Computer simulation process of neutron transport in liquid scintillator filled multi-module PFN detector

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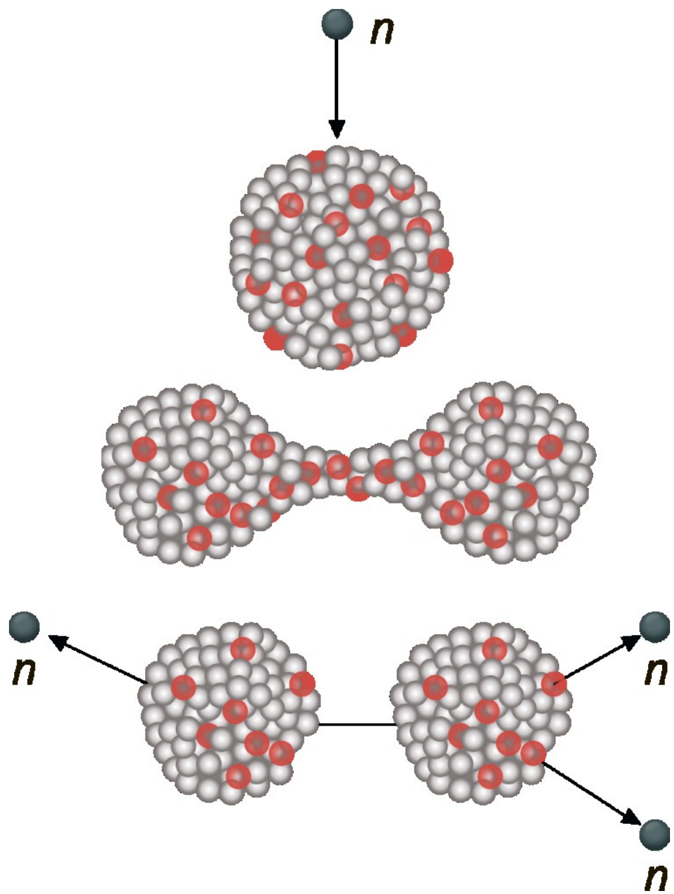
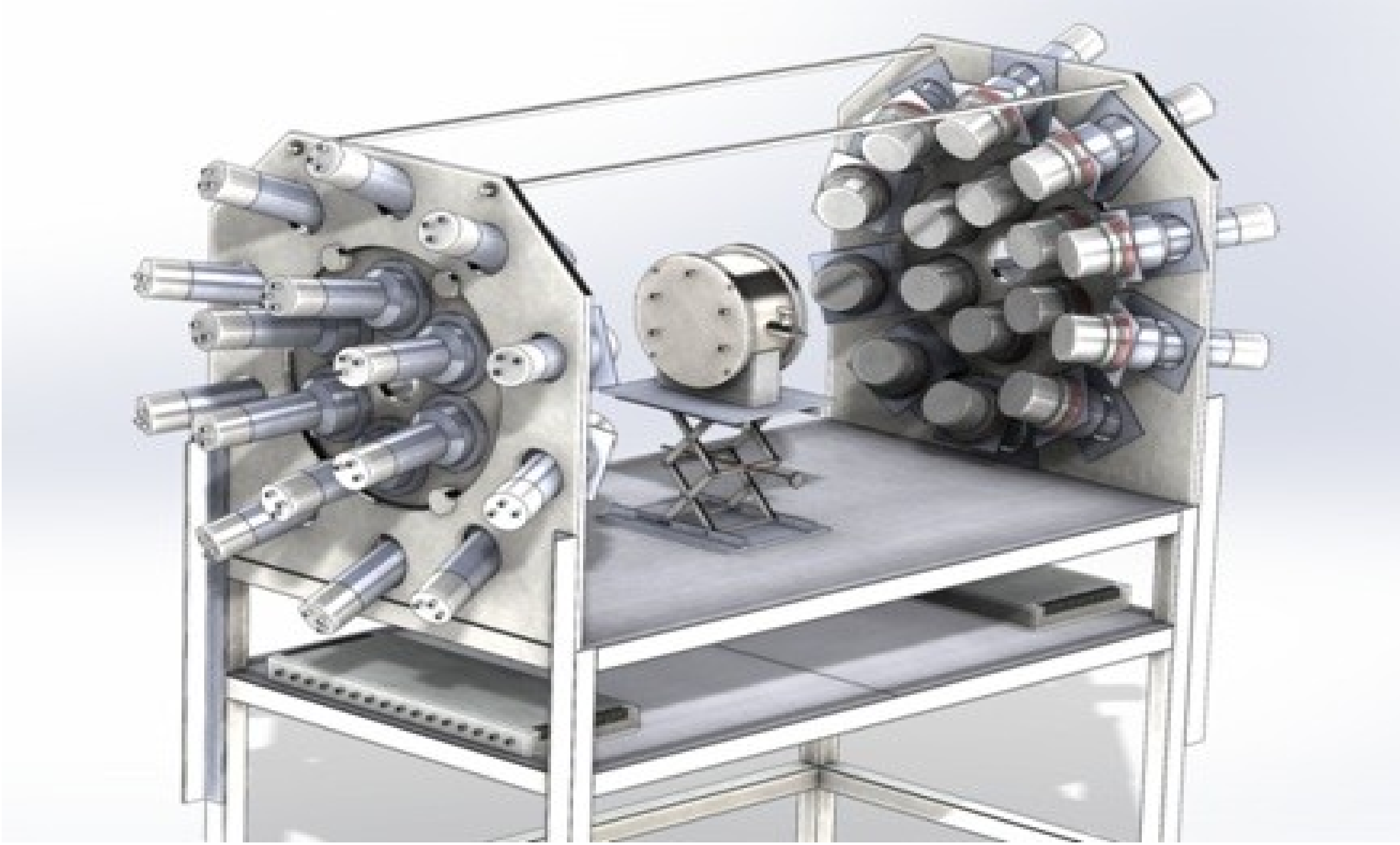
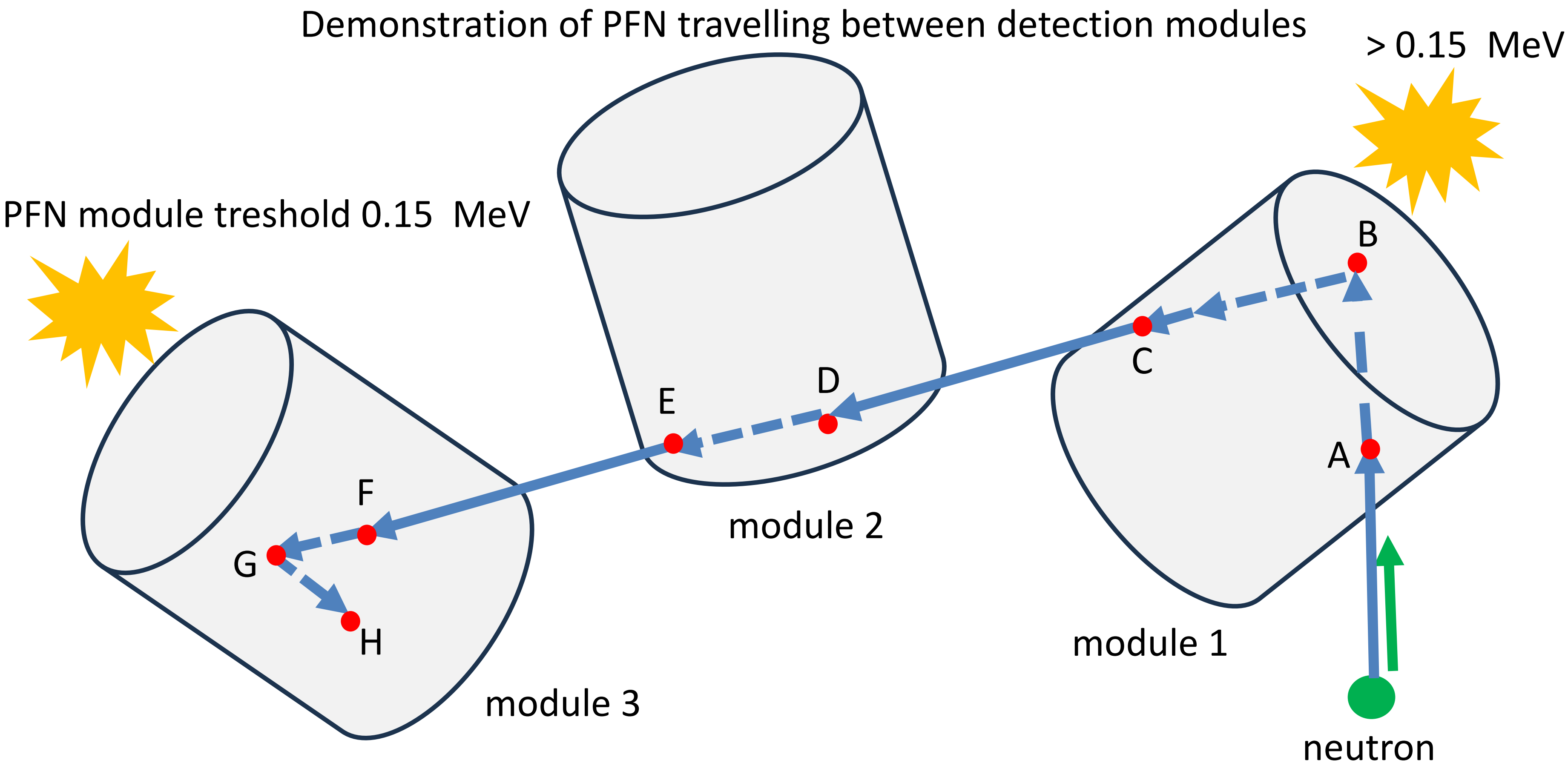
Investigation of PFN properties is important for understanding of fission process due to PFN carry information on excitation energy of fissioning nucleus.



T ~ 10^{-14} sec



We have developed setup for investigation of fission process including fission fragments kinetic energies and PFN emission.
The setup consists of double Frish-gridded ionization chamber and 32 PFN detection modules manufactured by SIONICS (Nederland).
32 PFN detection modules were used to increase the efficiency of PFN detection. The source of resonance neutrons is the IREN facility.



B – elastic scattering with **O** atom**,** G – elastic scattering with **H** atom
H – capture by **H** atom, Light sparks generated in modules 1 and 3

The multi-modular structure of the PFN detector has the advantage of higher PFN detection efficiency, but multiple neutron scattering in such a neutron detector can simulate false multiplicity. In this regard, there is a need to determine the proportion of multiple scattering events using computer simulation of the neutron transport process in the detector.

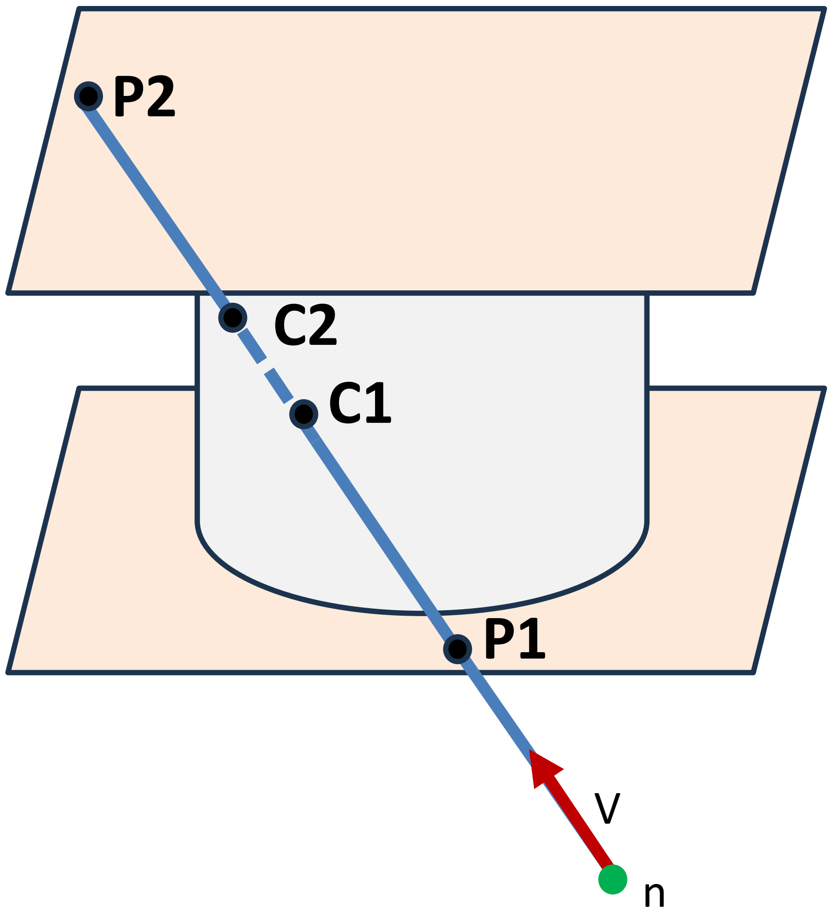
To do this, we created a computer code that generated 20 scenarios with 500,000 PFN emission events in each. A random neutron emission point uniformly distributed over the target area is played out. The isotropic direction of neutron emission is played out. The initial neutron energy is played out of Maxwellian distribution:

$$F(E_0) = \frac{2\pi}{\sqrt{(\pi kT)^3}} \cdot \sqrt{E_0} \cdot e^{\frac{E_0}{kT}}, \qquad kT = 1.0MeV, k$$

The trajectory and loss of neutron kinetic energy were traced from the point of PFN emission to the point where the neutron was captured by the scintillator substance or the value of its kinetic energy decreased to a level below the threshold level of

$$10^{-5}MeV$$

or left the system.



P1, P2 – points of intersection of the neutron motion line with the base planes of the detector module.
C1, C2 or C1 or absence – are intersection of the neutron motion line with the side surface of the detector module. The relative positions of these points for each module allows us to determine the module into which the neutron will fall at a given stage of motion and determine the trajectory of the neutron inside this module before colliding with the scintillator material.

Free path length of neutron in scintillator material has exponential distribution as:

$$p(X = x) = \lambda \cdot e^{-\lambda x},$$
$$\lambda = N \cdot \sigma_{CH_2O}^{total}(E),$$
$$\sigma_{CH_2O}^{total}(E) = \sigma_C^{total}(E) + 2 \cdot \sigma_H^{total}(E) + \sigma_O^{total}(E),$$

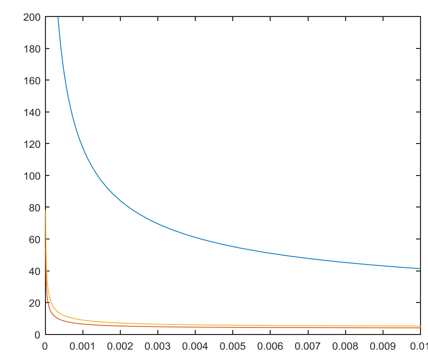
N– is the number of molecules in 1 sm^3 of scintillator volume. Scintillation liquid molecule formula is CH_2O with the density of

$$\rho = 0{,}815\ {}^{g}/_{cm^3}$$

Neglecting binding energy, one could find atomic weigh of CH_2O was 30,02109, then the number of molecules could be calculated using the following formula:

$$N = \frac{6{,}0221408 \cdot 10^{23} \cdot 10^{3} \cdot 815}{30{,}022109} = 163{,}4866 \cdot 10^{20}$$ molecules.

Values of cross sections dependence for atoms H, O, C are taken from the literature.



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Liquid BC-501 had the chemical formula CH_2O.

$\sigma_C^{elastic}(E), \sigma_H^{elastic}(E), \sigma_O^{elastic}(E)$ and $\sigma_{CH_2O}^{elastic}(E)$

- the elastic scattering reaction cross-section of PFN with kinetic energy value with the atoms: C, H, O, composing the molecule CH_2O respectively.

$\sigma_C^{capture}(E)\sigma_H^{capture}(E), \sigma_O^{capture}(E)$ and $\sigma_{CH_2O}^{capture}(E)$

– the capture reaction cross-section of PFN with kinetic energy value with atoms C, H, O and molecule CH_2O respectively.

$\sigma_C^{total}(E), \sigma_H^{total}(E), \sigma_O^{total}(E)$ and $\sigma_{CH_2O}^{total}(E)$

– the total cross-section of PFN interaction with kinetic energy value with the atoms C, H, O, or molecule CH_2O respectively

Probability of the reactions between PFN and the atom of the scintillator

$$\rho_C^{total}(E),\ \ \rho_H^{total}(E)\ and\ \rho_O^{total}(E)$$

are proportional to corresponding cross-sections and taking into account the multiplicities of atoms in the molecule we have got the following relation:

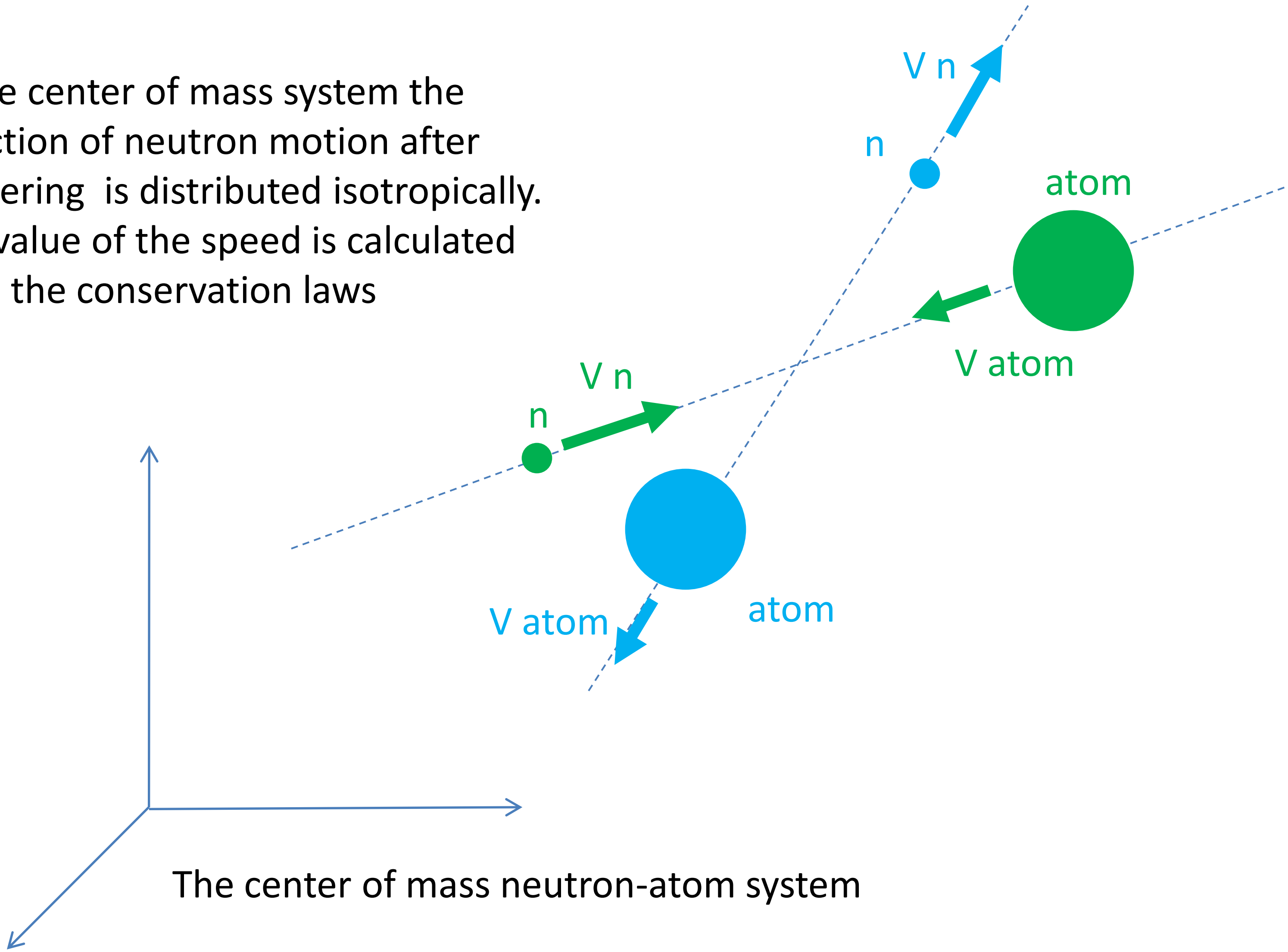
$$\rho_C^{total}(E)/\rho_H^{total}(E)/\rho_O^{total}(E) = \sigma_C^{total}(E)/2 \cdot \sigma_H^{total}(E)/\sigma_O^{total}(E)$$

Probability of interaction type between the neutron and selected atom of the scintillator molecule was proportional to respective cross-sections:

$$\rho_{atom}^{capture}(E)/\rho_{atom}^{elasic}(E) = \sigma_{atom}^{capture}(E)/\sigma_{atom}^{elastic}(E), atom = C, H, O.$$

The picture illustrates an elastic scattering of a neutron and a scintillator atom:

In the center of mass system the direction of neutron motion after scattering is distributed isotropically. The value of the speed is calculated from the conservation laws



The center of mass neutron-atom system

Results of simulation

The goal of this work was to estimate the share of multiple scatterings (2,3,4,5) Results obtained in simulation process presented in Table with the following identifiers:

R - serial number of the scenario

N_R^i - the number of neutrons detected in scenario R in I modules;

$N_R^{\geq 5}$ - the number of neutrons detected in scenario R in 5 or more modules;

N_R^{real} - the real number of neutrons, registered by system in scenario R:

$$N_R^{real} = \sum_{i=1}^{\infty} N_R^i ;$$

$N_R^{visible}$ - the number of sparks, registered by ND in scenario R:

$$N_R^{visible} = \sum_{i=1}^{\infty} N_R^i \cdot i$$

This table summarize the results of simulations.

$$N_R^{real} \approx 0,95 \cdot N_R^{visible}$$

R	N_R^1	N_R^2	N_R^3	N_R^4	$N_R^{\geq 5}$	N_R^{real}	$N_R^{visible}$	ε_R
1	19169	1055	25	0	0	20249	21354	0.052
2	19281	1108	25	0	0	20414	21572	0.054
3	19290	1071	34	0	0	20395	21534	0.053
4	19032	1058	29	1	0	20120	21239	0.053
5	19102	1120	33	0	0	20255	21441	0.055

Conclusion

In this investigation of PFN registration process inside the detector, consisting of 32 BC501 liquid scintillator filled modules was done. Computer simulation of neutron transport inside the detector volume was done along with estimation of systematic errors caused by multiple scattering of neutrons. Statistical accuracy of simulation was estimated to be less than 5%:

$$N_R^{real} \approx 0{,}95 \cdot N_R^{visible}.$$