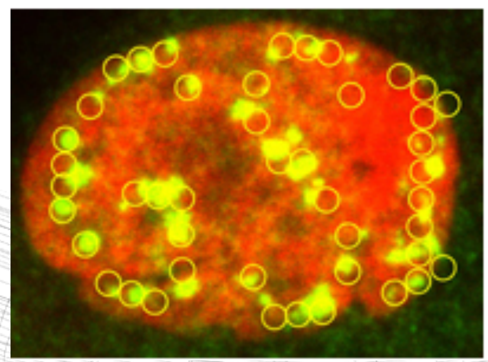
Biophysics

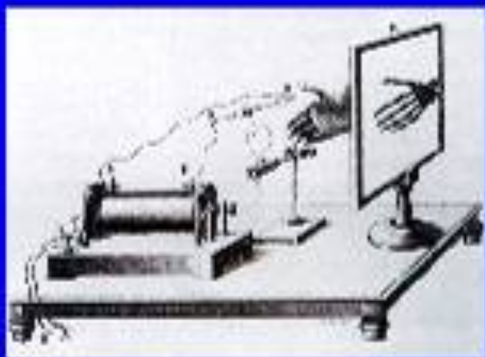
Prof. Dr. Marco Durante



GSI Summer School 23.7.2019

Table of contents

1. Radioactivity



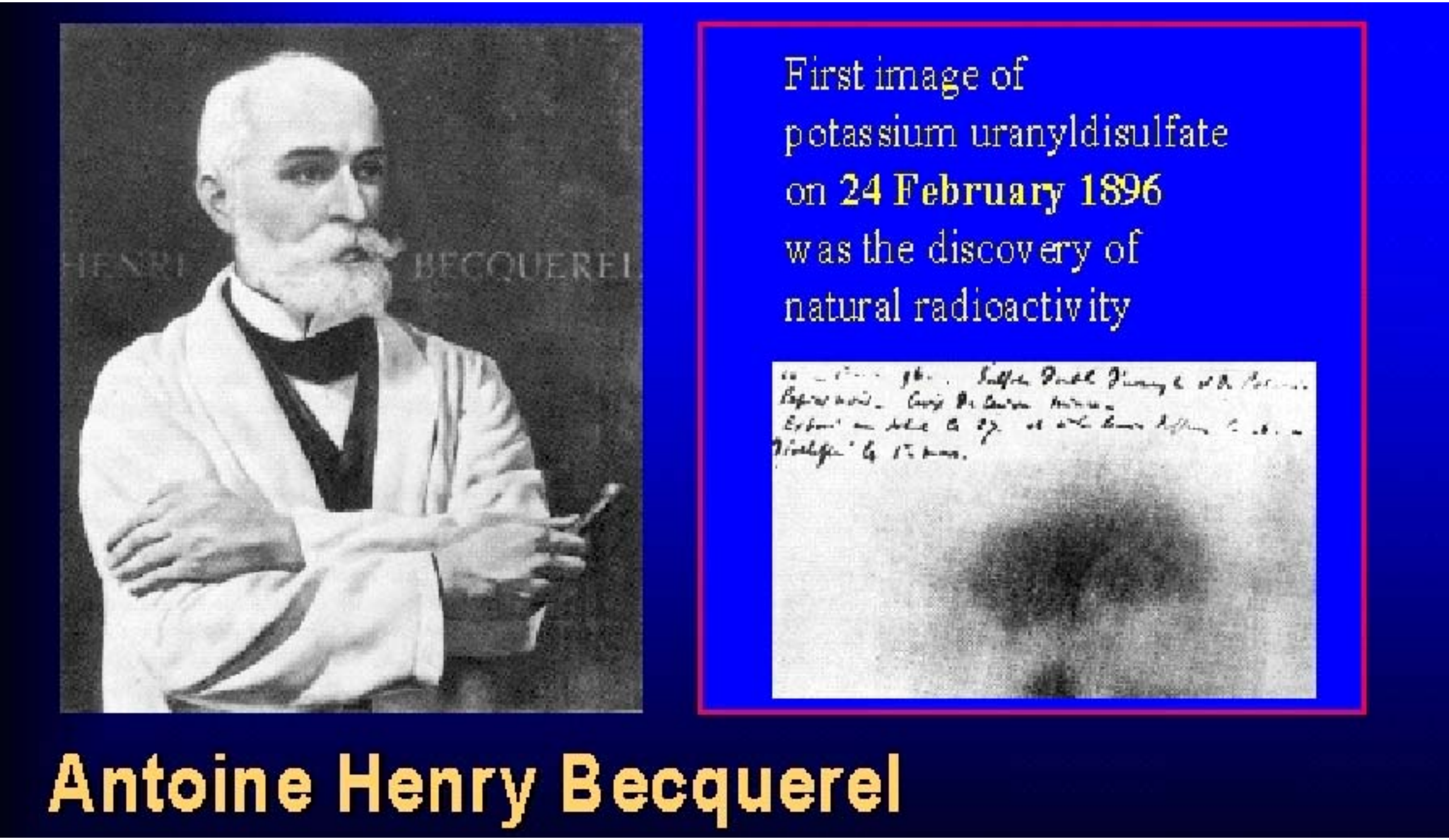
W.C.Röntgens experiment in Würzburg

An early XX th century X-ray tube

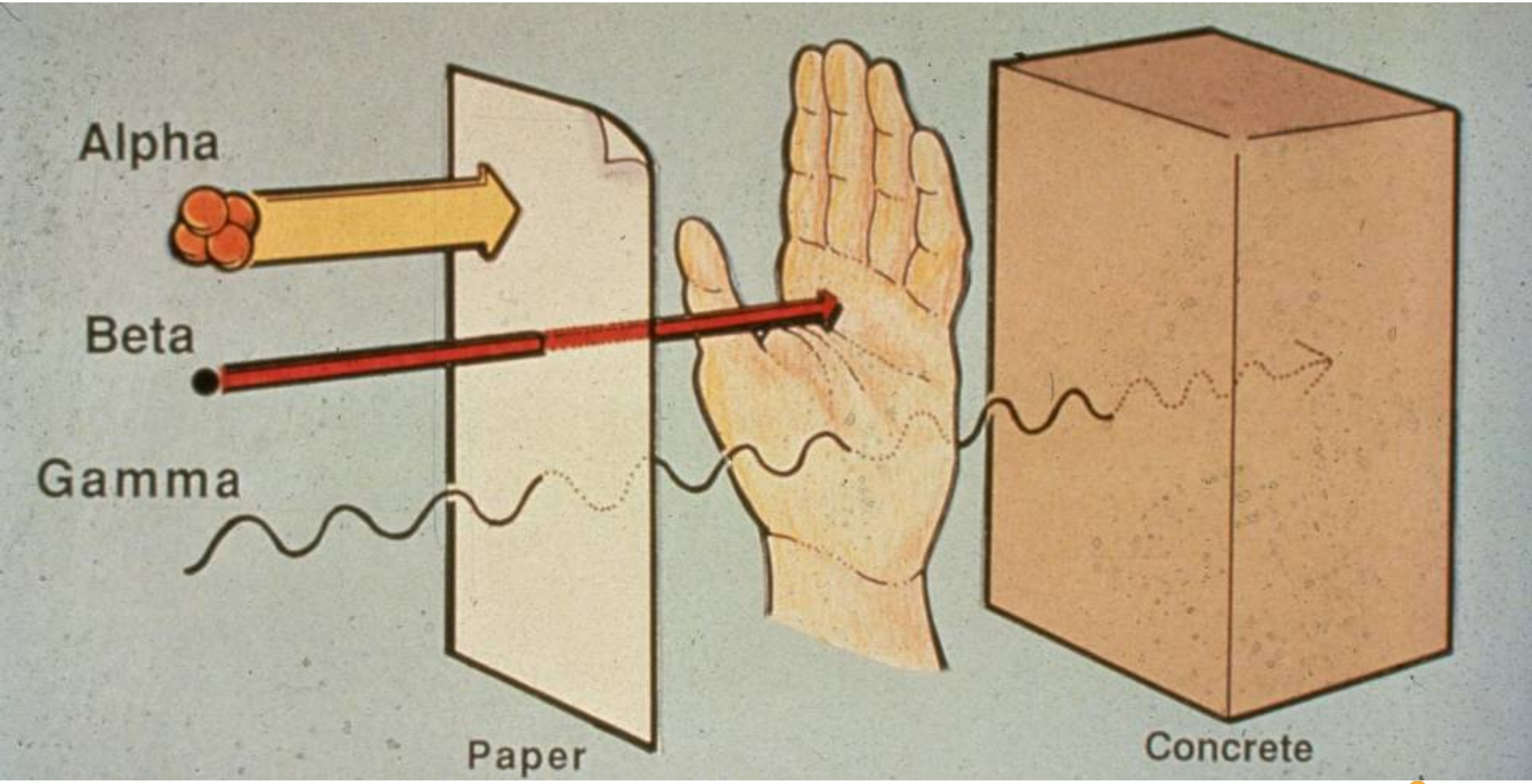
Radiograph of Mrs. Röntgens hand, the first x-ray image ever taken, 22.Dec.1895, published in The New York Times Januay 16, 1896

February 1896: Becquerel discovers radioactivity

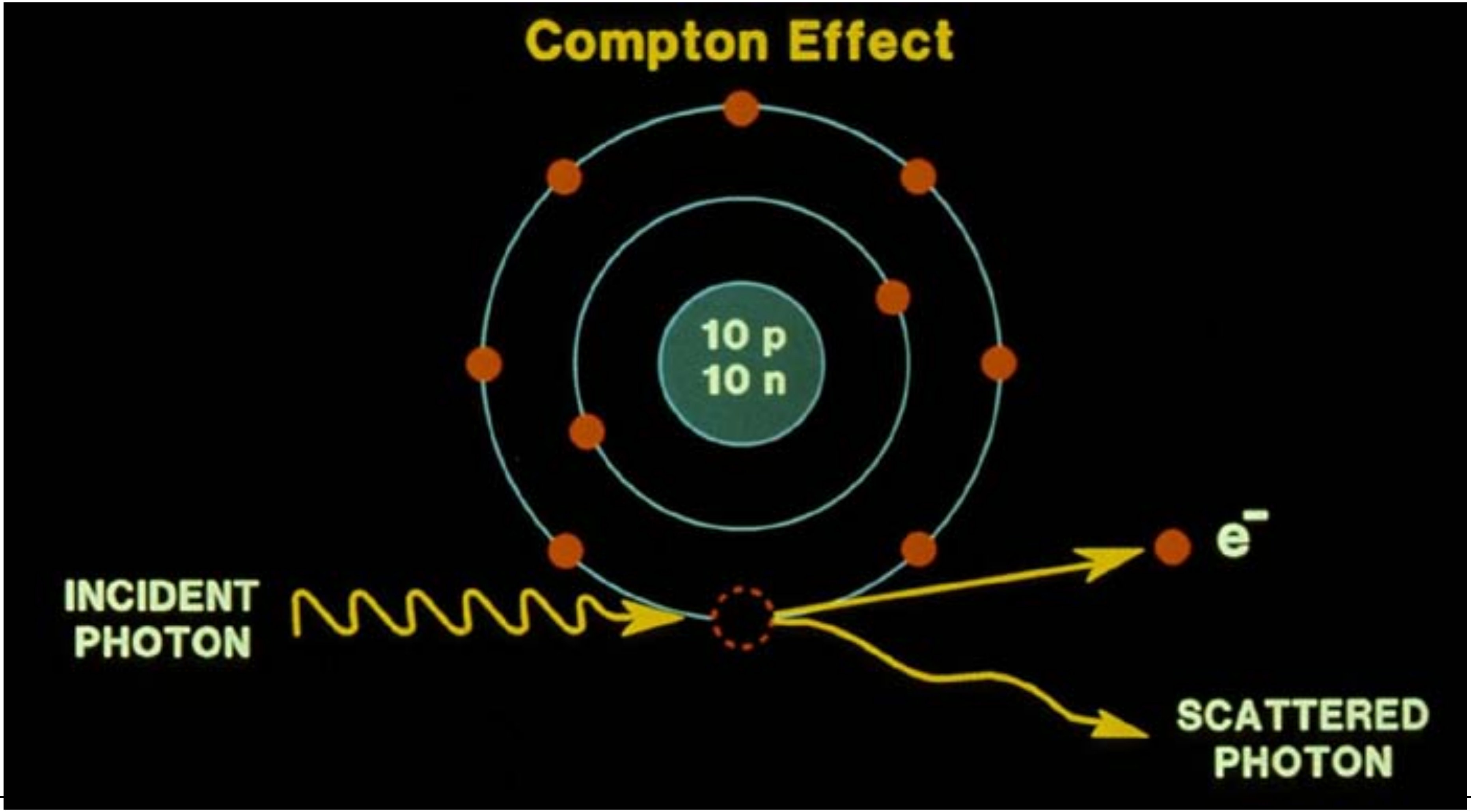
1 Bq= 1 disintegration/second



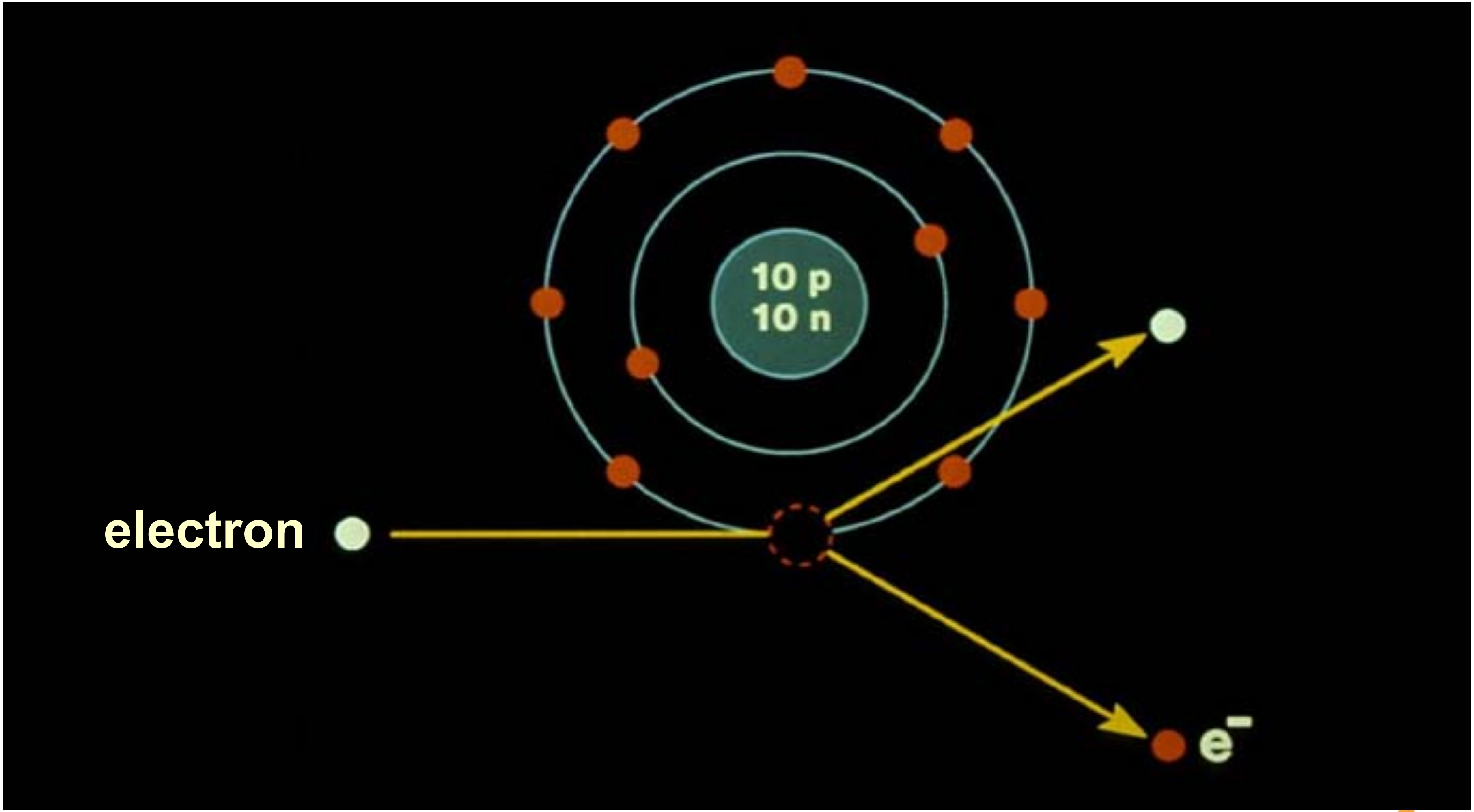
2.Interaction of radiation with matter



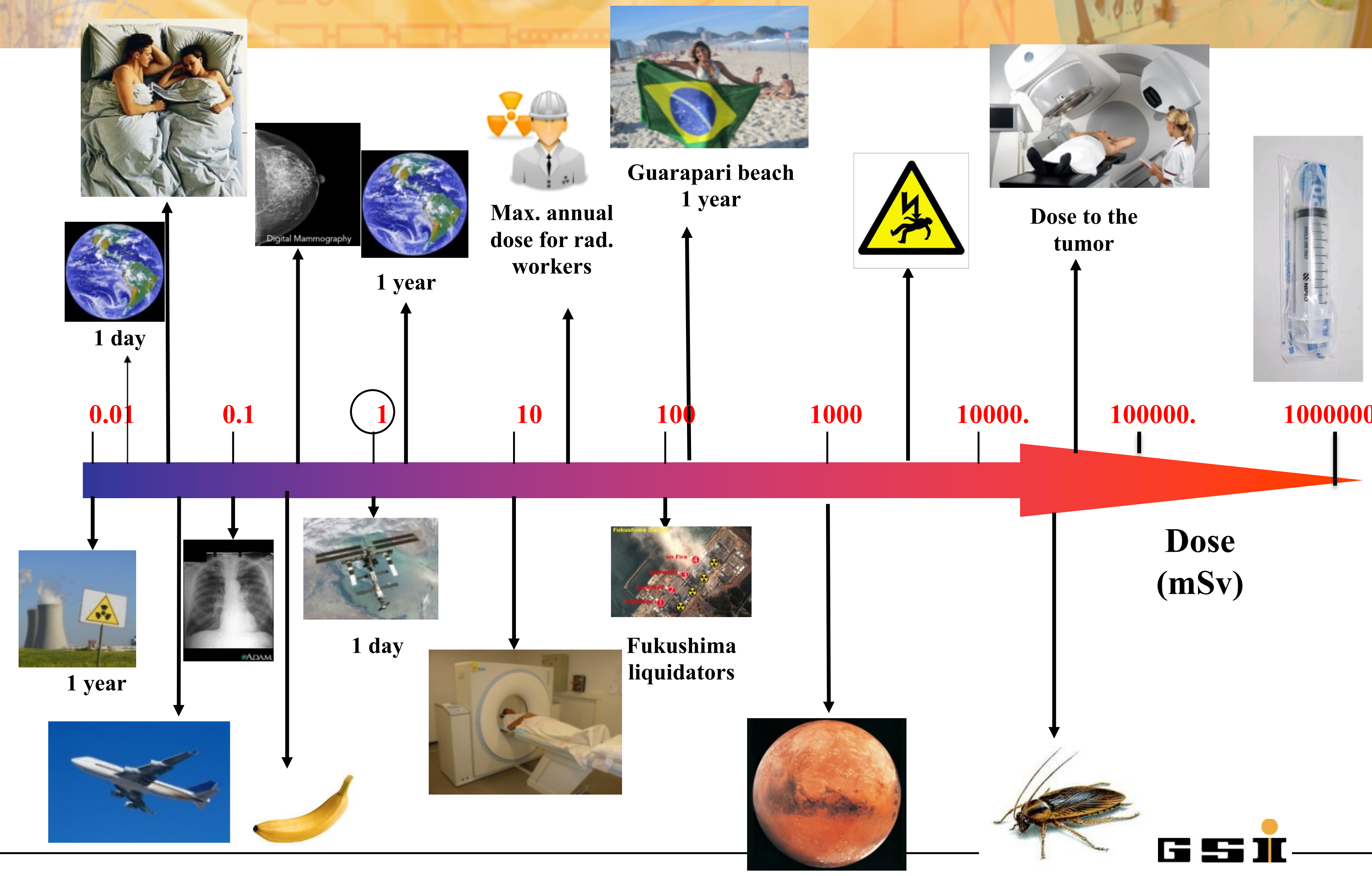
Interaction of x or γ rays (photons) with matter: Ionization



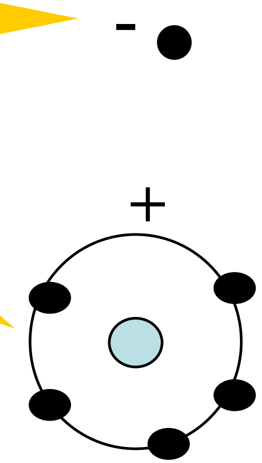
Interaction of electrons or ions with matter:
Ionization (Coulomb interaction)



Radiation effects depends on the DOSE
Dose is an energy per unit mass and is measured in Sievert =Joule/kg



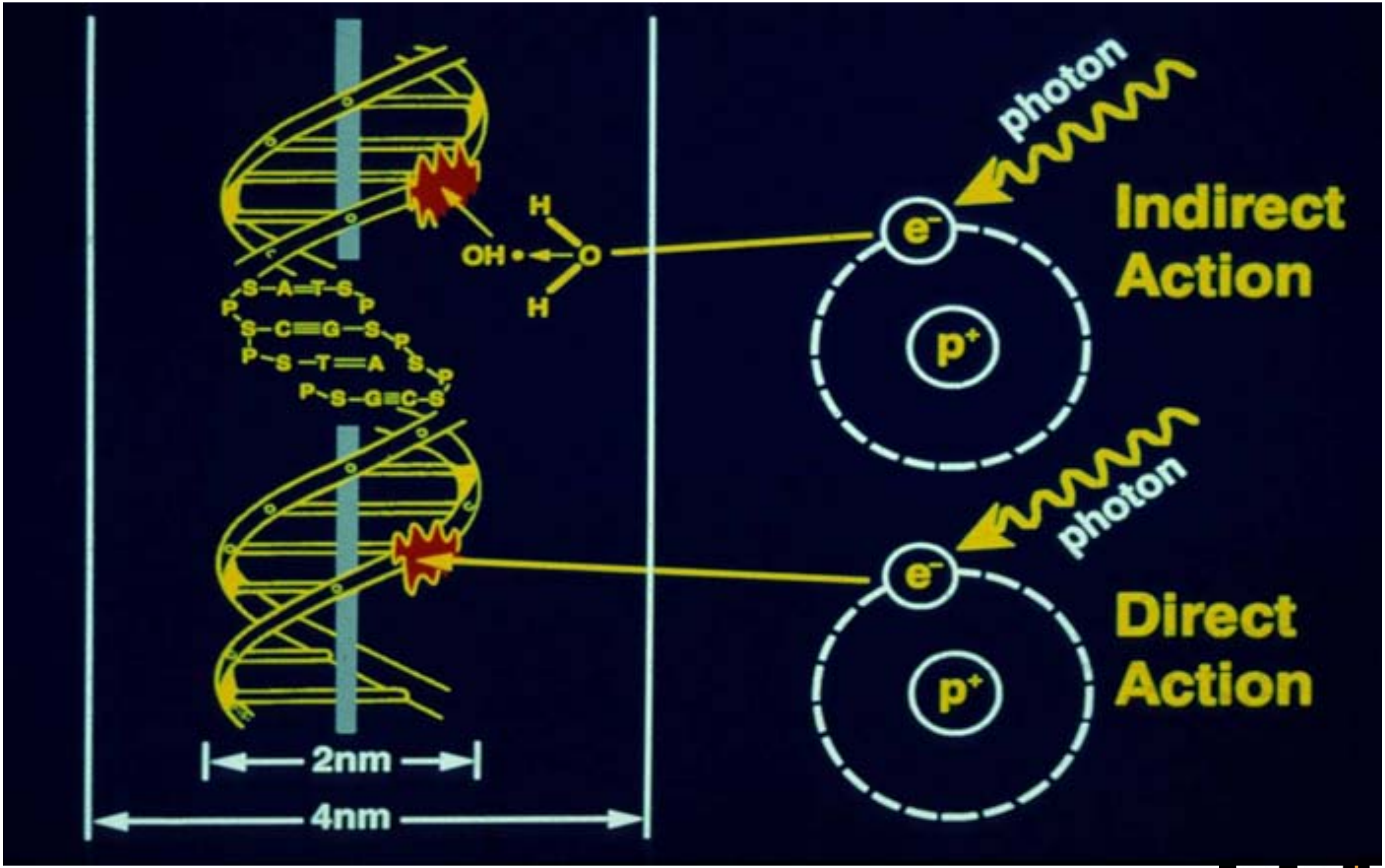
3. Radiobiology



- **High energy radiation breaks chemical bonds.**
- **This creates free radicals, like those produced by other insults as well as by normal cellular processes in the body.**
- **The free radicals can change chemicals in the body.**

The most unkindest cut of all

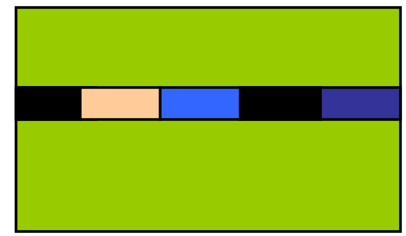
(W. Shakespeare, Julius Caesar)



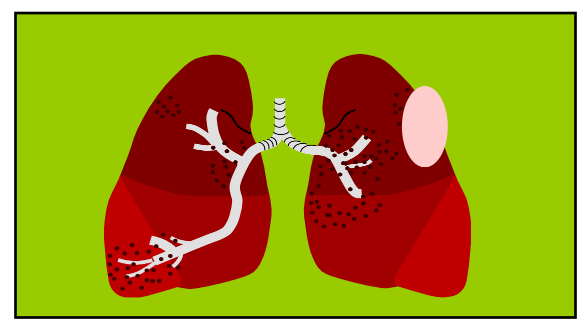
How does this damage from ionizing radiation effect our bodies?

Sufficient Cell Killing

Deterministic effects

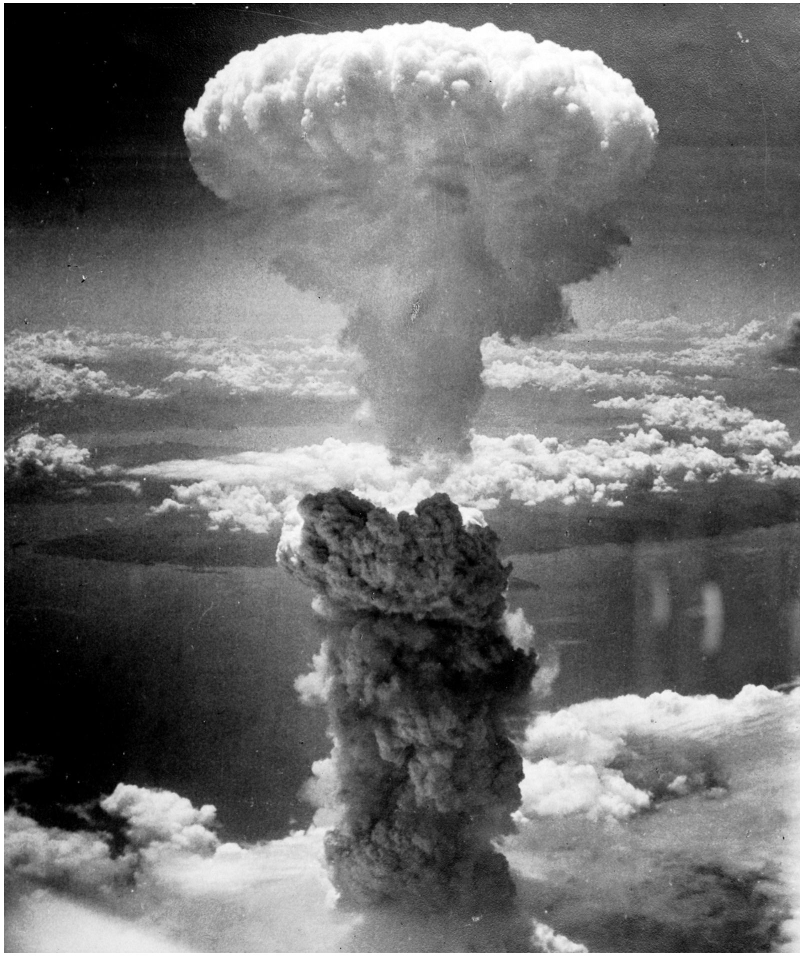


Sufficient Genetic Alterations

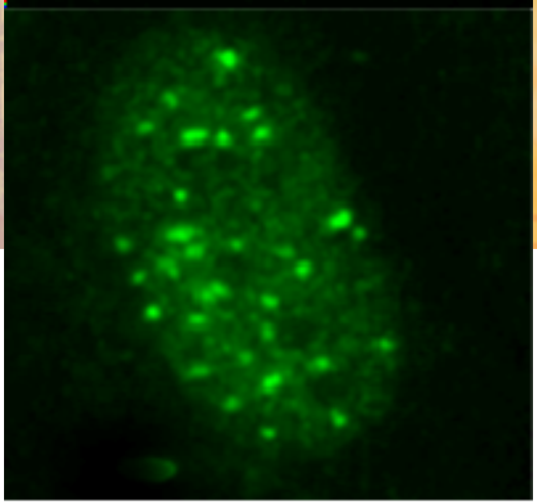


Stochastic effects

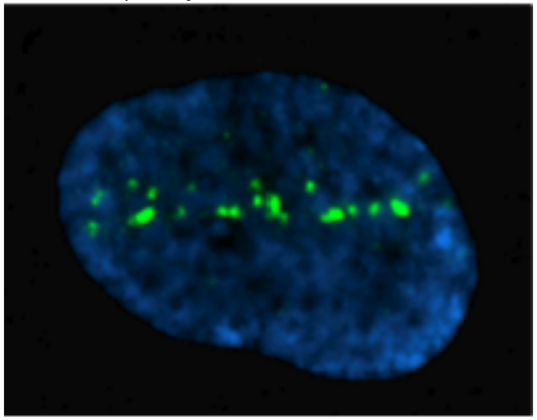
What we know about effects of terrestrial radiation (γ, X-rays) in humans



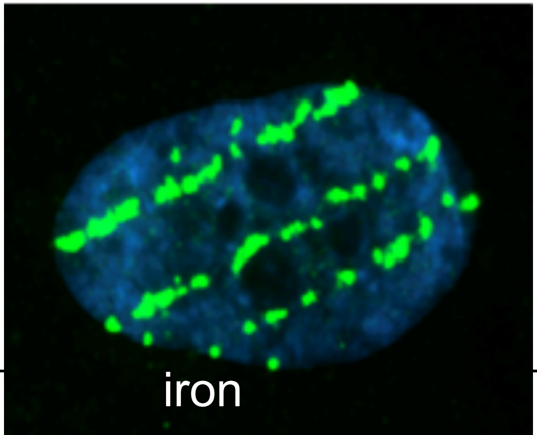
But we know little about **charged particles**….



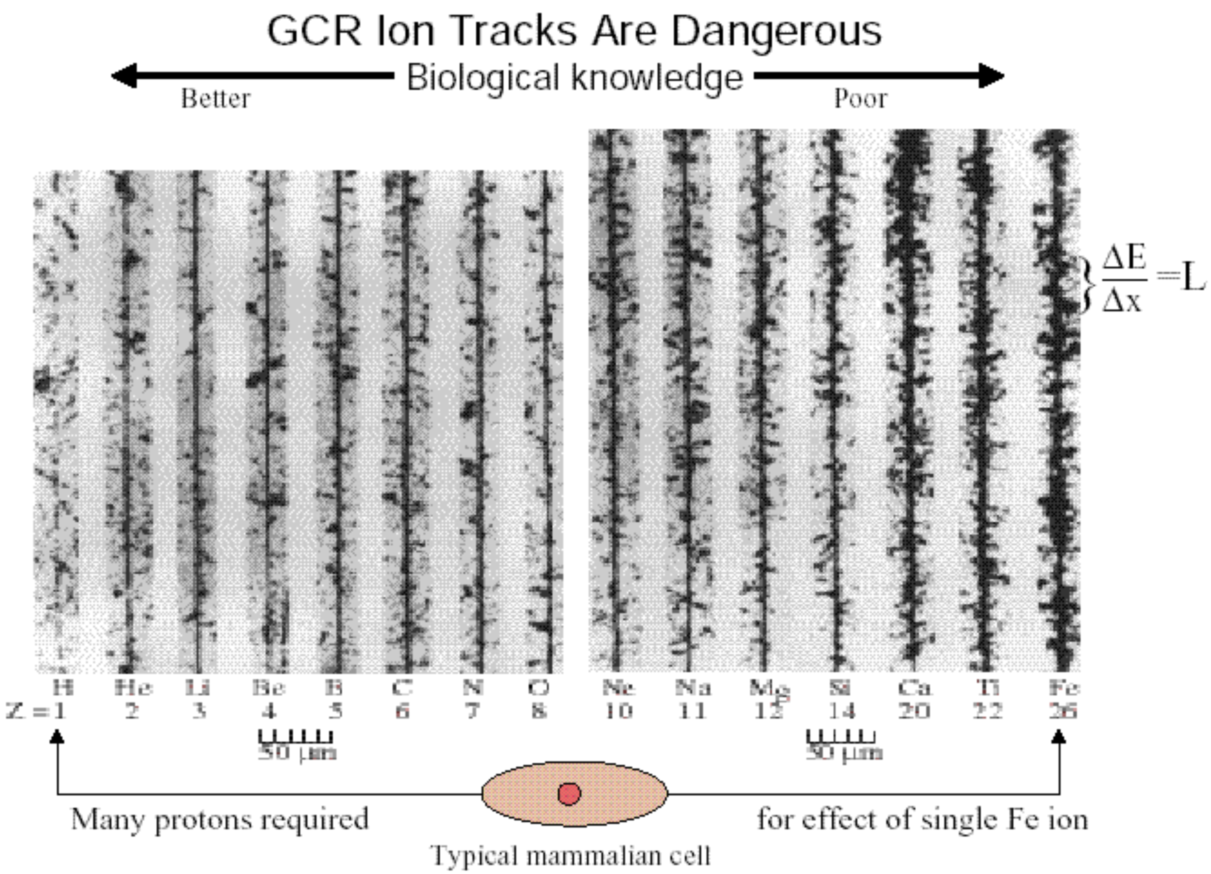
γ-rays



silicon

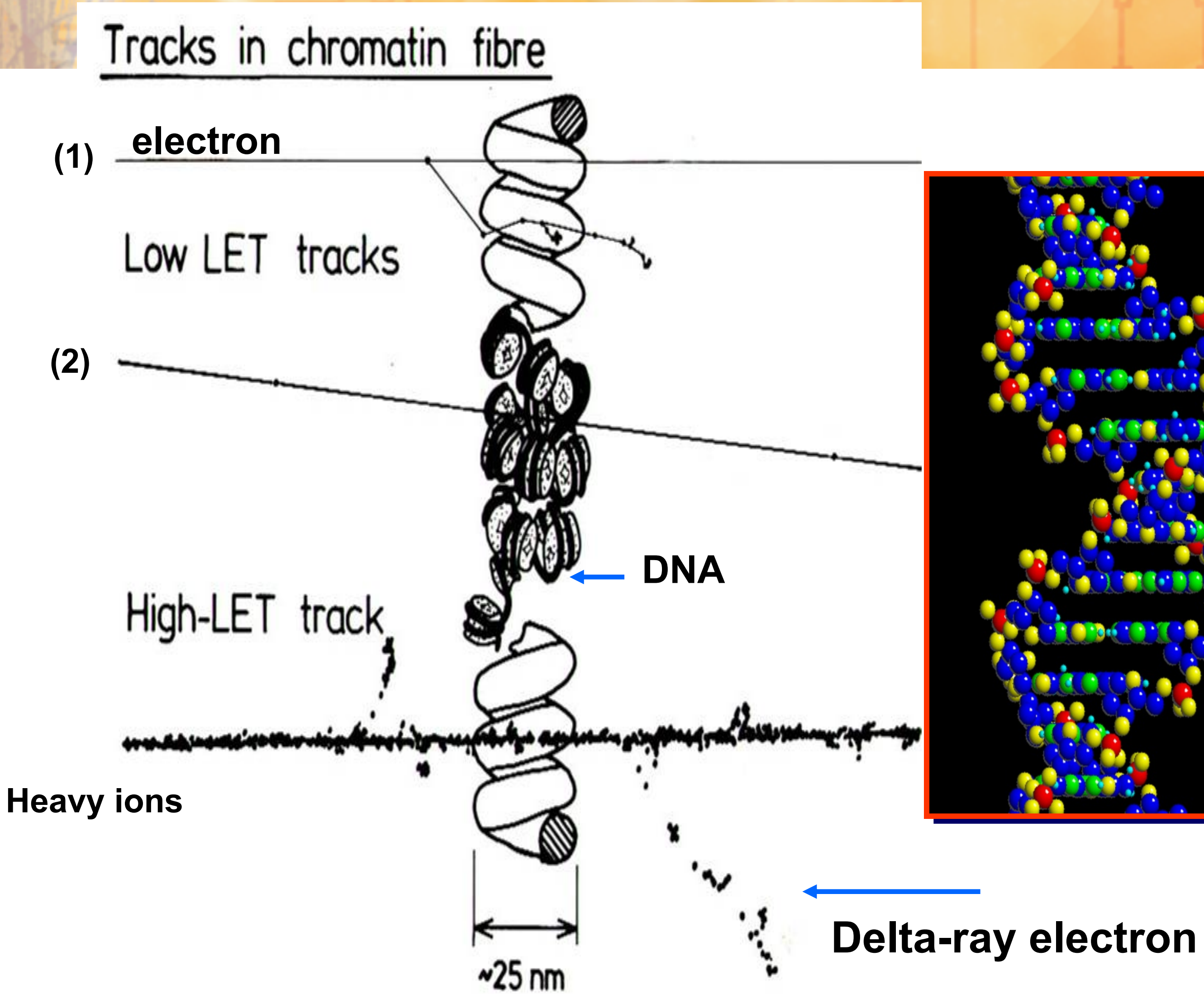


iron

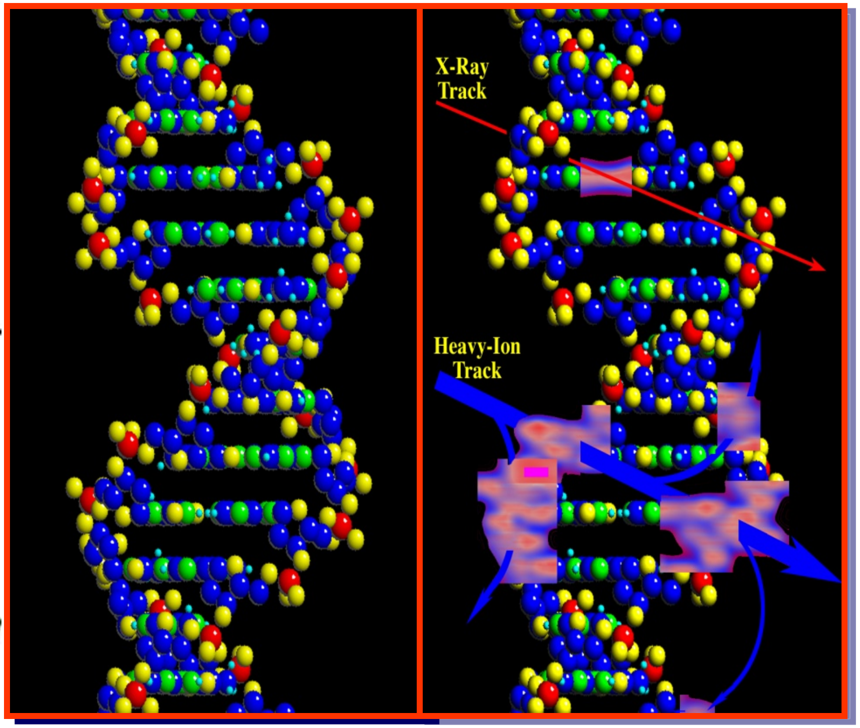


Cucinotta and Durante, *Lancet Oncol.* 2006

4. Heavy ions



Tracks in chromatin fibre
(1)
electron
Low LET tracks
(2)
DNA
High-LET track
Heavy ions
~25 nm
Delta-ray electron



X-Ray Track
Heavy-Ion Track

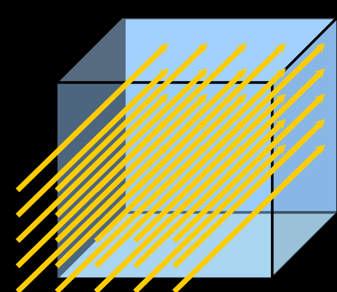
An Analogy for Structured Energy Deposition and its Consequences

Low LET radiation produces isotropic damage to organized targets.

High LET radiation produces correlated damage to organized targets.

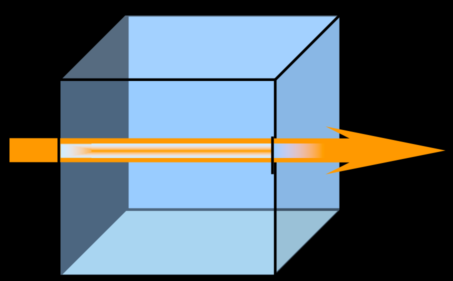
LET: Linear Energy Transfer

1 Dose Unit



Low LET radiation deposits energy in a uniform pattern

1 Dose Unit



High LET radiation deposits energy in a non-uniform pattern

Why are we interested in energetic heavy ions?

Heavy ion radiation is not present naturally on Earth

The Space Radiation Environment

Solar particle events (SPE) (generally associated with Coronal Mass Ejections from the Sun):

- medium to high energy protons
- largest doses occur during maximum solar activity
- not currently predictable
- MAIN PROBLEM: develop realistic forecasting and warning strategies

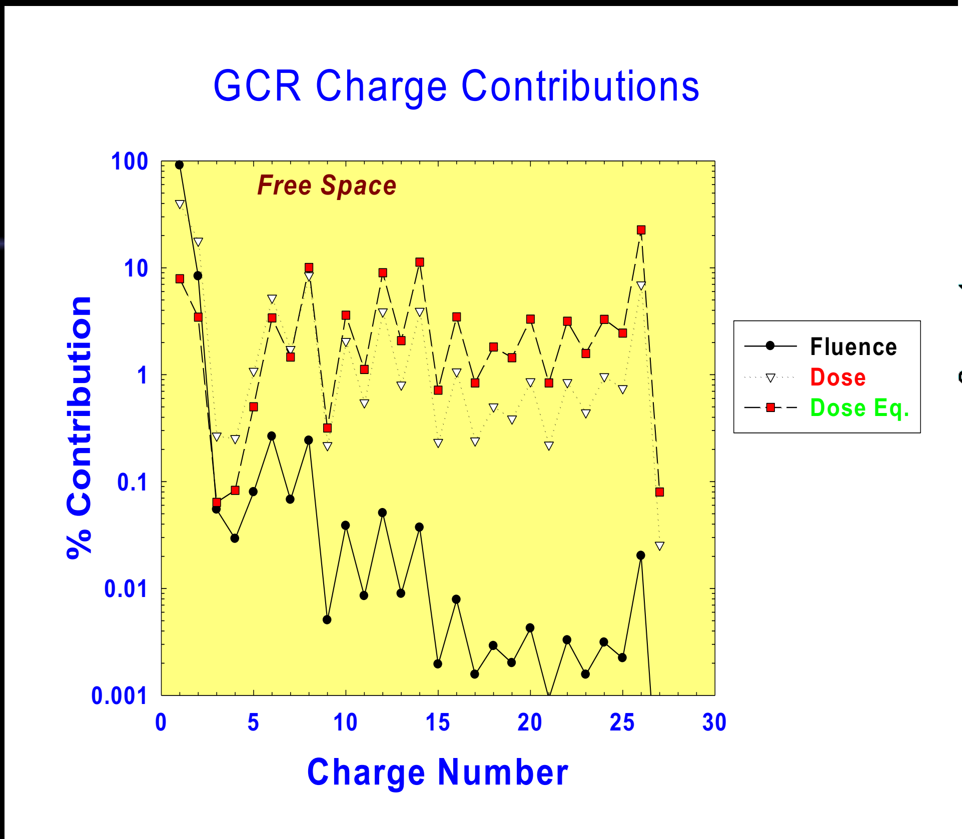
Trapped Radiation:

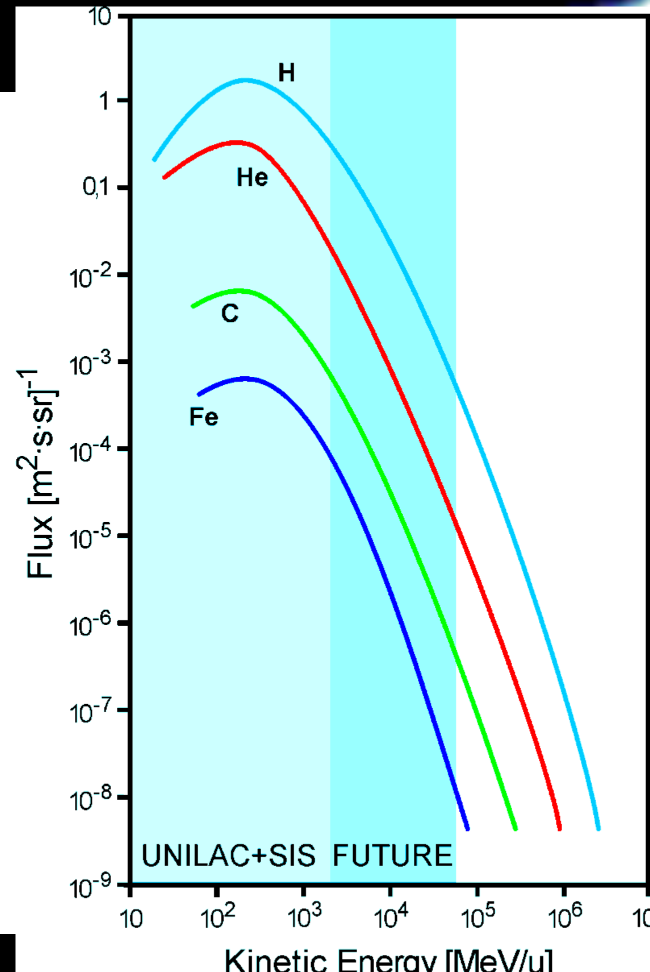
- medium energy protons and electrons
- effectively mitigated by shielding
- mainly relevant to ISS
- MAIN PROBLEM: develop accurate dynamic model

Galactic Cosmic Rays (GCR)

- high energy protons
- **highly charged, energetic atomic nuclei (HZE particles)**
- not effectively shielded (break up into lighter, more penetrating pieces)
- abundances and energies quite well known
- MAIN PROBLEM: biological effects poorly understood but known to be most significant space radiation hazard

Galctic Cosmic Radiation





Durante & Cucinotta, *Rev. Mod. Phys.* 2011


DAILY EXPRESS

MONDAY JULY 21 1969

3.56 am: 'One small step for man but one giant leap for mankind'

MAN STEPS ON TO MOON

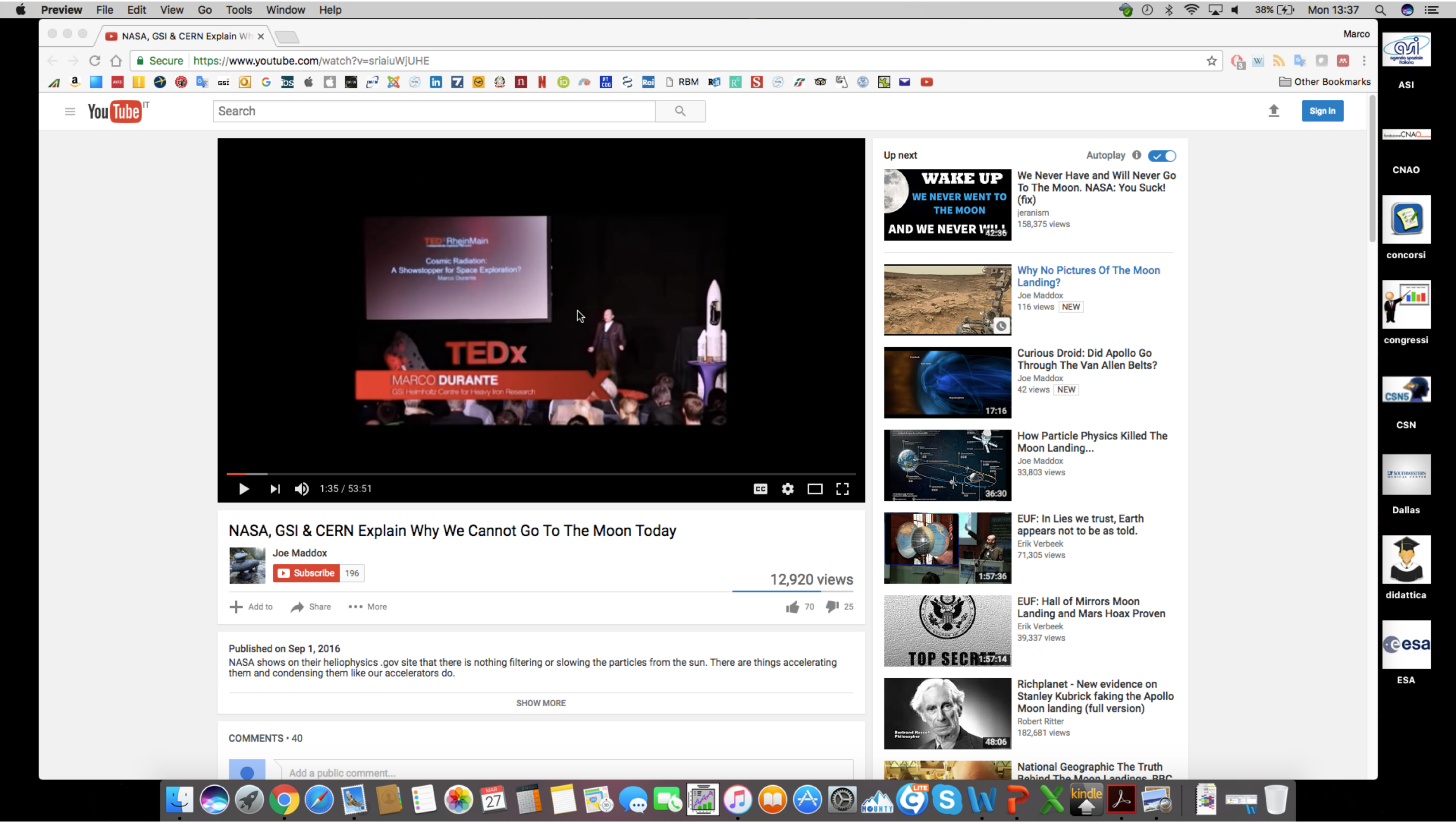
The landing: Page 2

Where next? and OPINION: Page 6

POCKET CARTOON

LATEST NIXON TALKS TO MOONMEN

Disclaimer



I do believe that humans landed on the Moon!

Health in Deep Space

1. Protection from space radiation (particularly very high energy heavy ions)
2. Psychosocial and behavioural problems
3. Physiological changes caused by microgravity

Modified by Mike Lockwood

NASA 1-year ISS twin study (March 2015-2016)

μ-gravity

- Body mass changes
- Vascular health
- Ocular structural changes

Ionizing radiation

- Telomere length regulation
- Chromosome stability
- Cognitive performance

Synergistic impairment

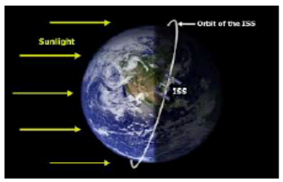
Impact by other space flight-associated stressors such as noise, isolation, loss of circadian clock, etc.

Science

AAAS

Observations for:

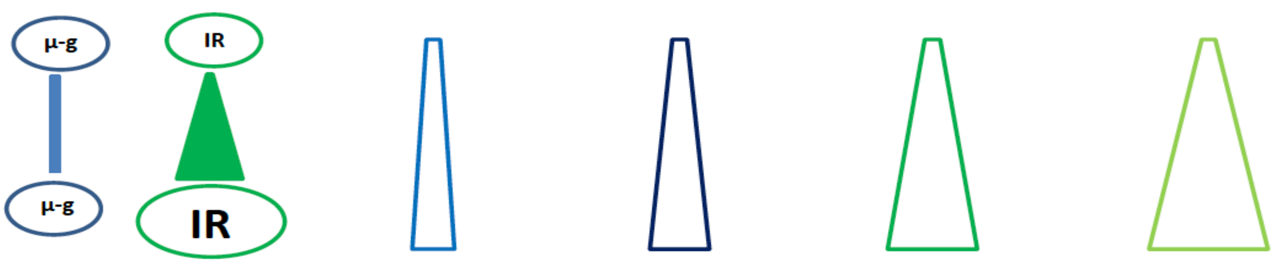
1 year in ISS orbit



Predicted risks for:

1 year in ISS orbit

Vision impairment	Cardiovascular disease	Cognitive decline	Tumour development



Predicted risks for:

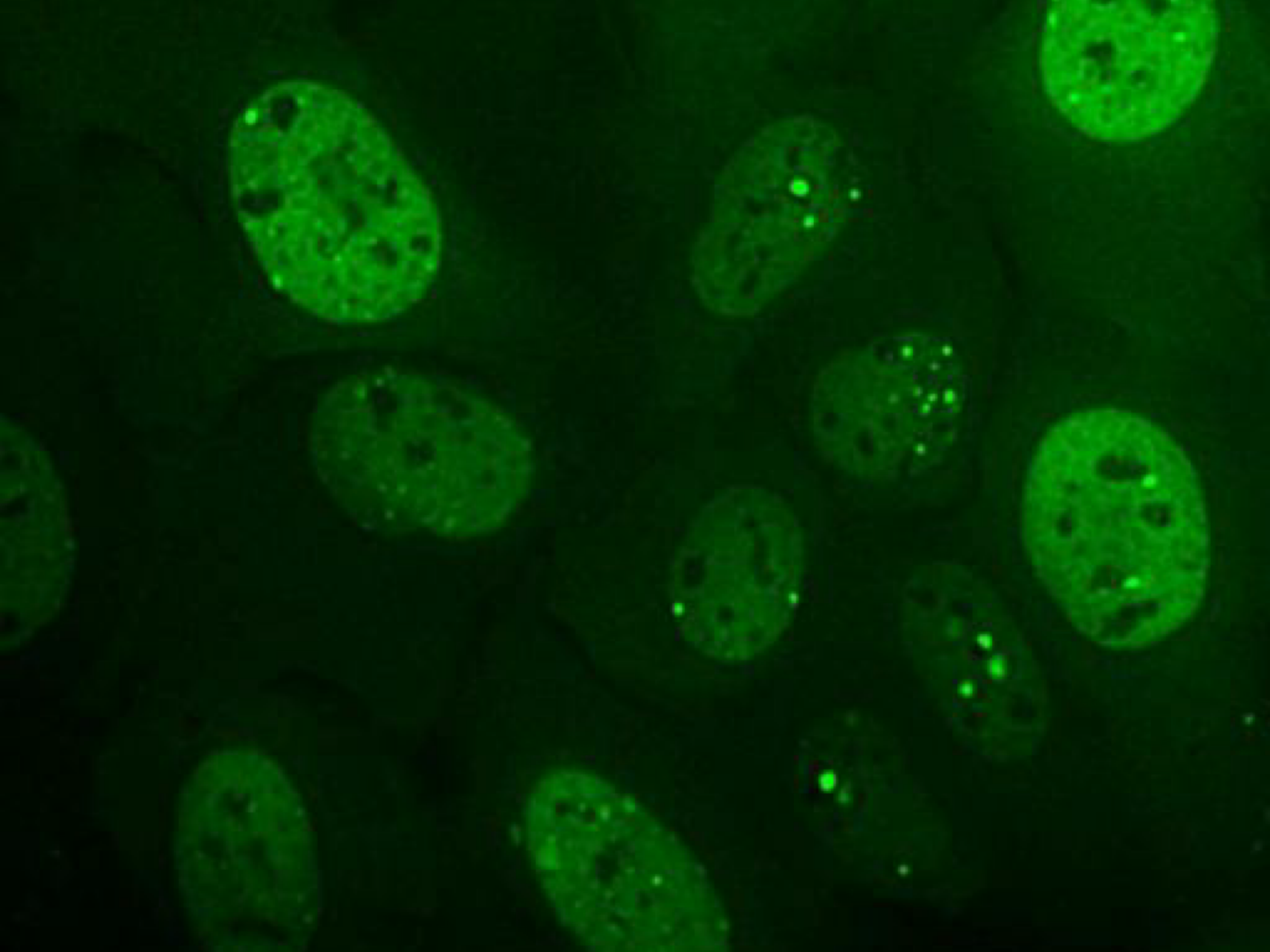
1 year Mars travel

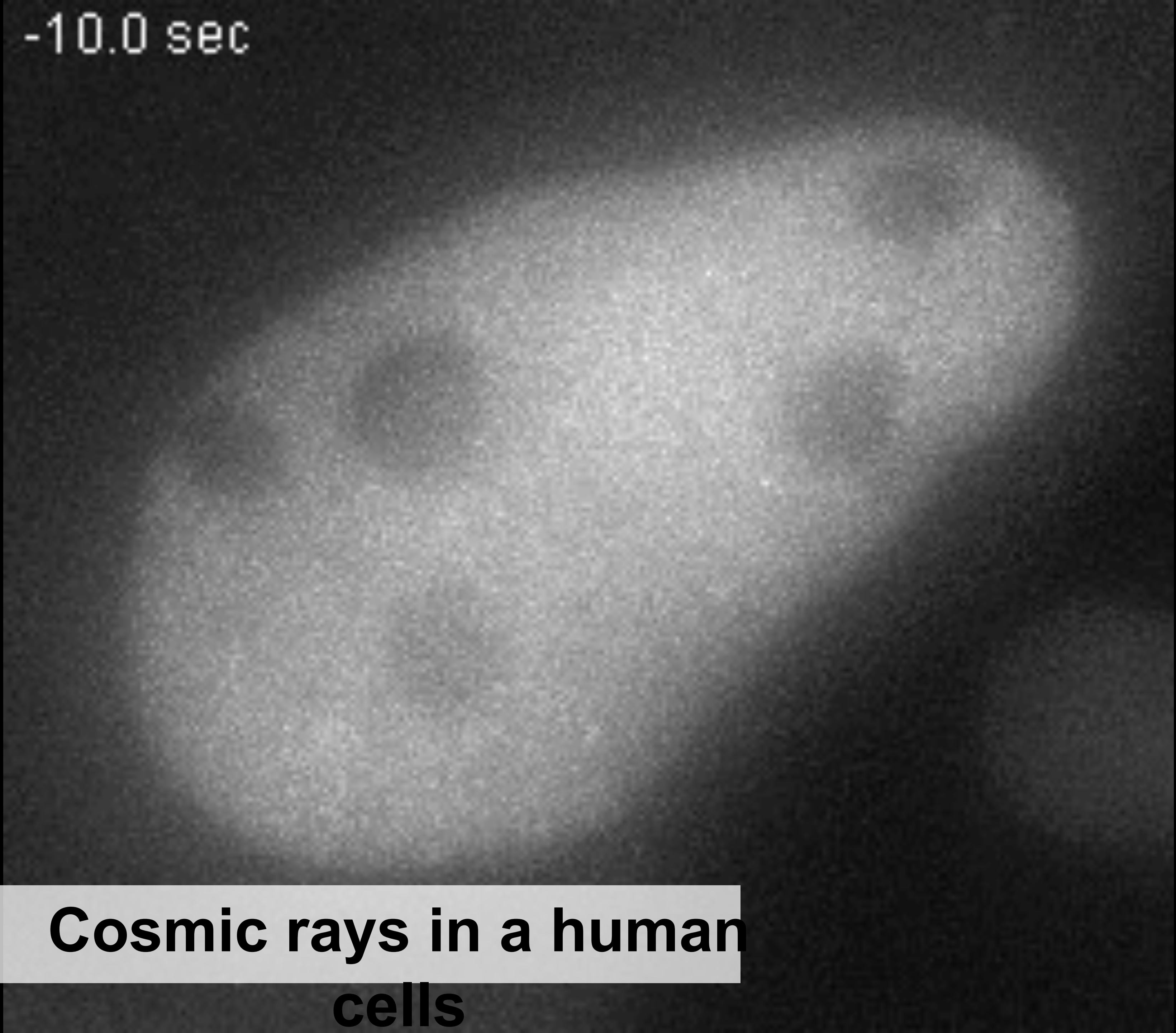
Vision impairment	Cardiovascular disease	Cognitive decline	Tumour development

Biological effects of heavy ions

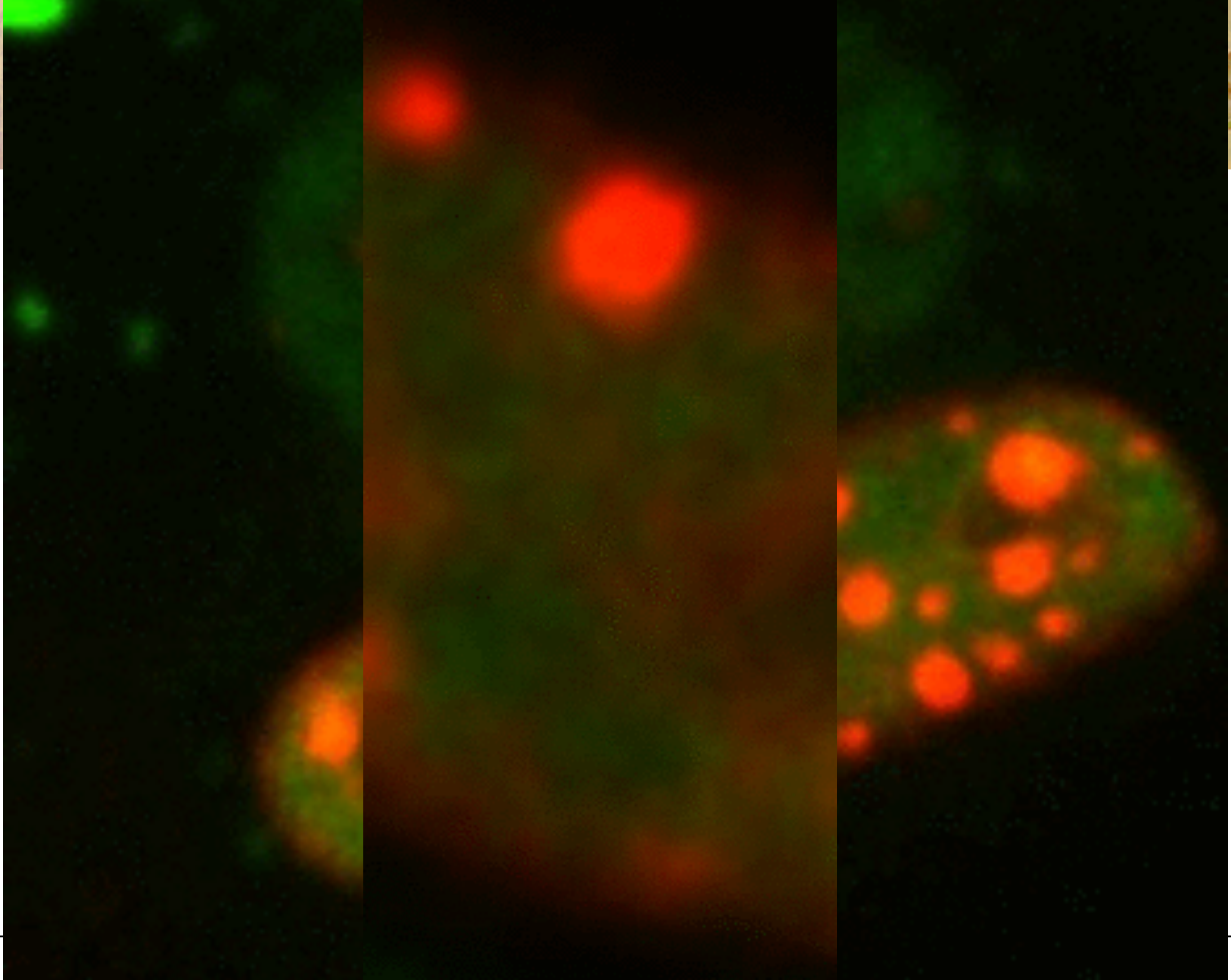
No human epidemiological data

An accelerator can simulate cosmic rays on Earth

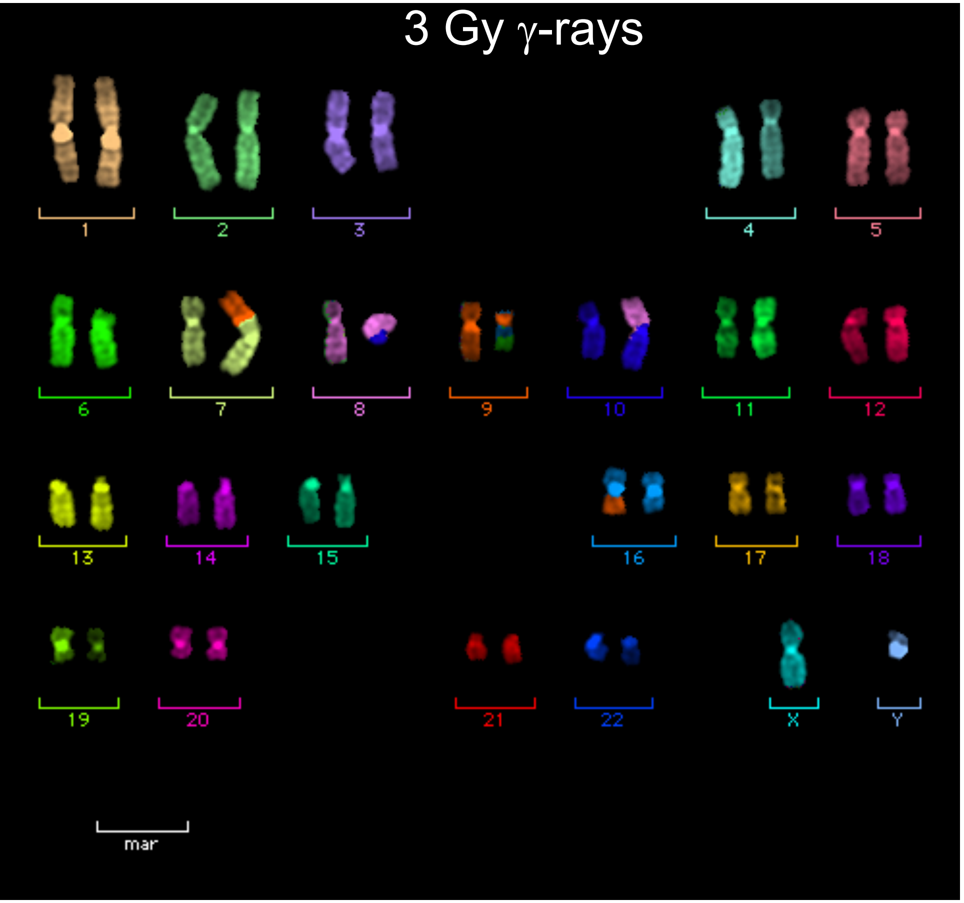


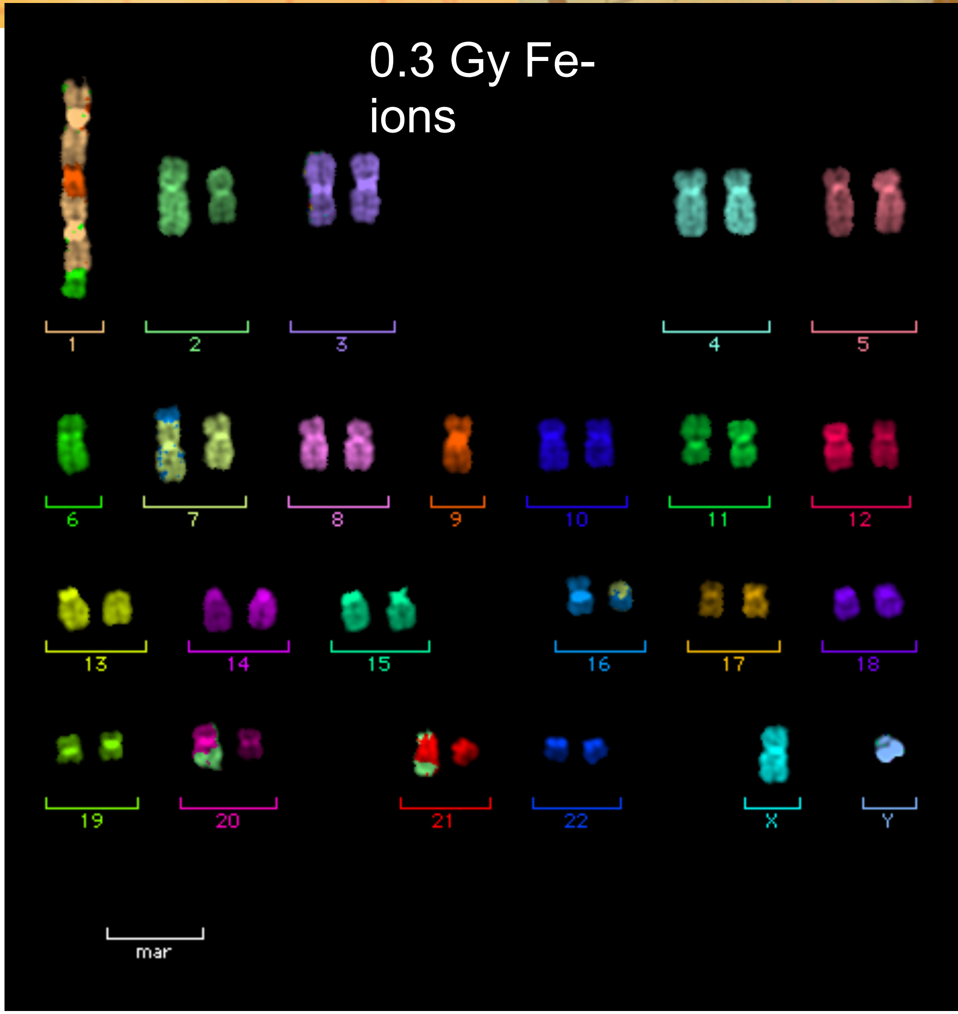


Cosmic rays in a human cells



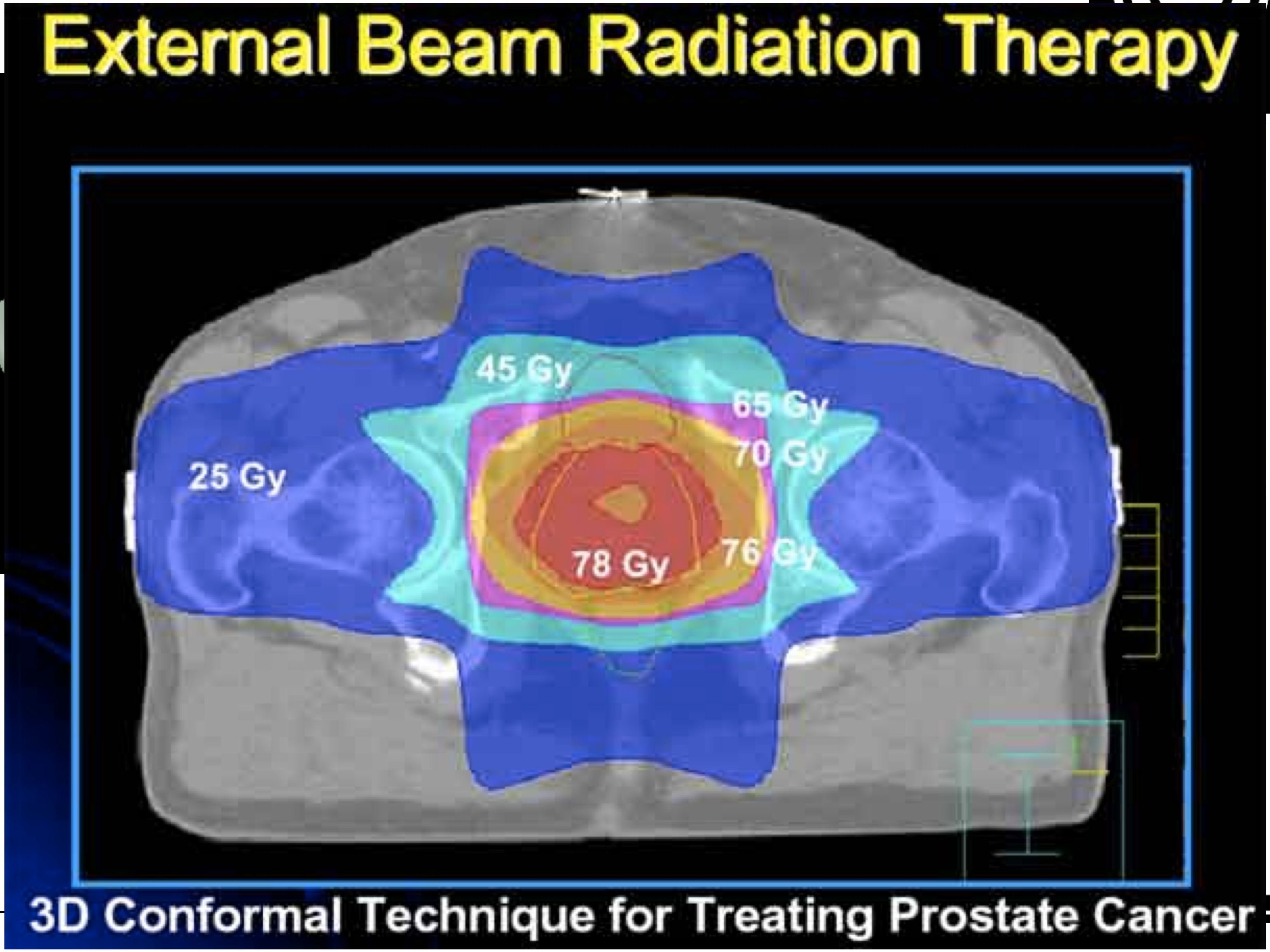
Chromosomal aberrations induced by heavy ions





Durante *et al.*, *Radiation Research* 2002

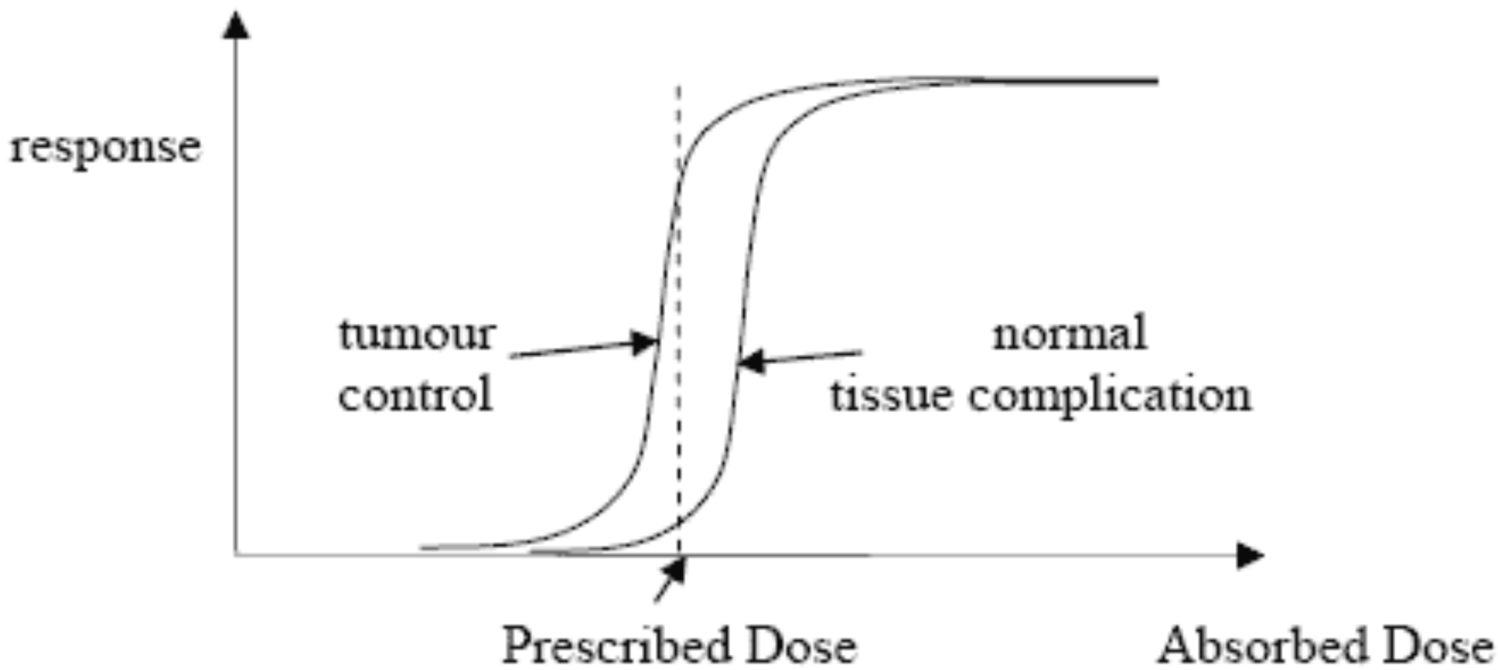
5. RADIOTHERAPY



Radiotherapy

- Also called “Radiation Therapy”
- Part of multi-disciplinary approach to cancer care
- Useful for 50-60% of all cancer patients
- Can be given for cure or palliation
- Mainly used for loco-regional treatment
- Benefits and side-effects are usually limited to the area(s) being treated

Therapeutic window



Dose-Response Curves for tumour and normal tissues

Side-effects of Radiotherapy

Acute (<1 month)

Depend on area(s) being treated

Often fatigue can occur

mucositis/esophagitis, nausea, diarrhea and redness of skin

Late (>1 month)

Pneumonitis/fibrosis of lungs

Hypothyroidism

Xerostomia

Enteritis

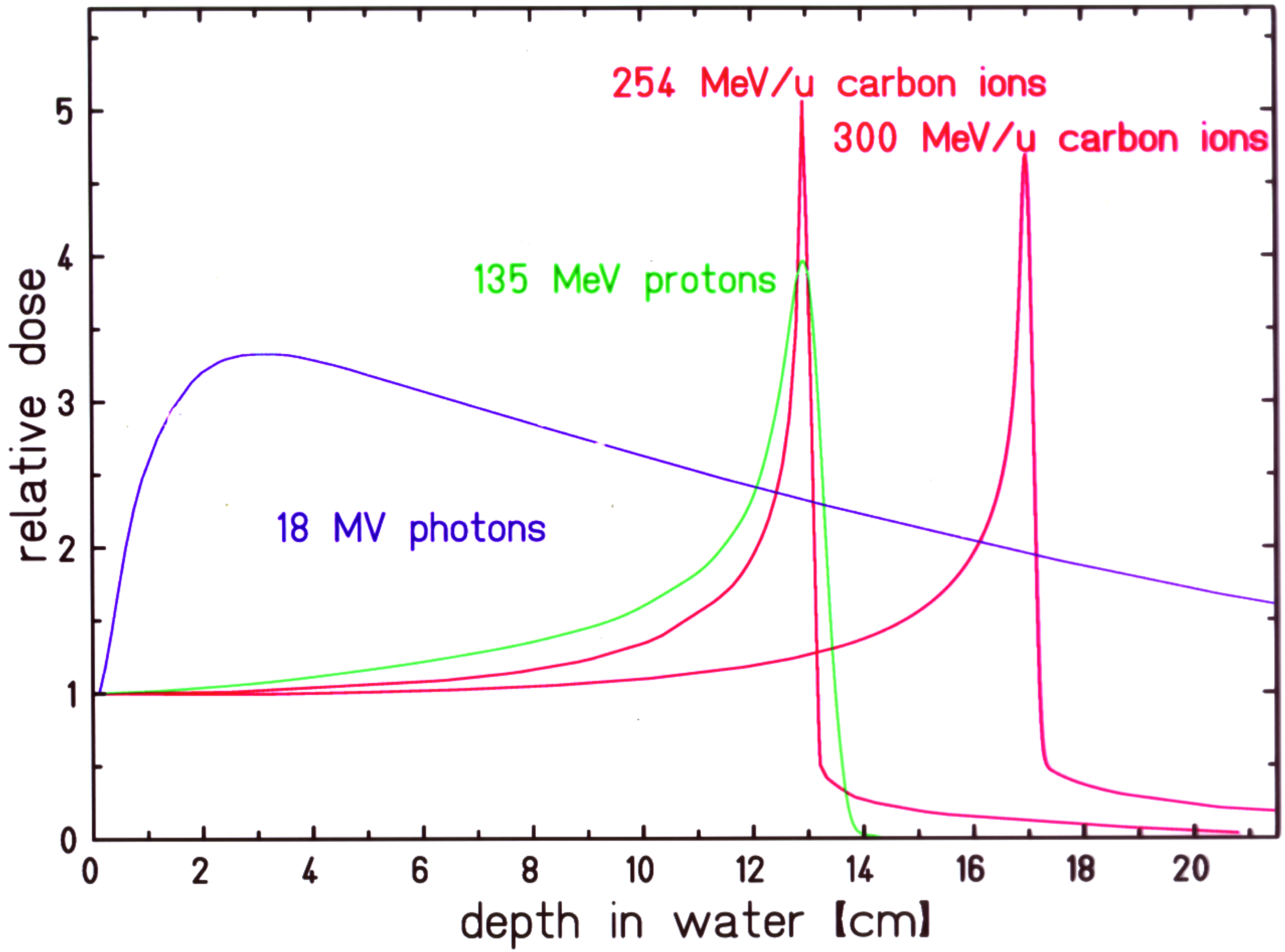
Infertility/menopause

Long-term (10-20 years)

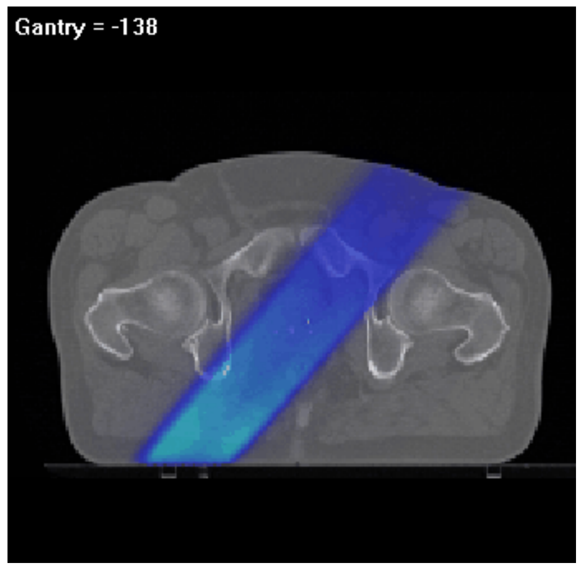
Increased risk of secondary cancers

Increased heart disease if chest region treated

Depth dose distribution of various radiation qualities

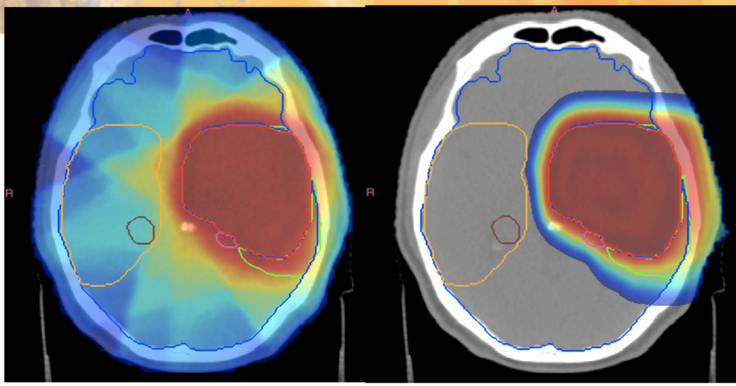


X-ray dose decrease with depth
We have to cross-fire on the tumor from many angles

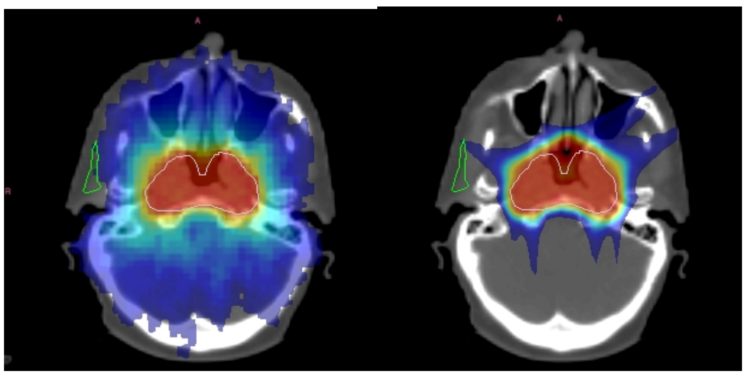
Single field	Dose per field	Total dose
		

Excellent target conformity
Large normal tissue volume irradiated

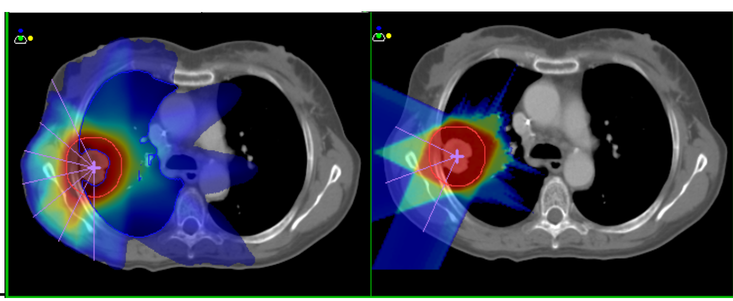
The physical advantages of particle therapy



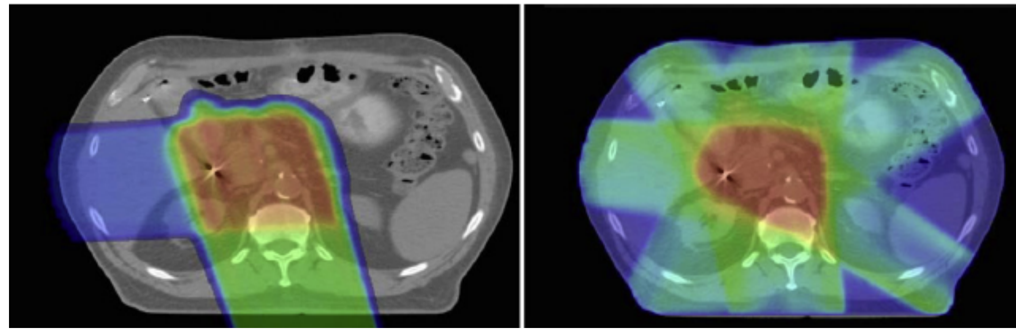
CNS



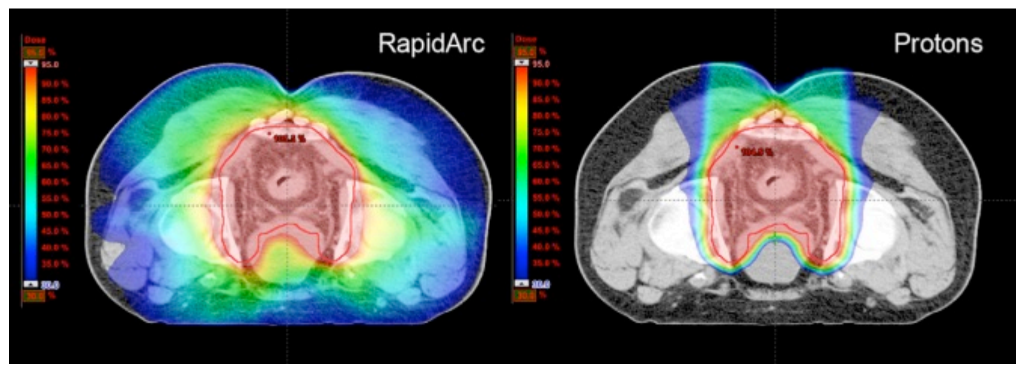
H & N



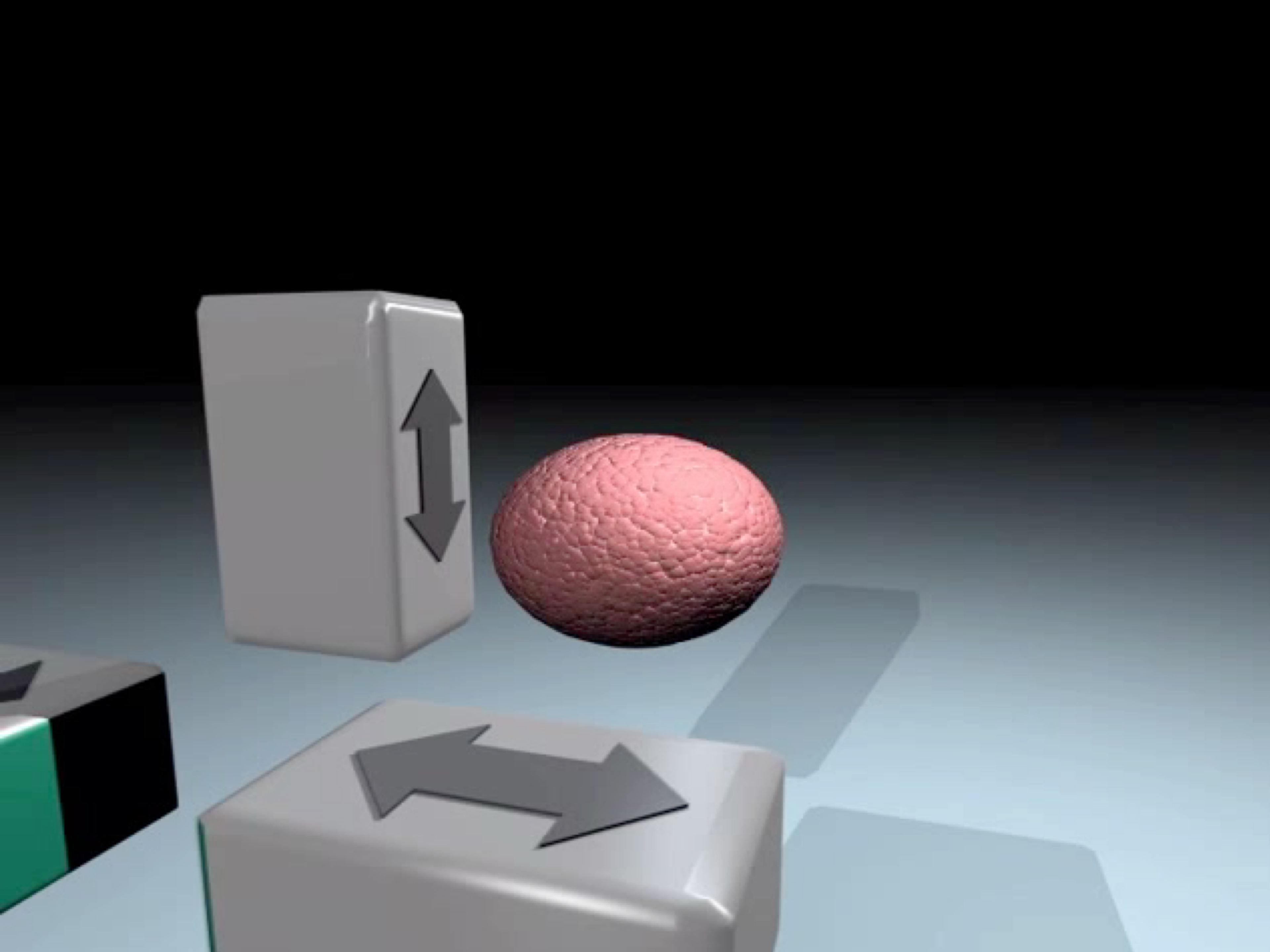
LUNG



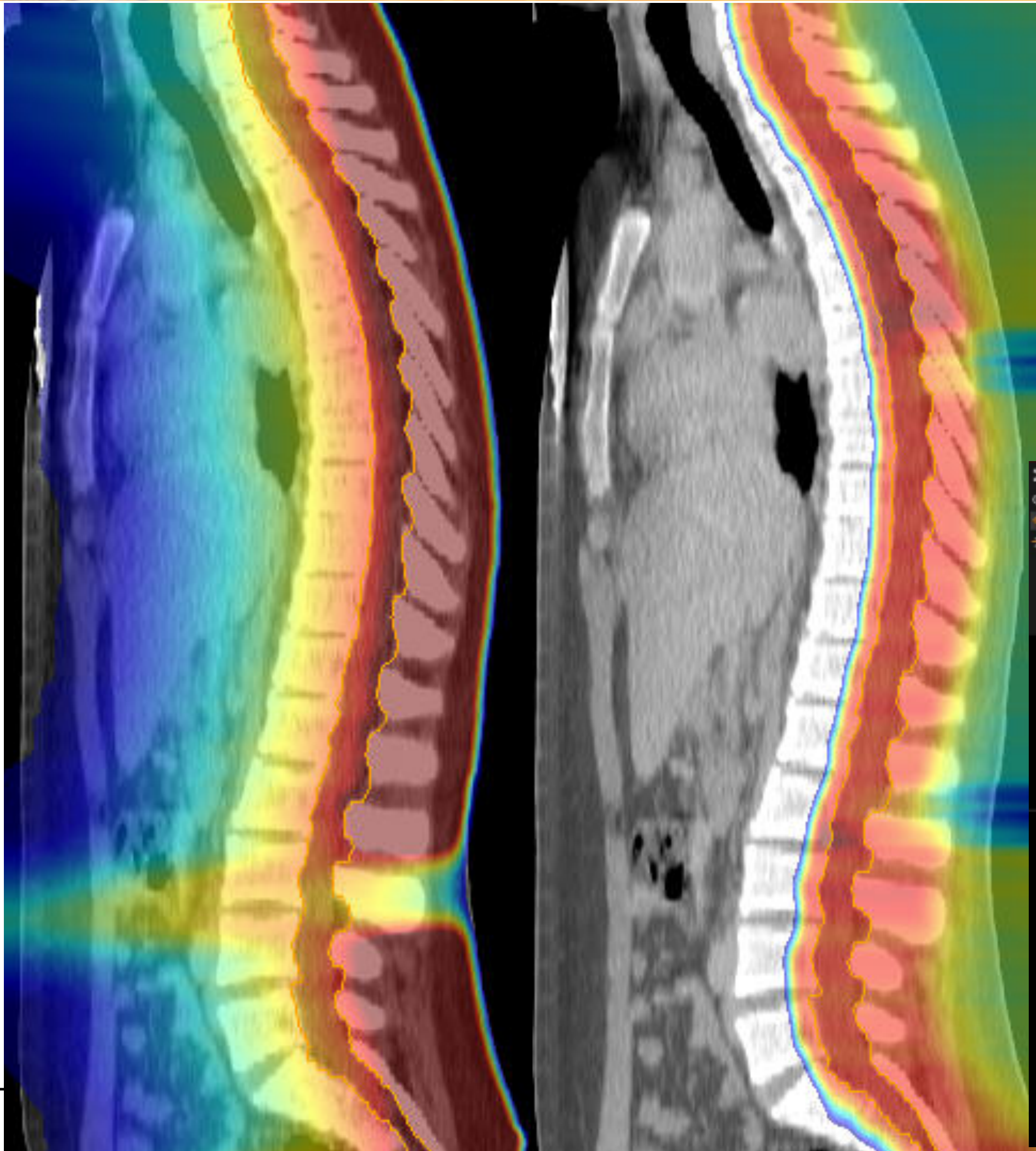
ABDOMEN

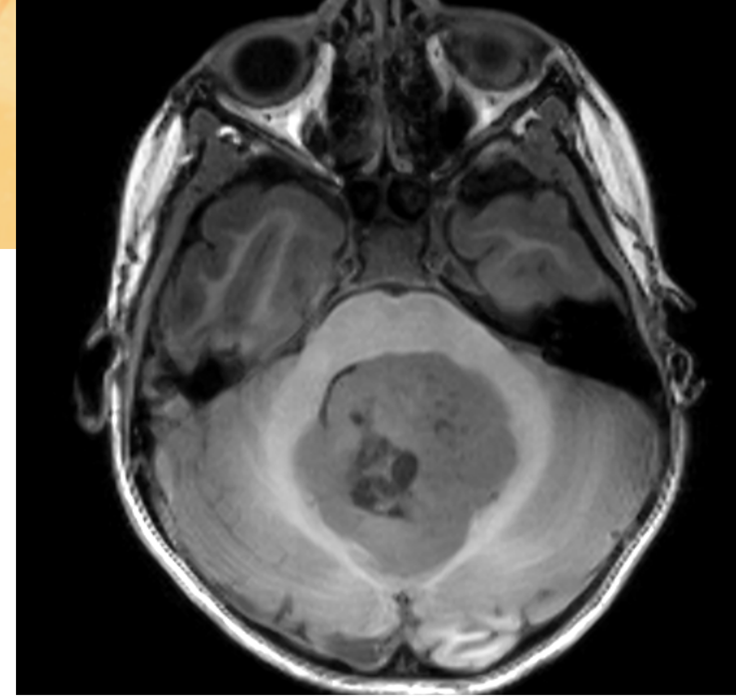


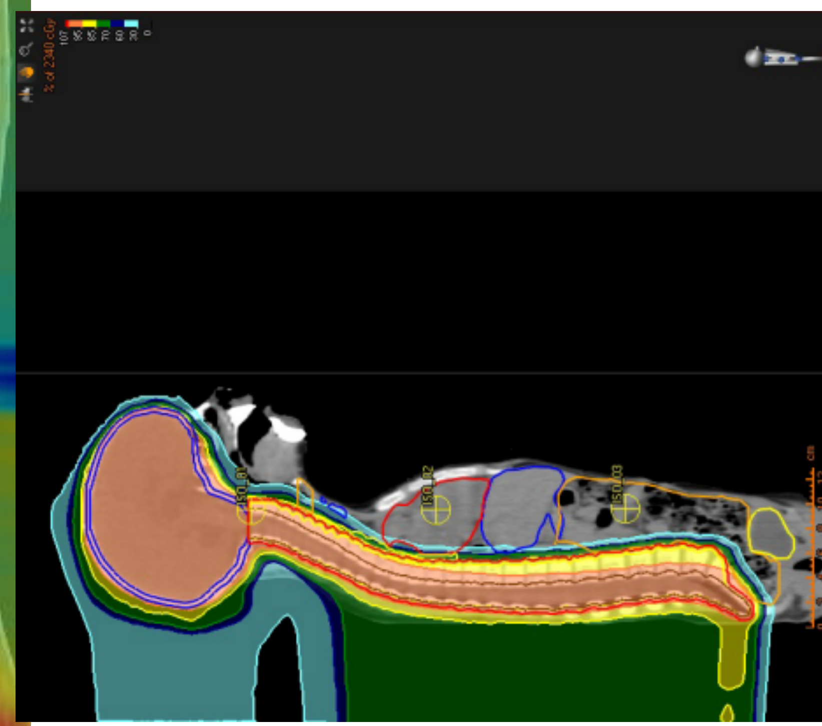
PELVIS



PEDIATRIC MEDULLOBLASTOMA







Pediatric tumors

Planning

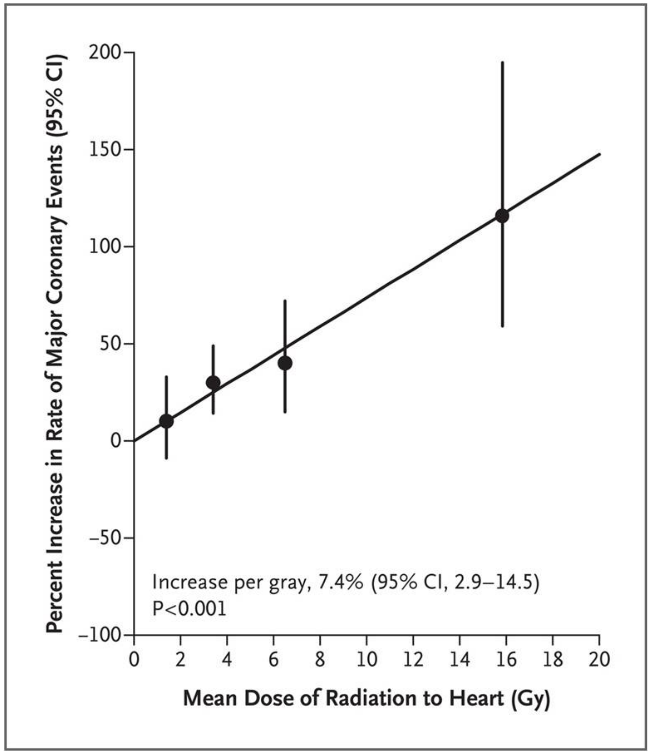
In treatment

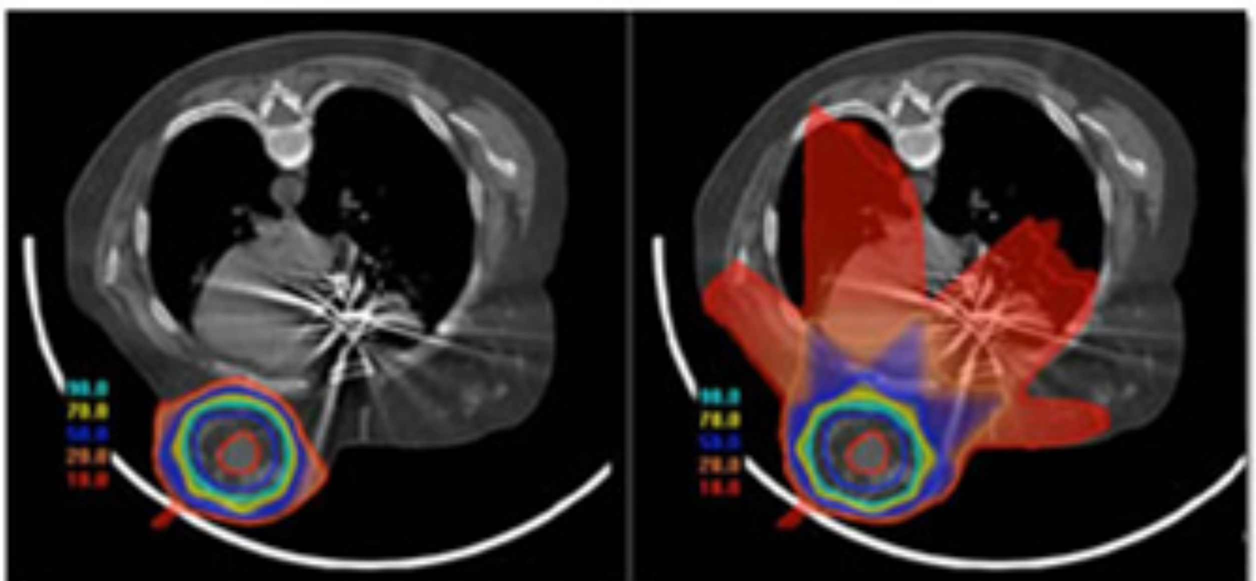
last day

6 m post- P

Breast cancer

- 1st cancer in women (1 in 8)
- survival rate 80%
- high risk of late cardiac morbidity





Breast cancer treatment: Proton left, IMRT right

14.3.2013

Bestrahlungsraum: Cave M

Röntgenröhre

Bildverstärker

Patientenmaske

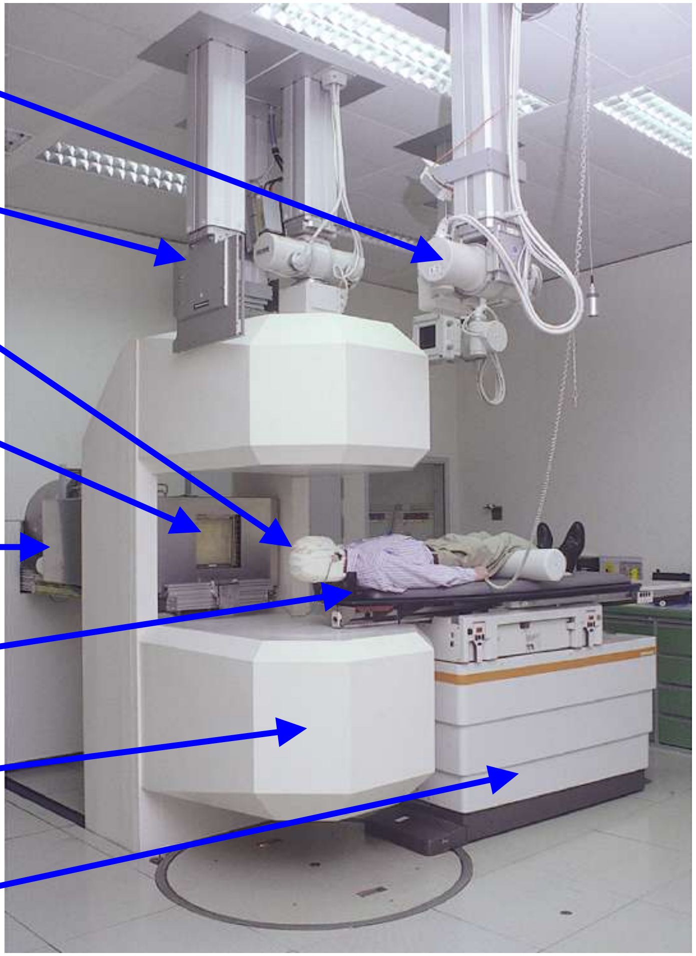
Strahlaustrittsfenster

Patientenmonitor

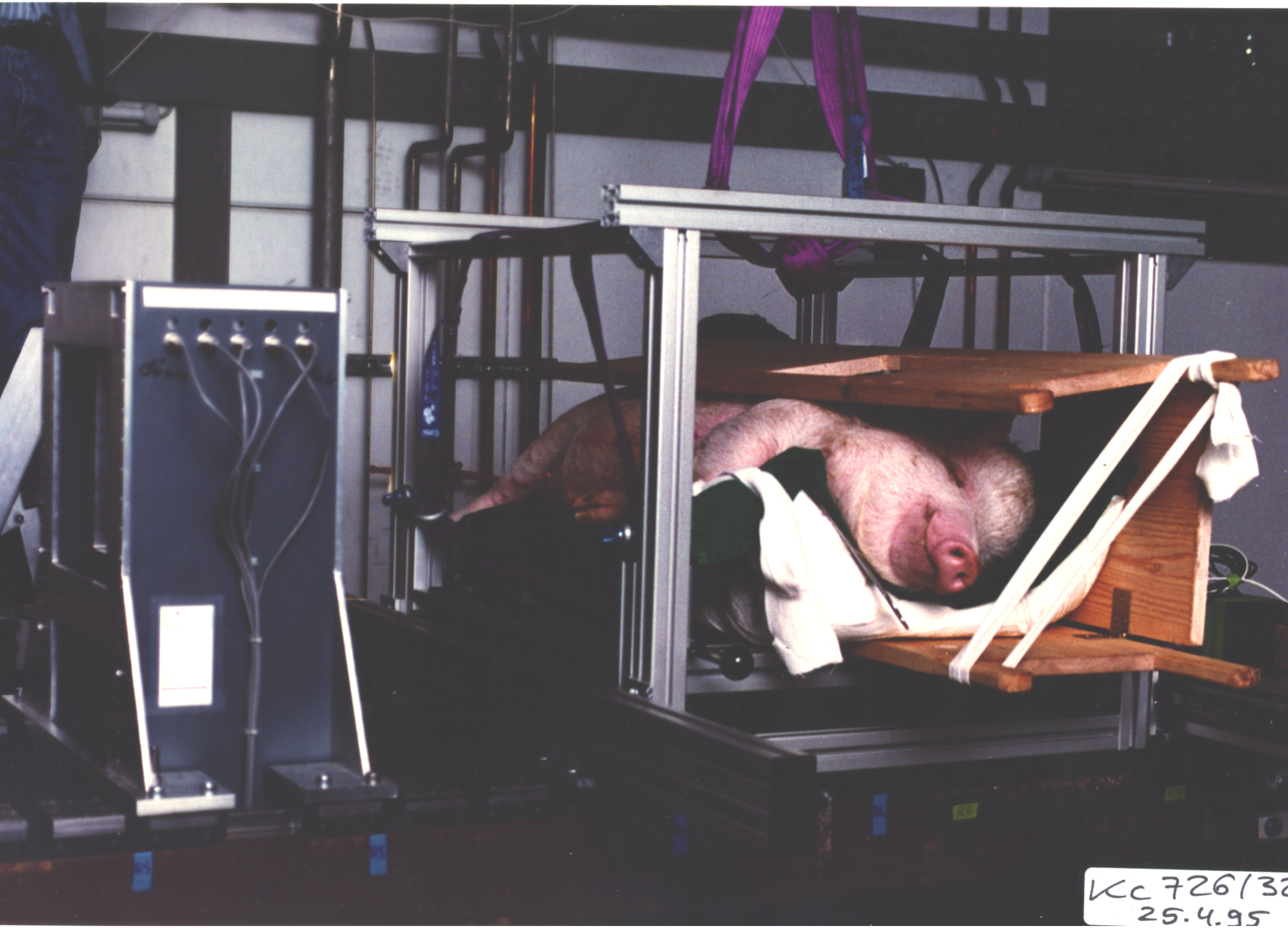
Patient

PET-Kamera

Patiententisch

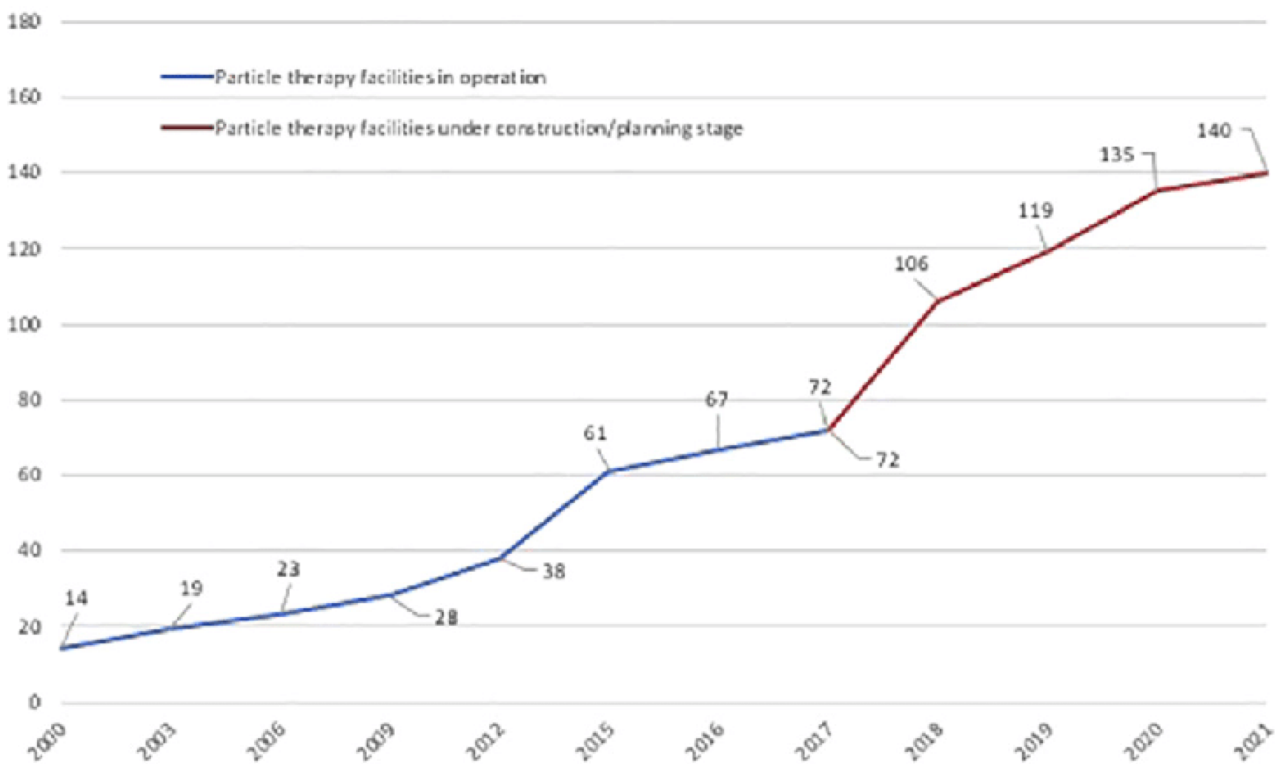


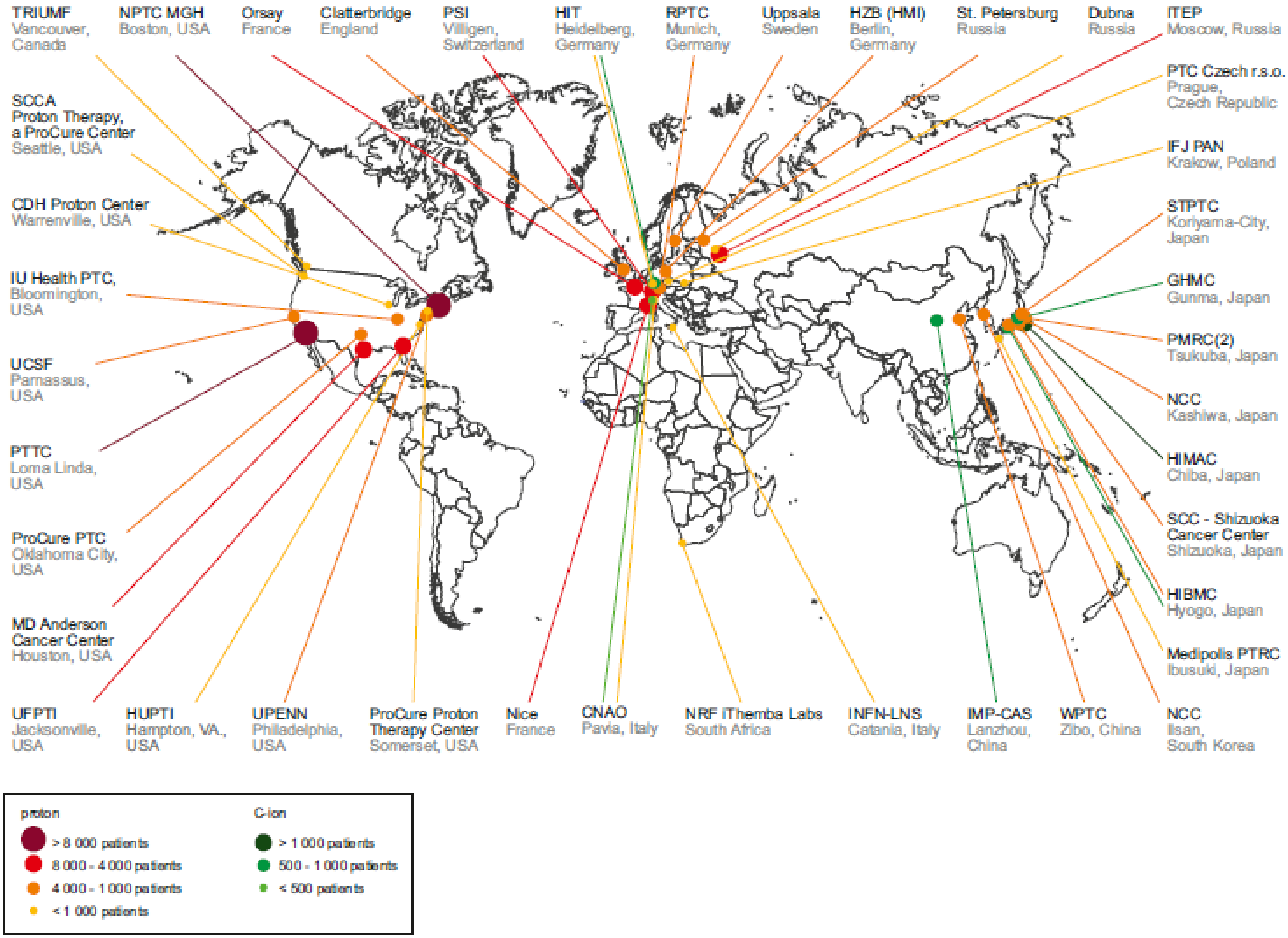

ALARM


Kc 726/3
25.4.95


Kc 879 (17A)
11.3.98

Particle therapy facilities in operation

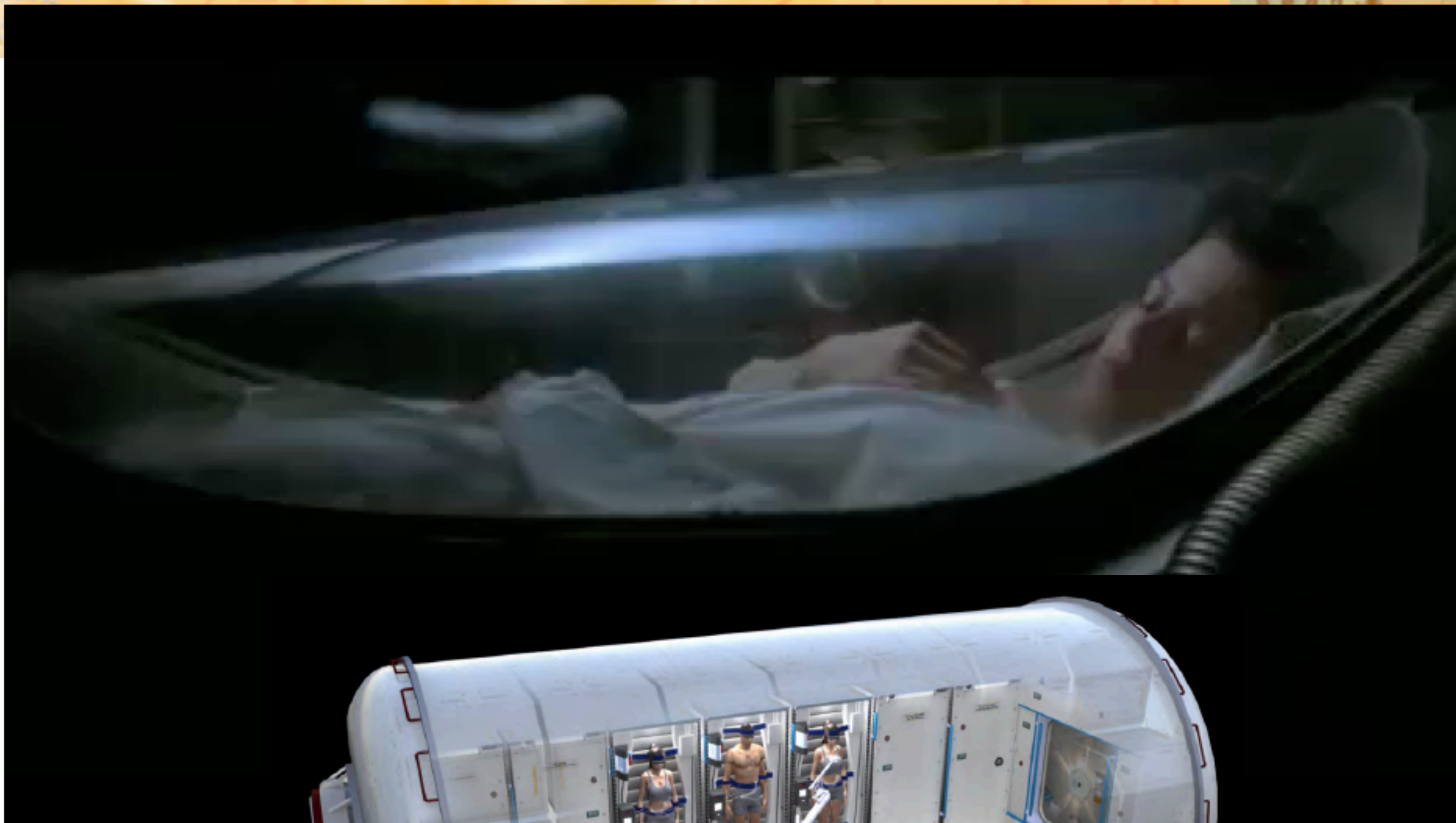


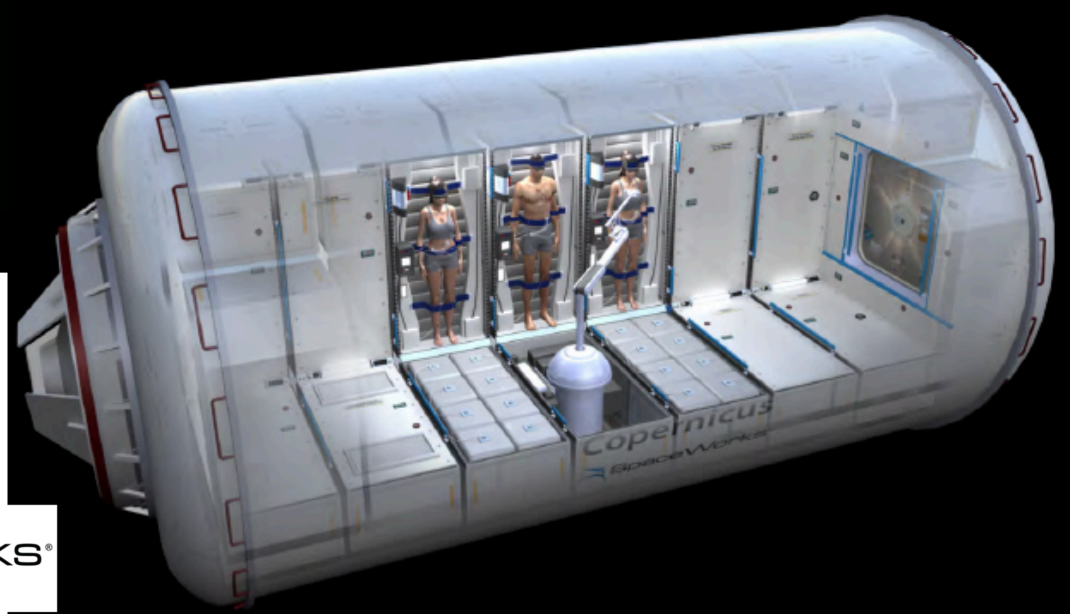


NuPECC report „Nuclear Physics in Medicine“, 2014

Available online www.nupecc.org

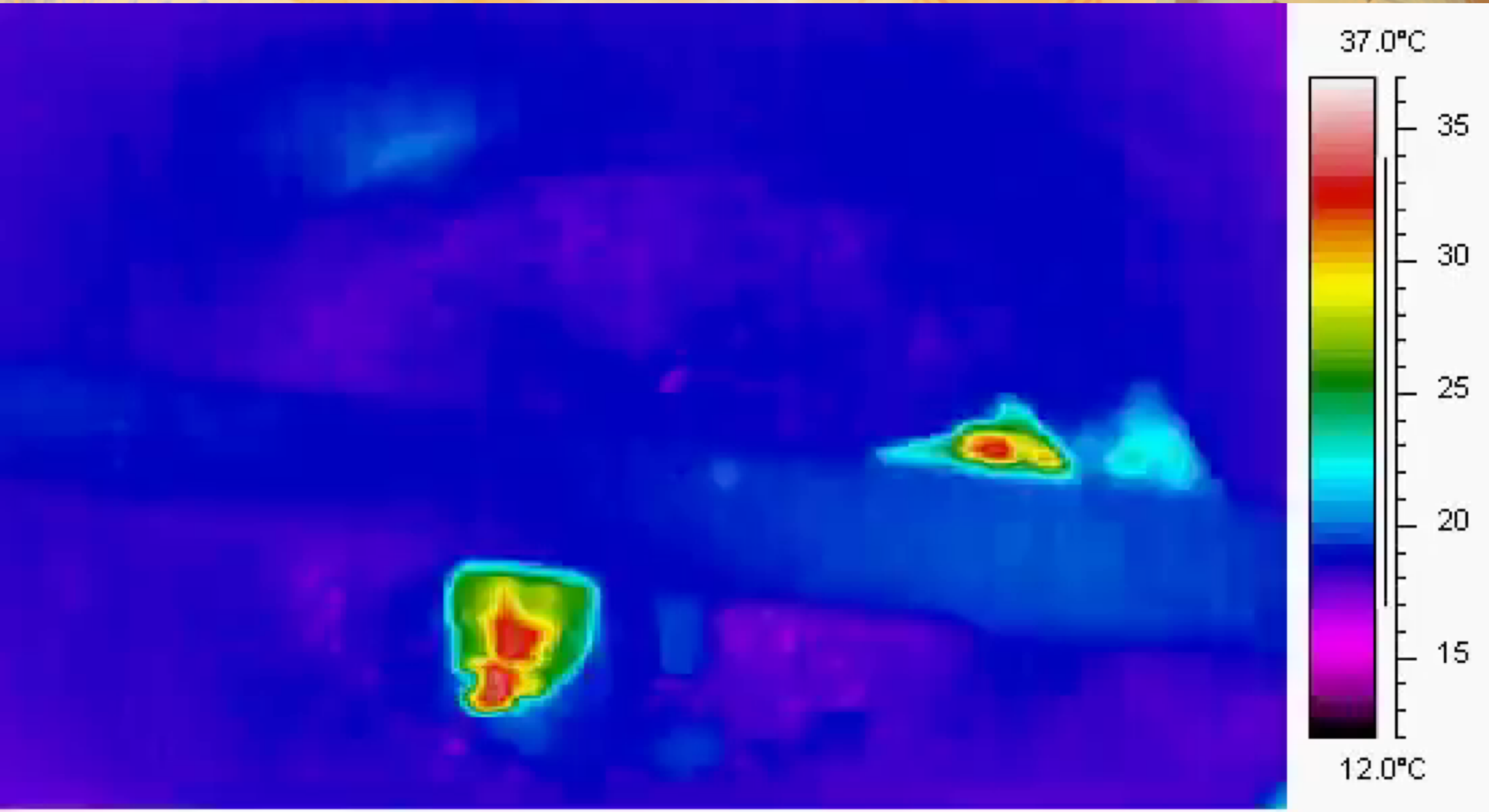
6. Space & therapy





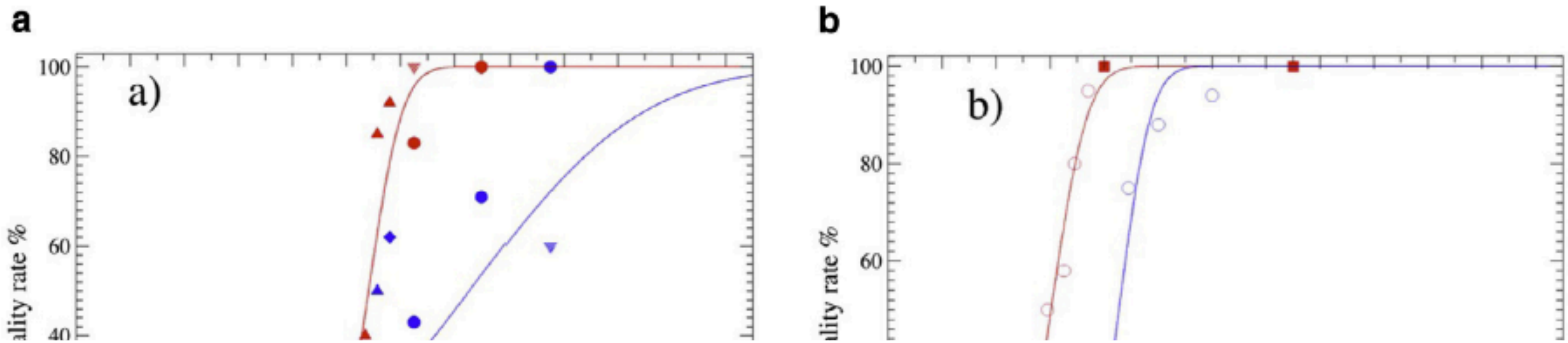
SpaceWorks

GSI



Courtesy of Prof. Matteo Cerri,
University of Bologna

Cerri *et al.*, *Life Sci. Space Res.* 2016



International Journal of
Molecular Sciences

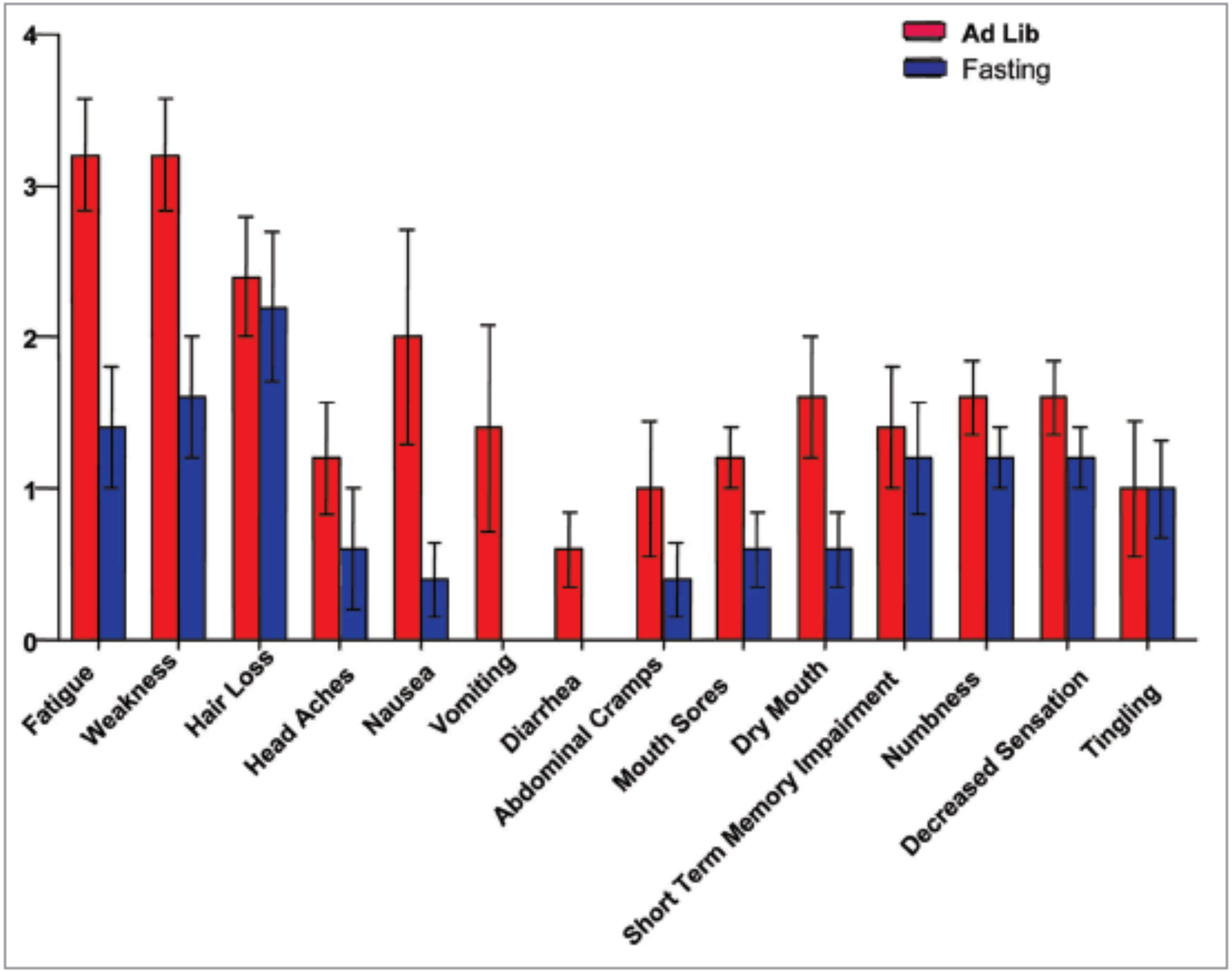
MDPI

Article

Hibernation and Radioprotection: Gene Expression in the Liver and Testicle of Rats Irradiated under Synthetic Torpor

Walter Tinganelli [1,2,†], Timna Hitrec [3,†], Fabrizio Romani [4], Palma Simoniello [5], Fabio Squarcio [3], Agnese Stanzani [6], Emiliana Piscitiello [3], Valentina Marchesano [2], Marco Luppi [3], Maximiliano Sioli [7,8], Alexander Helm [1], Gaetano Compagnone [4], Alessio G. Morganti [9], Roberto Amici [3], Matteo Negrini [7], Antonio Zoccoli [7,8], Marco Durante [1,10,*] and Matteo Cerri [3,7,*]

Hibernation in therapy?



Lee *et al.*, *Sci. Transl. Med.* 2012

International Biophysics Collaboration

iCal export More GSI Home Europe/Berlin M. Durante

Biophysics 1st International Biophysics Collaboration Meeting

20-22 May 2019
GSI Helmholtzzentrum für Schwerionenforschung GmbH
Europe/Berlin timezone

Registration is now open

- Overview
- Scope
- Scientific Programme
- Timetable
- Contribution List
- Author List
- Participant List
- Registration
  - Registration Form

Local support
r.pleskac@gsi.de

FAIR GSI TECHNISCHE UNIVERSITÄT DARMSTADT

The Facility for Antiprotons and Ion Research (FAIR) is the new International accelerator facility presently under construction at the site of the GSI Helmholtz Institute in Darmstadt, Germany. The new facility, where various physics programs can be operated in parallel, will offer outstanding research opportunities and discovery potential for about 3000 scientists from about 50 countries. International Collaborations in hadronic physics, nuclear structure etc. are already actively working to prepare the experiments for the opening of FAIR.

FAIR will also host an intense and innovative program in applied nuclear physics (APPA), and in particular in biophysics. In fact, FAIR can offer unique opportunities for biomedical research. The production of very high energy (10 GeV/n) heavy ions is very important for studies in space radiation protection, both in biology and microelectronics. The high energy can also be used for particle radiography and theranostics, whereas the high intensity of the FAIR beams gives opportunities for using high-energy radioactive ion beams and ultra-high dose rates in particle therapy, and for the production of new radioisotopes.

On **May 20-22, 2019** we will host at GSI in Darmstadt the

1st Meeting of the International Biophysics Collaboration

Every scientists interested in biomedical applications at particle accelerator is invited to contribute with your ideas and proposals. The participation is free, but registration on this webpage is mandatory. All information on the meeting will be posted on this website.

The International Biophysics Collaborations goes beyond FAIR. In fact, there are many new accelerator facilities under construction all over the world (e.g. NICA in Russia, RAON in Korea, FRIB in USA, SPIRAL2 and SPES in Europe, etc.) where applied nuclear physics program are planned and biomedical research will be possible. The International Collaboration that we want to create will serve all these facilities, and will develop research programs and specific devices for use at various accelerators. The meeting will create a community of applied nuclear physics at accelerators that will look for new exciting research opportunities generated by the new facilities. To give a structure to the Collaboration, we will elect a spokesperson and an executive committee that will establish working groups and task forces on different topics.

We look forward to seeing you in Darmstadt!

Prof. Dr. Marco Durante

Director, Biophysics Department
GSI Helmholtzzentrum für Schwerionenforschung

Future biomedical research at FAIR and other new accelerators

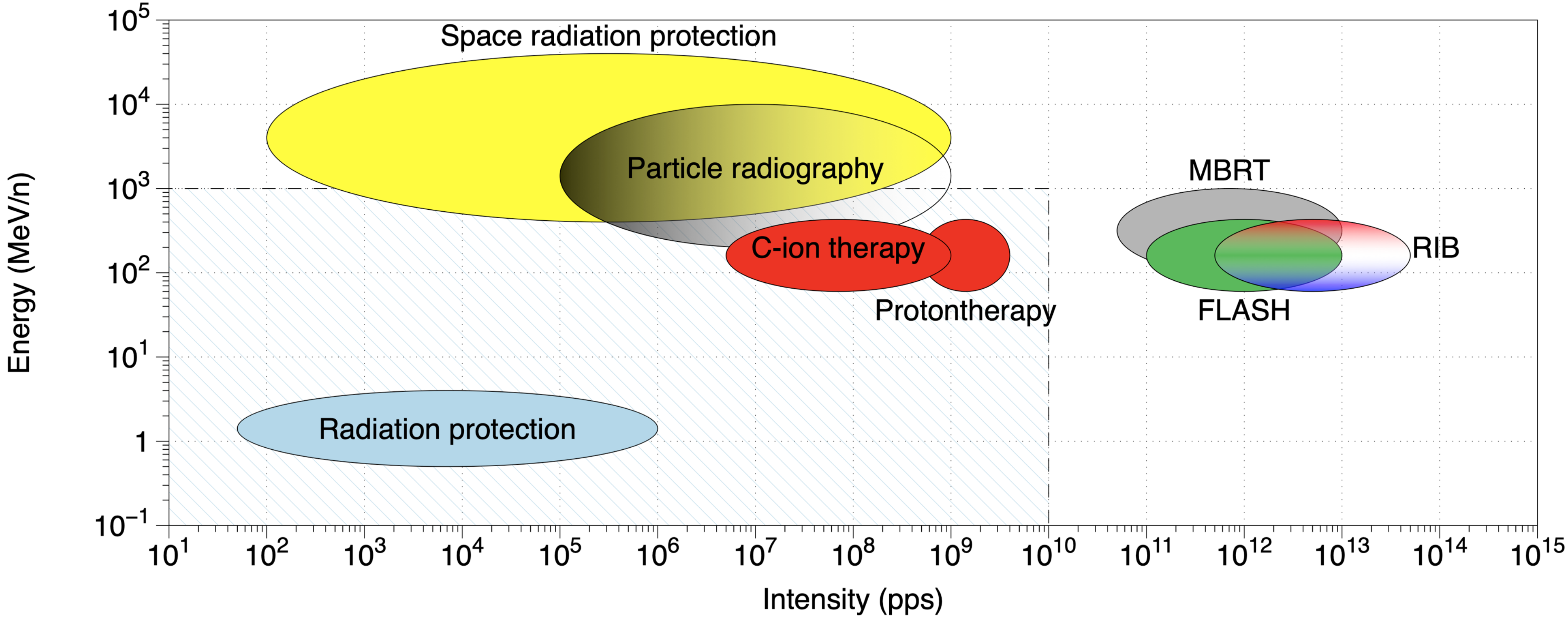
Darmstadt, Germany

May 20-22, 2019

www.gsi.de/bio-coll

GSI

Biomedical applications at particle accelerators



Thank you very much!