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Activation Studies in the ESS HEBT region

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ESS shielding calculation

• Spallation reactions will produce large amounts of isotopes, both stable and radioactive. In addition, radioactive isotopes will contribute to the total activity of the target.
• The shielding will be necessary for the target, the accelerator tunnel and at the instruments.
• The shielding design will be done to account for the uncertainties in, for example calculations and drawings, but also to accommodate the potential upgrades of the accelerator.

MCNPX computer code is used to estimate the particle fluxes and the ambient dose rate.

Methods

- MCNPX used, out of the box, no tuning.
- FBM845 deck (now superseded) used to describe target. 2.5 GeV energy, non-raster
- High statistic from running jobs on computer cluster, several hundred jobs at time.
- Study effects on
  - backsplash from target
  - beam losses, 1W/m
  - halo on collimator
- Look at
  - Activation of various nuclei in components and shielding
  - Activation of the air
  - Neutron flux distributions

Isotopes

Energy deposition in components

^{64}Cu(12 h) from $^{63}Cu(n,\gamma)$

^{65}Cu(5 min) from $^{66}Cu(n,\gamma)$

^{60}Co(5.1 y) from $^{63}Cu(n,\alpha)$

From Iron

^{55}Fe(2.7 y) from $^{54}Fe(n,\gamma)$

^{59}Fe(45 days) from $^{58}Fe(n,\gamma)$, $^{59}Co(n,p)$

From Steel

^{56}Mn(2.64 h) from $^{55}Mn(n,\gamma)$

^{51}Cr(27.7 days) from $^{50}Cr(n,\gamma)$

^{65}Zn(245 days) from $^{64}Zn(n,\gamma)$

From Concrete

^{22}Na(2.62 y) from $^{23}Na(n,2n)$

^{24}Na(15h) from $^{23}Na(n,\gamma)$

From Copper

^{57}Co(272 days), ^{58}Co(77 days)

^{64}Cu(12 h) from $^{65}Cu(n,2n)$

^{54}Mn(312 days)

^{51}Cr(28 days) from $^{63}Cu(n,\alpha)$

^{59}Fe(45 days)

^{65}Ni(2.5 h)

^{66}Zn(45 days)

From Air

^{41}Ar(109 min) from $^{40}Ar(n,\gamma)$

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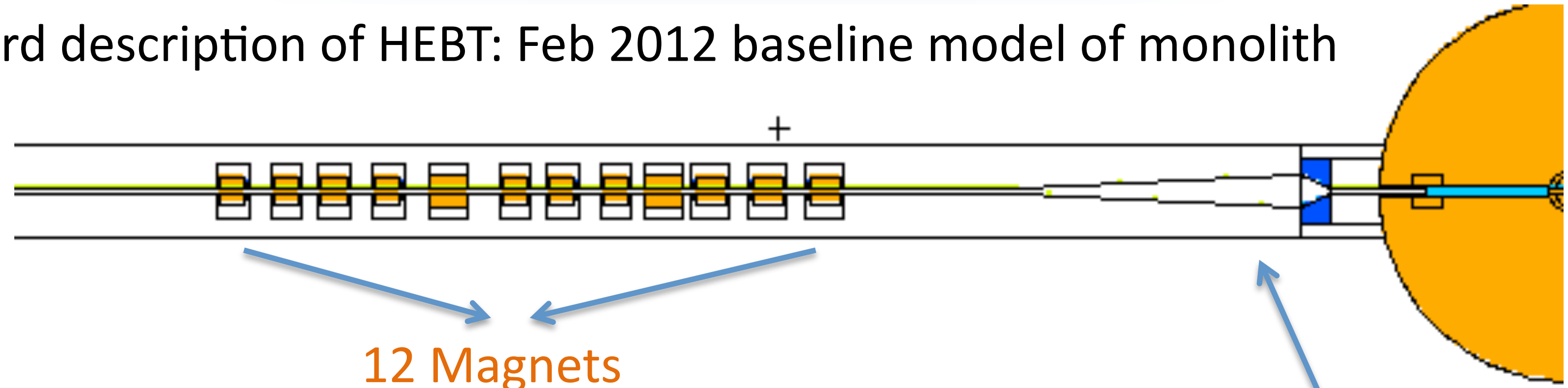
Geometry

Standard description of HEBT: Feb 2012 baseline model of monolith



12 Magnets

Quads: M1, M2, M3, M5, M6, M7, M9, M10, M11, M12

Oct: M4, M8

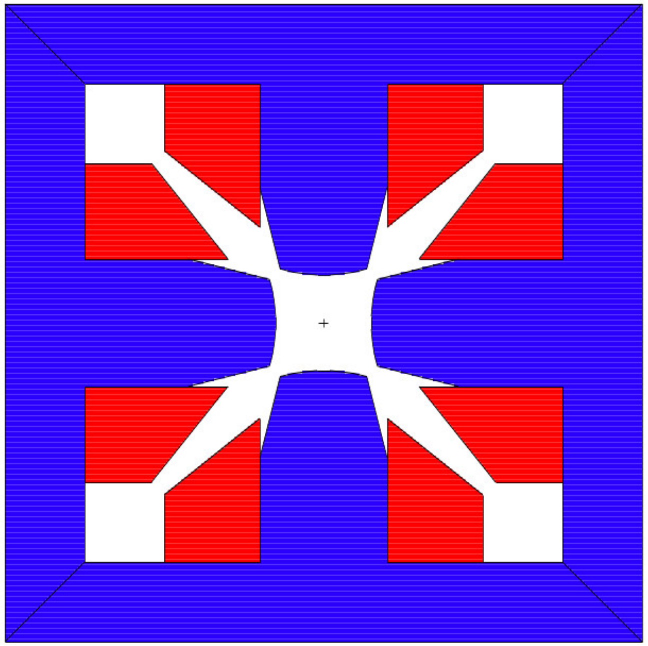
Initially modeled as cylinders with 50% Fe, 50% Cu.

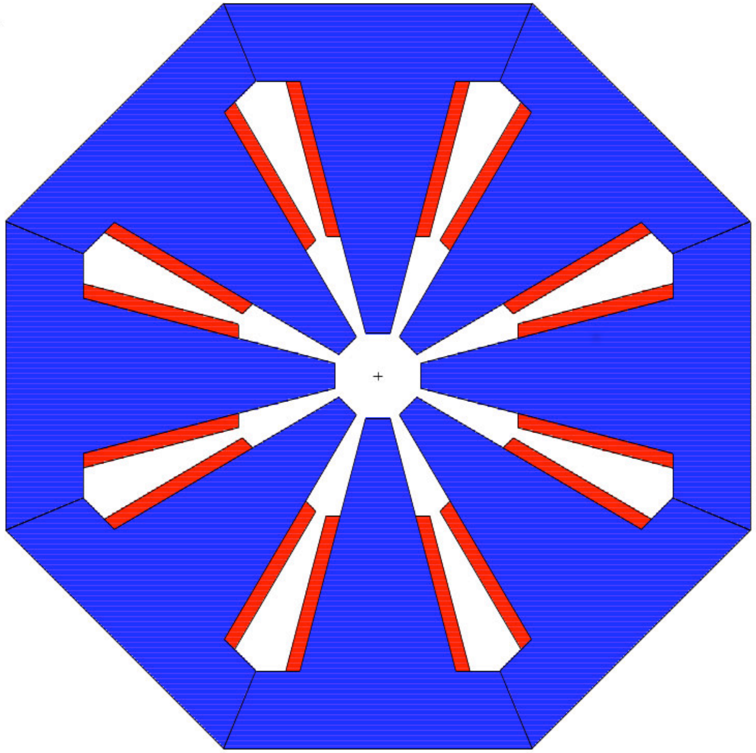
Beam pipe (stainless steal SS316)
tube of inner radius 5 cm
and thickness 1cm

Collimator
(1m long, external radius 50cm)
Mainly Copper with 2 cm Tungsten lining.

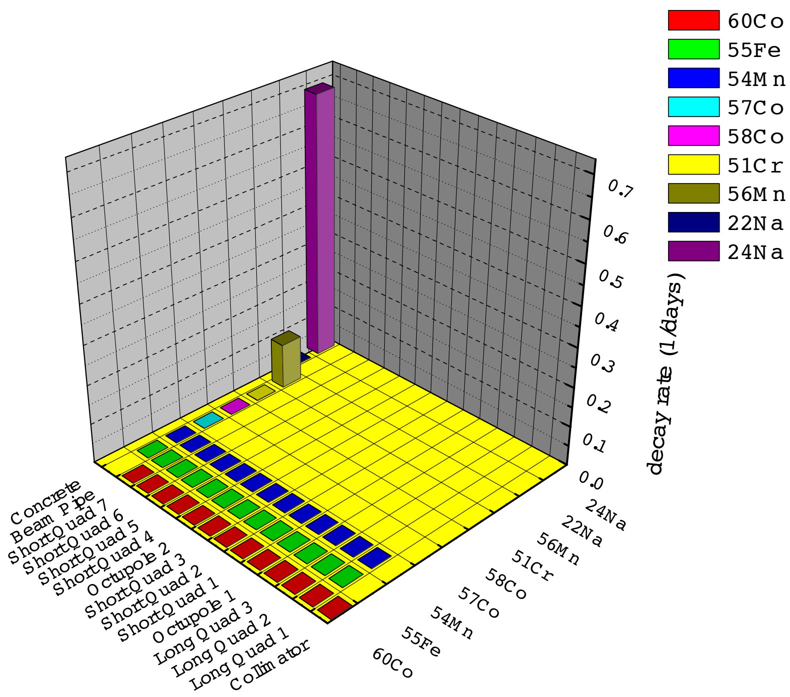
Geometry: Magnets

More realistic Magnets Design





Isotopes



Source 2: Beam losses

2.5 GeV protons hit the beampipe at grazing incidence, uniformly between 50m and 20m upstream.

Number is per proton – to normalise, multiply by 7.5 10^{10} x loss rate (W/m).

Biggest effect in beam pipe (no surprise), ^{56}Mn produced from ^{55}Mn(n,γ) in steel. The production of ^{55}Fe, ^{51}Cr and ^{56}Mn increases significatively when concrete is added to the basic A2T.

^{60}Co in Copper and ^{58}Co in steel could be problematic. ^{22}Na and ^{24}Na produced in concrete are also potentially significant.

Air

Different from components as air circulates
Use Sullivan's figure:

352 kBq/s/m /10^{12} particles

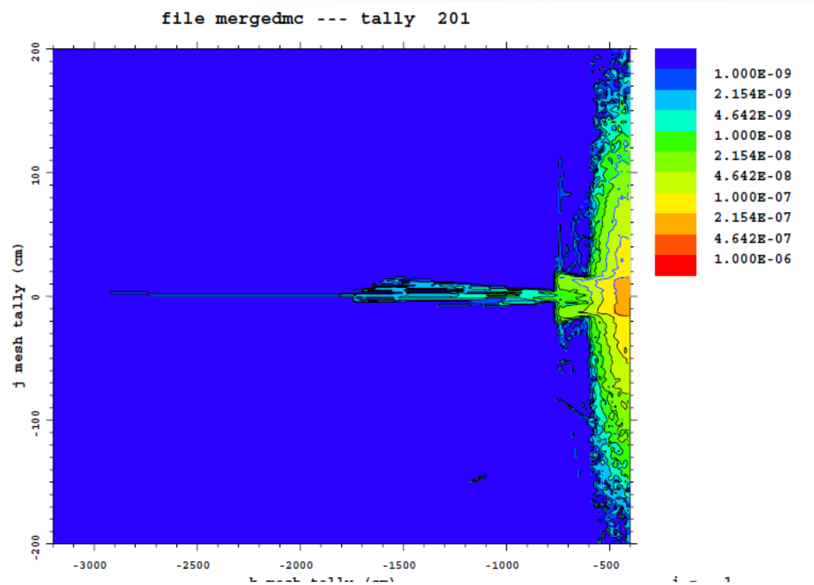
For Source 2, beam losses, 1 proton gives 31m of neuron track, 3m of proton track

Activity calculated as:

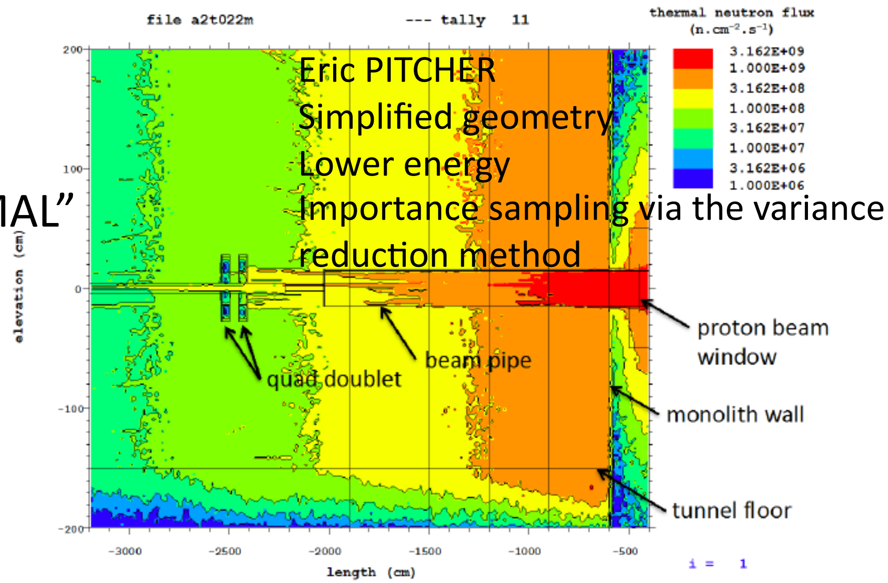
$34 \times 7.5\ 10^{10} \times 352\ 10^{-12}$ kBq/s = 900 kBq/s

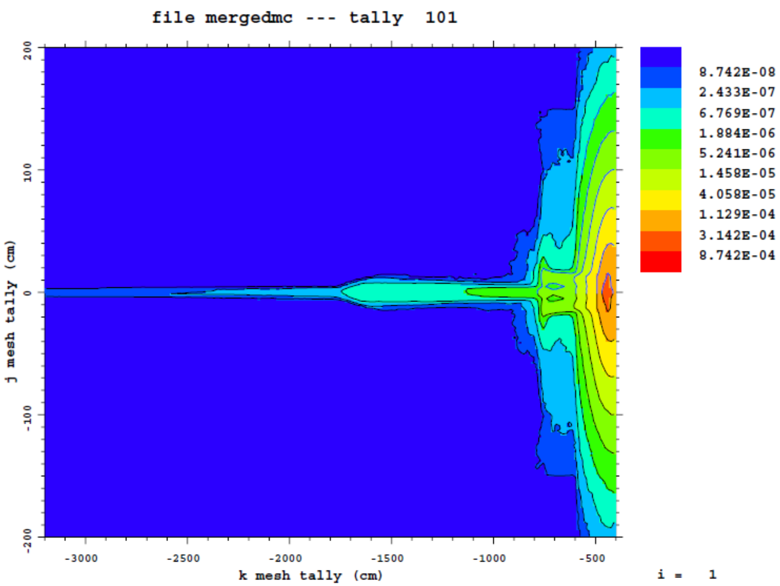
^{41}Ar production is even smaller.

Neutron flux
Backsplash from the target

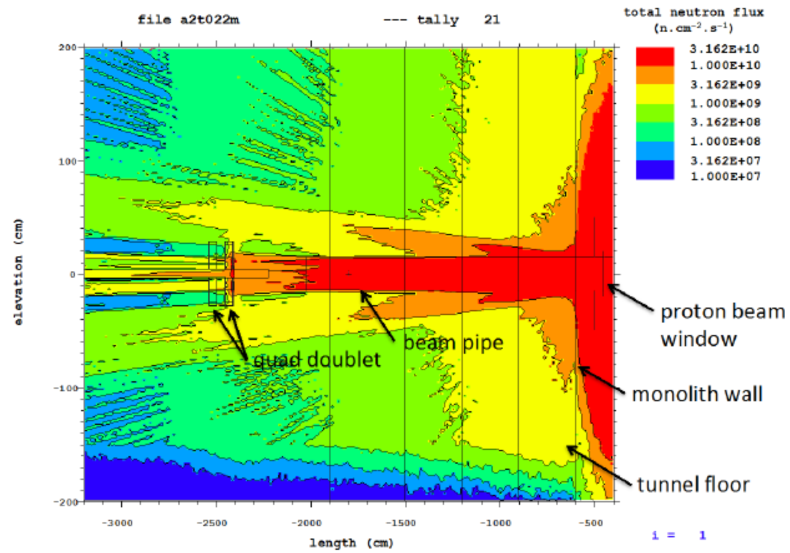


“THERMAL”

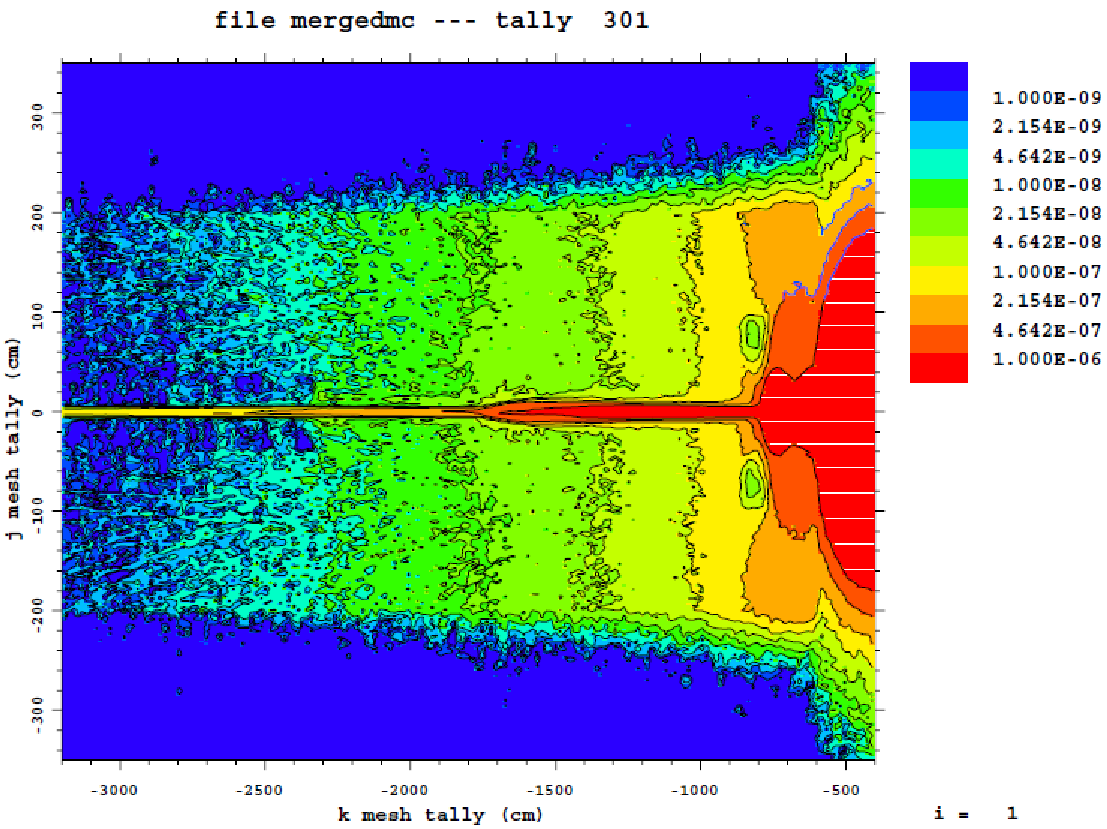




TOTAL



Neutron flux
Backsplash from the target



With added concrete cylindrical wall (200cm radius, 125cm thick)

The overall shape of neutron flux is broadly similar (different geometry).

Calculations agree (reasonably) well. We assume different beam energies. Our ~2 10^{-6} $n/cm^{2/s}$ multiplied by the number of protons per sec at nominal current, 1.25 $10^{16,}$ gives 2.5 10^{10} $n/cm^2/s$ and his ~3 10^{10} $n/cm^2/s$.

Flux drops rapidly further stream. Imposing a neutron energy upper bound of 0.625eV to examine "thermal" neutrons reduces the flux by 2 order of magnitude.

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Next Steps

- Implement further geometries down to A2T dog's leg
- A total of six quads and eight raster magnets shall be included.
- Calculate the energy deposition in various accelerator components
- Time dependence – consider daughter isotopes.
- Activity during shutdown - evaluate gamma ray fluxes and and the ambient dose rate from active nuclei for the given geometry.
- Estimate neutron background.

IOP PAB Meeting on Accelerators for Future Spallation Sources: ESS, MYRRHA, ISIS Upgrade

Cockcroft Institute, Daresbury, UK

https://eventbooking.stfc.ac.uk/news-events/accelerators-for-future-spallation-sources–ess-myrrha-and-the-isis-upgrade-184