Astronaut Career Exposure Records

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Outline

- Content of Records
- Utilization of Environmental Data
- Utilization of In-flight Dosimetry
  - ISS CHECS
- Utilization of Biodosimetry
- Weighting Factor Issues

Content of Records

- Best estimates of age, sex, and tissues specific probability for all aspects of detriment/risk are included
  - Cancer Mortality
  - Cancer Morbidity
  - Hereditary Effects
  - Deterministic effects
- Estimates are made for cumulative dose from all occupational exposures
- New initiatives include:
  - Re-evaluation of career effective doses; TLD, QF, and self-shielding corrections
  - Re-evaluation of dose to risk conversion using new information from NCRP
  - Inclusion of confidence intervals for dose and risks
- New format for records (Software issues)
- Annual and career termination reports are being developed

Environmental Data Utilization

- Space Environment Components contributions to Effective Dose:

$$E_T = E_T\ (\text{GCR}) + E_T\ (\text{trapped p+}) + E_T\ (\text{albedo n\&p}) + E_T\ (\text{trapped e-}) + E_T\ (\text{SPE})$$

- On ISS, EVCPDS will make measurements of pitch-angle distribution, charge-particle spectrum, and GCR transmission probability (CHeCS Hardware and other)
- In addition to baseline models following environmental indexes are known and can be used to scale environment models:
  - GCR- Magnetic field parameter, NMC, or Sun-spot Number
  - Trapped radiation- F10.7
  - Earth magnetic field parameters (Kp, ap)

HZETRN/QMSFRG: Model for Proton, Neutron, and Heavy Ion Transport/ Reaction

- Boltzman equation describes energy loss and nuclear production processes: Solution for the flux of ions, $\phi_{\varphi}(\xi,E)$, of type j and energy E, at depth, *x* is given by the integro-differential equation

$$\boldsymbol{\Omega} \cdot \nabla \phi_j(x,\Omega,E) = \Sigma_k \int \sigma_{jk}(\Omega,\Omega',E,E') \, \phi_k(x,\Omega',E') dE' d\boldsymbol{\Omega}'$$

$$- \sigma_j(E) \, \phi_j(x,\Omega,E)$$

- $\sigma_{\varphi\kappa}$ are the production cross sections, and σ_{φ} are the total interaction cross sections
- HZETRN code solves numerically using *CSDA and straight-ahead approximations*
  - –QMSFRG (quantum multiple scattering model of nuclear fragmentation) provides data base for heavy reaction over GCR spectrum of energies and isotopes

Nuclear Scattering Processes

- Heavy Ion Fragmentation:
  - Projectile fragments; gaussian spread near projectile velocity
  - Target Fragment low-energy, high LET ions
- Production Processes- Light particles (n, p, d, t, h, α):
  - Evaporation
  - Intra-nuclear cascade
  - Knock-out / fragmentation
- Mesons with E&M Cascades
- Elastic Scattering
  - Large importance for neutron transport

CHECS (Dosimetry) Utilization

- Detector Responses
  - TLD
  - TEPC
  - Plastic track detectors
  - IVCPDS, EVCPDS
- Minimization Procedure:

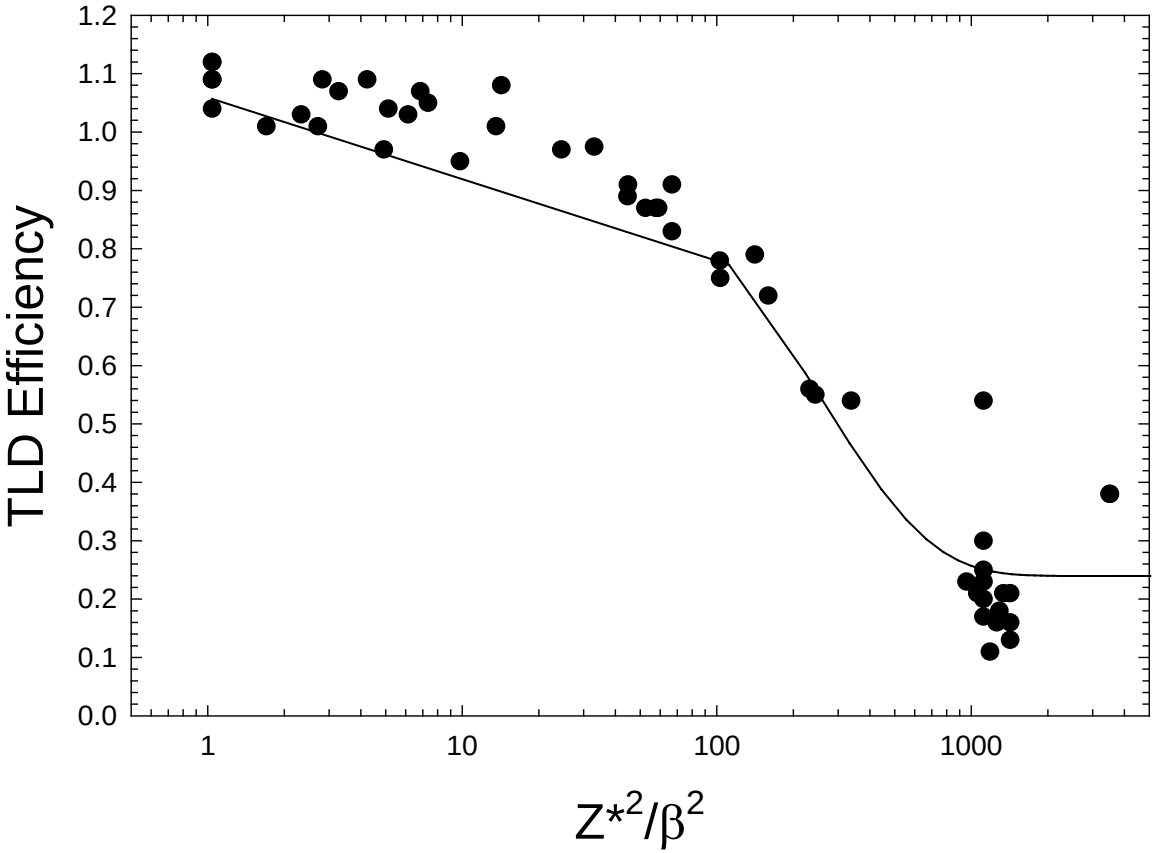
  a) Baseline environmental model compared to ISS exterior data

  b) Baseline models (Environment, HZETRN, ISS-Shield) normalized to CHeCS data for interior ISS

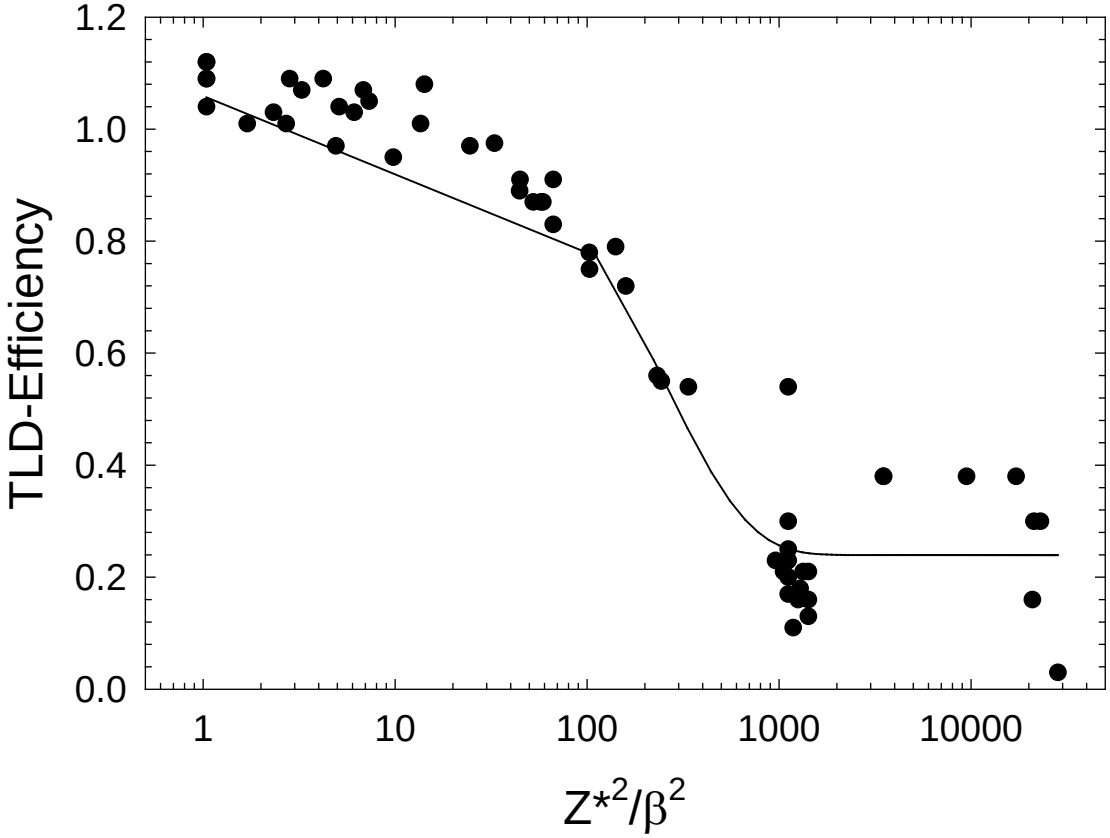
  b) ISS Interior-Normalized baseline model adjusted to Crew personal dosimetry

  c) ‘Final’ model is use to estimate organ doses using CAM/CAF scaled to Astronaut size/weight

TLD-100: Proton and Alpha Data

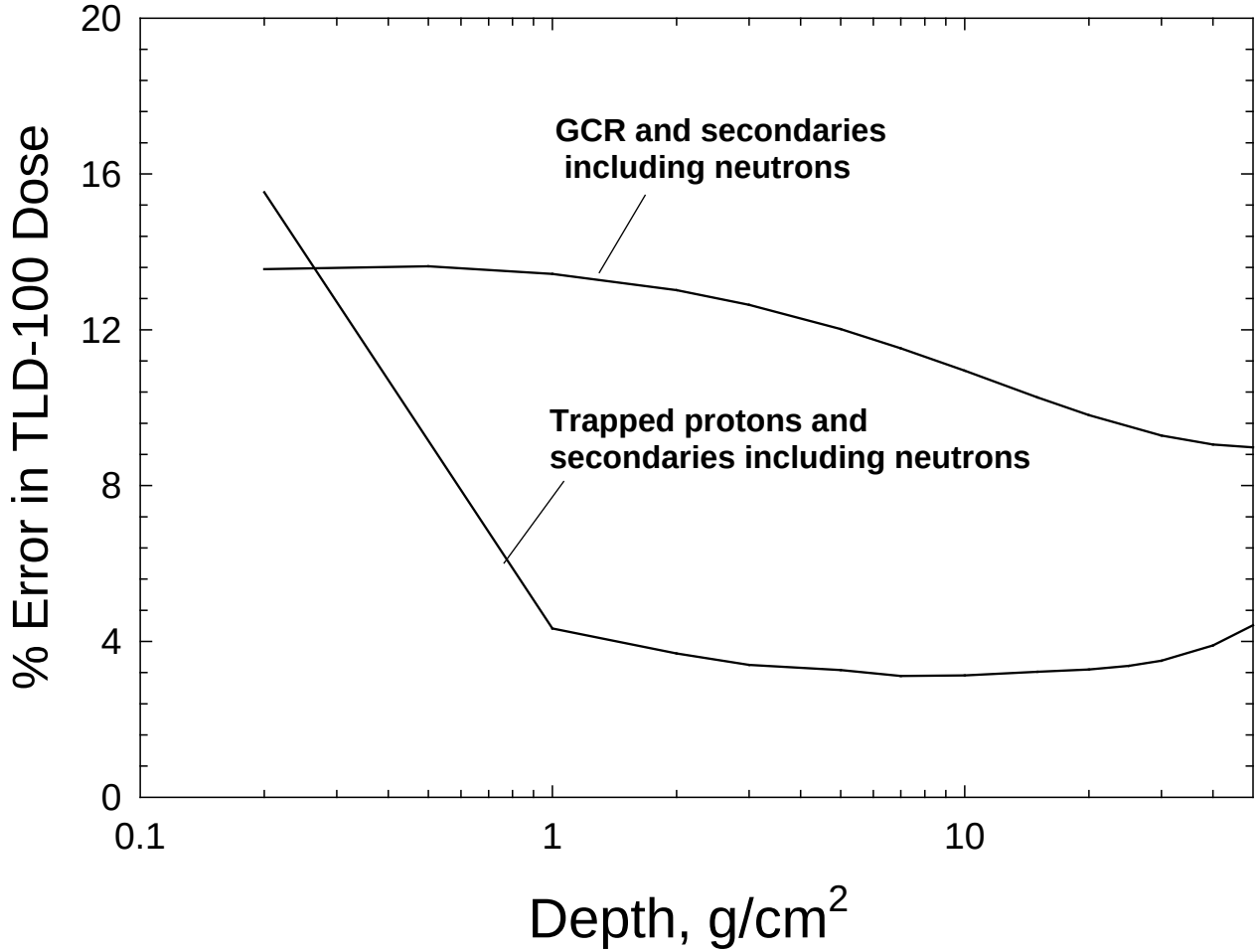


TLD-100 Response to Protons and Heavy Ions

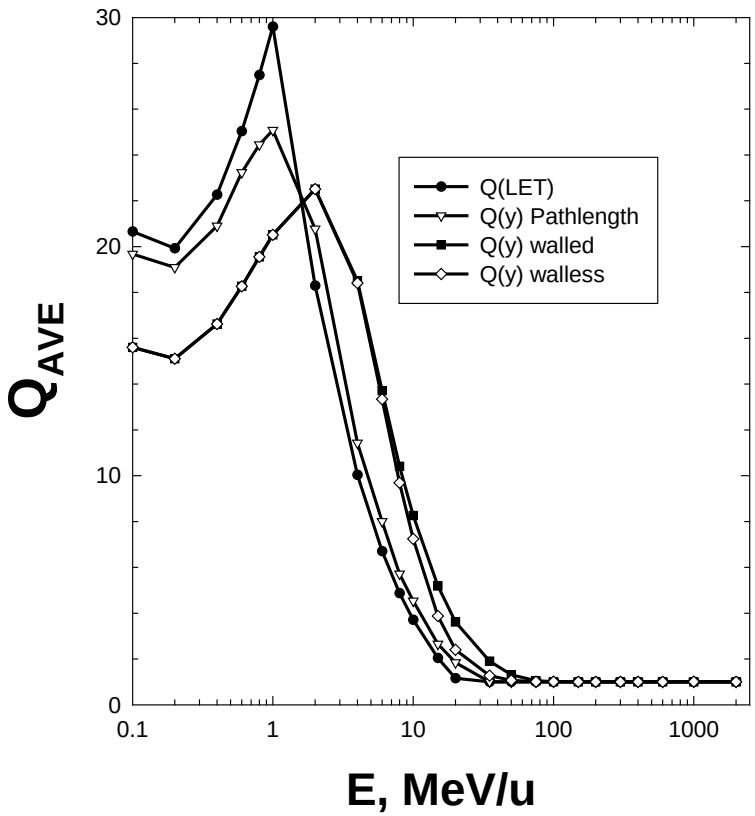


TLD-100 Response in Low Earth Orbit

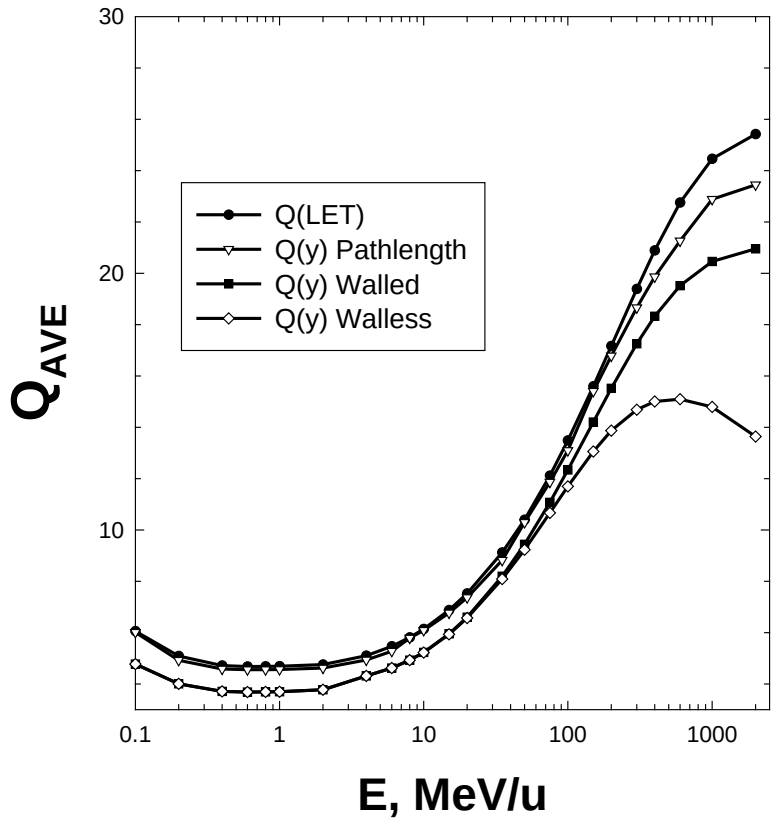
Solar Miniumum (51.6 deg x 390 km)



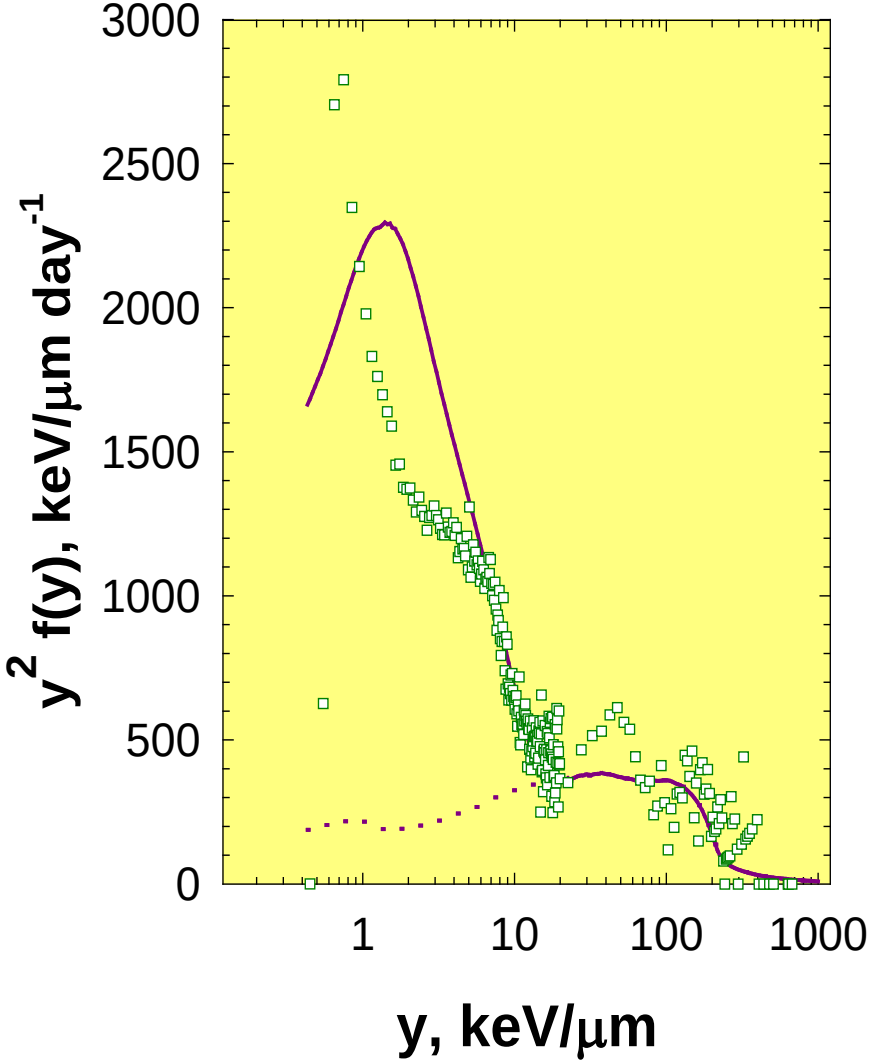
TEPC RESPONSE: ^{4}He (d = 2 μm)

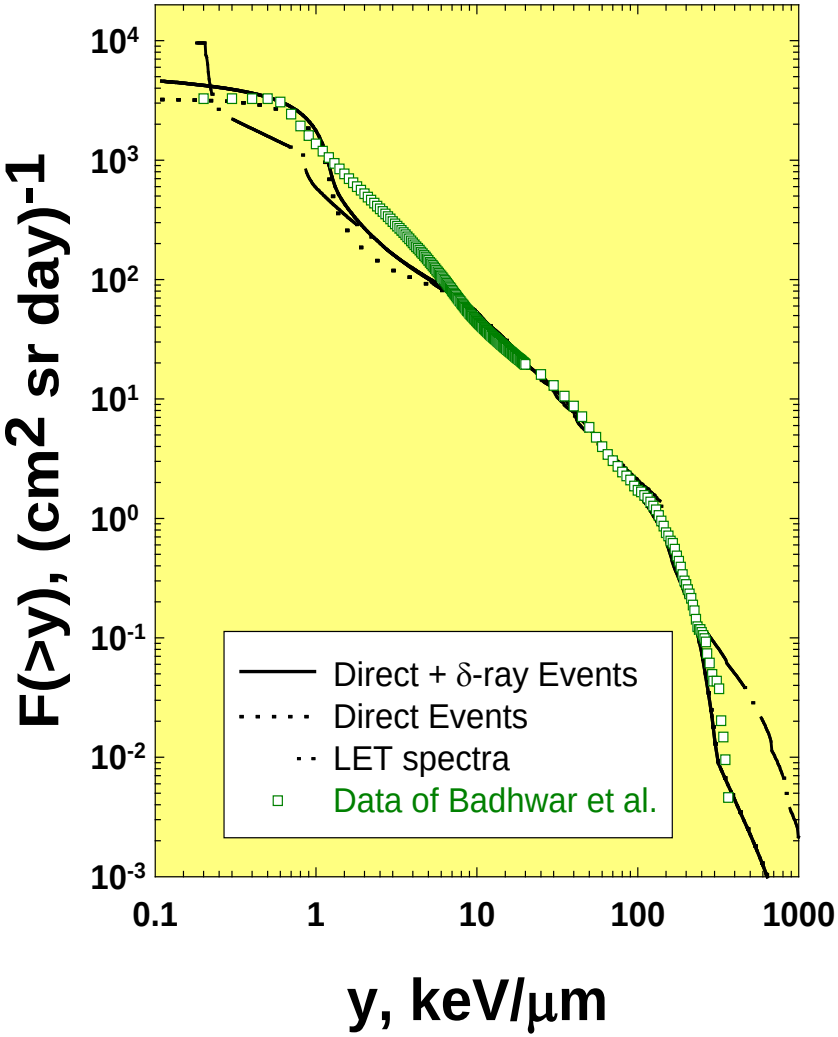


TEPC RESPONSE: ^{56}Fe (d = 2 μm)



GCR Microdosimetry from STS-56
(TEPC diameter = 2 μm)





Biodosimetry Utilization

- Biodosimetry provides unique information in following areas:
  - In-vivo endpoints in Humans
  - Test of radiation quality issues
  - Test of DDREF
  - Informative of dose to BFO
  - Informative of interaction of radiation with other space factors
- For low dose-rate exposures risk is assumed linear dose/ fluence increase
  - For mixed-radiation field occurring in space risk evaluation

$$Risk = \sum_j \int dE \quad \phi j(E,x) S(E) \alpha(E,Z) = \sum_j \int dE \quad \phi j(E,x) \sigma(E,Z)$$

Where: ϕ_φ is energy spectra of ion j

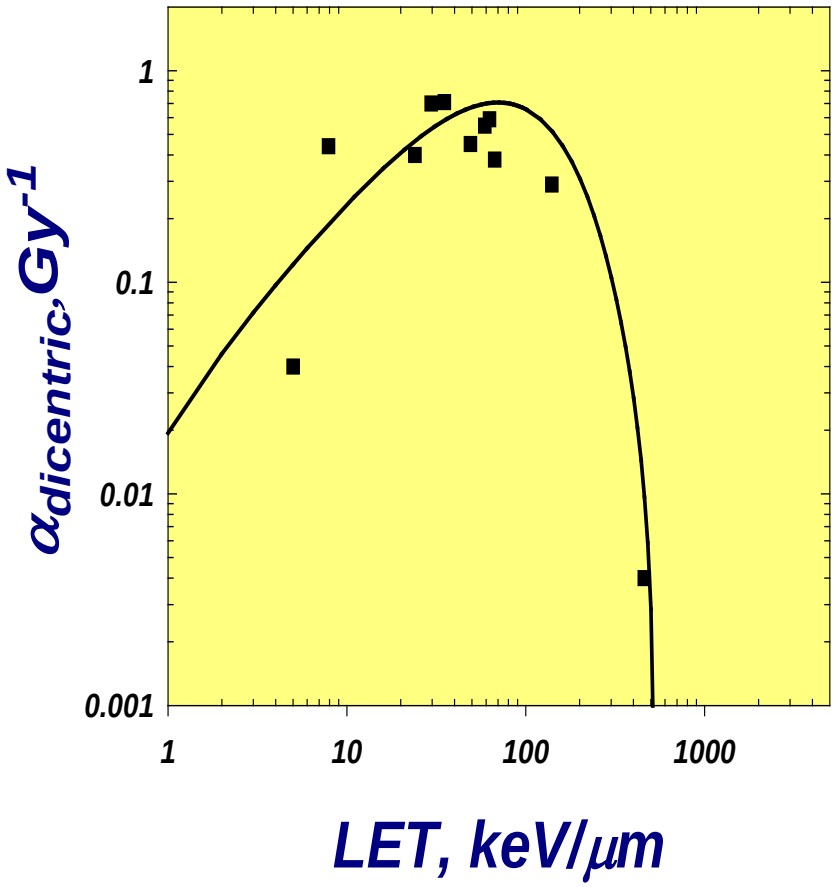
S(E) is stopping power or LET

α(E,Z) is risk coefficient

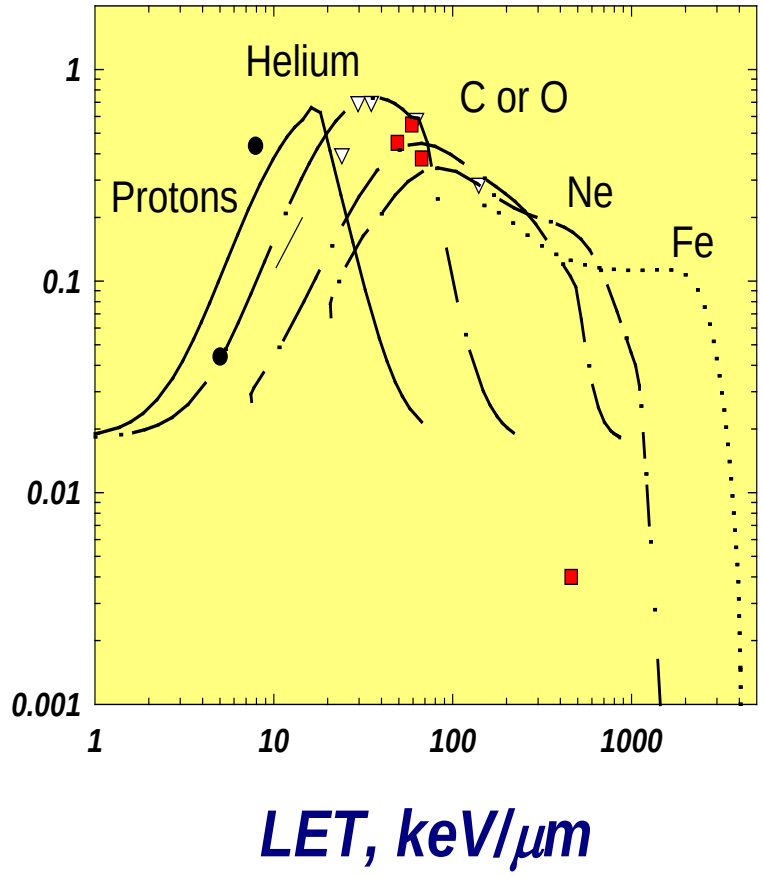
σ(E,Z) is biological action cross section

Risk Methodologies: Energy Deposition Models and Linear Hypothesis

α–β Model



Katz Track Structure Model



Comparison to Biodosimetry on Mir Station

Comparisons of Calculations to Measurements for Fraction of dicentrics in lymphocytes from Mir-18 Crew Member

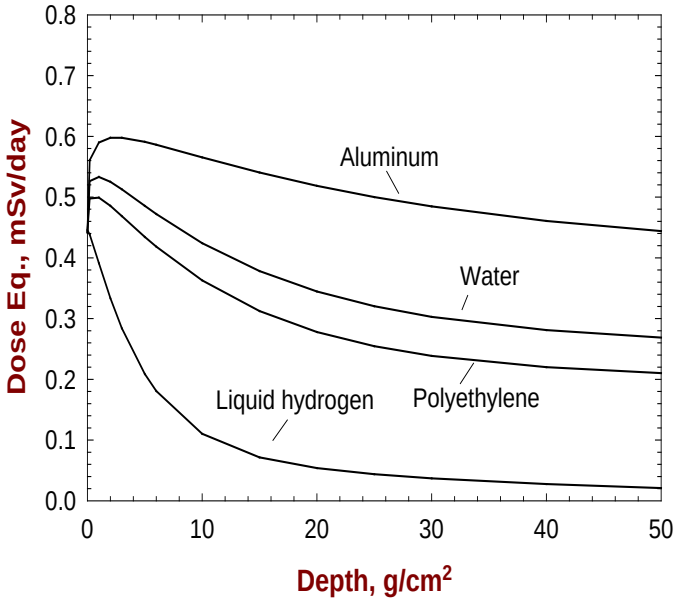
Shielding	Model	GCR	Trapped p+	*Total*
Naussica	LET	2.20×10^{-3}	2.19×10^{-3}	*4.39×10^{-3}*
Naussica	Track	2.78×10^{-3}	2.66×10^{-3}	*5.44×10^{-3}*
Lyulin	LET	2.23×10^{-3}	2.46×10^{-3}	*4.69×10^{-3}*
Lyulin	Track	2.76×10^{-3}	3.02×10^{-3}	*5.78×10^{-3}*
Mir-18-Crew Member	Biodos.			*$6.4(\pm 2) \times 10^{-3}$*

Comparisons to of models to measurements for dose- and dose equivalent rate on Mir-18.

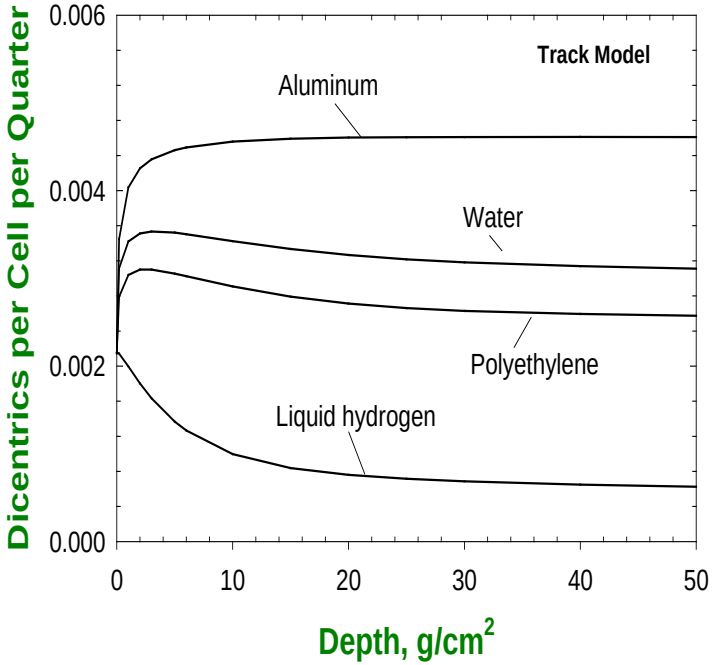
	GCR		Trapped Protons		TOTAL	
	Dose mGy/day	Dose Eq. mSv/day	Dose mGy/day	Dose Eq. mSv/day	Dose mGy/day	Dose Eq. mSv/day
TEPC	0.142	0.461	0.153	0.298	0.299	0.781
HZETRN Naussica	0.138	0.535	0.191	0.295	0.329	0.830
*TEPC Location Lyulin	0.141 0.134	0.526 0.547	0.140 0.254	0.219 0.391	0.281 0.388	0.745 0.938

Risk Mitigation through Shielding

GCR Dose Equivalent on ISS



Chromosome aberrations on ISS



Organ Dose and Weighting Factors

- **Organ dose evaluation**: For shielding depth, x and tissue depth, y-

$$D(x,y) = \Sigma_j \int dE\, S_j(E)\, \phi_j(E,x,y)\ ;\ \ H(x,y) = \Sigma_j \int dE\, S_j(E)\, \phi_j(E,x,y)\, Q(S_j(E))$$

- Summation is over particle type j E is energy in MeV/u
- $S_j(E)$ is stopping power of ion j of energy E Q is quality factor
- $\phi_j(x,y)$ is particle flux from HZETRN/QMSFRG model

Average quantities evaluated using spacecraft shielding model and computerized anatomical male/female model:

$$D_T = \Sigma\, b_y \Sigma\, a_x\, D(x,y) \qquad E_T = \Sigma\, b_y \Sigma\, a_x\, H(x,y) \qquad Qave = E_T / D_T$$

- **Chromosome Aberrations:**

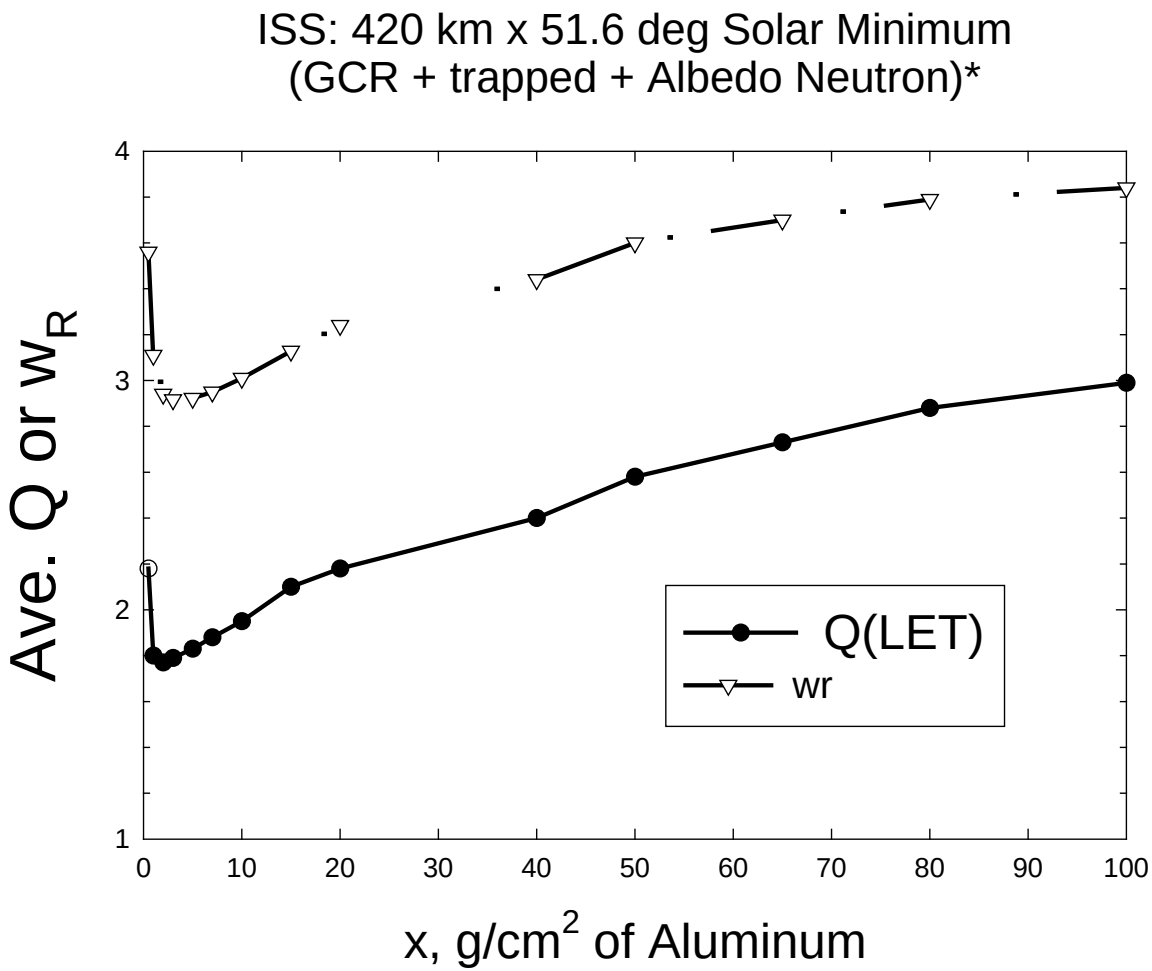
$$A(x,y) = \Sigma_j \int dE\ \phi_j(E,x,y)\, \sigma_j(E)$$; σ_j is action cross section for aberration

Organ Doses and Quality Factors in LEO -Model Comparisons for 10 days

	51.6 deg x 390 km				28.5 deg x 450 km			
	GCR		Total		GCR		Total	
Organ	**H, rem**	**Qave**	**H, rem**	**Qave**	**H, rem**	**Qave**	**H, rem**	**Qave**
Point	0.5	4.1	1.08	2.0	0.18	3.3	1.02	1.6
Skin	0.39	3.3	0.72	2.0	0.18	3.3	0.67	1.6
Eye	0.40	3.4	0.71	2.0	0.16	3.0	0.67	1.6
BFO	0.34	3.0	0.51	2.1	0.16	2.9	0.46	1.7
Stomach	0.32	2.8	0.45	2.1	0.16	2.9	0.39	1.8
Colon	0.34	2.9	0.51	2.1	0.16	2.9	0.45	1.7
Liver	0.32	2.8	0.47	2.1	0.16	3.0	0.41	1.7
Lung	0.33	2.9	0.49	2.1	0.16	2.9	0.44	1.7
Bladder	0.31	2.7	0.44	2.1	0.16	2.9	0.38	1.8
Thyroid	0.35	3.0	0.53	2.1	0.17	3.0	0.48	1.7

Radiation Weighting Factors

- Ambiguities arise in interpretation of application of ICRP radiation weighting factors (w_r vs. Q(LET)):
  - Protons 5 or 2 or 1?
  - High-energy alpha particles w_r of 20?
  - Relativistic heavy ions w_r of 20?
  - What energy defines relativistic (290 MeV/u? 938 MeV/u?)
  - ICRU sphere or computerized anatomical model?
  - External field components at tissue site in a mixed-field including neutrons?
- Use of Q(LET) with CAM/CAF model is approach used by JSC:
  - Differences in use of w_r and Q(LET) are non-trivial for space radiation applications



*Using wr = 2 for Protons above 2 MeV and wr=1 for E>100 MeV
wr = 3 for α above 2 MeV/u; wr = 2 for α with E> 100 MeV/u