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Estimate of the Total Decommissioning Radioactive Waste of the High Intensity Proton Accelerator (HIPA) Facility at PSI

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Motivation

Authorities require an estimate of the amount of the radioactive waste after the final shutdown of the proton accelerator facility (HIPA)

reason:

- cost estimate for the decommisioning
- input for the planning of the final repository

Nowadays: Estimate of total rad. waste required for operational approval of the facility.

History:

1974: First proton beam

1986: First estimate of amount of waste based on measurements

- documentation of the considerations are poor
- lower current integral
- different exemption limits

2008: Estimate using spheres (pure concrete or pure steel) around loss points

- unrealistic: shielding consists of steel inside and concrete outside

in addition: exemption/clearance limits will change soon!

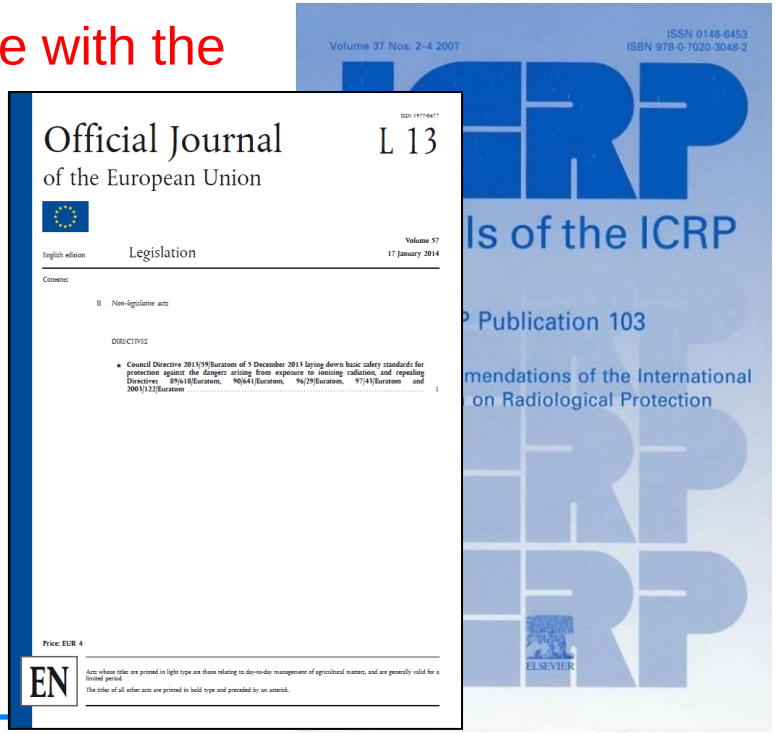
Reason for the change of the exemption limits

The Euratom Community has established a set of basic safety standards = BSS to protect workers, members of the public and patients against the dangers arising from ionising radiation.

The latest Basic Safety Standards Directive entered into force on 6.2.2014 and EU countries must ensure compliance by 6 February 2018.

The exemption limits of BSS are not compatible with the actual ones in the Swiss regulation (StSV)

The final version of Euratom BSS includes the IAEA Safety Guide RS-G-1.7, which was initiated by the implementation of ICRP 103 and based on the former BSS (2003)



Present and future radioprotection regulation in CH

Present regulation in Switzerland (StSV)

controlled by authority
CI(LE) > 1

Clearance index:

$$CI(LE) = \sum_i \frac{A_i}{LE_i}$$

LE = limit de exemption

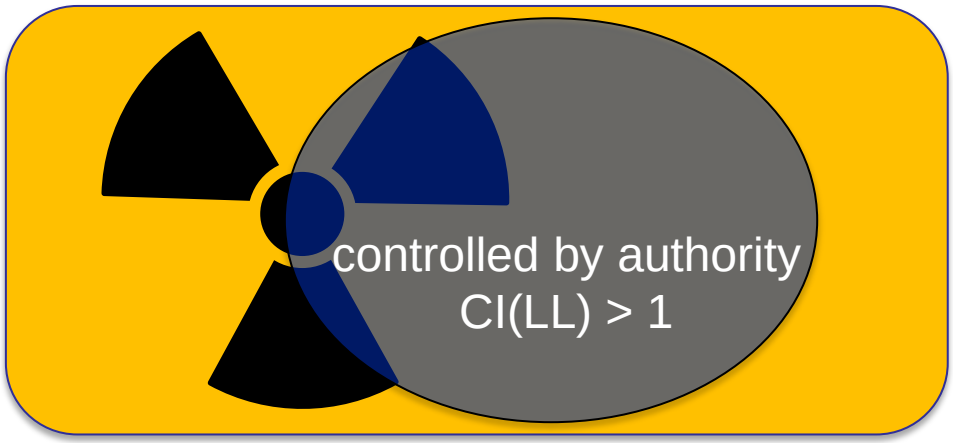
Future regulation in Europe

Everything is radioactive!

Clearance index:

$$CI(LL) = \sum_i \frac{A_i}{LL_i}$$

LL= limite de libération



New and old exemption values

Nuclide	LE present regulation [Bq/g]	LL future regulation [Bq/g]	LE/LL
H-3	200	100	2
Co-60	1	0.1	10
Ni-63	70	100	0.7
Eu-152	7	0.1	70
Eu-154	5	0.1	50

Most of the limits for important isotopes (steel, concrete) are considerably reduced

Radioactive waste in Switzerland

Radioactive material (CI > 1) have to be stored for a maximum of 30 years, if the material is non-radioactive (CI < 1) after it.

PSI proposal (2008): 75 years
→ reduce amount of waste

BAG (department of health): too long, more than 1 generation
knowledge/documentation of waste might be lost

ENSI (authority for nuclear power plants and packing/storage of waste):
in favor of 100 years

max. cooling time is still under discussion
→ waste calculation for 30, 75, 100 years storage time
+ 10 years for the planning of decommisioning
(post-closure phase)

Applied technique for waste estimate

Monte Carlo particle transport program **MCNPX2.7.0** : n,p,γ,α,π,d,^{3}H....

Input: dedicated geometry, material compositions,
cross sections: for n<20MeV ENDF-B-VI.6, otherwise ***models***

Output: n-fluxes (E<20 MeV), residual nuclei production rates
with rnucs-card (former active htape) in *.o file
- avoids huge histp file (can be several GB)
- developed by F. Gallmeier & M. Wohlmuther
- patch in the Cinder2008 release on RSICC

activation script

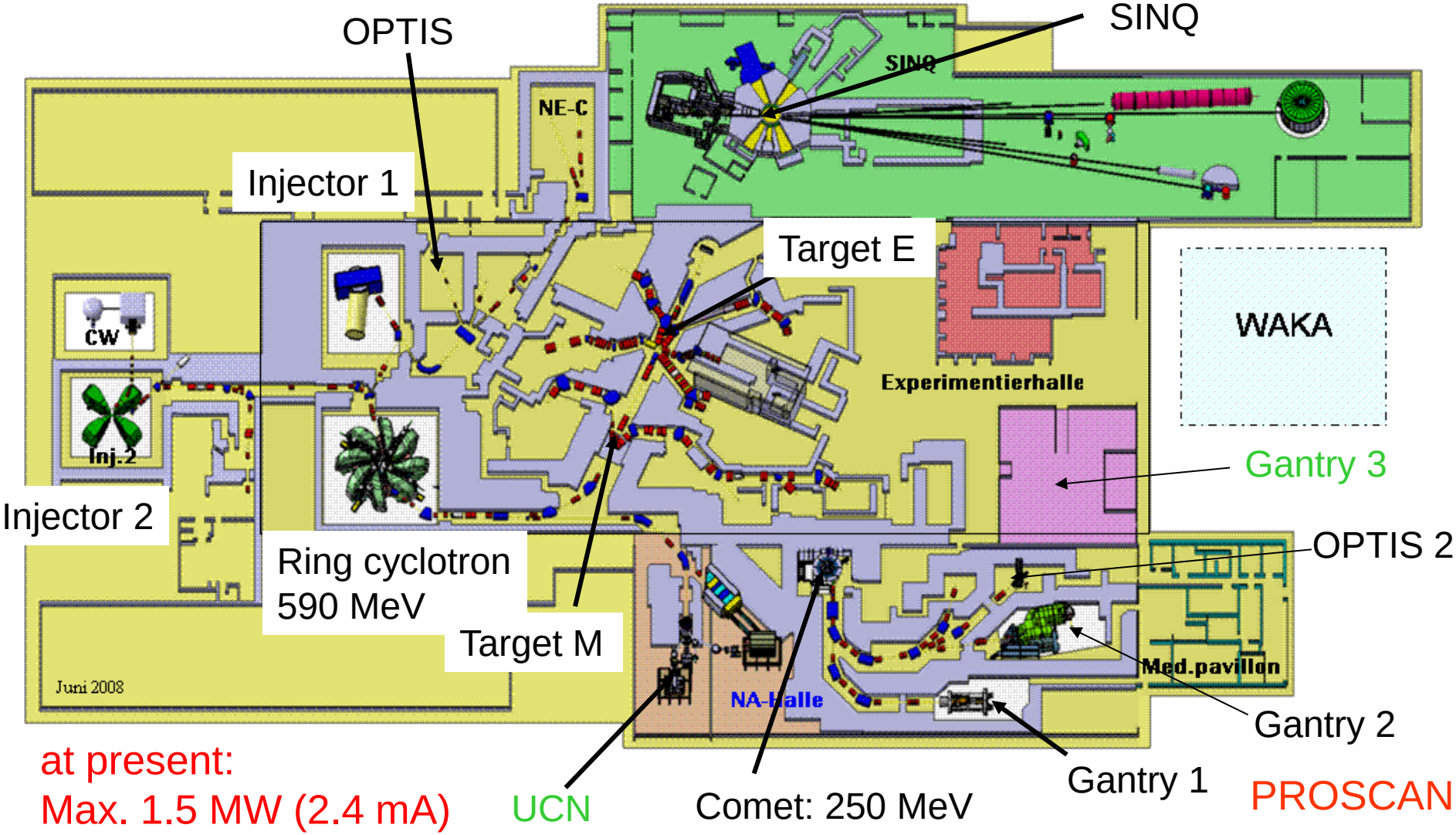
Cinder + c.s. library or **SP-Fispact** + EAF2007 or **Orihet3**

Activation script:

M. Wohlmuther et al., Proc. AccApp *2007*, Pocatello, p. 226.
F.X. Gallmeier, dito, p. 207

Exemption/clearance values eaf_clear_20070 modified to use present and future Swiss exemption values
→ clearance index in FISPACT output files

PSI Proton Accelerator Facilities



at present:
Max. 1.5 MW (2.4 mA)

Length scale: Target M to beam dump = 35.5 m

Major (defined) loss points

- p-channel: 590 MeV beam line

Target M, 2 secondary beam lines:	rebuild in 1985		1 %
Target E: 4 secondary beam lines:	rebuild in 1991		10 %
KHE2/3	rebuild in 1991		20 %
Beam dump	rebuild in 1991	<=1996	70 %
		>=1997	1% * 70 %

- Spallation neutron production targets :

SINQ: thermal neutrons (~ 25 meV)		
cold neutrons (< 5 meV)	>= 1997	70 %
UCN: ultra cold neutrons (~ μeV)		
pulsed operation with 1 % duty cycle	>= 2011	1 %

Concentrate on the regions of major loss points first:

- Target E + KHE2/3
- SINQ : 16 m x 16 m x 13.5 m

Irradiation histories

Target M region:

- Start of operation in 1974 (low intensity: negligible)
- Rebuilt in 1985

1985-1992	1993-2013	2014-2058
0.684 Ah	7.51 Ah	10 Ah
0.078 mA	0.857 mA	1.14 mA

max current integral nowadays

Target E region:

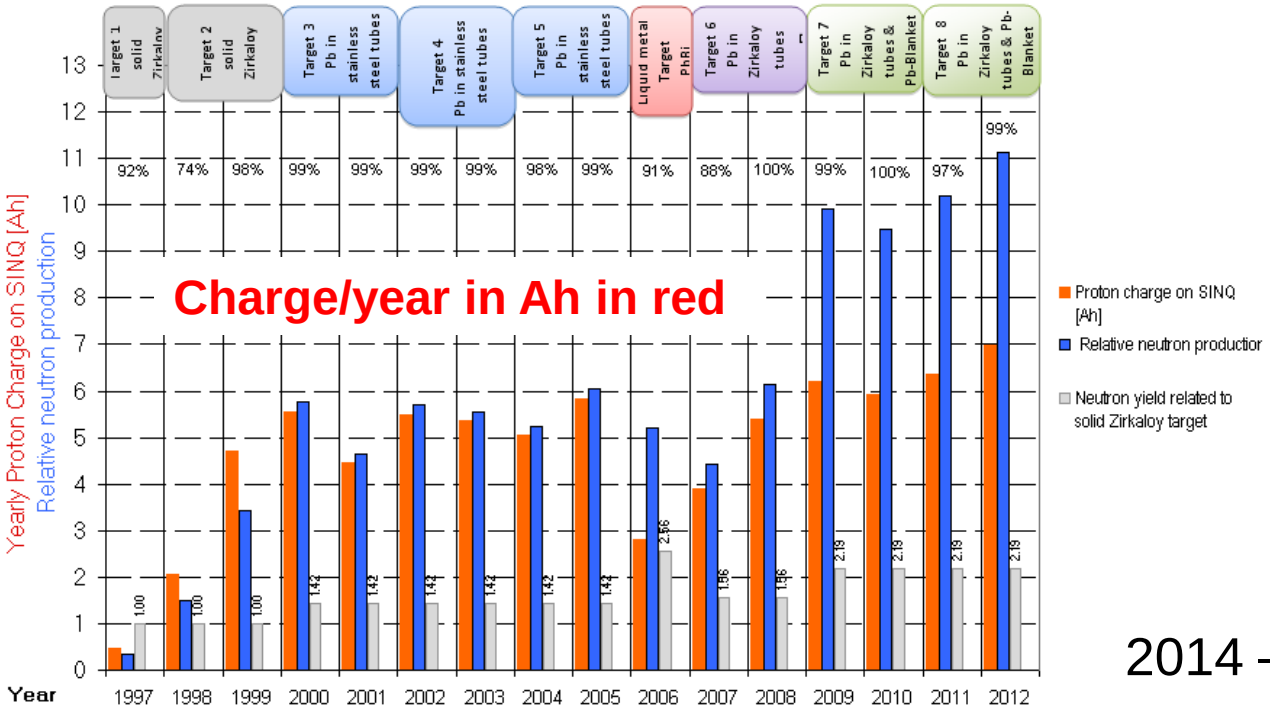
- Start of operation in 1974 (low intensity: negligible)
- Rebuilt in 1990

1991-2013	2014-2058
6.79 Ah	10 Ah
0.775 mA	1.14 mA

Assumption of a long future operation ensures saturation of the activity ~ max. activity

Irradiation histories

SINQ region: started in 1997



2014 – 2058: 70% * 10 Ah

UCN region: started in 2011

2011 – 2058: 20 μA

corresponds to a duty cycle of 1%

Material definition

- Some trace elements are particular important due to large neutron capture cross section
- For cooling times > 30 years in concrete and steel:
  Eu-152 ($T_{1/2}$ = 13.5 years), Eu-154 ($T_{1/2}$ =8.6 years) ,Co-60 ($T_{1/2}$ = 5.3 years)

Element	Steel	Concrete
Co	170 ppm	1 ppm
Eu	1 ppm	3 ppm

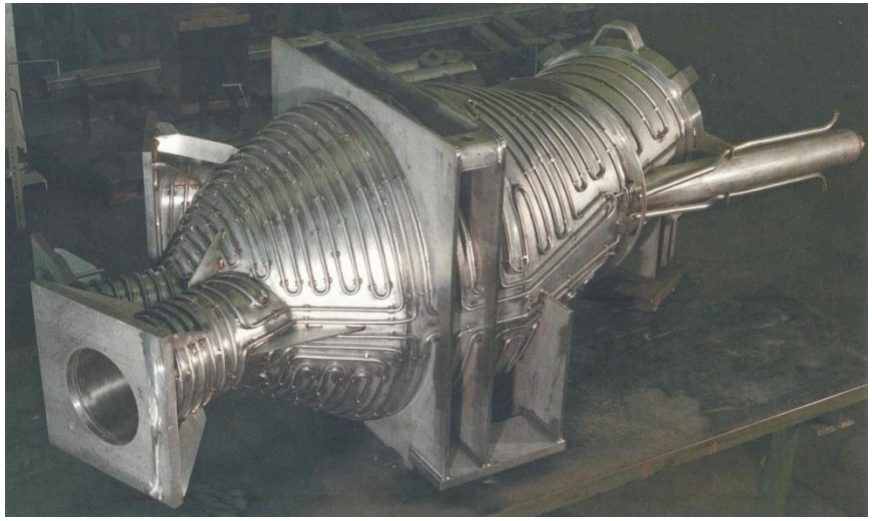
conservative values as used for the calculation of the nuclide inventory of operational waste

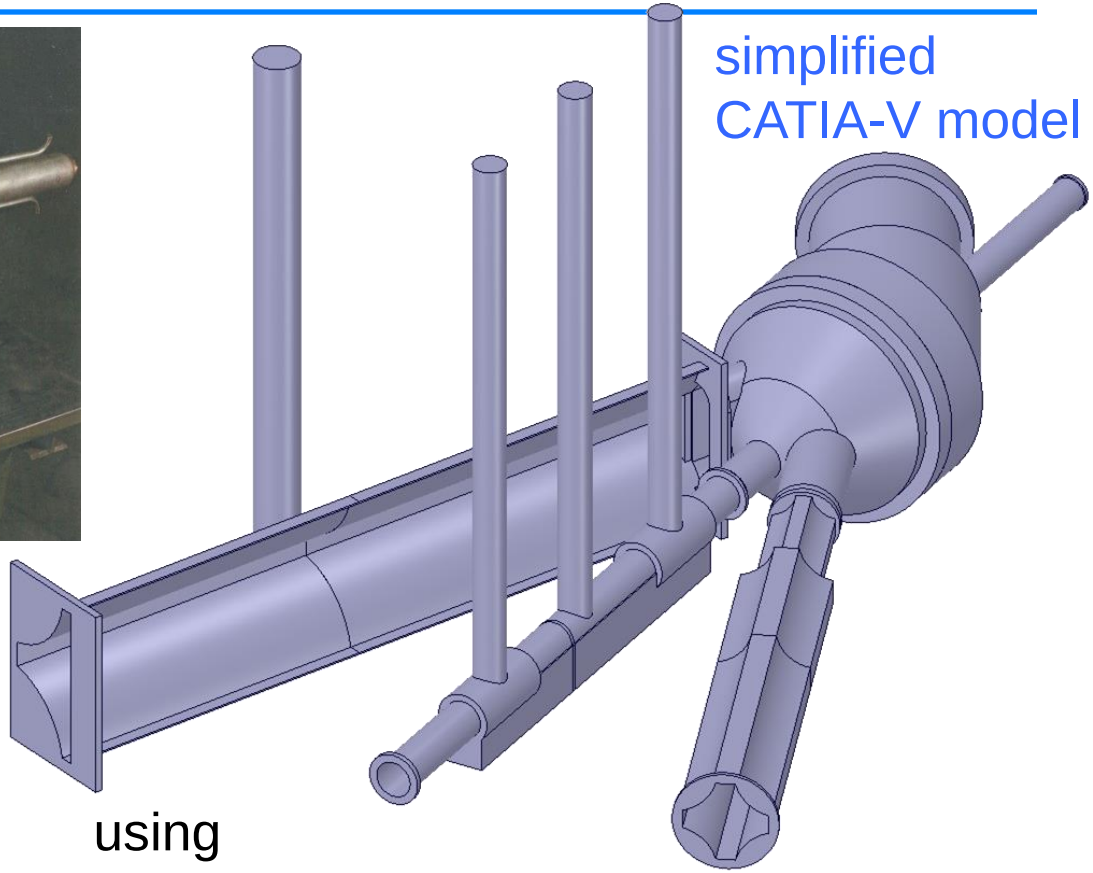
- Comparison to recent material analyses:

Element	Steel (St52.3)	Steel (St37)	Concrete
Co	140 ppm	110 ppm	4 ppm
Eu	-	<0.007 ppm (?)	0.5 ppm

more material analyses needed

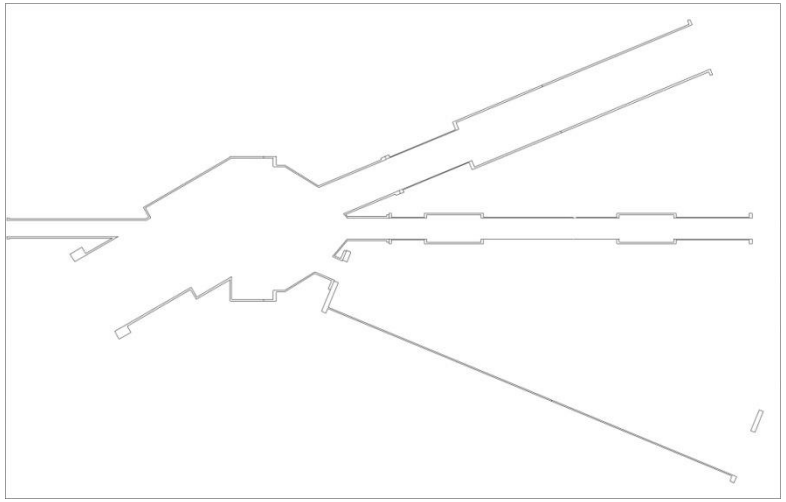
Target M region: vacuum chambers





simplified CATIA-V model

Converted in MCNPX



using

- MCAM interface code developed by the FDS Team, China
- McCad, a CAD to Monte Carlo Geometry conversion software, Karlsruhe Institute of Technology

Remarks to the process

- CATIA-V model → step file → MCAM/McCAD
  loss of infomation about the material
  → solved by an additional material list

- Restriction in MCAM, McCAD: 1000 cells
  → combination of several parts possible

- Modyfying the step file (e.g. cutting into pieces) was done in ANSYS SpaceClaim direct modeler

- Target M region designed in the 80ies
  → no CAD models, just hand drawings

- Drawings are in the archive, however, difficult to find the right ones

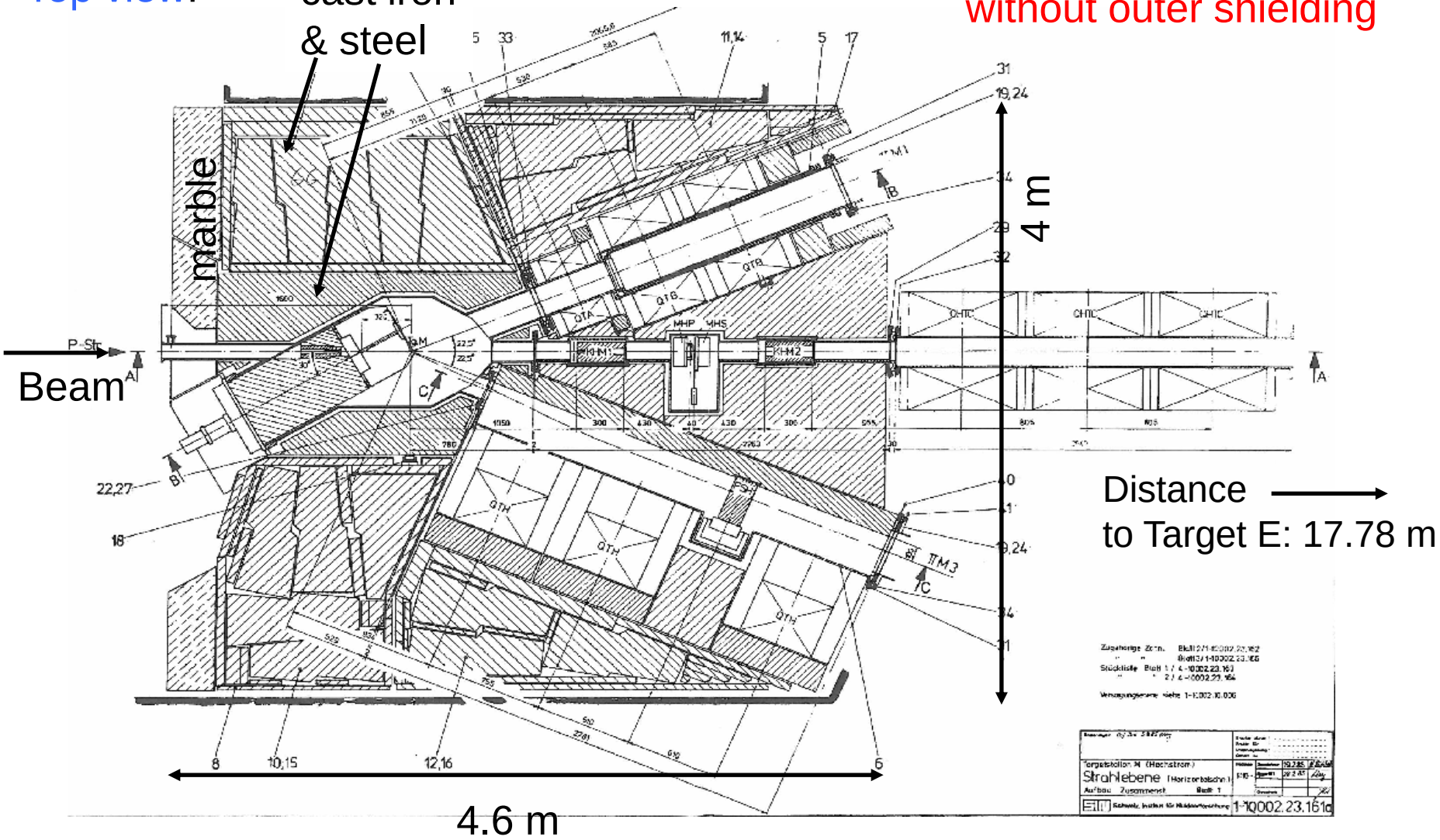
- Difficult to teach the CAD engineer how to simplify the model
  → too many details leads to too many surfaces

Drawing of Target M environment

Top view:

cast iron
& steel

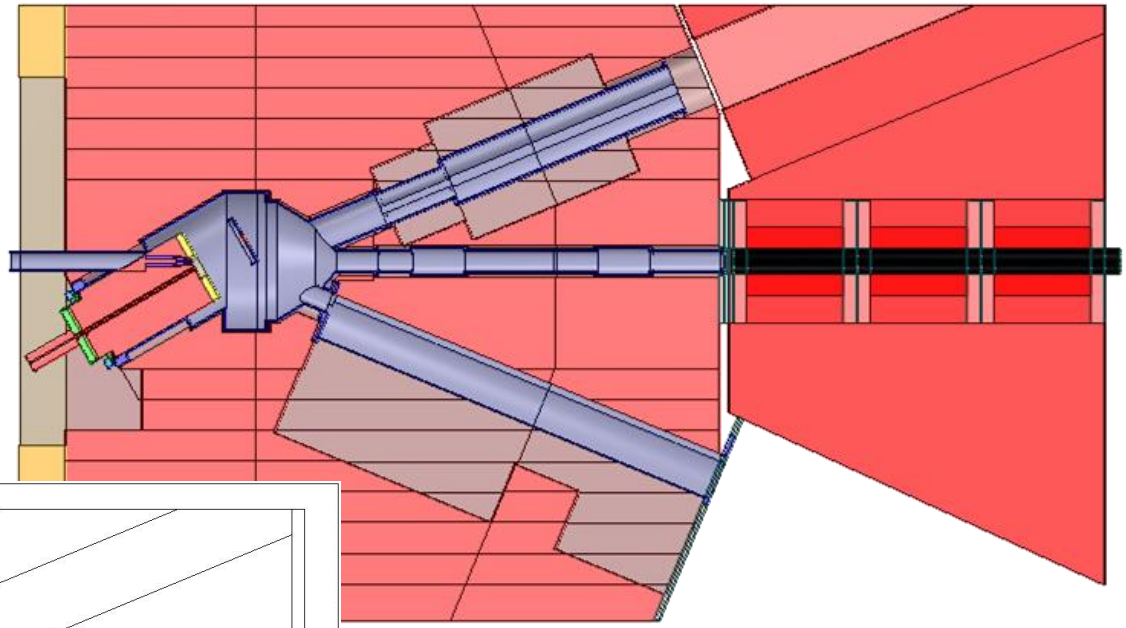
without outer shielding

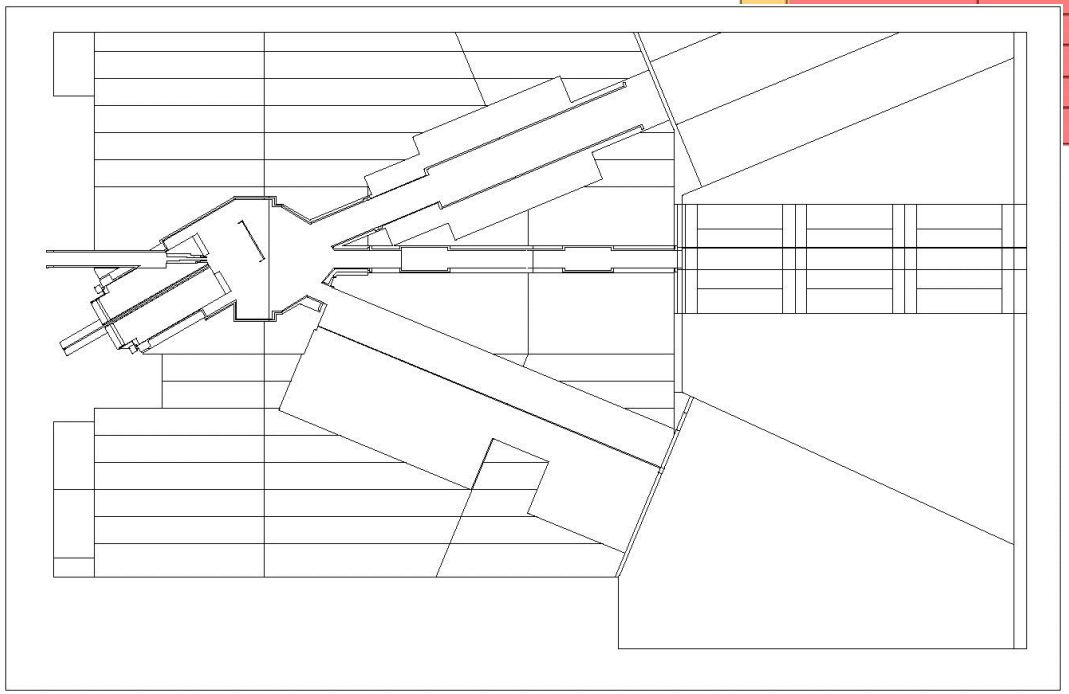


... and MCNPX model

ANSYS
SpaceClaim direct modeler

MCAM





MCNPX2.7.0

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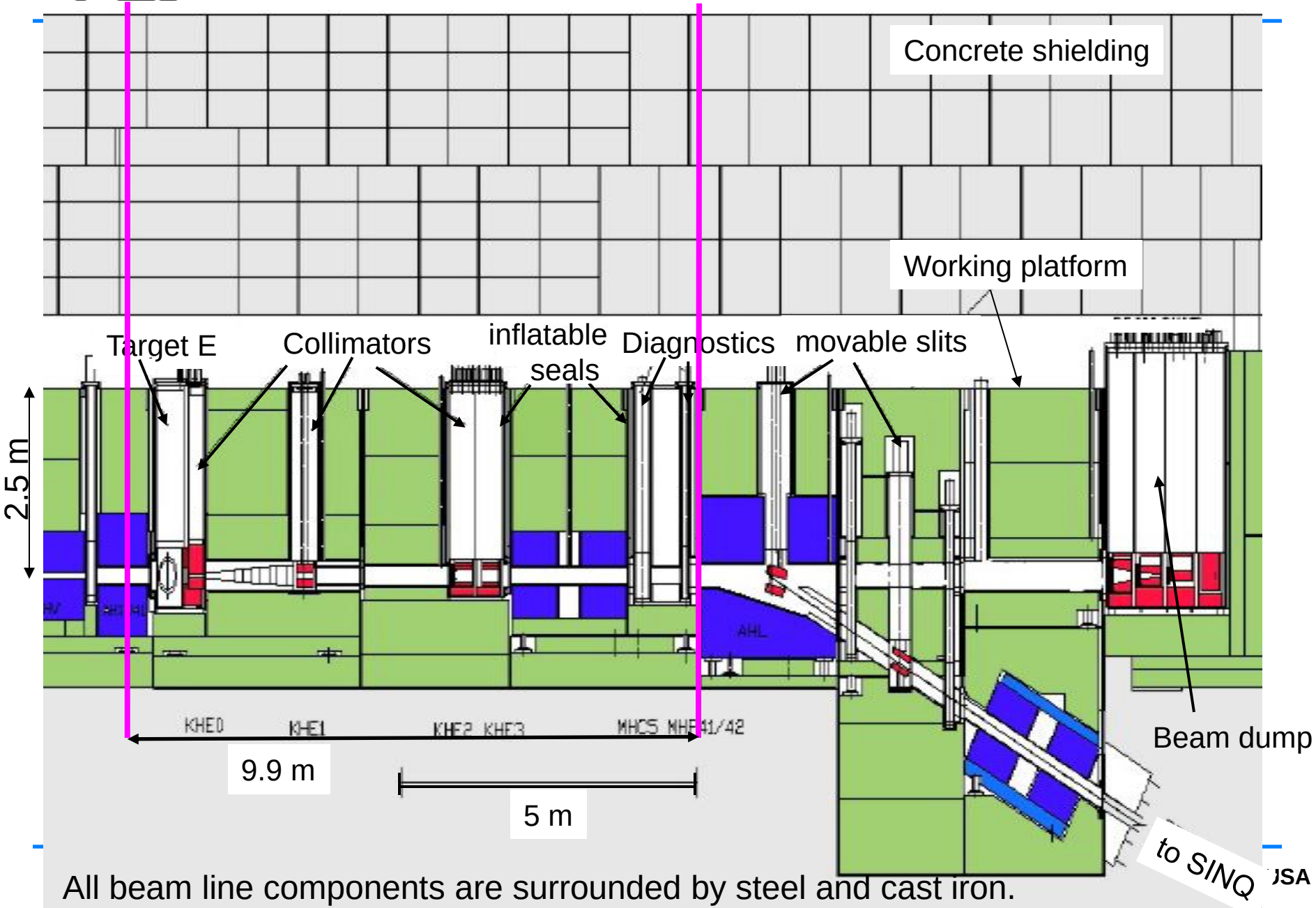
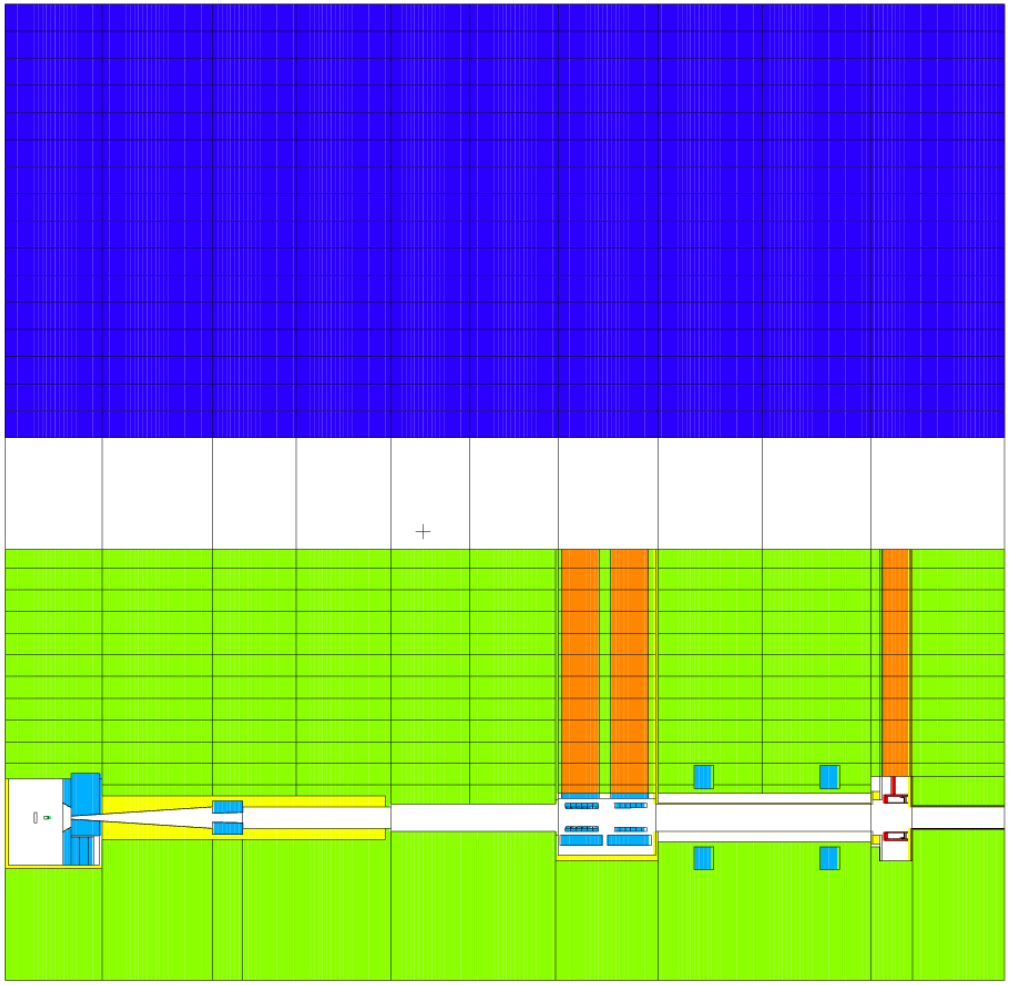
Beam line from Target E to beam dump (side view)



All beam line components are surrounded by steel and cast iron.

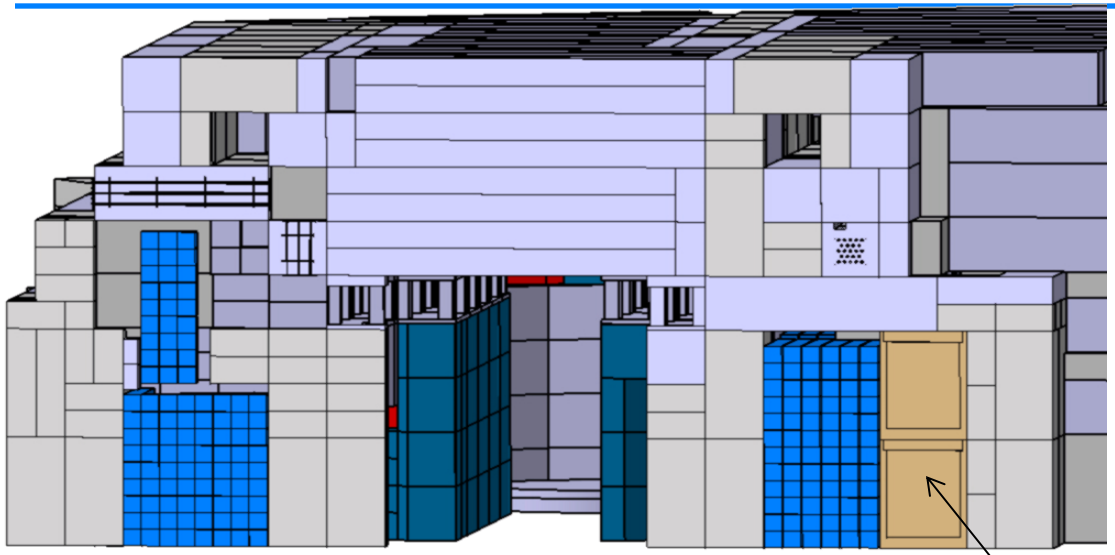
Implementation of the geometry in MCNPX

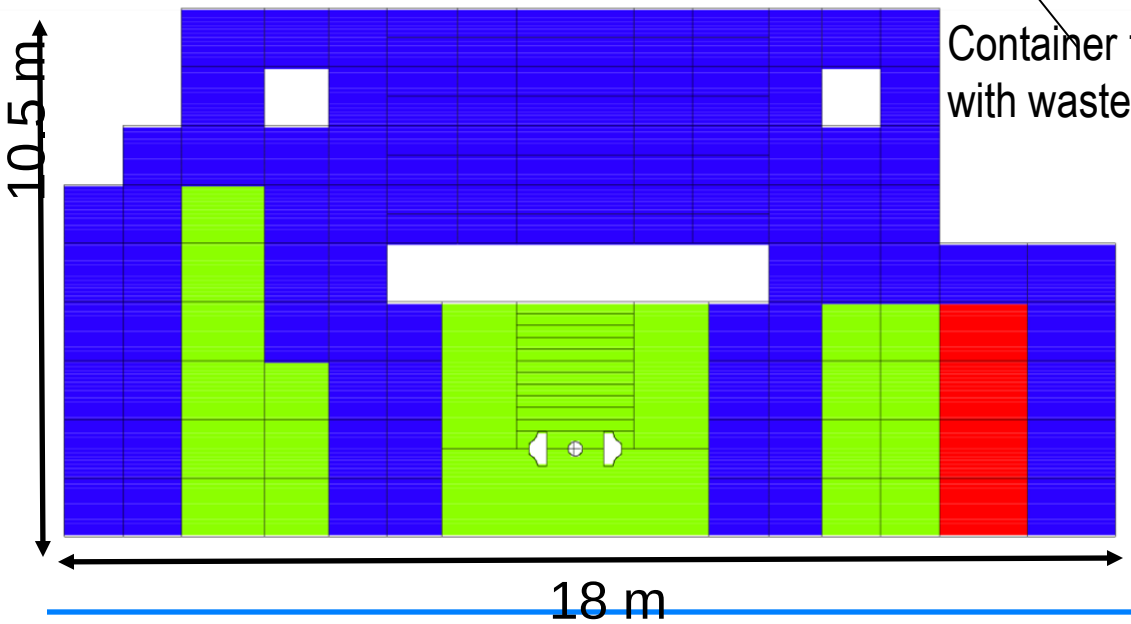


9.9 m

General guidelines:

- close to the beamline more details, particularly at loss points
- subdivision of the shielding: activity/CI per cell → reduce uncertainty in volume
- exploit symmetries of geometry: steel below the beam line ~ steel above the beam line



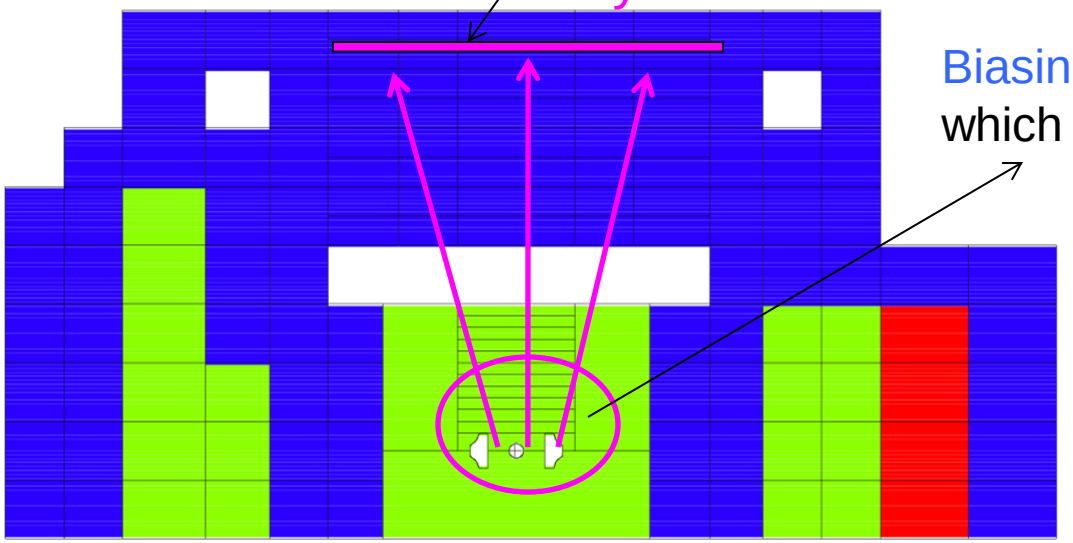


Large dimensions:
→ biasing techniques needed
to get statistics in outer regions

- importances:
  - based on cells
    → fine structure needed!
  - non-automatic
    tedious work in large regions
- weight windows:
  - meshed (or cell) based
  - energy dependend
  - semi-automatic

main problem:
optimization on 1 tally/detector

Biasing



Biasing only on high energetic neutrons, which will contribute to neutron flux in tally

←→ from the 3. cell on thermal n-flux important for the production of radioisotopes

Problems:

- optimization/biasing only possible in one direction
- only (formerly) high energetic neutrons contribute to the outer cells

For activation calculations:

- Biasing in every cell, not only 1 direction
- Biasing also in thermal n-flux in every cell

Every cell is important !

Approach

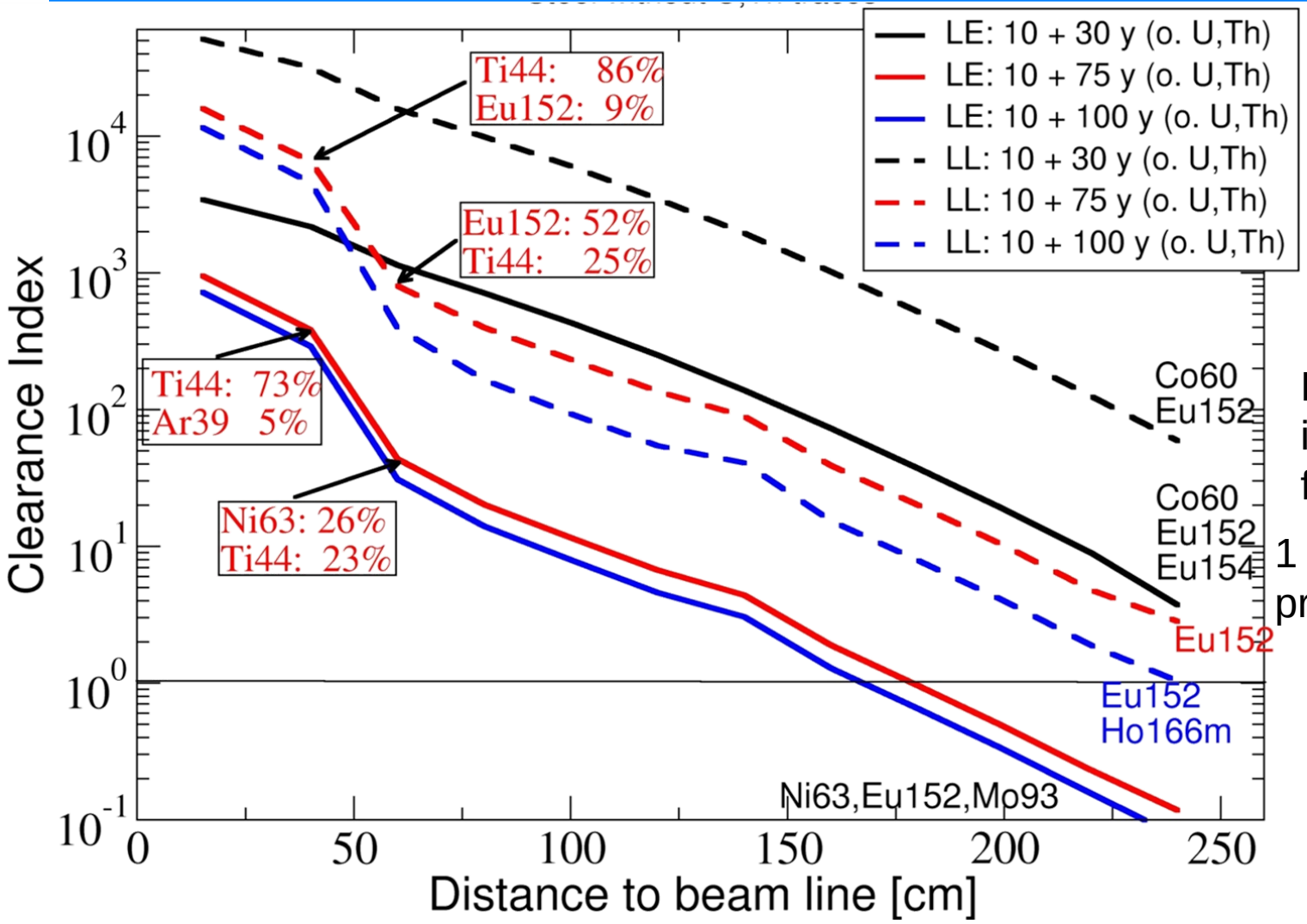
- mesh of flux type in the region of interest
- energy binning on neutron flux: from thermal to high energetic
  6 Bins: 0 10^{-7} 10^{-4} 0.01 1.0 20. 600. MeV

- convert neutron flux to weight windows: (done by external prg.)
  weight windows(E) ~ neutron flux(E)

- some manipulations:
  min. weight window → 0 (high energetic flux is not everywhere important)
  reason: save computional time

Advantage:
- independent of direction
- all regions are treated in the same way

Results for the Target E region: Steel 2 m after TgE

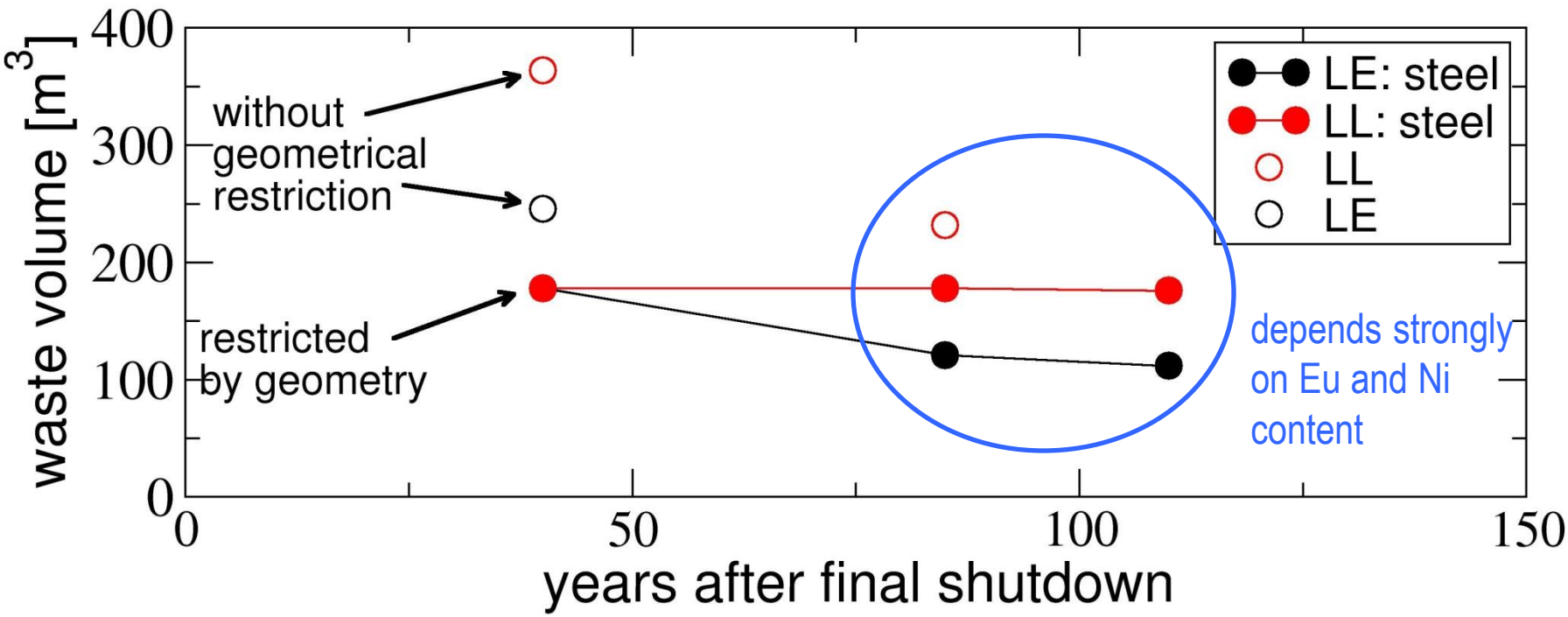


Eu content in steel important for > 85 y cooling

1 ppm Eu in steel is propably too much

CI (LL)/CI(LE) ~ 10 CI(40y)/CI(85y) ~ 35

Steel waste volume along 9.9 m of p-channel

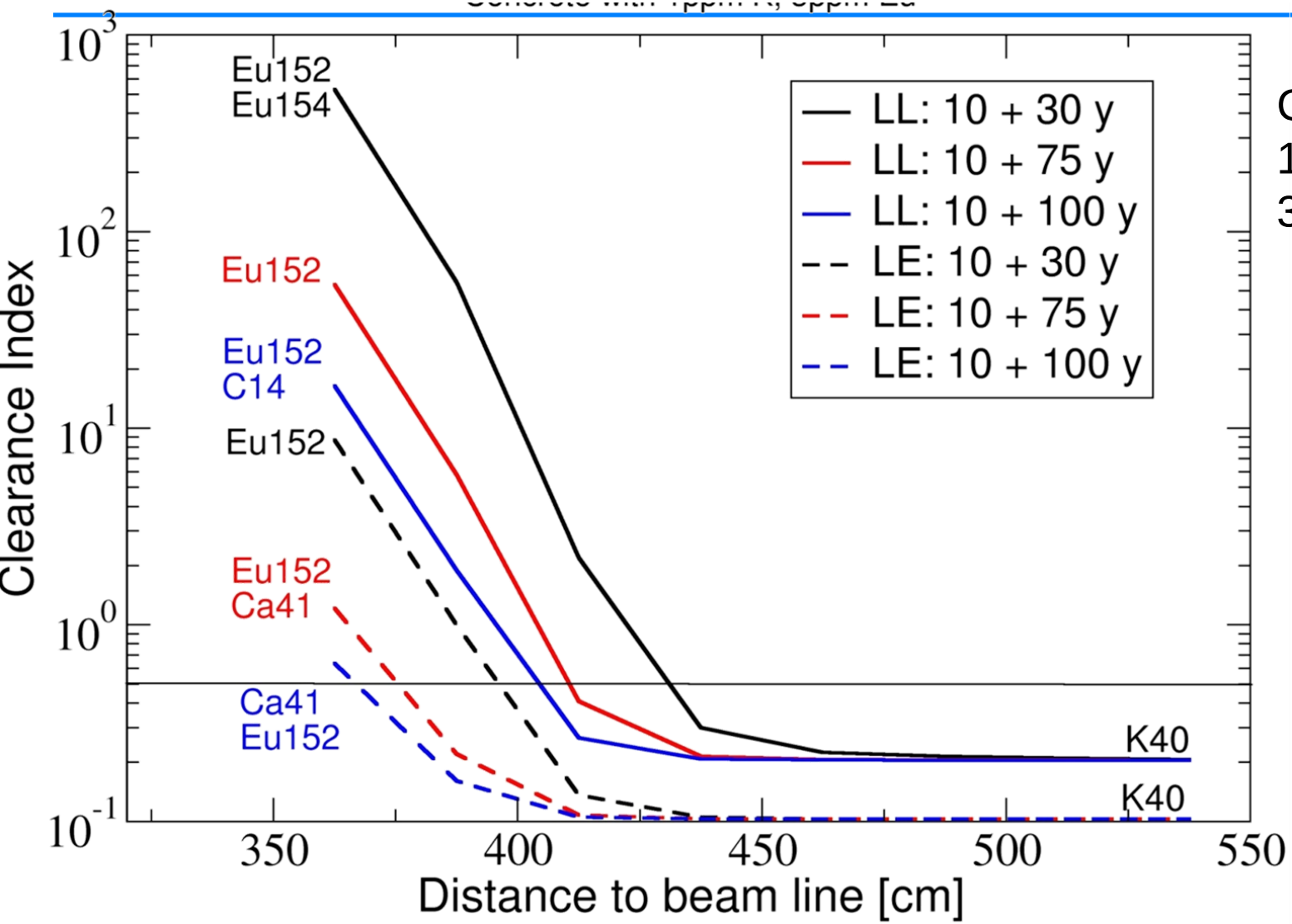


Steel volume restricted by geometry in p-channel:
otherwise: volume increase (LL40y)/(LE40y) ~ 1.5

85 y instead of 40 y: reduction of the volume by ~ 2 (LE)
~ 2 (LL)

No benefit from 110 y storage time.

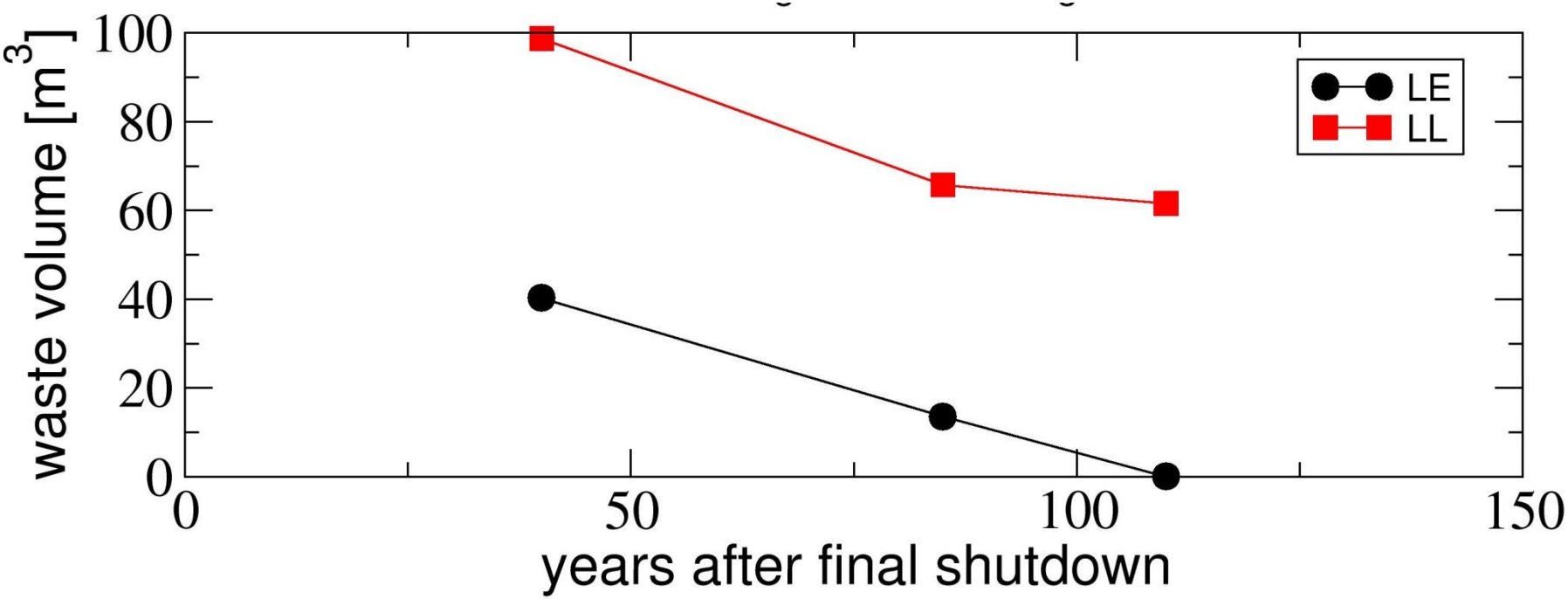
Results for the Target E region: Concrete 2 m after TgE



Concrete with
1 ppm K
3 ppm Eu

CI (LL)/CI(LE) ~ 60 CI(40y)/CI(85y) ~ 10

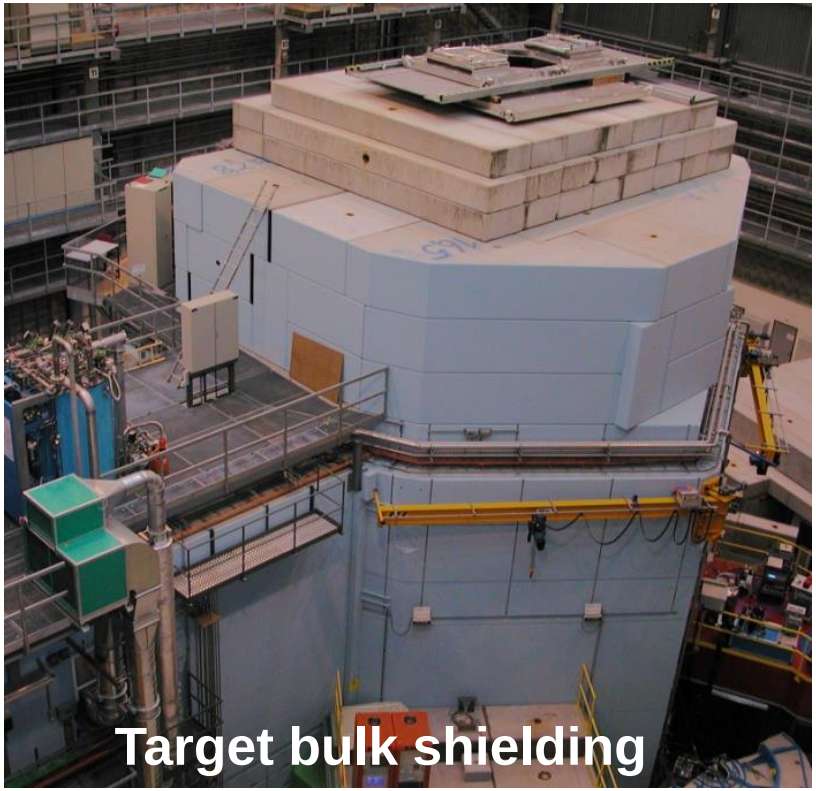
Concrete waste volume along 9.9 m of p-channel



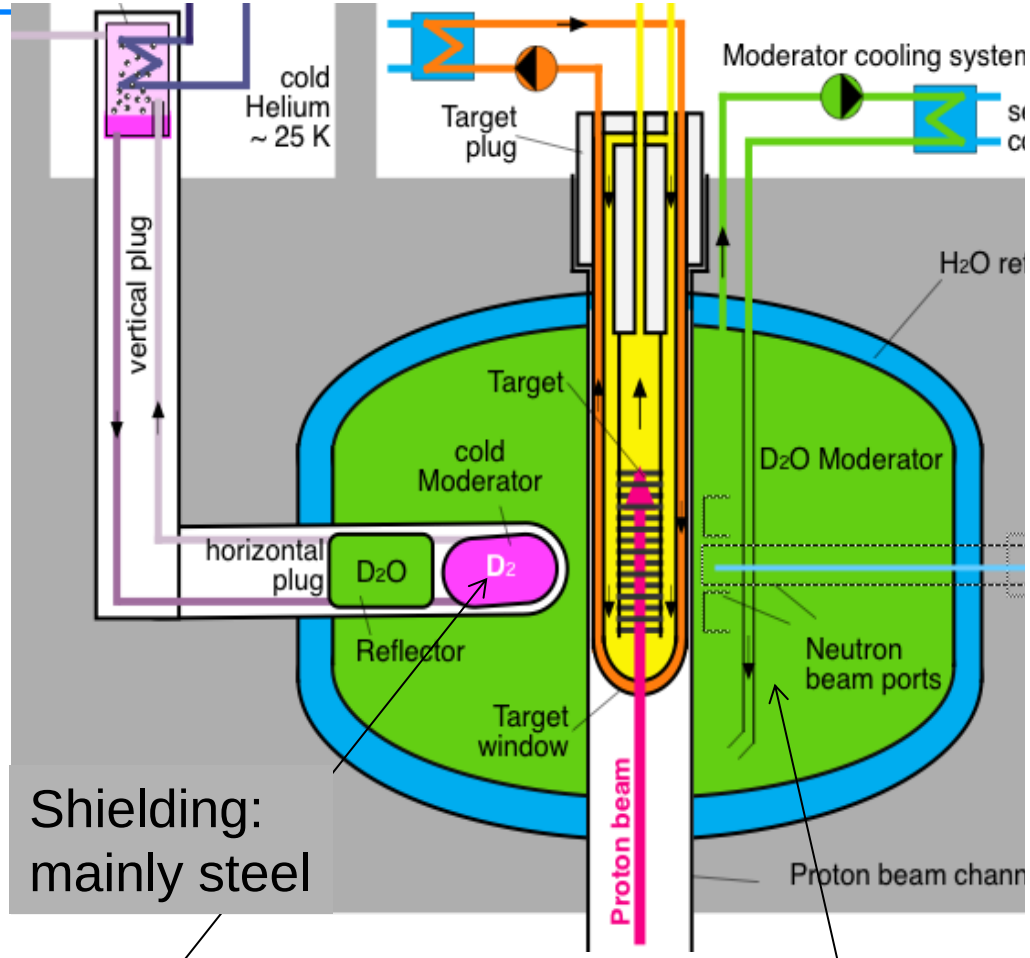
Volume increase (LL40y)/(LE40y) = 2.5

85 y instead of 40 y: reduction of the volume by ~3 (LE)
1.5 (LL)

Spallation neutron source SINQ



~16 m x 16 m x 13.5 m



Shielding:
mainly steel

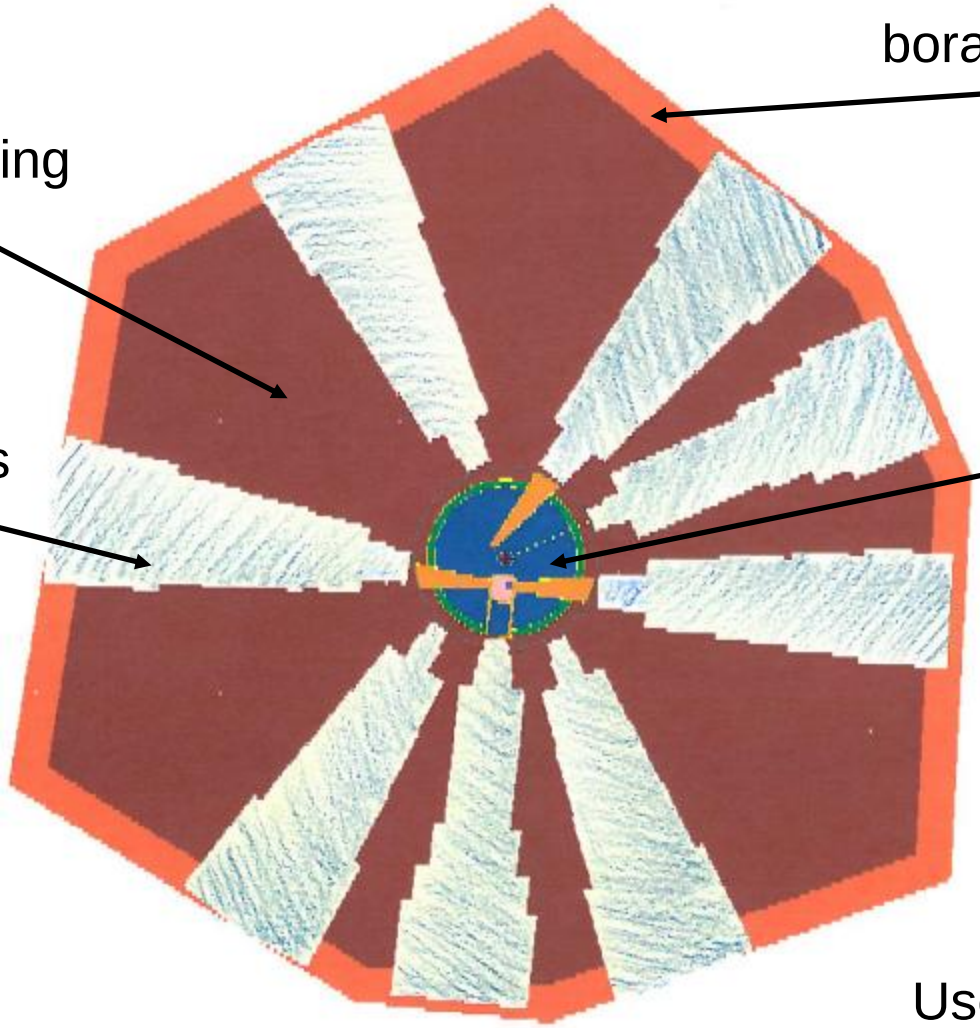
D_2 moderator (25 K)

D_2O moderator

Neutron production by spallation on heavy target Pb:

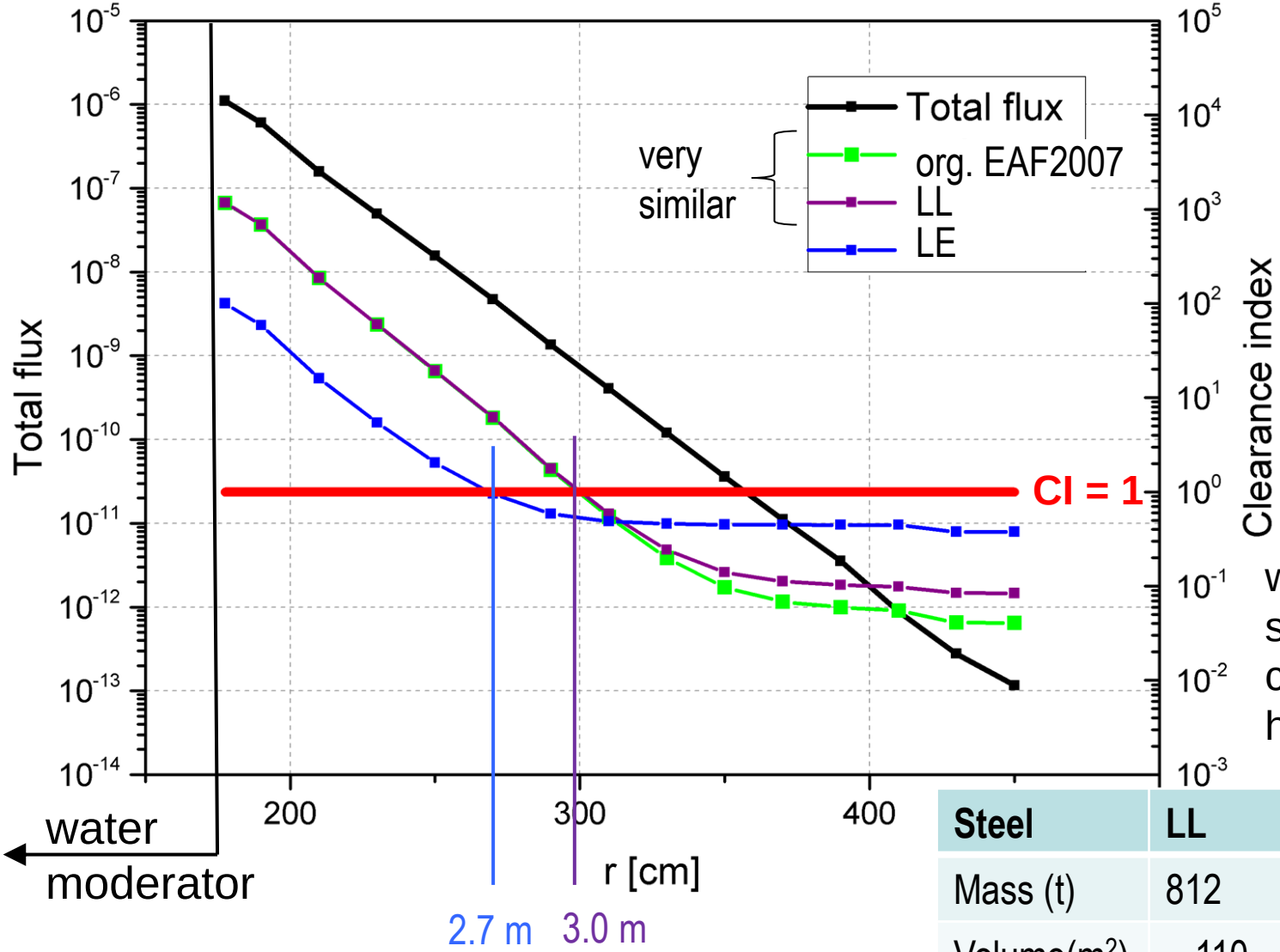
Neutron flux of about 10^{14} n/cm^2/s.

MCNPX model for SINQ



Used in MCNP6

Results for SINQ (steel)



waste determined strongly by the Co content:
here: 150-170 ppm

Steel	LL	LE
Mass (t)	812	558 → x 1.5
Volume(m^2)	~ 110	~75

Summary

- Our task:

  - Waste estimate of HIPA with different cooling times and exemption levels

- Approach:

  - restriction to the most activated regions: Target M/E to beam dump, SINQ
  - geometrical models:

    classical handwork and CATIA to MCNPX conversion with MCAM, McCAD
  - importances/weight windows:

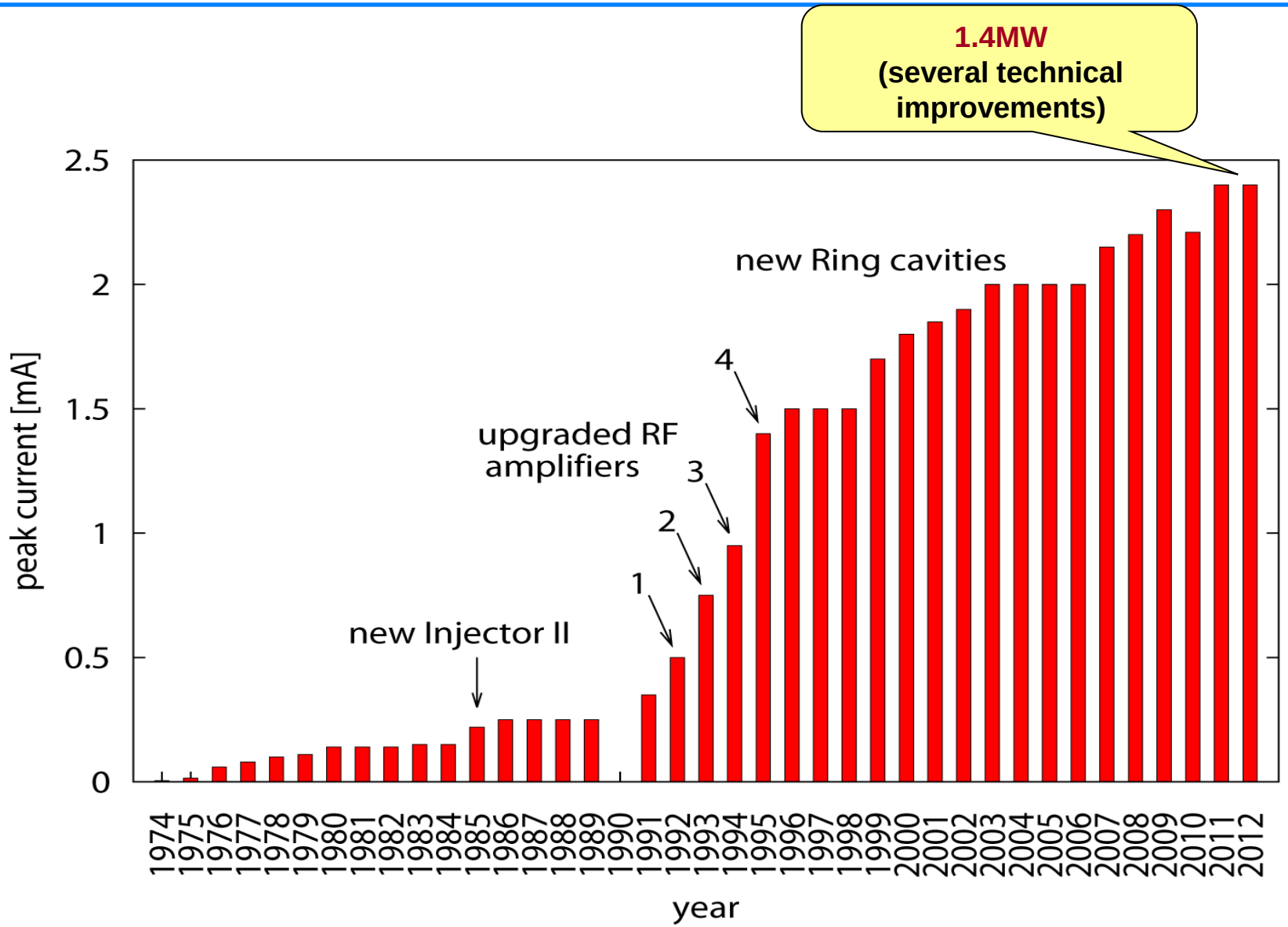
    better use energy dependent fluxes than weight window algorithm

- Results:

  - LL(40y)/LE(40y): steel vol. x 1.5 , concrete vol. x 2.5
  - 85y/40y: steel reduction of factor 2, concrete factor 3 (LE), 1.5 (LL)

These are very preliminary results!

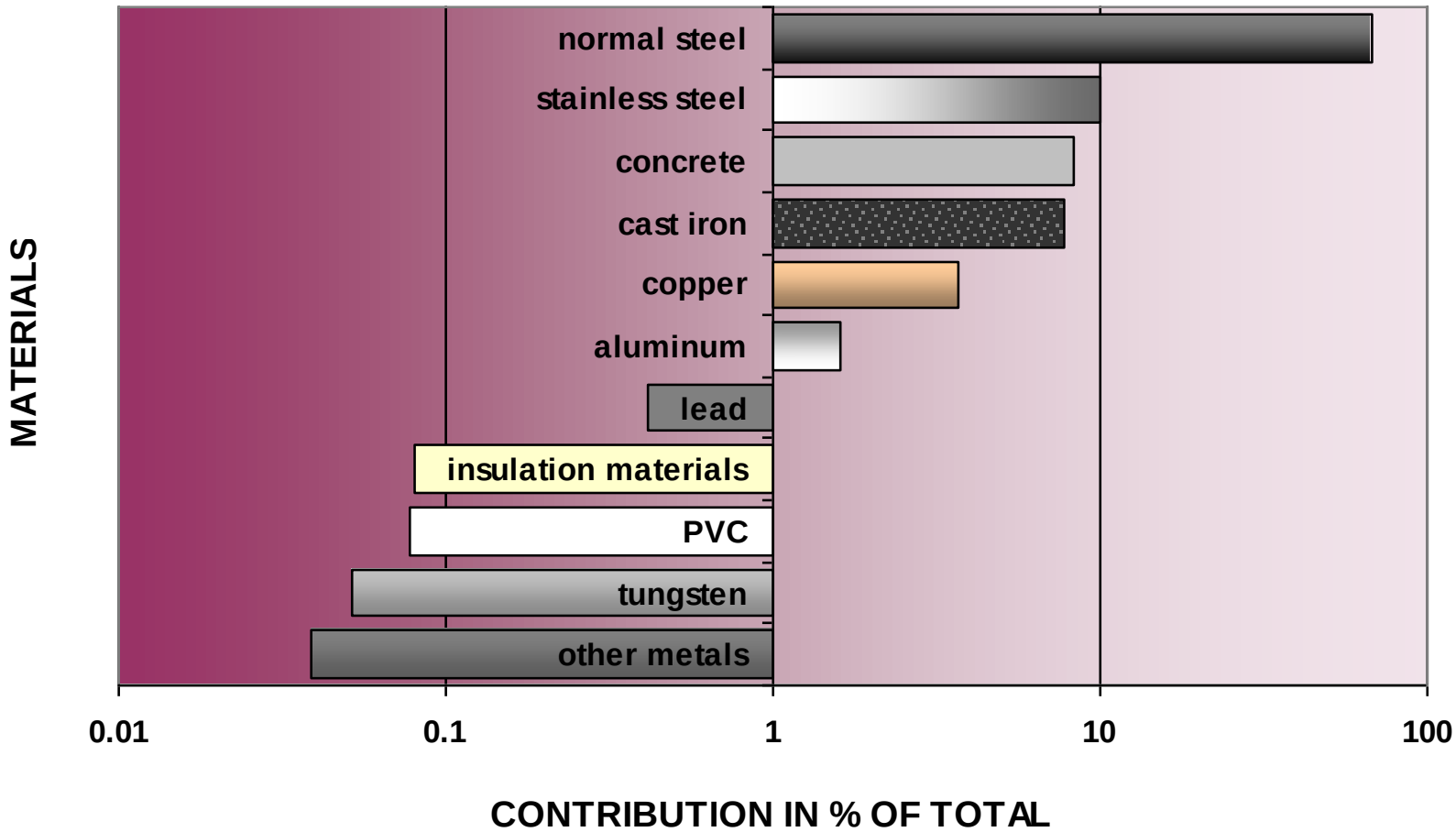
Peak current extracted from ring



Radioactive waste filled into Containers

Total activity per container: 10^{10} – 10^{12} Bq (4.5 t of waste)

Material compositon:

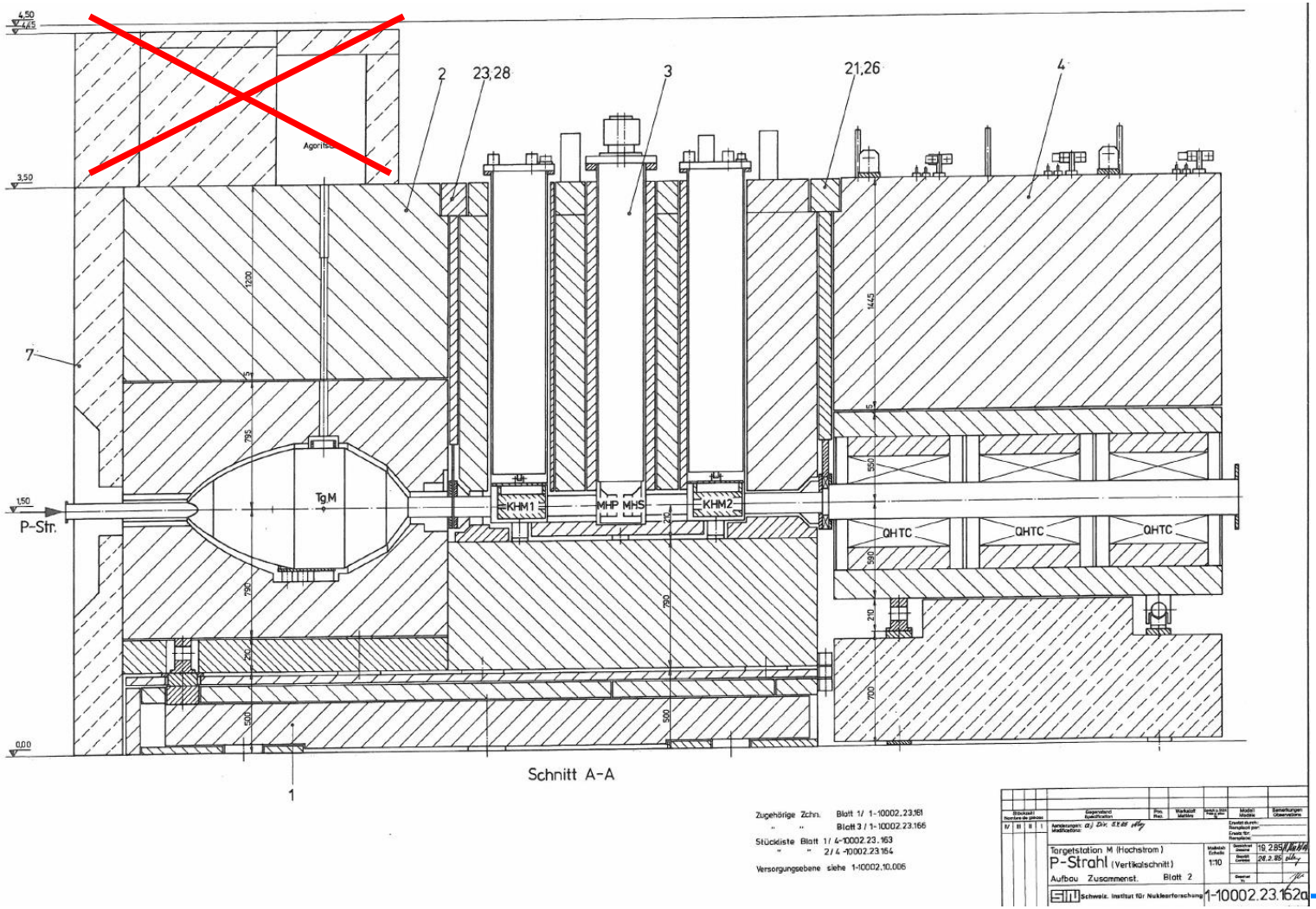


Operational waste per year: 3-6 Container

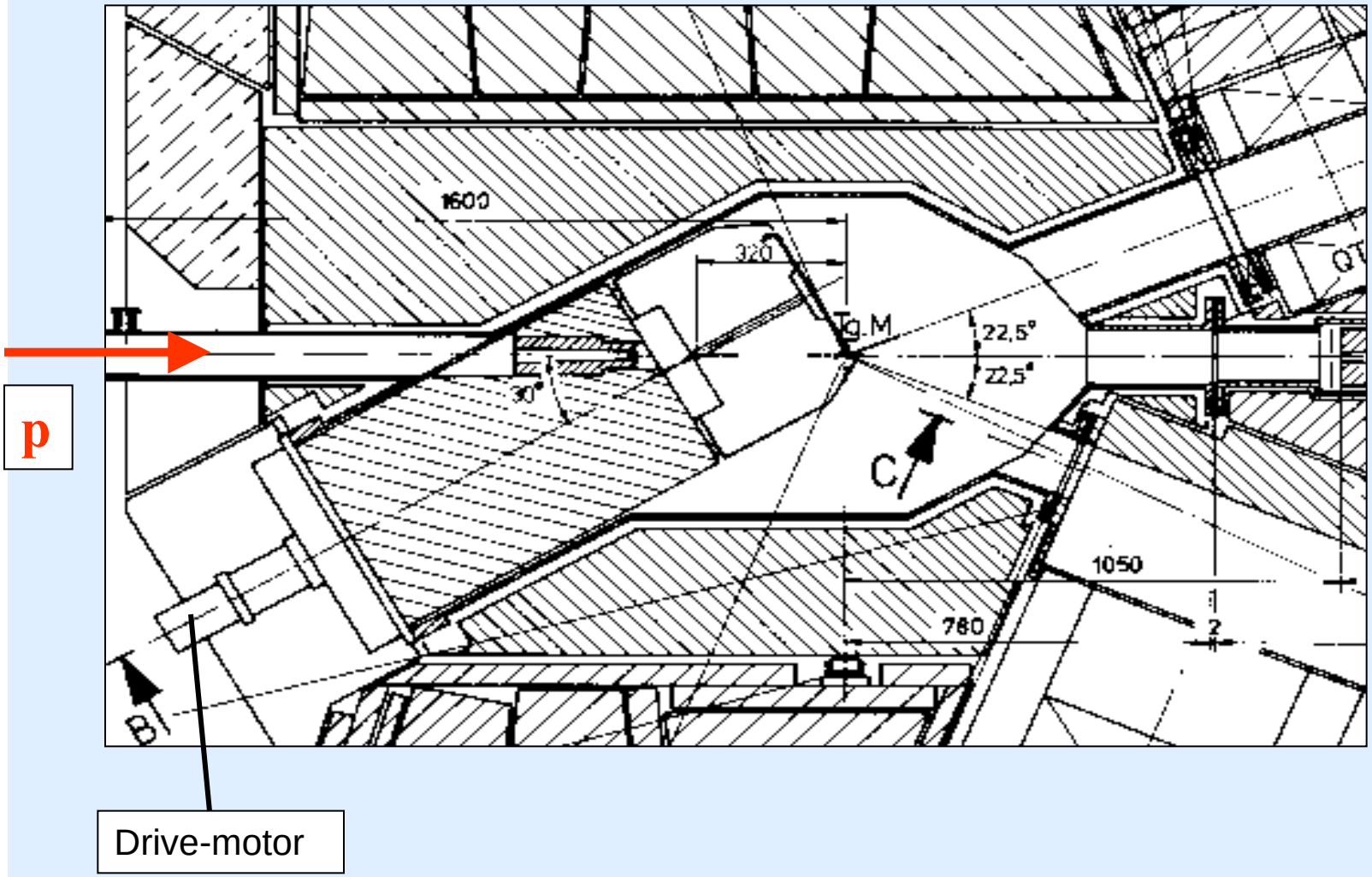
No.of containers up to now: 213

Geometry model of Target M

- Steel shielding, xy-plane (z=0): Side view

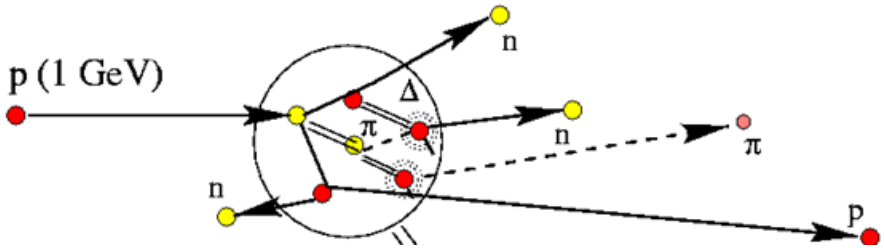


Target-M layout

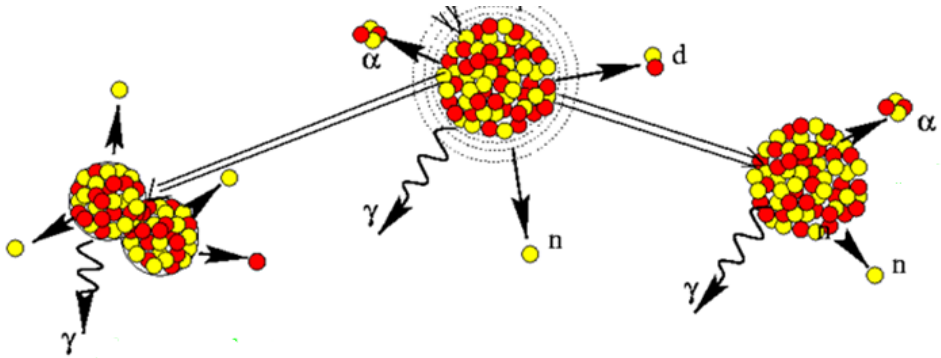


Selected physics models in MCNPX

1) Intra-Nuclear Cascade:



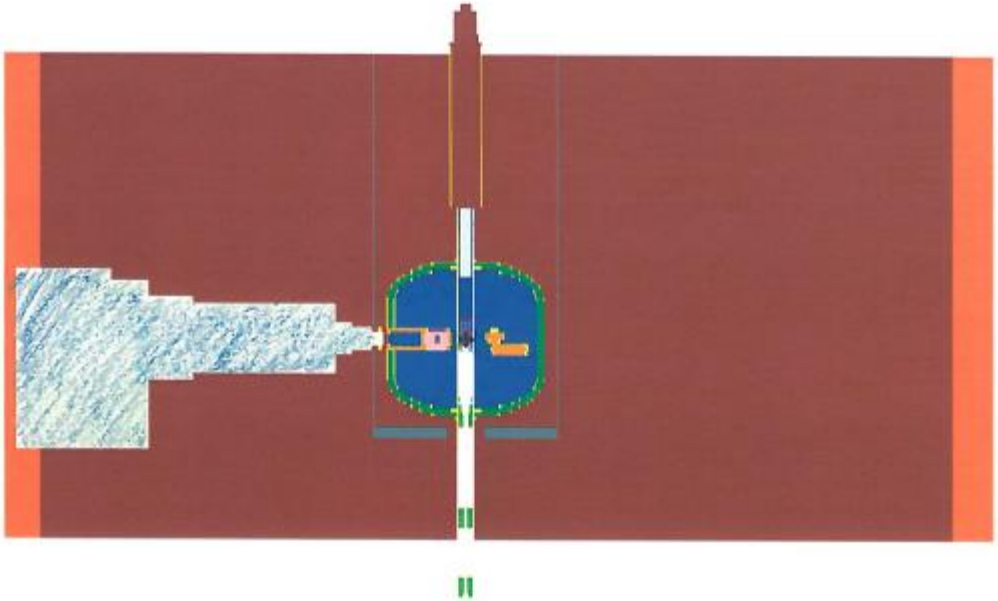
2. Evaporation/Fission

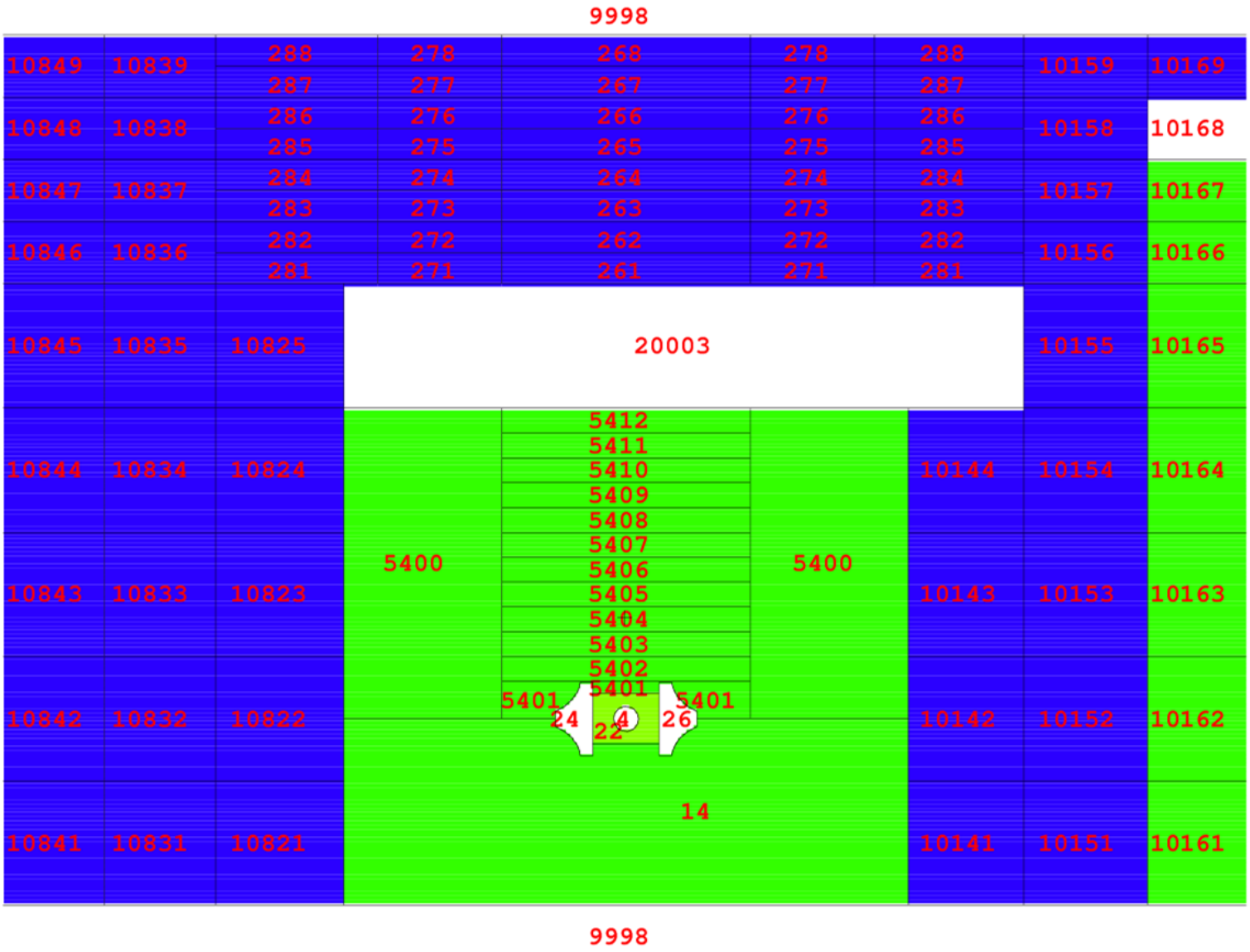
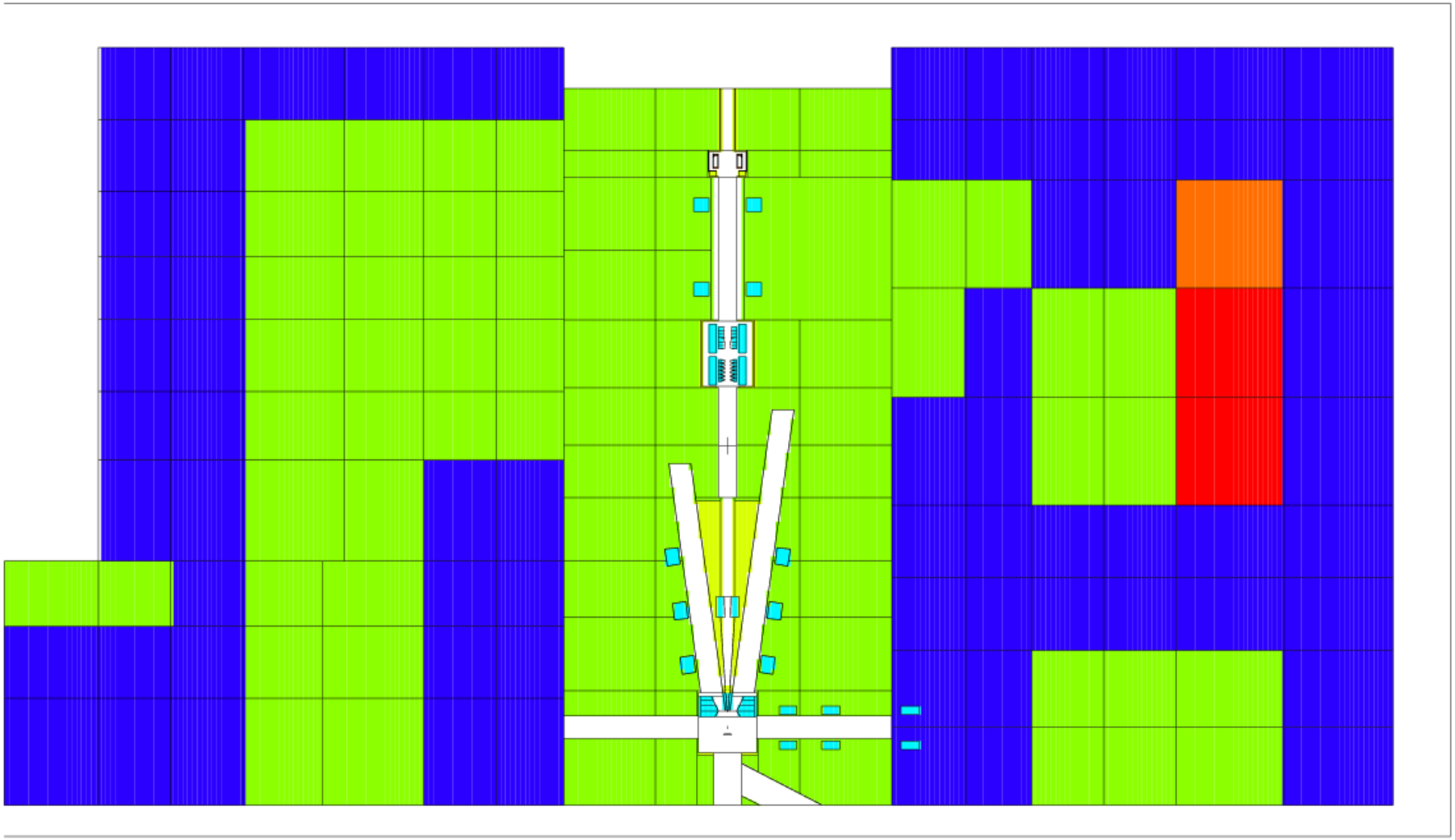


MCNPX default option:

- for n & p: < 3.5 GeV
  BERTINI (INC) + Dresner (evaporation) + RAL (fission):
  - BERTINI: based on Serber's model, spacelike realization
  - DRESNER: EVAP-A, based on Weisskopf's statistical model
  - RAL (Atchison): fission in between of the evaporation stages

- for light ions (d, t, α): < 1 GeV
  ISABEL (INC) + Dresner + RAL:
  - ISABEL: based on Serber's model, timelike realization

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