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EVALUATION OF NEUTRON PRODUCTION IN SPALLATION TARGETS WITH MCNPX AND FLUKA CODES

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1. Introduction

The concept of ADS consists of a proton accelerator coupled to a subcritical core by a spallation target. The proton beam collides with the spallation target producing neutrons that starts the subcritical core. Due to its subcritical core, the nuclear reaction is not self-sustaining, which makes this model of reactor intrinsically safer.

The ADS concept drew attention after C. Rubbia's [1] proposal for a fast energy amplifier system (EA) and also, as a consequence, of the proposal for a concept with modifications focusing on transmutation.

In the last two decades, as shown by Rubbia et al [1], research with subcritical hybrid reactors, such as ADS, has again become attractive for providing better use of natural resources and has been widely recognized as being highly safe. The main advantage of this type of reactor is the operation of a reactor with a multiplication factor less than the unit ($k_{eff} < 1$), in which the fission reactions must be triggered by a beam of charged particles that are accelerated by protons or heavy ions with energy between 0.5 - 5.0 GeV per nucleon [2]. Also, one of the objectives of its use is the minimization of nuclear waste through the transmutation of minor actinides such as americium, neptunium and curium. Thus, these reactors are loaded with fuel that contains large amounts of minor actinides. Transmutation is carried out by these reactors that use neutrons in the fast spectrum. In this range of energy, the fission cross section is more favourable for the transmutation of minor actinides. Such hybrid reactors are characterized by a low fraction of prompt neutrons, implying rapid and large variations in power for a small variation in reactivity [3]. For an ADS, the spallation target is the most important component because it represents the coupling between the particle accelerator and the subcritical core. Protons, slowed down at a target, can induce nuclear reactions. Spallation nuclear reactions can occur when particles with high energies interact with a heavy nucleus, these particles can be, for example, protons. According Mongeli [4], the energy of the incident particles for the generation of these reactions varies from about 100 MeV to a few GeV. Some models divide the interaction process in two stages [4]. In a first stage, known as the intranuclear cascade, the incident nucleons incoherently scatter the target nucleons, depositing a fraction of their energies.

The incident nucleons, due to their high energy, have a short wavelength and therefore interact directly with the nucleons of the target nuclei. This nucleon-nucleon scattering stage leads to the ejection of nucleons (including a large amount of neutrons) from the target and the excitation of the residual nucleus which will deexcite in a second stage. Deexcitation of the residual nucleus can occur in two ways: evaporation or fission. In evaporation, deexcitation of the nucleus results in the emission from other residual nuclei or light particles. The second mode of deexcitation is fission. In this process, the residual nucleus gives rise to two other nuclei of different masses and neutrons are emitted. These spallation processes produce a large amount of neutrons, in addition to other nucleons and charged particles. It is verified that spallation reactions increase with the energy of the incident particle, and it also increase with the mass number of the target.

In view of the previous presentation, it is evident that the objective of the researched ADS project is to transmute transuranics from the reprocessing of spent fuels spiked with Th (thorium) or with depleted U (uranium). In both cases there will be conversion, and there may be breeding in case the fuel is spiked with Th. So, with this objective, it is intended to find a neutron spectrum that presents a high flux, i.e., that there is a high multiplicity, defined as the rate of neutrons produced by an incident próton (n/p), distributed in a more hardenied neutron spectrum, in another words, that presents a higher percentage of fast neutrons in relation to the produced thermal ones. This is because the transmutation of transuranics by fission is more likely for neutrons with high energies [3].

2. Methodology

The spallation target constitutes the physical and operational interface between the accelerator and the subcritical core, and it is the neutron source term for ADS, so it is of great importance to know the number of neutrons emitted by the incident proton (n/p), the energy deposited on the target, the angular energy distribution and neutron energy distribution and the distribution of spallation products. From this point will be analyzed how the spallation process and the subsequent reactions in each of the codes. Once the source spectrum has been evaluated, the complete hybrid system will be evaluate, which has already been modelled on the MCNPX using FLUKA and its modifications will be made to the energy of the source, the dimensions of the target and its material composition

The work, initially, will be modelled on the MCNPX [5] from approaches previously carried out by the DEN/UFMG team [6]. Then, the same system will be modelled using FLUKA code [7], to compare and verificate the model. Initially, a lead cylinder with a radius and height equal to 15 and 50 cm, respectively, on which a beam of 1 GeV will fall on the same axis on which the cylinder is oriented, and which will have a range of about 7 cm in the cylinder and with a parabolic spatial profile [8] will be used as the spallation target. This model has already been used in previous studies at DEN / UFMG. Thus, it will be used as a starting point and then we will propose changes in the energies, the beam profile and the dimensions and material of the target.

3.1 Simulation with different beam energies

For this work, it is observed that in relation to beam energy it is important to consider, according to Abderrahim et al [9], that "the ideal energy of protons for neutron production by spallation in a heavy metal target, in terms of costs, heating of the target and system efficiency, is in the range of 600 MeV to 1 GeV". Although the specific efficiency of neutron production (neutrons per unit of beam power) continues to increase up to about 2 GeV, an optimized cost performance installation minimum is generally achieved with slightly lower energies due to other factors, such as beam current, acceleration gradient and electrical efficiency of the accelerator. Within the proposed range, the source energy is varied at previously defined intervals.

3.2 Simulation with different materials for the target

Then attention is paid to the characteristics of the target using different materials. There are some considerations. In principle, all heavy materials of high density are suitable spallation targets because the spallation reaction occurs in all elements, although with an increasing number of neutrons released as the atomic number of the element increases and therefore the number of neutrons present in the core.

3.3 Simulation with different dimensions of the target.

Choosing the target thickness to contain the incident particle interval is important and a balance between the beam energy and the target dimensions must be considered. Thus, it is intended to vary the L (width) and d (diameter) values of the target., as it is expected to estimate the ideal target sizes as a function of the number of neutrons that escape from it. Studies have shown that number of neutrons escaping the target increases with increasing target radius and reaching maximum after which it decreases with increased target radius.

3. Expected Results

It is expected to achieve the objectives of this work, that is, the nuclear reactions present in the targets of the subcritical systems driven by source (ADS). Knowing that there is a lack of experimental nuclear data and modelling studies are needed that can bring relevant results from these systems. It is wished thus: (a) A detailed study of the nuclear models of the ADS and in particular, the understanding, analysis and evaluation of the spallation reactions; (b) Development, evaluation and implementation of models via codes (FLUKA and MCNPX) that comparatively allow their validation against similar results; (c) We want the simulation of spallation targets as well as the definition of efficient targets for this project.

As discussed earlier, multiplicity is a crucial parameter to be studied. Such importance is due to the fact that the target must produce the largest flux of neutrons in its surroundings being as compact as possible. Also, knowing how the target produces neutrons is relevant, as their production will impact the entire physics of the reactor [10]. The two graphs below (fig. 1), part of the initial study for several targets, show the variation in multiplicity as a function of the variation in radius from 5.0 to 30.0 cm (left) and as a function of source energy from 0.3 to 1 .6 GeV (right) for a tungsten (W) target at room temperature (293.6 K) and other to liquid LBE target at 400 K. For energy variation, target radius and length were kept constant at 15.0 cm and 50.0 cm respectively.

The study of this parameter will be applied to targets of different materials, radius and lengths.

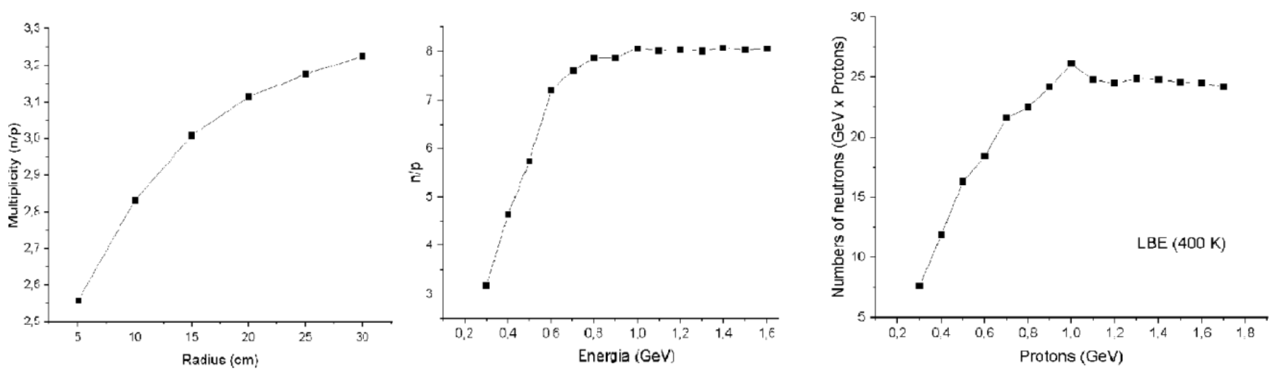

Figure 1: Multiplicty observed as a function of radius (left) Neutron multiplicity as a function of the energy of the proton source in a tungsten target (center). Neutron multiplicity per unit energy and per incident proton as a beam energy for a LBE target (left). It was used MCNPX code.

Previous work carried out by researchers from DEN/UFMG for Pb and LBE target notice that a maximum occurs in the range of energy of 0.75 - 1.25 GeV, therefore this is the range of protons energy that provides "neutron value", defining the optimum conditions, when economy is considered. This parameter will necessarily be considered and calculated for other materials [11].

4. Conclusions

In this subcritical system were used neutrons from spallation reactions between protons produced by a point source and different targets. Following this work, we intend to vary the source energy from a range of 0.6 GeV to 1.2 GeV and also model for different materials that will compose the target, producing a comprehensive and comparative study. It is expected to find a hardened neutron spectrum, that is, a high rate of multiplicity with a higher percentage of fast neutrons in relation to the thermal ones produced. This is because the transmutation of transuranics by fission is more likely for neutrons with high energies. Information on the neutrons produced by spallation reactions, such as energy, position and direction can be obtained using the codes MCNPX and FLUKA.

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