# Radiation safety aspects of an accelerator coupled High Flux Research Reactor

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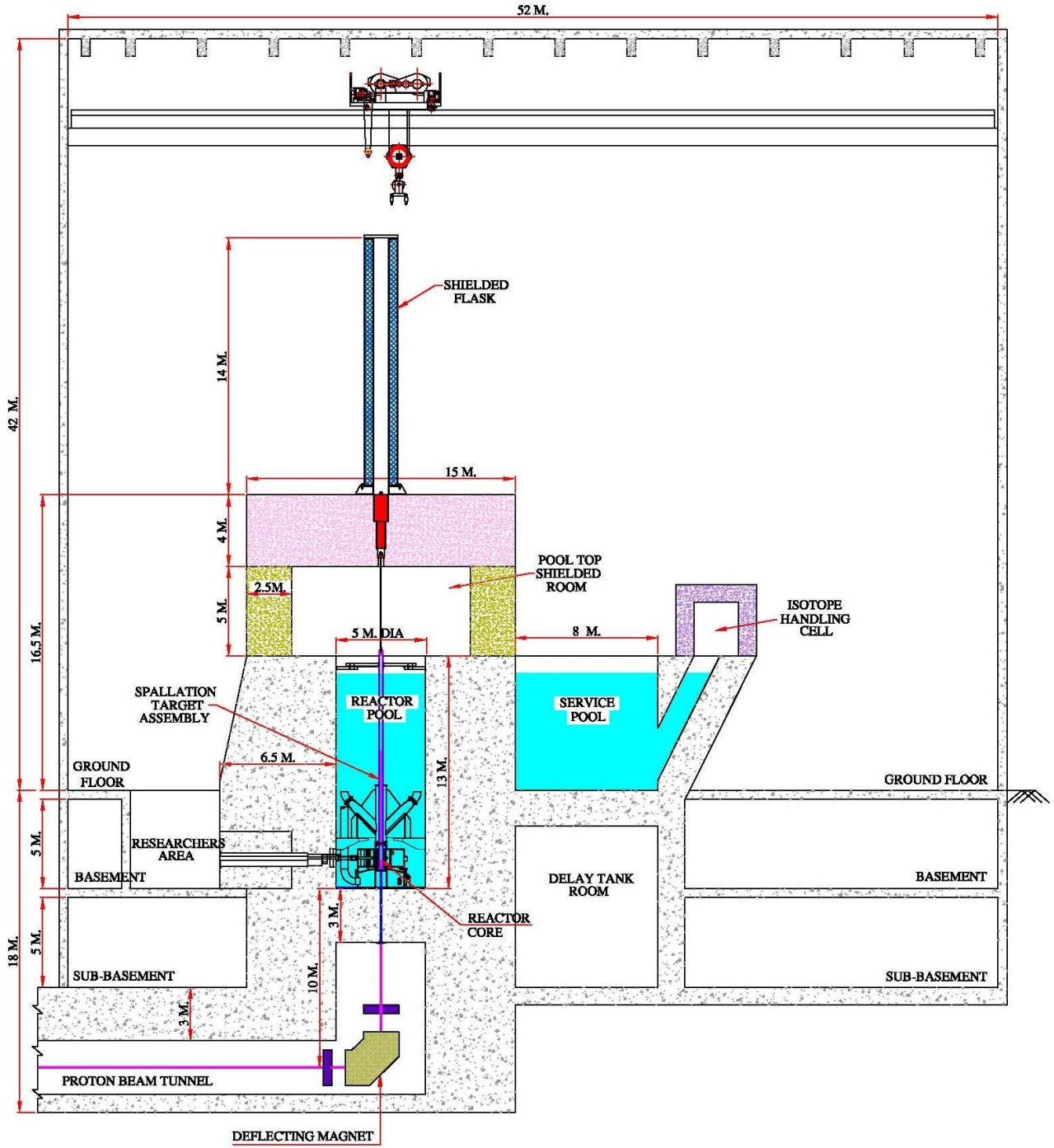
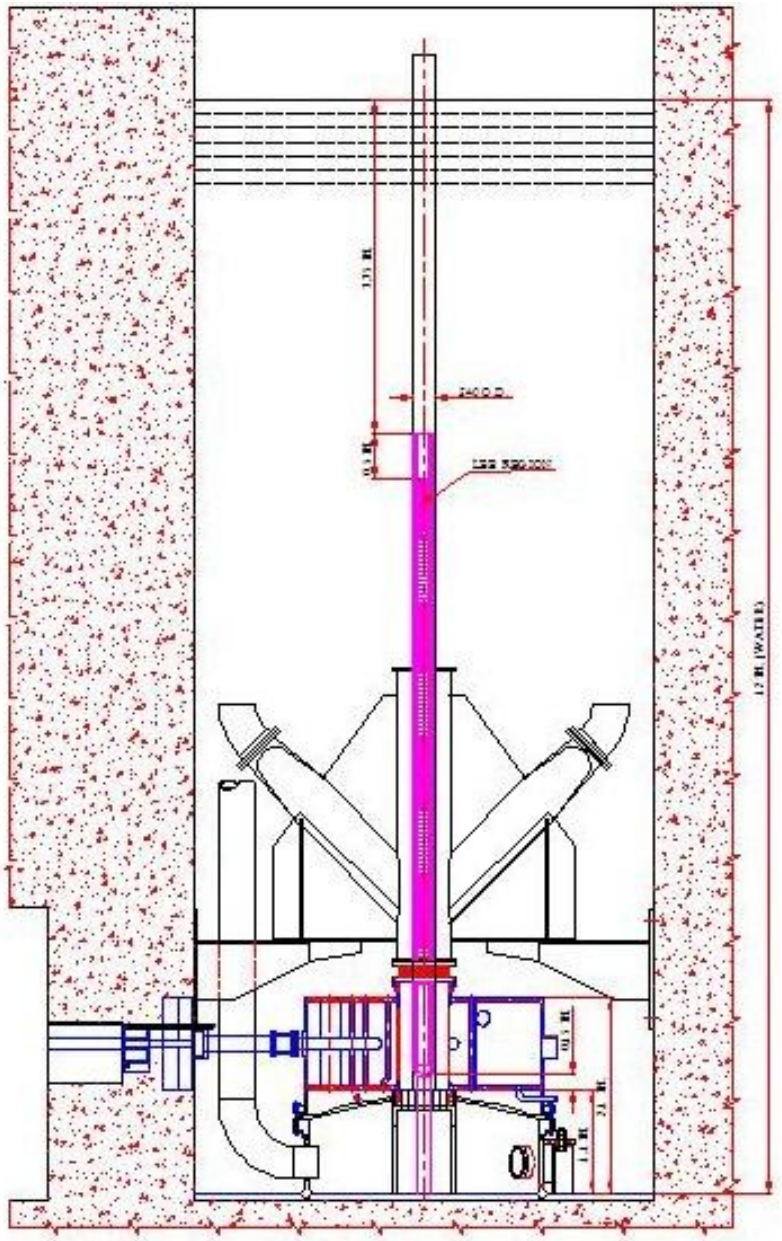
# ADSS in Indian Context

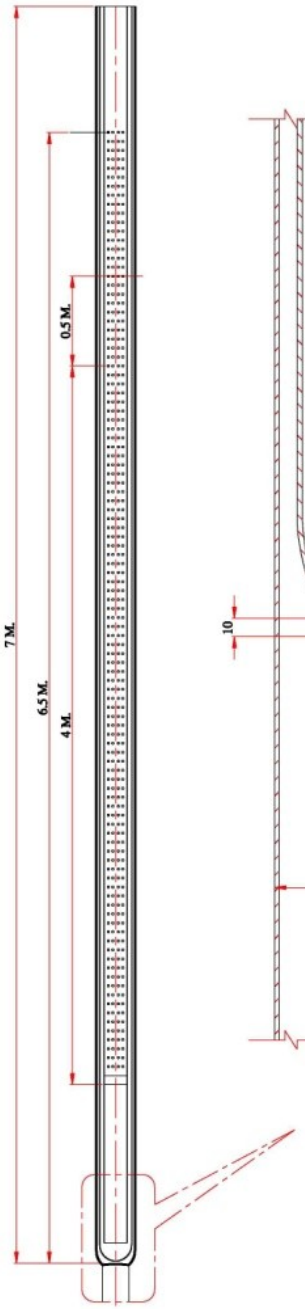
- Thorium ! India has large Th deposit.
- ADS systems are being pursued vigorously by various techniques.
- A swimming pool type research reactor is being proposed to be operated in ADSS mode.

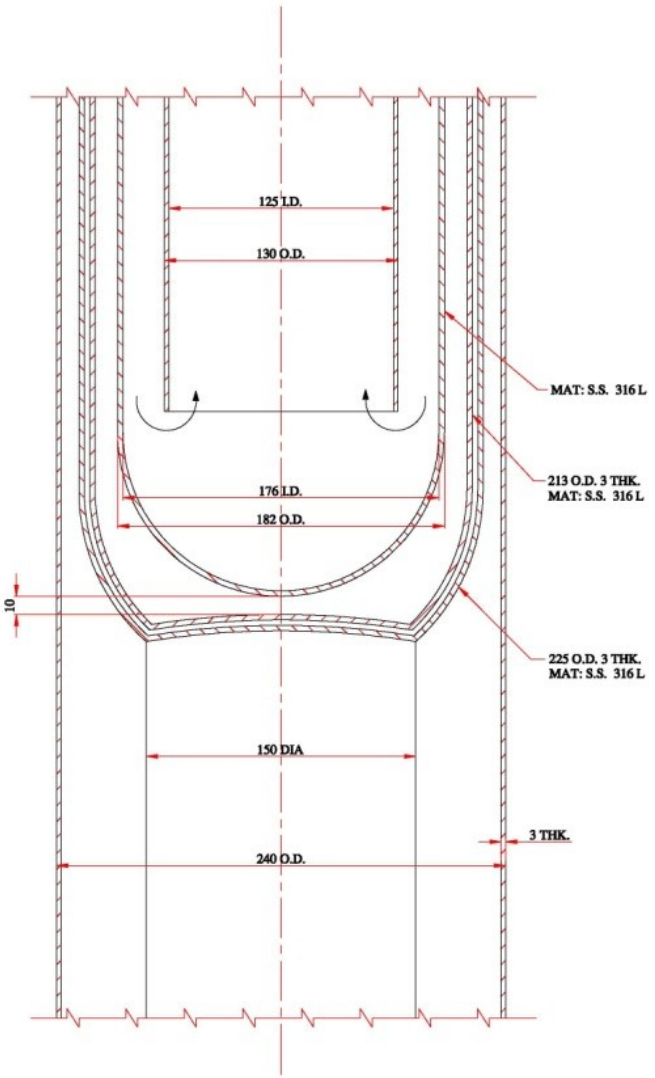
# The project

- Open tank pool type research reactor
- Fuel is cylindrical pin type rods made of $UAl_3$-Al with Zr-2 cladding.
- Heavy water reflector
- Accelerator at a lower level (bottom injection)


52 M.
42 M.
14 M.
SHIELDED FLASK
15 M.
4 M.
5 M.
2.5M.
POOL TOP SHIELDED ROOM
ISOTOPE HANDLING CELL
16.5 M.
5 M. DIA
8 M.
SPALLATION TARGET ASSEMBLY
REACTOR POOL
SERVICE POOL
6.5 M.
13 M.
GROUND FLOOR
GROUND FLOOR
5 M.
RESEARCHERS AREA
BASEMENT
DELAY TANK ROOM
BASEMENT
3 M.
REACTOR CORE
18 M.
5 M.
SUB-BASEMENT
10 M.
SUB-BASEMENT
3 M.
PROTON BEAM TUNNEL
DEFLECTING MAGNET






SPALLATION TARGET ASSEMBLY

# Design Considerations

- A high flux research reactor is being planned to be coupled to a 650 MeV 1mA proton accelerator.
  1. The reactor should work as a research reactor
     - Neutron beam lines
     - Medical isotope production
  2. The reactor should also work as technology demonstration setup for ADSS.
     - LBE window life time studies
     - Neutron multiplicity, handling, radio-toxicity

*Raina et al., Multi purpose research reactor, Nuclear Engineering and Design, 236, pp770, 2006*

# Solutions sought for

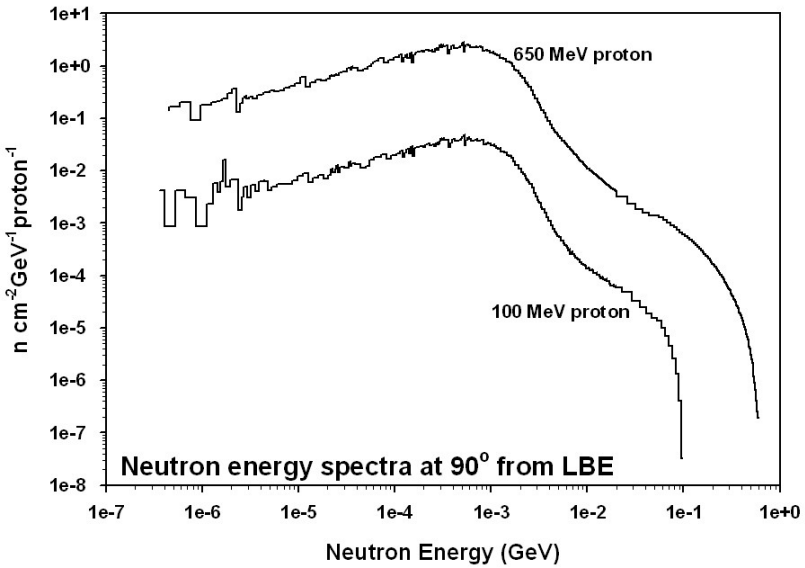
- Lateral shielding of the accelerator
- Residual nuclei inventory in LBE
  - $^{210}Po$!
- Prompt neutron dose rates
- Gamma dose rate at the pool top after shutdown
- Induced activity in the pool top SS platform.
- Induced activity in the SS linings of the tube.

# Lateral shielding of accelerator

- FLUKA code used to calculate the source term.
  - Neutron spectrum, dose, total yield
- Lateral shielding of proton accelerator by analytical techniques.
  - Source term from FLUKA calculations
    - Energy spectrum, dose, neutron to proton ratio
  - Attenuation lengths from IAEA –tecdoc 283
  - Dose rate outside shield for every energy bin with appropriate attenuation length

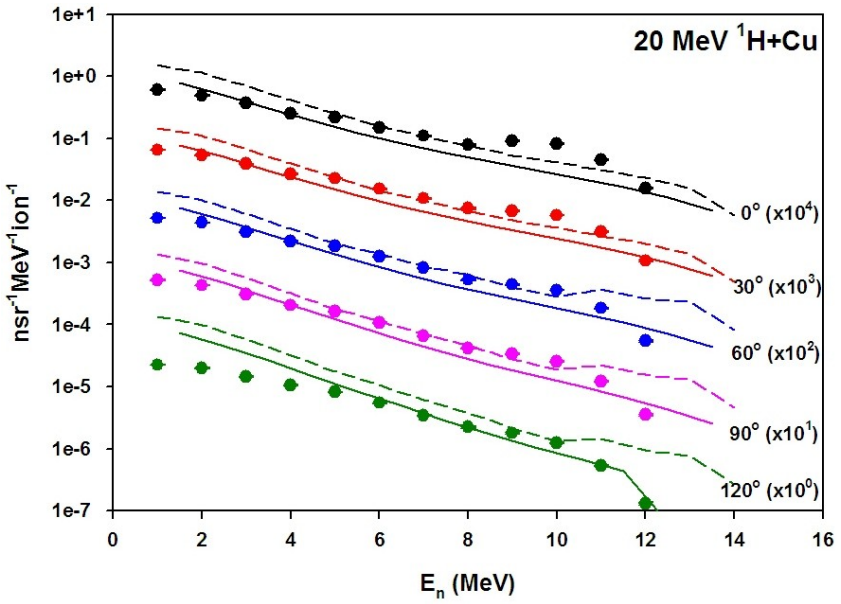
# Source term -high energy

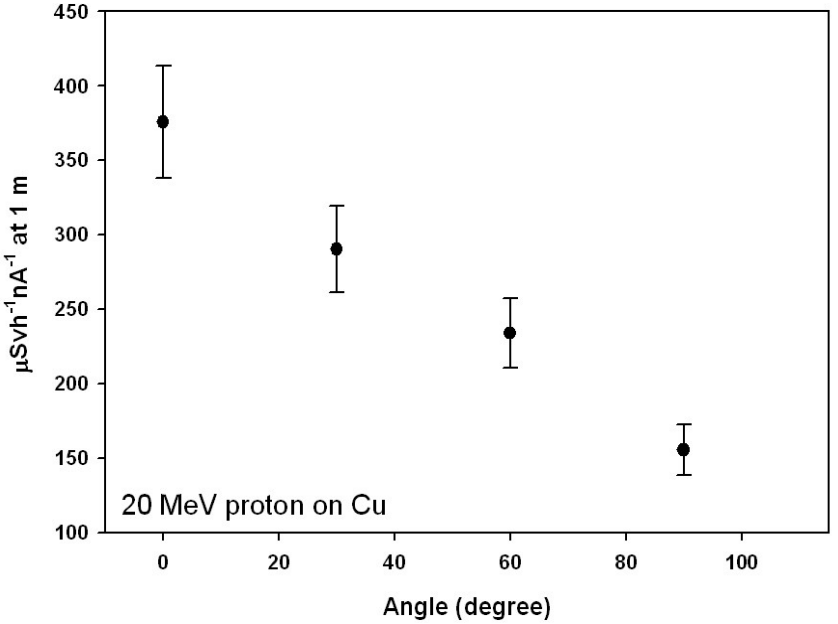
- A slab of target material (RPP) is enclosed inside a sphere.
- Neutron spectra scored using USRBDX card from RPP.
- AUXSCORE used to invoke deq99.f for dose with SDUM =AMB74
- The $4\pi$ neutron yield scored using USRBDX out of the sphere.




| $E_p$ (MeV) | (n/p) from Cu | |
|---|---|---|
| Source | FLUKA | Sullivan |
| 100 | 0.18 | 0.2 |
| 650 | 4.9 | 4.6 |

# Source term- low energy




- Experiments carried out at Pelletron Accelerator at TIFR.
- Spectrum measurements performed by liquid scintillators.
- Dose measurements done by conventional dose meters.
- Source term for calculations here derived from these experiments.

*Sunil et al., Rad. Prot. Dosi. 136, 67 (2009)*

# Induced Activity

# Induced activity calculations

- Assumptions
  - The beam is injected from the bottom of the LBE loop.
  - Radionuclides production by nuclear interactions in LBE by the slowing down primary protons and by secondary neutrons from the resulting (*p,xn*) and (*n,xn*) reactions.
  - After one month of irradiation, the radioactivity produced is uniformly distributed in the entire 6.5 meter LBE column.

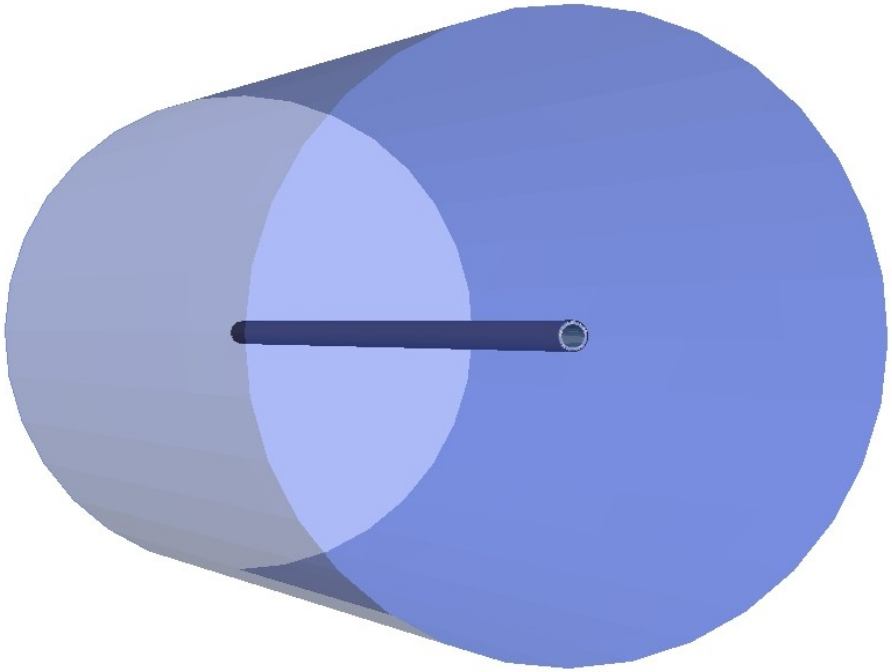
# Input

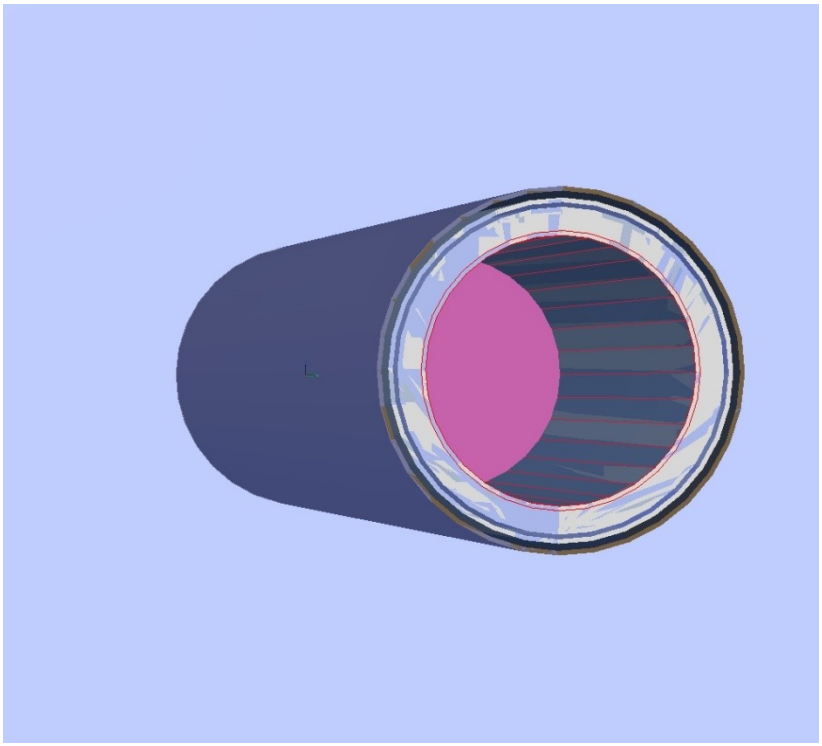
- 1 mA, 650 MeV proton irradiation carried out using IRRPROFI card.
- RADDECAY card invoked for radioactivity calculations
- DCYSCORE used to set cooling times.
- PHYSICS cards used with both heavy fragment evaporation and COALESCE options.
- One RESNUCLE card used for every 50 cm section for three SS layers.

# Cards

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
EVENTYPE                              2.0                                DPMJET
PHYSICS          3.0                                                     EVAPORT
PHYSICS          1.0                                                     COALESCE
RADDECAY         1.0
IRRPROFI     2.592E6  6.250E15
DCYTIMES         0.0     600.0    3600.0   43200.0   86400.0   2.592E6
DCYSCORE         1.0                           1.0       2.0           USRTRACK
DCYSCORE         2.0                           3.0       4.0           USRTRACK
DCYSCORE         3.0                           5.0       6.0           USRTRACK
DCYSCORE         4.0                           7.0       8.0           USRTRACK
DCYSCORE         5.0                           9.0      10.0           USRTRACK
*********************************************************************
DCYSCORE         1.0                           1.0                     RESNUCLE
DCYSCORE         2.0                           2.0                     RESNUCLE
DCYSCORE         3.0                           3.0                     RESNUCLE
DCYSCORE         4.0                           4.0                     RESNUCLE
DCYSCORE         5.0                           5.0                     RESNUCLE
DCYSCORE         5.0                           6.0                     RESNUCLE
```

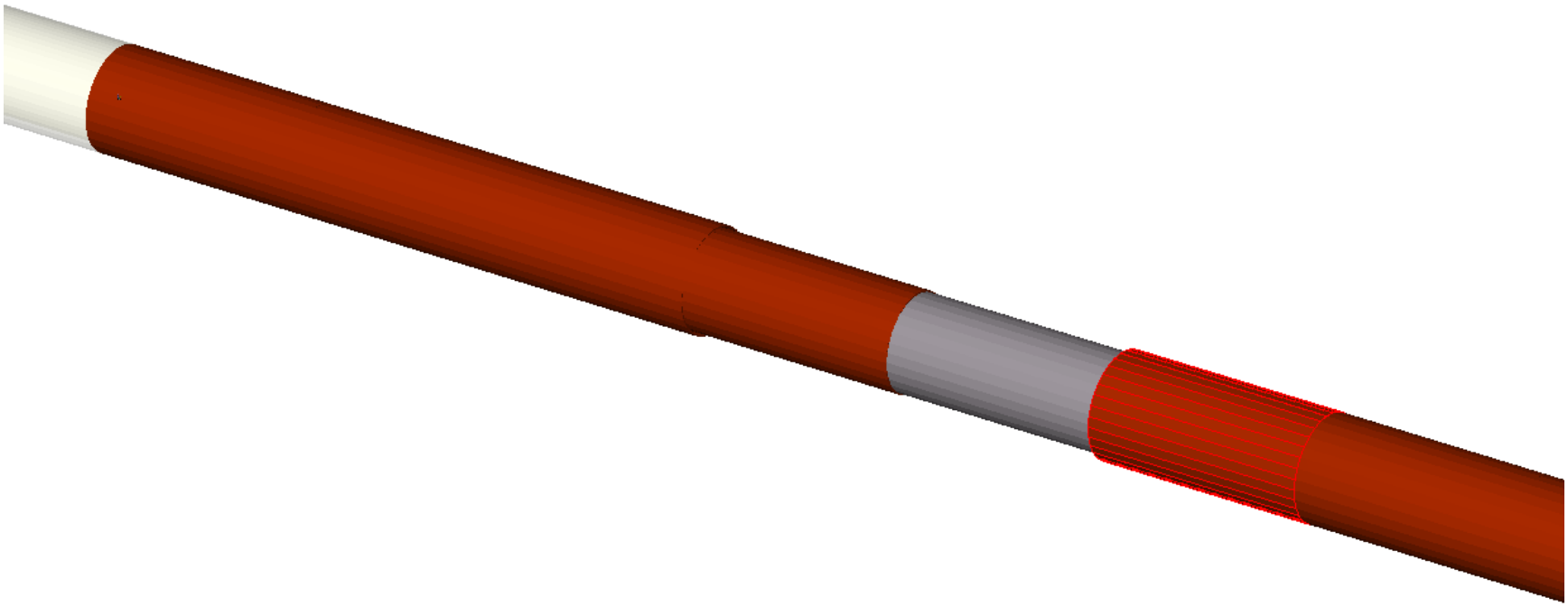
# Geometry in FLUKA





Geometry representation by SimpleGeo

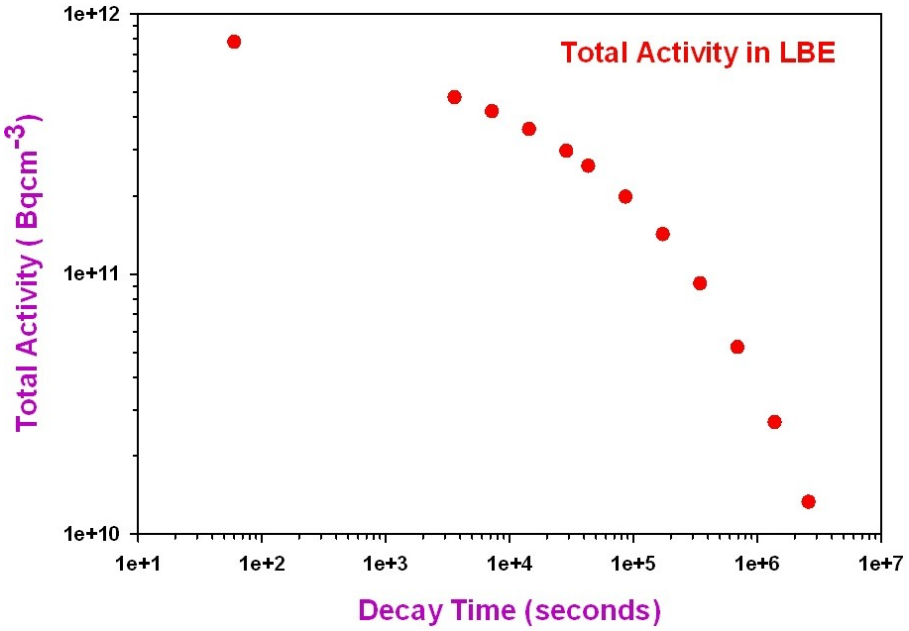
# Sectional view



# Extracting the results

- About 70 regions to score the residual nuclei production, each at six different cooling times.
- Tedious to note down the numbers even after processing with FLAIR.
- USRSUW was modified to obtain the total nuclei production in a different file in table form.
- Use a shell script to execute the modified USRSUW for all 70 x 6 results. Obtain a text file.

# Induced Activity in LBE

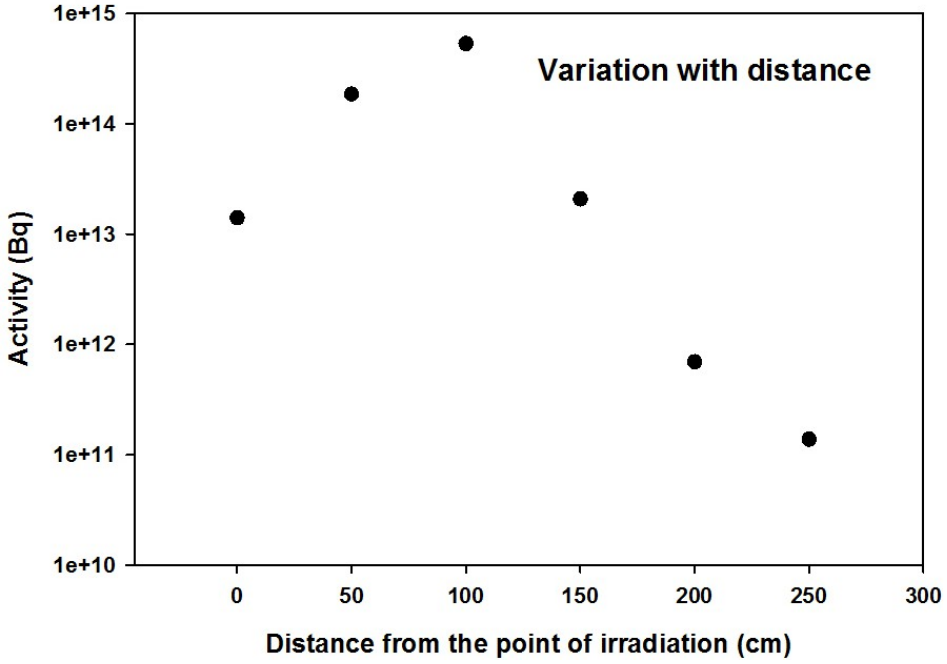


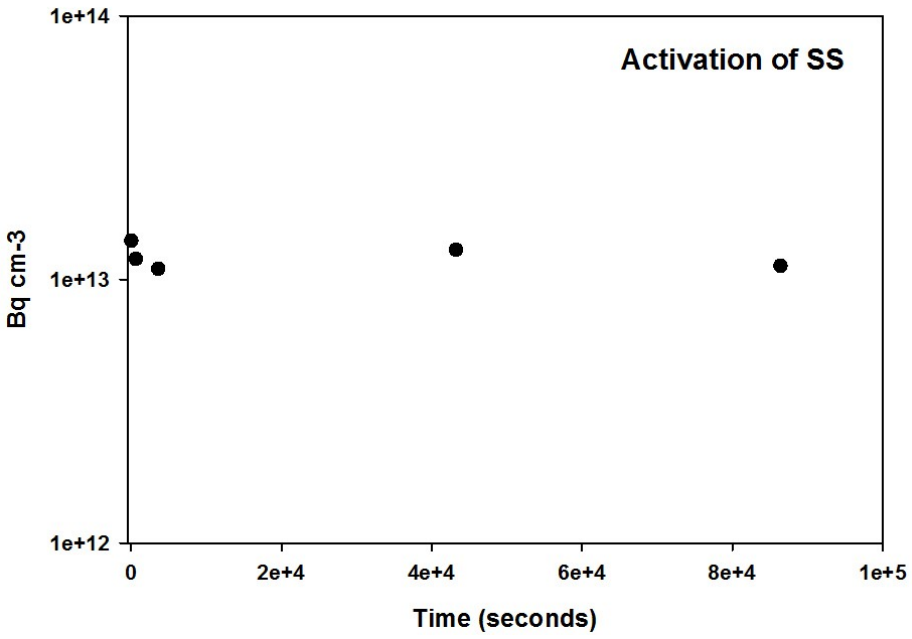

- Induced activity from primary protons and secondary neutrons produced by spallation.
- Activity considered here does not include radionuclides produced by thermal neutrons generated in the reactor core and entering the LBE.

# Decay of induced activity

| Cooling time | Total Activity (Bq) |
|---|---|
| 0 seconds | 3.32E+17 |
| 600 seconds | 2.53E+17 |
| 1 hour | 2.01E+17 |
| 12 hours | 1.07E+17 |
| 24 hours | 8.04E+16 |
| 1 month | 5.26E+15 |

# Activation of SS



# Improvements required

- CPU Intensive
- Errors in the activation results in the class of 10-15% for the SS regions close to the source.
- No biasing introduced yet.
- Region independent biasing required to obtain activation of SS platform with reasonable errors.

# Comparison

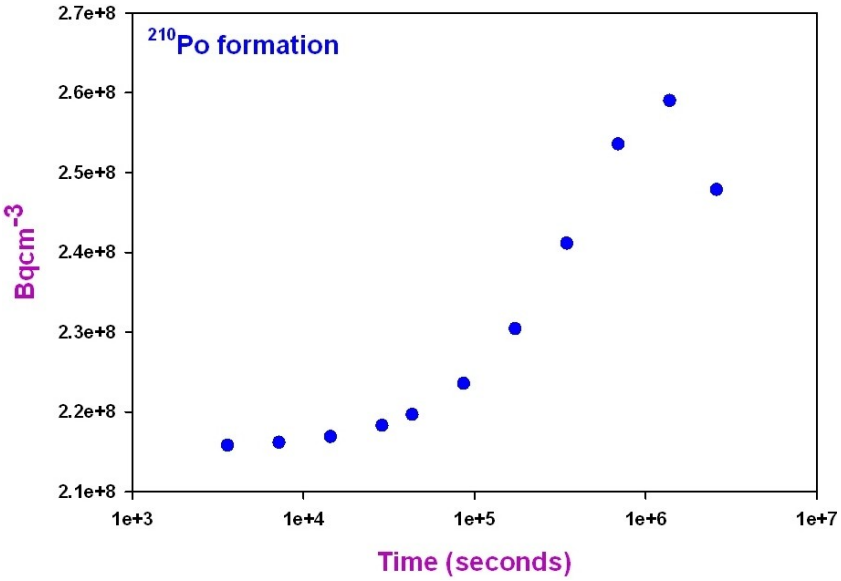
| Radionuclide | Percentage formation | |
|---|---|---|
| | This work | MEGAPIE* |
| $^{203}$Pb | 4.5 | 4.2 |
| $^{201}$Tl | 3.3 | 3.5 |
| $^{201}$Pb | 3.0 | 2.8 |
| $^{200}$Tl | 3.0 | 3.0 |

** Konobeyev, Fischer, Zanini, Nucl. Instr. Meth. A605, 224 (2009)*

# Polonium formation

| Isotope | Activity ($Bqcm^{-3}$) | Half life |
|---|---|---|
| 210 | 2.1E+8 | 138.4 days |
| 209 | 1.4E+5 | 102 years |
| 208 | 2.4e+7 | 2.9 years |
| 207 | 1.6e+9 | 5.8 hours |
| 206 | 2.0e+9 | 8.8 days |
| 205 | 1.9e+9 | 1.7 hours |
| 204 | 2.2e+9 | 3.5 hours |
| 203 | 1.6e+9 | 37 minutes |
| 202 | 1.7e+9 | 45 minutes |
| 201 | 7.4e+8 | 15 minutes |
| 200 | 9.4e+8 | 11 minutes |
| 199 | 2.3e+8 | 5 minutes |
| 198 | 2.8e+8 | 2 minutes |
| 197 | 4.4e+7 | 84 seconds |
| 196 | 3.0e+7 | 6 seconds |

Evolution after beam shut off




**The time evolution of $^{210}$Po formation in LBE after irradiation with 650 MeV 1mA protons for one month.**

# Activation by thermal neutrons

- Thermal neutrons produced by the reactor also contributes to the activation products in LBE.
- After irradiation, $1\times10^{14}$ Bq residual activity formed in LBE by activation by thermal neutrons generated in the reactor.
  - $^{206,207,208}$Tl 4m (686 keV), 5m (597 keV), 3m (2.6 MeV) (Maximum $\gamma$ energy)
  - $^{209}$Pb 3.2 h (pure beta)
  - $^{203}$Hg 46 d (280 keV)
- Negligible compared to $3\times10^{17}$ Bq obtained from proton irradiation.
- Calculations carried out using MCNP.

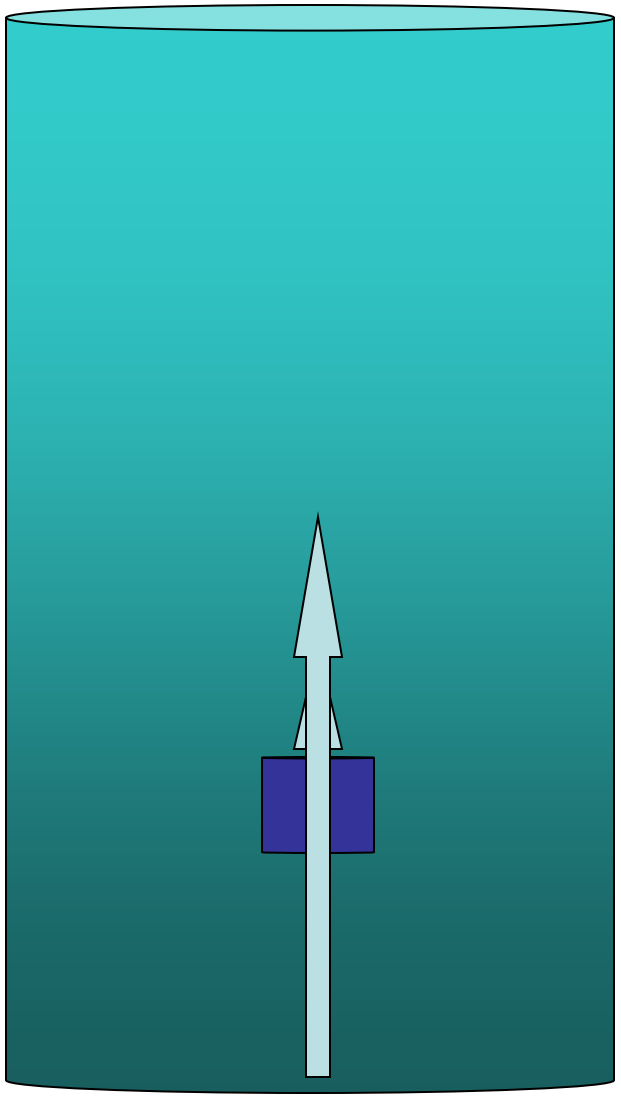
# $^{210}$Po by thermal neutrons

- $4\times10^{14}$ Bq of $^{210}$Po formed in 80 cm of LBE under constant irradiation for 3 months.
- Amounts to $3.2\times10^{15}$ Bq in the LBE column assuming constant irradiation.
- This is two orders of magnitude higher that the inventory as a result of proton irradiation.
- Calculations carried using MCNP.

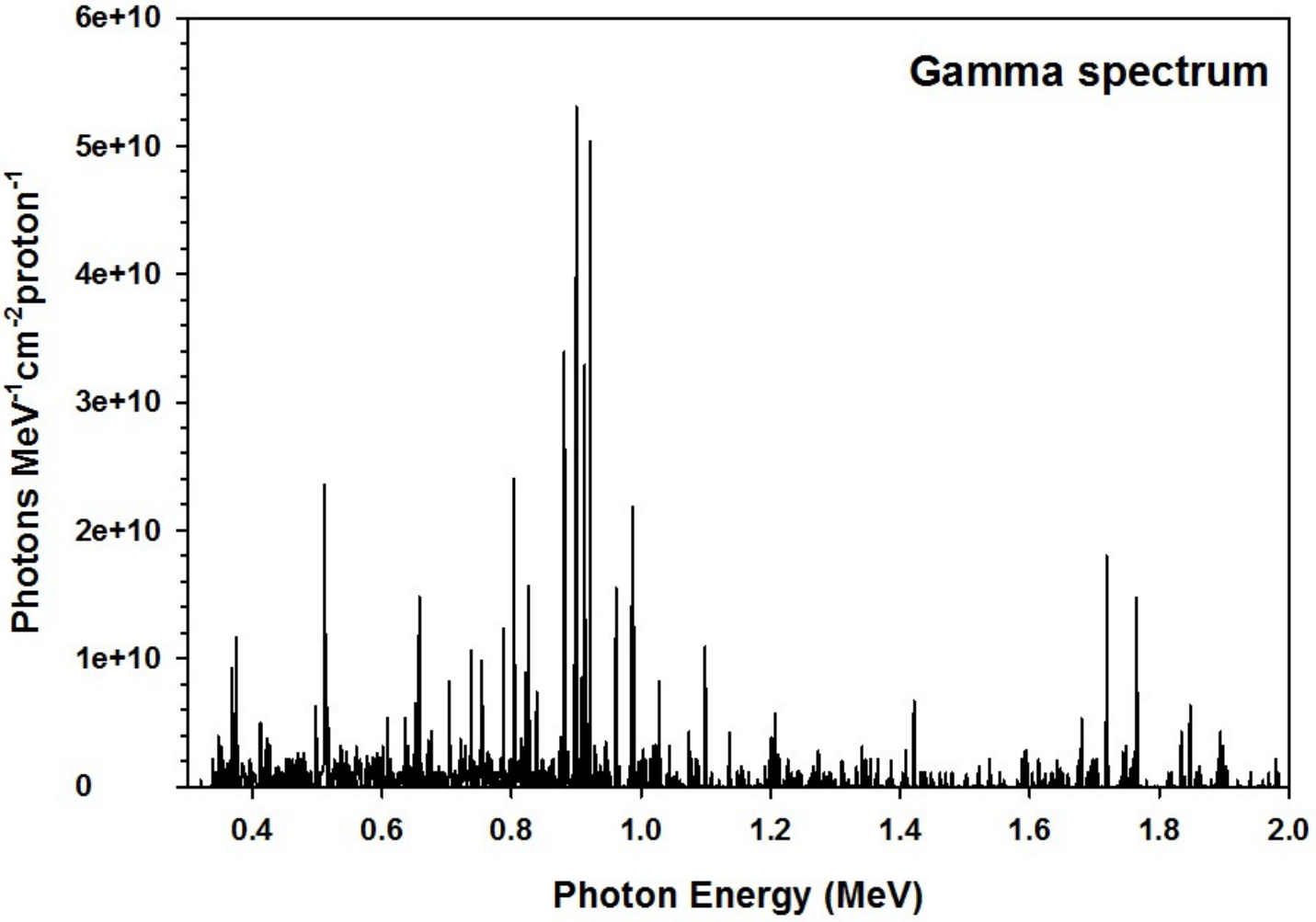
# Residual dose rate

# Dose at pool top after shutdown

- For calculation of residual dose rate after shutdown, the following assumptions were made.
  - Upper 70 cm of LBE considered to be made of two 35 cm long columns.
  - Pool top dose rate calculated as sum of all contributions from the activation of LBE due to
    - 650 MeV protons on the uppermost 35 cm
    - Neutrons (from 650 MeV protons) incident on the uppermost 35 cm. Sampled using source.f
    - 650 MeV protons on the uppermost 70 cm
    - Neutrons (from 650 MeV protons) incident on the uppermost 70 cm.
- Dose rate calculated directly above the LBE.



# Gamma spectrum at t=0



# Residual Dose rates

| Delay | Dose rate (Sv $h^{-1}$) | |
|---|---|---|
| | Pool top | Magnet room |
| 0 seconds | 2.91 | 1.33 |
| 10 minutes | 1.85 | 1.08 |
| 1 hour | 1.48 | 0.90 |
| 12 hours | 0.79 | 0.45 |
| 24 hours | 0.66 | 0.33 |
| 30 days | 0.13 | 0.07 |

Thank You