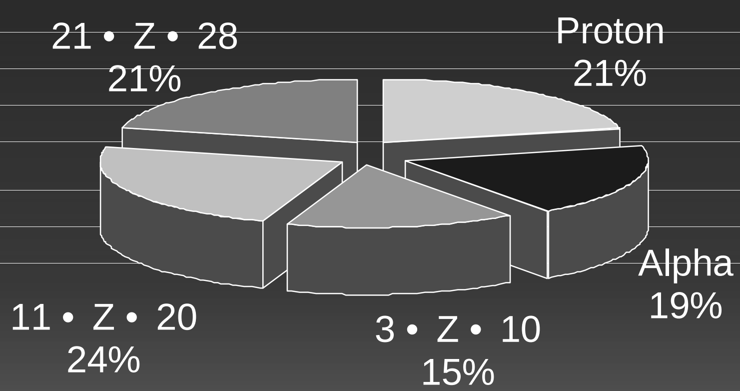


C3H10T1/2 Cell Transformation

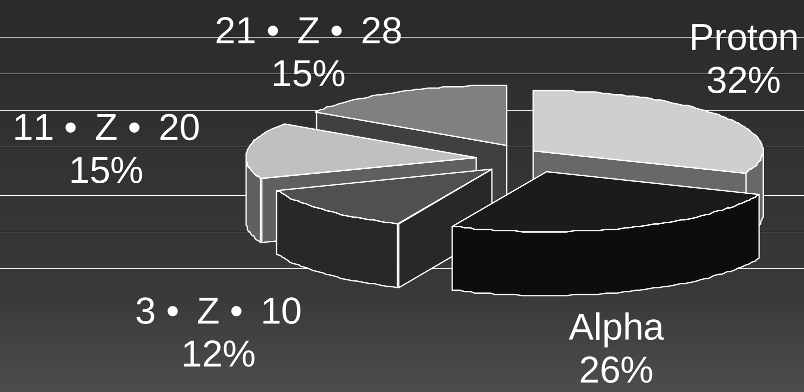


Different Biology

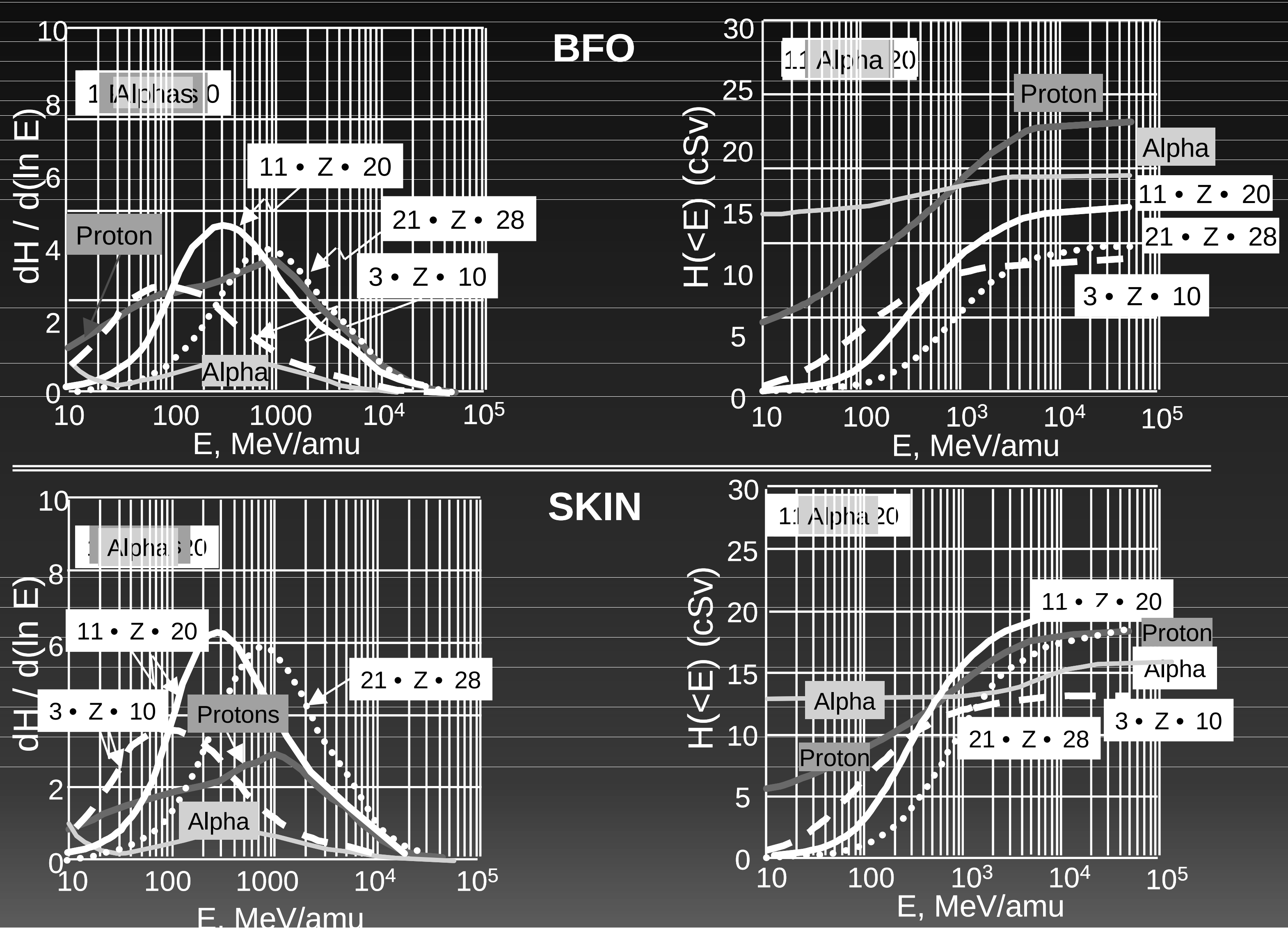
Dose Equivalent to Skin



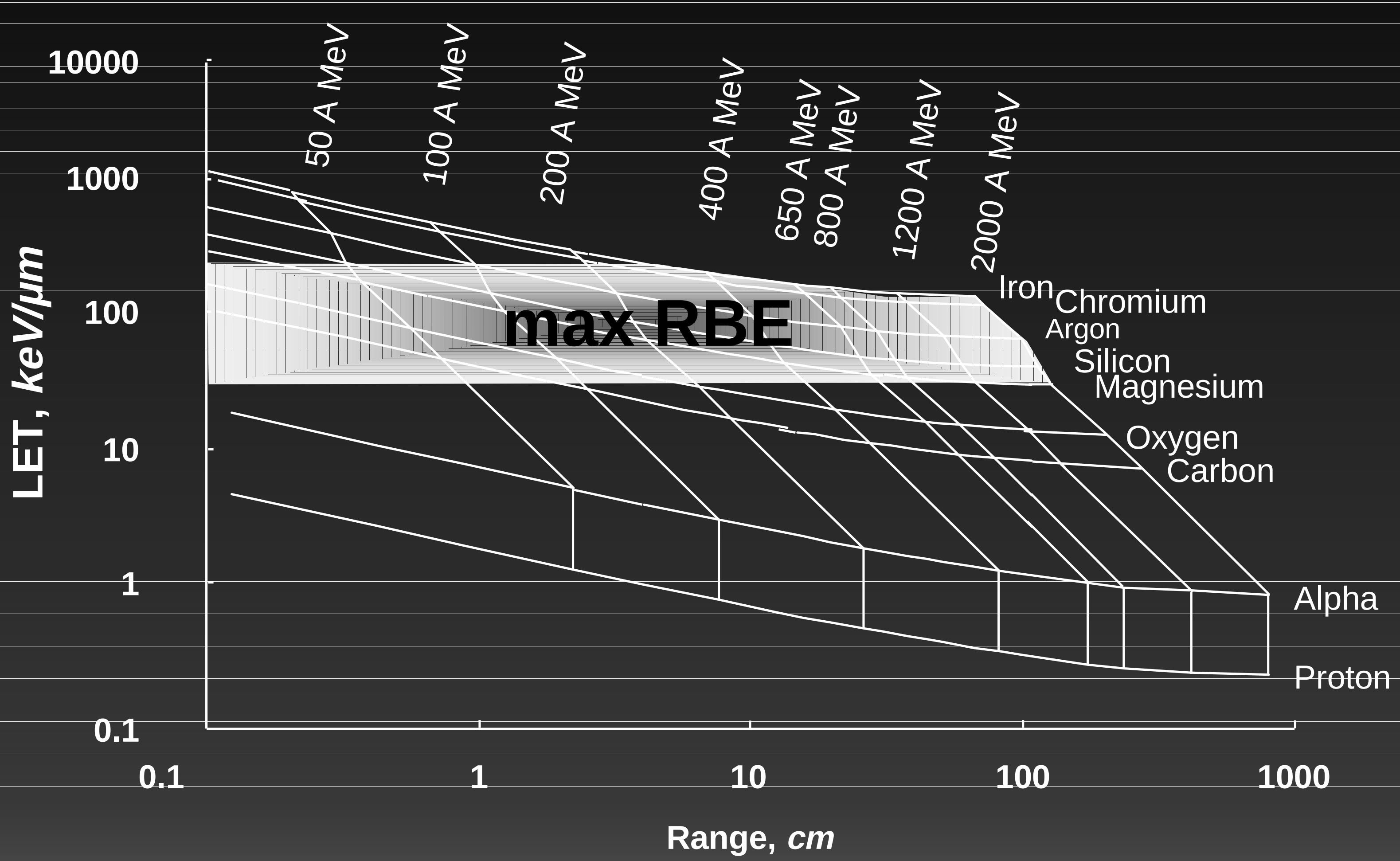
Harderian Gland



Annual Dose Equivalent Behind 5 g/cm^2 of Aluminum
(1977 Solar Minimum)



LET vs. Range


10000
1000
100
10
1
0.1
LET, keV/µm
0.1
1
10
100
1000
Range, cm
50 A MeV
100 A MeV
200 A MeV
400 A MeV
650 A MeV
800 A MeV
1200 A MeV
2000 A MeV
max RBE
Iron
Chromium
Argon
Silicon
Magnesium
Oxygen
Carbon
Alpha
Proton

Critical Questions Related to Space Dosimetry

- **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?

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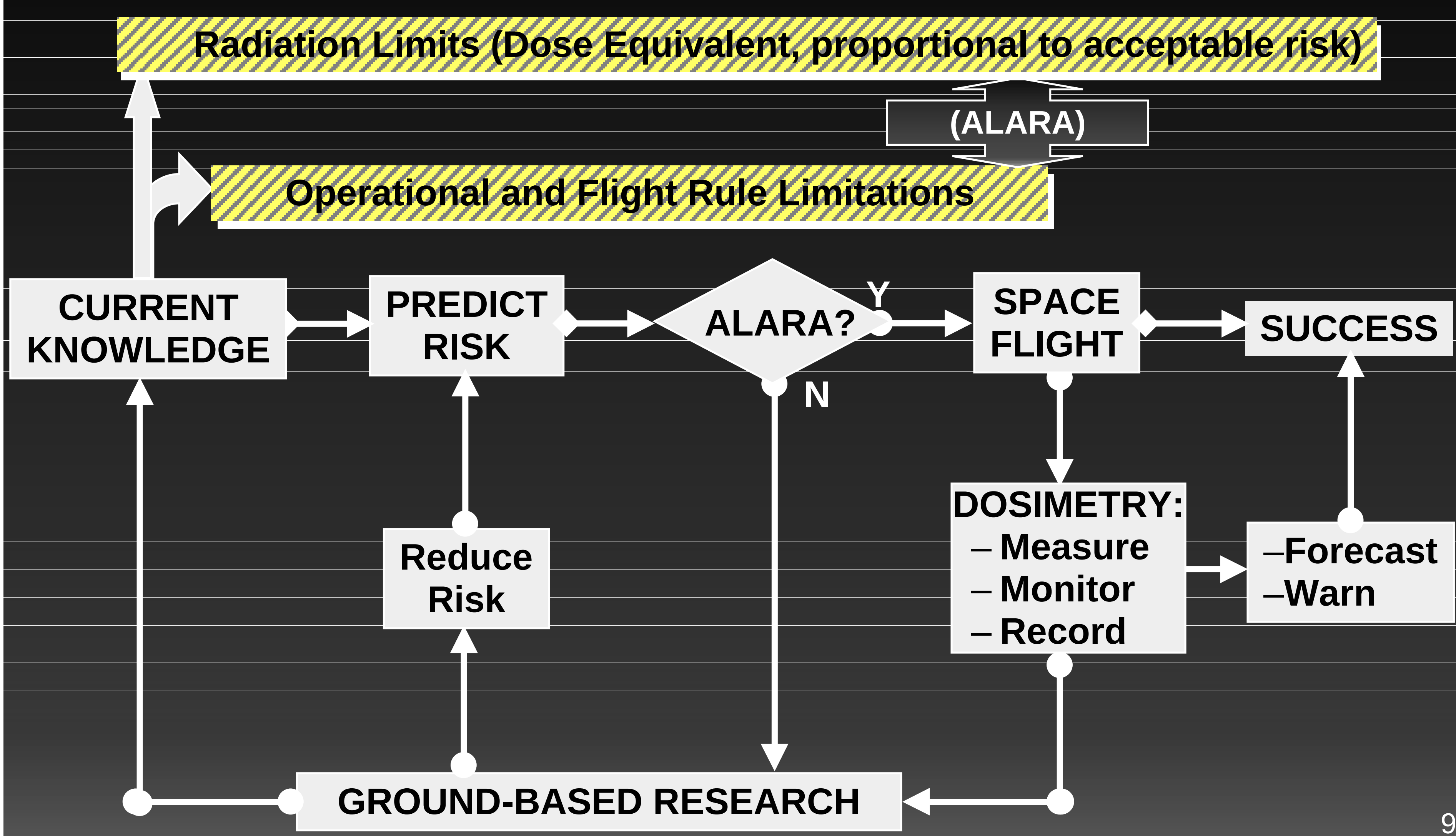
Radiation Protection Model



Risk Prediction Model

Space Radiation Dosimetry

Current

A-bomb survivors → γ-rays, neutrons → **Quality Factor (LET)** (ICRP 60, 1990) → cancer, genetic effects, acute effects

Low-LET radiobiology → **DDREF (LET),** age, gender → risk (UNSCEAR, BEIR V)

PPA, LBL, BNL (USA), GSI(Germany), HIMAC (Japan) → **φ(A,Z,Ω,m,B, ...)** → RBE → cancer, CNS, cataracts, etc.

Future

Space radiation environment → shielding, radiation biology → risk; countermeasures

Risk Issues Related to Space Dosimetry

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

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Detector Considerations

- Accuracy
  - Signal-to-noise ratio
  - Calibration, pre-experiment testing
  - Detection artifacts
  - Timing and location
- Precision
  - Sensitivity adequate for statistically significant results
  - Geometry factors and acceptance
- Dynamic range
  - Spectrum of particles and energies
  - Spectrum of LET
  - Doses, dose rates and flux
- Data acquisition
  - On-line vs. off-line
  - Stability of data, especially for integrating detectors
  - Availability of records

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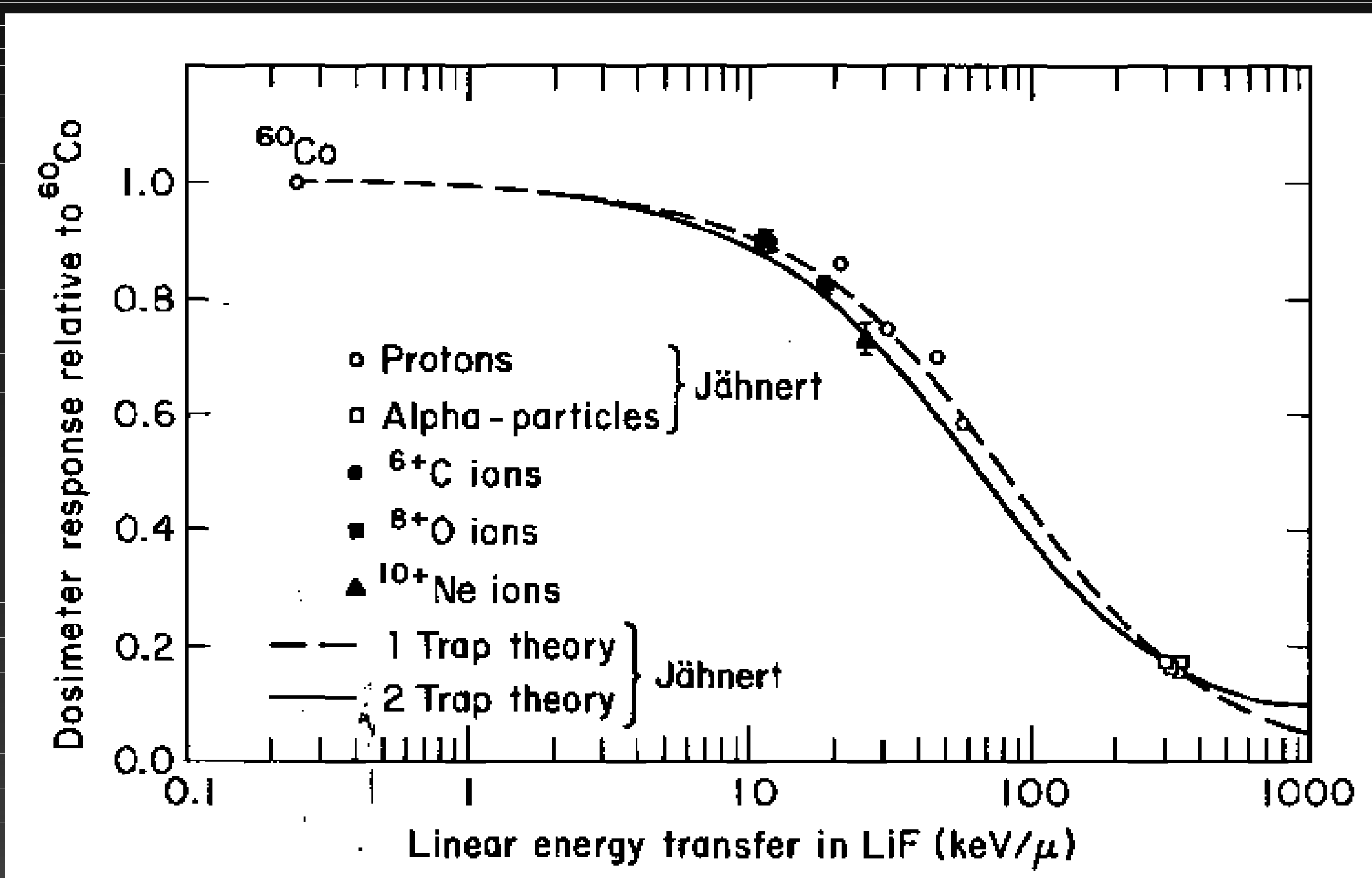
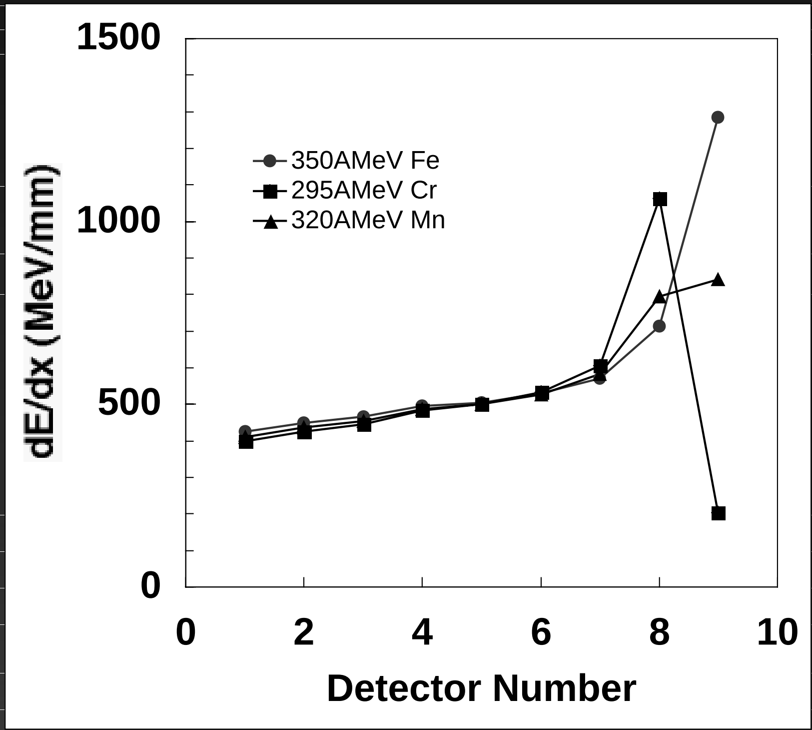
TLD Efficiency(*)



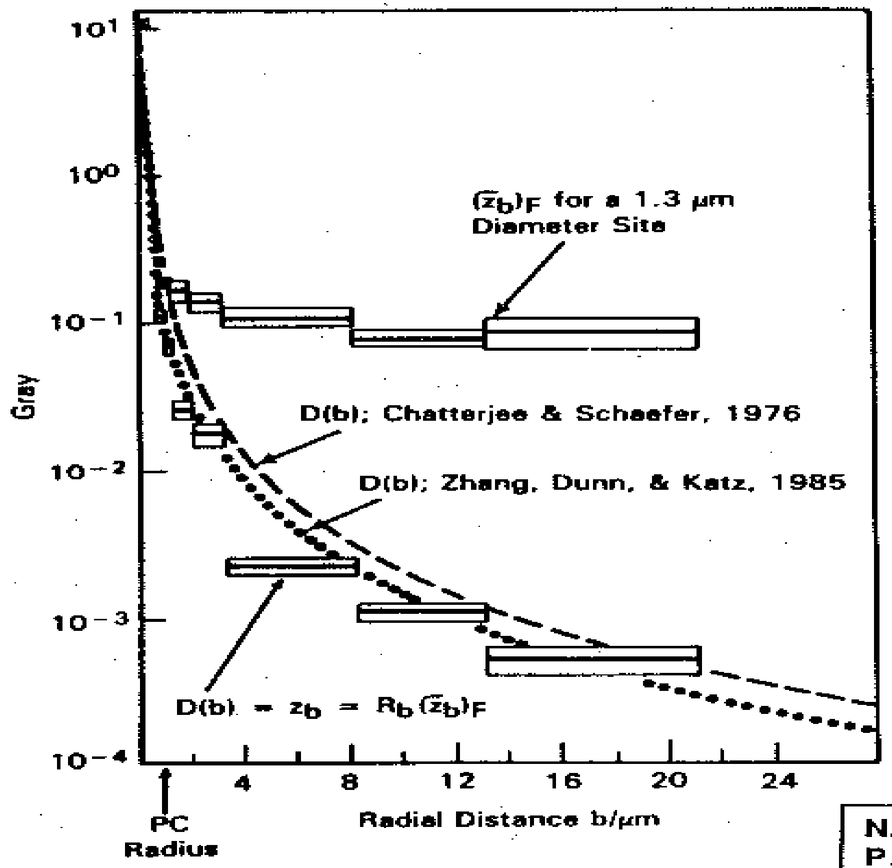
(*) R.H. Thomas,Passive Detectors. In: Advances in Radiation Protection and Dosimetry In Medicine (R.H. Thomas and V. Perez-Mendez, Eds.) Plenum Press, New York, 1980, p. 218

Separating Species

- Ions with differing M, Z, and E can have similar dE/dx over a substantial portion of their paths.
- Need good energy calibration (< 3% or so) and information from many detectors.
- Measure efficiencies of triggers
- Using these efficiencies, apply corrections.



Radial Energy Deposition



N.F. Metting, H.H. Rossi, L.A. Braby, P.J. Kliauga, J. Howard, M. Zaider, W. Schimmerling, M. Wong, and M. Rapkin, Radiat. Res. 116,183-195 (1988).

Biodosimetry

- Biological monitoring of radiation exposure:
  - record accumulated radiation exposure for individuals
  - supplement area monitors
  - weigh components of environmental radiation according to their biological efficacy
  - <u>desired goal</u>: predict risk
- Different types:
  - intrinsic biological dosimeters: biomarkers for genetic or metabolic changes
  - extrinsic biological dosimeters/indicators for radiation and other genotoxic substances and agents

Biomarker Requirements

- **sensitivity** to the levels of radiation exposure of concern
  - unequivocal: not sensitive to confounding factors (high signal-to-noise ratio)
- **accuracy** of predictions
  - predict risk and health care decisions at a well-defined level of confidence
- **specificity** of prediction
  - plausible causal relationship based on testable mechanisms of radiation action, rather than just a contingent correlation with radiation exposure
- **precision:** the results are not significantly distorted by individual or circumstantial variations in radiation response
- lead to **diagnostic procedures** that are:
  - practical under actual circumstances of exposure rather than only under highly restricted laboratory conditions
  - cost-effective , to screen large populations where required

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Single Instrument Specifications

φ(A,Z, LET, …), D(LET), QF(LET), …

- **Particle identification:**
  Positive charges vs. neutrons, electrons, γ-rays
  (1,1) • (A,Z) • (56,26) [p to Fe]
  ΔZ/Z • 0.2]
  ΔA/A • 1
- **Energies**:
  10 • ε_{HZE} • 1000 MeV/nucleon
  10 keV • ε_{n} • 100 MeV
  700 keV • $\varepsilon_{x,\gamma,\beta}$ • 10 MeV
- **LET range**:
  0.1 • LET • 2000 keV/µm
- **Acceptance**
  - Solid angle (statistics) • 2•
  - detection efficiency • 10%
  - Δø/ø (angular resolution) • 3°
- **Rate Dependence**
  R • 10^5 particles/sec; N • 10^4 particles/cm^2
  0.01 µGy/min • •D/•t • 1 Gy/min
- **Localization**
  - Portability
    - » Personnel dosimetry
    - » Area monitoring
  - Shielding: traceable to mass distributions
- **Data acquisition and recording**
  - Telemetry and on-board readout
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- Not every ISS dosimetry measurement will necessarily be used for implementing ALARA
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