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Geant4 and Serpent codes simulation of the response of the detector based on ZnS(Ag)+^{6}LiF for registration of neutrons generated by EAS and by various nuclear objects

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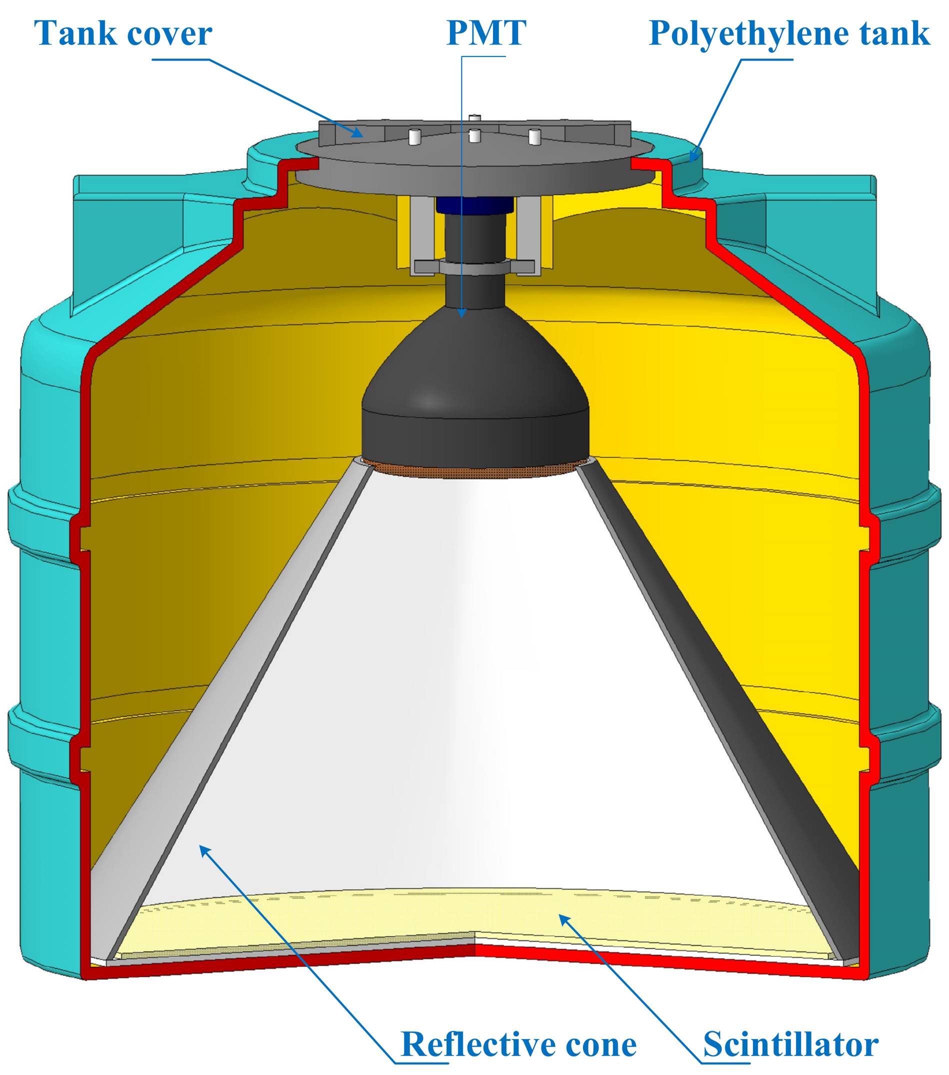
Introduction

Nowadays, our society has a tendency to be highly relied to nuclear practices, which can be found in different areas like energy, medicine, industry, science etc. For all these activities the safety is a major issue as far as safety concerns people and environment. Since neutrons are the most often released particles in case of a nuclear accident, we need to have a sensitive instrument to ensuring the monitoring of these installations in neutron component. The heart of any neutron monitoring system is the neutron detector. Registration of neutrons is a non-trivial task, since neutrons do not ionize matter. Hence, low energy neutrons are typically detected indirectly through absorption reactions, in which a certain isotope reacts with the neutron by emitting a high energy ionized particle. The commonly used isotopes and reactions include ^{3}He(n, p), ^{10}B(n, α), ^{6}Li(n, α), etc.

For monitoring of neutron flux around nuclear installations, in the Experimental Complex (EC) NEVOD (MEPhI, Moscow) the idea to use a new type of neutron detector developed for different setups of the EC NEVOD with the aim of studying of the neutron component in extensive air showers (EAS) and neutron background near the ground surface, was proposed .

Description of the detector

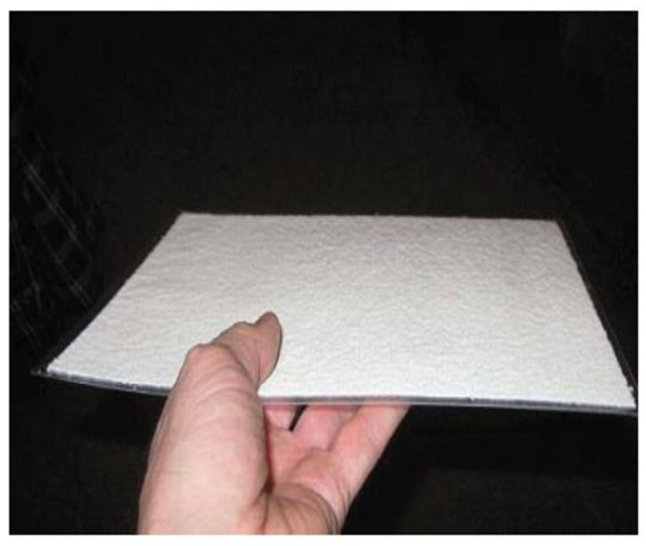
Detector construction is a typical for scintillation detectors. The difference is in the scintillator: instead of standard thick plastic, a special thin scintillator is used. The layer of inorganic scintillator laminated into a thin plastic film is situated on the bottom of commercial polyethylene tank of 570 mm height and 740 mm diameter. The scintillator is viewed by a PMT-200 of 15 cm photo-cathode diameter. Reflecting cone is used to improve light collection [1].

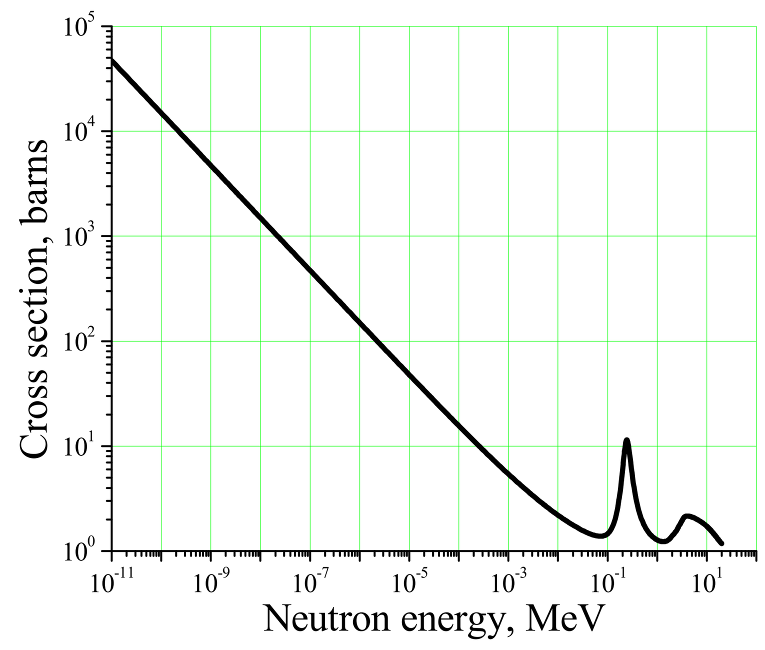


Construction of the neutron detector based on ZnS(Ag)+^{6}LiF scintillator

Detector characteristics

The detector is used for registration of hadronic (thermal neutron) and electromagnetic (e) components of EAS. Its long time of work was sufficient to approve its efficiency and reliability. These advantages are due to the special inorganic scintillator used in the form of a granulated alloy of ZnS(Ag) and LiF_2 enriched to 90% with ^{6}Li isotope. The average scintillator thickness is only 30 mg/cm^2 that makes it almost insensitive to single charged particle passage. At the same time, the scintillator is sensitive to a coherent passage of charged particles. The large cross section for neutron capture in ^{6}Li(n,α)^{3}H+4.78 MeV reaction and a high, nearly point like, energy deposit make this scintillator very effective for recording heavy particles (and thermal neutrons as well) even in thin layers. The scintillator produces about 160 000 photons per neutron capture.





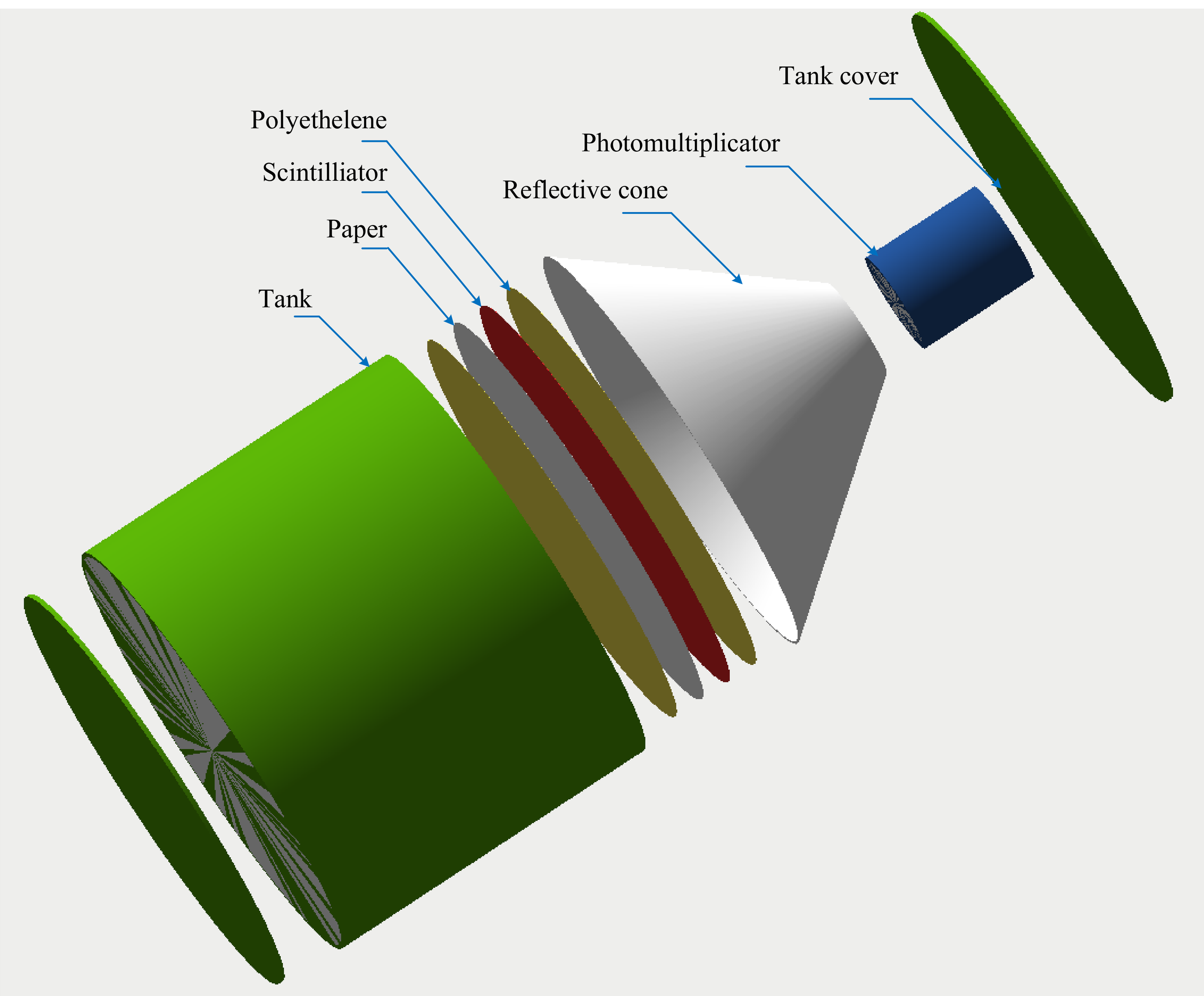
Left – a sheet of ZnS(Ag)+^{6}LiF scintillator, right – the ^{6}Li(n,t)^{4}He total cross section

The purpose of this work

The work is aimed to create a model of the neutron detector in the Geant4 toolkit [2] to assess the possibility of its use in monitoring of nuclear setups. During the development of the detector model it is very important to assure correct simulation of the physical processes of neutron component. For this task, the code Serpent [3] intended for neutron-physical calculation of the reactor core, was chosen. A series of comparisons of neutron propagation in different mediums (air, water and concrete) were done between these two codes.

Detector model

In frame of the Geant4 toolkit, the neutron detector model was developed, in which real dimensions and composition of the detector were taken into account. All the necessary physical processes for primary and secondary particles are included.

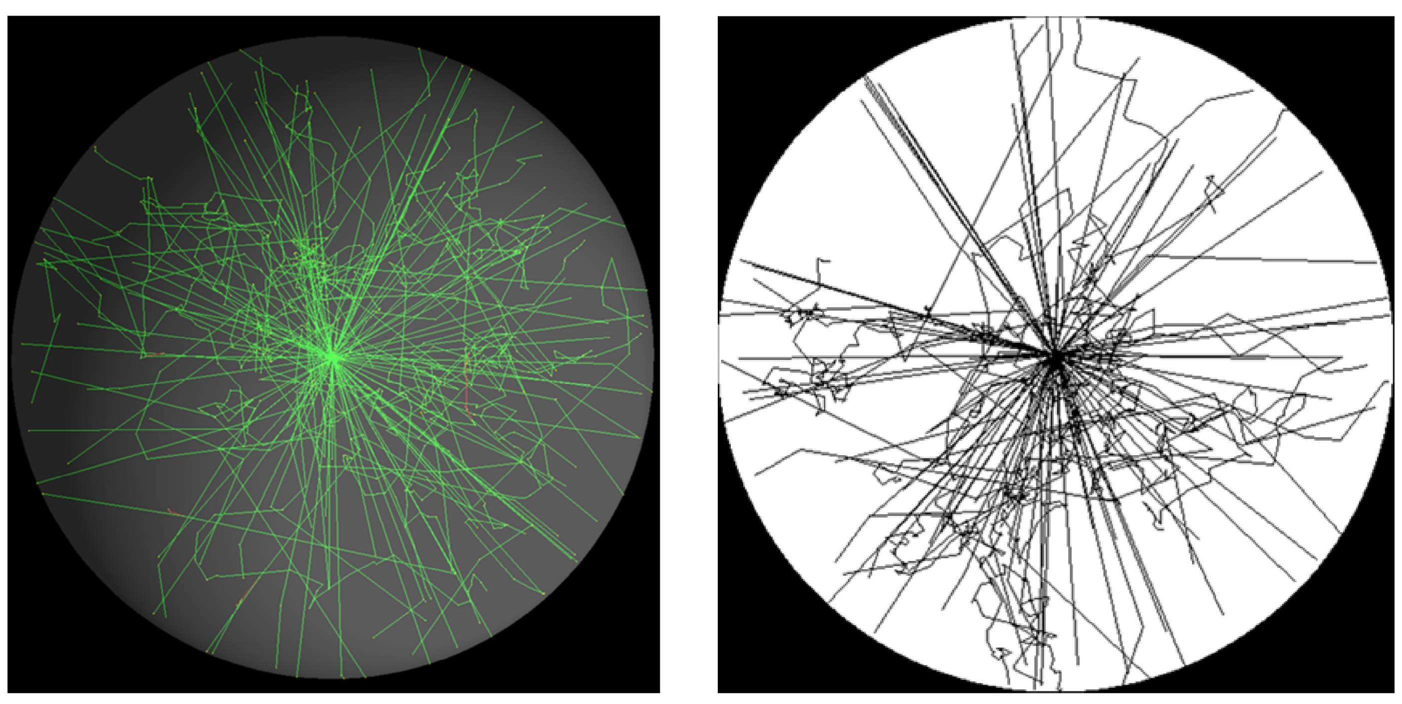


Visualization of neutron detector geometry in Geant4

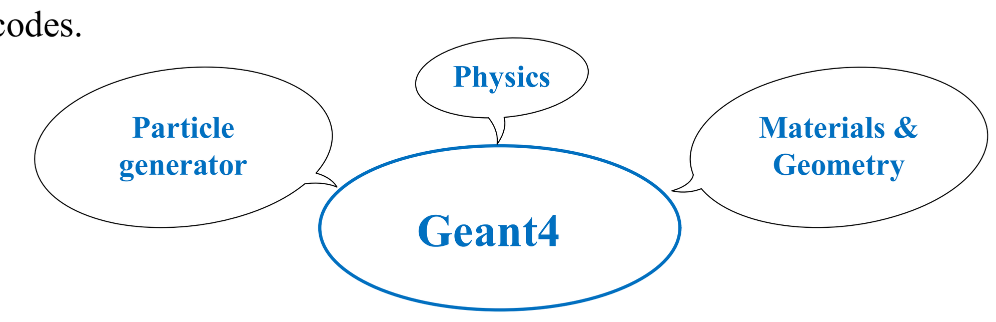
Materials and definitions used in the simulations

Materials	Density (g/cm^3)	Used data
I- Geant4		
Water (H_2O)	0.99823	2 atoms of H (TSL), 1 atom of O (free-gas*)
Concrete	2.3	H, C,O, Na, Mg, Al, Si, K, Ca, Fe (free-gas)
Air	-	G4-Air (free-gas)
II- Serpent		
Water (H_2O)	0.99823	2 atoms H (lwtr lwe7.00t), 1 atom of O (ENDF/B-VII)
Concrete	2.3	H, C,O, Na, Mg, Al, Si, K, Ca, Fe (ENDF/B-VII)
Air	1.205E-3	C, N, O, Ar (ENDF/B-VII)

** A neutron interaction model based on the elastic scattering cross section.*



Visualization of the propagation in water of 100 neutrons (2 MeV) in Geant4 (right) and in Serpent (left)



Geant4 work sheme

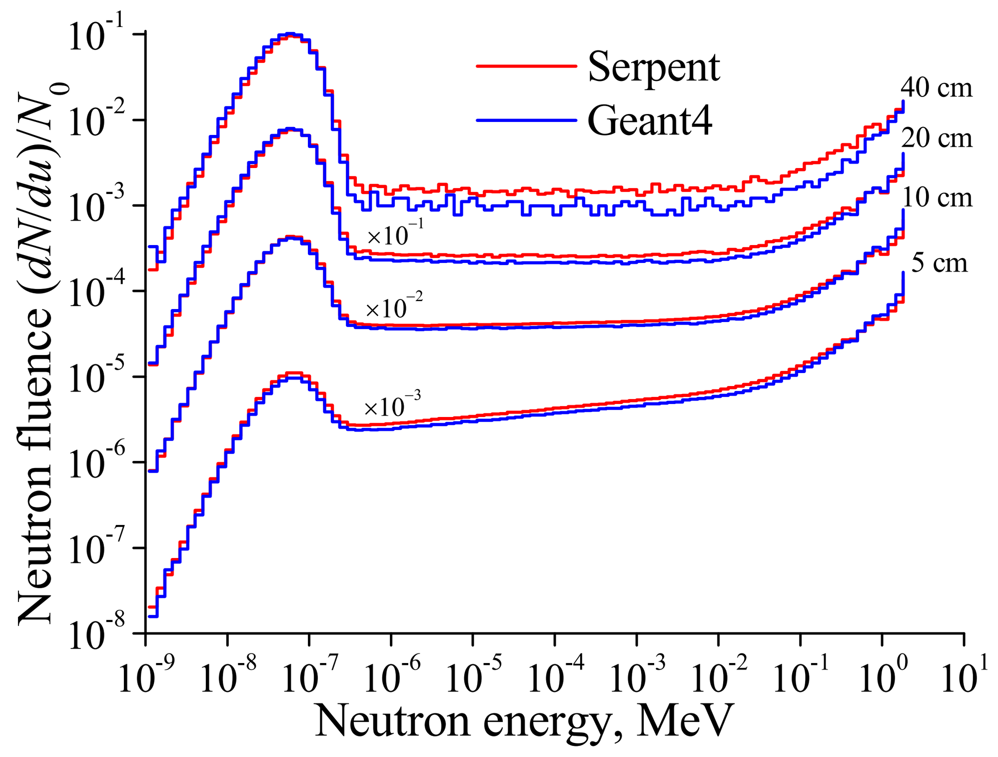
The simulation

The simulation of the propagation of neutrons in different environments was done by using a spherical geometry with different radii 5 cm, 10 cm, 20 cm and 40 cm for water and concrete, and 300 m, 500 m and 1000 m for air. An isotropic, monoenergetic (with an energy of neutrons 2 MeV) and point-like neutron source was placed in the center of the sphere.

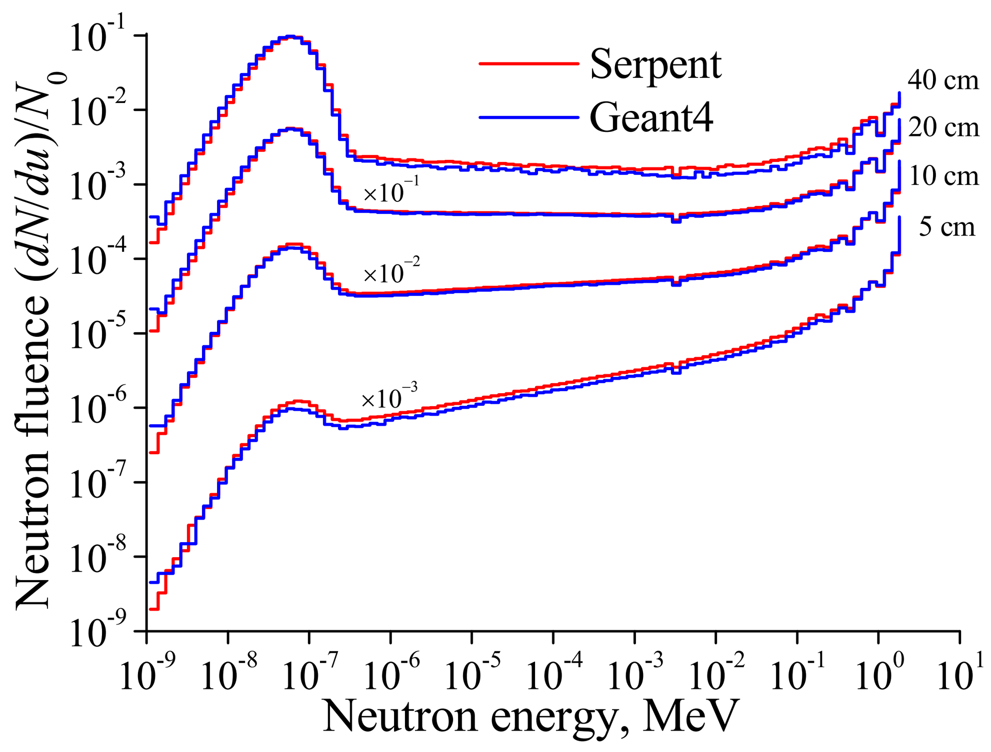
Simulation results

Comparison of the neutron fluences in water, concrete and air calculated in Geant4 and Serpent is shown in figures below. The neutron fluence $(dN/du)/N_0$ was normalized, where $u = \ln(E_{max}/E)$, E_{max} = 10 MeV, N_0 is the total event number.

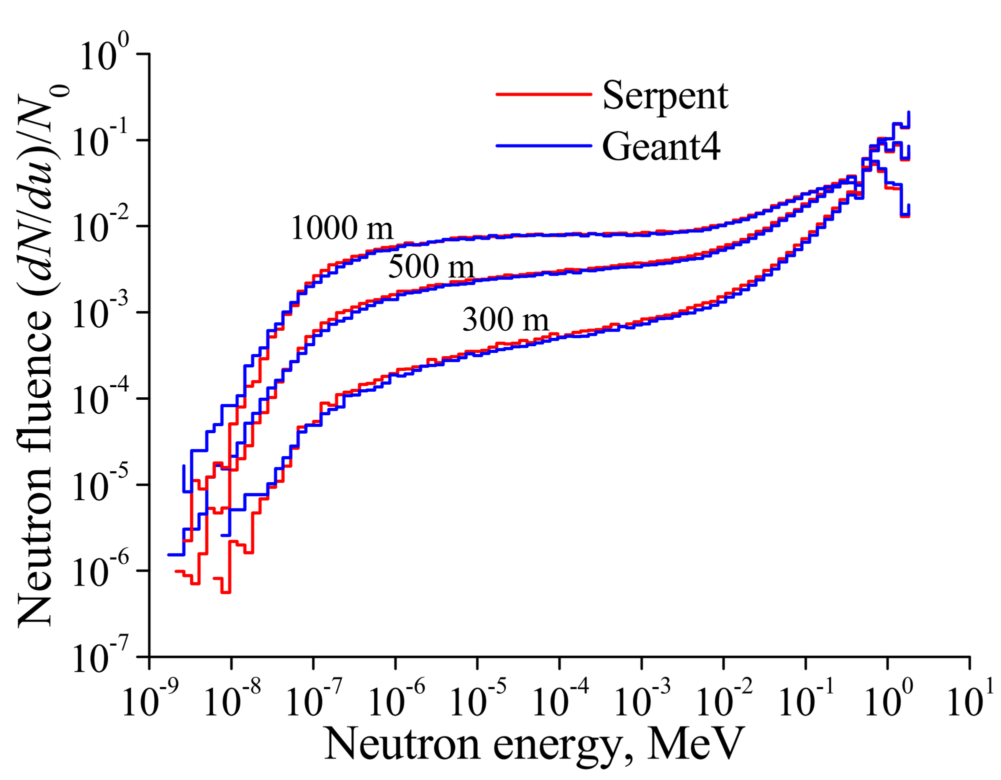
Water



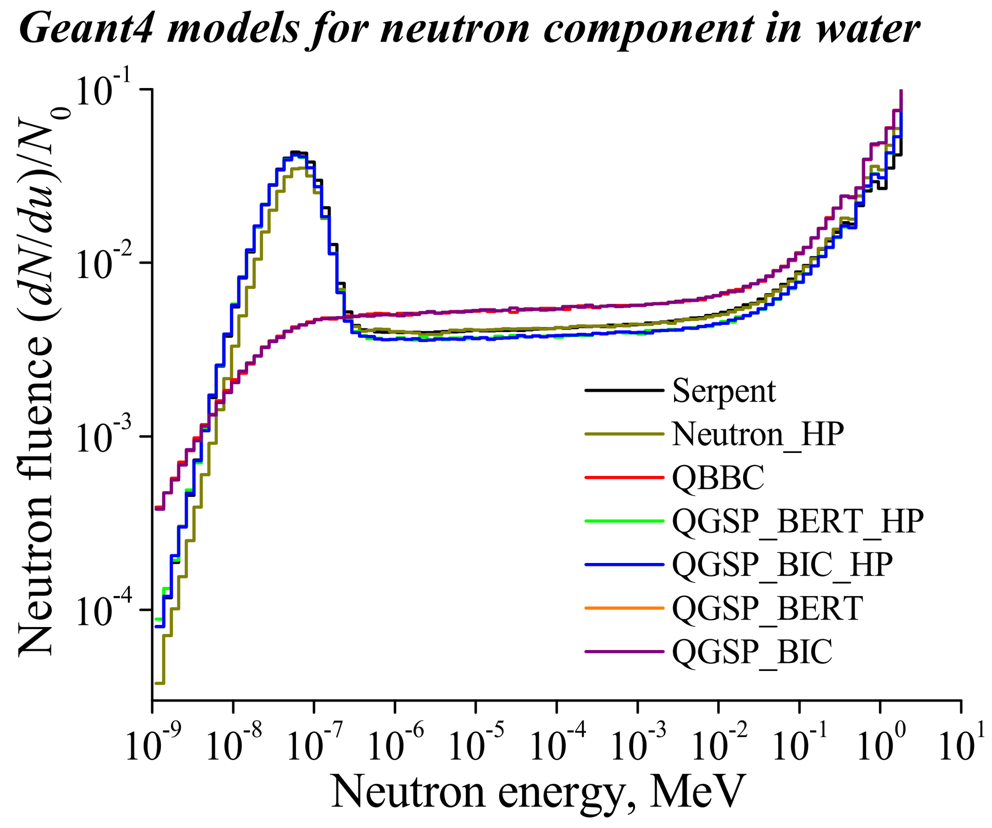
Concrete



Air



Geant4 models for neutron component in water



Conclusion

- A model of the neutron detector was created in frame of the Geant4 toolkit.
- A comparison of the neutron propagation was made in Geant4 and Serpent in water, concrete and air, which showed:
  - ✓ In water, an agreement was found within 15% for radii 5, 10 and 20 cm, the difference reaches 30% for 40 cm.
  - ✓ In concrete, an agreement was found within 7% for radii 10, 20 cm, and 15% for radii 5, 40 cm.
  - ✓ In air, an agreement within 10% was found.
  - ✓ An agreement within 10% has been found around the energy 0.0253 eV for all cases.
  - ✓ Discrepancy in the region of cold neutron is due to insufficient statistics.
- The physical model QGSP_BIC_HP has been chosen for simulating the neutron component as giving the best agreement with the Serpent.

References

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3. J. Leppänen, et al. The Serpent Monte Carlo code: Status, development and applications in 2013. Ann. Nucl. Energy. V. 82. P. 142–150 (2015).