ARIES WP17 (PowerMat): Introduction to Task 17.4

A. Lechner (CERN)

ARIES WP17 (PowerMat) Kick-off Meeting

May 5$^{\mathrm{th}}$, 2017

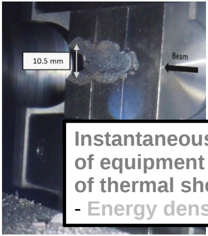
Introduction to Task 17.4

- **Title: Simulation of irradiation effects and mitigation methods**
- **Main goals:**
  - *Investigation and simulation of material damage induced by irradiation with protons and ions at various energies and doses*
  - *Quantify Displacement Per Atom (DPA), gas production, nuclear transmutation for equipment in complex accelerator environments and provide a relationship with radiation experiments at lower energies and/or with different particle species*
  - *Ideally, relate radiation damage quantities (e.g. DPA) with change of relevant macroscopic material properties*
  - *Assess annealing and temperature-related effects*

  ⇒ *Open to co-operate with other international collaborations such as RaDIATE (Radiation Damage In Accelerator Target Environment)*
- **Participants: CERN, GSI, POLIMI**

A brief reminder: consequences of beam losses

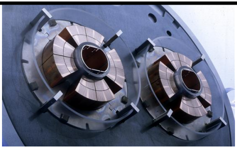
Beam losses in accelerators can have many different consequences...

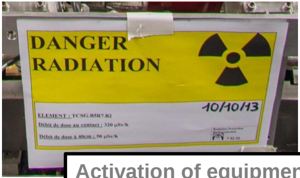


Instantaneous damage of equipment because of thermal shock:
- Energy density

Figure courtesy of A. Bertarelli

Quench of supercond. magnets:
- Energy density (transient losses)
- Power density (steady state losses)





Activation of equipment:
- Residual dose rate
- Induced radioactivity

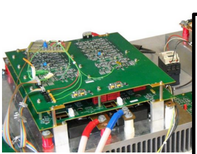


Fig. courtesy of TE/EPC

Radiation effects in electronics:
- High-energy hadron fluence (single event effects)
- Total ionizing dose (cumulative effects)
- Si 1 MeV neutron equiv. fluence (cumulative effects)

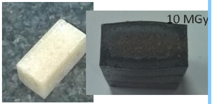


Fig. courtesy of P. Fessia

Change of mechanical and physical material properties (on the long term):
- **Displacement per Atom** (non-organic materials)
- **Dose** (insulators)
- **Gas production (H, He) and transmutations**

Focus of Task 17.4

Complex accelerator environment ⇔ irradiation experiments

Example DPA:

- related to **non-ionizing energy loss (nuclear stopping)** of charged particles
- DPA/incident particle depends strongly on **particle species** and **energy**

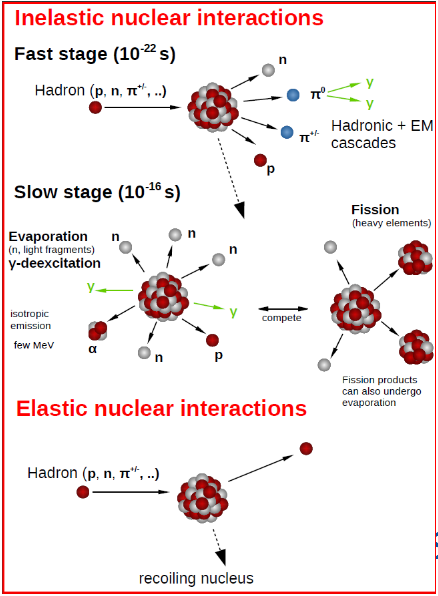
High-energy proton/ion accelerators (GeV-TeV)

- All shower particles can contribute to DPA
- In particular **recoils from nuclear interactions**, but also **EM showers**

Task 17.4: provide relationship ⇕

Irradiation experiments to probe effects of radiation damage in materials

- Often with **much lower-energy** protons, neutrons, ions (with different fluences)
- Example MeV protons/ions: DPA mainly through nuclear stopping of **primaries**



Simulation tool at hand: FLUKA Monte Carlo code

Powerful simulation tool to quantify relevant quantities like DPA, gas production in complex radiation environments

Standard shower code for CERN accelerators (LHC, HL-LHC, SPS, PS, ...), also used at many other facilities

1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524

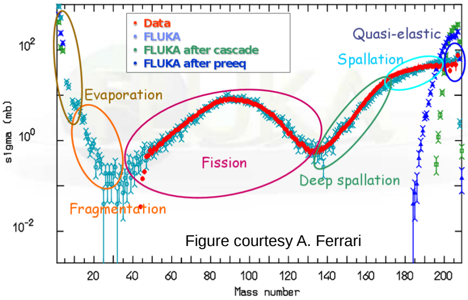


Figure courtesy A. Ferrari

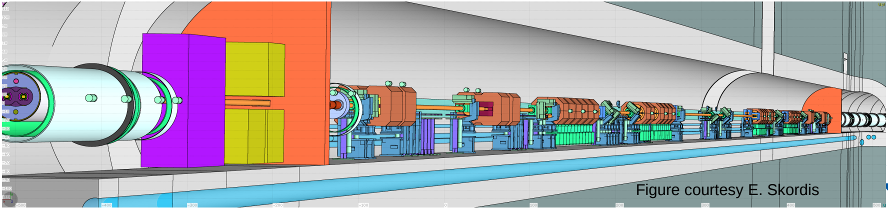
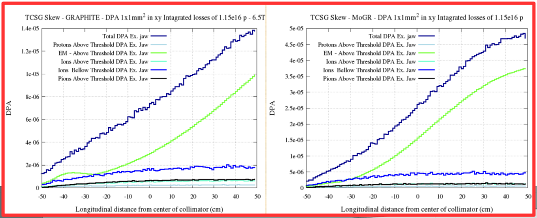
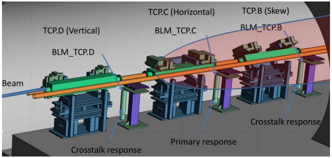


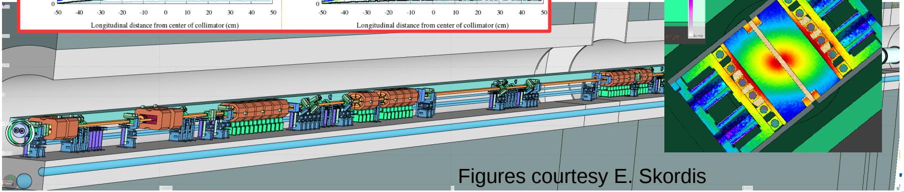
Figure courtesy E. Skordis

Example: DPA calculations for LHC collimators

Multi-turn **particle tracking** in accelerator lattice (SixTrack-FLUKA coupling) ⇒ Detailed **shower simulations** in accelerator components like collimators (FLUKA)







Figures courtesy E. Skordis

See E. Skordis et al, "FLUKA estimation of DPA for ion irradiation and update on IR7 DPA calculations for LHC operations", EuCARD2 WP11 Topical Meeting Collimator Materials for Fast High Density Energy Deposition , Malta, 2016.

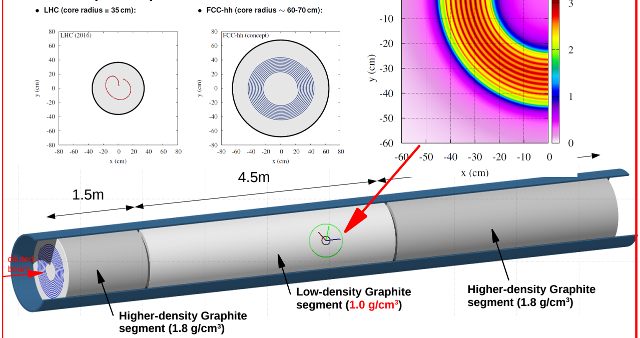
Radiation damage simulations: predicting the future

Face extreme material challenges for next generation machines

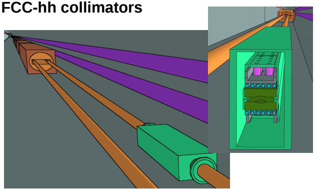
- **Example: FCC-hh**
  - **50 TeV protons**
  - **10600 bunches (10^{11} ppb)**
  - **20–25 ab^{-1}**

Prediction of expected radiation damage in collimators, dumps etc. essential for design and material research

FCC-hh dump concept



FCC-hh collimators

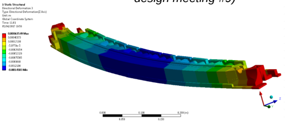


About a factor 15 higher wrt to LHC (6.5 TeV, 500 kW power losses)

Secondaries	
Collimator Jaws	[kW]
TCSG_A6L	233.6
TCSG_B5L	8.2
TCSG_A5L	35.7
TCSG_D4L	27.6

A factor of 2-2.5 higher than LHC

Radiation damage will also be much higher than for LHC



Figures courtesy of M.I. Besana and F. Carra (FCC collimation design meeting #9)

Radiation damage ⇔ change of material properties

- **Damage-related change of physical/mechanical properties:**
  - *Ideally, a key point would be to relate radiation damage quantities (like DPA) with the change of relevant macroscopic material properties*
  - *First step could be analysis of previous experiments (e.g. ion-implantation experiments at GSI as suggested by Marilena)*
  - *Open to co-operate with other international collaborations such as RaDIATE*
- **Assessment of mitigation methods:**
  - *Simulation of annealing etc. requires other simulation methods/codes*
  - *Collaborations to be assessed*

Deliverables

- **Deliverables:**
  - *Task 17.2) Comparative compendium of the developed materials [month 40]*
  - *Task 17.4) Report on simulations on irradiation effects [month 44]*
  - *Task 17.3) Irradiation test results: Beam impact on new material and composite [month 48]*
  - *Task 1.4) Production of material samples (as large as possible for each industry to demonstrate workability) [month 24]*

Milestones

- **Milestones:**
  - *Task 17.1) Organisation of PowerMat kick-off meeting, with publication of talks on Web [month 6]*
  - *Task 17.2) Material characterisation , with publication of results on Web [month 18-24]*
  - *Task 17.3) Irradiation, with publication of report on web [month 27]*
  - *Task 17.4) Irradiation effects analysis, with publication of report on web [month 36]*
  - *Task 17.5) Report on studies, with publication of report on web, [month 46]*
  - *Task 1.4) Prepare first samples [month 12]*