TARC Analysis using Geant4

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Outline

- Why TARC ?
- TARC Basics.
- The Role of BARC.
- Geant4 Results.

Why TARC?

First experiment $< \text{PS-211} >$ (TARC) was conceptualized by Carlo Rubbia and his collaborators at CERN-PS.

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- Nuclear waste management transforming transuranic isotopes.
- Production of new radio-isotopes by neutron capture for medical importance [*e.g.* for cancer treatment] using accelerator driven system (ADS).
- Transformation of actinides by fission and thereby producing energy [*Energy Amplifier*] using a fast neutron sub-critical system driven by proton accelerator.

Initial ideas

The discovery of the Spallation technique by Goeckerman and Perlman (*ref: Phys. Rev 73, 1127 (1948)*) influenced Lewis (*ref: Report AECL-968 (1952)*) to suggest the use of high current proton accelerators for the purpose of breeding fissile ^{233}U or ^{239}Pu from the fertile ^{232}Th or ^{238}U respectively.

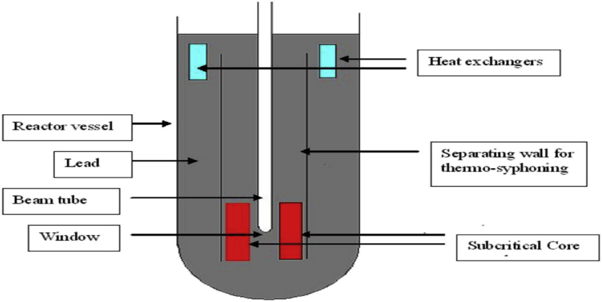

Figure: The first design proposal of the 600 MWe fast energy amplifier (EA) ADS of CERN for power production using Thorium fuel (*Ref: CERN/AT/95-55(ET)(1995)*).

TARC basics : Key components

- A proton accelerator which may be part of *ADS* (accelerator driven system),

TARC basics : Key components

- A heavy metal spallation target that may produce neutron when bombarded by high energy proton from accelerator.

TARC basics : Key components

- A sub-critical core containing fuel (solid or liquid) that is neutronically coupled to the spallation target. Higher fission cross section reduce principal isotopes like ^{239}Pu.

TARC basics : Key components

Number of fission neutrons produced by multiplication of a single neutron injected in core = $\frac{\kappa}{1-\kappa}$.

Let 1 fission produce ν fission neutrons.
Source producing S_0 neutrons/second would produce $\frac{S_0\kappa}{\nu(1-\kappa)}$ fission / sec.

Let e_f is power released / fission.
Hence total power released = $\frac{e_f S_0 \kappa}{\nu(1-\kappa)}$ /second.

For $\kappa_{eff} = 0.95$ and $\kappa_{eff} = 0.98$ the source strength must be of the order of 6.2×10^{18} n/sec and 2.4×10^{18} n/sec respectively to produce about 1500 MWt power i.e. the power of **Energy Amplifier**.

TARC basics : Properties of spallation target

"Natural Lead" [1.4% ^{204}Pb, 24.1% ^{206}Pb, 22.1% ^{207}Pb, 42.4%^{208}Pb] : spallation target.

- MeV region to thermal energy: Transparent to neutron.

  Very low absorption cross section [^{204}Pb : 0.65b, ^{206}Pb : 0.03b, ^{207}Pb : 0.699b, ^{208}Pb : 0.00046b].

  Lead also possess high and energy independent elastic scattering cross section (mean free path $\lambda \sim$ 3cm) which means lead behaves as transparent to neutron.

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- Moderate slowing down effect due to very small lethargic ($\xi \approx 9.6 \times 10^{-3}$) steps of neutron.

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- Below the capture resonance energy ($E_n < 1$ keV) down to epithermal energy, the elastic scattering process is nearly isotropic : "long storage time" (3 ms time for about 1800 scatterings to cover a total path of about 60 m to thermalize 1 MeV neutron).

TARC basics: Properties of spallation target

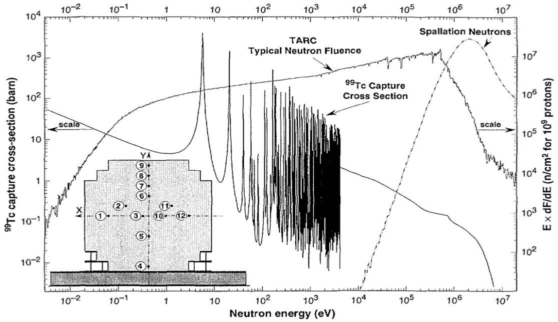
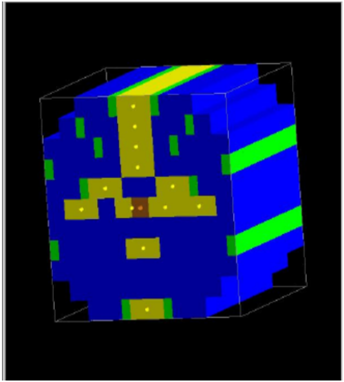


Figure: ^{99}Tc capture cross section 4000b @ 5.6eV (vide JENDL 3.2 database) as a function of neutron energy (left hand scale), typical neutron fluence energy distribution in TARC (hole 10, z=+75 mm) as a function of neutron energy in isolethargic bins, for 3.5 GeV/c protons (right hand scale), Energy distribution of neutrons from the spallation process. *Ref*: CERN 99-11 Dec 15, 1999: The TARC Experiment (PS-211) report

TARC Experiment :: CERN

- Proton Beam : 2.5 GeV/c, 3.5 GeV/c
- 334 tons of Pb with dimension $3.3m \times 3.3m \times 3m$ block.
- Beam enters through a 77.2 mm diameter, 1.2m long blind hole.
- 12 sample holes are located inside the lead volume to measure capture cross sections of some samples.



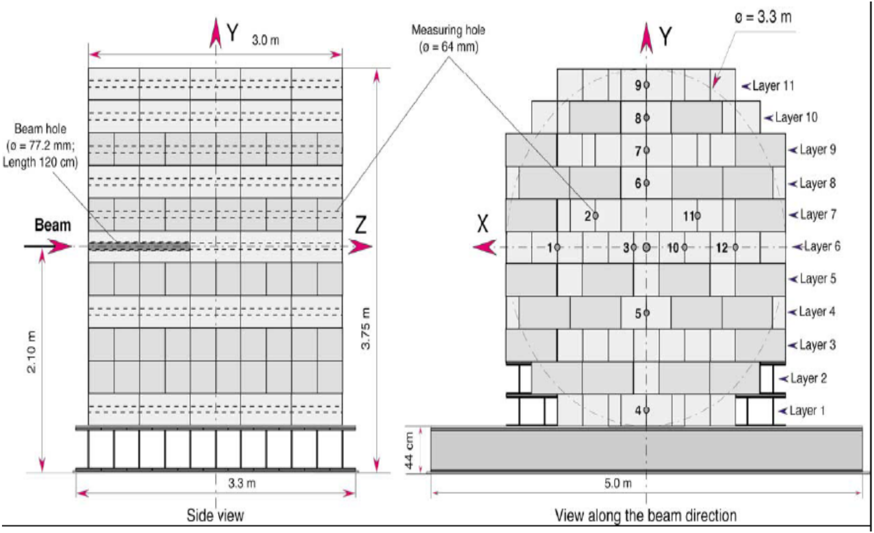


Figure: TARC Lead Assembly *Ref*: CERN-SL-2001-033 EET, PS-211 REPORT

The Role of BARC

The development at BARC has been conceptualized in three phases:

- A 20 MeV, 10 mA normal conducting front-end, called the Low Energy High Intensity Proton Accelerator.
- A 200 MeV, 10 mA, superconducting accelerator using single-spoke resonators, called the Medium Energy High Intensity Proton Accelerator.
- The full 1 GeV, 10 mA, CW, High Energy High Intensity Proton Accelerator, using elliptic cavities from 200 MeV to 1 GeV.

Geant4 Results : Validation

- Spallation neutron production in lead target by protons,
- Validation of energy - time relationship for thermalization of neutrons,
- absolute neutron fluence variation over energy and radial distances verifying neutron transport properties.

Geant4 Results : Distribution of Neutron Energy Deposition

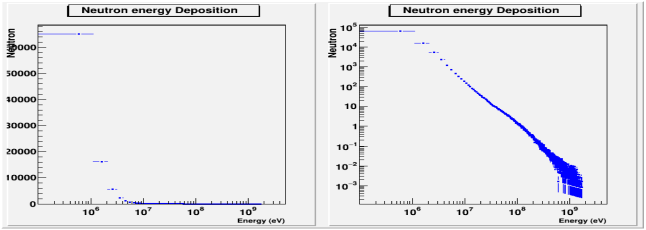


Figure: QGSP_BIC_HP

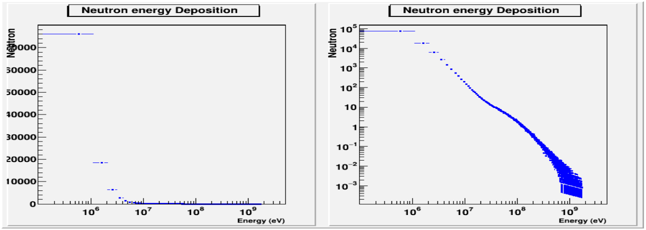
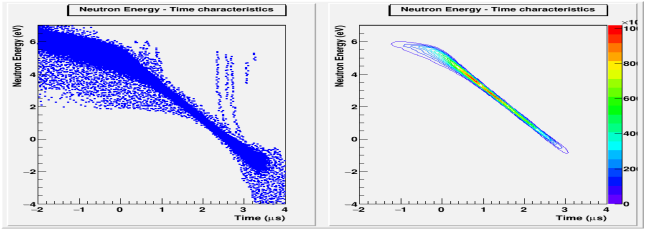


Figure: QGSP_BERT_HP

Geant4 Results : Correlation of Neutron Energy - Time



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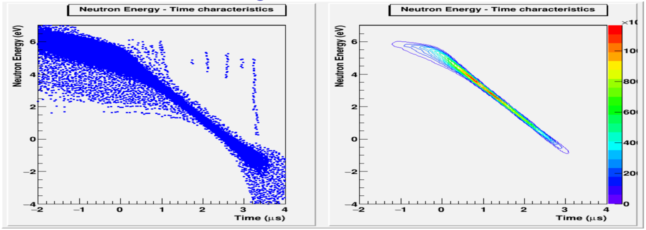


Figure: QGSP_BERT_HP

Geant4 Results :Correlation of Other particle Energy - Time

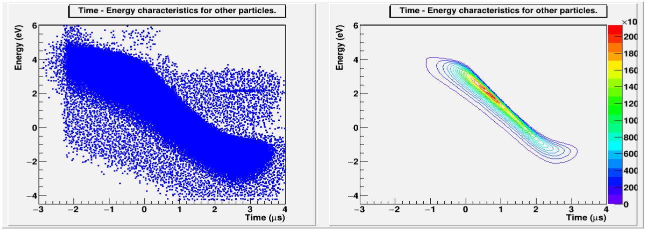


Figure: QGSP_BIC_HP

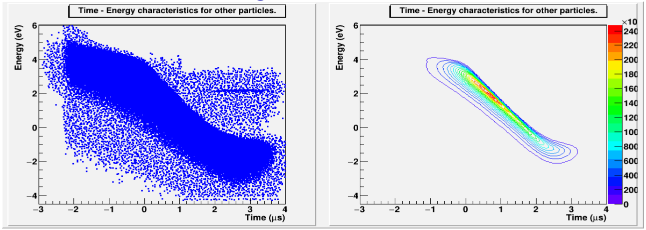
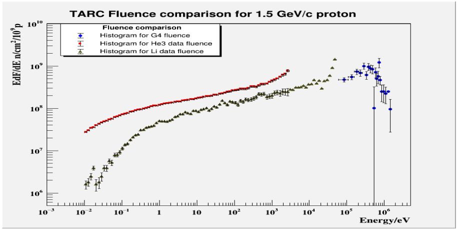


Figure: QGSP_BERT_HP

Geant4 Results : Distribution of Fluence with Energy



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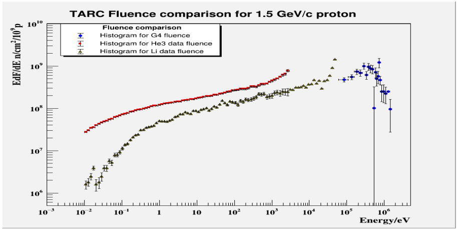

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Geant4 Results : Distribution of Fluence with Radial distance from center

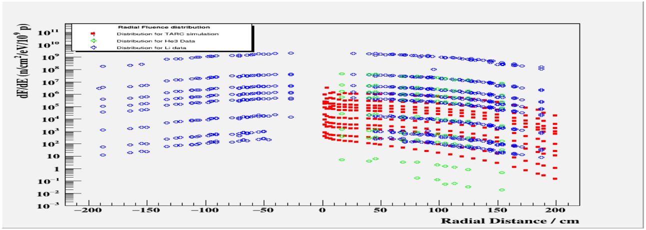


Figure: QGSP_BIC_HP

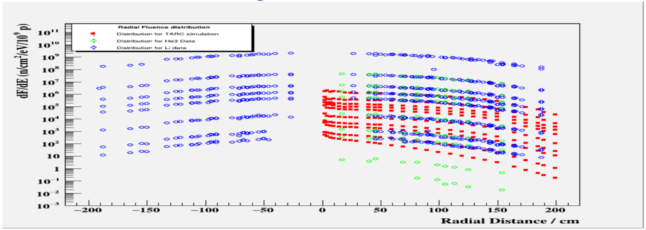


Figure: QGSP_BERT_HP

Geant4 Results : Ratio plot of Fluence G4/data

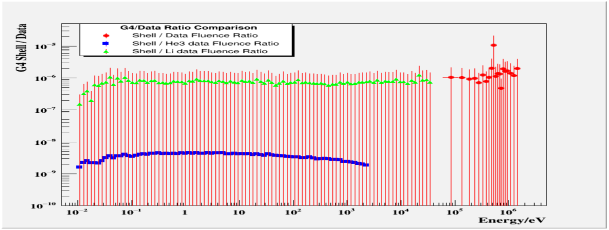


Figure: QGSP_BIC_HP : Ratio of fluences for 4π shell:data

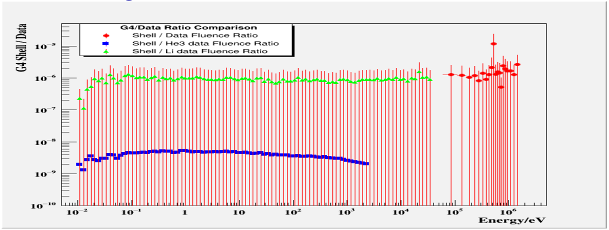
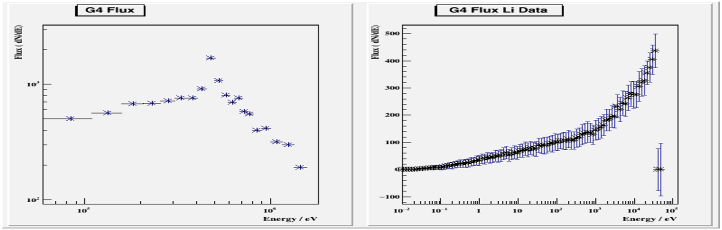


Figure: QGSP_BERT_HP : Ratio of fluences for 4π shell:data

Geant4 Results : Distribution of Flux



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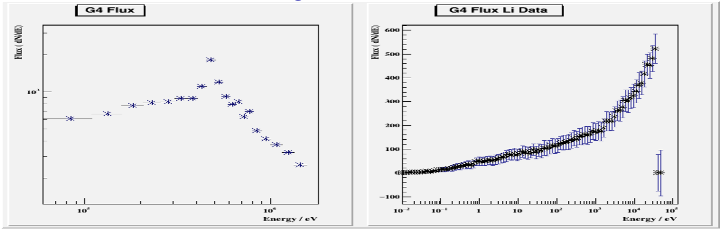

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The following topics are either performed or in progress:
(a) Studies like specific energy release per proton per 10^{10} protons at different positions.
(b) Breeding with ^{99}Tc and *k_eff* calculations with neutron spectra and concentration of relevant element as a function of burn-up.

Thank You