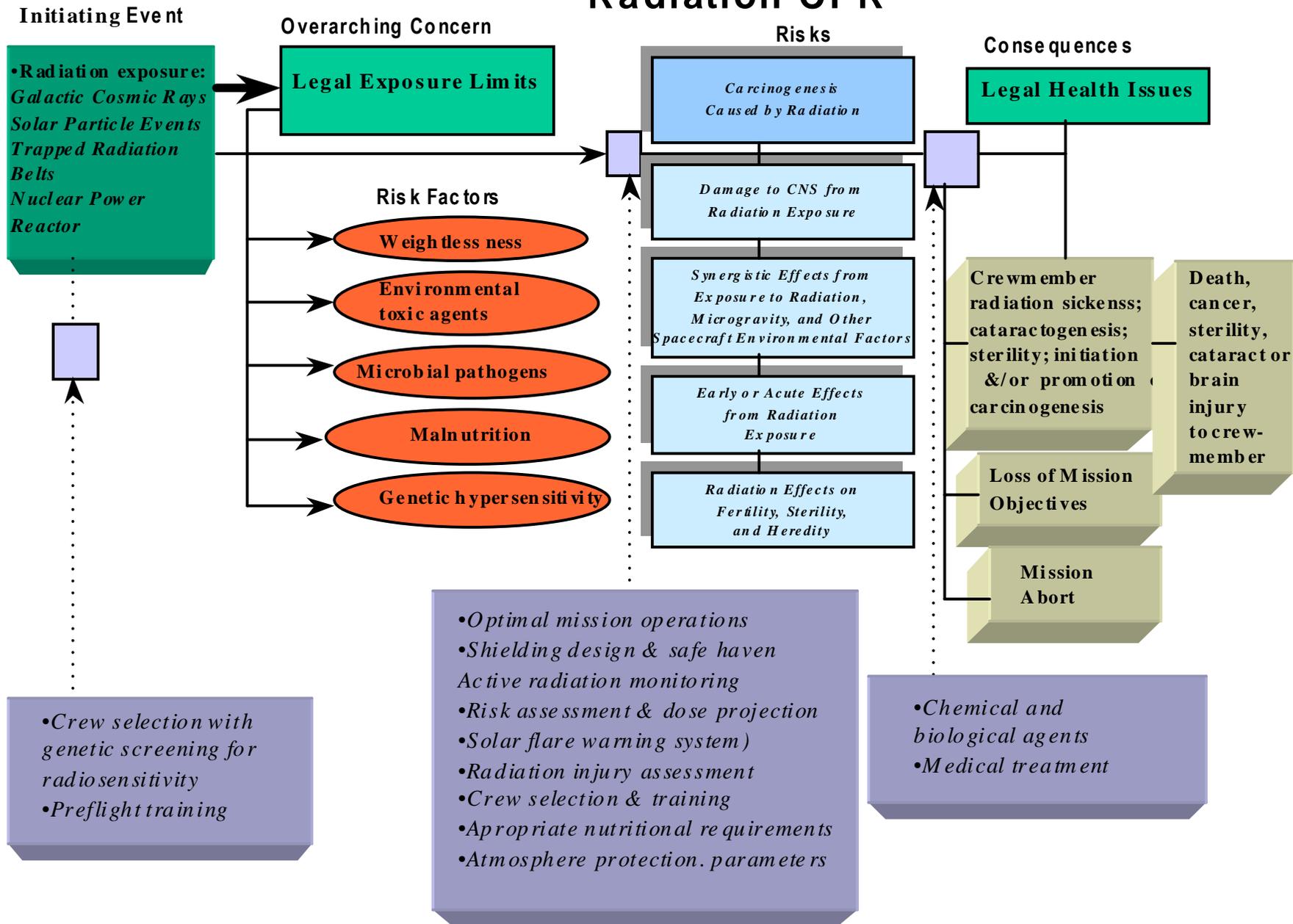


Risk Assessment for CNS Damage from Space Radiation

**Francis A. Cucinotta
NASA, Johnson Space Center
Houston TX 77058**

December 5, 2000

Radiation CPR



Risk Assessment for CNS Damage

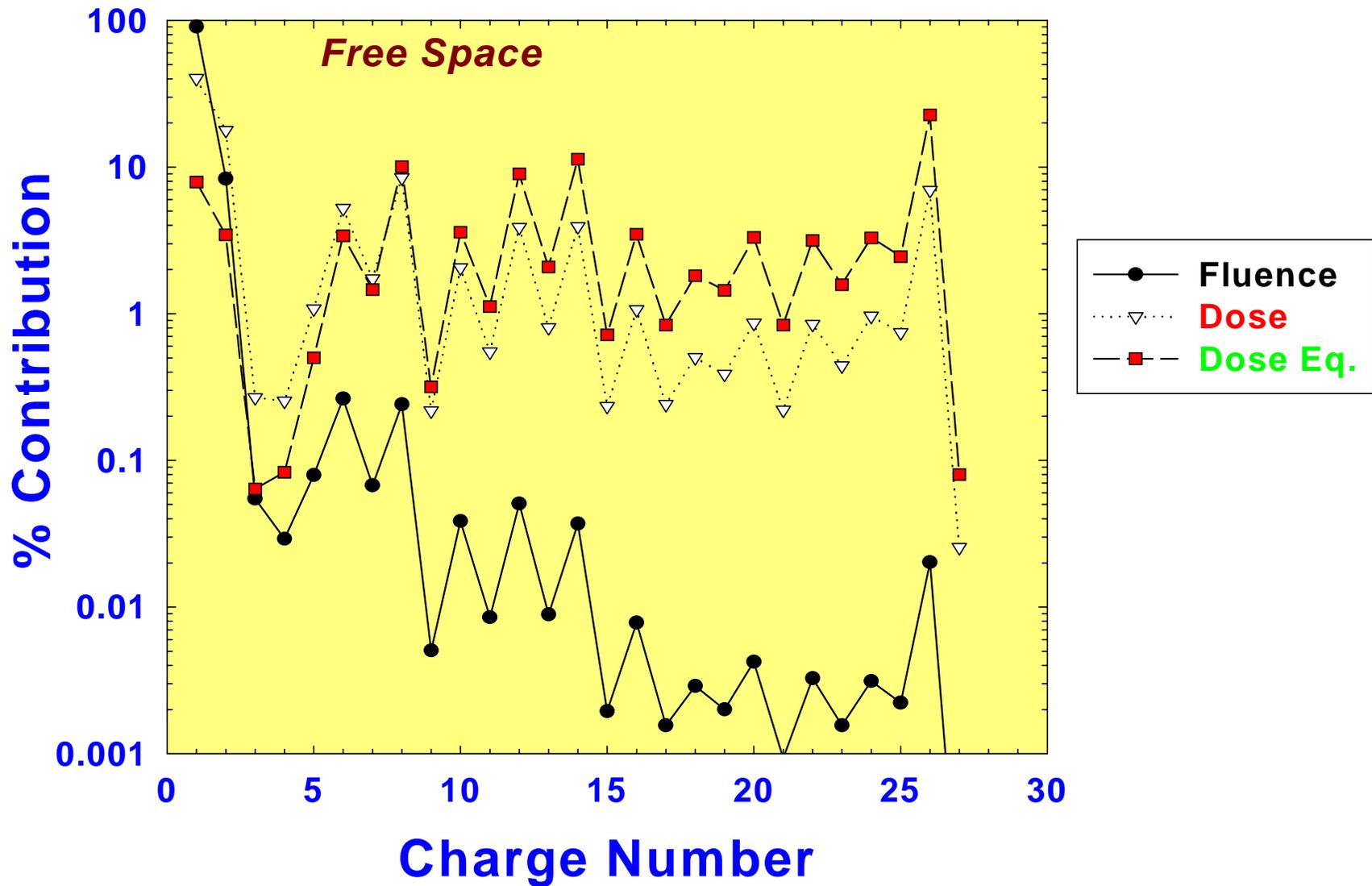
- **NASA Radiation CPR-**

- Risks to the CNS from space radiation is Priority-2 in roadmap
- Risk of CNS damage from HZE ions is highly uncertain due to distinct energy deposition from HZE tracks
- Lower species models indicate important differences with high-LET ions
- Insufficient data to place in category-1 of CPR

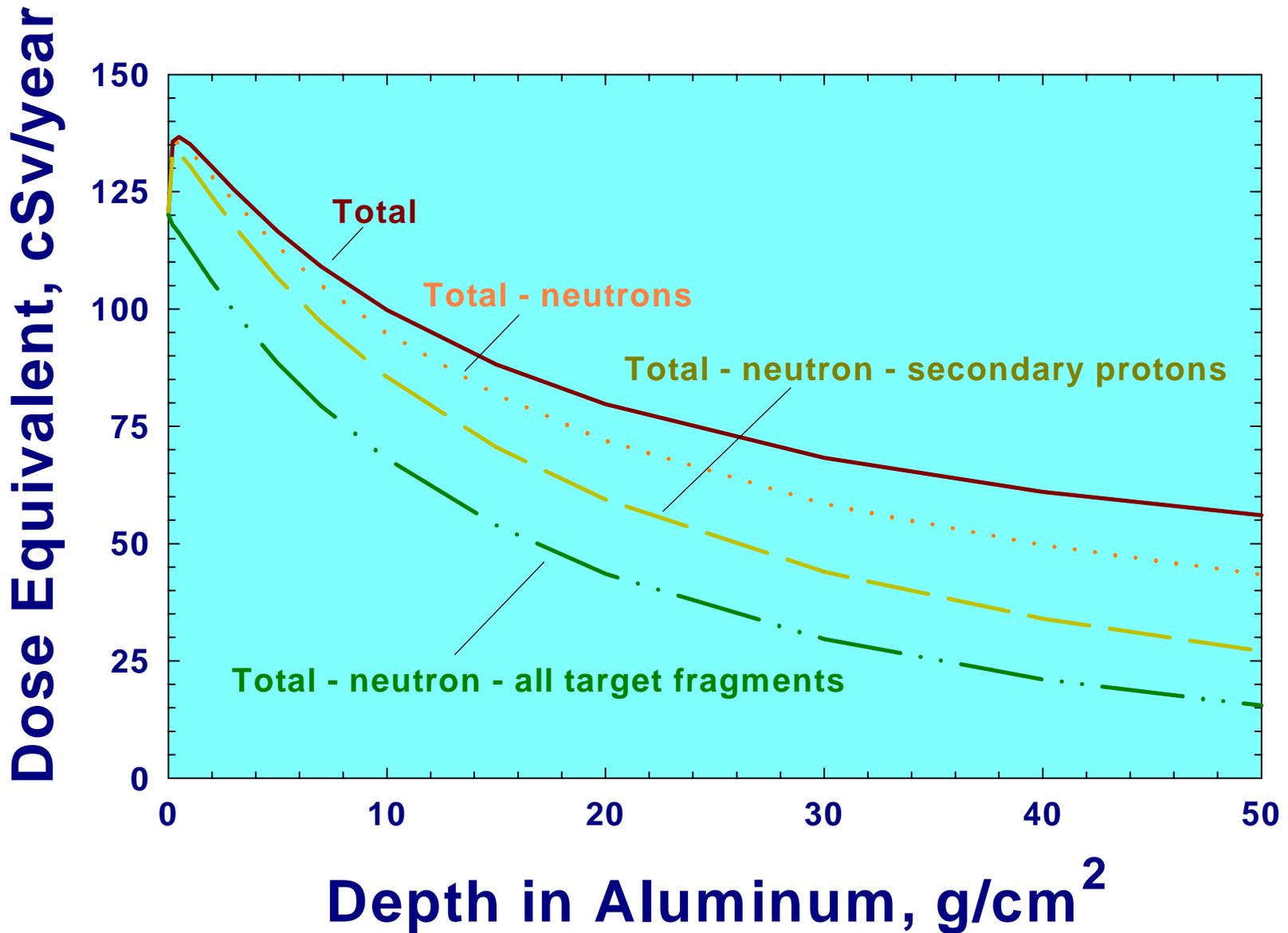
- **Future**

- Is there a risk for Mars mission from GCR or Solar Particle Events?
- Are there human data that can be used to bound problem?
- How can new science support development of risk assessment model?
- What risks would be included in such a model?

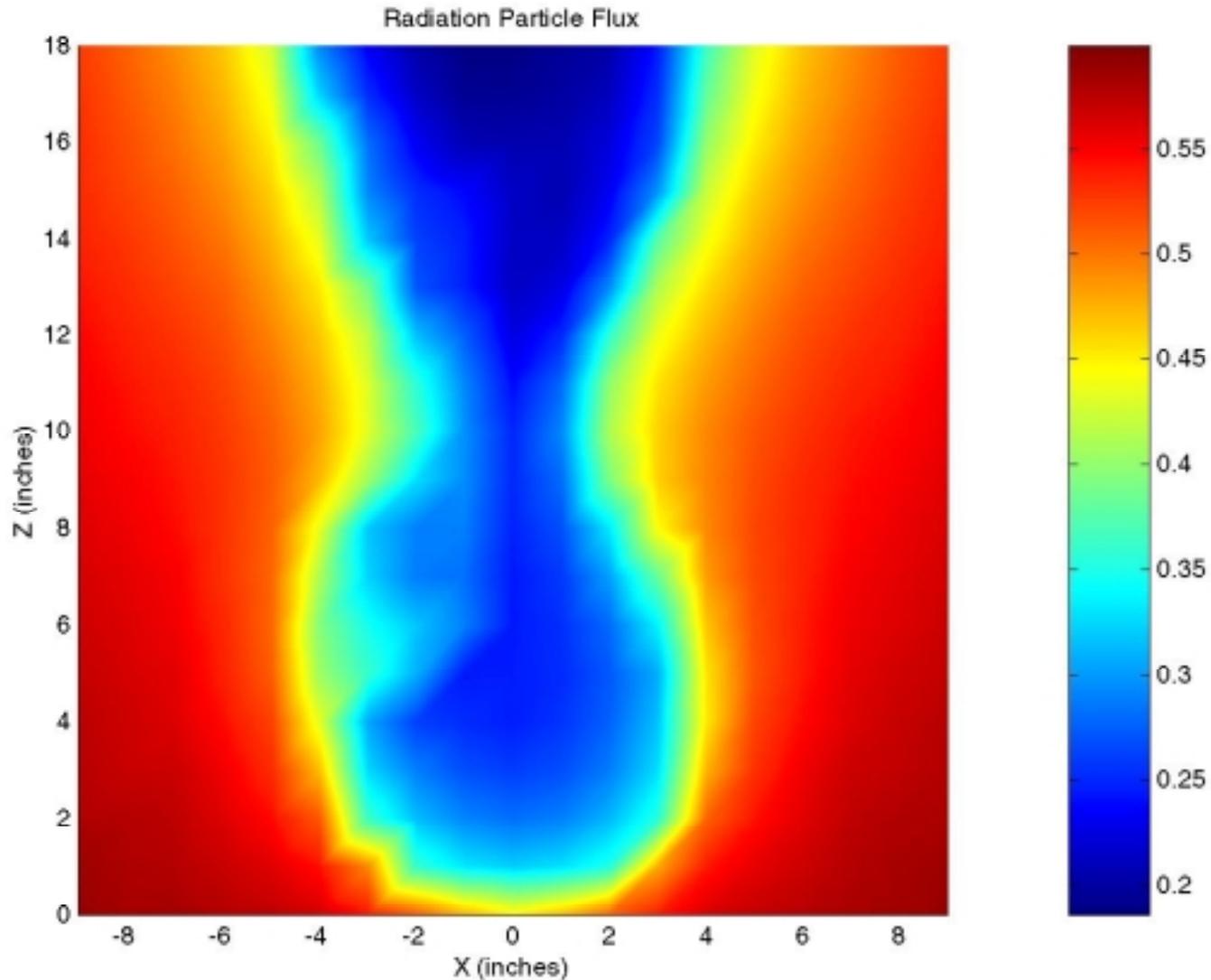
GCR Charge Contributions



Nuclear Reaction Mechanisms in GCR Risk



Particle Hits per Cell for HZE's with $Z > 12$ (1000 day mission)



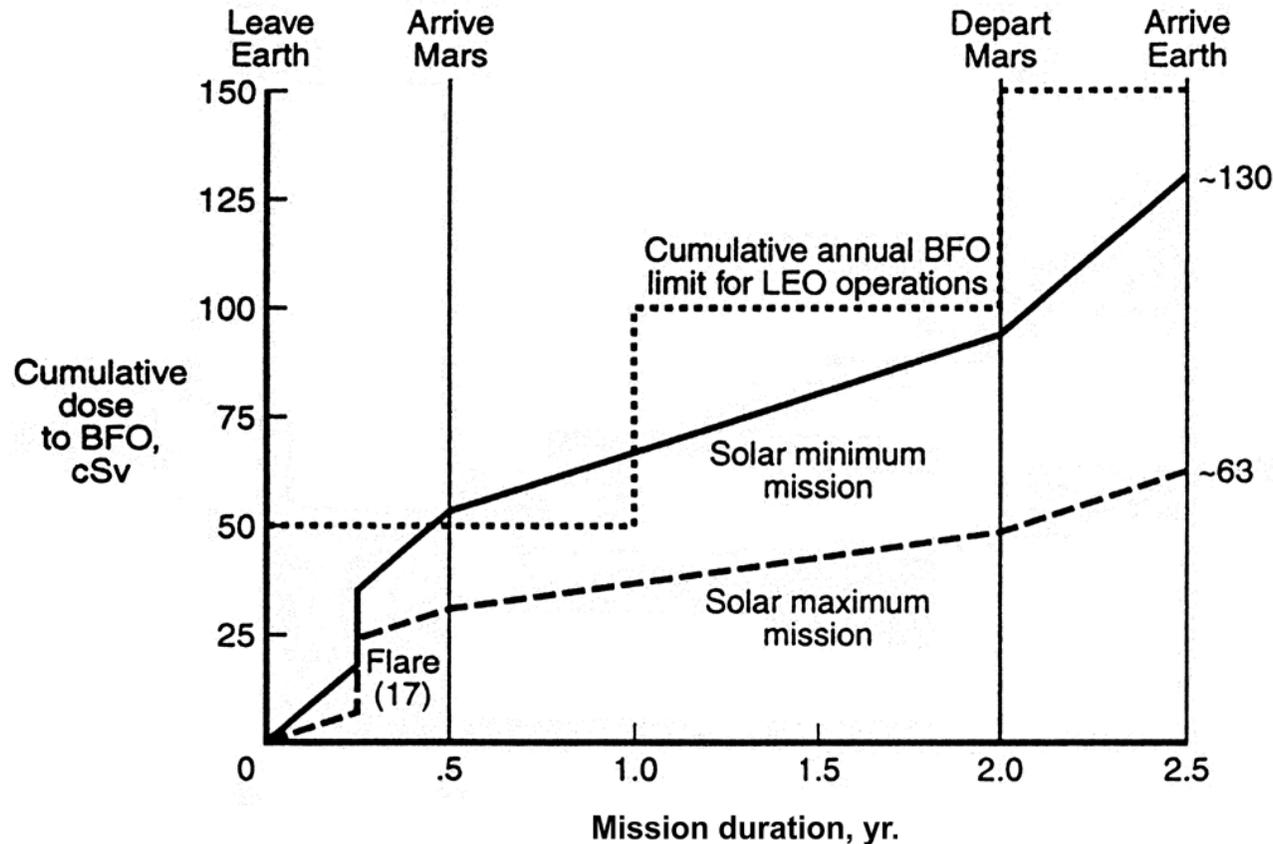
Doses in Individual Programs

Program	Average* Altitude	Inclin.	Dose* (cSv)	Dose-rate (cSv/day)	N
Gemini	454 km (1370 km)	30	0.053 (0.47)	0.087 (0.47)	20
Apollo	-	-	1.22 (3.3)	0.13 (0.39)	33
Skylab	381 (435)	50	7.2 (17.0)	0.12 (0.21)	9
STS Alt > 450 km	570	28.5	2.65 (7.8)	0.32 (0.77)	85
STS Alt.< 450 km	337	28.5	0.21 (0.71)	0.023 (0.04)	207
STS/Mir	341 (355)	51.6	9.9 (14.0)	0.072 (0.10)	4
ISS	360-450	51.6	8-18	0.05-0.1	280
Mars	**	**	40-120	0.15-0.2	4 - 8

***Maximum value in parenthesis**

Mars Reference Design Mission

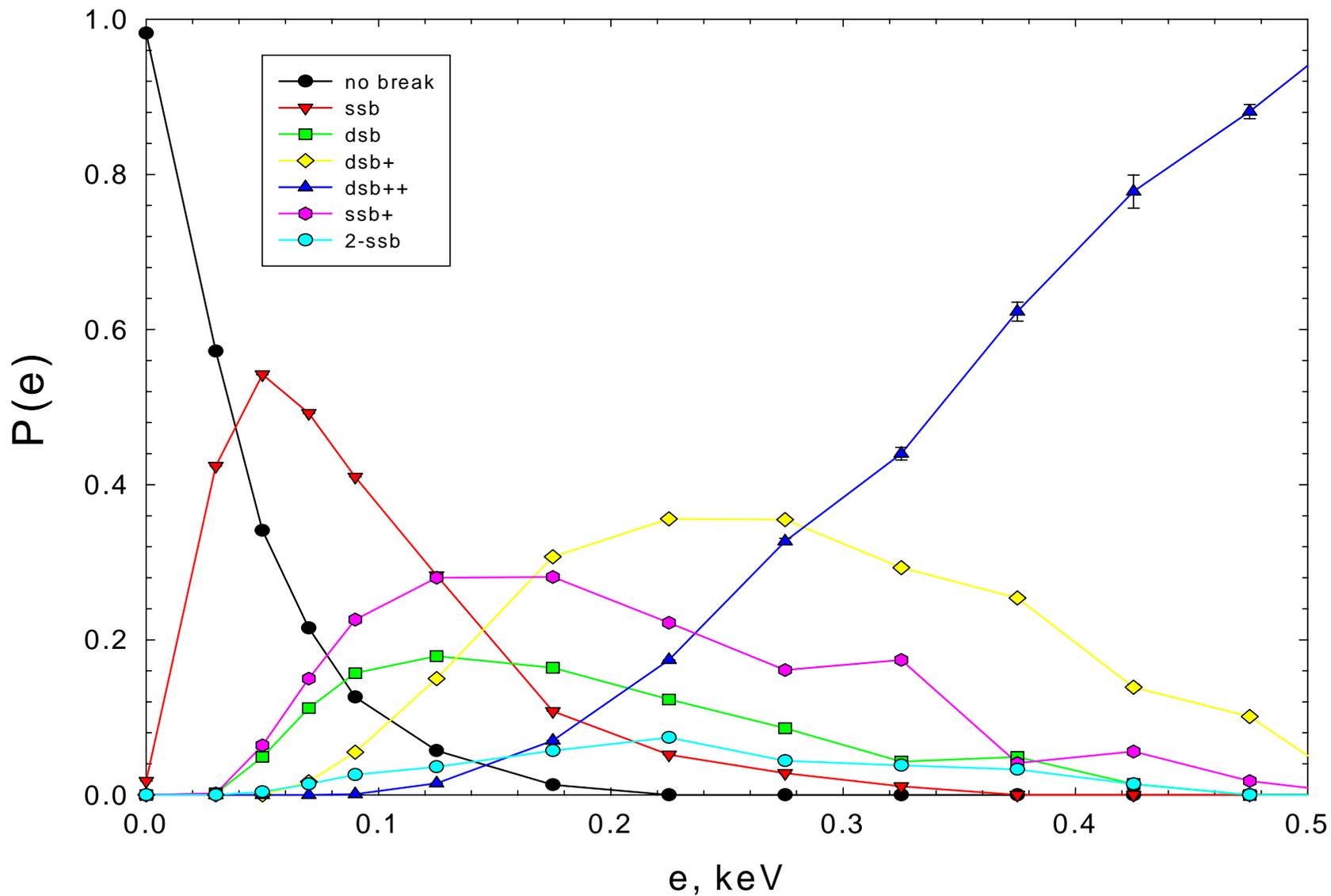
- Used by NASA for design studies of costs and necessary technologies and science
- Model predictions using HZETRN and nominal shielding



Initial Events Produced by Single High-Energy Nuclear Tracks

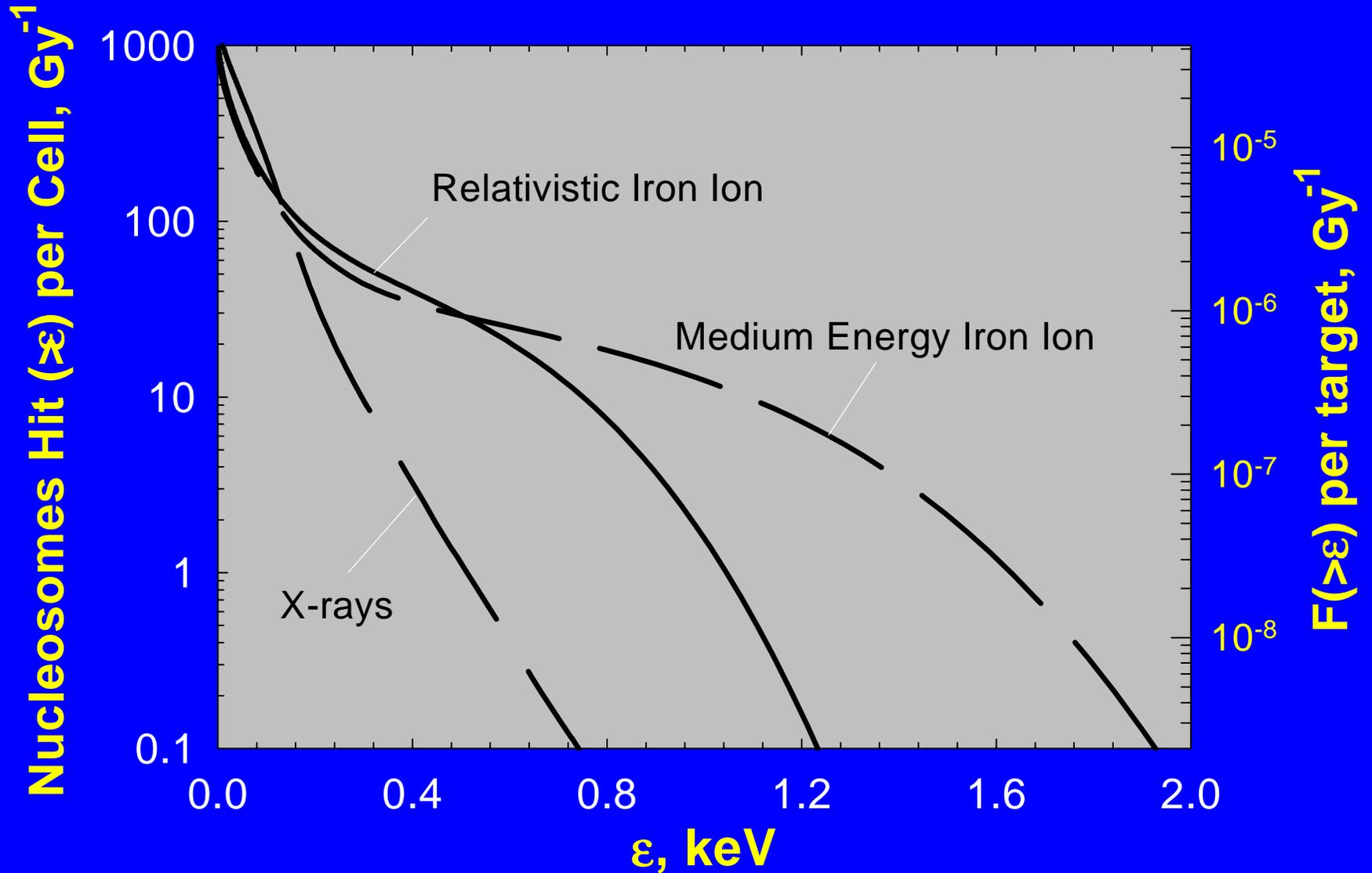
- Hierarchy of Damage Regions
 - **Correlated DNA damage (clustered SSB, DSB, etc.)**
 - **Correlated genomic damage (regionally multiply damage sites)**
 - **Correlated tissue damage (Micro-lesions and bystander effects)**
 - » **High-multiplicity nuclear reactions in tissue**
- Does Correlated damage lead to unique effects?
 - **Track structure of ions and delta-rays**
 - **Nuclear fragmentation in cells or tissue**
 - **Bystanders (transmittable factors, apoptotic bodies etc.)**
 - **CNS damage**

Complex DNA Breaks and Energy Imparted to DNA

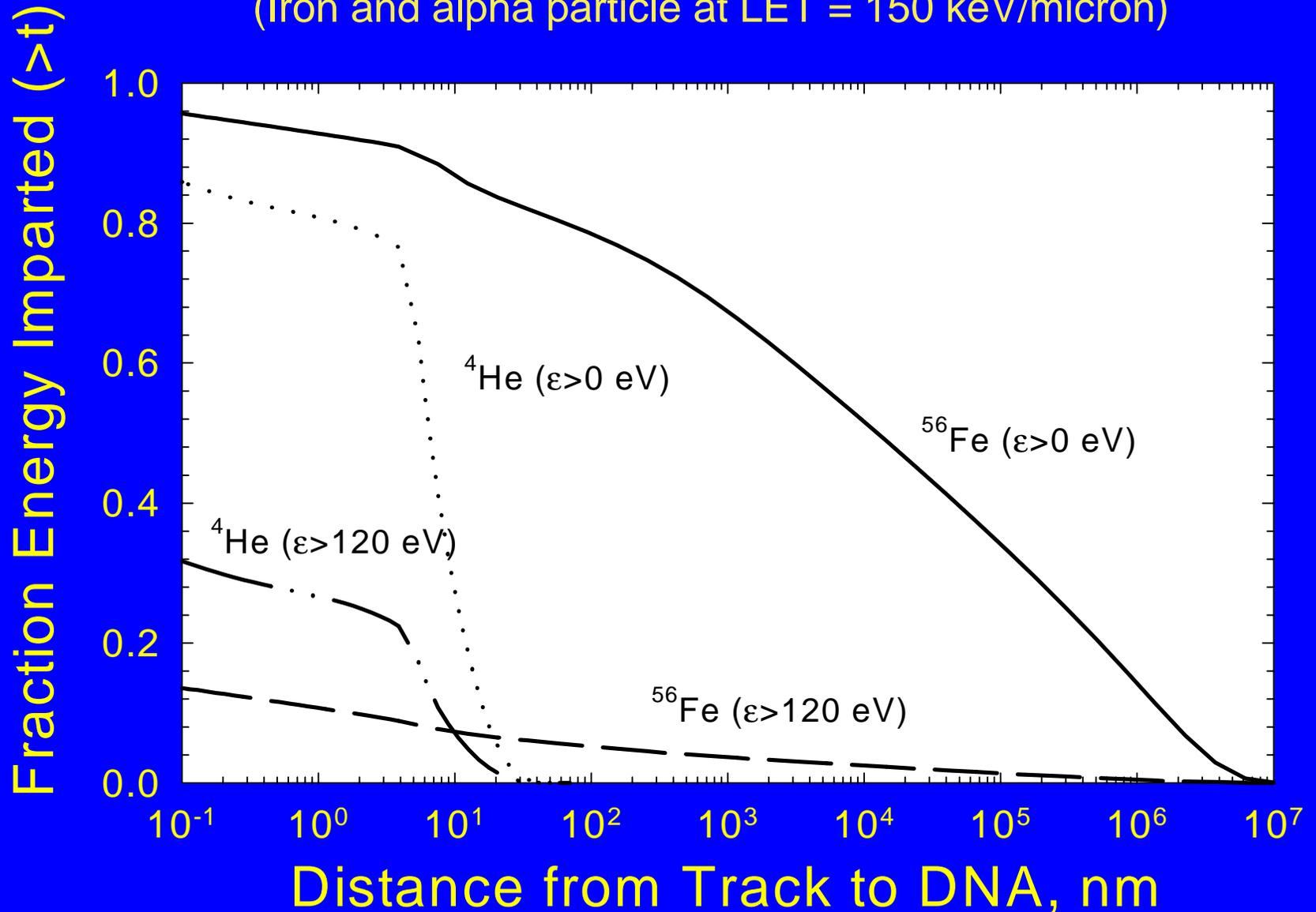


Energy Deposited in DNA

X-rays and Heavy ions are qualitatively different

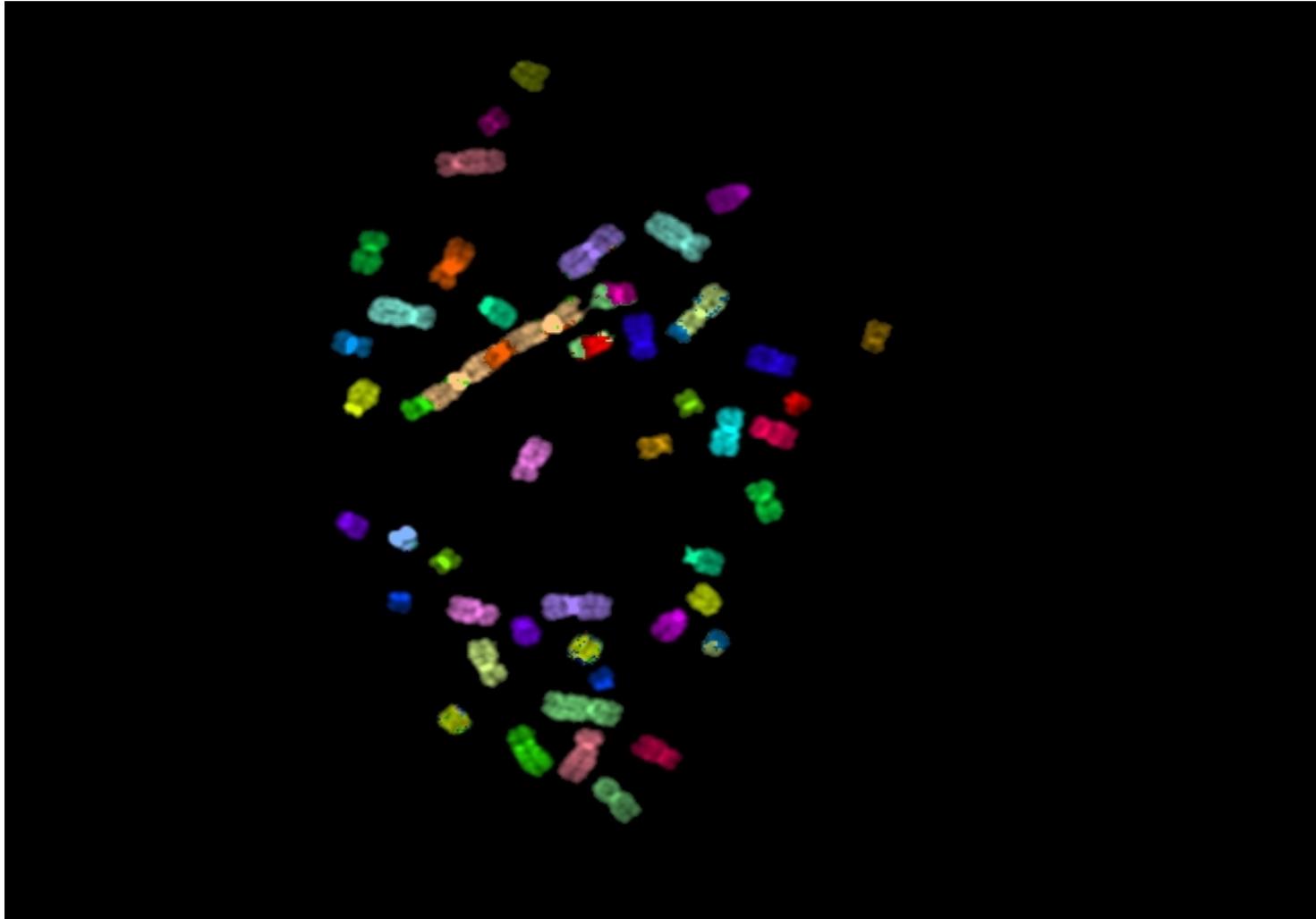


HZE Ions are Distinct from Terrestrial High-LET Radiation (Iron and alpha particle at LET = 150 keV/micron)



Multicolor FISH of Lymphocytes

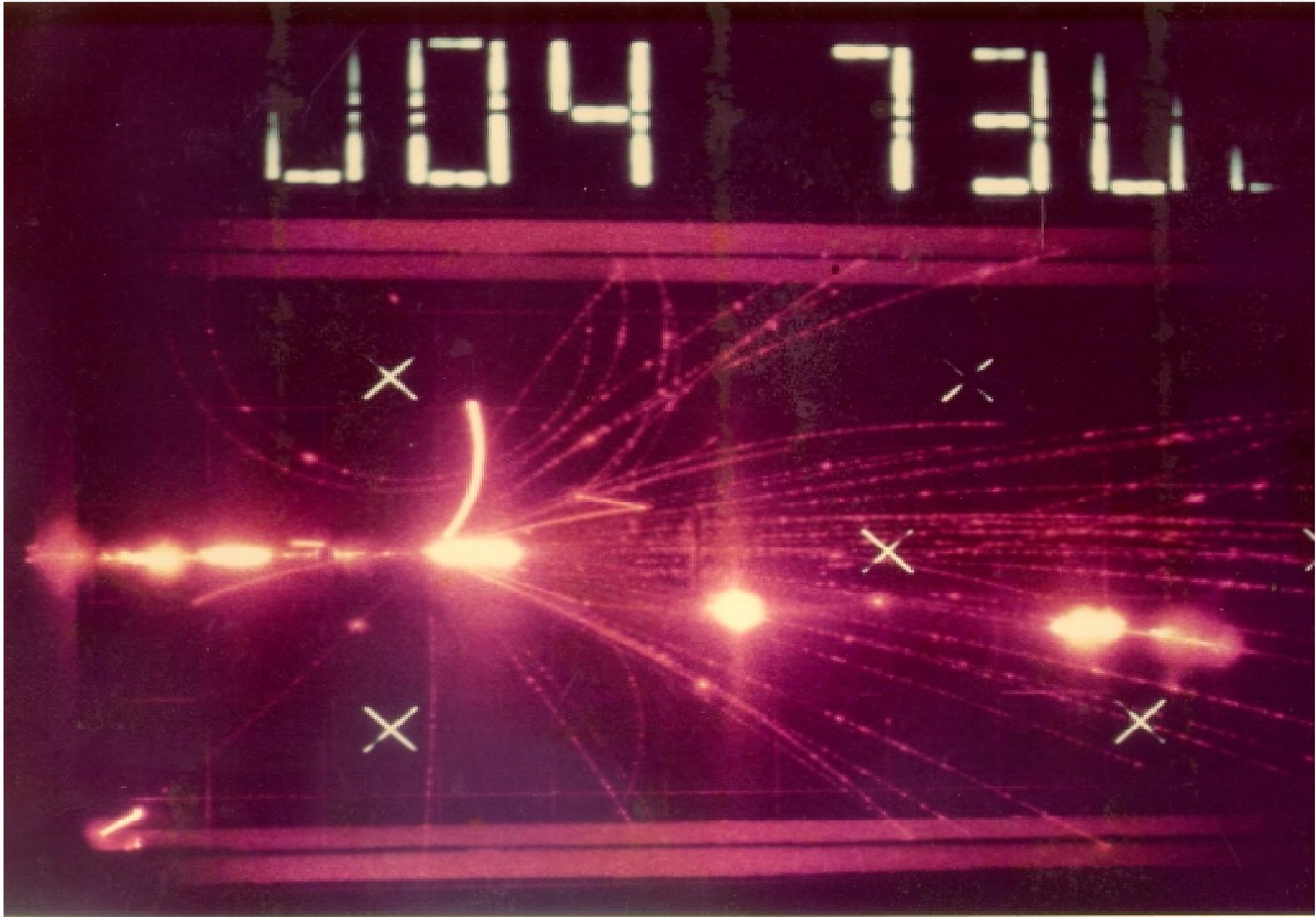
Exposed to 0.3 Gy Fe Ions (1 GeV/u)



Nuclear Reaction Events and Tissue Damage

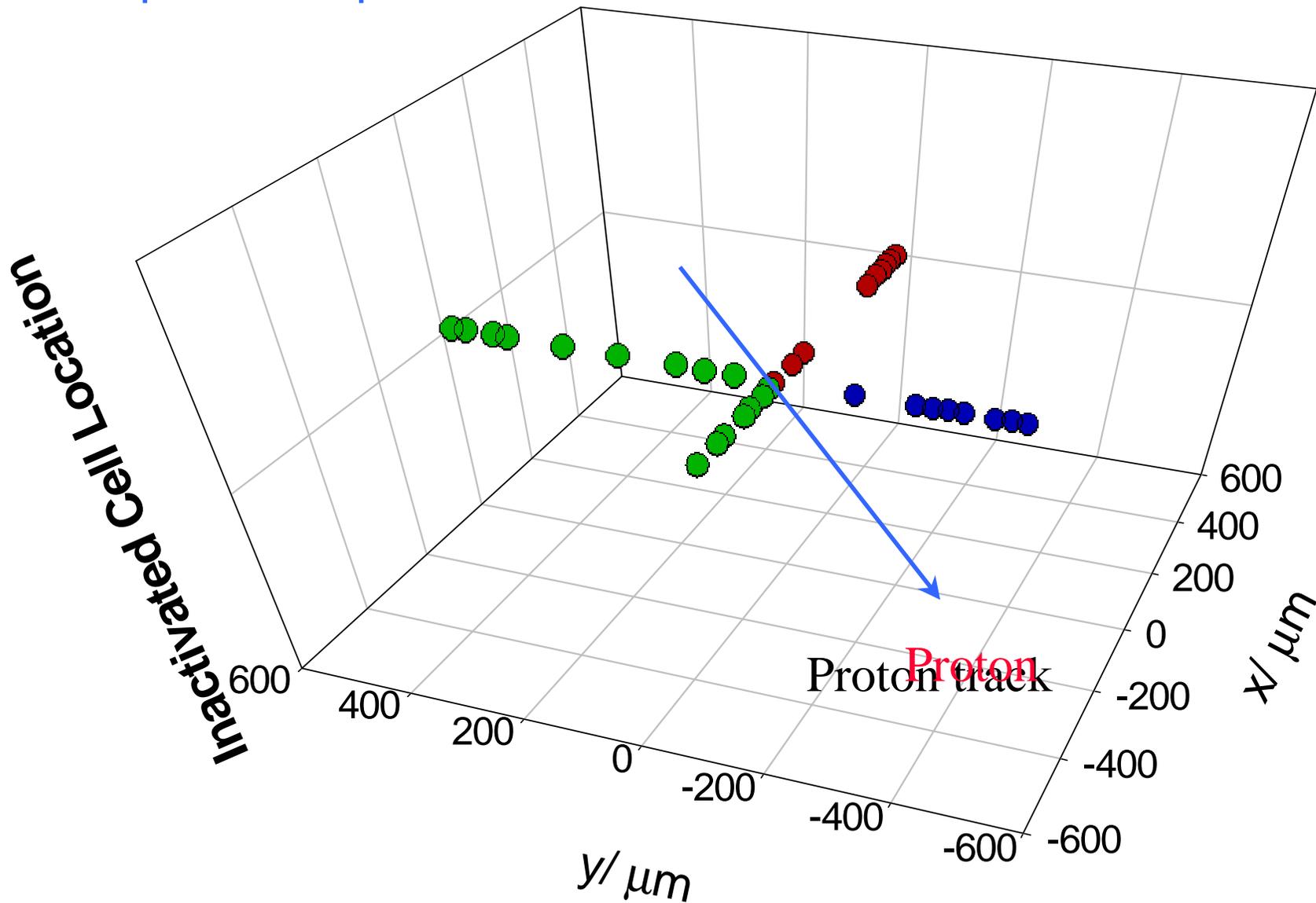
- **Event frequency:**
 - Increases with projectile mass ($A_p^{1/3}$)
- **Event Multiplicity's (M)= No. of ions produced:**
 - M = 3-6 for proton and neutron events
 - M = 3-20 for Heavy ion events
- **Energy deposition in Events**
 - Up to several MeV deposited within a few cell layers with isotropic production of tissue fragments
 - Events may be suppressed for large primary dose
 - Are importance of events apparent using cell culture models?

Streamer Chamber Photograph Showing Nuclear Reaction

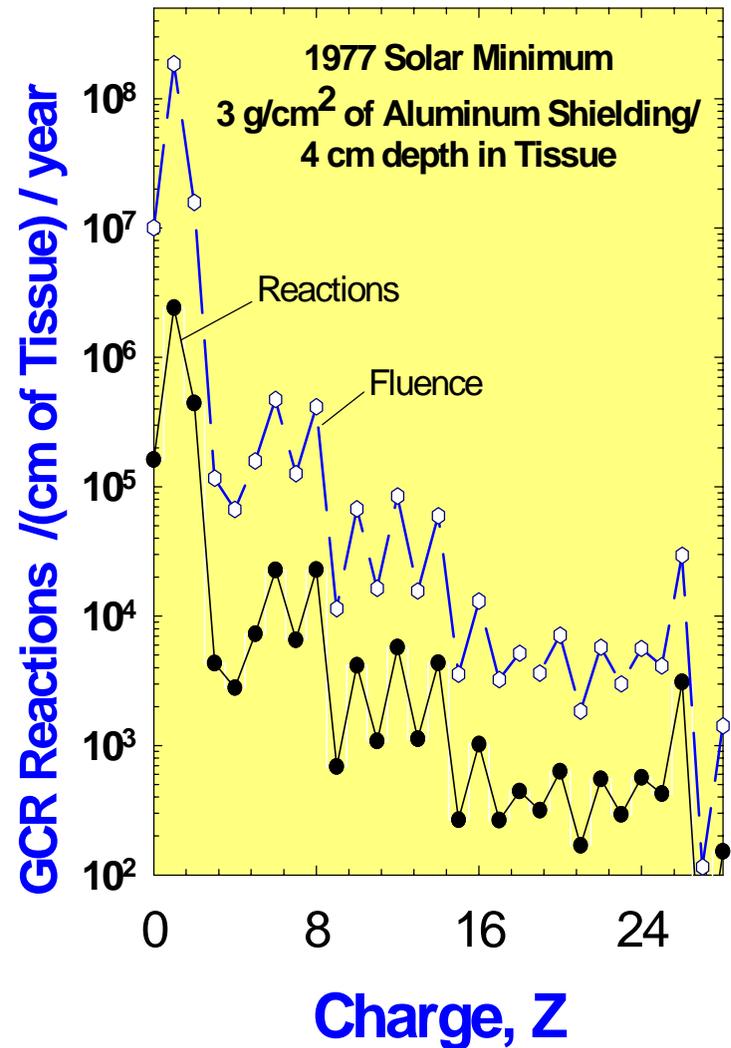
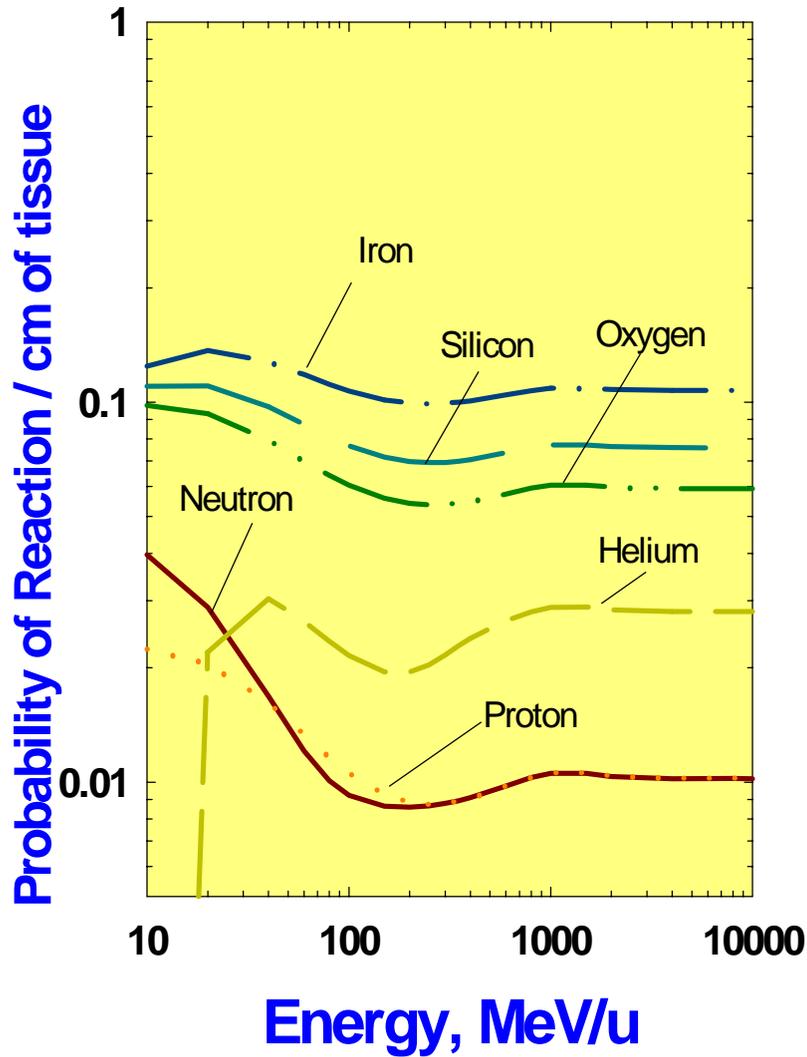


High Dose Events with Low LET Protons

$p + {}^{16}\text{O}$ to $p + 4\alpha$



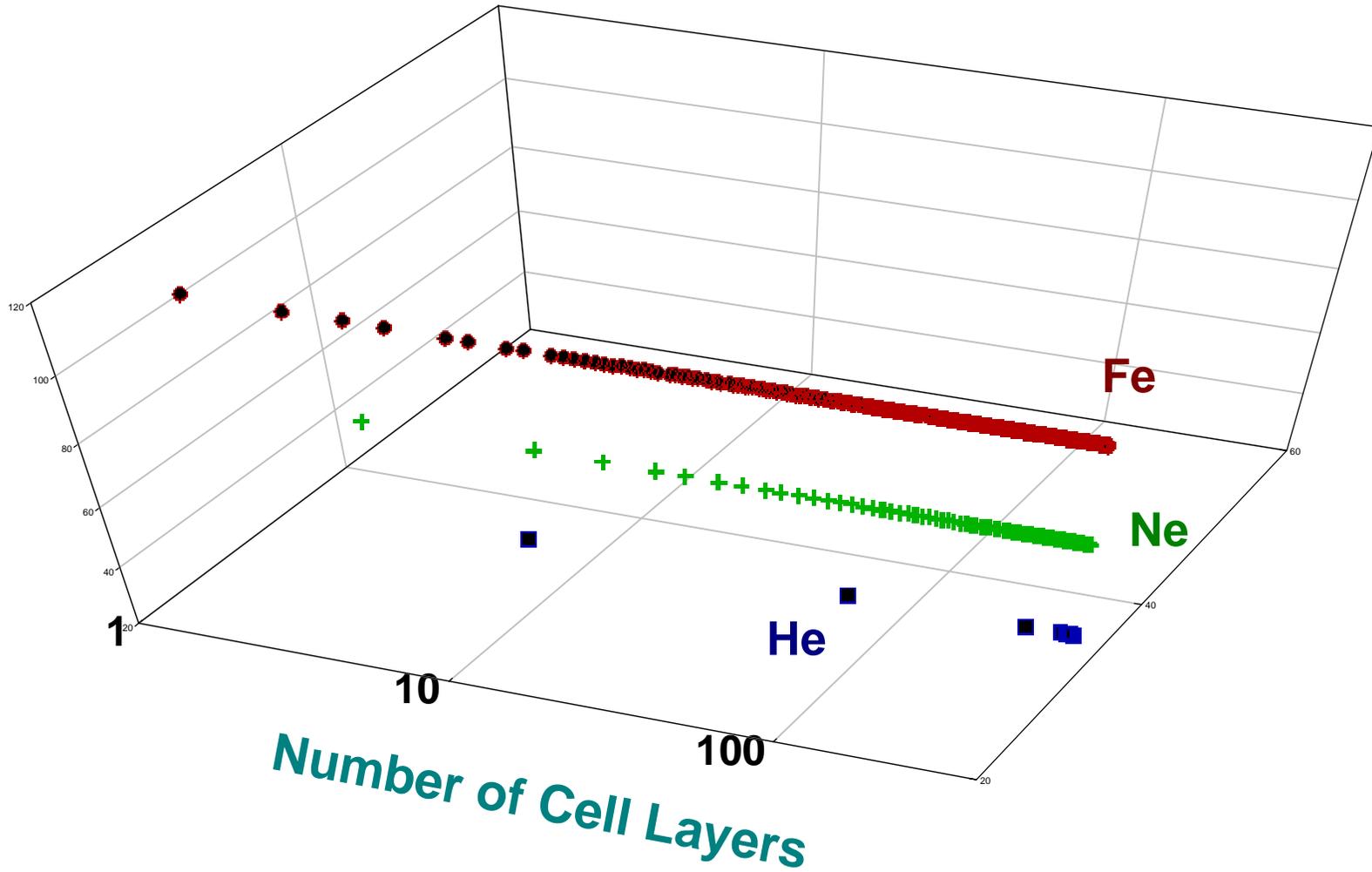
Number of Nuclear Reactions from GCR in Tissue



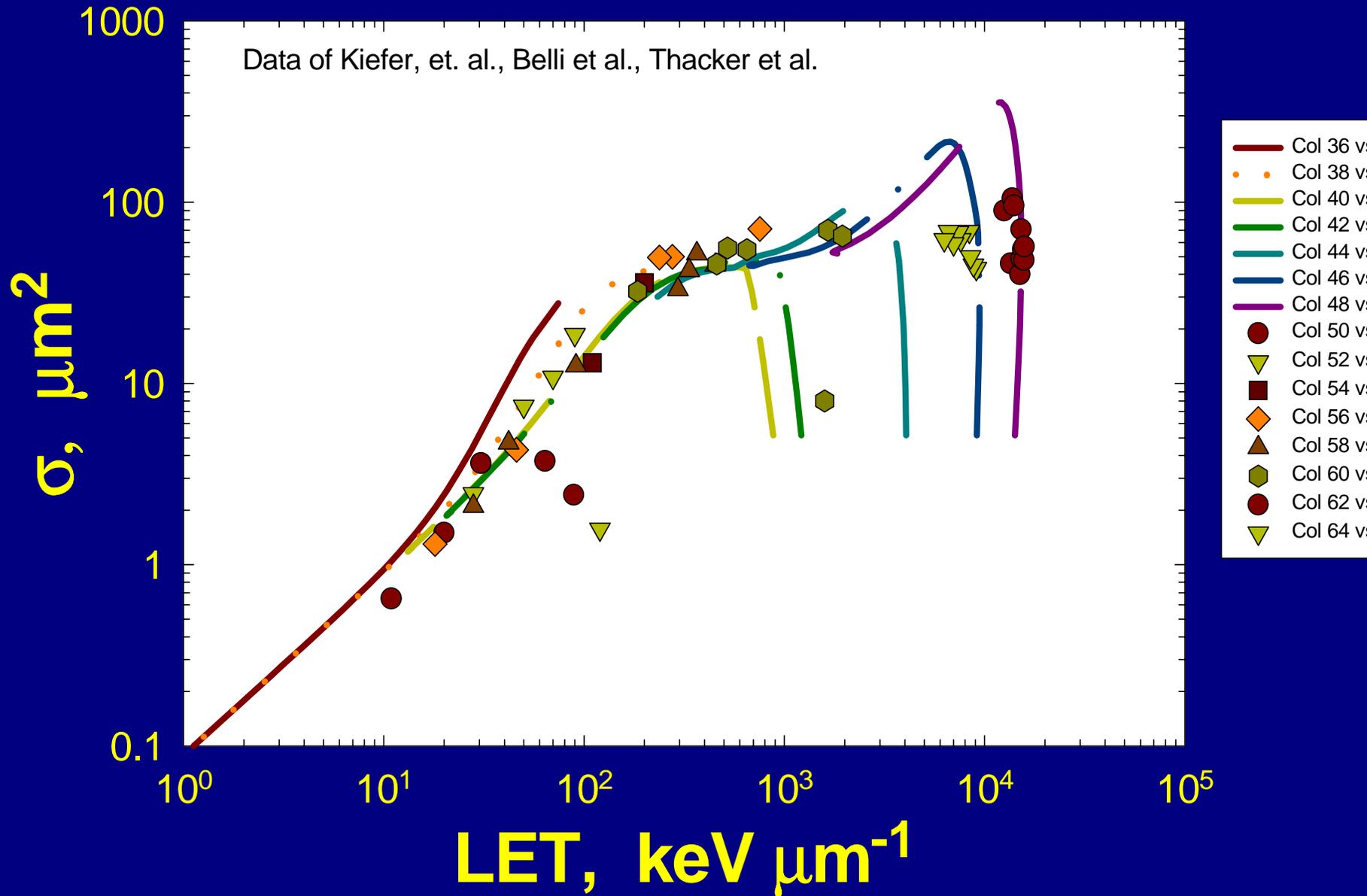
Possible Late Effects in the CNS

- Damage to terminally differentiated cells in the CNS were noted as a particular concern by NAS (1970, 1973, and 1996) for Space explorations as well as by Todd, and Lett et al.
- Concern was prompted by observation of light flashes by astronauts on Apollo and Skylab (continues today)
 - **Can the destruction of a small number of un-replaceable cells lead to deterministic effects in the CNS?**
- Effects observed in Cancer Patients treated with radiation for brain tumors (25-70 Gy in 1-2 Gy fractions) include loss of IQ, dementia, and loss in motor function
- Effects observed in animal models with low to moderate doses of heavy ions:
 - **Accelerated aging (Rabin and Joseph)**
 - **Late degradation of DNA (Williams and Lett)**
 - **Altered motor function and taste aversion (Phillpott, Joseph and Rabin)**
 - **Altered Dopamine expression (Joseph and Rabin)**
- Are their initial cellular and tissue effects possible by heavy ions and protons that are not possible with low to moderate doses of X-rays?

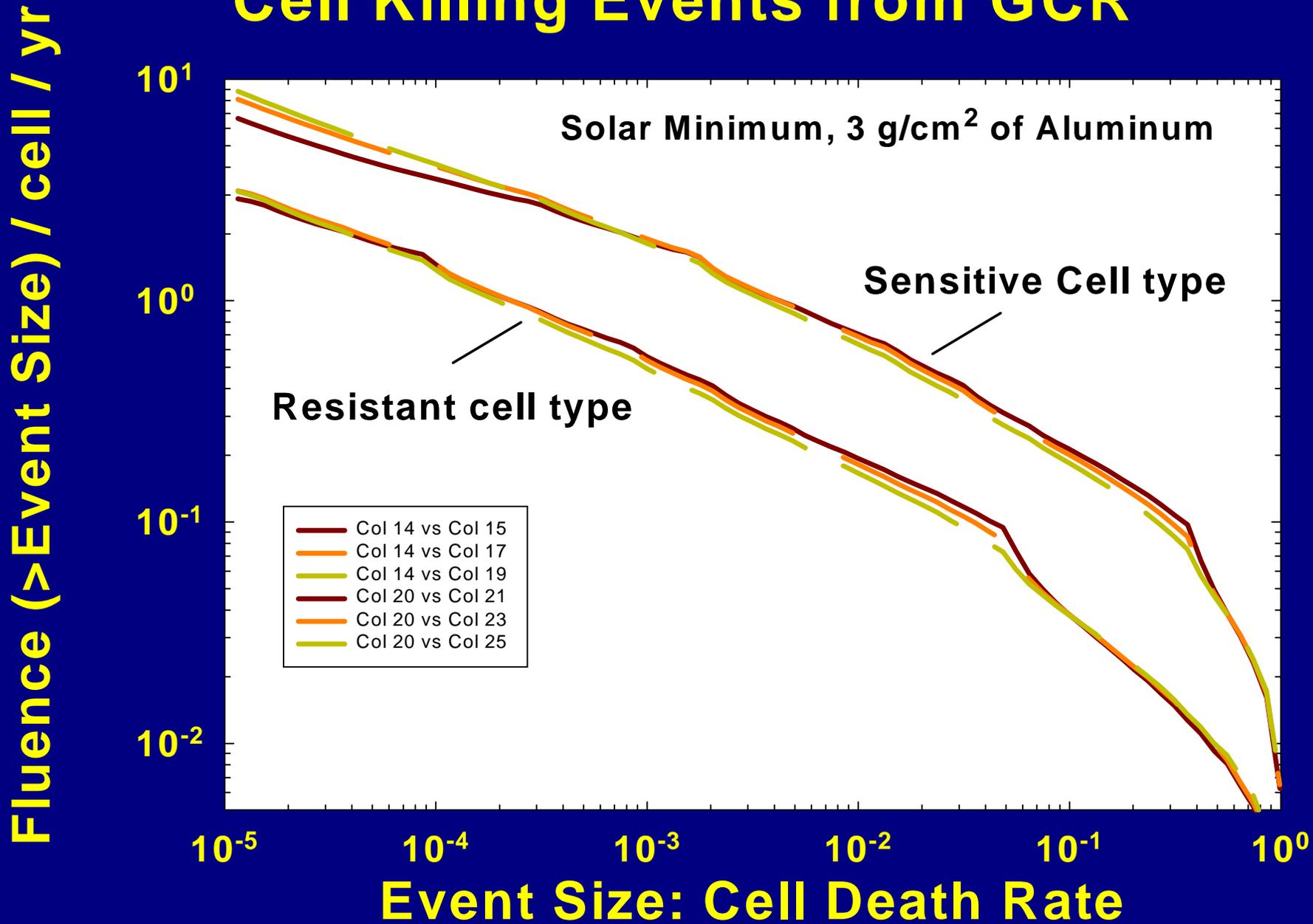
Micro-lesions in Tissue: Location of Inactivated Cells for Ions with Range of 1 cm (Monte-Carlo simulations)



Cell Inactivation Final Slope Cross Sections



Cell Killing Events from GCR



Nominal Mission Doses

Solar minimum- nominal shielding
Low density Mars Atmosphere

	Dose	Eq. Dose	% Probability of
	(rad)	(rem)	Microlesion / cell
ISS (120 d)	6	13	0.3
Deep Space (120 d)	7	30	1.3
Lunar Base (120 d)	4	19	0.8
Mars Surface (120 d)	5	21	0.6
Mars Mission (1000 d)	35	150	6.7