MSX - A MONTE-CARLO CODE FOR NEUTRON EFFICIENCY CALCULATIONS FOR LARGE VOLUME Gd-LOADED LIQUID SCINTILLATION DETECTORS *

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Some properties of the code newly developed to simulate the neutron detection process in a NMM are briefly described.

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1. Introduction

Recent ALADIN Collaboration experiments [1] presented an extensive evidence that the hot projectile prefragments created in the peripheral to semicentral relativistic heavy-ion collisions are thermally equilibrated. Temperature *(T)* and excitation energy *(E_x)* are the essential variables specifying their thermodynamic properties. The dependence of T on E_x (caloric curve) revealed a plateau [2] interpreted as indication of the liquid-gas phase transition in finite nuclear systems. Therefore, a progress in measurement of E_x and T is a necessary prerequisite for the further comprehensive study of the phenomenon.

The predictions of Friedman [3] indicate that an excitation energy of a prefragment, whose mass and charge are generally unknown, can be determined by means of the multiplicities of the emitted neutrons and light charged particles *($Z \leq 2$)*. We intend to apply this method to the *target spectators* by employing a large-volume Gd-loaded liquid scintillation detector (a neutron multiplicity meter - NMM) to count neutrons originating from their decay. A study of feasibility and limitations of the Friedman's method

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in the ALADIN environment asked for a program giving a more comprehensive description of the neutron detection process in a NMM than offered by DENIS [4], presently used in several laboratories [5]. These considerations prompted us to develop MSX, a Monte-Carlo code containing several improvements in comparison with its predecessor.

2. Neutron detection process in a NMM

The detection process in a NMM [5] consists of the following stages:
i) Neutron slowing down due to the multiple scattering on the hydrogen and carbon nuclei of the scintillator. Ultimately, the neutron comes into thermal equilibrium with the medium and diffuses within the scintillator volume.

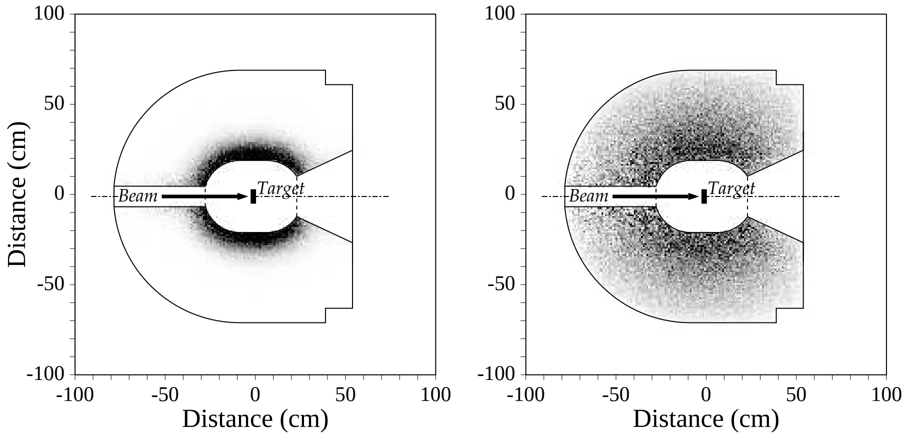

Fig. 1. Distribution of capture events within the volume of the tank for 1 MeV (left) and 30 MeV (right) neutrons.

ii) Radiative capture following one of the three possibilities: in ^{1}H with the emission of a single 2.224 MeV γ-ray, in ^{155}Gd or ^{157}Gd accompanied by the emission of a cascade of γ-rays with the summed energies of 8.536 and 7.937 MeV, respectively.
iii) Gamma-ray thermalization due to the consecutive Compton scattering from the electrons of H and C atoms of the scintillator.
iv) Electron stopping in the medium. Part of the electron's energy loss, determined by the scintillation efficiency, is converted into visible light.
v) Transport of light to the photocathodes of photomultipliers (PMs) through multiple reflections on the diffusely reflecting coating of the interior of the tank.

The above stage *(i)* involves two vastly different time scales. The dissipation of neutron's total initial kinetic energy occurs within a nanosecond time scale, giving the initial prompt part of the scintillation signal. The signal coming from the γ-rays follows with a random delay of up to 50 μs, the time scale determined by the probability of capture, terminating the diffusion process. Therefore essential for the operation of a NMM is the stretching of the capture probability over tens of microseconds which allows to count one-by-one over hundred neutrons emitted in the interaction.

3. Novelties in MSX

• *Throughout the program*
A. Algorithm optimized to maximize the calculational speed.
B. Memory utilization optimized with the aid of pointers allows to track simultaneously (practically) an arbitrary number of particles.
• *Stage (i)*
A. Use of the cross section files supplied by the international Nuclear Data Centers. They contain periodically updated data for many reactions on H, C, and Gd (23 total and 5 differential cross sections used by us).
B. Exact treatment of $d\sigma/d\Omega$ for: ^{1}H(n,n)^{1}H, ^{12}C(n,n)^{12}C, ^{12}C(n,n')^{12}C (first, second and third excited state). This permits to follow the main tendencies of the angular distributions - rapid changes across the groups of prominent resonances in the n + ^{12}C interaction at low energies and increasing forward peaking as the energy exceeds the resonance region.
C. Multiple neutron emission in the ^{12}C(n,2n)^{11}C reaction taken into account. It permits to determine the number of misclassified events (two neutrons detected instead of the incident one).
• *Stage (ii)*
A. Radiative capture in the resonance region for the ^{155}Gd(n,γ)^{156}Gd and ^{157}Gd(n,γ)^{158}Gd reactions included.
B. γ-ray cascades following neutron capture taken into account by combining the available experimental data with the calculated continuous part of the spectrum. Calculations were done on base of the Hauser-Feshbach statistical model for the decay of the $J^{\pi} = 2^{-}$ capturing state. Besides mean multiplicities, defining mean capture γ-ray energies, also fluctuations around the mean taken into account.
• *Stage (v)*
A. Simulation of light transport to the PM photocathodes incorporated into the program. It permits to determine the effect of electronic thresholds on the detection efficiency. Moreover, the distribution of photon arrival times determines the PM current pulse shape, thereby defining the double-pulse resolution.
B. Calorimetric mode (in the stage of implementation). It will permit to simulate the dependence of the prompt peak on the energy deposited in the

scintillator by the incident neutrons.

4. Representative results for the selected geometry

The geometry of a NMM destinated to count neutrons from the target residue in coincidence with the charged products of the projectile-target interaction is shown in Fig. 1. The escape cone with 50° opening angle enables undisturbed detection of the intermediate mass fragments from the projectile-like source by means of the ALADIN heavy fragment detectors.

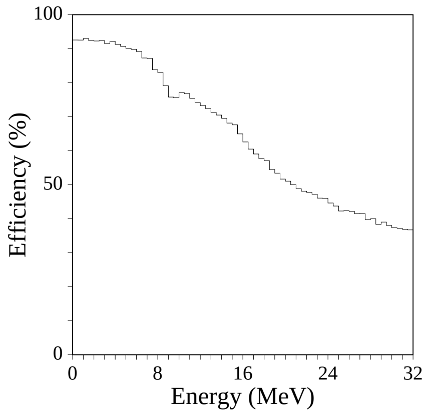

Fig. 2. Energy dependence of the neutron detection efficiency in the energy range 0.5-32 MeV.

Light charged particles arising from the intermediate-velocity source are registered with the 92-element Si-CsI(Tl) array [1]. These are used to tag the impact parameter involved in the collision. In the same time neutrons from the latter two sources are prevented from interacting with the scintillator and the tank walls. The results of MSX simulations for the indicated geometry are presented in Figs. 1 and 2.

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