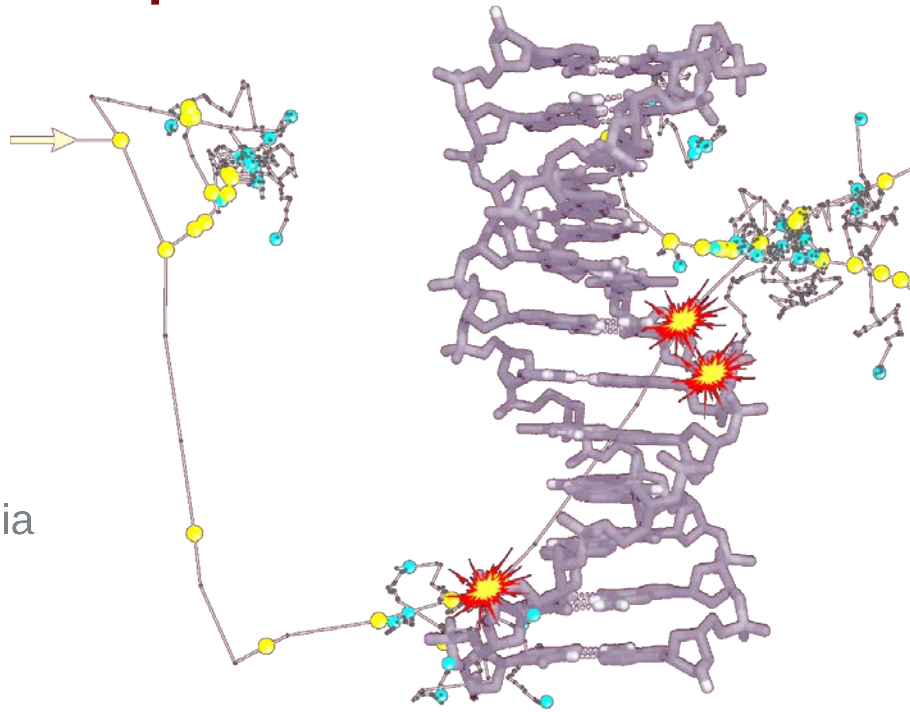
Application of Microdosimetry for Radiation Protection in Aviation and Space

Invited Lecture



Peter Beck

AIT Austrian Institute of Technology, Vienna

25 April 2012, RAD2012 Conference, NIŠ, Serbia

Content

- Basics of Microdosimetry
- Applications in Aviation and Space
- Outlook – What comes after?
- Conclusion

AIT Austrian Institute of Technology

- Largest non-university research institute in Austria
- SHAREHOLDERS
  - **50,46%** Republic Austria (Federal Ministry for Transport, Innovation and Technology, BMVIT)
  - **49,54%** Federation of Austrian Industries
- Employees
  - ~ 1.100 employees at 11 locations

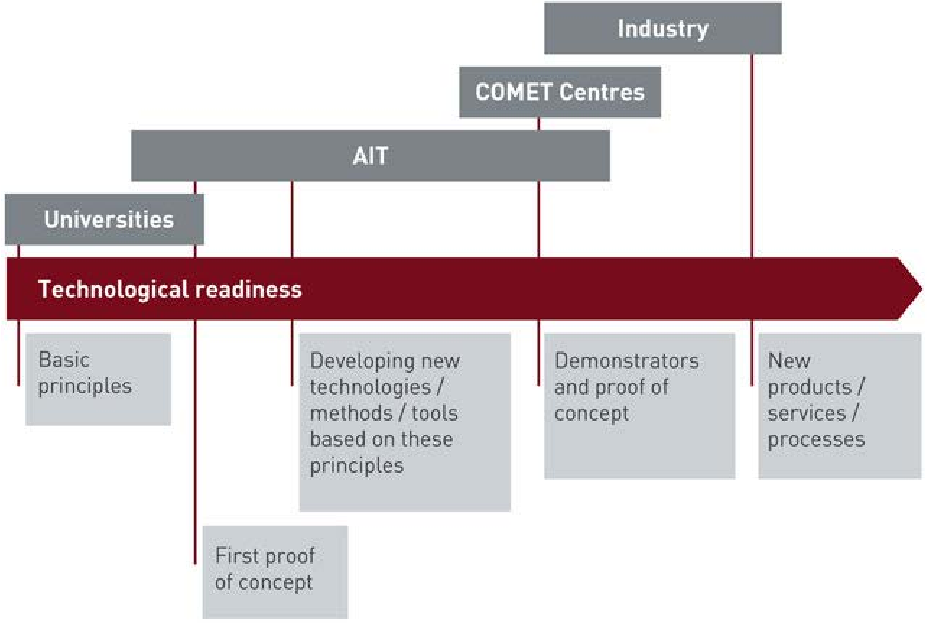
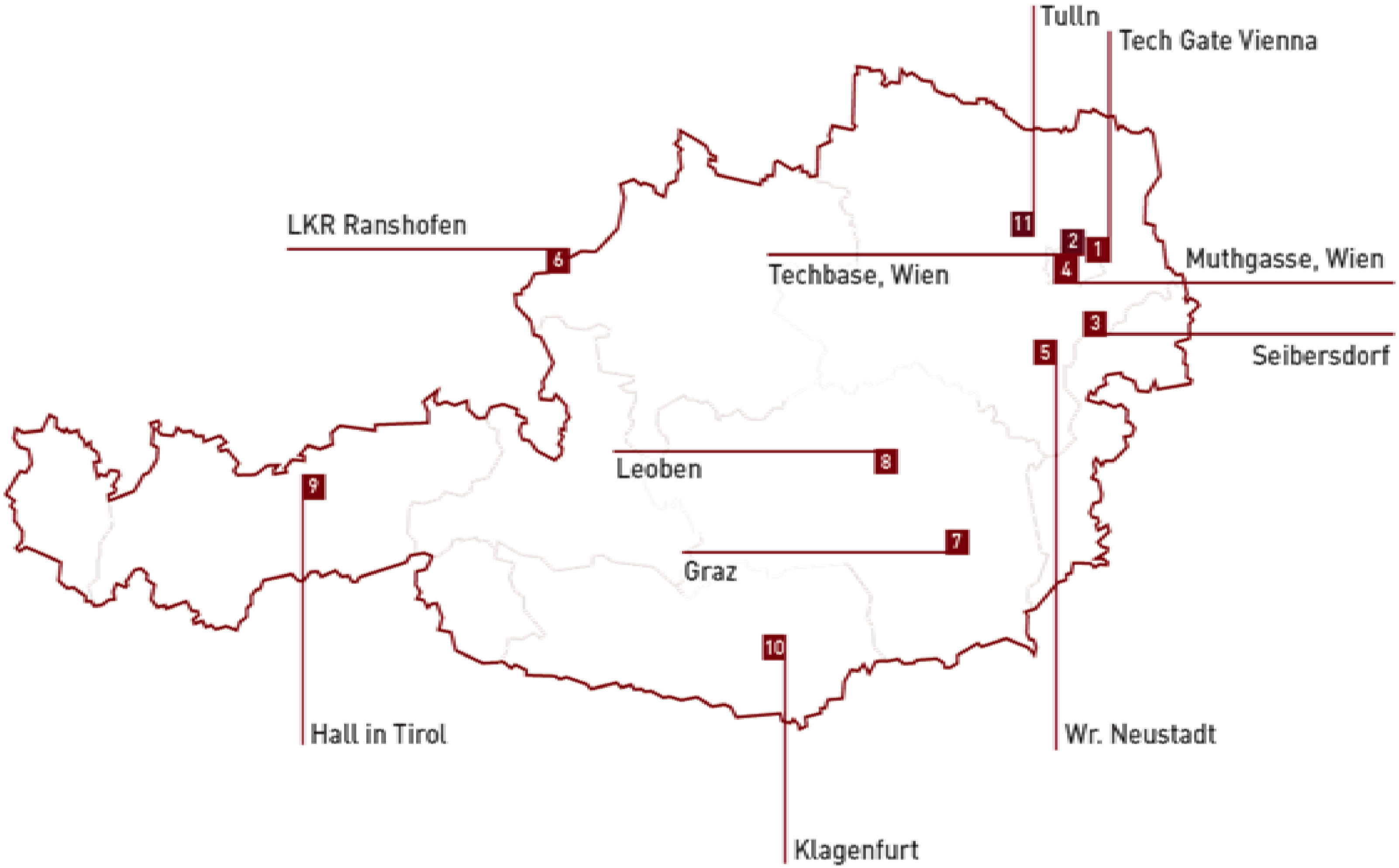


Figure 1: key players and their contributions in the Austrian innovation system

Ref: http://www.ait.ac.at

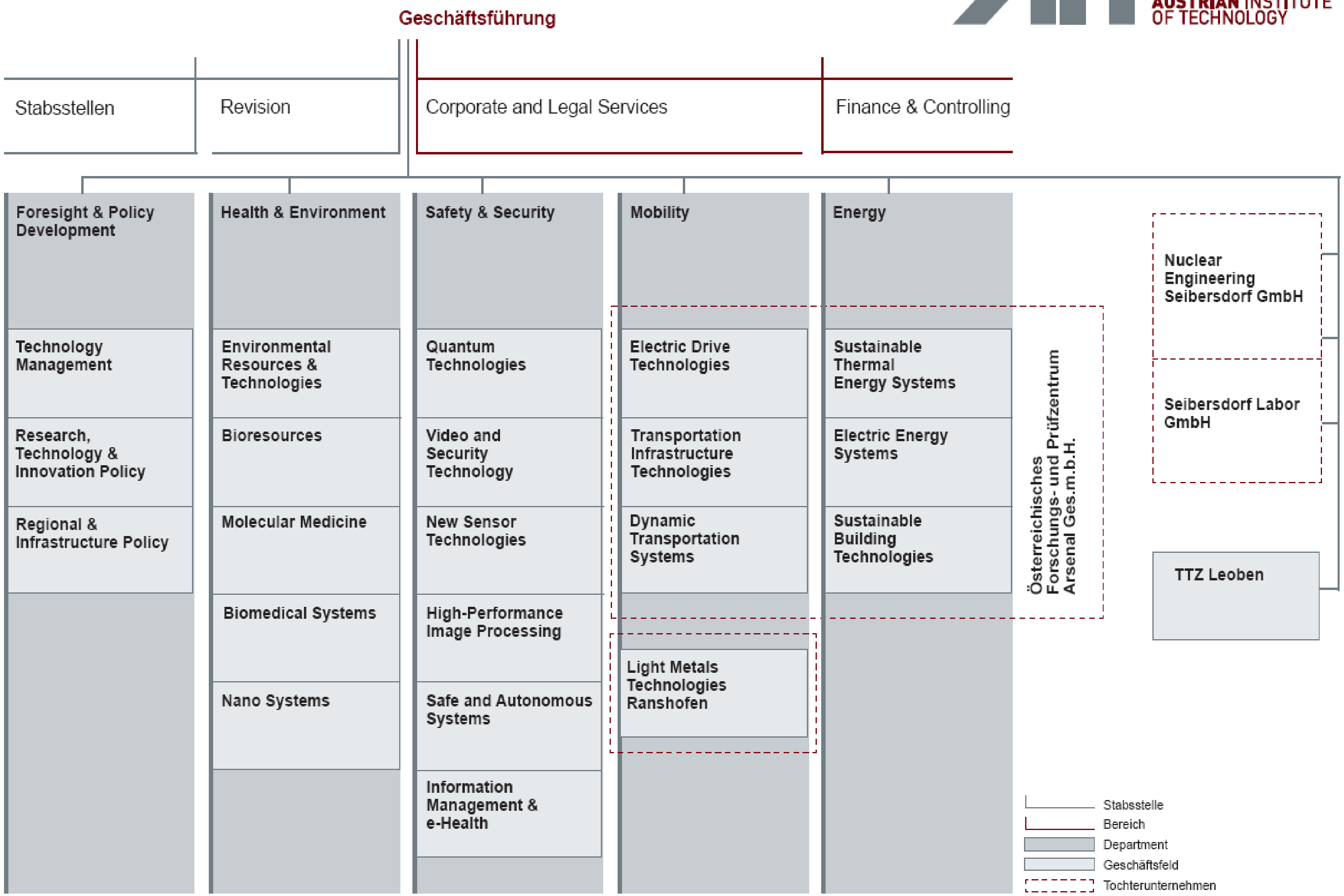
AIT Locations

AUSTRIAN INSTITUTE OF TECHNOLOGY



AIT-Organigramm

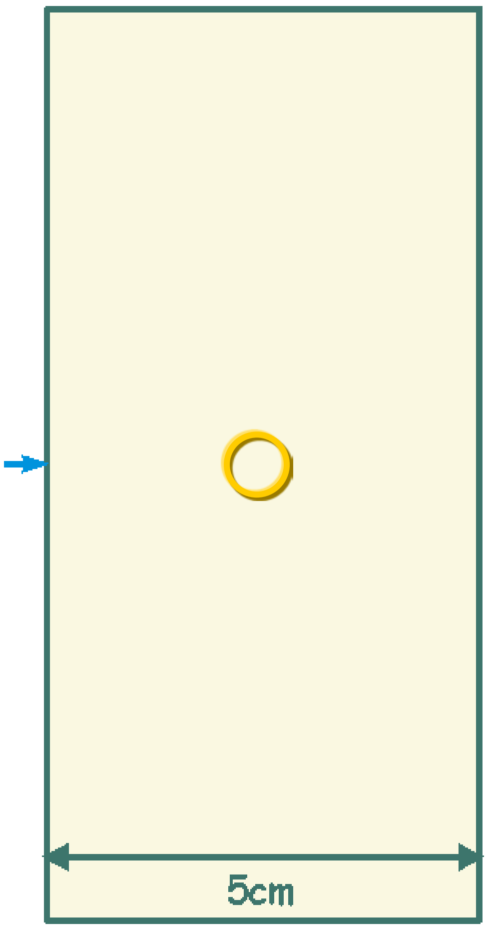
Stand: Februar 2011

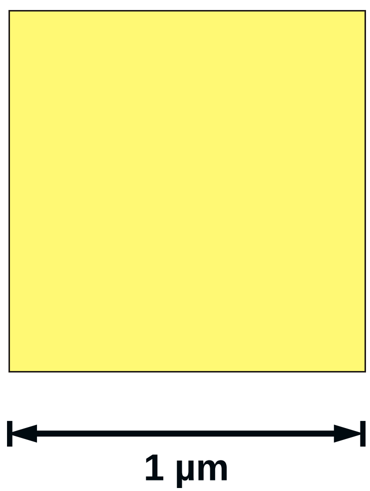


Basics of Microdosimetry

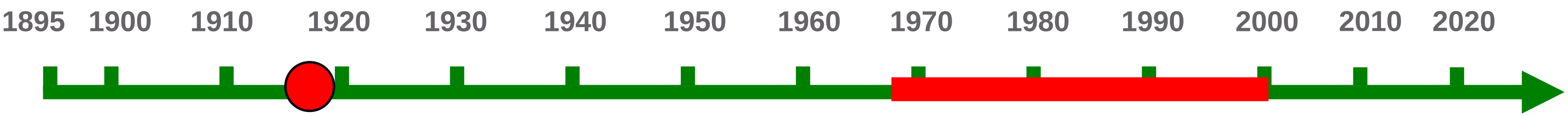
Conventional Dosimetry - Microdosimetry

100 keV photons in a water cube in cm and µm dimentions





- Ionizing radiation deposits energy in discrete packages
- Packages are distributed non-uniform throughout the irradiated volume
- Not only the average energy imparted (absorbed dose, *D*) is important, but
  - number of energy deposited
  - magnitude
  - spatial distribution (density)
- All these influences biological and other structures
- => RBE relative biological effectiveness



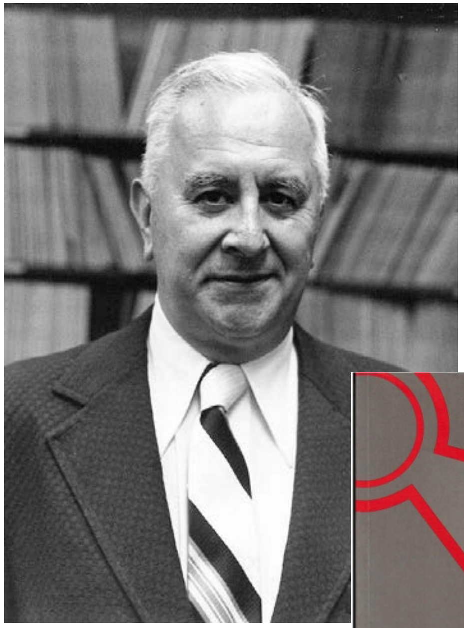
Harald Rossi (1917-2000): Developed Microdosimetry

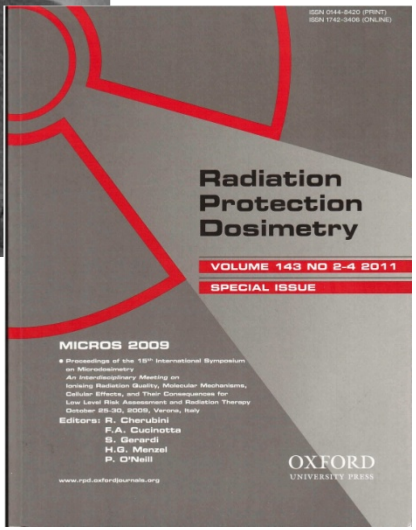
- **1917**: H. Rossi born in Vienna
- **1939**: Emigration with parents to England
- **1942**: PhD in USA
- Worked at Columbia University,

  Brookhaven National Labs
- **1967 – 1998**:

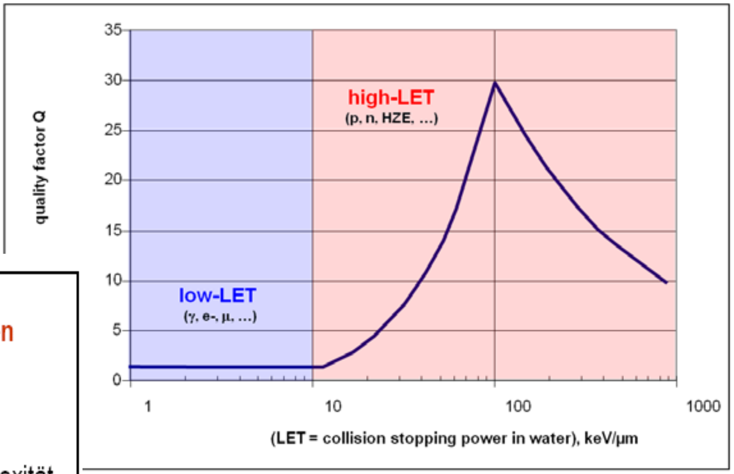
  Important publications e.g. ICRU Reports

  1967 – now: Microdosimetry Symposium (**MICROS**)

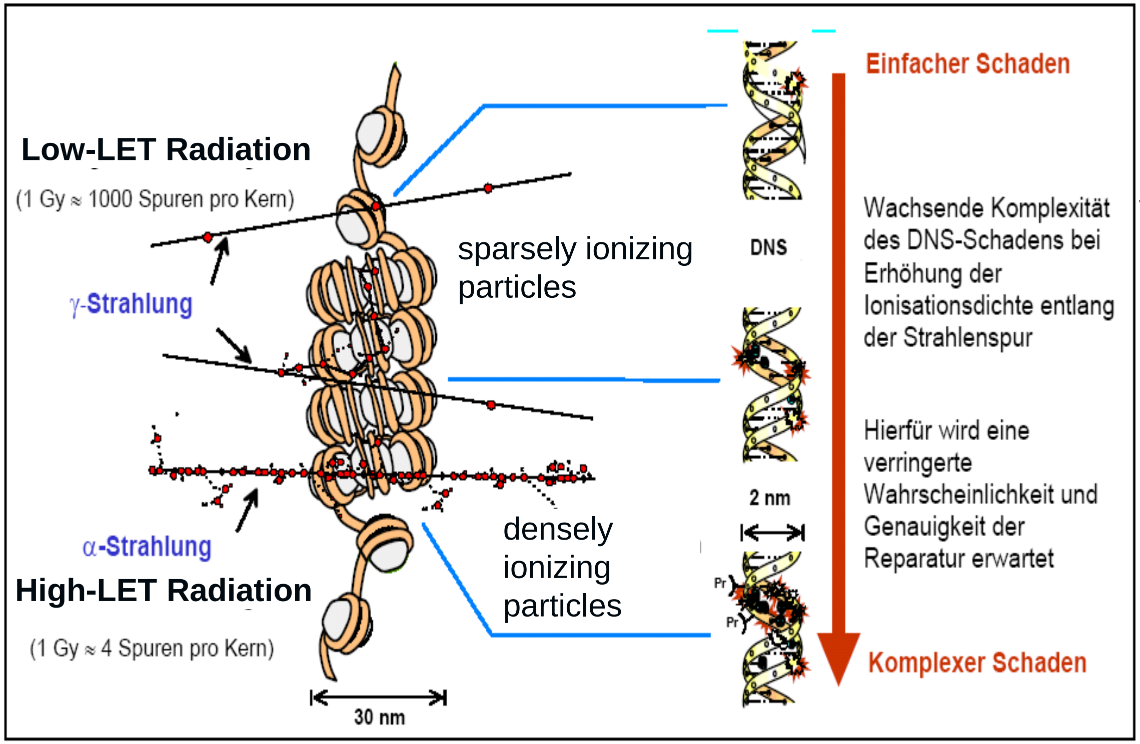




Low-LET and High-LET Radiation



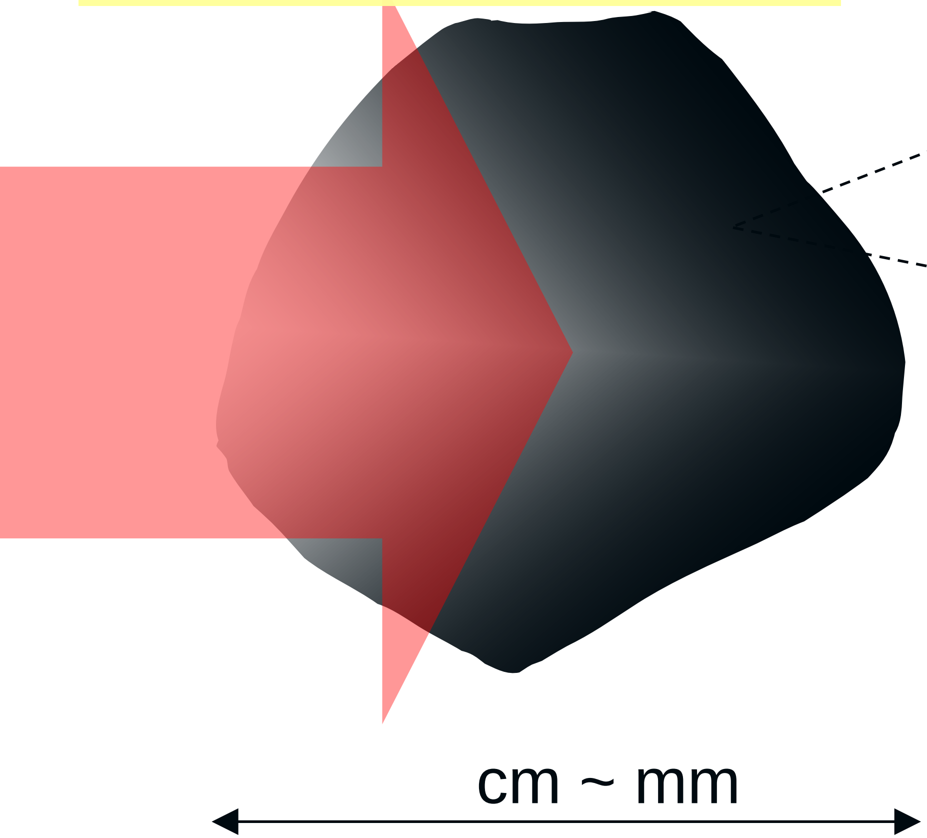
ICRP 60, ICRP 103

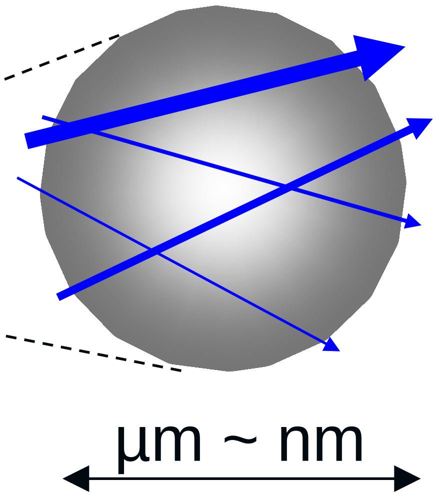


Conventional Dosimetry - Microdosimetry

Non-Stochastic quantities

absorbed dose: [D] = Gy = J · kg^{-1}





Stochastic quantities

energy deposit by an event [$\boldsymbol{\varepsilon}_\mathbf{i}$] = J, keV

energy imparted: [$\boldsymbol{\varepsilon}$] = J, keV

specific energy: [z] = J · kg^{-1} (Gy)

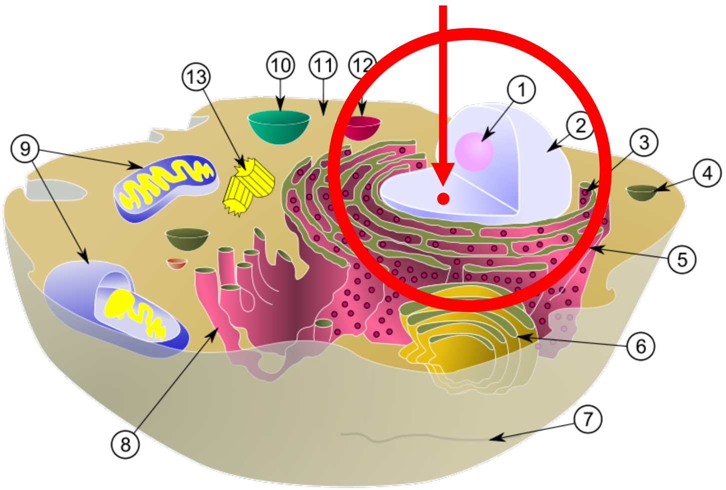
lineal energy: [y] = keV · µm^{-1}

Site Size in Microdosimetry

- How large is the sensitive volume of interest?
- **H. Rossi:** "*The dimensions of the volume of interest are those of the regions in the irradiated material where the concentration of absorbed energy determines the probability of a given effect.*"

- **Given effect**: "cell damage due to interaction of radiation with the cell nucleus"
  => Site size: ~µm

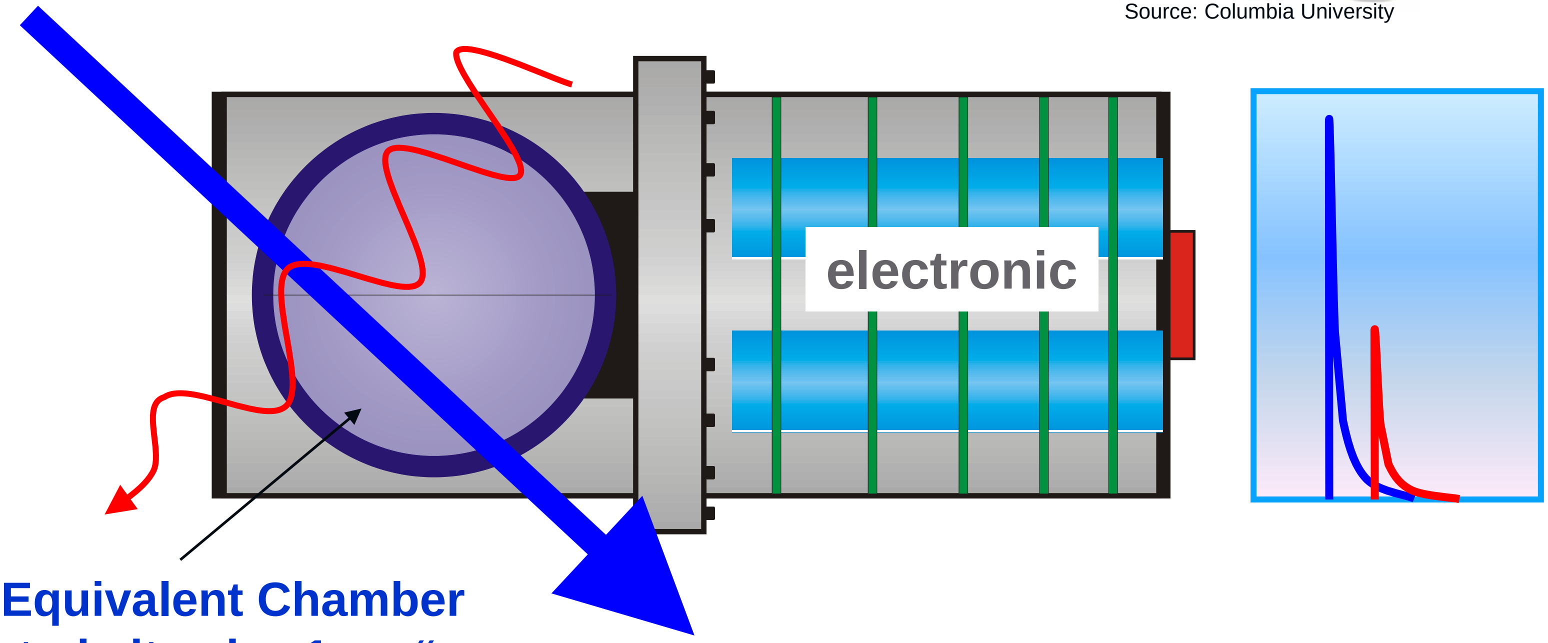
- **Given effect**: "DNA damage due to interaction of radiation with DNA (SSB, DSB, …)"
  => Site size: ~nm



Microdosimetric Measurements

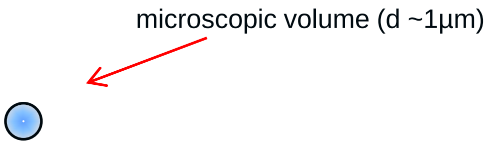
TEPC - Tissue Equivalent Proportional Counter

Source: Columbia University

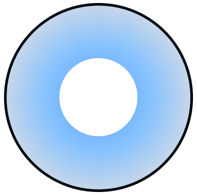


Tissue Equivalent Chamber
„Simulated site size 1 µm“

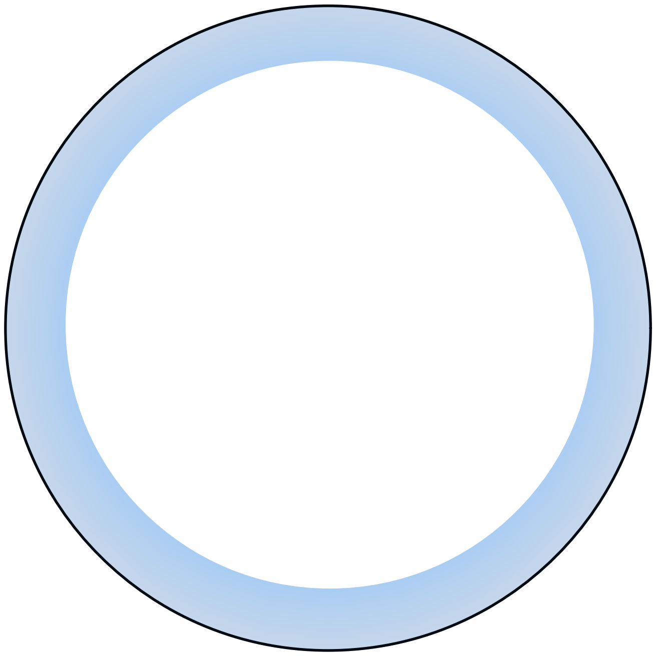
“Simulated” Site Size?



“Simulated” Site Size



“Simulated” Site Size

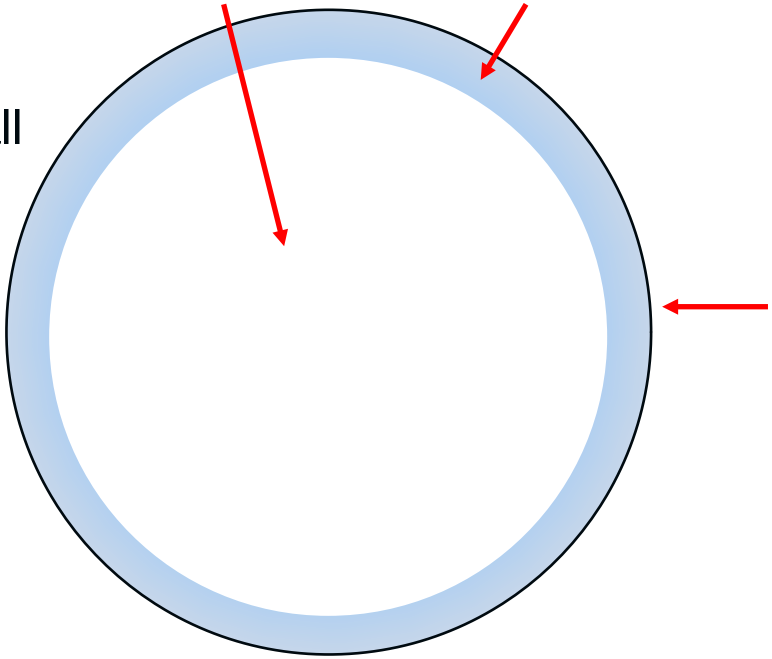


"Simulated" Site Size

- Equal effective dimensions of gas and chamber wall

- Equal products of wall and gas diameter and density

- Same tissue elemental composition of wall and gas



Tissue Composition for Chamber Wall and Gas

TABLE C.1—*Elemental composition of muscle-equivalent compounds and mixtures in percentage by weight*

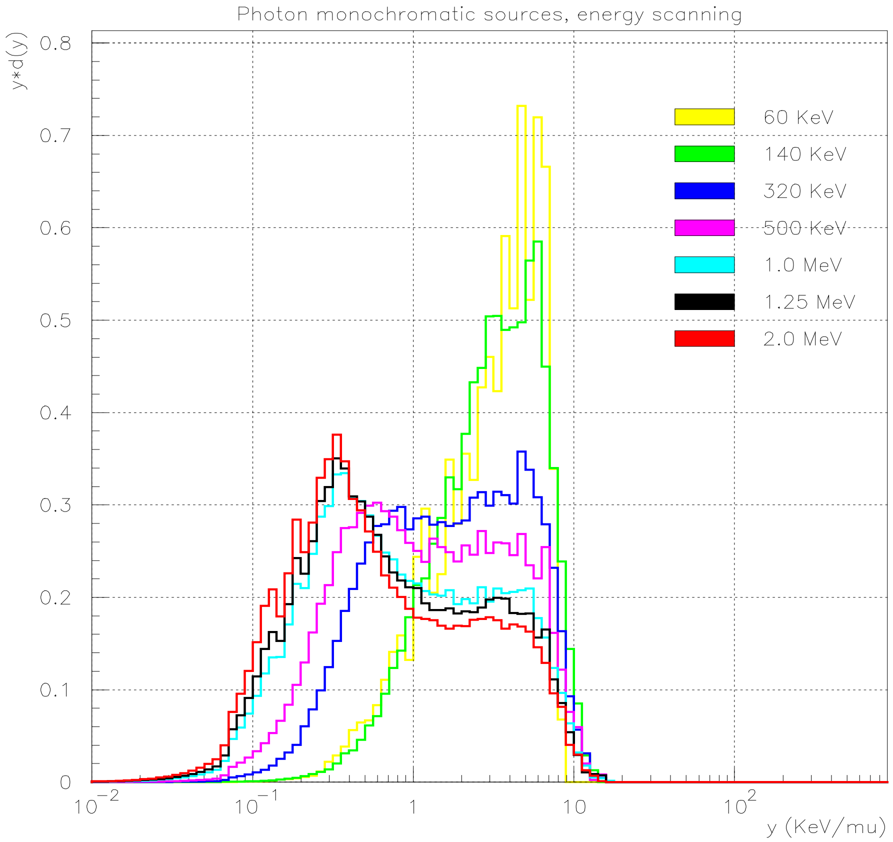
No.	Name	H	C	N	O	F	Na	Mg	Si	P	S	K	Ca
1	ICRU tissue, muscle (ICRU, 1964)	10.2	12.3	3.5	72.9	—	0.08	0.02	—	0.2	0.5	0.3	0.007
2	Muscle-equivalent plastic A 150 (Smathers *et al.*, 1977)	10.1	77.6	3.5	5.2	1.7	—	—	—	—	—	—	1.8
3	Muscle-equivalent gas, with methane (Rossi and Failla, 1956)	10.2	45.6	3.5	40.7	—	—	—	—	—	—	—	—
4	Muscle-equivalent gas, with propane (Srdoc, 1970)	10.3	56.9	3.5	29.3	—	—	—	—	—	—	—	—
5	Air-equivalent plastic C-552 (Spokas, 1975)	2.5	50.2	—	0.4	46.5	—	—	0.4	—	—	—	—

TABLE C.2—*Conversion factors for muscle-equivalent gases*

Parameter	Muscle-equivalent gas with methane (Table C.1)	Muscle-equivalent gas with propane (Table C.1)
Density, ρ, at 20°C and 100 kPa (750.1 torr) $\rho/\frac{\text{kg}}{\text{m}^3}$	1.050	1.798
Thickness ρd at 20°C and 1 kPa (7.501 torr) $\rho d \Big/ \left(\frac{\mu\text{g}}{\text{cm}^3}\cdot\text{cm}\right)$	10.50	17.98
1 μm of muscle ($\rho = 1\ \text{g/cm}^3$) is simulated by a distance of 1 cm in muscle equivalent gas of 20°C and a pressure p	9.524 kPa (71.44 torr)	5.562 kPa (41.72 torr)

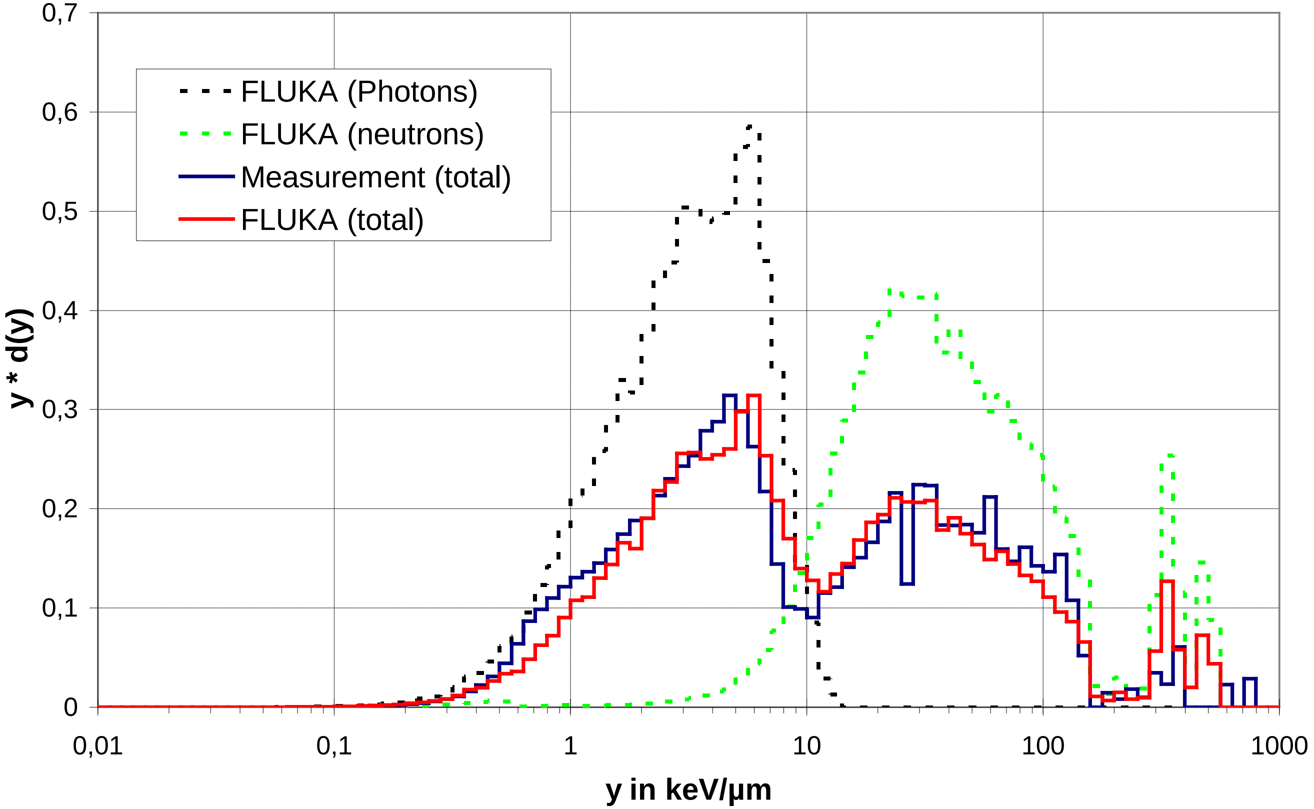
Ref: Microdosimetry, ICRU Report 36, 1983.

Distribution of lineal energy, *y* of absorbed dose, *D* in µm tissue due to different photon irradiation (60keV – 2 MeV)



Source: Rollet, S., Beck, P., Ferrari, A., Pelliccioni, M. and Autischer, M., Dosimetric considerations on TEPC FLUKA-Simulation and Measurements. Radiat. Prot. Dosim. 110(1–4), 833–838 (2004).

Distribution of lineal energy, *y* of absorbed dose, *D* in µm tissue due to ^{241}AmBe neutron irradiation



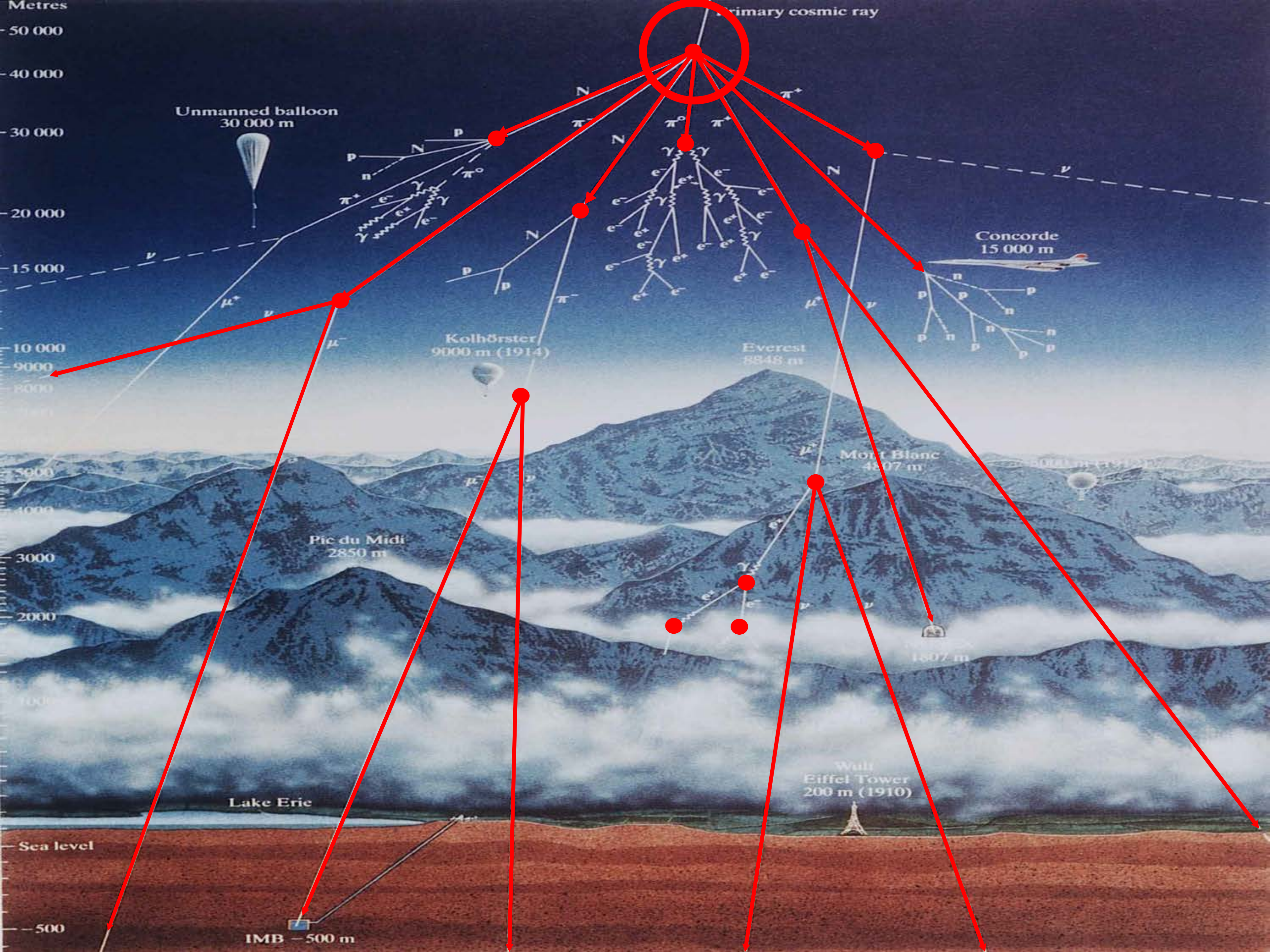
Source: Rollet, S., Beck, P., Ferrari, A., Pelliccioni, M. and Autischer, M., Dosimetric considerations on TEPC FLUKA-Simulation and Measurements. Radiat. Prot. Dosim. 110(1–4), 833–838 (2004).

Applications

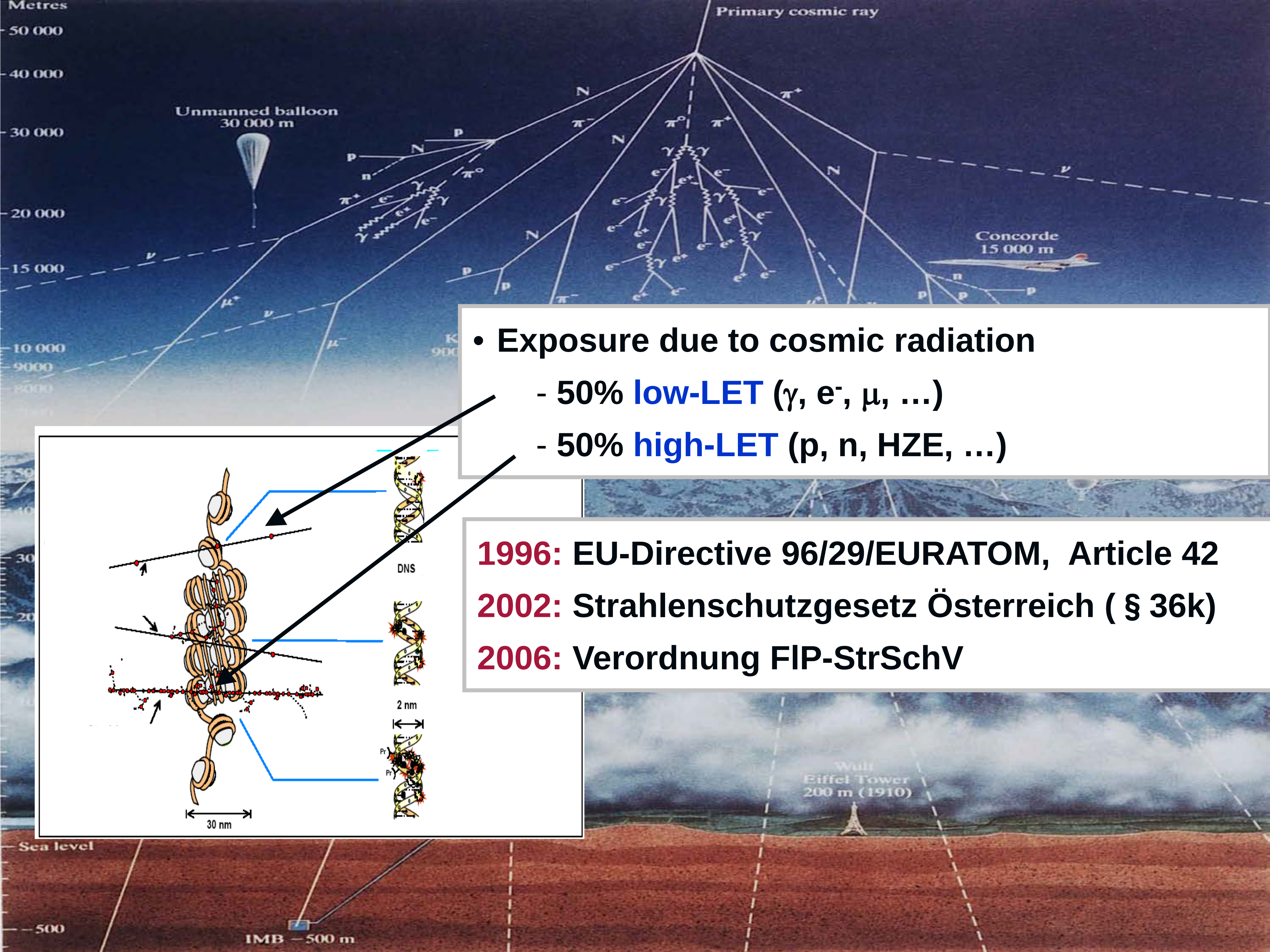
- Cosmic radiation at aviation altitudes
- Space Radiation at the International Space Station (ISS)

Application

1. Cosmic radiation at aviation altitudes



Metres
50 000
40 000
30 000
20 000
15 000
10 000
9000
8000
5000
4000
3000
2000
Sea level
-500
Primary cosmic ray
Unmanned balloon
30 000 m
Concorde
15 000 m
Kolhörster
9000 m (1914)
Everest
8848 m
Mont Blanc
4807 m
Pic du Midi
2850 m
Lake Erie
Wulf
Eiffel Tower
200 m (1910)
IMB −500 m



- Exposure due to cosmic radiation
  - 50% low-LET (γ, e^-, μ, …)
  - 50% high-LET (p, n, HZE, …)

1996: EU-Directive 96/29/EURATOM, Article 42

2002: Strahlenschutzgesetz Österreich (§ 36k)

2006: Verordnung FlP-StrSchV

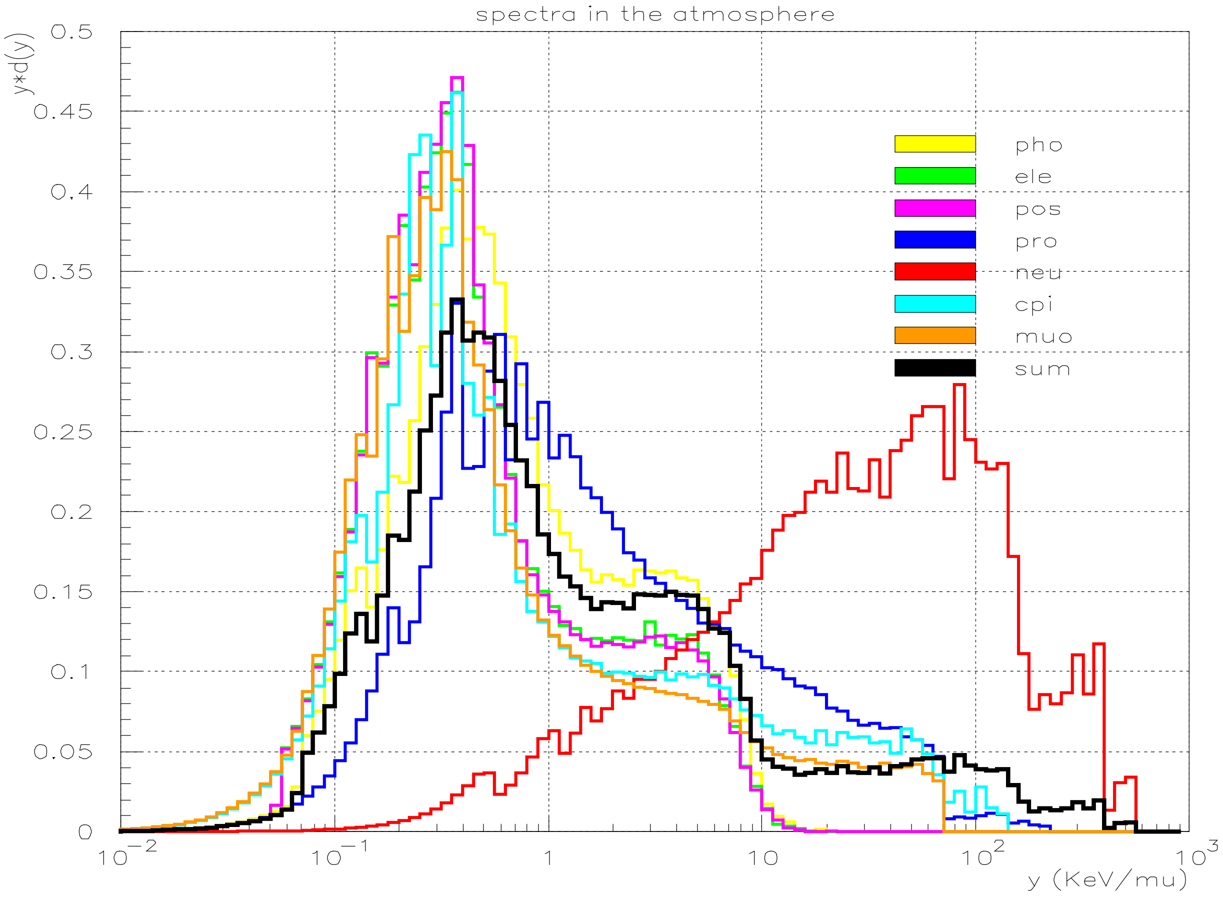
E

National and European Research
1995-2012: ACREM, DOSMAX, SOLARDOS

- ANPA / Italy
- ARCS / Austria
- AUA / Austria
- Brazilian Airforce / Brazil
- CERN /Swiss
- DIAS / Ireland
- DLH AG / Germany
- GSF / Germany
- INFN / Italy
- IPSN / France
- NPI / Czech
- NRPB / UK
- PTB / Germany
- SSI / Sweden
- TU - Graz / Austria
- Uni München / Germany
- University of Siegen / Germany
- VARIG / Brazil

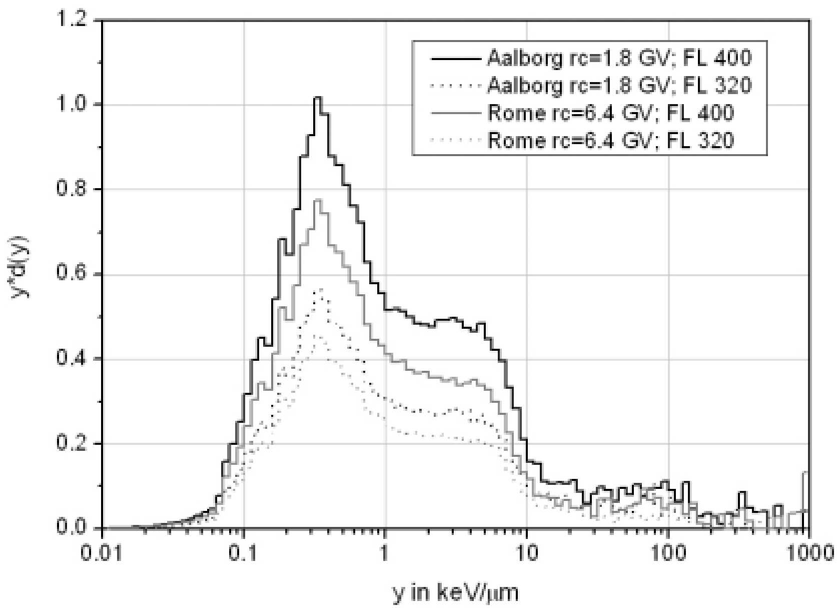
TEPC Reference-Dosimeter for On-Board Measurements

Calculated microdosimetric lineal energy, *y* distribution of absorbed dose in µm tissue due to cosmic radiation at flight altitudes (10km)

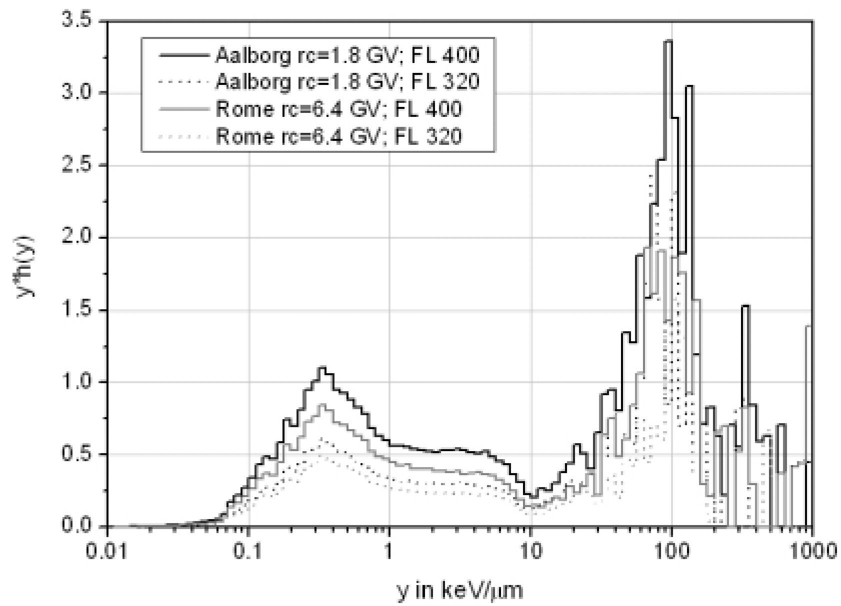


Measured lineal energy *y* distribution in different altitudes (12.2km, 9.8km) and latitudes (Rome: 42N12E, Aalborg: 57N10E)

absorbed dose, *D*

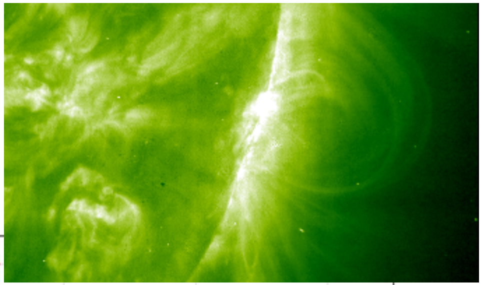


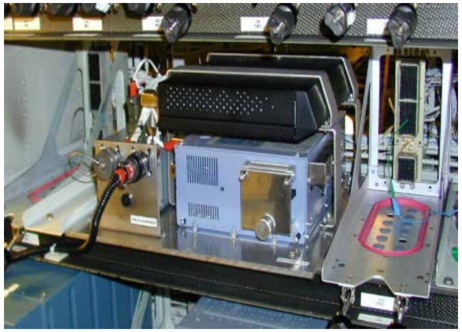
dose equivalent, *H*

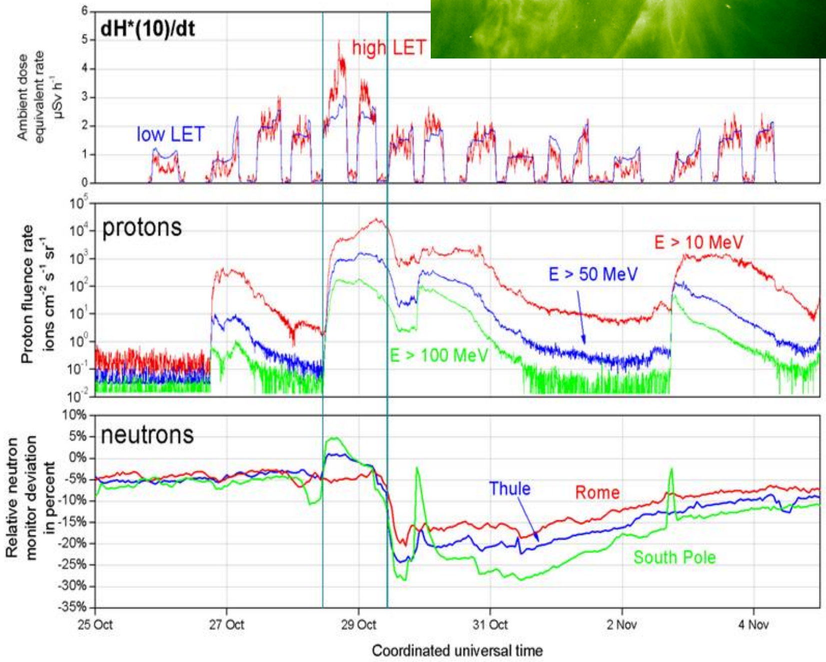


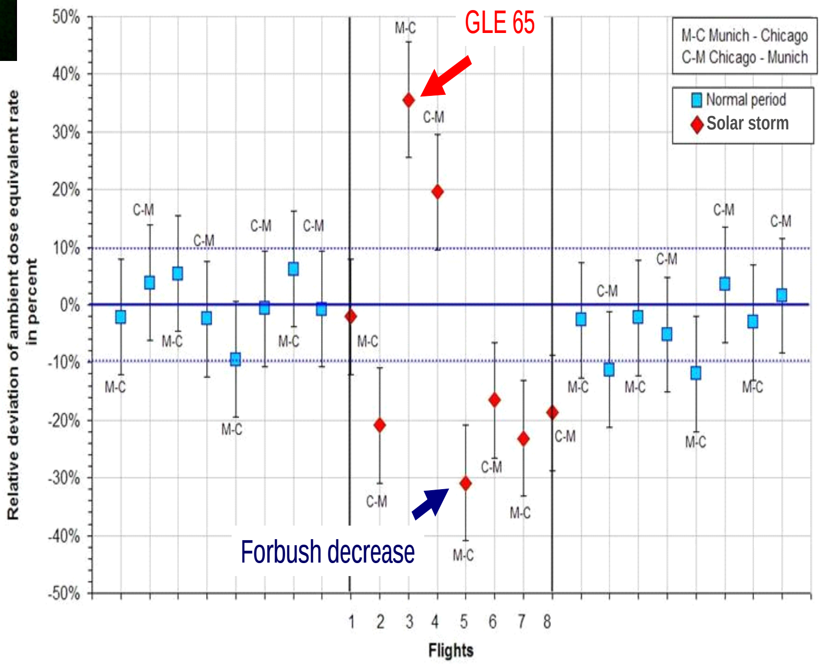
Ref: M. Latocha, M. Autischer, P. Beck, J. F. Bottolier–Depois, S. Rollet and F. Trompier, THE RESULTS OF COSMIC RADIATION IN-FLIGHT TEPC MEASUREMENTS DURING THE CAATER FLIGHT CAMPAIGN AND COMPARISON WITH SIMULATION, Rad. Prot. Dosim., Radiation Protection Dosimetry (2007), Vol. 125, No. 1–4, pp. 412–415, doi:10.1093/rpd/ncl123.

October / November 2003:
Solar Storm Measurements with TEPC



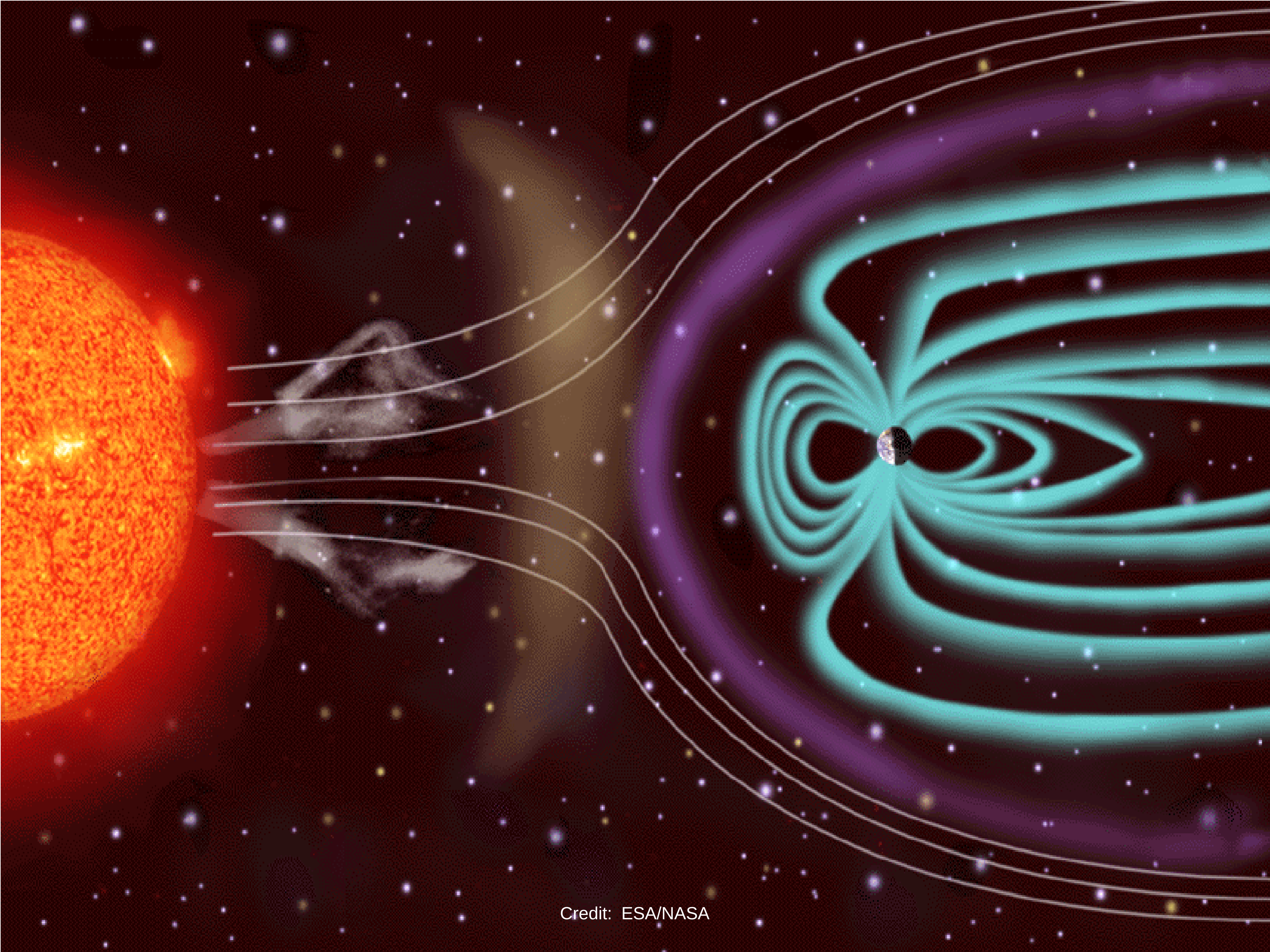




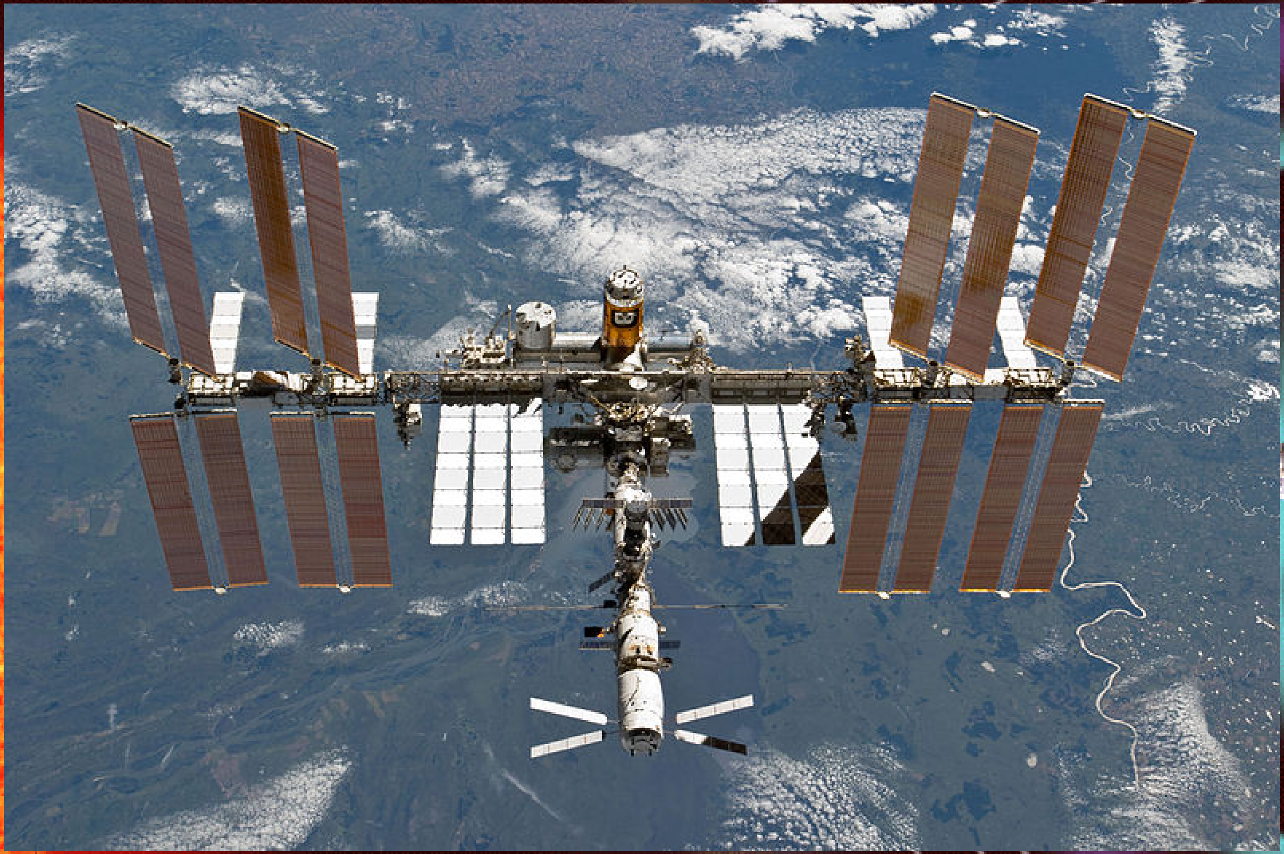


Application

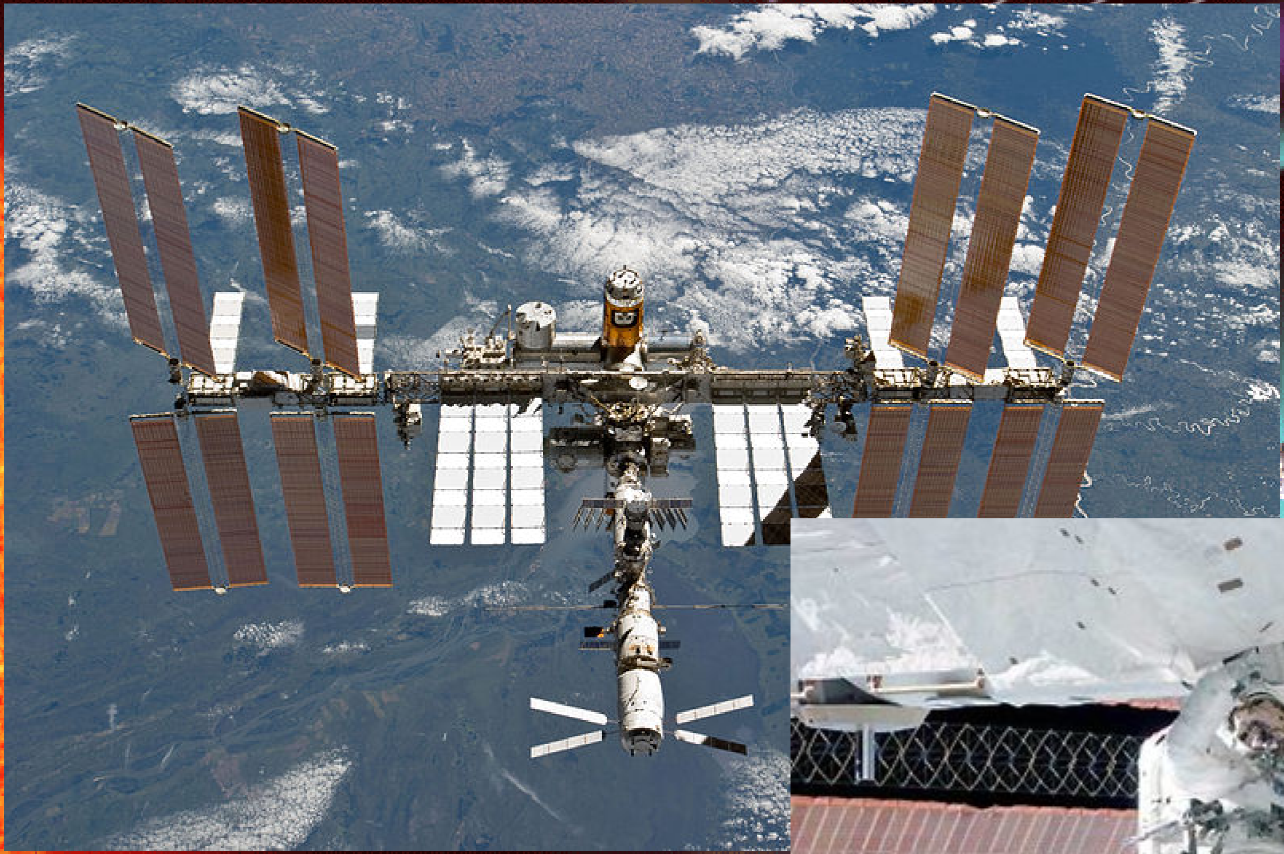
2. Space Radiation



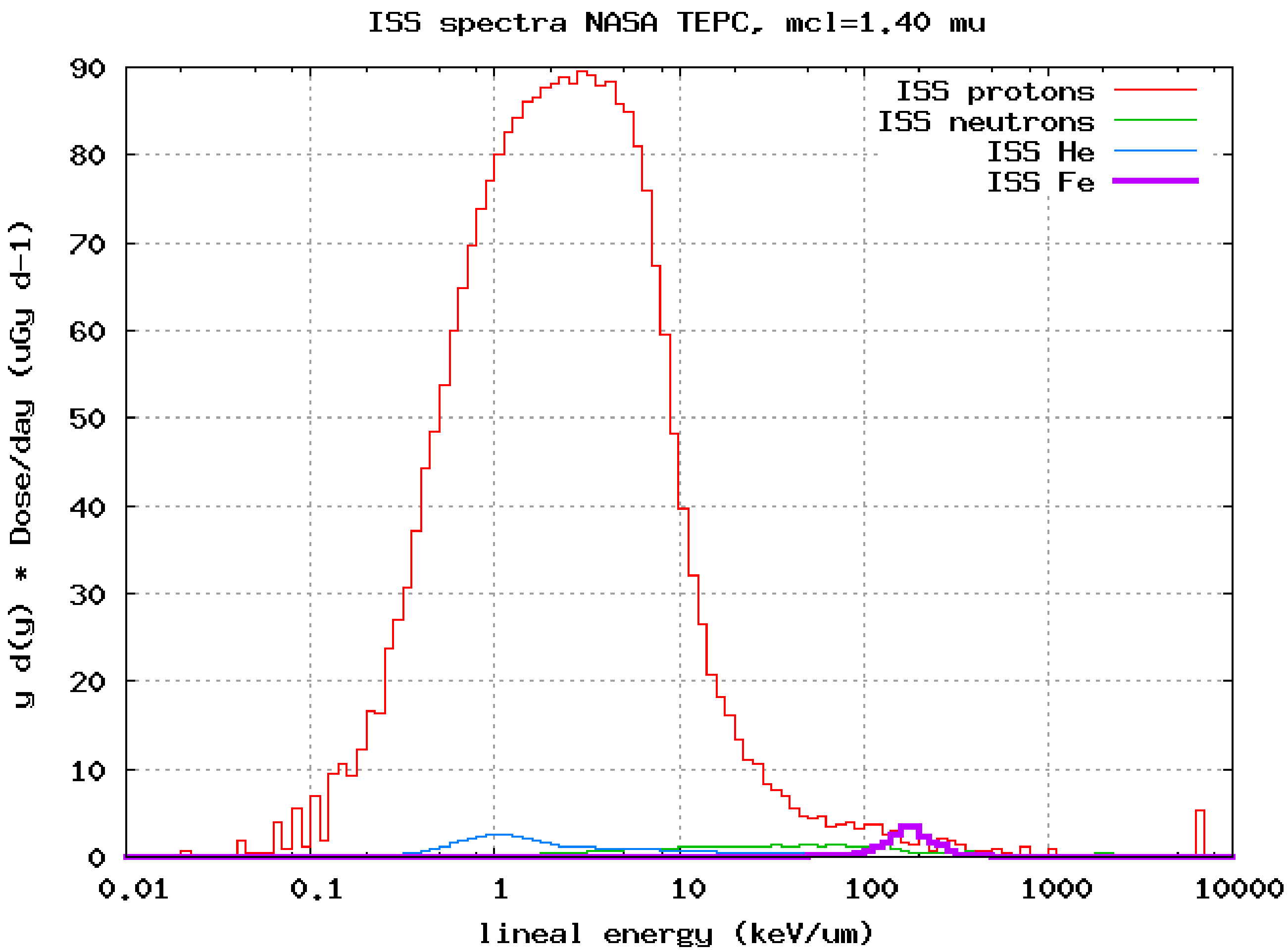
Credit: ESA/NASA



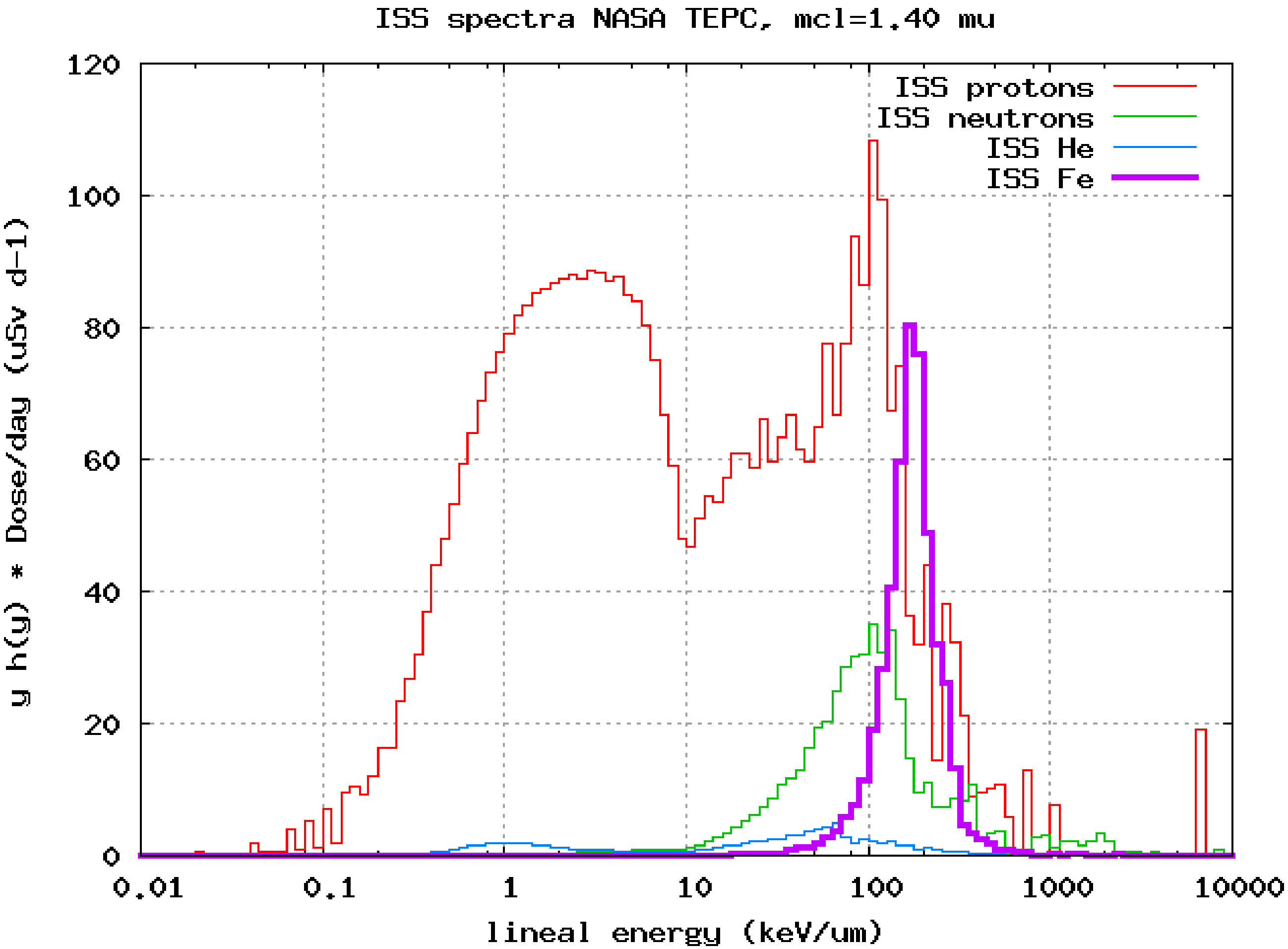
Credit: ESA/NASA




Simulated lineal energy, *y* distribution of absorbed dose, *D* in µm tissue due to space radiation at the International Space Station (ISS)



Simulated lineal energy, *y* distribution of dose equivalent, *H* in µm tissue due to space radiation at the International Space Station (ISS)

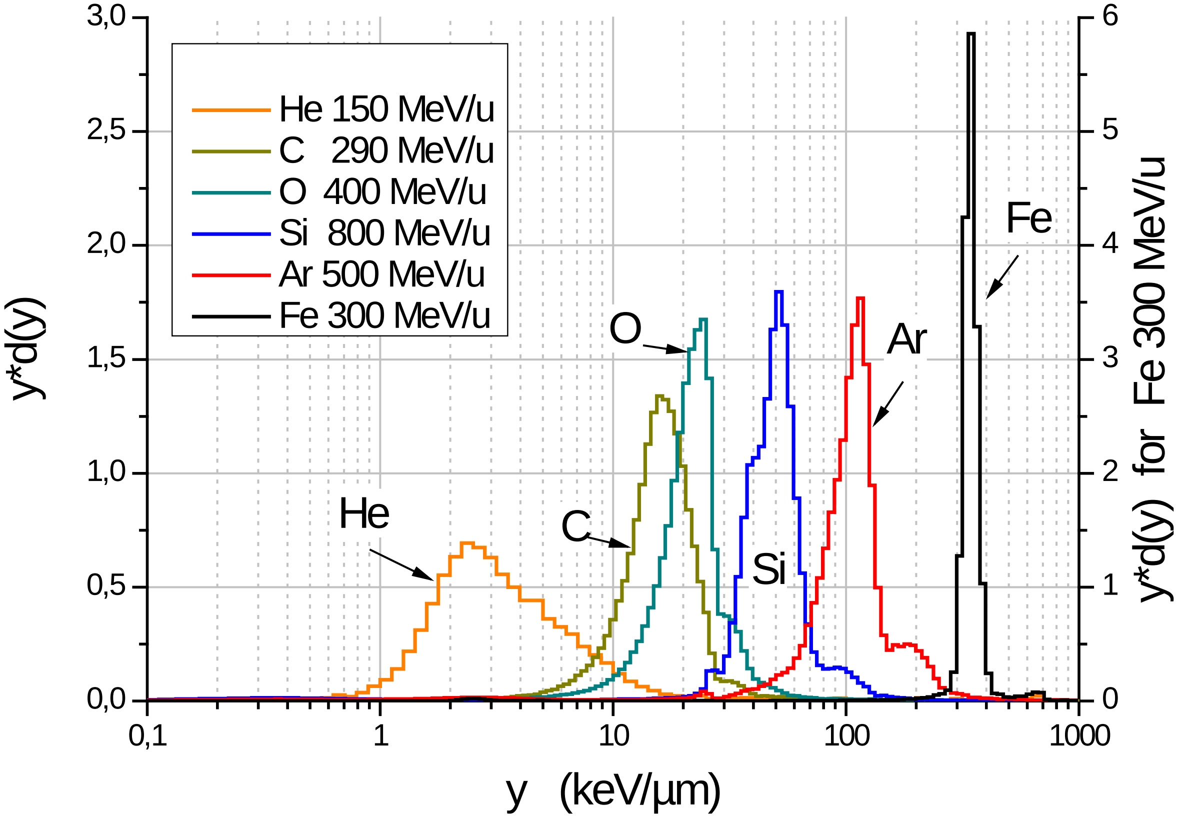


HIMAC - Heavy Ion Medical Accelerator, Chiba, Japan

- HIMAC
  - is used for cancer therapy
  - is available for scientific experiments during night time and weekends
- Projects
  - MOHZARTS
  - ICCHIBAN
- Tissue (& Silicon) irradiation measurements

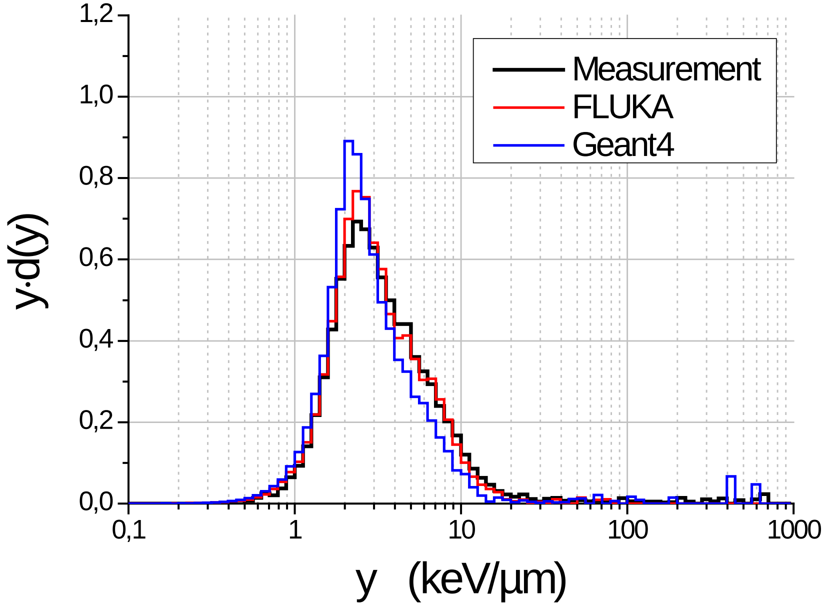
Ion	LET MeV cm² mg^{-1} Tissue (A150)	LET MeV cm² mg^{-1} Silicon	LET keV / µm Tissue (A150)	LET keV / µm Silicon
He 150 MeV/u	0.022	0.02	2.5	4.1
C 290 MeV/u	0.13	0.10	14.3	23.7
O 400 MeV/u	0.19	0.16	21.8	36.3
Si 800 MeV/u	0.45	0.37	51.1	86.0
Ar 500 MeV/u	0.88	0.74	103.3	172.8
Fe 300 MeV/u	2.34	1.86	263.6	437.5

Measured lineal energy, *y* distribution of absorbed dose in 1µm tissue for several ions

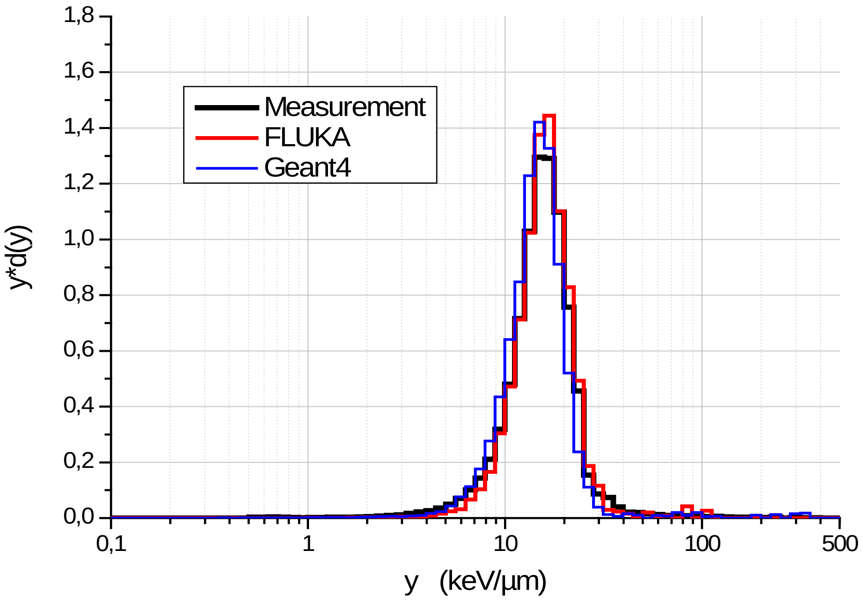


Comparison of measured and simulated lineal energy *y* distribution of absorbed dose in 1µm tissue due to Helium and Carbon Ions

Helium irradiation (150 MeV/ nucleon)



Carbon irradiation (290 MeV/ nucleon)

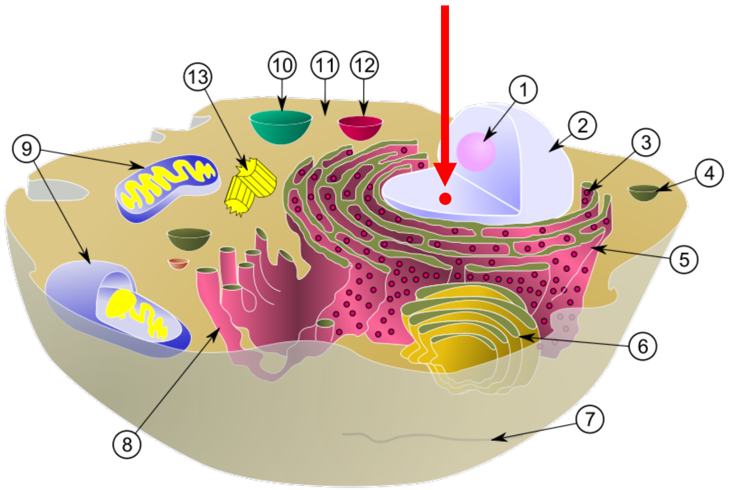


Outlook - What comes next?

Site Size Microdosimetry

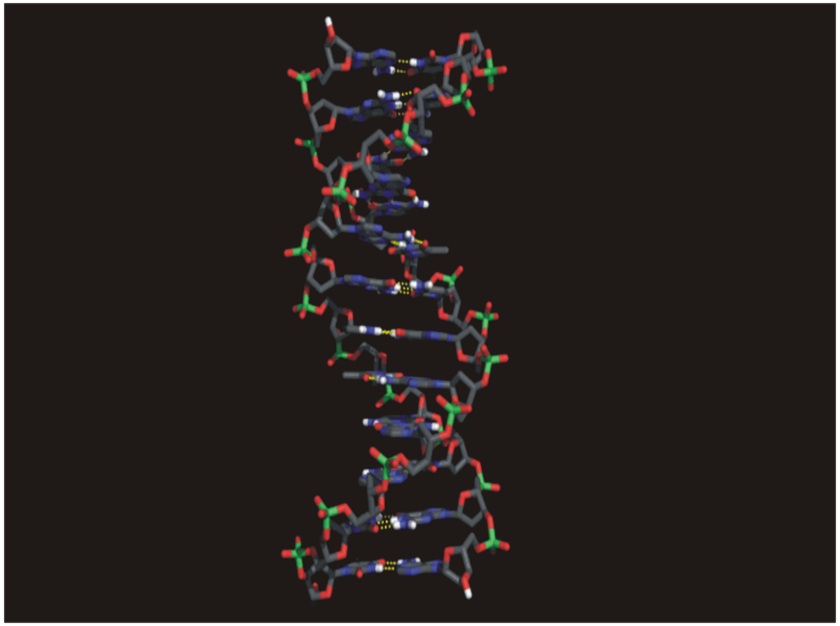
- How large is the sensitive volume of interest?
- **H. Rossi:** “*The dimensions of the volume of interest are those of the regions in the irradiated material where the concentration of absorbed energy determines the probability of a given effect.*”

- **Given effect**: cell damage due to interaction of radiation with the cell nucleus, etc.
  => Site size: ~µm
- **Given effect**: DNA damage due to interaction of radiation with DNA (SSB, DSB, …)
  => Site size: ~nm



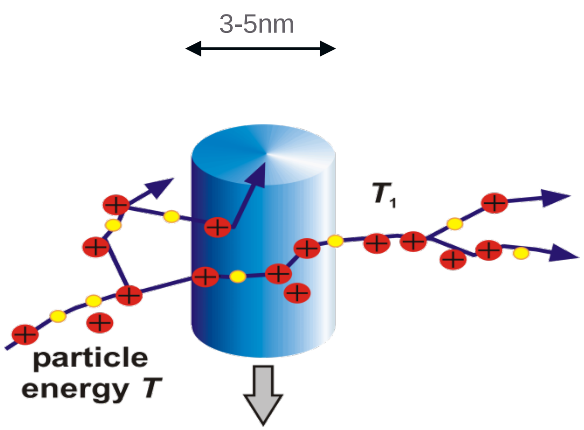
Radiation effects in tissue are caused mainly by DNA damage in the nanometre region

Radiation damage is caused in 3 – 6 nm segments of the DNA



Courtesy: Bernd Grosswendt

Developments of "nano-dosimetry" - Particle Track Structure Analysis



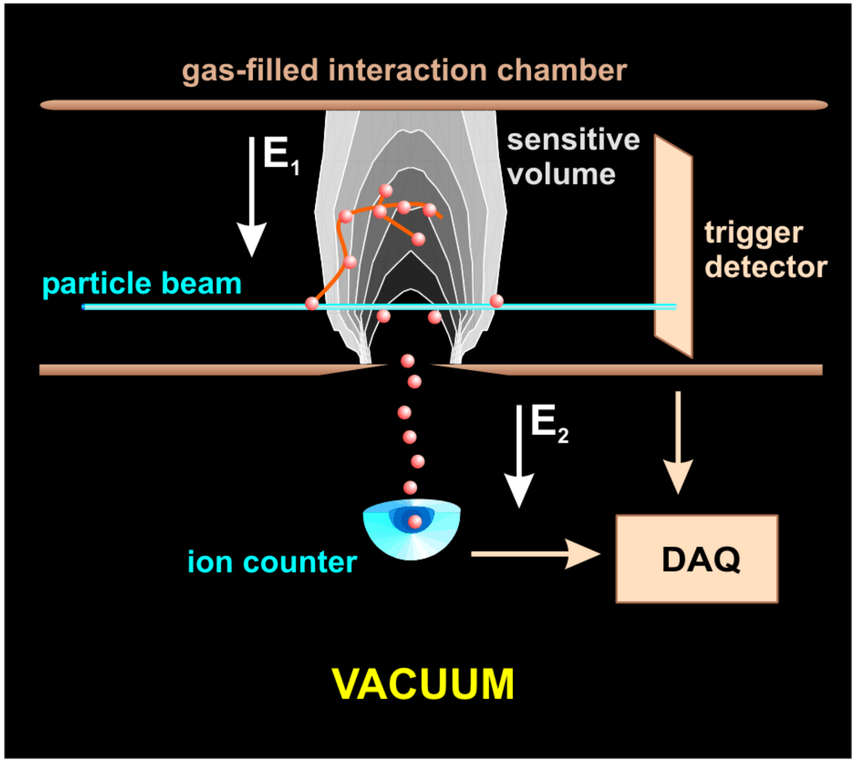
A relation between frequency distribution of ionizing events in nano-metre region and DNA damage were identified

P_1 … Probability of Single Strand Breaks

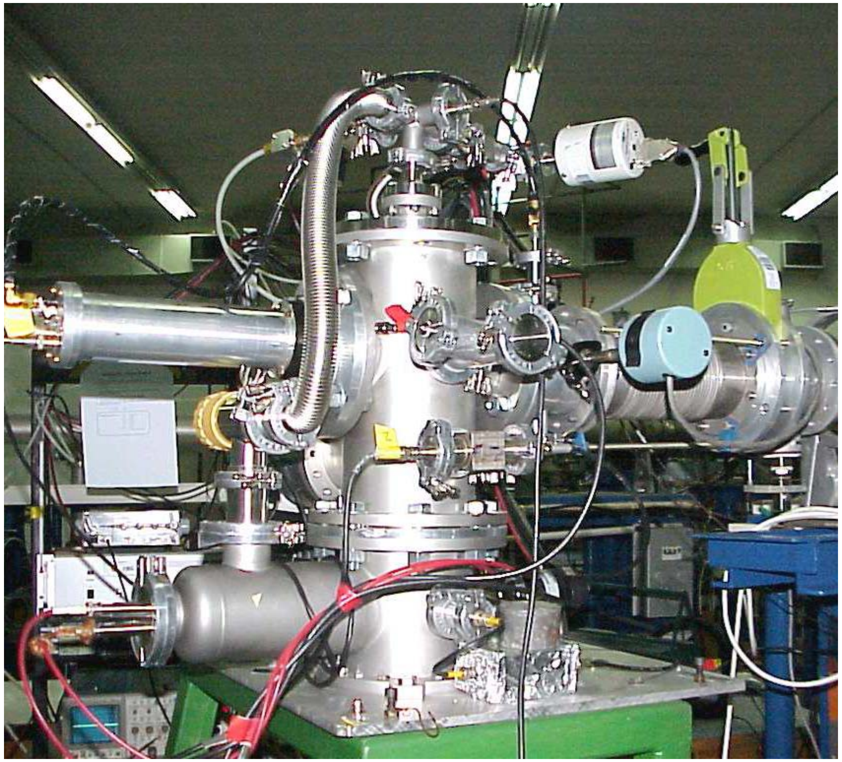
F_2 … Probability of Double Strand Breaks

Nano-Dosimeter Gas Counter

Principle of nano-dosimetric measurement system for single ion counting



Set-up of nanodosimeter (Weizmann-Institute, Rehovot/Israel, PTB, BRD)

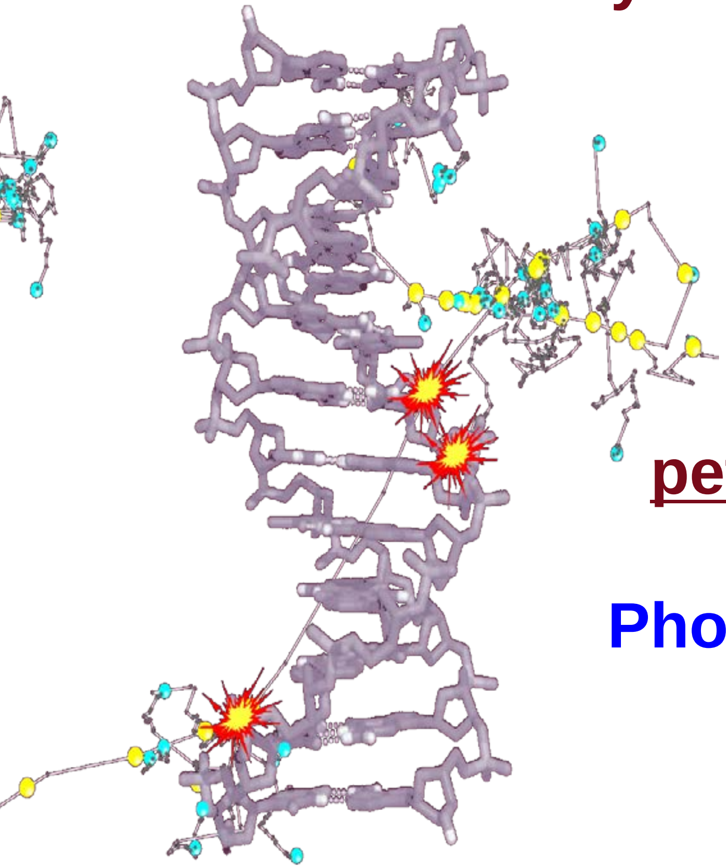


Courtesy: Bernd Grosswendt

Conclusion

- Microdosimetry shows significant advantage of assessing the absorbed dose in complex, mixed radiation environment
- Microdosimetry provides the distribution of lineal energy, *y* of absorbed dose, *D*
- The lineal energy, *y* distribution of absorbed dose can be folded with the definition of q(*L*) to calculate dose equivalent, *H.*
- Microdosimetry provides most reasonable dosimetric concept for mixed radiation fields such as:
  - Cosmic radiation at aviation altitudes
  - Space radiation at ISS, space mission
  - Accelerator fields
  - Proton, light and heavy ion therapy
- Dosimetric concepts in the nanometre region show promising future applications

Many thanks for your attention!



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