

GSI space research program

Extended version

Introduction

Biophysics group 2017



G. Otto

Subgroups

- Molecular Radiobiology & Imaging
- Stem Cell Differentiation and Cytogenetics
- Immune system and tissue radiobiology
- Radiobiological Modelling
- Treatment Planning and Validation
- Medical Physics
- Space Radiation Physics

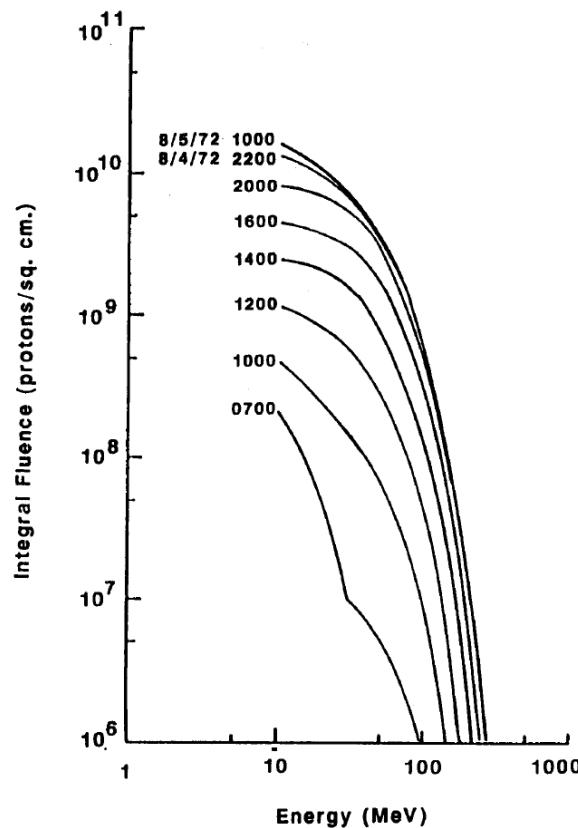
Outline

- Motivation
- Interaction of radiation with matter
- GSI irradiation facilities
- Experiments
- Summary / Outlook

Motivation

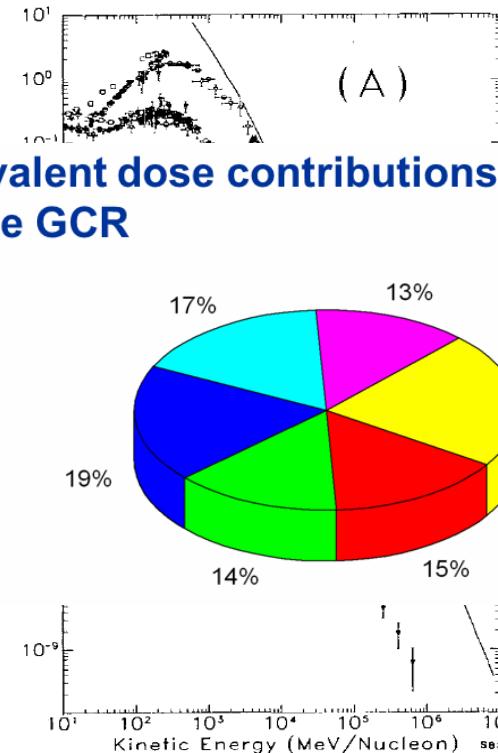
Deep space radiation environment

- Solar particle event (SPE)
- Galactic cosmic rays (GCR)



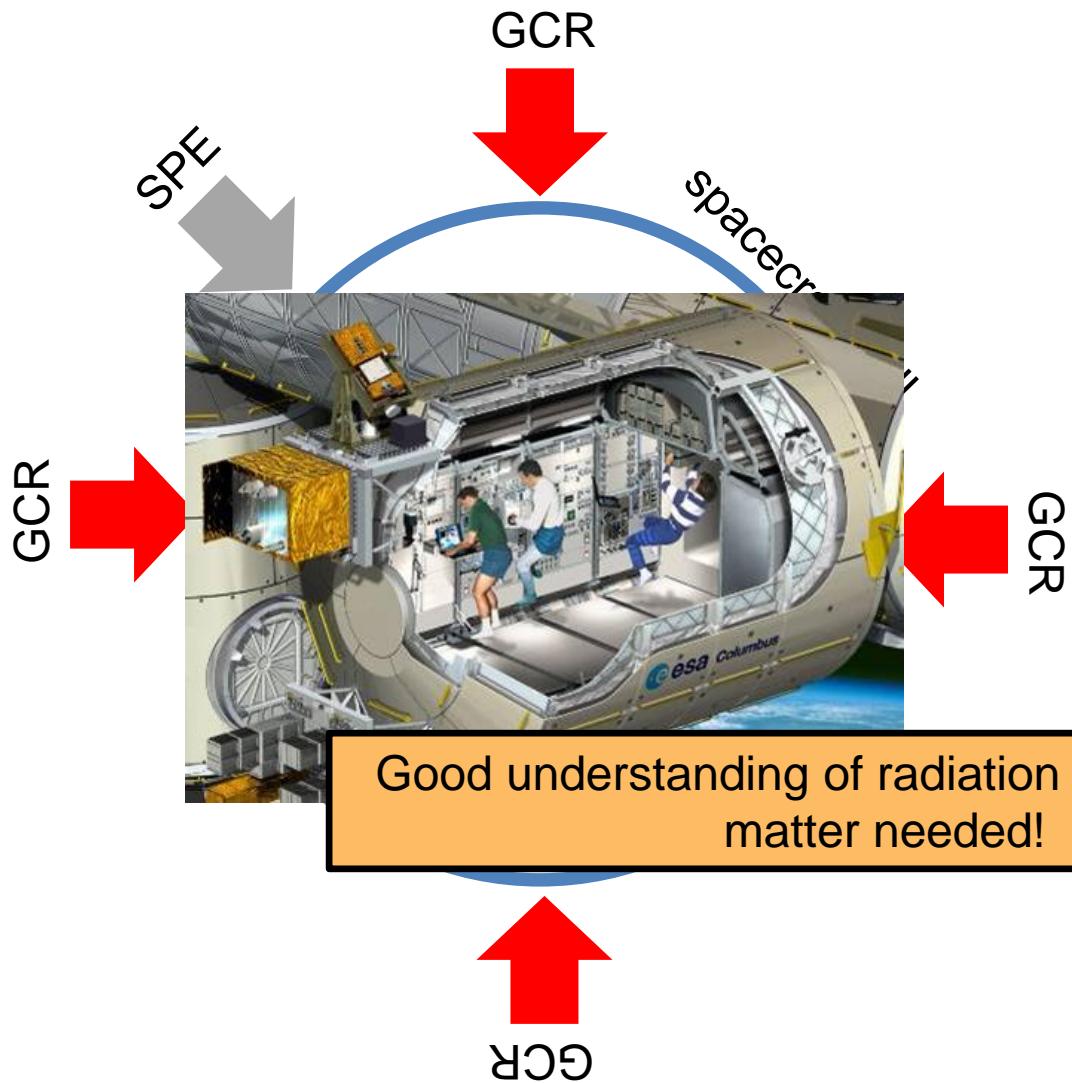
Townsend et al. 1992

Equivalent dose contributions for the GCR



Simpson et al. 1983

Motivation



- Question: Risk?
- Problem: Charged particles interact with matter e.g.

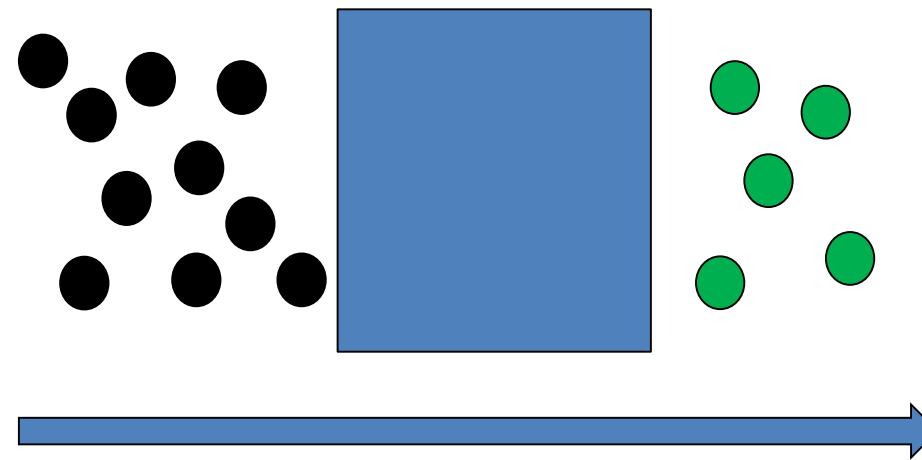
- Energyloss
- Scattering
- Fragmentation

More complex radiation field

depends on the quality of the radiation field

Interaction of radiation with matter

- Cross section \approx “Probability for a process to happen”

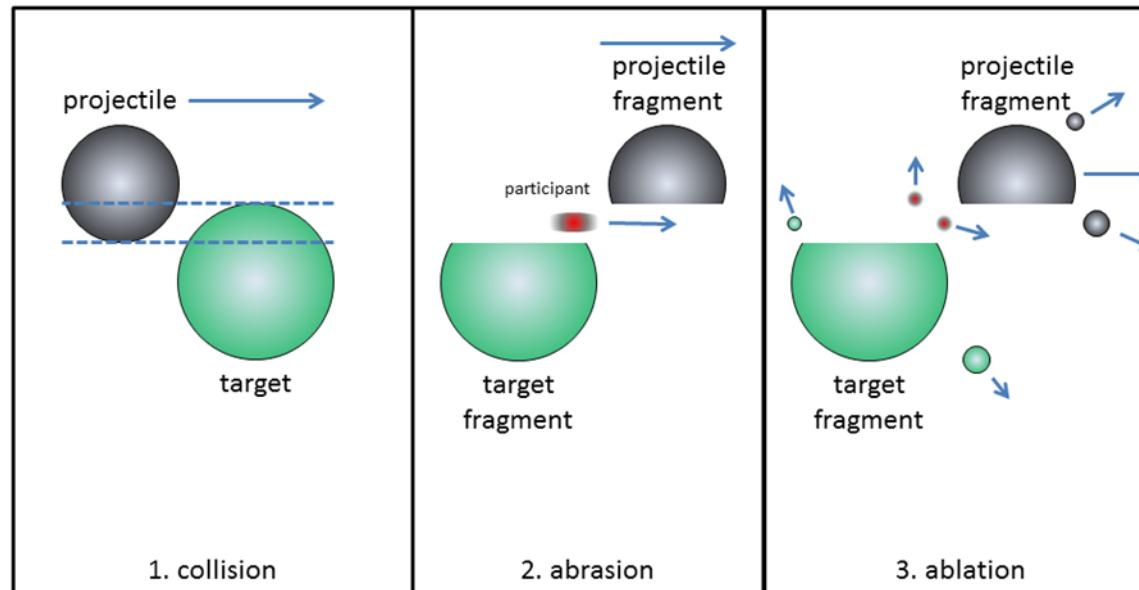
 N_0 N_R 

$$Yield \equiv \frac{N_R}{N_0}$$

$$Cross\ section \equiv Yield * \frac{A_{Target}}{\rho d N_A}$$

Interaction of radiation with matter

■ Fragmentation

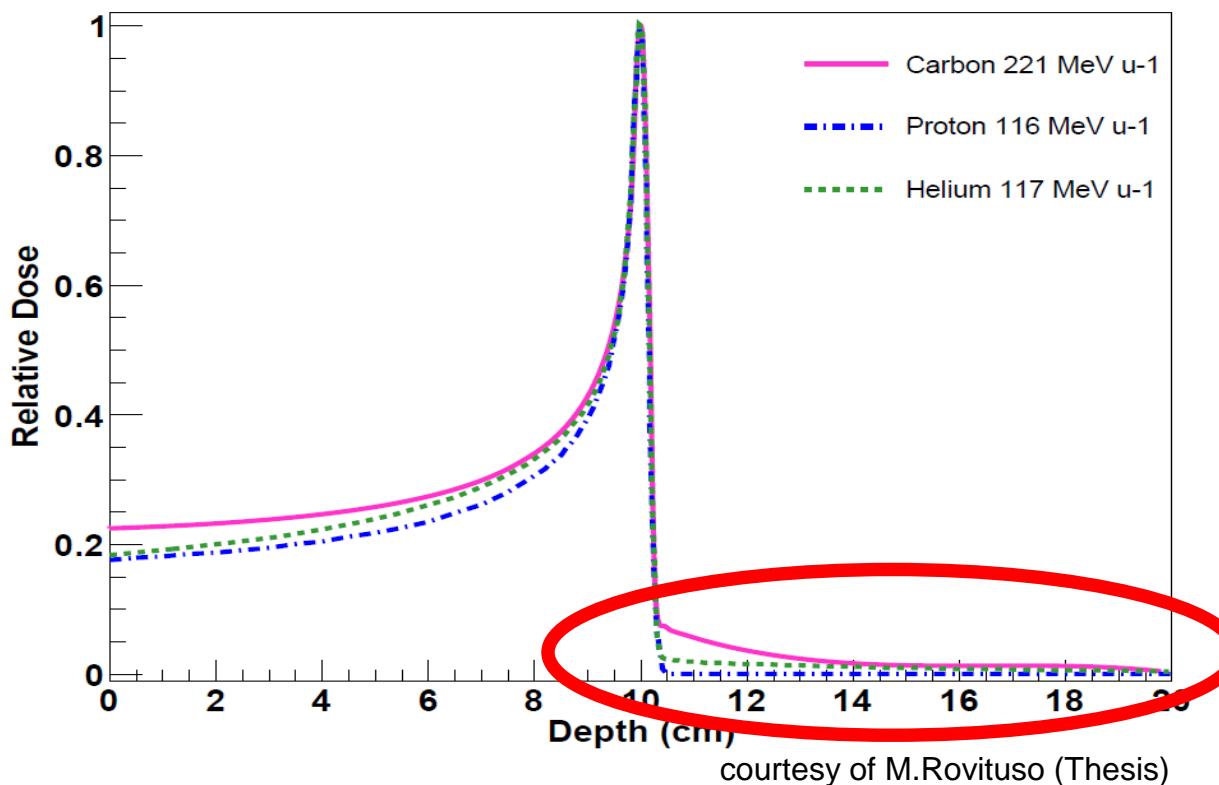


Fragmentation changes typically one or more of the following:

- kinetic energy
- direction
- multiplicity
- charge

Interaction of radiation with matter

- Energyloss



At equal energies



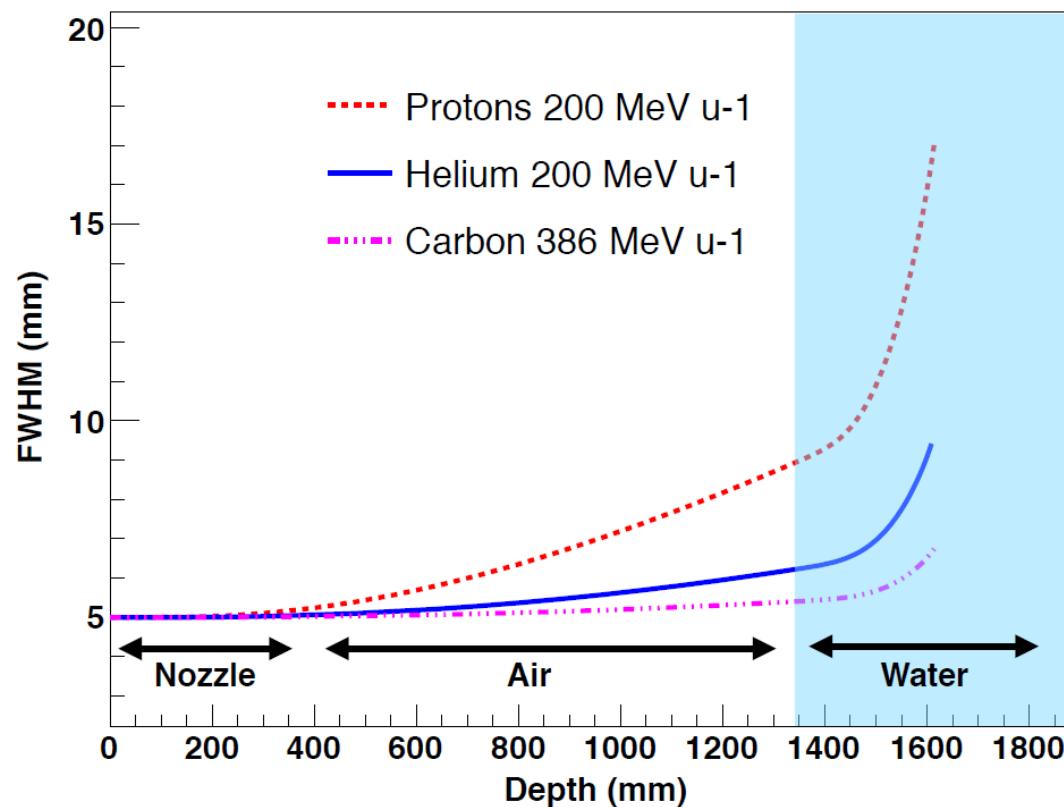
lower charge



higher penetration depth

Interaction of radiation with matter

- Multiple scattering



higher charge
↓
less scattering

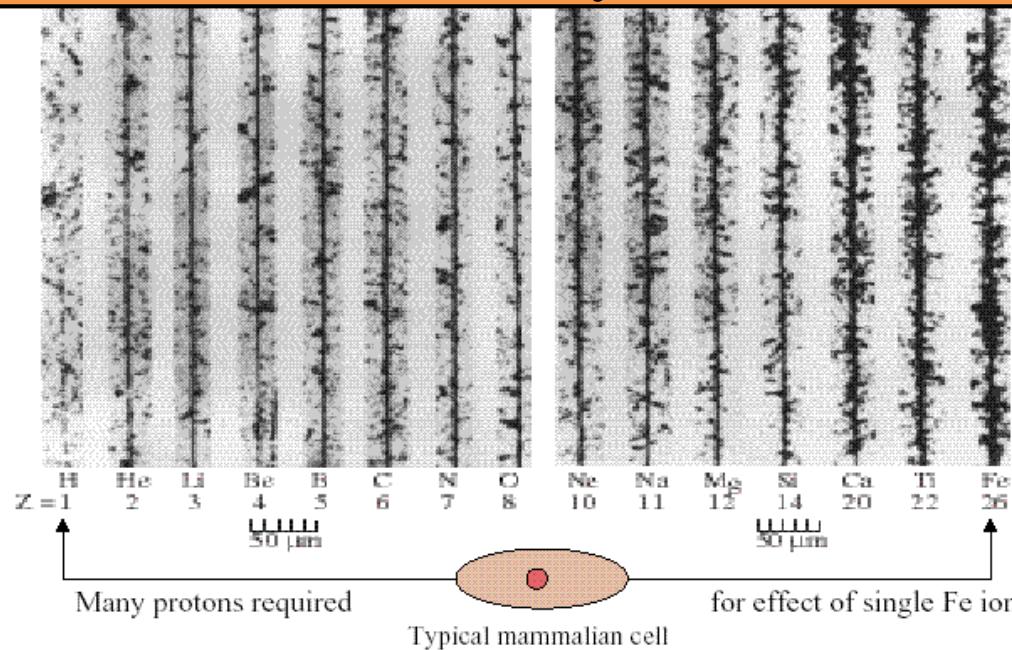
courtesy of M.Rovituso (Thesis)

Interaction of radiation with matter

- Biological effect

Higher charge \longrightarrow More complex damage

More complex damage \longrightarrow More difficult to repair



Cucinotta and Durante, *Lancet Oncol.* 2006

Interaction of radiation with matter

- Radiation protection ~~on earth~~ in space
 - ALARA - “As Low As Reasonably Achievable.”

- ~~▪ Limit exposure time~~

longer missions

faster travel?

- ~~▪ Increase distance~~

GCR has “no source”

- Use “shielding”

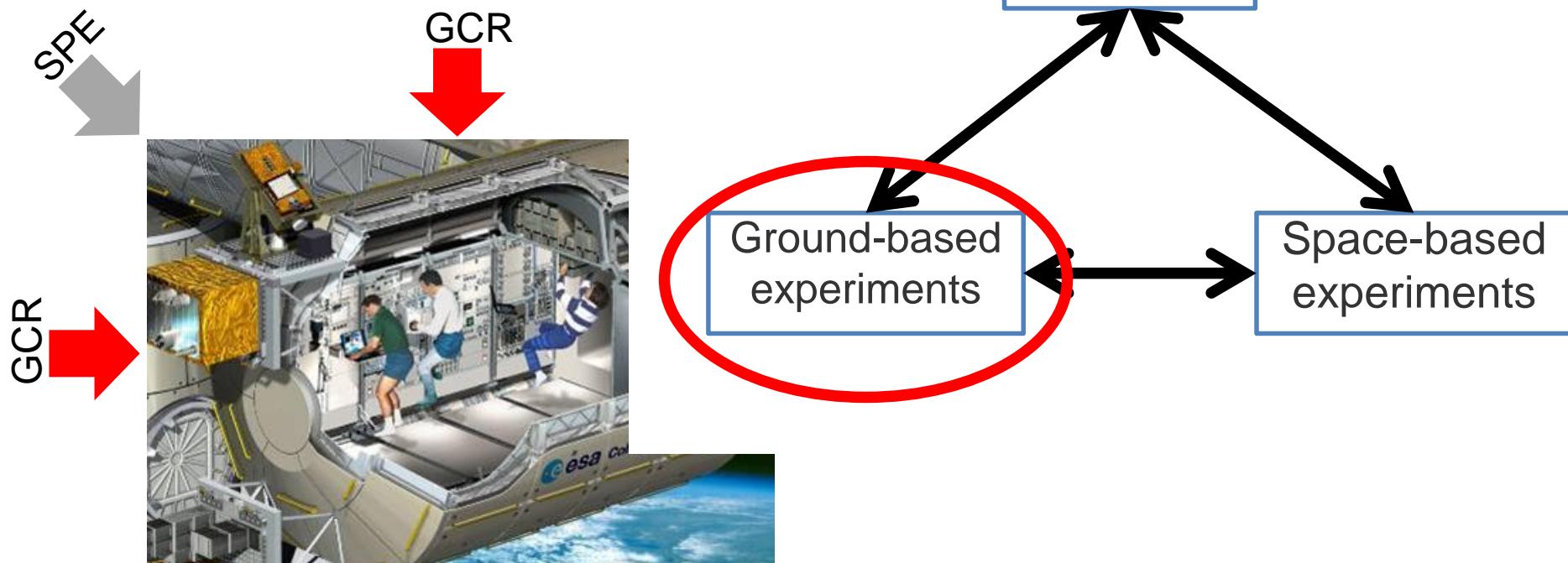
weight and volume constraints

GCR high energies

SPE can be shielded “easily”

Can be shielded with
in-situ materials for
habitat

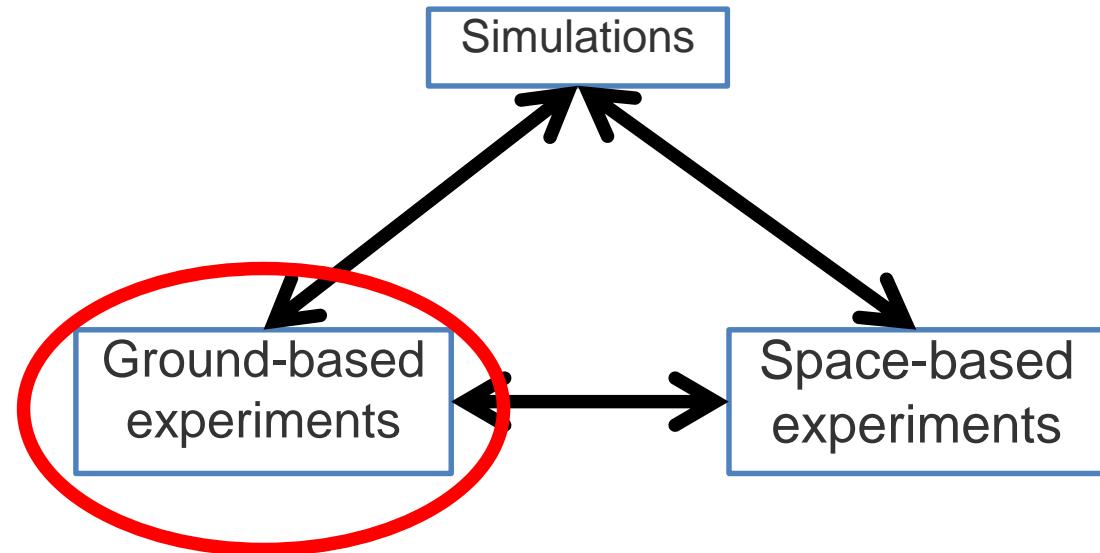
Back to the main question...



Question: Risk?

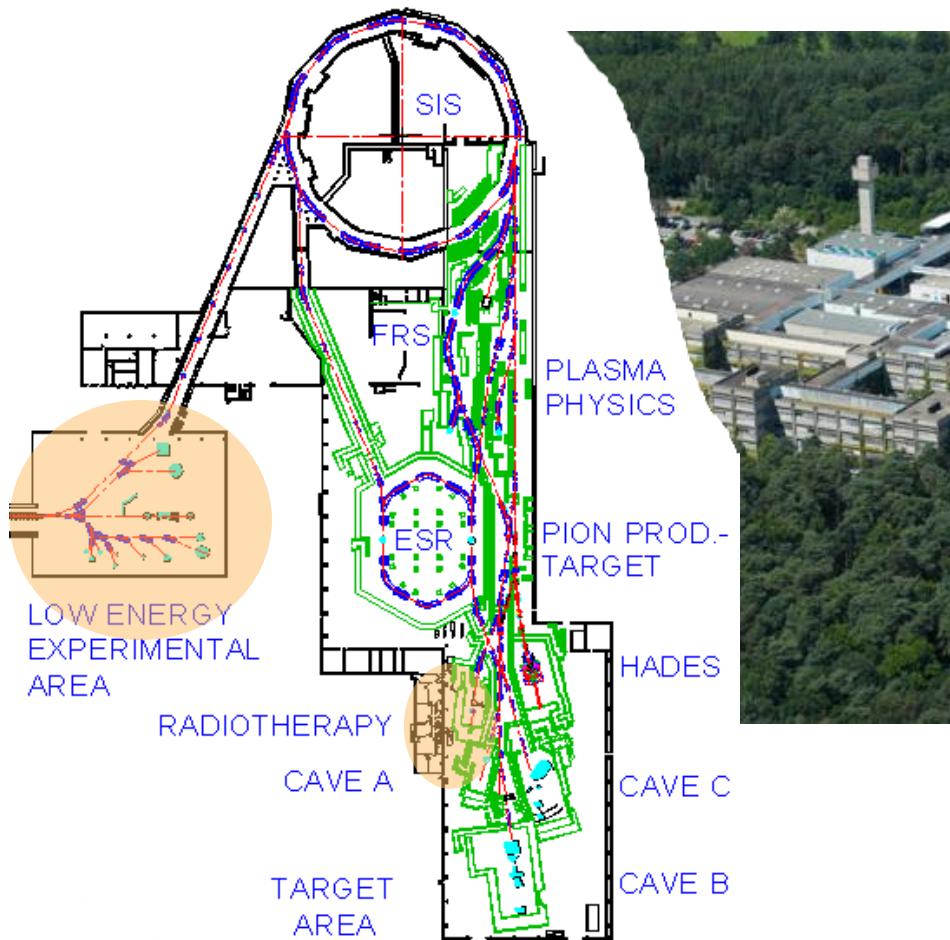
Back to the main question...

- GCR
 - ions up to iron
 - low flux
 - kinetic energy up to some GeV/u
- SPE
 - typically protons
 - high flux
 - some hundred MeV



→ Accelerator requirements

GSI overview



Accelerator

Ions: p - U

UNILAC \approx 11 MeV/u

SIS18 \approx 1 GeV/u



Experimental sites

X0 - microprobe

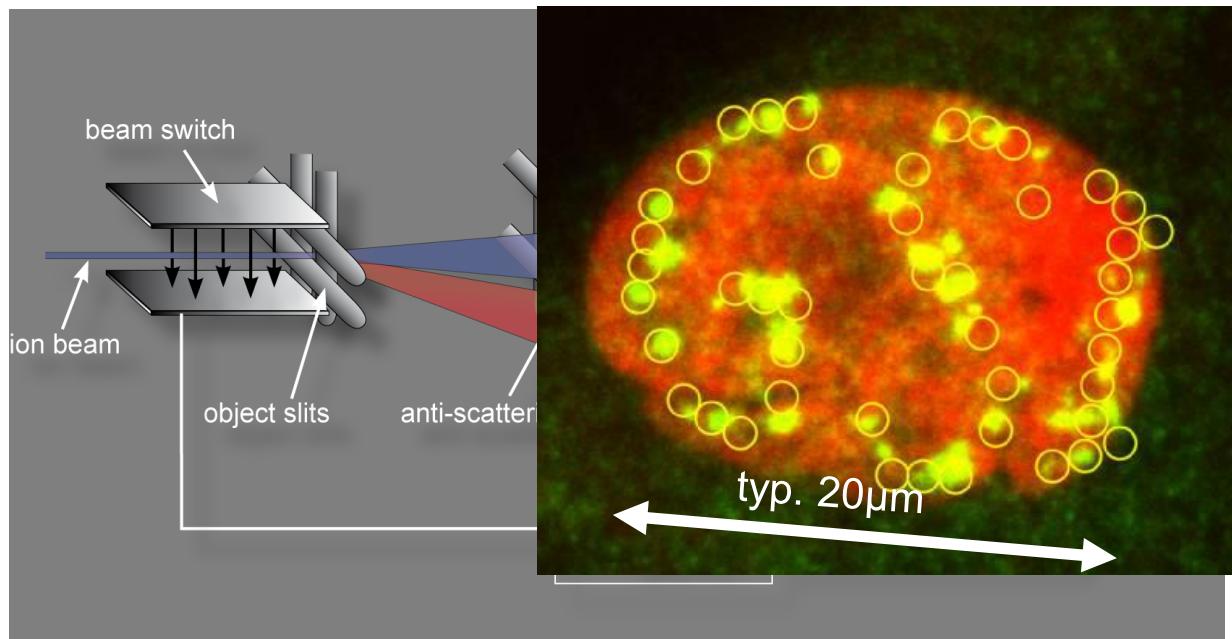
X6 - cell biology

Cave A

[.gsi.de](http://gsi.de)

https://web-docs.gsi.de/~wolle/EB_at_GSI/GSI/ACCELERATOR/IMAGES/accel_overview.gif

X0 - Microprobe



- $E_{MAX}: 11.4 \text{ MeV/u}$
- Ions: p – U
- Accuracy < 1 μm
- Targeting rate
1000 *ions/s*

B.E. Fischer, K.O. Voss, B. Merk, (Material Research)
in-house collaboration with Biophysics Dept.

X6 – Cell irradiation



- Multi-purpose
- $E_{MAX}: 11.4 \text{ MeV/u}$
- Ions: p – U
- Cell Irradiation



Live cell imaging, B. Jakob,
GBS/DNA-Repair , Sept 2012



Cave A

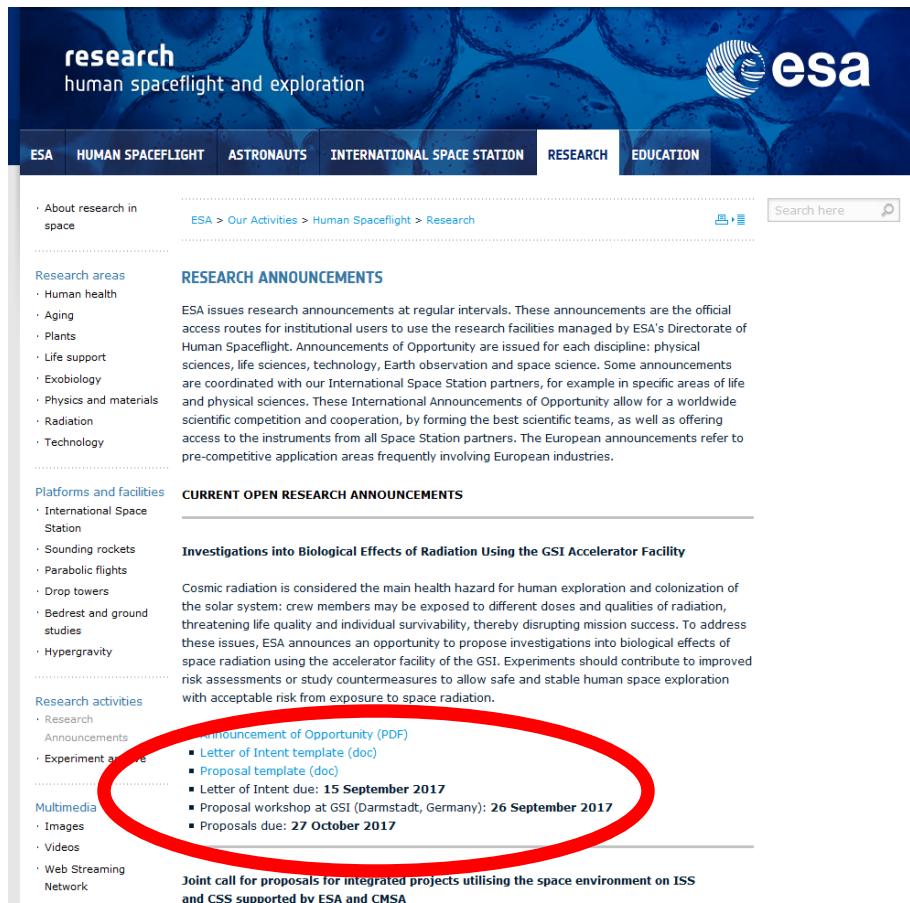


C. La Tessa, source: G.Otto

- Multi-purpose
- Ions: p – U
- $E_{MAX} \approx 1 \text{ GeV/u}$
- Intensity: $10 - 10^9 \text{ pps}$

- Active scanning
 - Size_{MAX}: $20 * 20 \text{ cm}^2$

Side note...



The screenshot shows the ESA Research website with a blue header featuring the word 'research' and 'human spaceflight and exploration'. The main navigation menu includes links for ESA, HUMAN SPACEFLIGHT, ASTRONAUTS, INTERNATIONAL SPACE STATION, RESEARCH (which is highlighted), and EDUCATION. Below the menu, there's a search bar and a 'Search here' button.

RESEARCH ANNOUNCEMENTS

ESA issues research announcements at regular intervals. These announcements are the official access routes for institutional users to use the research facilities managed by ESA's Directorate of Human Spaceflight. Announcements of Opportunity are issued for each discipline: physical sciences, life sciences, technology, Earth observation and space science. Some announcements are coordinated with our International Space Station partners, for example in specific areas of life and physical sciences. These International Announcements of Opportunity allow for a worldwide scientific competition and cooperation, by forming the best scientific teams, as well as offering access to the instruments from all Space Station partners. The European announcements refer to pre-competitive application areas frequently involving European industries.

CURRENT OPEN RESEARCH ANNOUNCEMENTS

Investigations into Biological Effects of Radiation Using the GSI Accelerator Facility

Cosmic radiation is considered the main health hazard for human exploration and colonization of the solar system: crew members may be exposed to different doses and qualities of radiation, threatening life quality and individual survivability, thereby disrupting mission success. To address these issues, ESA announces an opportunity to propose investigations into biological effects of space radiation using the accelerator facility of the GSI. Experiments should contribute to improved risk assessments or study countermeasures to allow safe and stable human space exploration with acceptable risk from exposure to space radiation.

Announcement of Opportunity (PDF)

- Letter of Intent template (.doc)
- Proposal template (.doc)
- Letter of Intent due: **15 September 2017**
- Proposal workshop at GSI (Darmstadt, Germany): **26 September 2017**
- Proposals due: **27 October 2017**

Joint call for proposals for integrated projects utilising the space environment on ISS and CSS supported by ESA and CMSA

■ ESA research announcement

■ Topics

- Risk assessment
- Countermeasures

■ More infos:

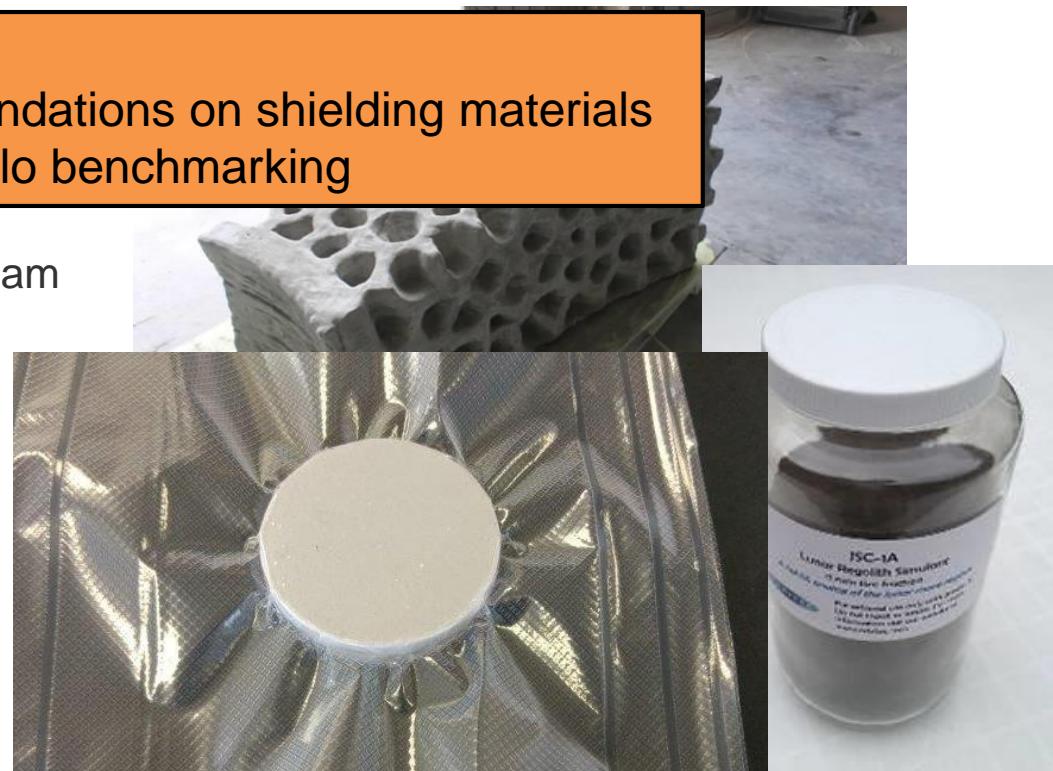
http://www.esa.int/Our_Activities/Human_Spaceflight/Research/Research_Announcements

Experiments

- ROSSINI 1 & 2
 - RadiationOn Shielding by ISRU and/or INovative MaterIals for EVA, Vehicle and Habitat
 - supported
- Experiments
 - Dose attenuation
 - Attenuation of the primary beam
 - Neutron production
 - Microdosimetry
- Labs
 - GSI, Germany
 - BNL, USA
 - PTC Trento / TIFPA, Italy

Goals:

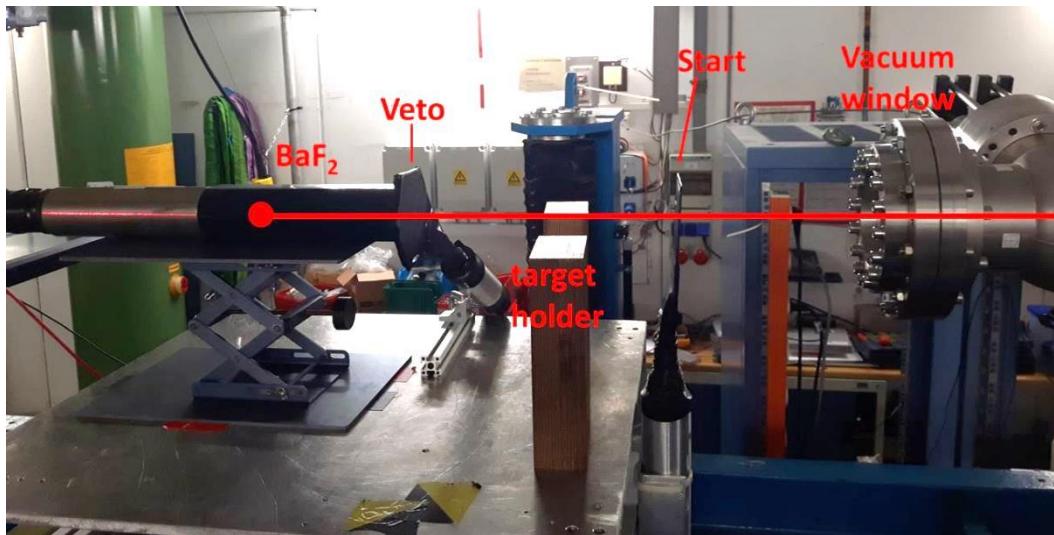
Recommendations on shielding materials
Monte Carlo benchmarking



Experiments

- Passive shielding → CGR energy too high to stop for deep space missions
 - Simplified idea → Use fragmentation to decrease received dose

→ Measure loss of primary ions per unit mass



Start: Count number of primaries
Veto: Energyloss
BaF2: Total energy

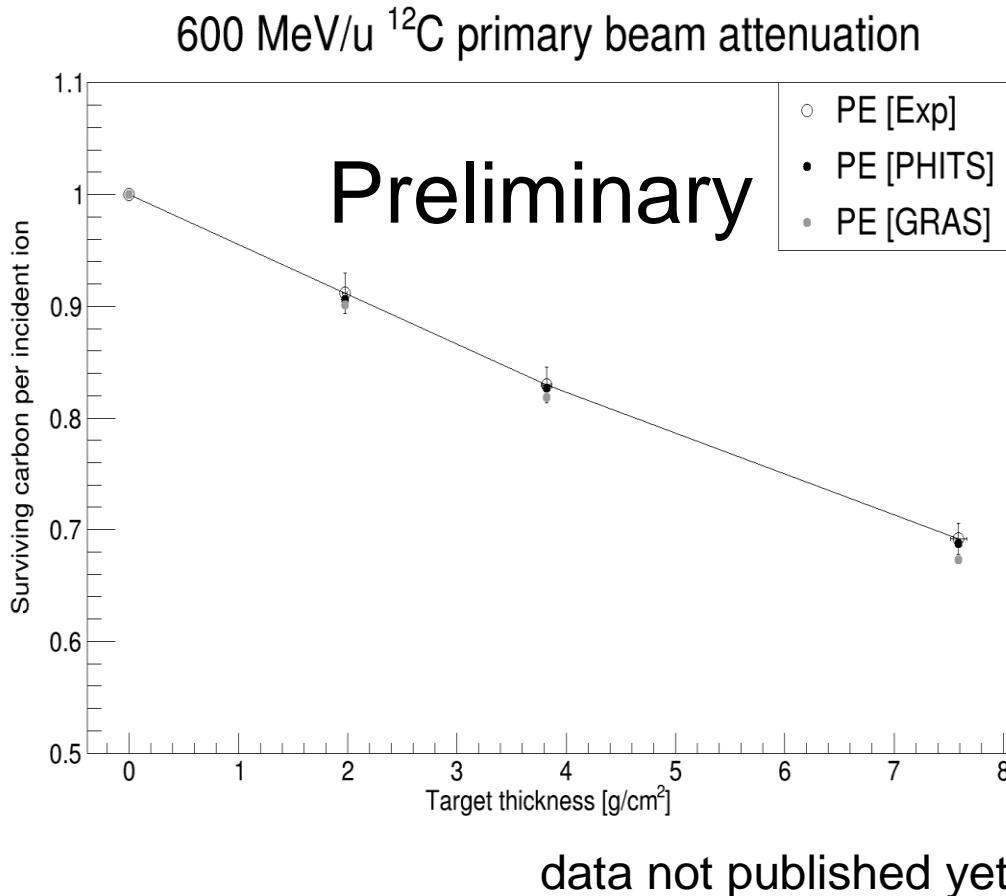


PID
Number of surviving primaries



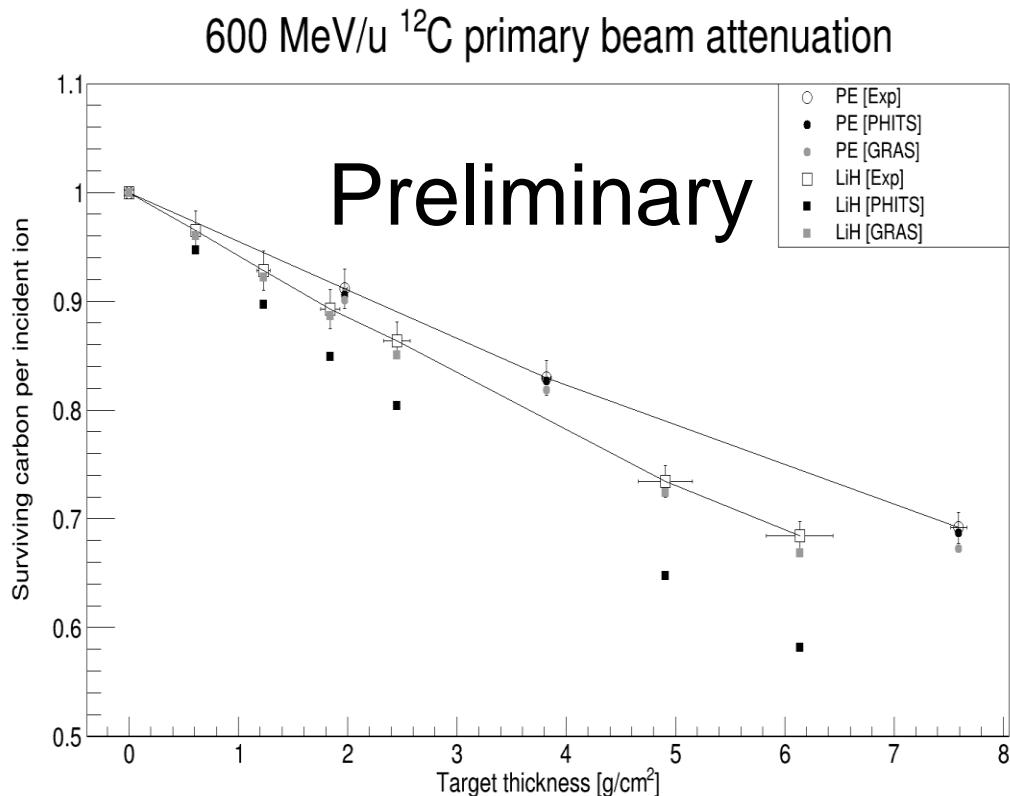
Compare with Monte carlo

Experiments



- PE “gold standard” for shielding
- used in therapy as well
- MC can reproduce results

Experiments



data not published yet

- LiH shows higher fragmentation
- PHITS can not reproduce results

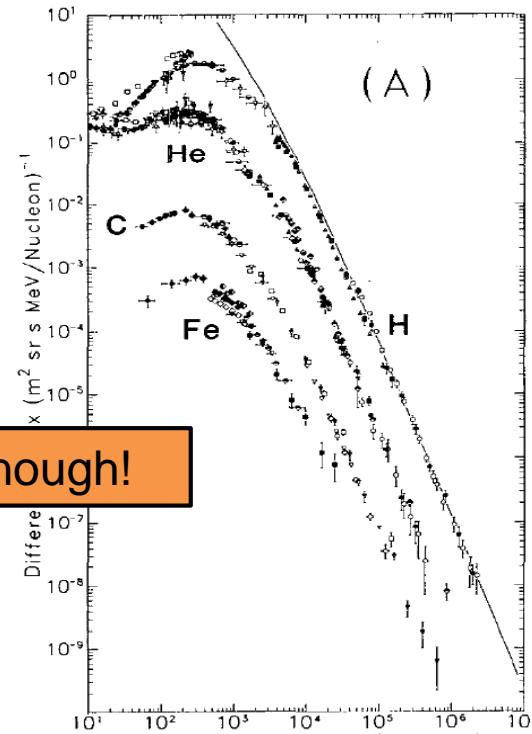
Experiments

- Passive shielding for habitats
 - no weight constraints if using in-situ materials

→ Fully stop CGR



Provided energies by SIS18 not high enough!



Simpson et al. 1983

Summary

- 3 pillars of space radiation risk assessment
 - Monte Carlo
 - Space-based experiments
 - Accelerator-based experiments
- GSIs UNILAC + SIS18 well suited for space research
 - but higher energies are needed to cover full GCR -> **FAIR**

Thanks for your attention