# Beam-Loss Criteria for Heavy-Ion Accelerators and Activation of Different Materials

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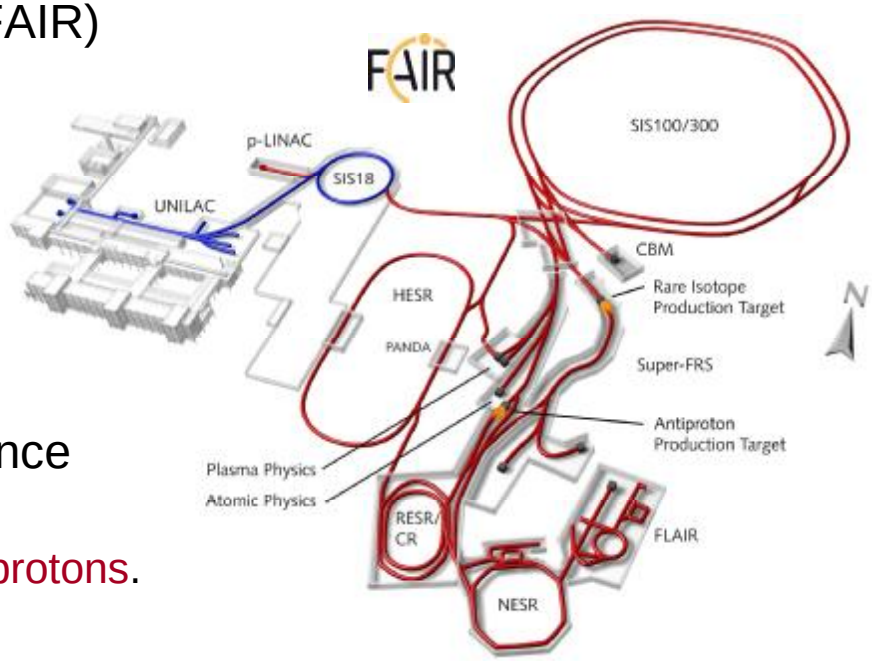
# Motivation

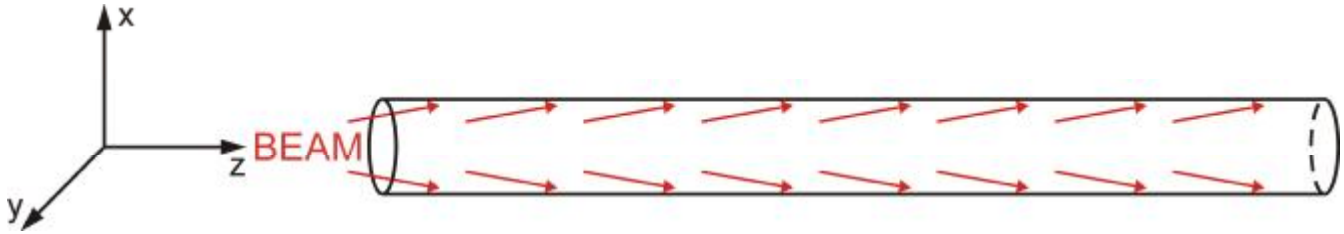
- Activation of accelerator structures due to beam-losses - important issue for existing (LHC, SNS, RHIC, …) and planned (FAIR) hadron facilities.




- Beam-loss criteria for "hands-on" maintenance
  - Proton accelerators: 1 W/m.
  - Heavy-ion accelerators: scaled criterion for protons.

- Activation of different materials
  - Beam-loss criteria: stainless steel and copper.
  - Isotope inventory and their relative activities depend on the target material →
    → study of other accelerator construction materials: carbon, aluminium and tantalum.

# Residual activity induced by heavy ions




primary beam: $^{1}$H, $^{4}$He, $^{12}$C, $^{20}$Ne, $^{40}$Ar, $^{84}$Kr, $^{132}$Xe, $^{197}$Au, $^{238}$U
beam energy: 200 MeV/u – 1 GeV/u
beam-pipe material: stainless steel
beam losses: 1 W/m
beam-pipe wall thickness: 2 mm
beam-pipe length: 10 m
beam-pipe diameter: 10 cm
angle of incidence: 1 mrad

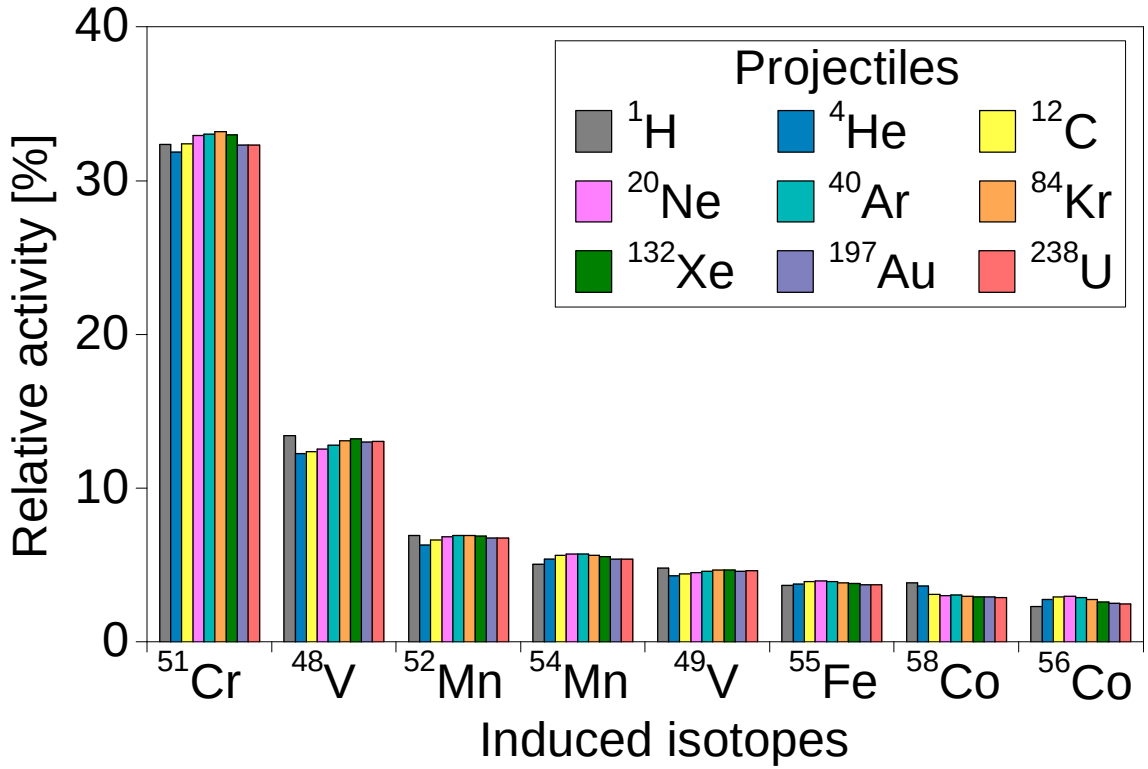
irradiation time: 100 days
"cooling-down" times: 0 days, 4 hours,1 day, 1 week, 2 months
simulation codes: FLUKA, SHIELD
calculated quantities: activity [Bq], effective dose-rate [mSv/h]

# Isotope inventory and their relative activities

simulation code: FLUKA

beam energy: 500 MeV/u

“cooling-down” time: 1 day

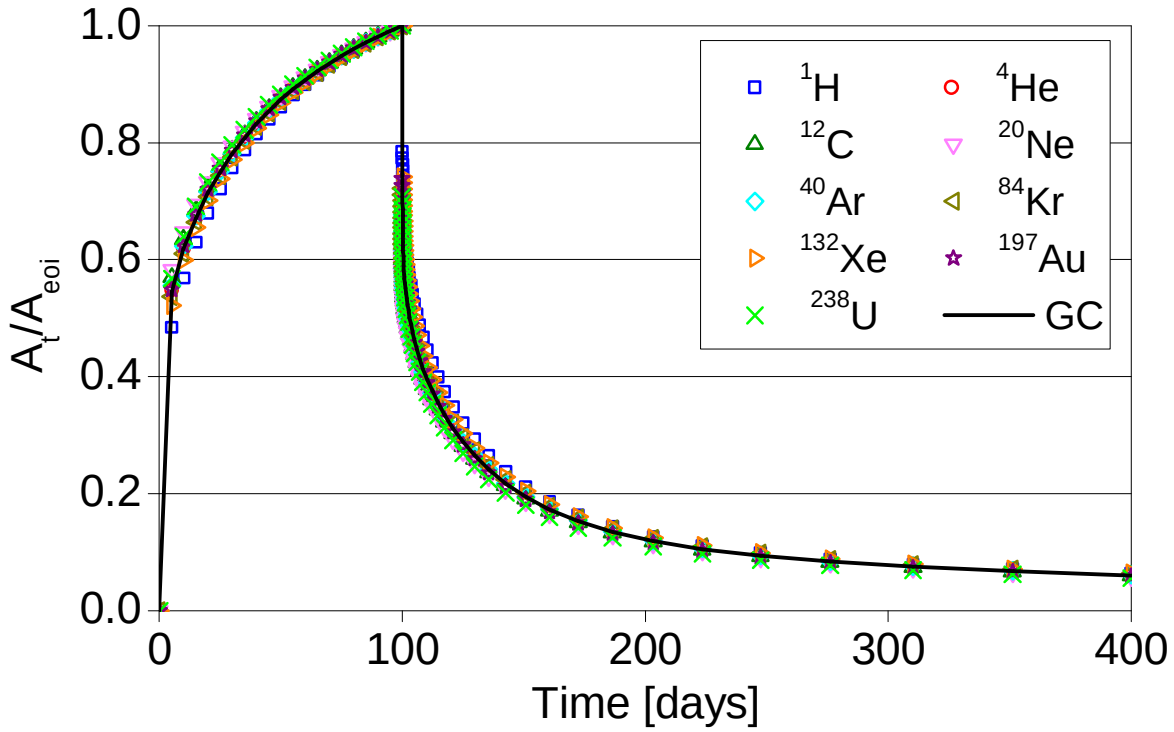



Isotope inventory and their relative activities do not depend on the projectile species.

# Time evolution of the induced activity

simulation code: FLUKA

beam energy: 500 MeV/u




$A_t$ – total activity at given time (t)

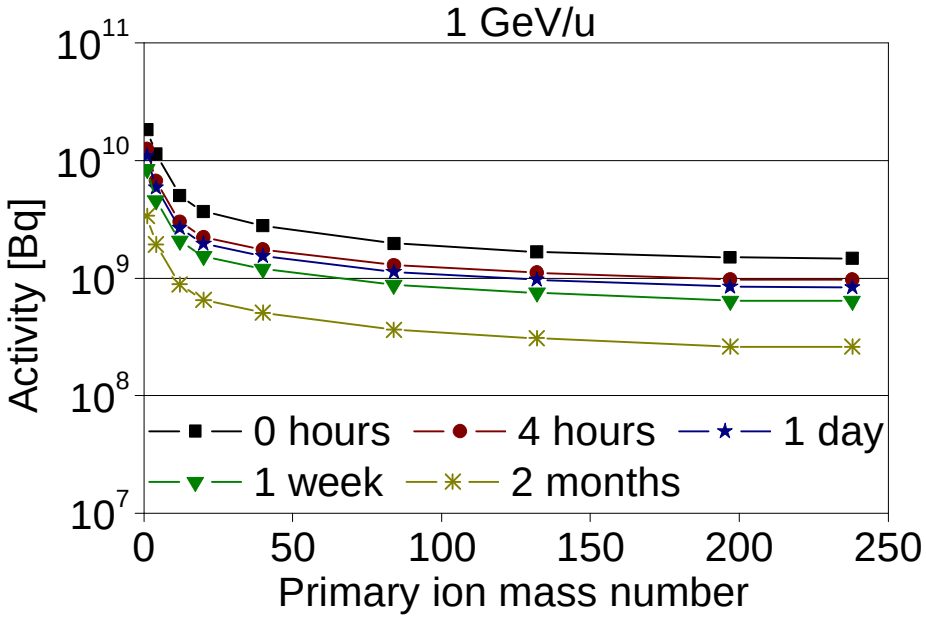
$A_{eoi}$ – total activity immediately after irradiation (eoi)

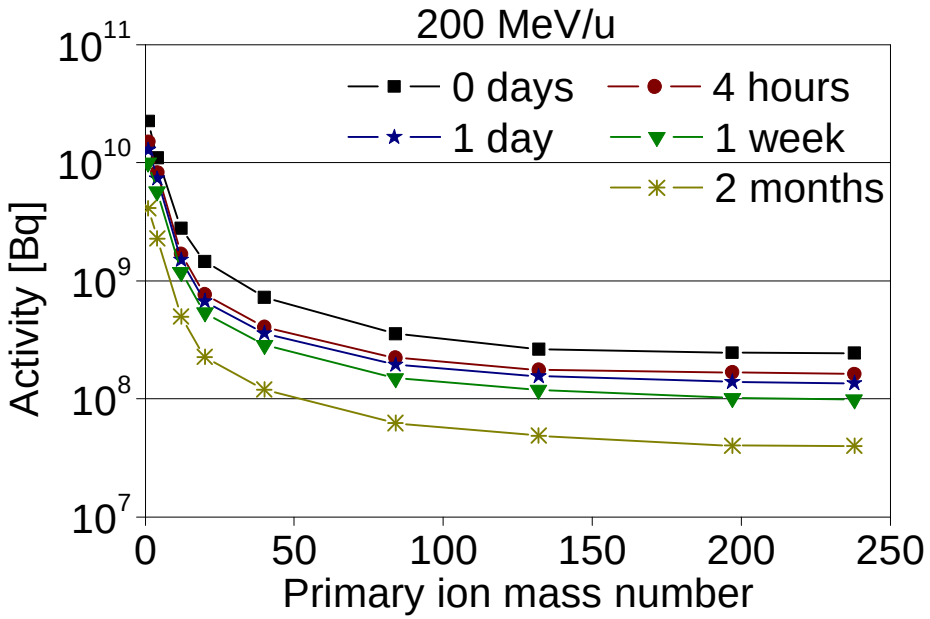
GC – generic curve

The time-evolution of the activity can be described by means of a generic curve.

# Dependence of the activity on beam parameters

Activity induced in the beam pipe by 1 W/m of primary beam-losses calculated with FLUKA.

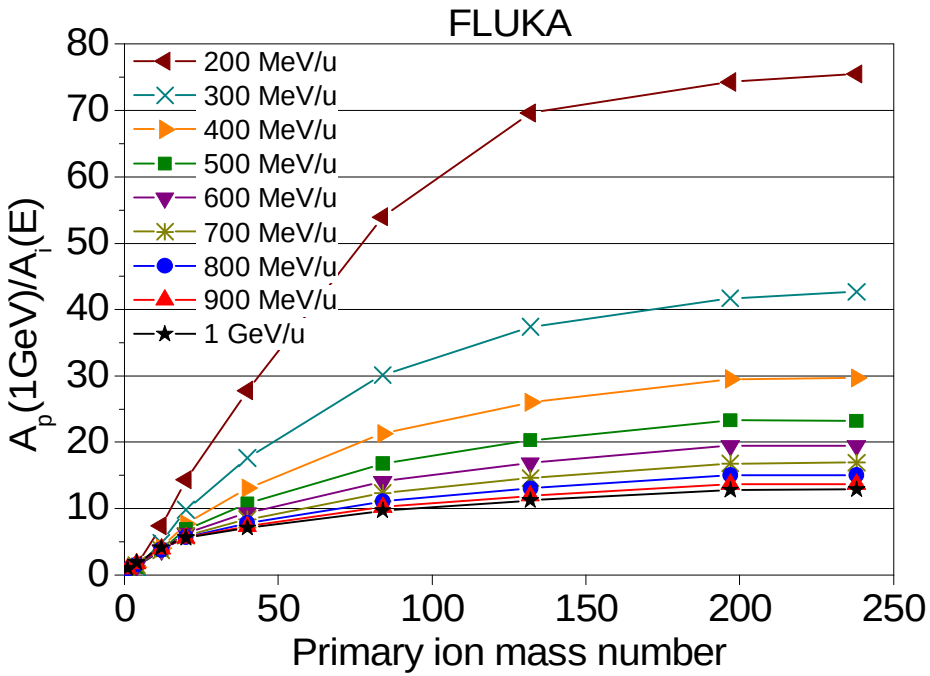


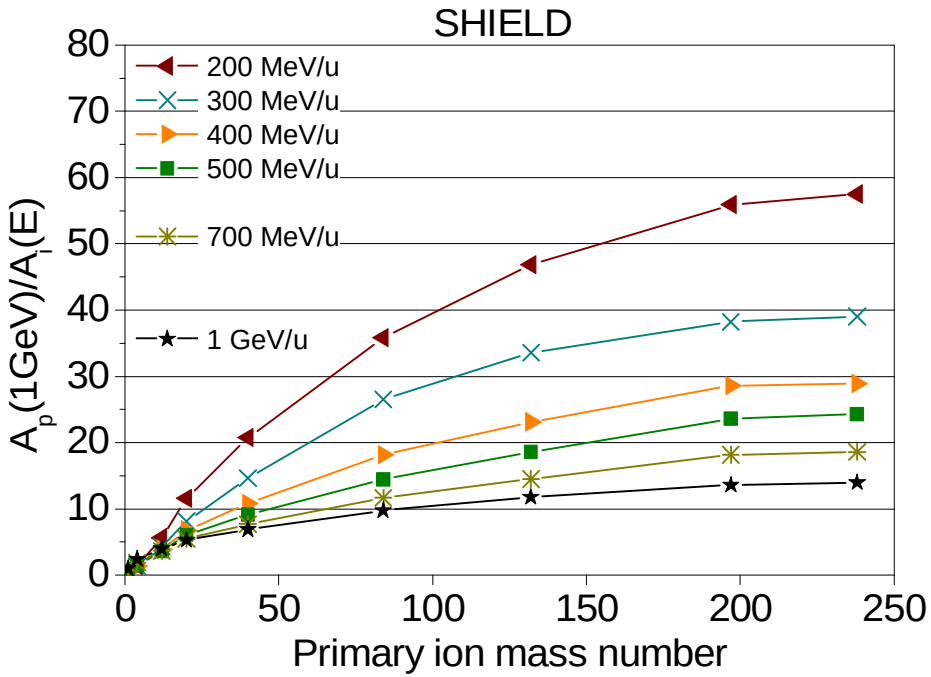




1. Activity is decreasing with increasing primary-ion mass.
2. Activity is decreasing with decreasing primary-ion energy.

# Beam-loss criteria for heavy ions

1) Inventory of the isotopes does not depend on the projectile species.
2) Time evolution of the activity correlates to the generic curve.
3) The activity induced by 1 W/m of beam losses is decreasing with increasing ion mass and with decreasing energy.




$A_p(1GeV)$ – normalized activity induced by 1 GeV proton beam (reference)

$A_i(E)$ – normalized activity induced by the beam of interest at given energy

normalized activity – activity induced by unit beam power of 1 W at given time

"cooling-down" time: 4 hours

# Activation of bulky accelerator-structures

- Besides the beam pipe, accelerators contain also bulky structures like a magnet yoke, a magnet coil or a collimator.

- Activation of the bulky target (cylinder)

  diameter: 20 cm, length: 60 cm

  materials: copper, stainless steel


primary beams: $^{1}$H, $^{4}$He, $^{12}$C, $^{20}$Ne, $^{40}$Ar, $^{84}$Kr, $^{132}$Xe, $^{197}$Au, $^{238}$U

beam energies: 200 MeV/u – 1 GeV/u

beam intensity: 1 W

irradiation time: 100 days

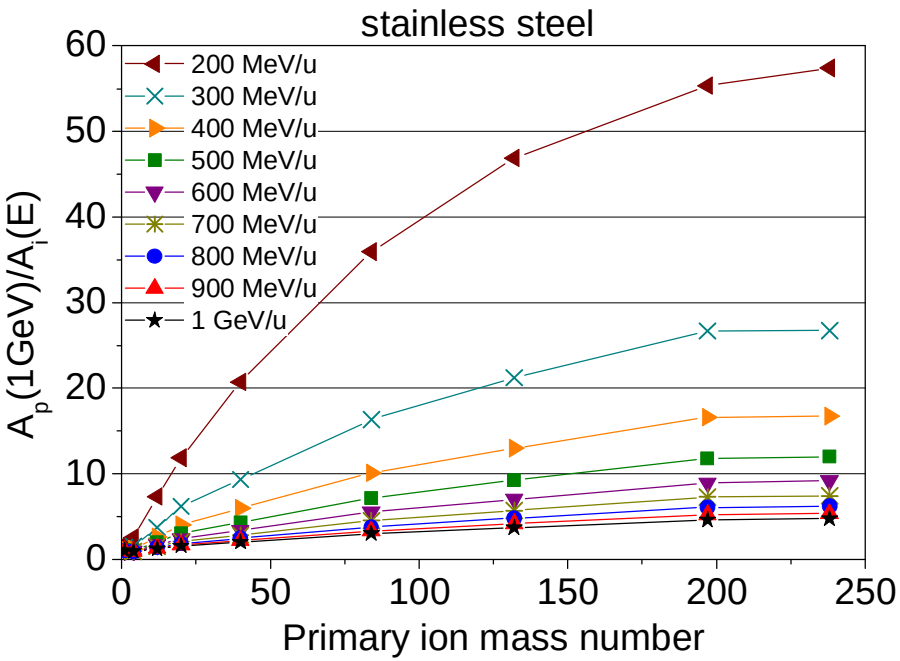
cooling times: 0 days, 4 hours, 1 day, 1 week, 2 months

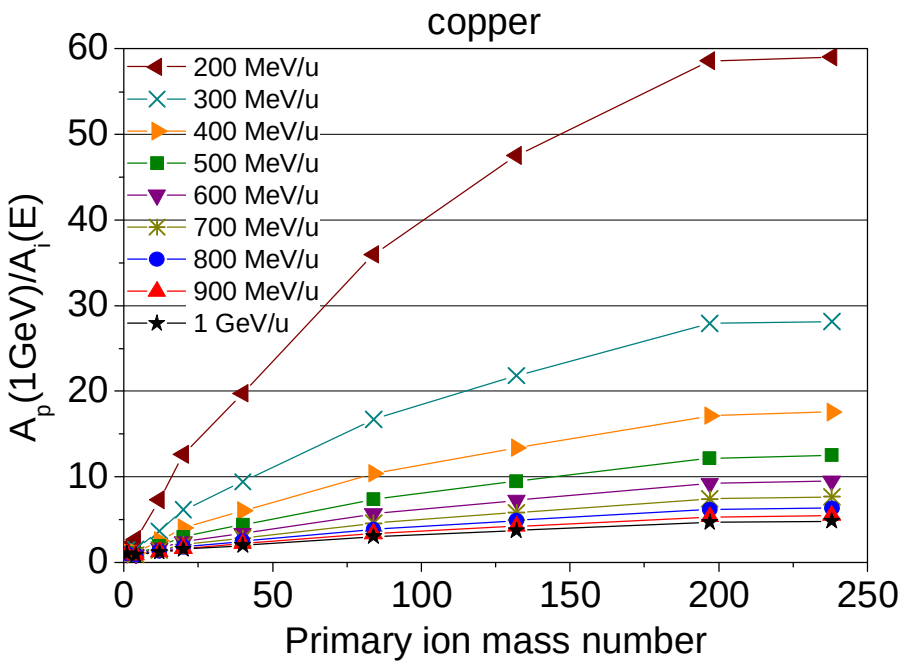
simulation codes: FLUKA, SHIELD

calculated quantities: activity [Bq]

# Beam-loss criteria for the bulky targets

simulation code: FLUKA
"cooling-down" time: 4 hours

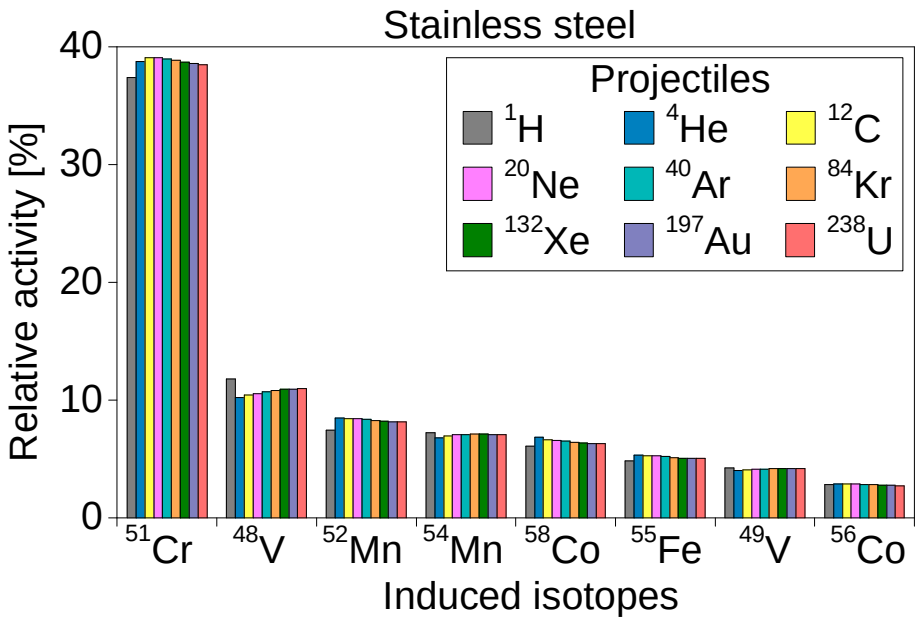


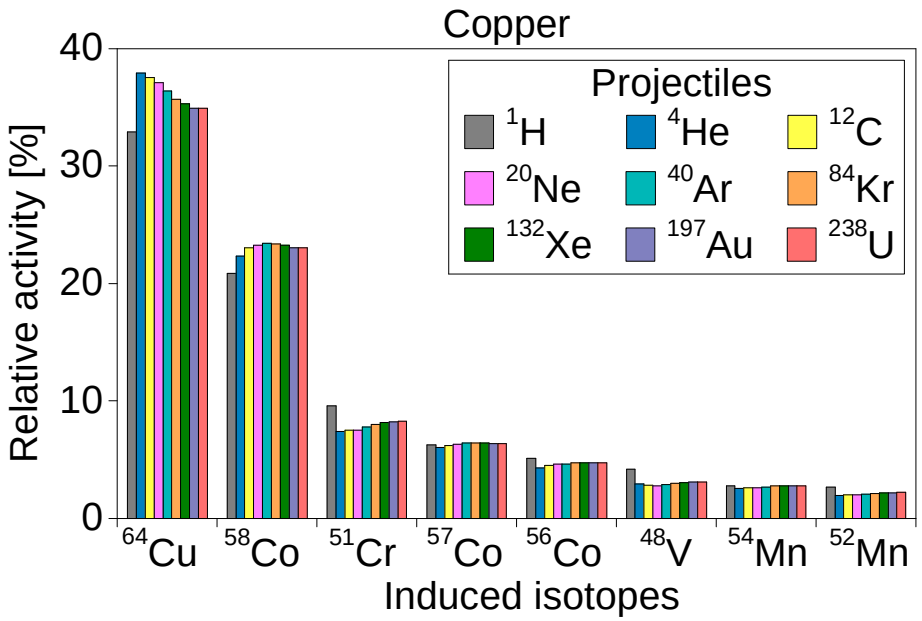




$A_p$(1GeV) – normalized activity induced by 1 GeV proton beam
$A_i$(E) - normalized activity induced by the beam of interest at given energy
normalized activity - activity induced by unit beam power of 1 W at given time

# Isotope inventory in stainless steel and copper

simulation code: FLUKA
beam energy: 500 MeV/u
"cooling-down" time: 1 day




Isotope inventory induced in the bulky targets and their relative activities depend on the target material.

# Stainless steel to copper ratio

Ratio of the normalized activity induced in stainless steel to the normalized activity induced in copper.

simulation code: FLUKA
beam energy: 1 GeV/u

| Cooling time / Projectile | 0 hours | 4 hours | 1 day | 1 week | 2 months |
|---|---|---|---|---|---|
| $^{1}H$ | 0.6 | 0.9 | 1.4 | 1.9 | 1.5 |
| $^{4}He$ | 0.6 | 0.9 | 1.5 | 2.0 | 1.7 |
| $^{12}C$ | 0.6 | 0.9 | 1.5 | 2.0 | 1.7 |
| $^{20}Ne$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.7 |
| $^{40}Ar$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.7 |
| $^{84}Kr$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.6 |
| $^{132}Xe$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.6 |
| $^{197}Au$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.6 |
| $^{238}U$ | 0.6 | 0.9 | 1.6 | 2.0 | 1.6 |

# Activation of carbon, aluminium and tantalum

- Study of other important accelerator construction-materials: carbon, aluminium, tantalum.

- Bulky target (cylinder)
  diameter: 20 cm, length: 60 cm

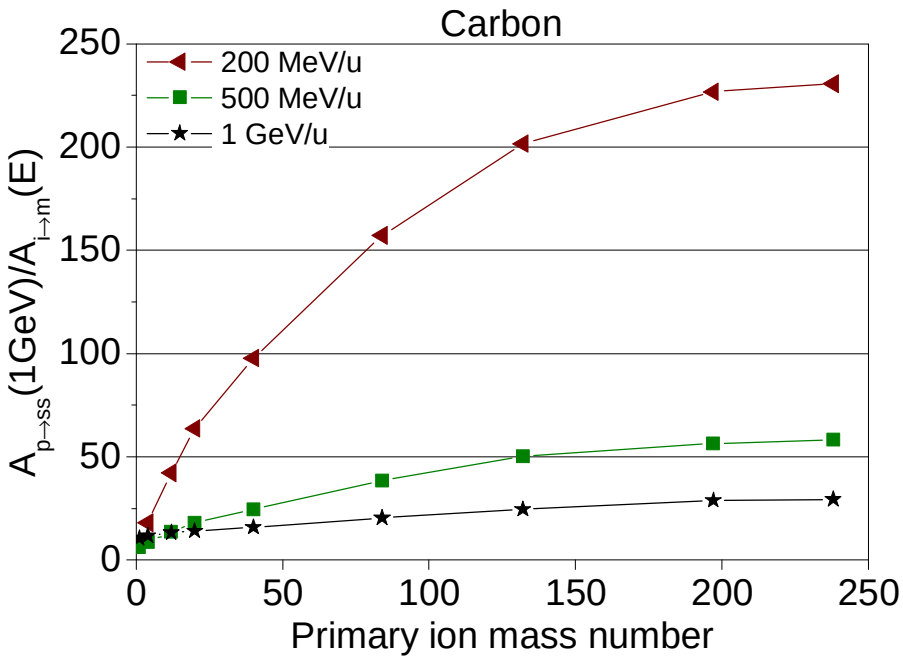

primary beams: $^{1}$H, $^{4}$He, $^{12}$C, $^{20}$Ne, $^{40}$Ar, $^{84}$Kr, $^{132}$Xe, $^{197}$Au, $^{238}$U
beam energies: 1 GeV/u, 500 MeV/u, 200 MeV/u

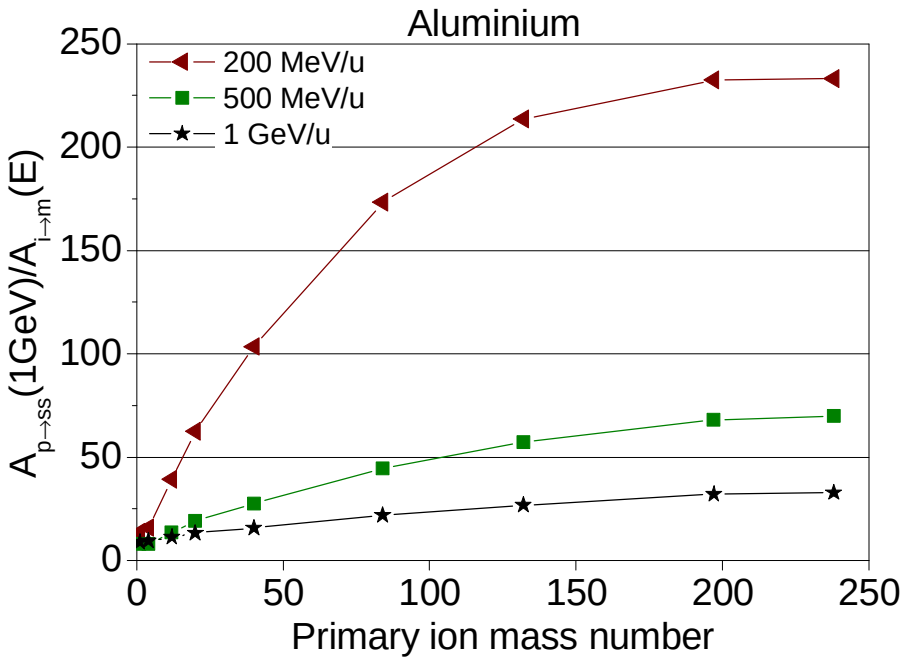
irradiation time: 100 days
"cooling-down" times: 0 days, 4 hours, 1 day, 1 week, 2 months
simulation code: FLUKA
calculated quantities: activity [Bq]

# Ratio of the normalized activities

Low atomic mass-number materials (carbon and aluminium).

simulation code: FLUKA
"cooling-down" time: 4 hours



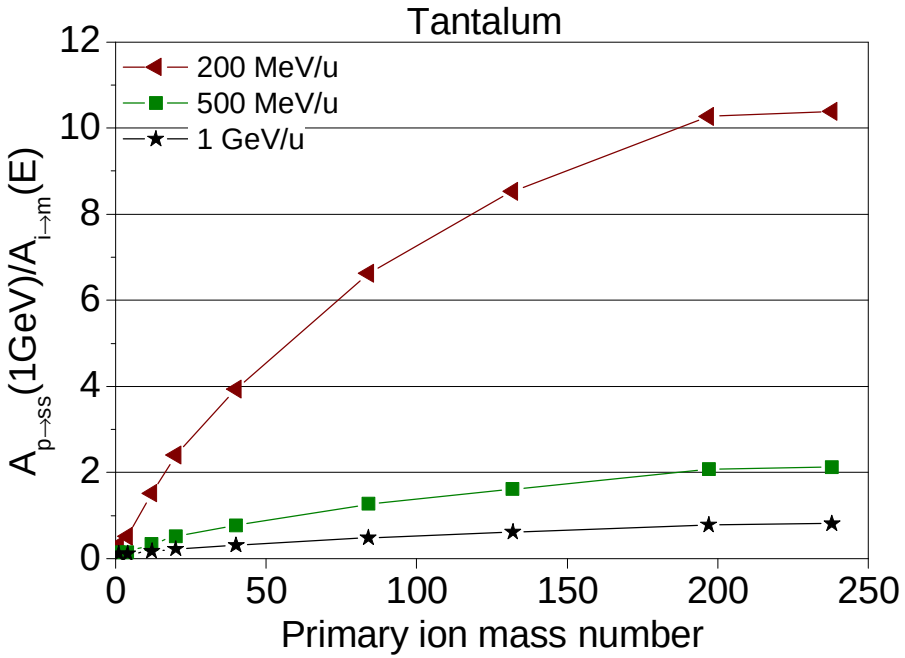




$A_{p\to ss}(1GeV)$ – normalized activity induced by 1 GeV proton beam in stainless steel
$A_{i\to m}(E)$ - normalized activity induced by the beam with the energy of interest in given material
normalized activity - activity induced by unit beam power of 1 W at given time

# Ratio of the normalized activities

High atomic mass-number material (tantalum).

simulation code: FLUKA
"cooling-down" time: 4 hours




$A_{p\rightarrow ss}(1GeV)$ – normalized activity induced by 1 GeV proton beam in stainless steel
$A_{i\rightarrow m}(E)$ - normalized activity induced by the beam with the energy of interest in given material
normalized activity - activity induced by unit beam power of 1 W at given time

# Ratio dependence on the ‘‘cooling-down’’ time

Ratio of the normalized activities for carbon, aluminium and tantalum depends on the ‘‘cooling down’’ time.

simulation code: FLUKA
beam: $^{238}U$

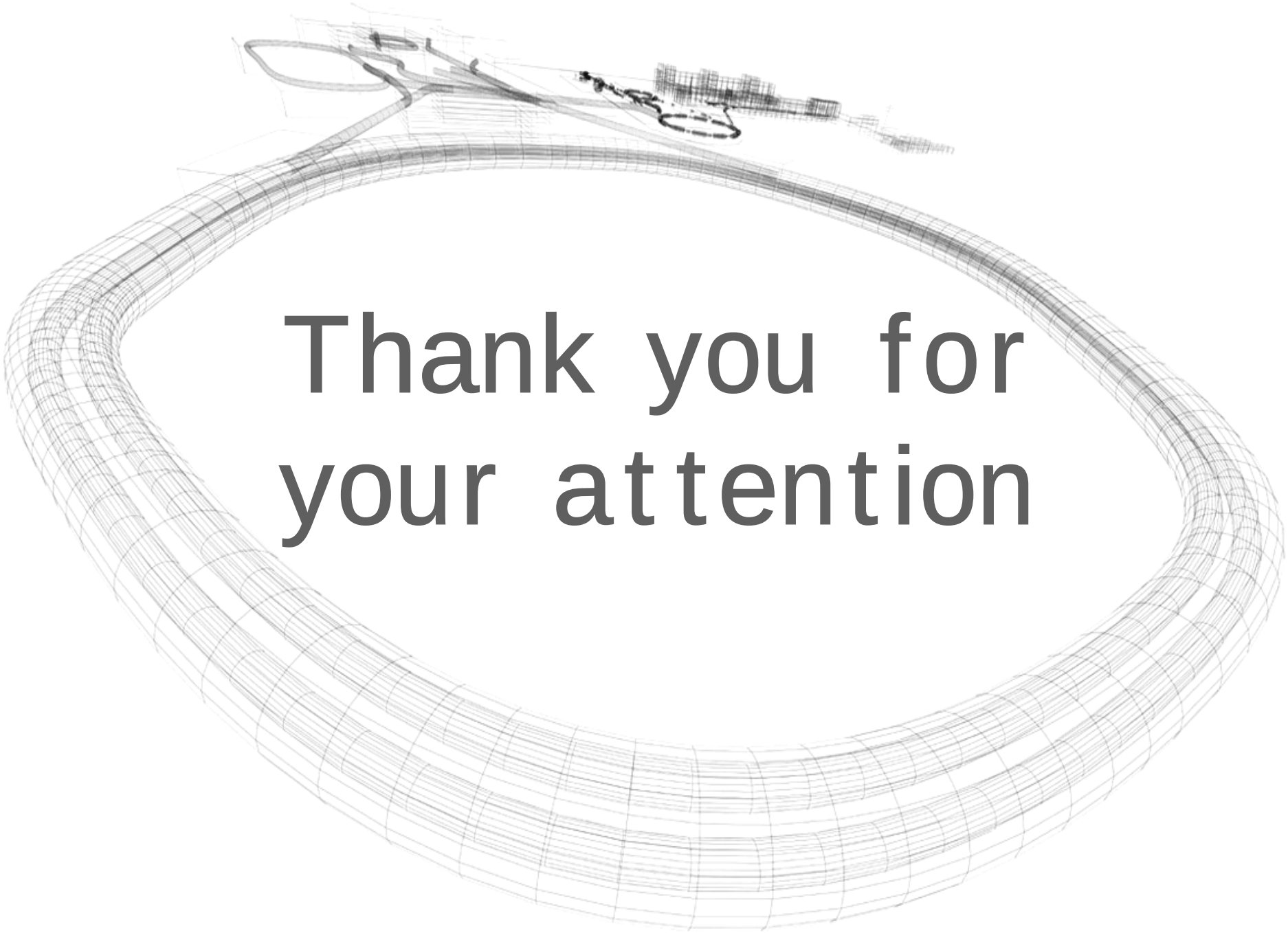
ratio: $A_{p\rightarrow ss}(1GeV)/A_{i\rightarrow m}(E)$ →

| 1 GeV/u | 0 hours | **4 hours** | 1 day | 1 week | 2 months |
|---|---|---|---|---|---|
| C | 7.2 | **29** | 27 | 24 | 20 |
| Al | 13 | **33** | 53 | 85 | 61 |
| Ta | 0.8 | **0.8** | 0.9 | 1.0 | 0.7 |
| 500 MeV/u | 0 hours | **4 hours** | 1 day | 1 week | 2 months |
| C | 16 | **58** | 58 | 56 | 49 |
| Al | 30 | **70** | 115 | 212 | 170 |
| Ta | 2.2 | **2.1** | 2.5 | 2.7 | 1.8 |
| 200 MeV/u | 0 hours | **4 hours** | 1 day | 1 week | 2 months |
| C | 80 | **231** | 236 | 257 | 251 |
| Al | 111 | **232** | 372 | 728 | 770 |
| Ta | 11.3 | **10.4** | 12.2 | 13.5 | 8.7 |

$A_{p\rightarrow ss}(1GeV)$ – normalized activity induced by 1 GeV proton beam in stainless steel
$A_{i\rightarrow m}(E)$ - normalized activity induced by the beam with the energy of interest in given material
normalized activity - activity induced by unit beam power of 1 W at given time

# Conclusions

- Tolerable beam-loss criteria for “hands-on” maintenance on heavy-ion accelerators were specified for the beam-pipe and the bulky-target geometry.
- The tolerable beam-losses for heavy ion accelerators were specified by scaling the existing value of 1 W/m for protons.
- The criteria for 1 GeV/u uranium beam: 12 W/m (beam pipe) and 5 W/m (bulky target).
- Isotope inventory and their relative activities strongly depend on the target material.
- Ratio of the normalized activities 4 hours after irradiation for 1 GeV/u uranium beam: 29 (carbon), 33 (aluminium) and 1 (tantalum).
- Dependence of the ratio on the ‘‘cooling down’’ time was observed.



# Thank you for your attention