Activation Calculations with FLUKA for the B*ERL*inPro Vacuum System

Seventh International Workshop on Radiation Safety at Synchrotron Radiation Sources (RadSynch13) at the National Synchrotron Light Source, Upton, USA

Manuela Helmecke, Klaus Ott
Helmholtz- Zentrum Berlin
BESSY II
Radiation Protection Department
Albert-Einstein-Str. 15
12489 Berlin, Germany

Contact: manuela.helmecke@helmholtz-berlin.de

Activation at Accelerators

Activation is a serious hazard, since the radiation remains after switching off the accelerator. Consequences: **Additional radiation exposition**.

How can it be reduced ?
One possibility during construction: Choice of material.

Outline:

- **Activation**
- **Activation Calculations with FLUKA**
- **Application: Activation at BERLinPro**
- **Consequences for its Vacuum System**
- **Summary**

At electron accelerators gamma-radiation occurs due to Bremsstrahlung and electron losses. This leads to neutron radiation and activation.

Element	Isotope	E_{Thr} [MeV]
Iron	^{54}Fe	13.8
Carbon	^{12}C	18.7
Aluminum	^{27}Al	14.4
Copper	^{63}Cu	10.9
	^{65}Cu	10.2
Magnesium	^{24}Mg	16.2
Calcium	^{40}Ca	15.9
Zinc	^{90}Zn	9.2

Threshold-Energy for photoreactions of some construction materials and alloying elements

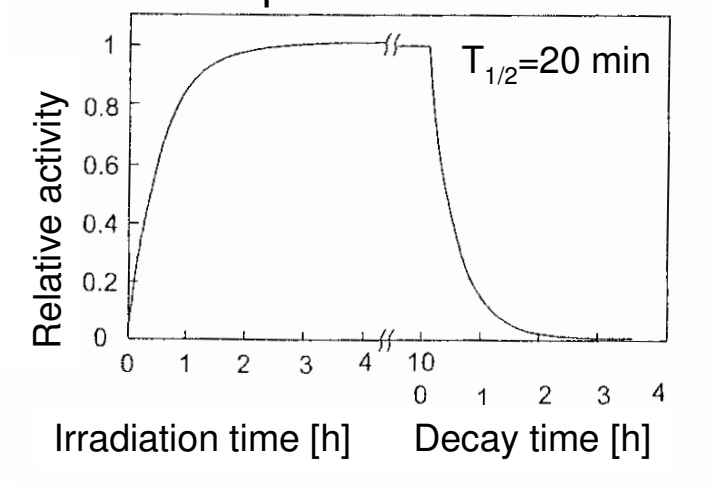
Calculation of activation: preliminiary considerations

Activation rate:

$$\dot{N}^+ = \rho \cdot N_L/A \int_0^{V_0} \int_0^{E_0} \sigma(E_P) \cdot \phi(E_P, \vec{r}) \cdot \mathrm{d}E_P \mathrm{d}V \qquad (1)$$

$\sigma(E_P)$: cross section
E_P: energy of photons
$\Phi(E_P, \vec{r}) \cdot dE_P$: flux density of photons with energies between E_P and E_P+dE at r
$n=\rho \cdot N_L/A$: number of nuclei per volume
ρ: density of nuclei
N_L=6.023E23/mol
A: mass number of nucleus

Example:



Activation Equation:

$$A_\nu = \dot{N}^+ \cdot [1 - \exp(-\lambda \cdot t_B)] \cdot \exp(-\lambda \cdot t_K) \cdot \frac{1 - \exp[-\nu \cdot \lambda(t_B + t_K)]}{1 - \exp[-\lambda(t_B + t_K)]} \qquad (2)$$

ν: number of irradiation periods
$\lambda=(\ln 2)/T_{1/2}$ ($T_{1/2}$: half-life of nucleus)
t_B: irradtiation time
t_K: decay time

= 1 for one radiation period

Method has been developped to automatise calculation by using FLUKA*.

*)G. Battistoni et al., "The FLUKA code: Description and benchmarking", Proceedings of the hadronic Shower Simulation Workshop 2006, Fermilab, United States (2006), M. Albrow ed., AIP Conference Proceeding 896, 31-49, (2007) A. Fasso et al., "FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

Calculation of dose of known reaction $^{59}Co + n \rightarrow {}^{60}Co^{*} \rightarrow {}^{60}Co + \gamma$

$\dot{N}^{+} = 0{,}5$ (nuclide / primary particle), λ (^{60}Co)=3.9E-9, $\Gamma(^{60}Co) = 0.354 \frac{mSv \cdot m^2}{h \cdot [GBq]}$;

A) „Old method by hand“:

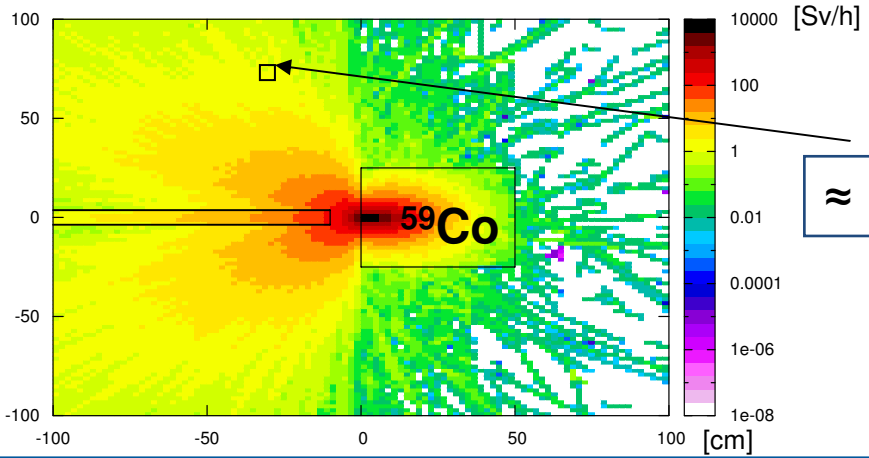
For t_B=1000 h (irradiation time) and t_K=5 years (decay time) follows with equation (2)

A= 3.76E-9 GBq / primary particle

With the gamma dose: $\frac{dH}{dt} = \Gamma \cdot \frac{1}{r^2} \cdot A$ (3) follows at a distance of 70 cm

$\frac{dH}{dt} = 2.71E-12 \frac{Sv/h}{pp}$ There are 360E9 primary particles / h: $\frac{dH}{dt} = 0.977$ Sv/h

B) Directly simulated Gamma dose rate:



≈ 1 Sv/h

If there are many different isotopes (e.g. steel alloys) a calculation by hand (method A) is very intense in time!
Do it directly in one step!

FLUKA: Syntax and options for activation calculations

----------INDUCED RADIOACTIVITY----------

RADDECAY
h/μ Int: ignore
e-e+ LPB: ignore
Decays: Active
h/μ LPB: ignore
e-e+ WW: ignore
decay cut: 0.0
Patch Isom: On
h/μ WW: ignore
Low-n Bias: ignore
prompt cut: 9999.0
Replicas: 0.0
e-e+ Int: ignore
Low-n WW: ignore
Coulomb corr:

IRRPROFI

Irradiation Profile

Δt: 28800.
Δt: 0.0
Δt: 0.0
p/s: 3E13
p/s: 0.0
p/s: 0.0

DCYTIMES

Decay times

t1: 3600.
t4: 28800.
t2: 2592000.
t5:
t3: 1.57248E8
t6:

Scoring:

----------Gamma Activity---

DCYSCORE

USRBIN
Type: X-Y-Z
Part: DOSE-EQ

AUXSCORE

Equivalent dose after decay time 1

DCYSCORE

USRBIN
Type: X-Y-Z
Part: DOSE-EQ

AUXSCORE

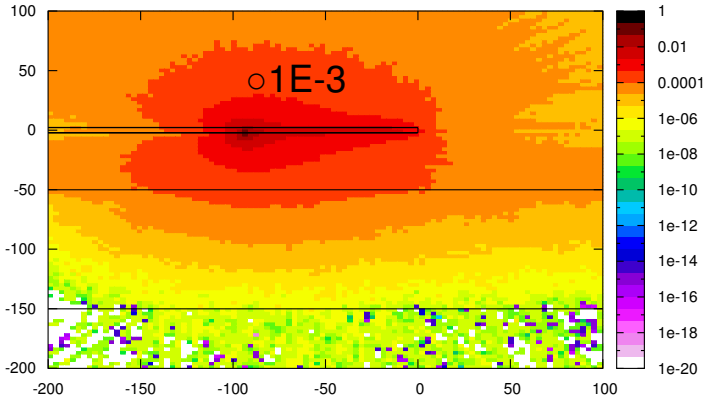
Equivalent dose after decay time 2 etc.

RADDECAY
requests simulation of radioactive decays and sets the corresponding biasing and transport conditions

Activation calculations: Comparison of steel and aluminium I

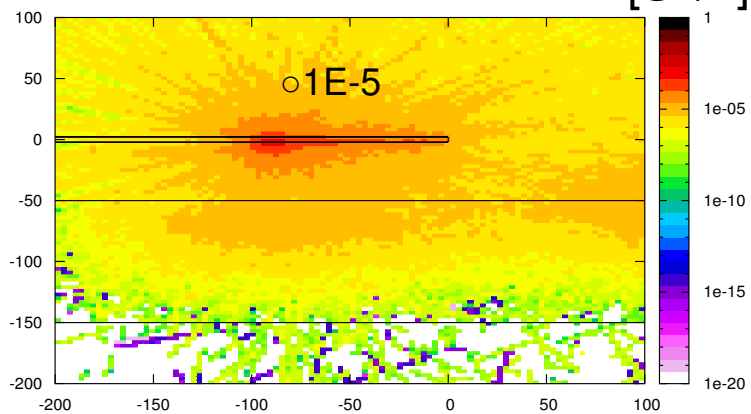
Electron loss (50 MeV) of 5 µA/m for 8 hours causes the following dose rates:

After 1 hour of decay time [Sv/h]



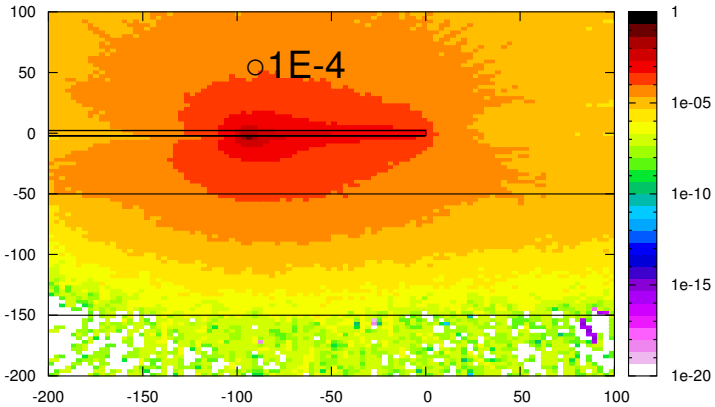
Steel tube

[Sv/h]



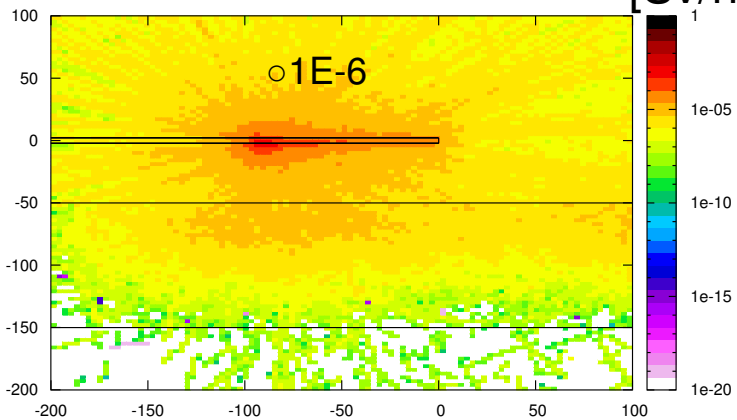
Aluminum tube

After 8 hours of decay time [Sv/h]



Steel tube

[Sv/h]

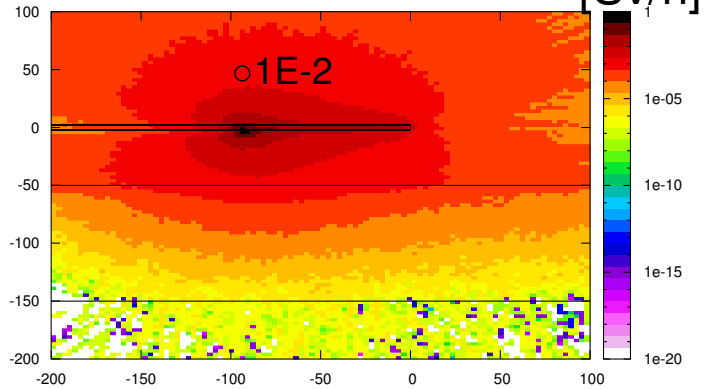


Aluminum tube

Activation calculations: Comparison of steel and aluminium II

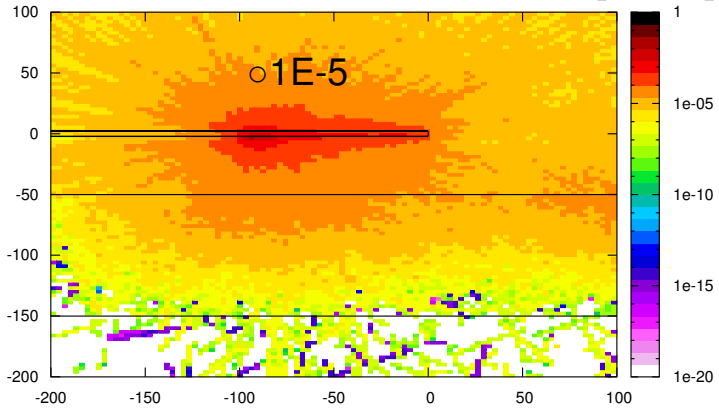
Electron loss (50MeV) of 5 µA/m for 2000 hours causes the following dose rates:

After 1 hour of decay time [Sv/h]



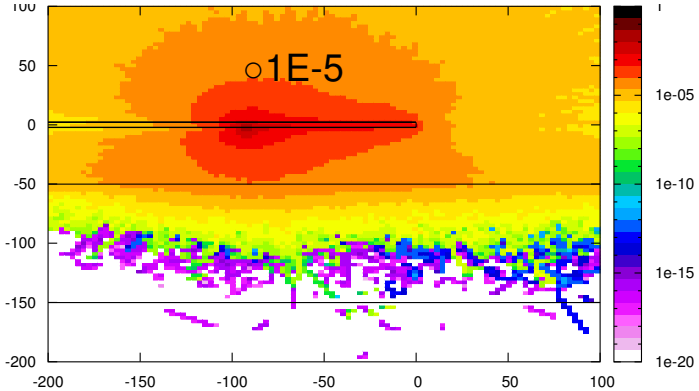
Steel tube

[Sv/h]



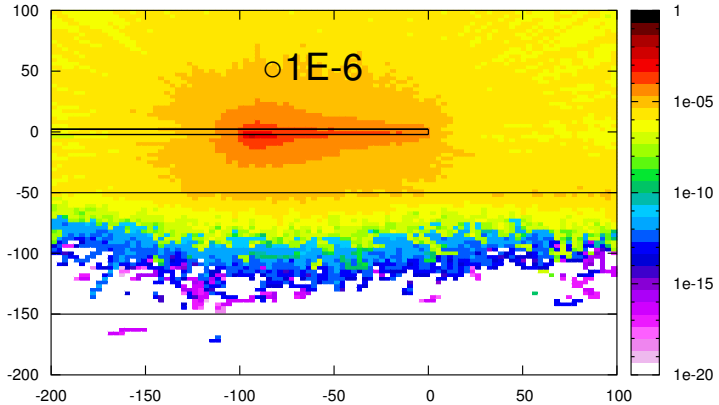
Aluminum tube

After 1 year of decay time [Sv/h]



Steel tube

[Sv/h]



Aluminum tube

For simulation used alloys:

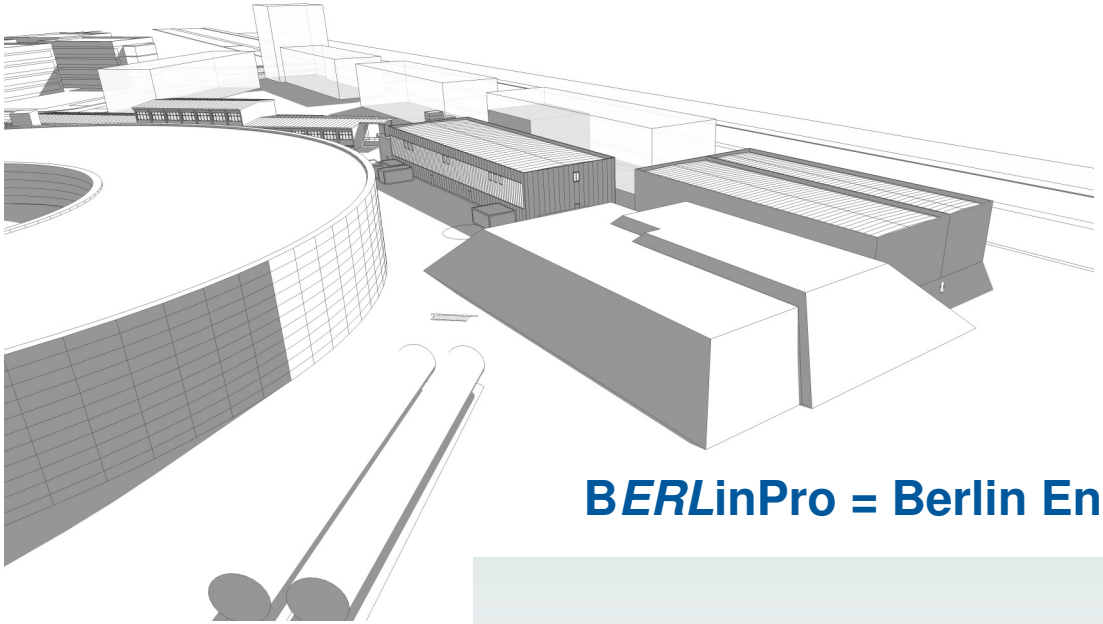
Aluminum (Al5080)
Densitiy: 2.66 g/cm³

- 94.8% aluminum
- 4.5% magnesium
- 0.7% manganes

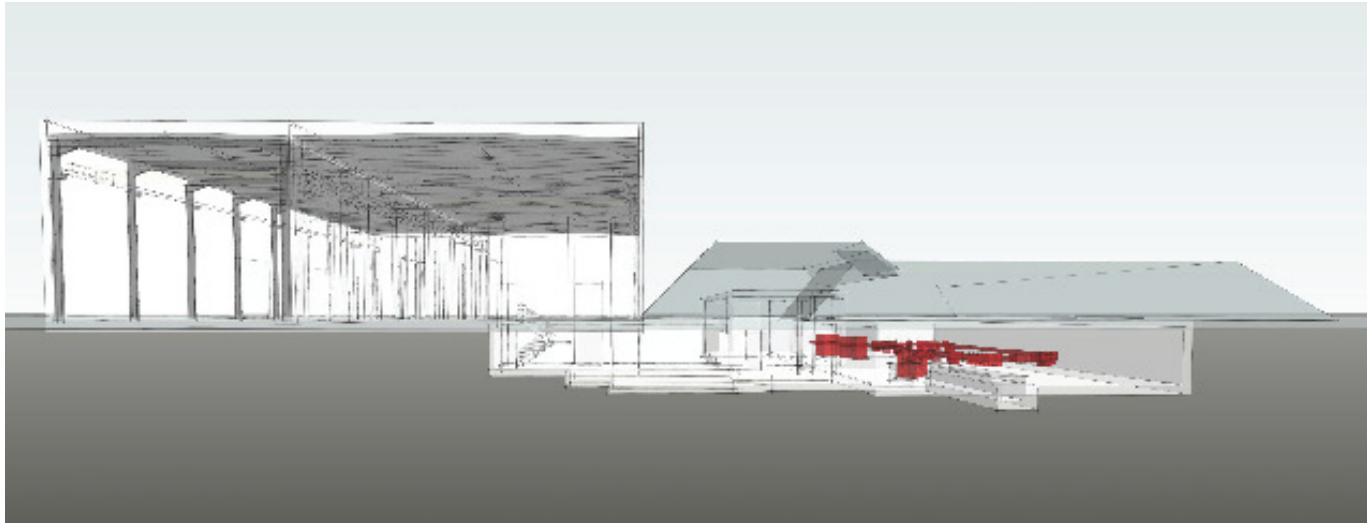
Steel:
Density: 8.11 g/cm³

- 62.81% iron
- 18.5% chromium
- 13.0% nickel
- 2.5% molybdenum
- 2.0% manganes
- 1.0% silicon
- 0.1% nitrogen
- 0.045% phosphor
- 0.03% carbon
- 0.015% sulfur

BERLinPro: Position at BESSSY-site I

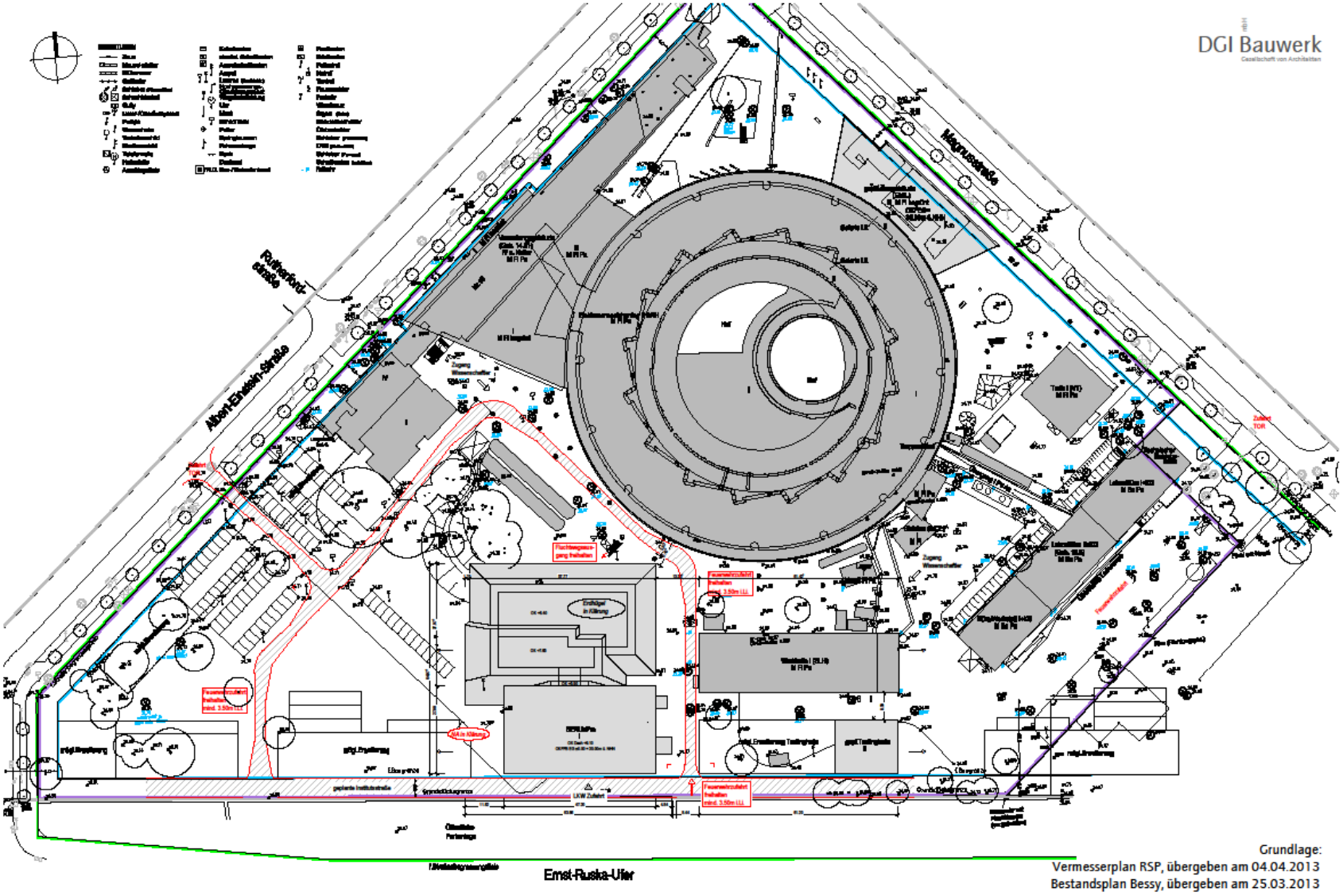


B*ERL*inPro = Berlin Energy Recovery Linac Project

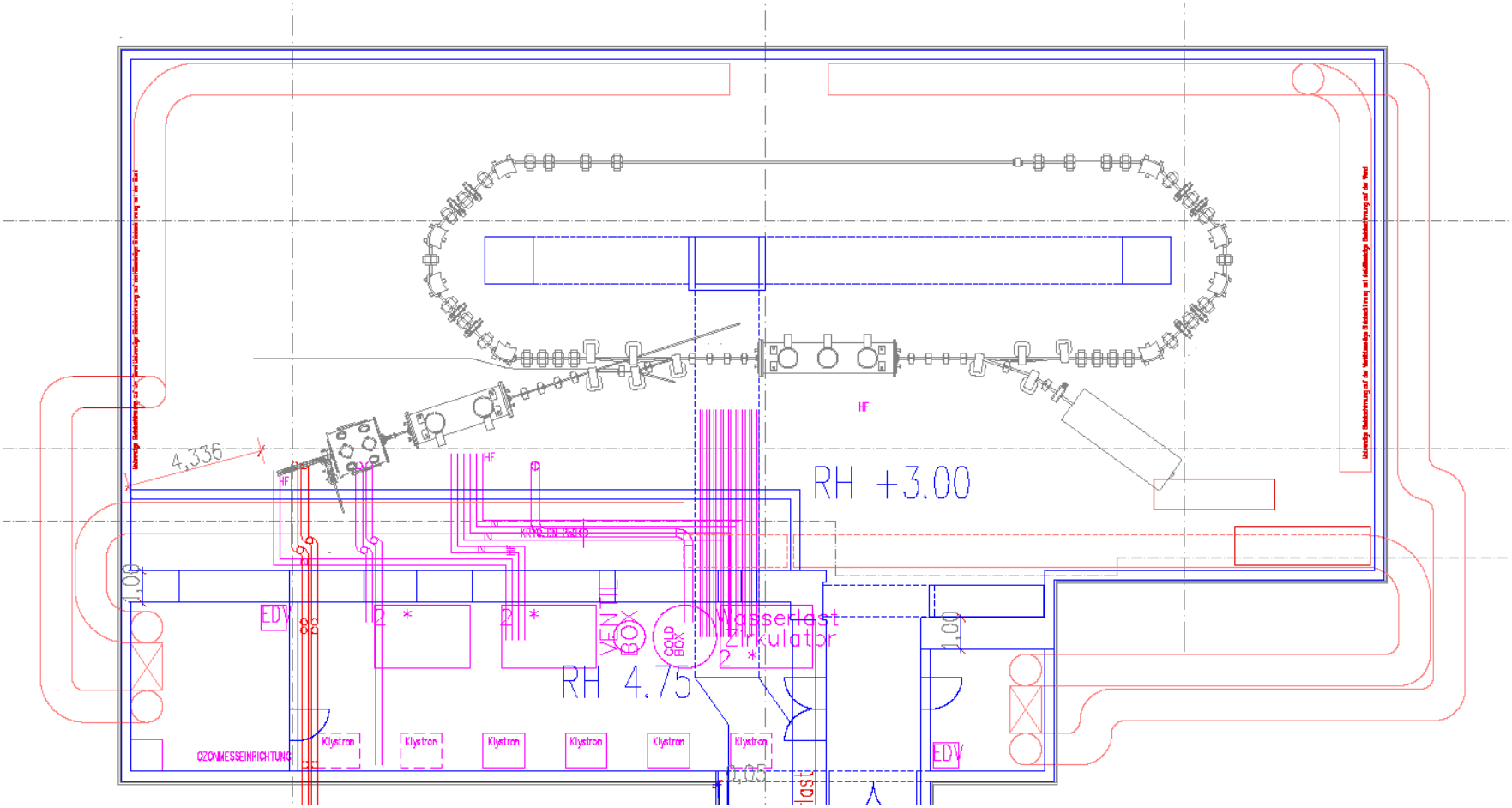


Constanze Tibes, DGI Bauwerk Gesellschaft von Architekten mbH (arcitect‘s office)

BERLinPro: Position at BESSSY-site II



BERLinPro: Accelerator hall

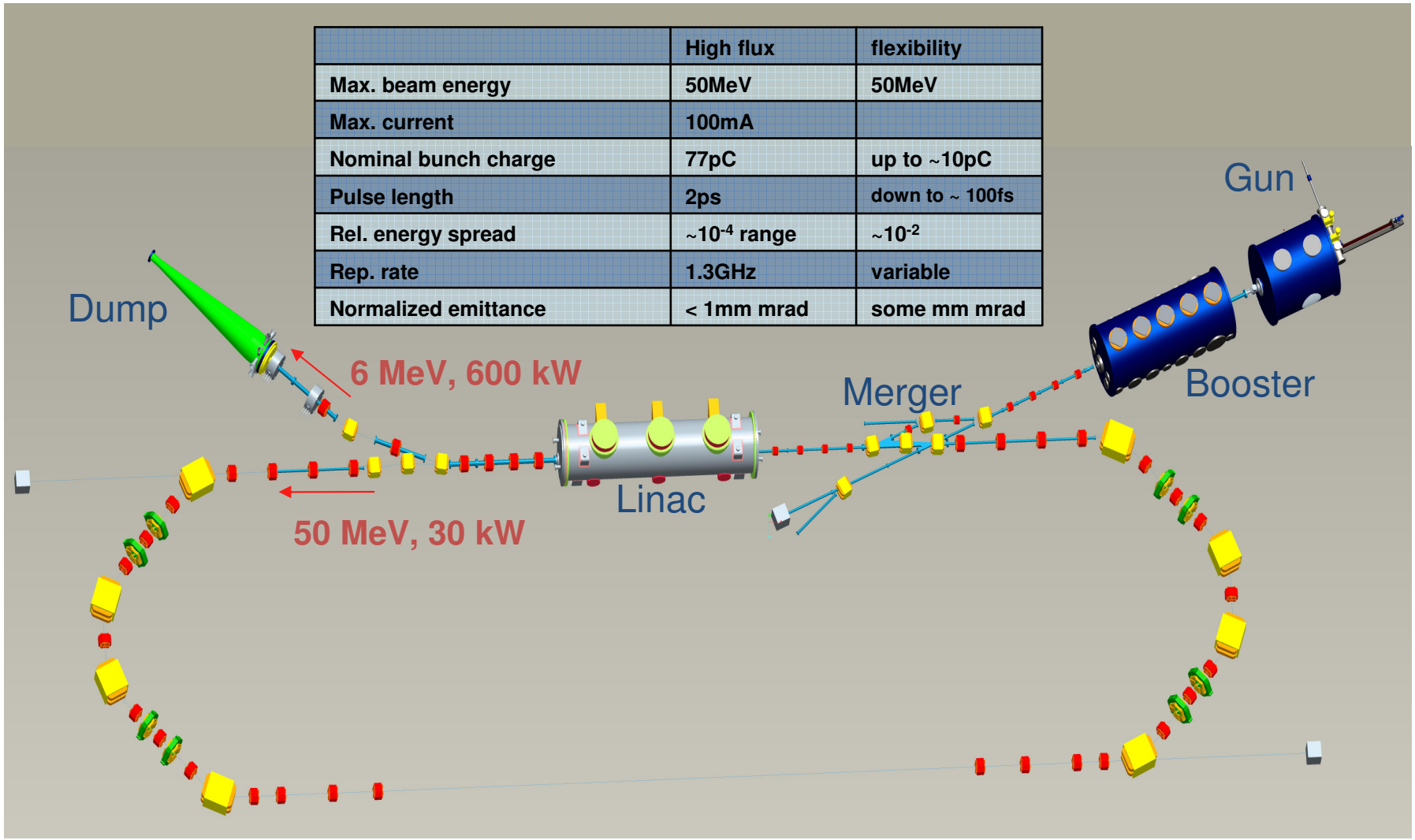


Shielding considerations:

K. Ott, M. Helmecke, “The shielding design of B*ERL*inPro”, IPAC 2011, San Sebastian, Spain (2011)
M. Helmecke, K. Ott, “Shielding Considerations for B*ERL*inPro”, RADSYNCH 2011, Pohang, South Corea (2011)

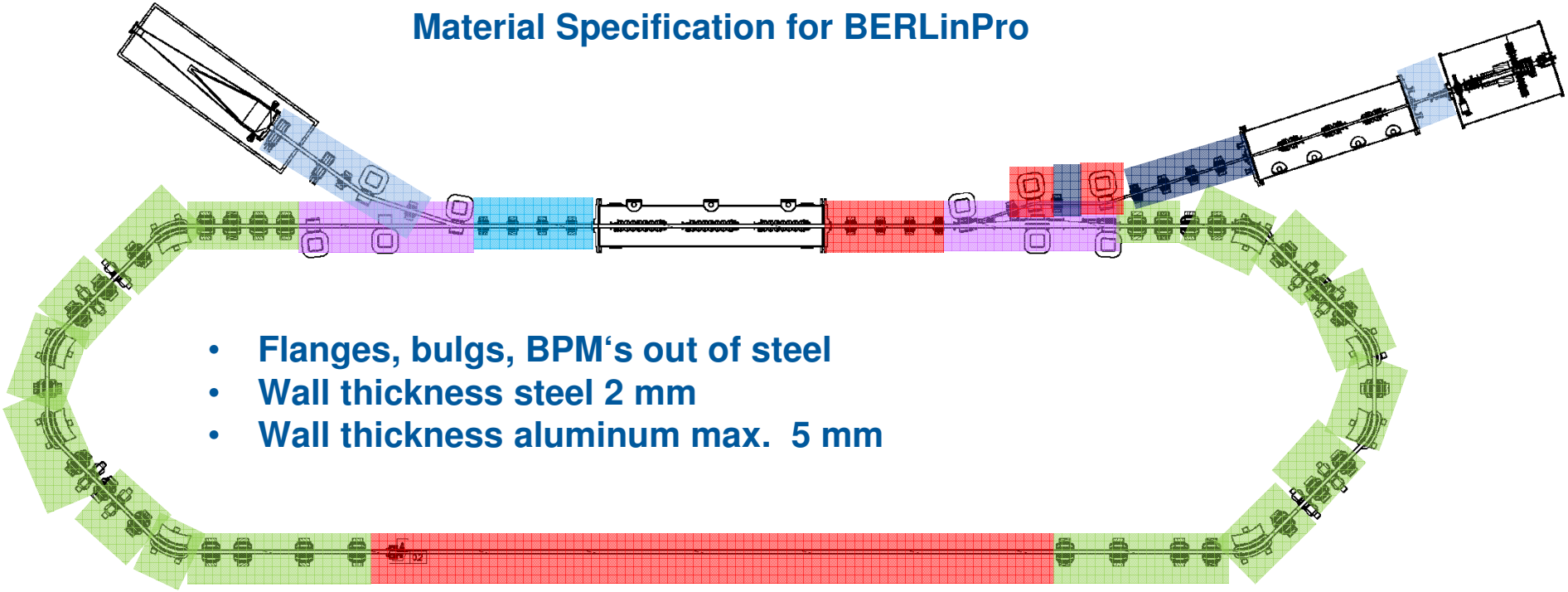
BERLinPro: Layout Overview

	High flux	flexibility
Max. beam energy	50MeV	50MeV
Max. current	100mA	
Nominal bunch charge	77pC	up to ~10pC
Pulse length	2ps	down to ~ 100fs
Rel. energy spread	~10^{-4} range	~10^{-2}
Rep. rate	1.3GHz	variable
Normalized emittance	< 1mm mrad	some mm mrad



Conceptual design report B*ERL*inPro, B*ERL*inPro project team, Helmholtz-Zentrum Berlin (2012)

Material Specification for BERLinPro



- **Flanges, bulgs, BPM‘s out of steel**
- **Wall thickness steel 2 mm**
- **Wall thickness aluminum max. 5 mm**

Color code:

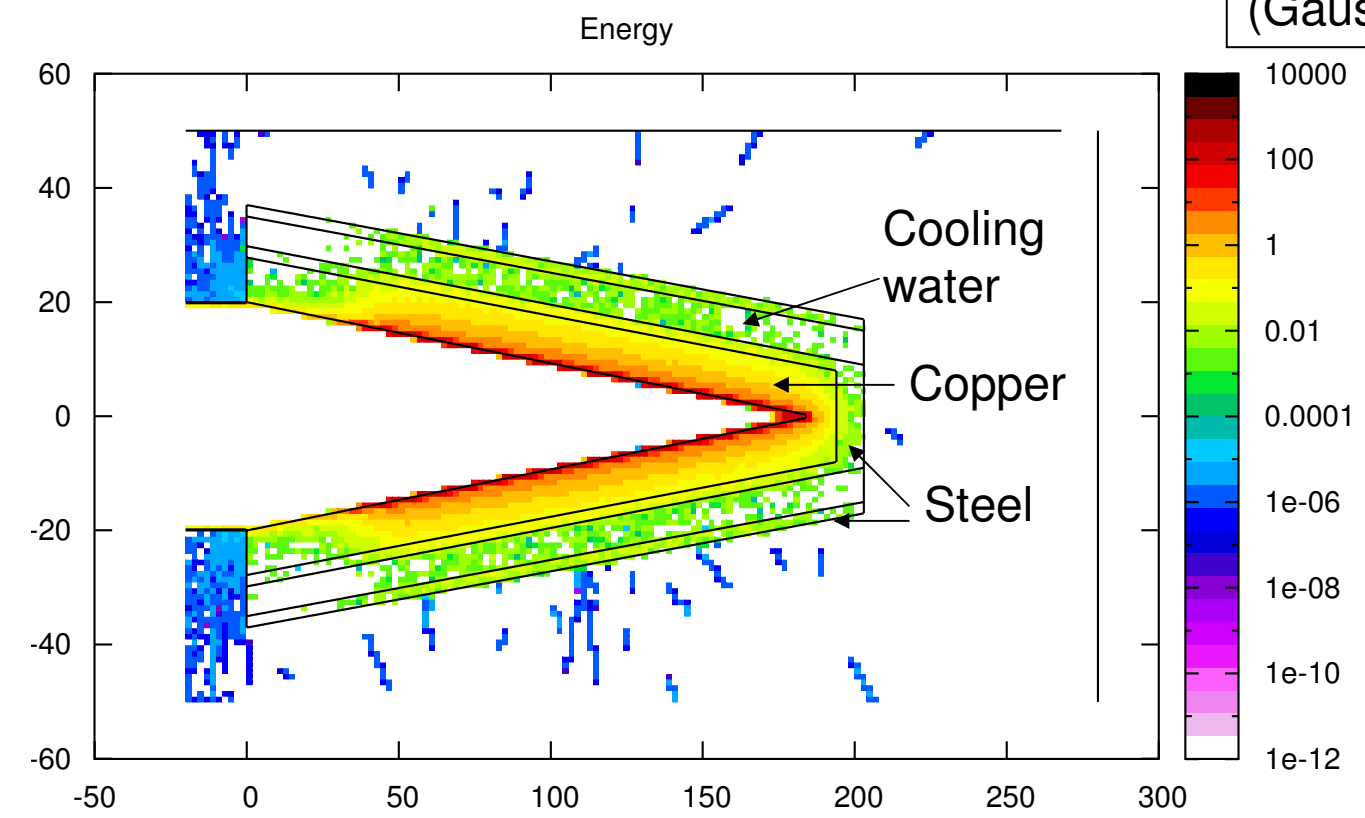
- round beam pipe Ø 70 mm Stainless Steel (1.4404) — without cooling
- round beam pipe Ø 40 mm Stainless Steel (1.4404) — without cooling
- round beam pipe Ø 40 mm Aluminum (6061 T6) — with optional cooling
- round beam pipe **Ø70 mm** Aluminum (6061 T6) — without cooling
- elliptic beam pipe 70 mm x 40 mm Aluminum (6061 T6) — with cooling
- rectangular beam pipe Aluminum (6061 T6) — with cooling

Volker Dürr, construction department

Simulation of main BERLinPro Beamdump

Energy deposition in W/cm³ (with I=100 mA)

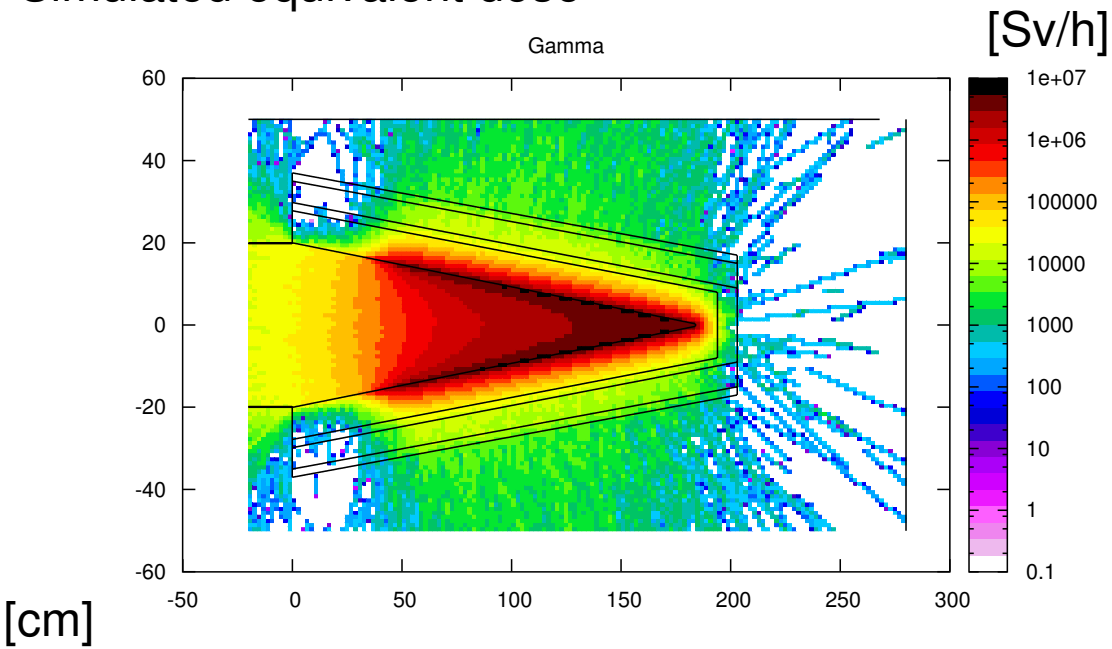
Beam properties:
Divergence: 150 mrad
Beamwidth: 2,5 cm
(Gaussian distribution)



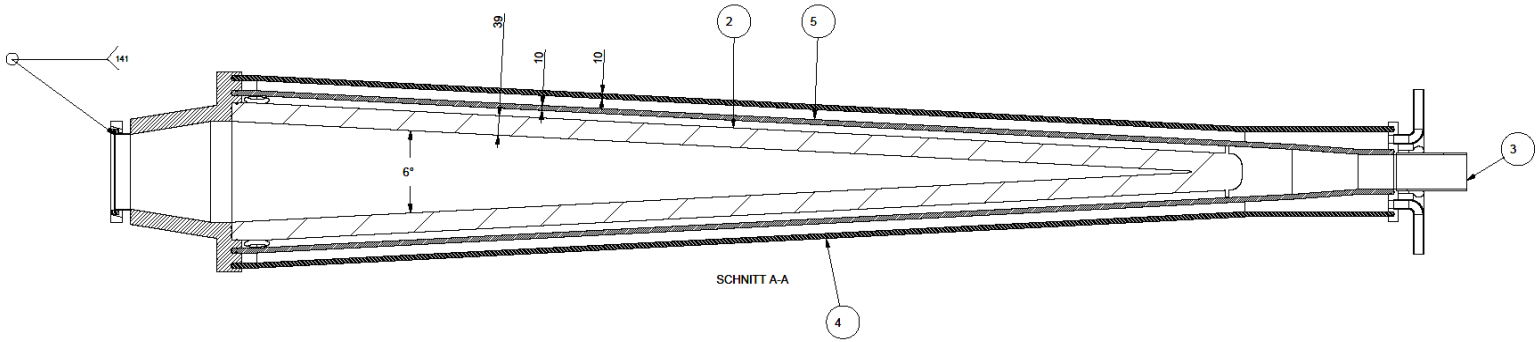
[cm]

Other radiation protection issues II

Simulated equivalent dose



Construction (Marc Dirsat):



Summary and Outlook

- Activation can be reduced by choosing appropriate materials
- Exact calculations are **very intense in time** -> Use of Monte-Carlo-Code FLUKA
- Comparison of electron induced activation of aluminum and steel
  (Electron energy 50 MeV, electron loss 5 µA/m)
- **Application & Consequences for the BERLinPro vacuum system**:

  -High energy part (50MeV): Out of aluminum except some dedicated parts

  -Low energy part (6MeV): Out of steel

Outlook concerning radiation protection:

- Detailed construction plans in progress, activation calculations considered
- First parts are delivered this year (e.g. beamdump)
- Shielding design will be completed in August 2013 in order
  to obtain **construction permit** (K. Ott)

Thank you for your attention!