GEANT4 SIMULATIONS OF PROTON-INDUCED SPALLATION FOR APPLICATIONS IN ADSR

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Introduction to spallation 1

Spallation

GEANT4

MYRRHA: Intro

ADS neutron

The spallation reactions refer to high-energy hadron-nucleus reactions in th e 200 MeV - 3 GeV energy range causing the emission of a large number of hadrons (mostly neutrons) or fragments.

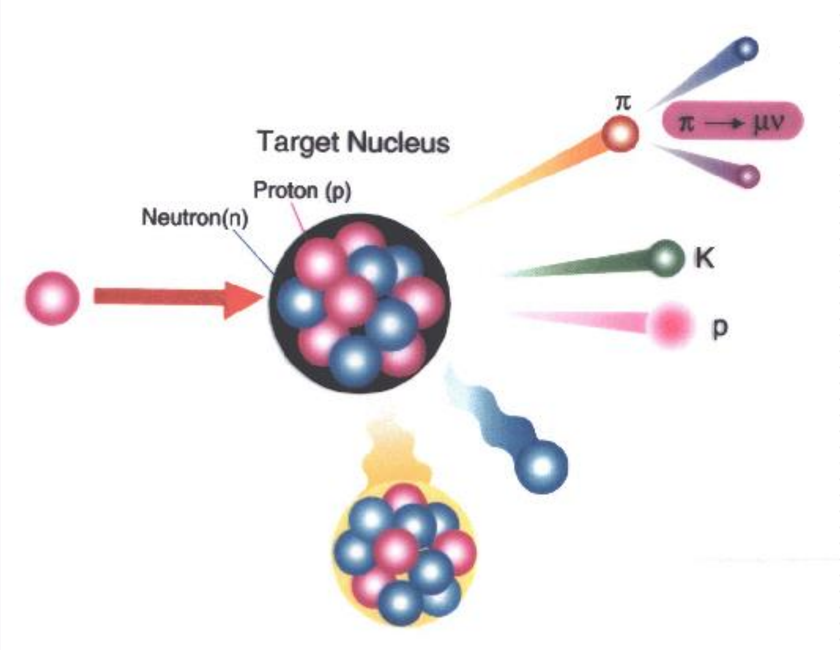

Illustration of spallation process

•The remnant nucleus loses its residual excitation energy by an evaporation-like process emitting neutrons or low energy light particles.

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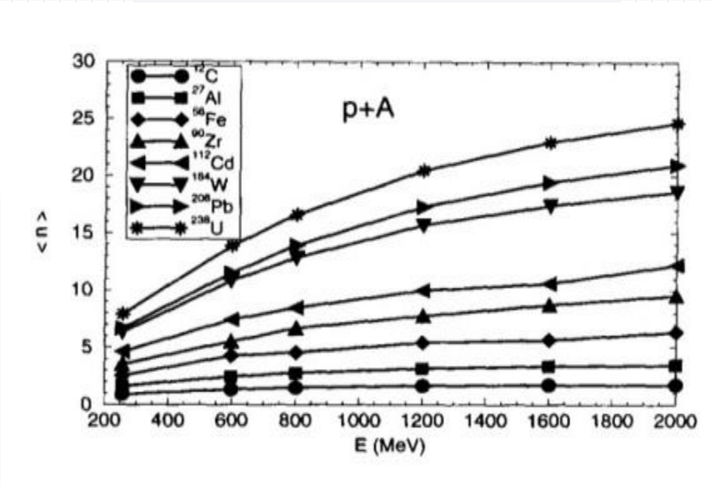
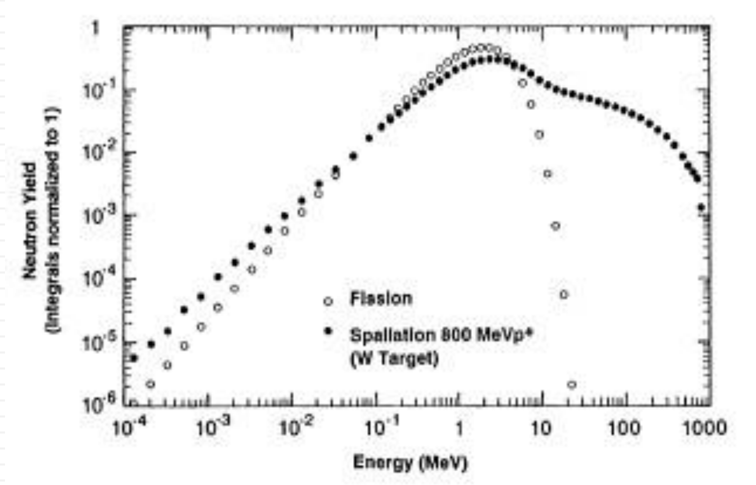
Importance of spallation neutron

- The neutrons produced from spallation are mostly categorised as fast neutron due to the their energy range is between 1-2 MeV
- With the fast neutrons, the rate of the neutron capture for plutonium and minor actinides is often larger than thermal neutrons.
- The transmuted elements have also less total radiotoxicity.
- Spallation source is the external source of supplying neutrons in ADSR



Neutron multiplicity as function of proton beam energy [1]



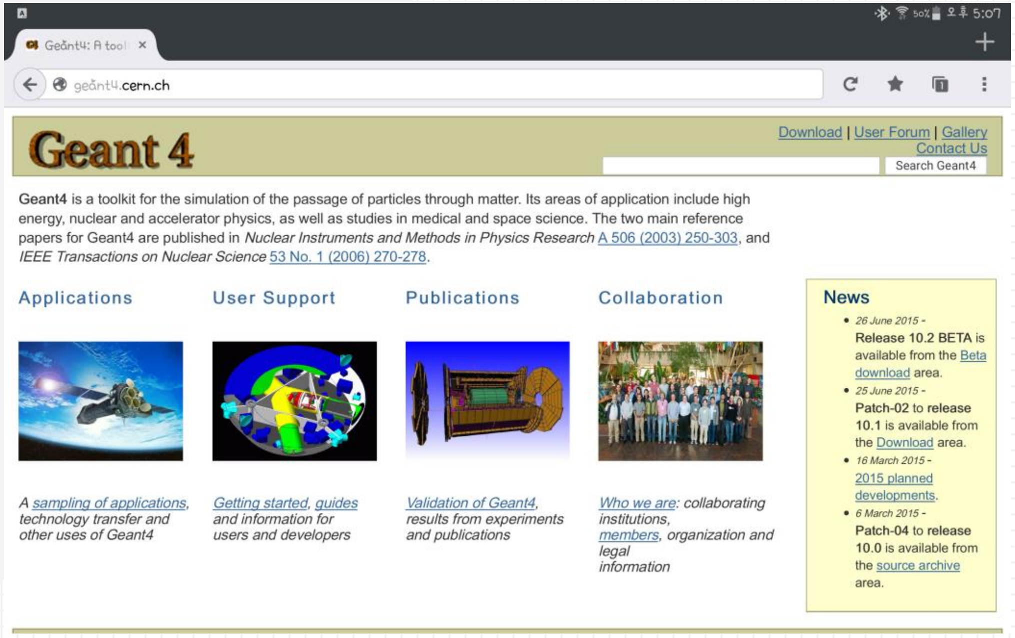
Energy spectrum of neutrons from spallation compared with fission neutrons [2]

[1] *H. Nifenecker, O. Meplan, and S. David, Accelerator Driven Subcritical Reactors CRC Press, 2003.*. [2] *G.J. Russell, Spallation physics–an overview, Proceedings of ICANS-XI, Tsukuba, 1990, KEK-Report Vol. 90-25,1991, pp. 291–299*

Introduction of GEANT4

- GEANT4 is a Monte-Carlo transport code developed by CERN. Its Hadron data library is maintained and updated by SLAC, Standford, US.
- Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science.

- GEANT4 provides an extensive set of hadronic physics models for energies up to 10 ~15 GeV both for the intranuclear cascade region and for the modelling of evaporation



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GEANT4 benchmarking studies-Introduction

- Despite the fact that the code is well conceived, the neutronic behaviour and the simulation code need to be studied extensively.

- In order to use GEANT4 for spallation studies and ADSRs neutron production, the detailed analysis for neutron production in heavy elements needs to be well studied.

- The data from GEANT4 also need to be compared with published data for the validation so that the results produced by GEANT4 can be proven to be reliable.

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GEANT4 benchmarking studies-Introduction

Spallation

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Current Work

- The paper *(Meigo, S. et.al(1999). Measurements of neutron spectra produced from a thick lead target bombarded with 0.5 and 1.5-GeV proton)* provides the validation study of MCNP4A code against experimental data taken from KEK, Japan on neutron spectra produced from a thick lead target bombarded with 0.5 and 1.5 GeV protons.
- The GEANT4 simulation was carefully designed to carry the exact geometry that the experiment used in KEK, Japan

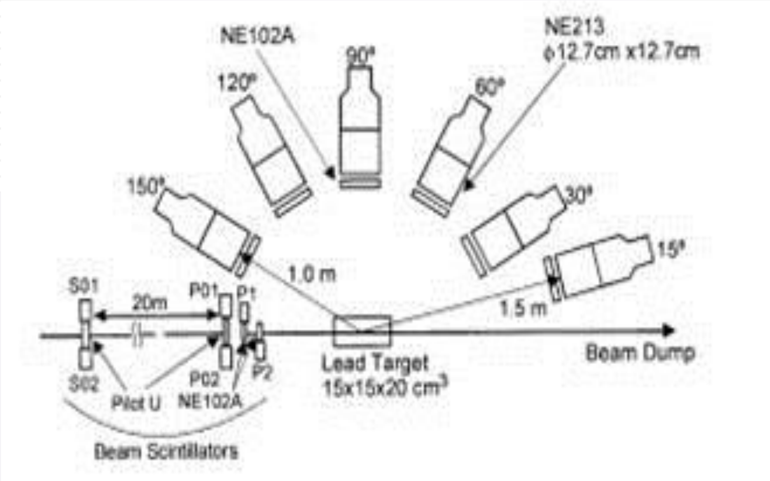

Illustration of experimental arrangement

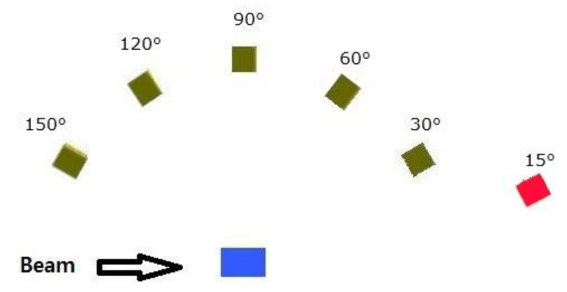

Illustration of simulation arrangement

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GEANT4 benchmarking studies-Results 1

Spallation

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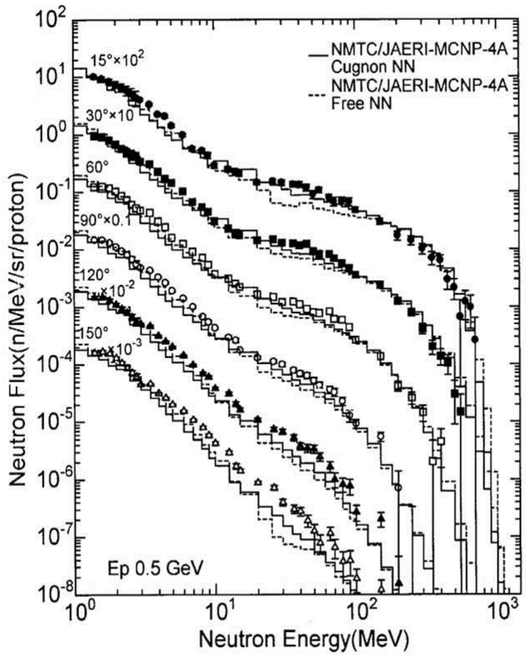
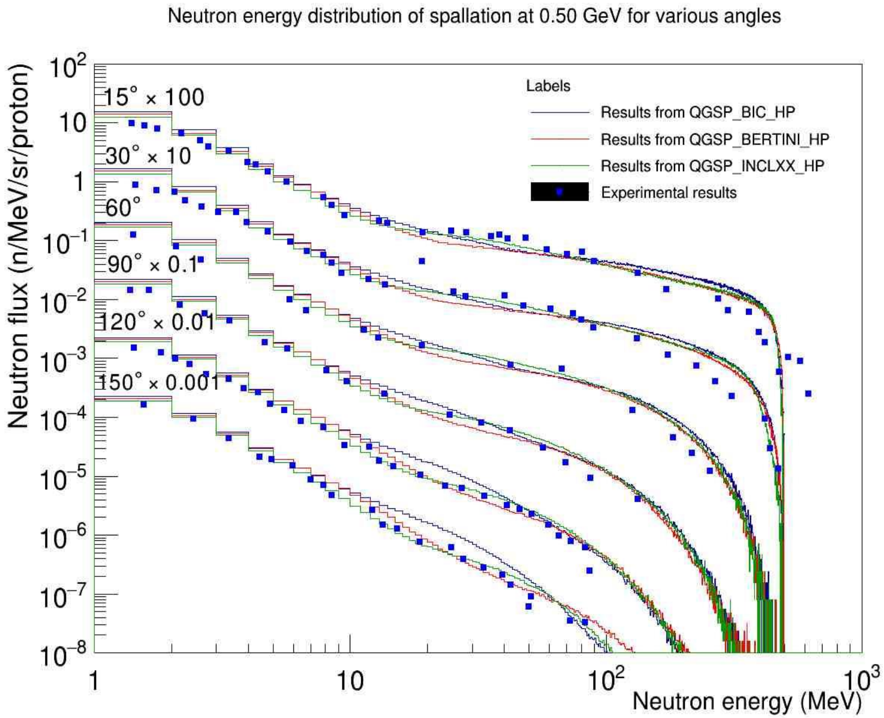
Current Work

- The neutron flux (n/MeV/sr/proton) was measured in all detectors over entire neutron energy range for both 0.5 GeV and 1.5 GeV incident proton beam energy.



Neutron flux at 0.5 GeV proton beam en ergy from MCNP4A simulation



Neutron flux at 0.5 GeV proton beam energy from GEANT4 with experimental data (shown as dots)

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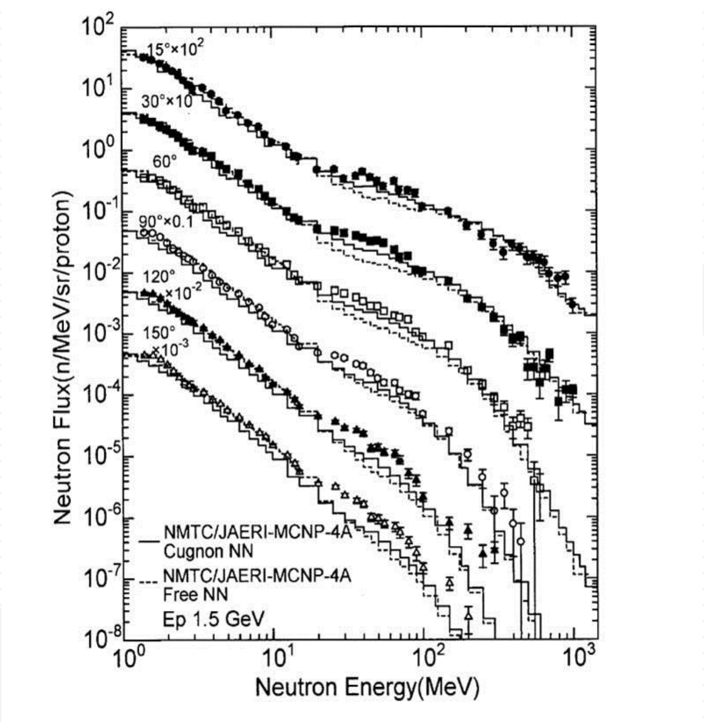
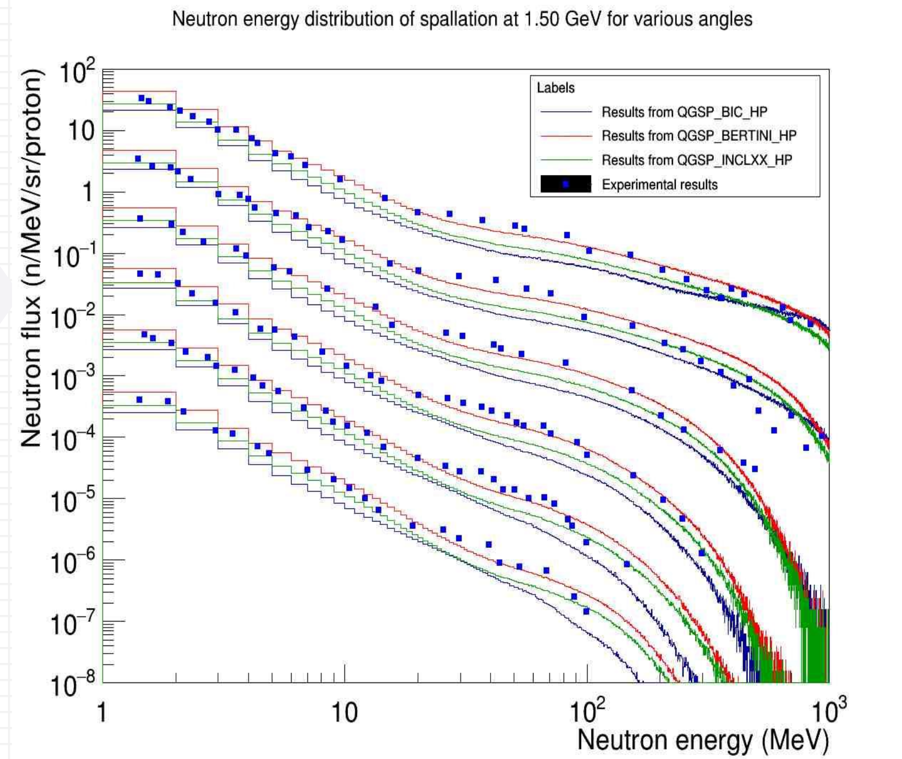
GEANT4 benchmarking studies-Results 2

- The neutron flux (n/MeV/sr/proton) was measured in all detectors over the entire neutron energy range for both 0.5 GeV and 1.5 GeV incident proton beam energ y.



Neutron flux at 1.5 GeV proton beam ener gy from MCNP4A simulation



Neutron flux at 1.5 GeV proton beam energy fro m GEANT4 with experimental data (shown as d ots)

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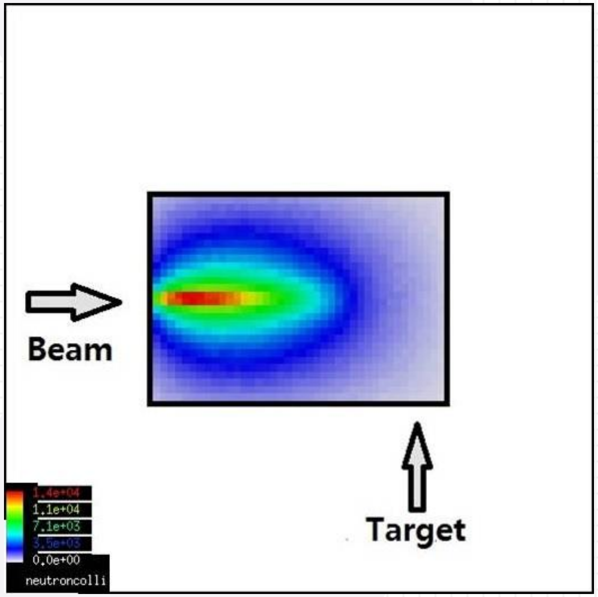
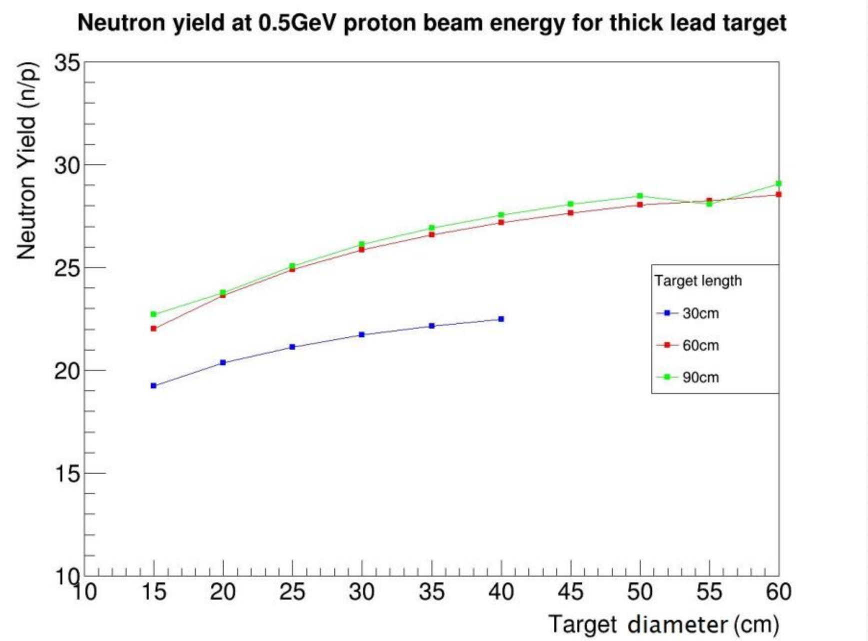
GEANT4 benchmarking studies-Results 3

- With same size of spallation target, neutron collision and the changes of neutron yield with different target size was measured.



Neutron collision at 0.5 GeV proton beam energy at various lengths



Neutron yields at 0.5 GeV proton beam energy for 30 cm, 60cm and 90cm target lengths and various target widths

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GEANT4 benchmarking studies - Conclusion

- The results from GEANT4 in the previous slides showed close matches with MCNP4A in terms of the line shape and close to the experimental results with corresponding neutron energies for each angle.

- This study of the neutron yield dependents on the target size showed that the neutron yield increases with target length. However, there was no significant increase in the neutron yield for target longer than 60 cm.

- This validation study shows that there is the good agreement between GEANT4 and MCNP4A prediction of neutron yields measured in various angles. Hence the GEANT4 is proven to be reliable to carry on further spallation and ADSRs simulation studies.

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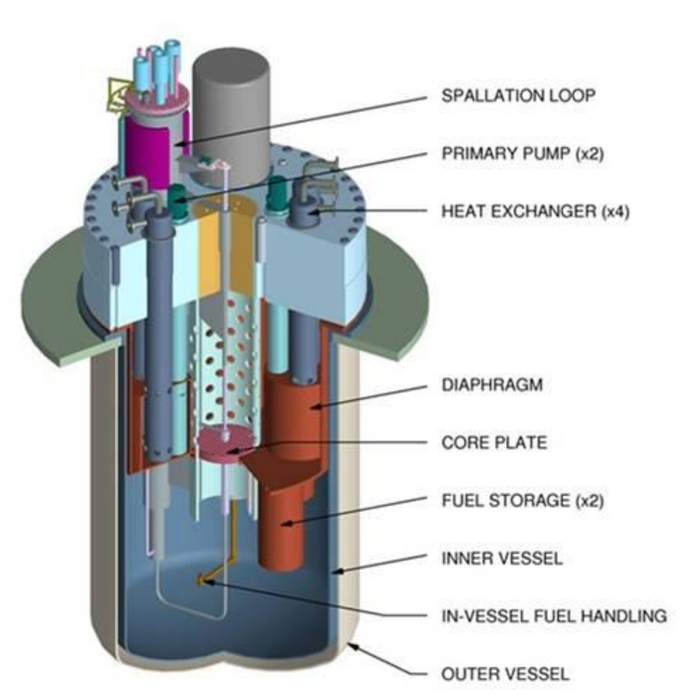
MYRRHA: first ADS in the world – Introduction

Spallation

GEANT4

MYRRHA

Current Work



•MYRRHA, a flexible fast spectrum research reactor (50-100 MWth) is conceived as an accelerator driven system (ADS), able to operate in sub-critical and critical modes located in Belgium.

• The facility consists of a proton accelerator of 600 MeV, a spallation target and a multiplying core with MOX fuel, cooled by liquid lead-bismuth (Pb-Bi).

(H. Aït Abderrahim, "MYRRHA An innovative and unique irradiation research facility," in Tenth International Topical Meeting on Nuclear Applications of Accelerators (AccApp'11), 2011., P. Baeten, et.al "MYRRHA : A multi-purpose nuclear research facility. 2014.)

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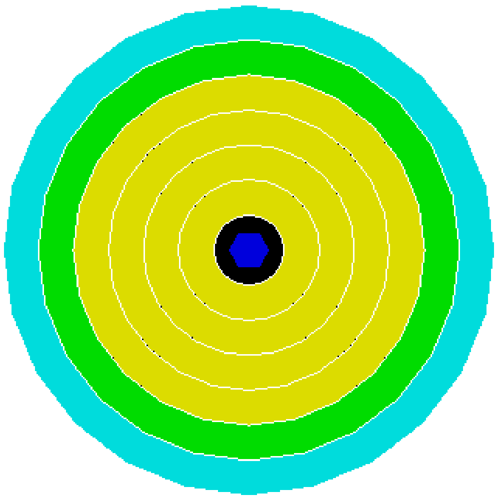
Research 1 : neutrons in different regions



MYRRHA geometry construction in GEANT4

Area	Material	Size (mm^2) (Annular radius X Length)
Spallation target (Blue)	PbBi	97.55 × 300
Fuel (Yellow)	Thorium	97.55 × 1400
Reflector: Inner dump (green)	PbBi	97.55 × 1400
Inner shielding: Outer dump (Cyan)	ZrO_2 Y_2O_3 Zr_2O_3	97.55 × 1400

Core specification used in the simulation

- A preliminary simulation of neutron distributions carried out in a thorium fuelled ADSR
- A simple geometry was constructed to monitor neutron production in each region
- The size of each region was placed as same as the size of the a fuel assembly in MYRRHA.

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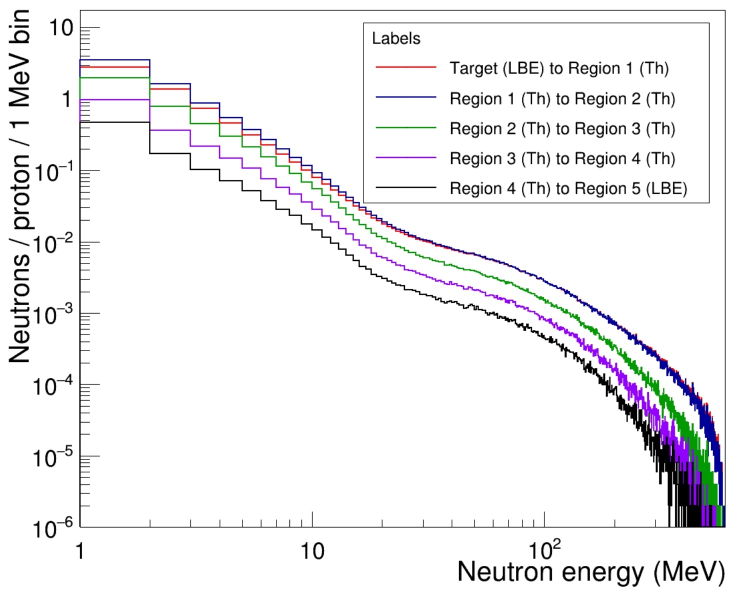
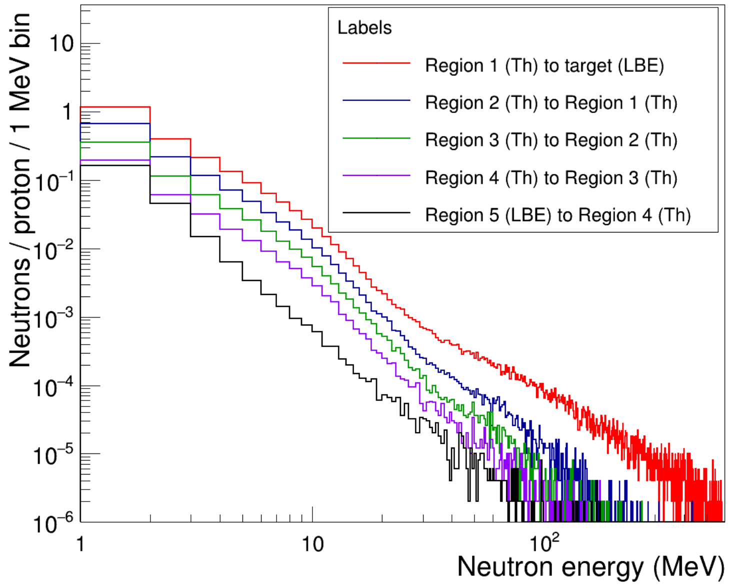
Research 1 : neutrons in different regions



Number of outer going neutrons in the core



Number of neutrons back-scattered into the core

•In the figure showing outer going neutrons, neutron spectrum for the region 1 to 2 shows the highest number of neutrons per incident proton.

•In the figure showing neurons back-scattered, the highest number of neutrons back-scattered was recorded from the region 1 to the spallation target.

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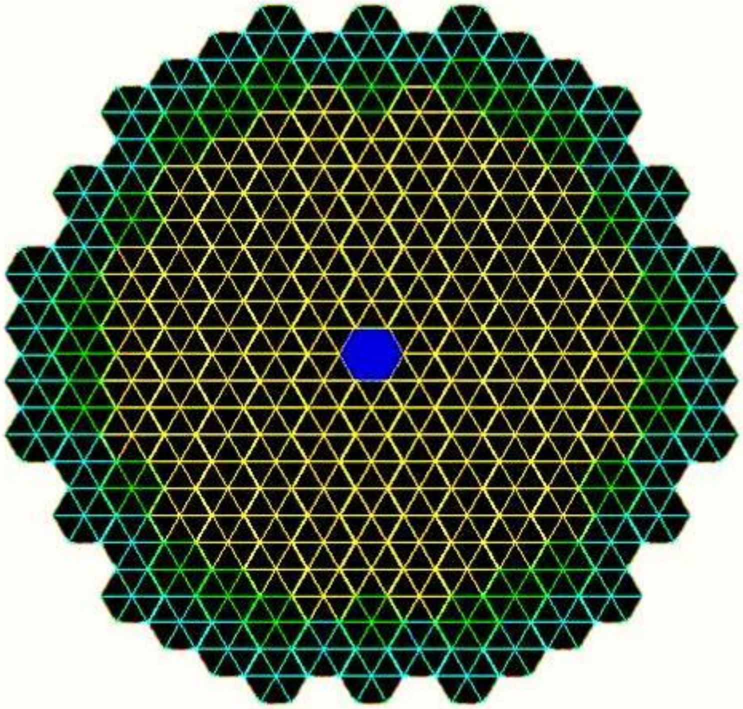
Research 2 : neutrons escaping from the core



MYRRHA core simulation arrangement

Area	Number of assembly placed
Spallation Target (blue)	1
Fuel (yellow)	76
Reflector: Inner dump (green)	36
Inner shielding Outer dump (Cyan)	42

- The current research focuses on neutron production with thorium fuel.
- For the purpose of this study, the reactor fuel was replaced with fertile thorium.
- In this study, the simulation did not include the extra shielding assembly area for understanding the effector of the reflector.

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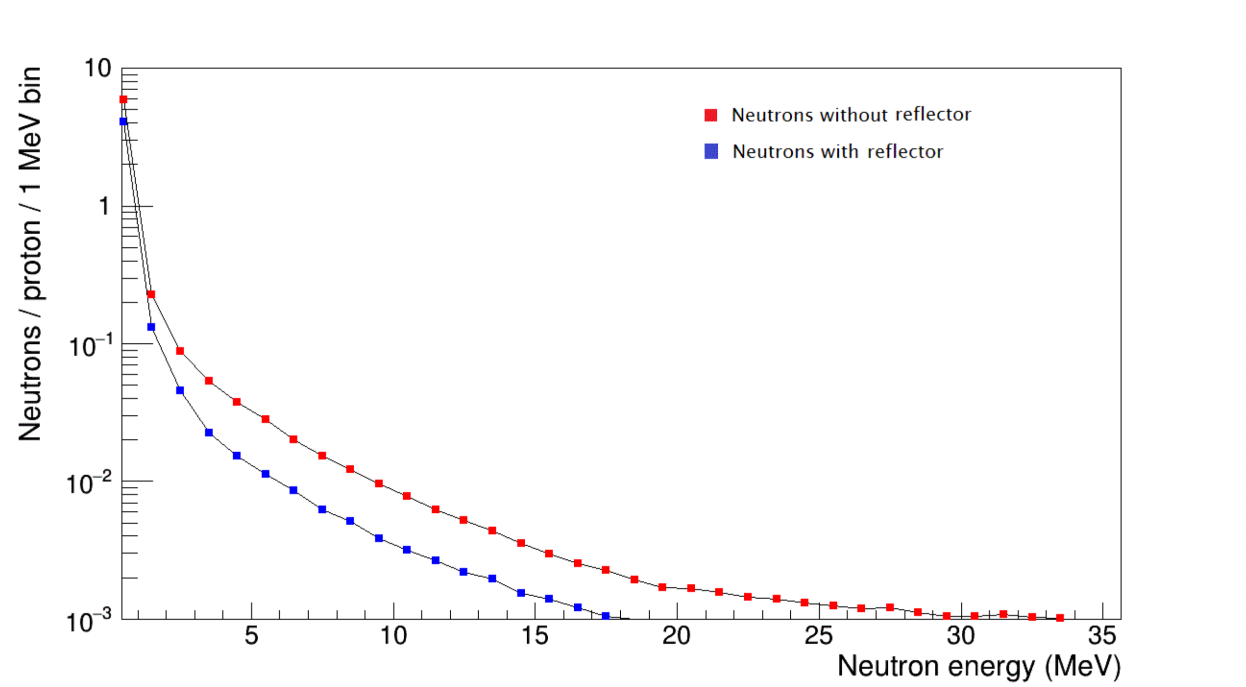
Research 2 : neutrons escaping from the core



The ratio of escaping neutron per incident proton

- The result shows that reflector decreases the ratio of neutrons escaped in high energy range.
- There is no significant difference at the neutron energy range of 0-2 MeV
- The ratio of escaping neutrons from the core is still high with the reflector so the additional shielding material is necessary for increasing neutron flux inside the core structure.

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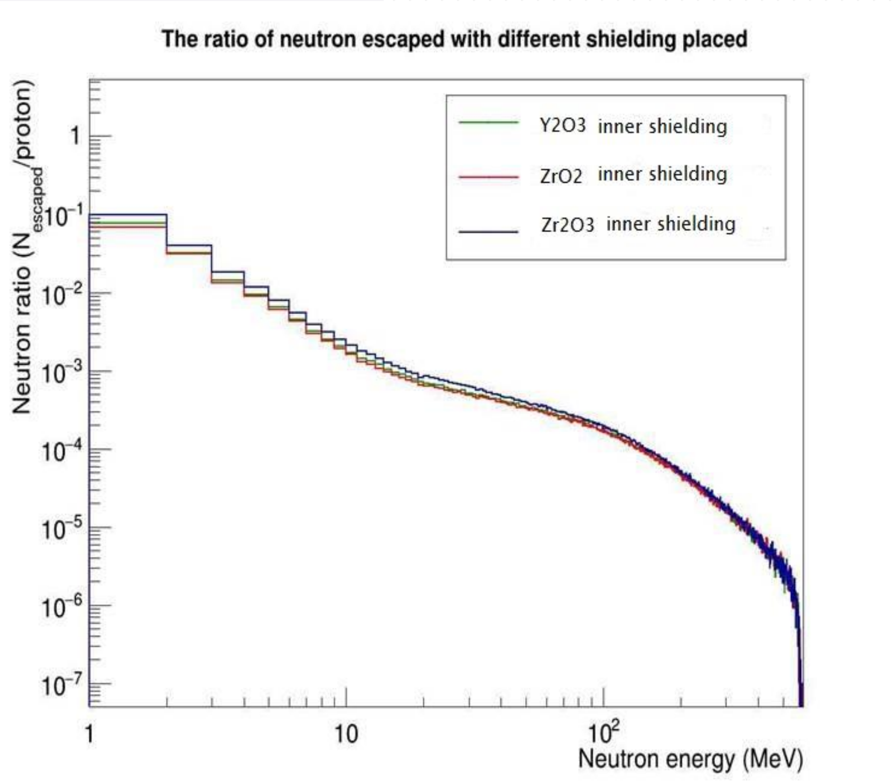
Research 3 : neutrons escaping from shielding



The ratio of escaping neutron with different shielding per incident proton as function of energy

- The results indicated that all three material show similar rate of preventing neutrons escaped.
- Amongst these types of shielding, Zirconium dioxide showed the lowest rate of neutrons escaped.
- The results suggested that further studies needed with the outer shielding in place.
- Shielding materials used
  1. Yttrium Oxide (Y_2O_3)
  2. Zirconium Sesquioxide (Zr_2O_3)
  3. Zirconium dioxide(ZrO_2)

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Conclusion

- GEANT4 simulation for the benchmarking with an experiment showed at least as accurate as MCNPX.
- The QGSP_INCLXX_HP physics list appears to reproduce the experimental results more closely.
- For MYRRHA study, the reflector (LBE) showed a significant effect to reduce the neutrons escaping from the core. However, extra shielding area is still needed for increasing neutron flux inside the core.
- The three materials tested in the inner shielding(i.e outer dump) area showed a similar rate of reducing neutrons escaping from the core.
- It is suggested that the results combined with the outer shielding area may show some significant changes of the results.

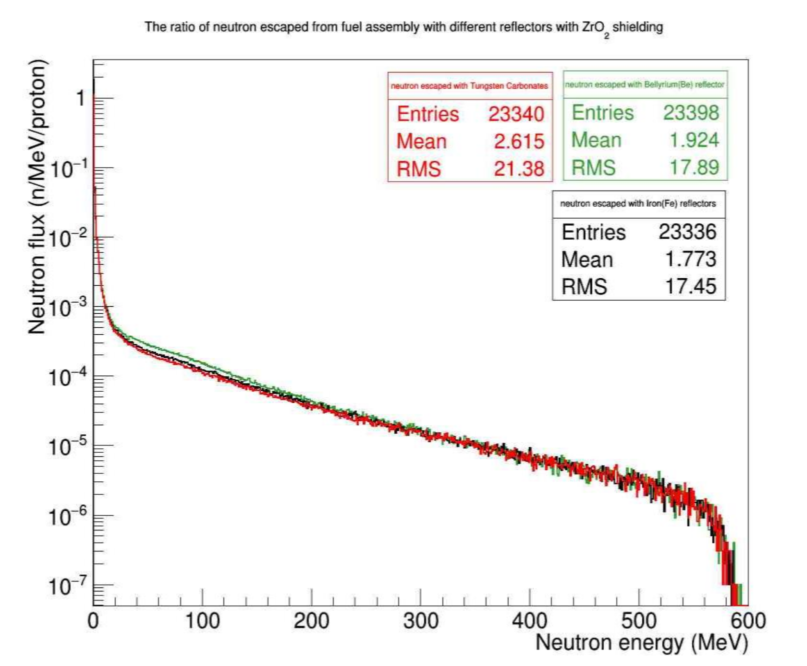
Acknowledgement

I would like to express my gratitude to

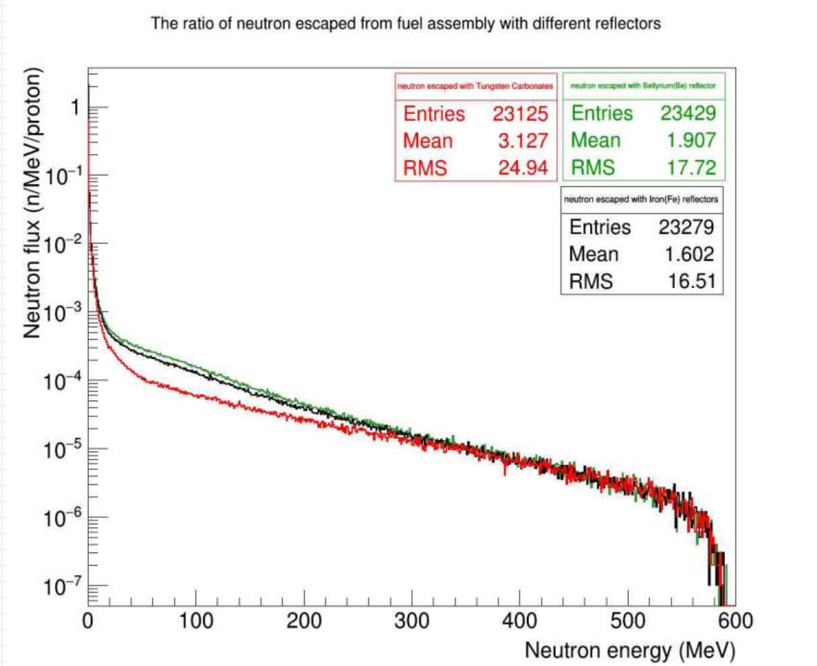
Prof Robert Cywinski for the guidance of this project, Prof Rebecca Seviour for the support of PhD program and Dr Cristian&Adriana Bungau for the technical support of Geant4 program.

Thank you.

Research 4 : neutrons escaping from outer shield



The ratio of escaping neutron with ZrO_2 shielding per incident proton as function of energy



The ratio of escaping neutron with Y_2O_3 shielding per incident proton as function of energy