Assessment of Radiation Exposure of Astronauts in Space

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ICRP Committee 2

Assessment of Radiation Exposure of Astronauts in Space

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Assessment of radiation exposure of astronauts in space

Special situation for astronauts in space

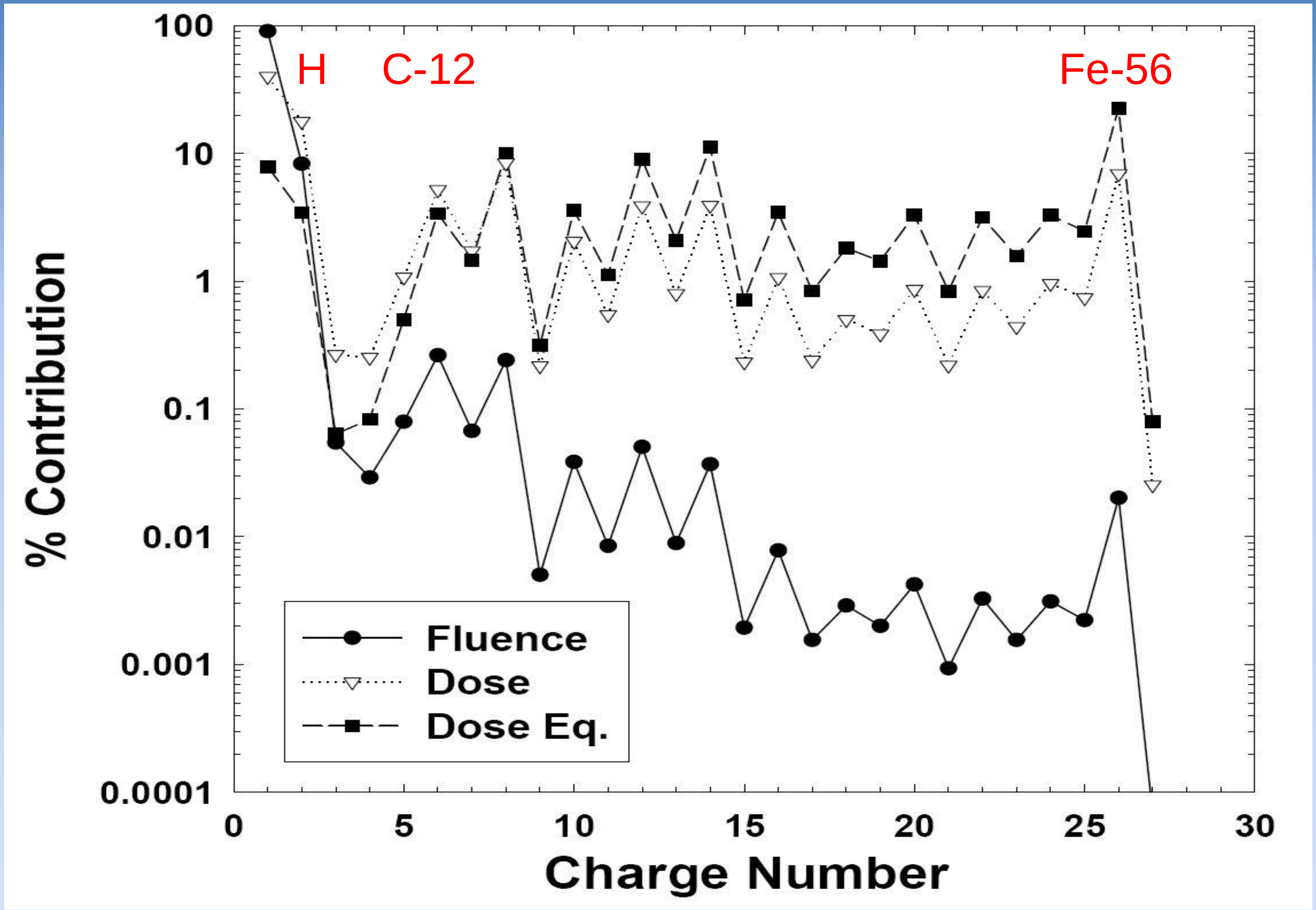
- extraordinary radiation field (high energies etc.)
- specific environment with limited protection possibilities
- only external radiation exposure
- few number of astronauts are involved only
- but high doses during missions (0.4 - 0.7 mSv/d)
- strong interest in risk values of detriment
- risk of deterministic effects

Assessment of radiation exposure of astronauts in space

Components of the radiation field in space

- galactic cosmic radiation (GCR)
  (protons, α-particles, heavy ions)
- solar cosmic particles
  (low energy electrons and protons)
- solar particle events (SPE)
  (electrons, protons, photons)
- earth albedo
  (electrons, protons, neutrons)
- secondary radiation in a spacecraft
  (photons, electrons, neutrons, charged particles)

Relative ion distribution of the galactic cosmic radiation (GCR)



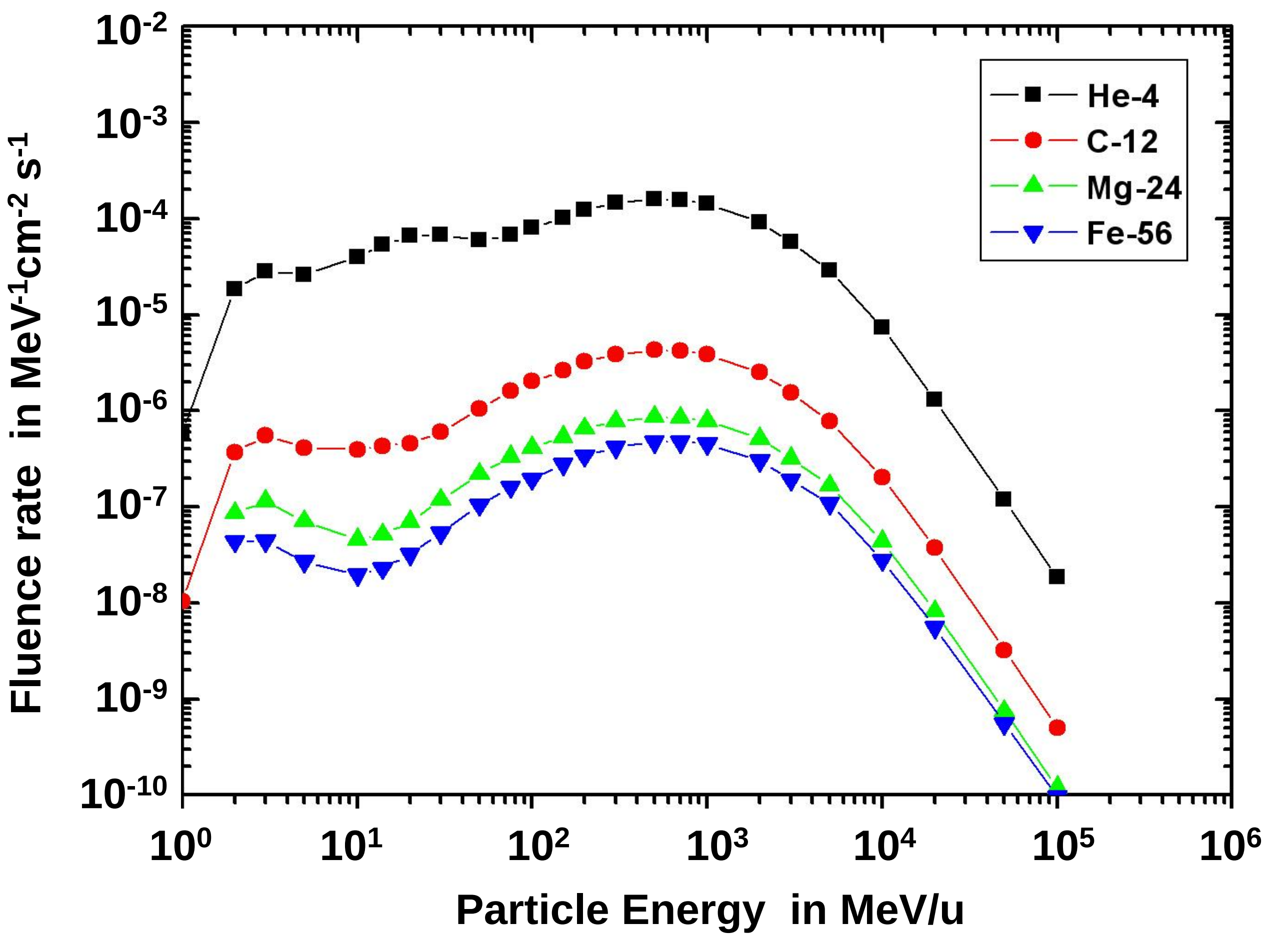
(Cucinotta et al., 2001)

Number of tracks for the same absorbed dose in soft tissue

Protons	1000
C-12	≈ 13
Fe-56	≈ 1.3

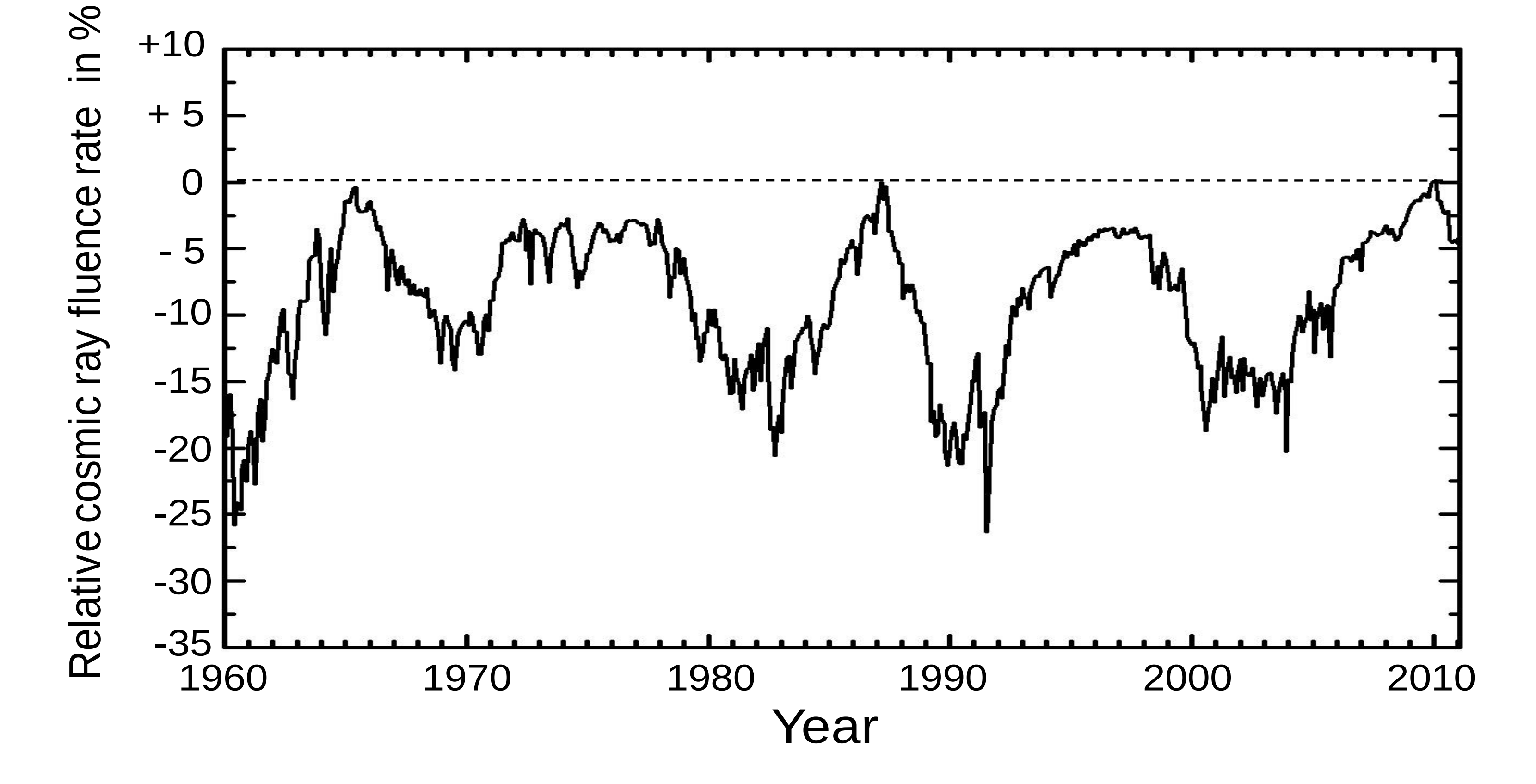
Mean absorbed dose, D_T ?

GCR fluence spectra at 380 km height
(calculated with creme96/creme03)



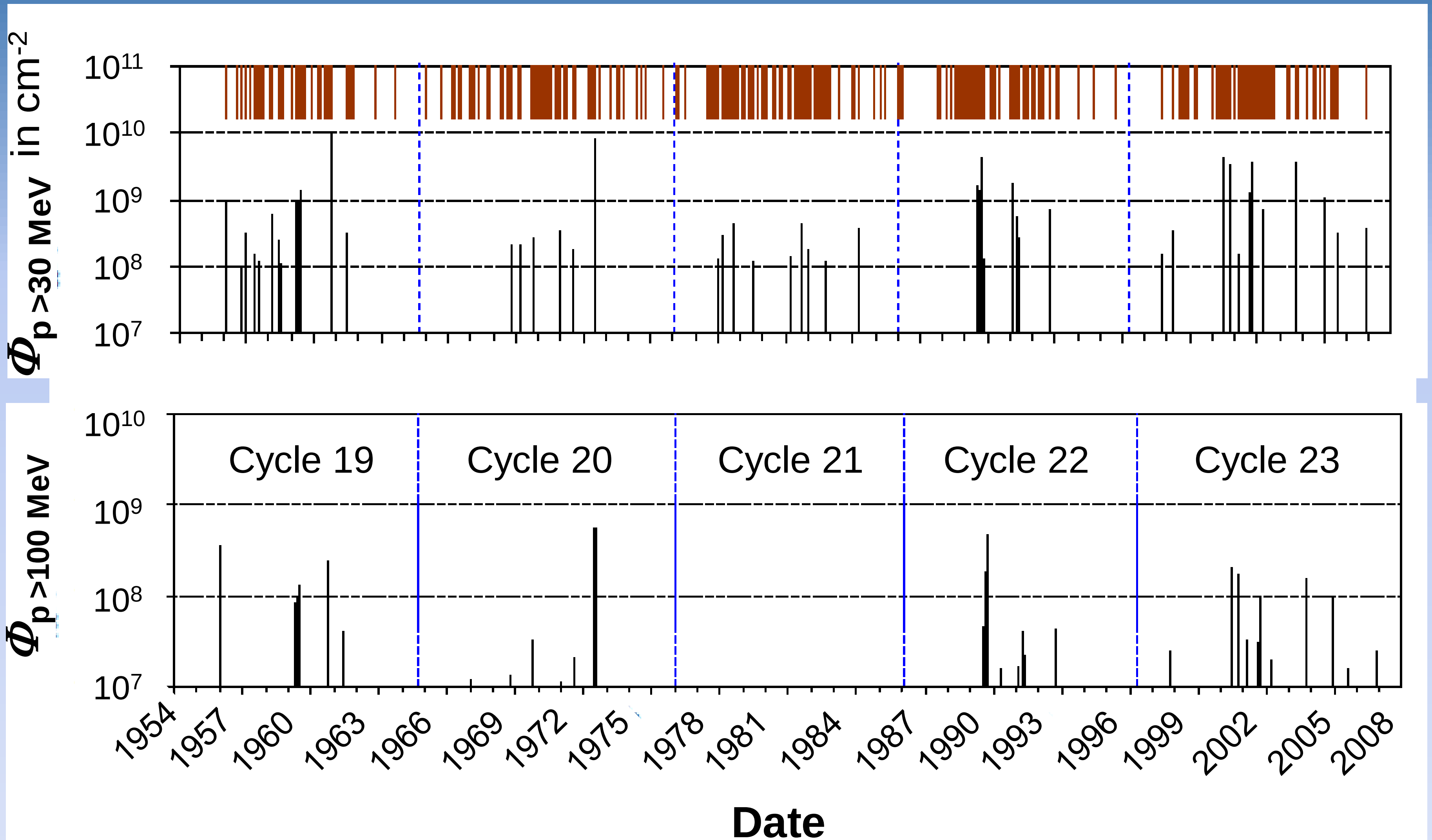
(Sato et al., 2010)

Relative cosmic ray fluence rate variation with time
In the solar cycle of the heliocentric potential



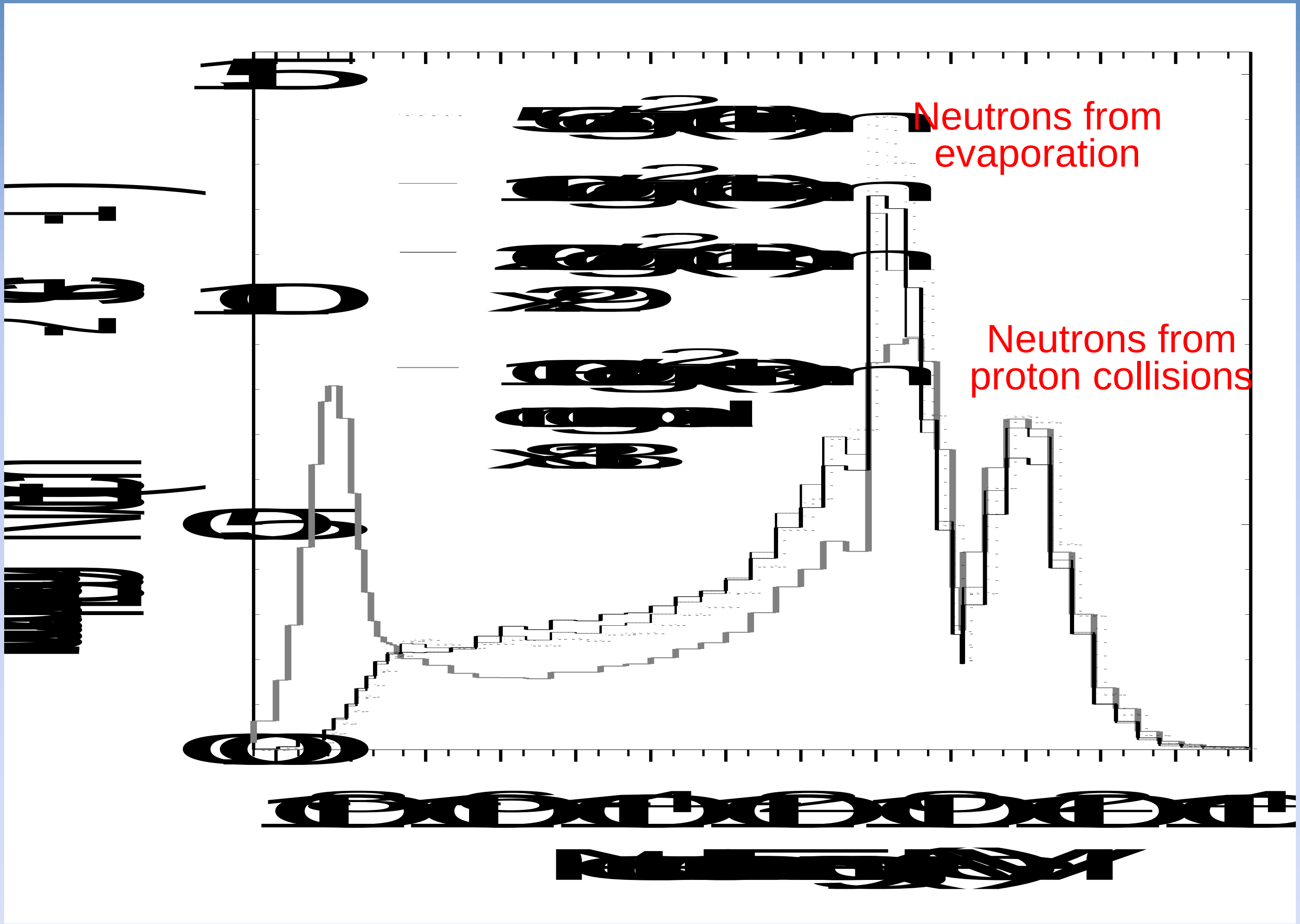
(http://www.nmdb.eu/?q=node/138)

Integral proton fluence (E_p > 30 MeV, 100 MeV) of various solar particle events



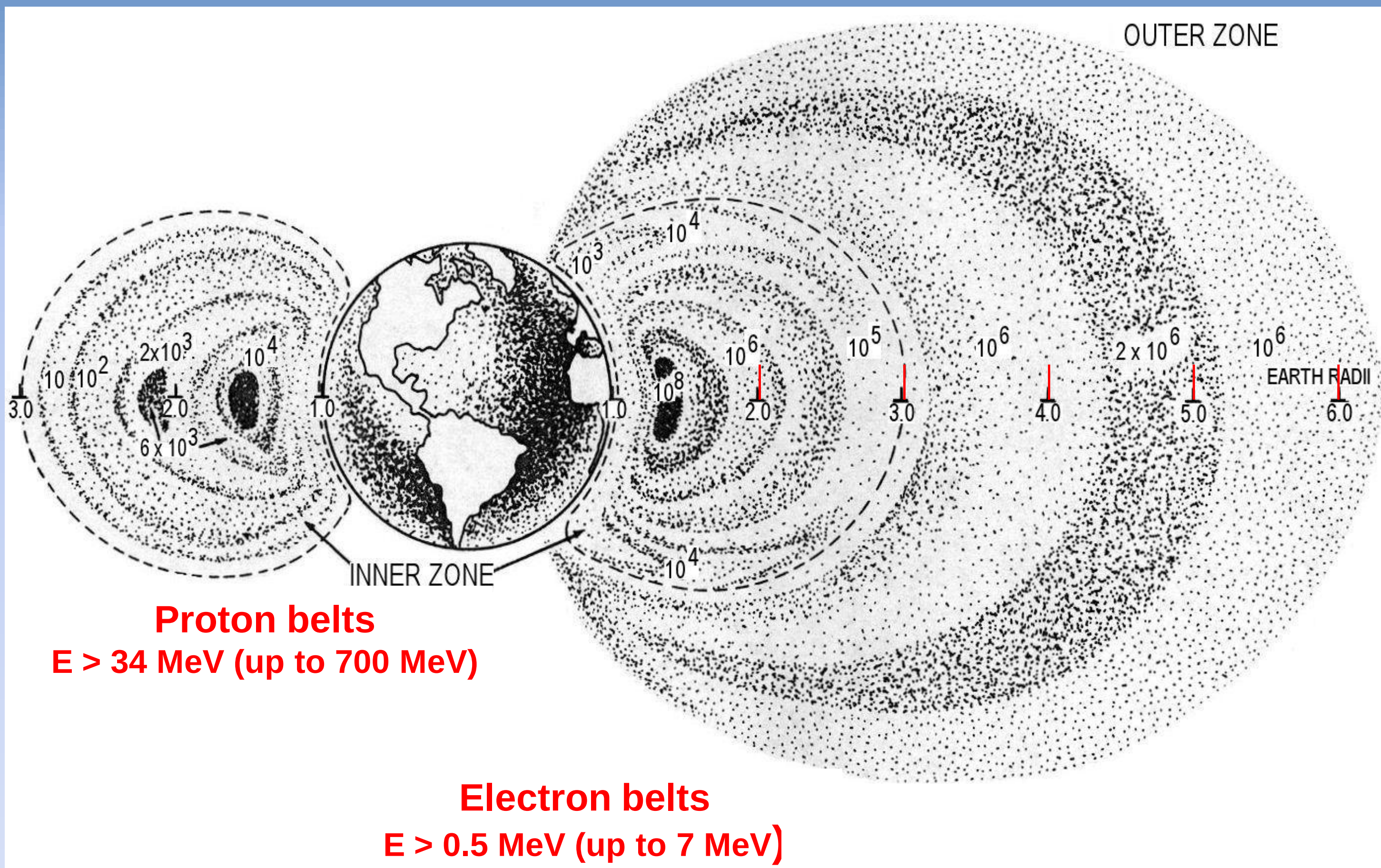
(Myung-Hee et al., 2011)

Neutron spectra measured with Bonner sphere spectrometer at different heights above ground



(Goldhagen al., 2002)

Particles fluence rates in trapped radiation zones – protons > 34 MeV and electrons > 0.5 MeV –



Mean weighted absorbed dose in an organ or tissue

Equivalent dose in an organ or tissue (ICRP 103)

A single w_R-value for each particle type except neutrons

$$H_T^M = w_R \cdot D_T^M \qquad H_T^F = w_R \cdot D_T^F$$

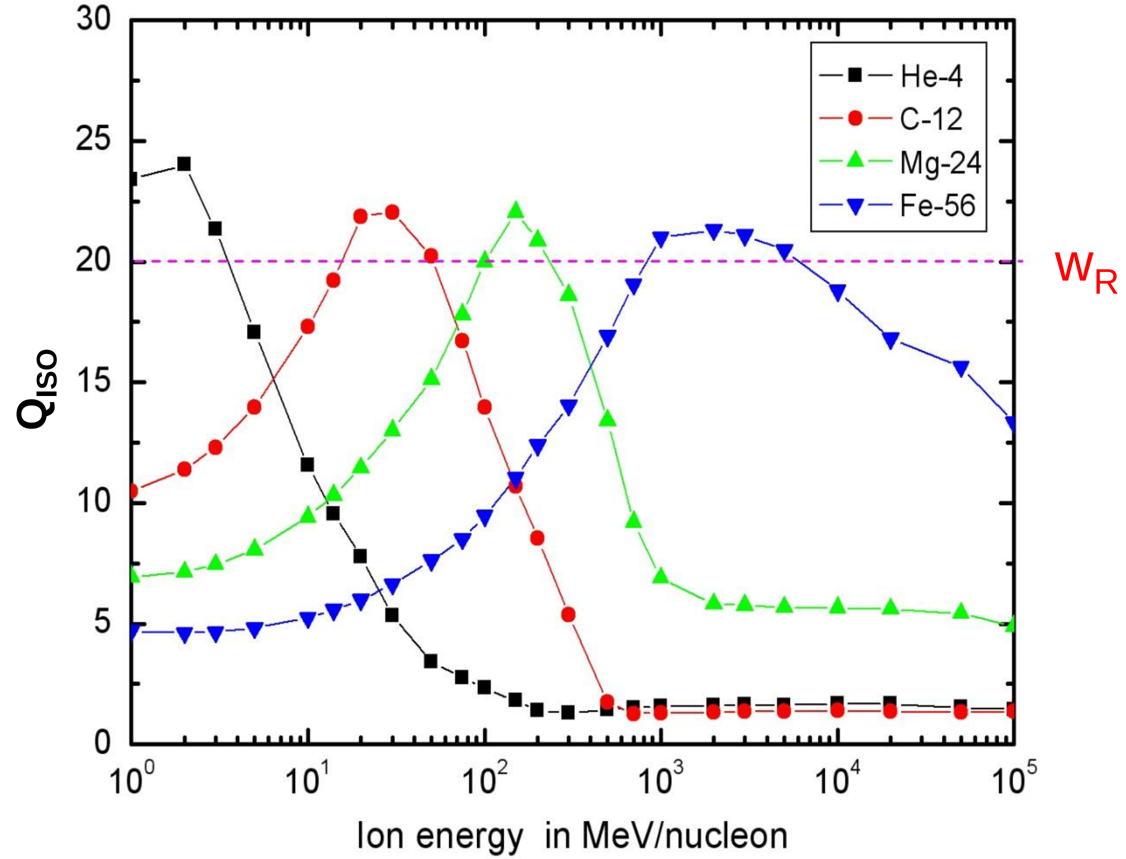
Organ dose equivalent (ESA, NASA, …; NCRP)

$$\overline{H}_T^M = \overline{Q}_T \cdot D_T^M = \frac{1}{m^M} \int_m \int_L Q(L) \cdot D(L) \mathrm{d}L \mathrm{d}m$$

$$\overline{H}_T^F = \overline{Q}_T \cdot D_T^F = \frac{1}{m^F} \int_m \int_L Q(L) \cdot D(L) \mathrm{d}L \mathrm{d}m$$

$$\overline{H}_T \approx H_T \quad ??? \quad E = 0.5 \cdot (H_T^M + H_T^F)$$

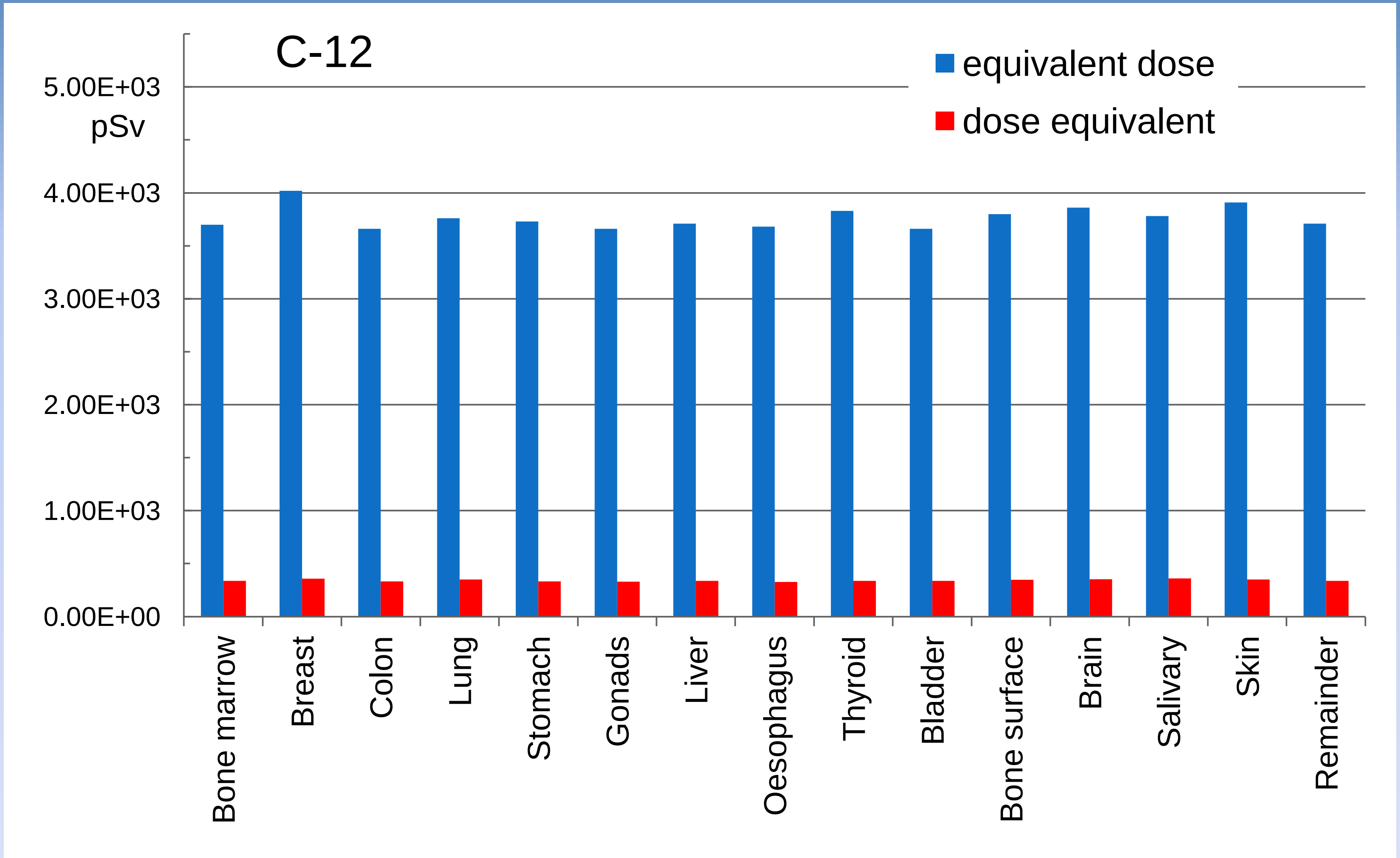
Human body averaged mean quality factors , Q_{ISO} for ISO exposure to GCR (data from Sato et al., 2009)



$$Q_{\mathrm{ISO}} = \frac{\sum_{\mathrm{T}} w_{\mathrm{T}} Q_{\mathrm{T}} D_{\mathrm{T}}}{\sum_{\mathrm{T}} w_{\mathrm{T}} D_{\mathrm{T}}}$$

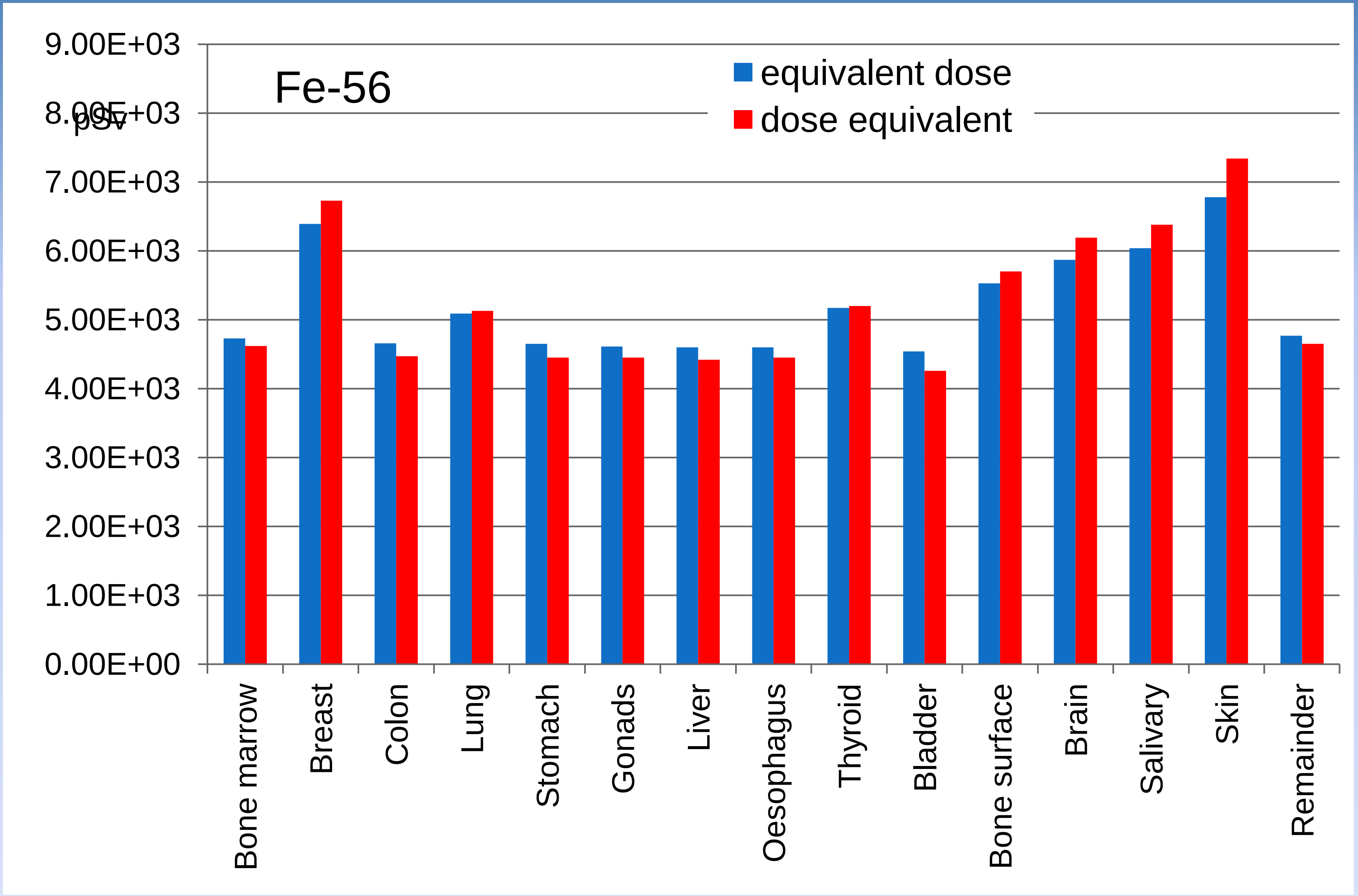
(Sato et al., 2010)

Equivalent dose and organ dose equivalent from the GCR C-12 component (ISO exposure)



(Sato et al., 2010)

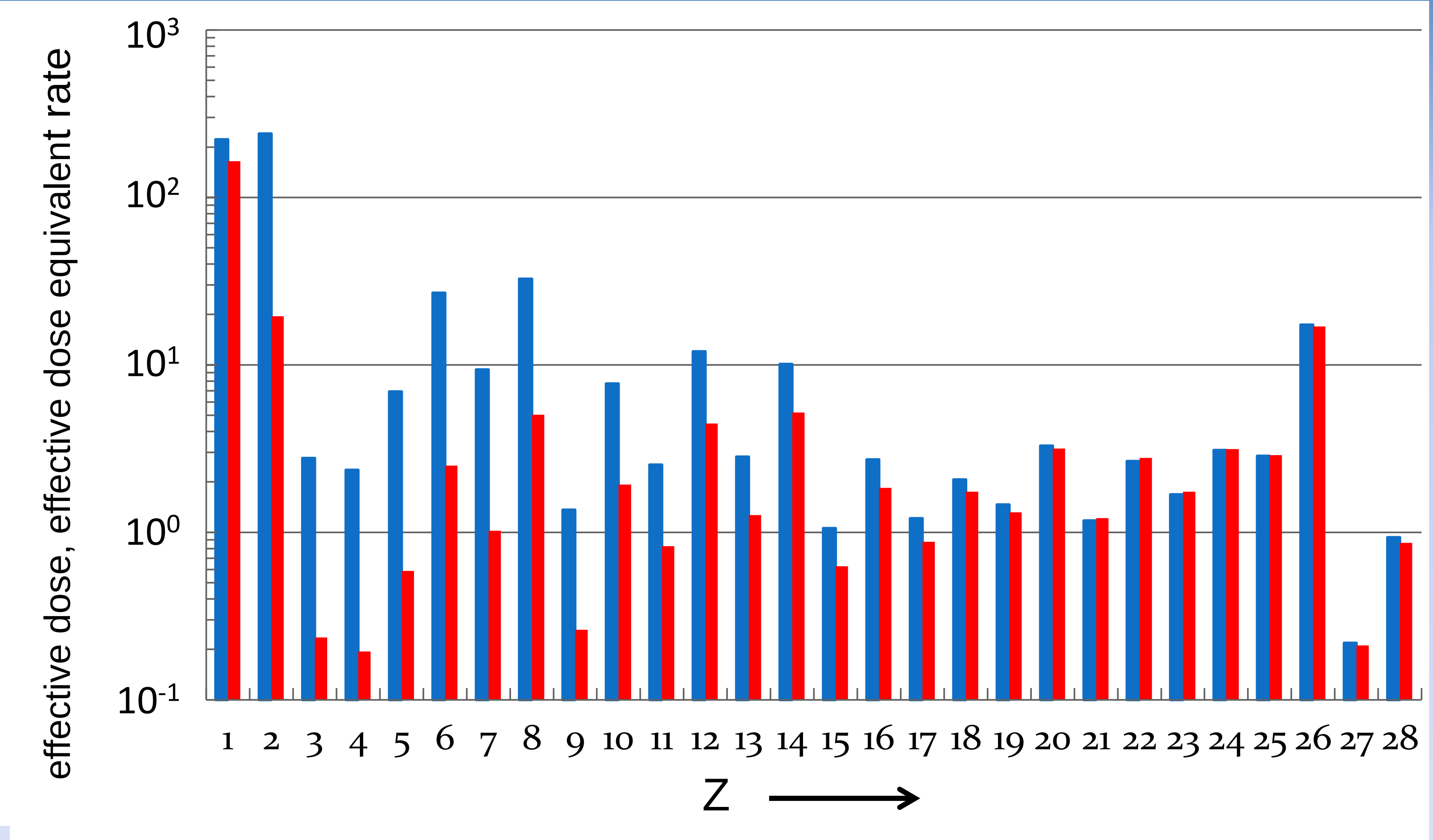
Equivalent dose and organ dose equivalent from the GCR Fe-56 component (ISO exposure)



(Sato et al., 2010)

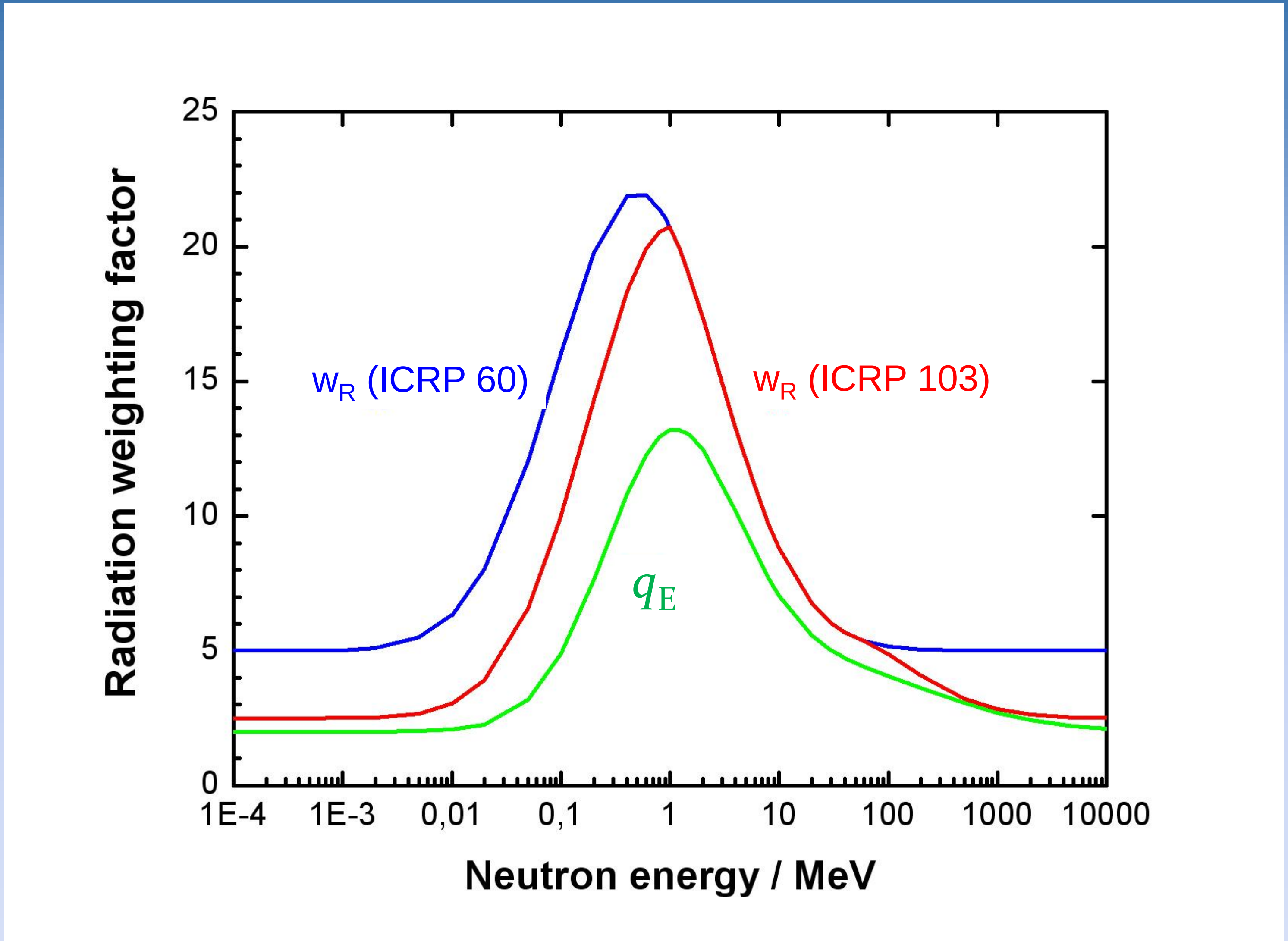
Effective dose and effective dose equivalent rate for ISO exposure to galactic cosmic radiation (GCR)

(data from Sato et al., 2009)



(Sato et al., 2010)

Radiation weighting for neutrons



(Sato et al., 2009)

Assessment of radiation exposure of astronauts in space

Measurements

Area monitoring (inside and outside of a space vehicle)
provide information about the radiation field
provide monitoring and warning capabilities

Individual monitoring
assessment of organ and tissue doses
and effective dose equivalent

Biodosimetry
investigation of lymphocytes in blood samples
(problem of individual response and background)

Area monitoring in space

Area monitoring: particle spectra, fluence rates, LET distributions

development of special instrumentation for use in space, but mostly using concepts also applied in dosimetry on Earth.

Active devices can provide real-time access and warning capabilities

- Tissue-equivalent proportional counters
  D, *D*(*L*), LET-distributions., mean *Q*, *H*
  *(*for all types of particles*)*
- Semiconductor devices
  Silicon diodes, multi-detector telescopes
  charged particle energies and charges,
  LET-values and doses,
  directions of radiation incidence
- Specific electron detectors (for electrons < 1 MeV)

Individual monitoring in space

Individual monitoring: assessment of individual exposure (risk assesment) and doses for the records

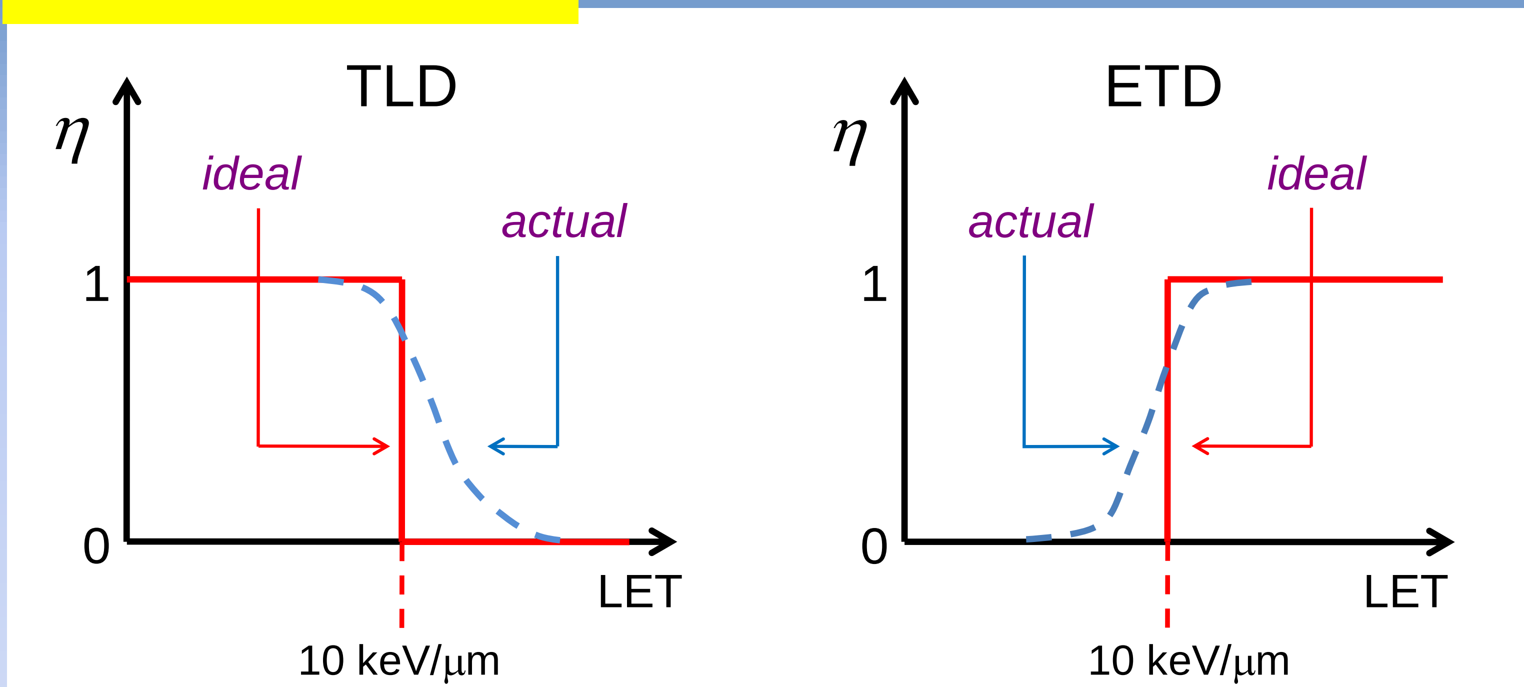
special devices measuring dose, LET, particle charges or specific particles only.

Active devices usually develloped for electron, photon and neutron fields can provide real-time access and warning capabilities

- Tissue-equivalent proportional counters (*D*, *D*, LET-distr., mean *Q*, *H*) (for all types of particles)
- Thermoluminescence and optically stimulated luminescence detectors
- Nuclear track detectors
- Superheated bubble detectors
- Combined detector systems

Combined detector system of thermoluminescence (TLD) and etched-track detector (ETD)

Detector response η



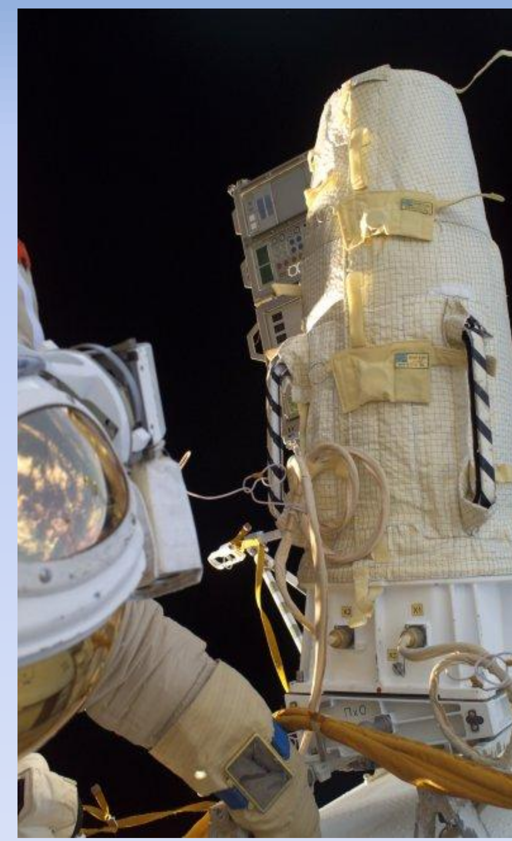
$$H = D_{\mathrm{TDL}} - \int_{L>10\ \mathrm{keV\mu m}} \eta_{\mathrm{TLD}} D_{\mathrm{TLD}}\, \mathrm{d}L + \int_{L>10\ \mathrm{keV\mu m}} D_{\mathrm{ETD}} Q(L)\, \mathrm{d}L - \int_{L<10\ \mathrm{keV\mu m}} \eta_{\mathrm{ETD}} D_{\mathrm{ETD}}\, \mathrm{d}L$$

Human Phantom - MATROSHKA

HAMLET Project
DLR
Deutsches Zentrum für Luft und Raumfahrt e.V.
G. Reitz

2004 -2010 Some Missions at the ISS

Phantom torso + Poncho + Container outside ISS in space



Biological dosimetry with astronauts

Mission doses of astronauts obtained by biological dosimetry and compared to results from measurements with individual dosemeters (TLD)

(Looking at total chromosomal exchanges, Cucinotta et al., 2008)

	Biolog. Dose, RBE·*D* in mGy		Individual dosem. reading	Skin dose equivalent	Effective dose equivalent
	Individual population based calibration		mGy	mSv	mSv
19 Astronauts	10 - 134	15 - 130	20 - 36	56 - 115	47 - 99
Mean value	85	81	28,9	83,8	71,9

While the mean values agree very well, the variation and discrepancies of individual doses are large.

Assessment of Radiation Exposure to Astronauts in Space

Conclusions (1)

- **The primary radiation field in space with many charged particle types and very high energies needs to be well known as a basis for a radiological protection concept and particle transport calculations.**
- **Depending on time and position in a spacecraft the radiation field varies considerably and needs active radiation monitoring.**
- **The relatively low number of astronauts involved in space missions and the risk of higher doses to be achieved needs a more individually based dose assessment than usual on Earth.**
- **For planning of missions in space individual risk assessment is as important as individual dose assessment which is needed for dose recording.**
- **The high contribution of various heavy ions to the exposure in space is not sufficiently reflected by applying a single radiation weighting factor $w_R = 20$**

Conclusions (2)

- An assessment of doses to astronauts in space needs both measurements with multidetector systems and radiation transport calculations.
- Specific instrumentation is needed for separately assessing the dose from low-penetrating radiation.
- If the dose component from low-penetrating radiation can be separately determined the measurement of the skin dose or dose near the surface of the body may be appropriate for the assessment of effective dose or organ doses.
- Missions outside of a spacecraft needs careful consideration of the low-energy electron and proton components for avoiding high exposures of the skin and the lens of the eye.

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