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THE UTILIZATION OF MCNPX 2.5 FOR ADS TARGET CALCULATION

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ABSTRACT

The Accelerator Driven System (ADS), is an innovative reactor which is being developed as a dedicated burner in a Double Strata Fuel Cycle to incinerate nuclear waste. The ADS consist of a sub-critical assembly driven by accelerator delivering a beam on a target to produce neutrons by nuclear reaction (e.g. Spallation, D-D, D-T, electrons etc). The target constitutes the physical and functional interface between the accelerator and the sub-critical reactor. For this reason it is probably the most innovative component of the ADS. The target design is a key issue to investigate in designing ADS and its performances are characterized by the number of neutrons emitted per incident particle, the mean energy deposited in the target per neutron produced, the neutron spectrum and the spallation product distribution. This paper will report some preliminary results for targets, such as those proposed .in the collaborative work on the Low Enriched Uranium Fuel Utilization in ADS for Serbia H5B Accelerator Sub Critical Research. Also a comparative study of the spallation models used in the MCNPX 2.5 will be reported for a cylindrical target irradiated by 1 GeV proton beam.

1. INTRODUCTION

The Accelerator Driven System is an innovative reactor which is being considered as a dedicated High Level Waste Burner in a double strata fuel cycle. The “status of the art” of the R&D in ADS has been intensively reported in the literature [1, 2]. In short an ADS consist of a particle beam from an accelerator inducing nuclear reactions in a target to produce secondary neutrons which are the external source in a sub critical core. Therefore the target is the physical and functional interface between the accelerator and the sub-critical reactor. For this reason it is probably the most innovative component of the ADS. The target design is a key issue to investigate in designing ADS and its performances are characterized by the number of neutrons emitted per incident proton, the mean energy deposited in the target for neutron produced, the neutron spectrum and the spallation product distribution.

Although no power ADS has been constructed, many projects like the MYHRRA, XADS, etc, are considering as target a lead bismuth Euthetic (LBE), and a proton beam with energies around 1 GeV, in a Window or Window Less target, to produce by spallation secondary neutrons. Therefore, since there are few experimental results for the interaction of high energy hadrons, nuclear models have to be used to describe the spallation phenomena. These nuclear models and the codes used to produce results for the secondary particles were presented in the INAC 2005 [2], and in the Brazilian Journal of Physics [3]. In this paper we wish to report a parametric study (different nuclear models) available in the recently released MCNPX 2.5[4], in a target of lead irradiated by 1 GeV protons. Moreover , although there are no power ADS, there are many zero power facilities operating or planned, such as the MUSE experiment at MASURCA , YALINA BOOSTER, which uses neutrons coming from a D-D, or D-T reaction as an external neutron source. Also, electron accelerators are being used in experimental power ADS [5], or Research Reactors (neutron source by photons). So, here we wish also to report some preliminary results using MCNPX 2.5 for the target of the planned H5B- Accelerator Sub Critical Research facility, which is being considered in the collaborative work of the IAEA on the utilization of LEU in ADS [6], in which a proton or deuteron beam of low energy produces secondary neutrons, mainly by (n,xn) reactions. In the present work, we focused on the target design of Accelerator Driven Systems calculating important parameters for the project of a ADS.

2. THE TARGET DESIGN IN LOW ENERGY BEAMS

For the Purpose of the H5B ADFSRF [5] only beams of protons and deuterons are studied. All the targets studied here are cylindrical as schematized in figure 1.

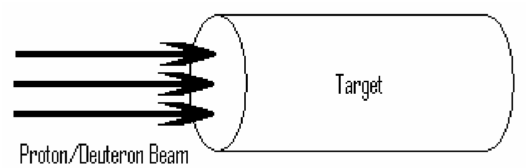

Figure 1. Schematical representation of the source (Target and Proton/Deuteron beam).

To simulate an ADS neutron source one needs to know the parameters of the ions beam used for production of neutrons on the source target by (*,xn) reaction. The preliminary results for neutron yield from different thin target materials are showed in the Table 1.

Table 1. Neutron yield from different target material

Material	Multiplicity (per particle of the source) by an 75 MeV proton beam	multiplicity (per particle of the source) by an 65 MeV deuteron beam
Pb-82	1,84E-01	1,46E-01
U-92	3,16E-01	6,87E-02
Th-90	2,68E-01	7,08E-02
Bi-83	1,87E-01	1,67E-01
Li-3	7,92E-02	7,30E-02
Be-4	5,44E-02	8,91E-02
W-74	2,01E-01	1,08E-01
Pb-Bi	1,90E-01	7,96E-02

The number of neutrons escaping from the target's surfaces, normalized per one incident particle was also calculated and the results are presented in the Figures 2 and 3.

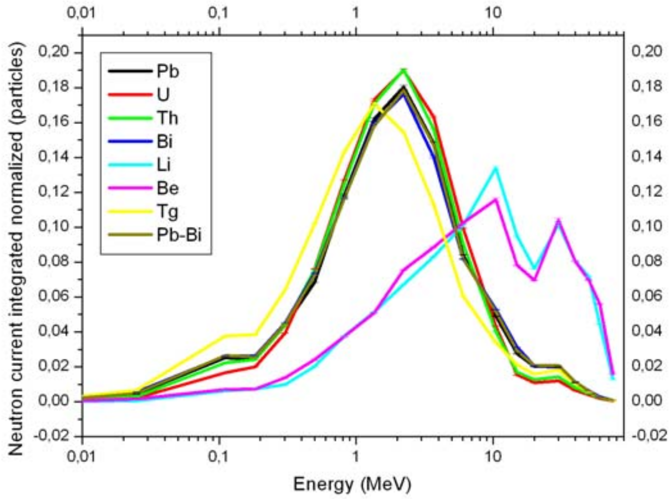

Figure 2. Neutron current integrated normalized (particles) by an 75 MeV proton beam for several materials.

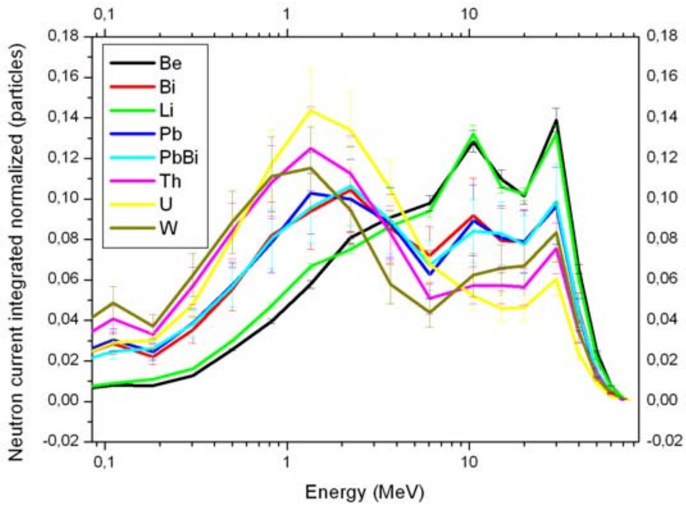

Figure 3. Neutron current integrated normalized (particles) by an 65 MeV deuteron beam for several materials.

The results presented are preliminary, and they will be compared with experimental data in the Research Coordinate Meeting of the CRP[5], planned to be held in Roma [5]

3. THE TARGET DESIGN IN SPALLATION SOURCE

Spallation is a nuclear reaction in which a relativistic light particle (e.g. protons, neutrons) hits a heavy nucleus. The energy of the incoming particle usually varies between a few hundred of MeV and a few GeV per nucleon. This reaction can be subdivided in two items, in the first stage, usually known as intra-nuclear cascade, depositing in this way some fraction of its energy. The incoming nucleon sees the substructure of the nucleus. This stage of nucleon-nucleon scattering interaction leads to the ejection of some of the nucleons and to the excitation of the residual nucleus which will cool itself afterwards. In the second stage, the de-excitation of the residual nucleus can proceed in two main ways: evaporation and fission. The evaporation is the dedicated de-excitation channel and the excited nucleus emits nucleons or light nuclei such as D, T, He, α, among others. The second important de-excitation mode is fission. In the fission process the nucleus is ultimately "cut" into two fragments of different masses. Generally the fate of the nucleus is its fragmentation.

For the definition of the source term for ADS, or for the project objectives of this system it is necessary, besides the knowledge of the time evolution of the spallation reaction, the description of the transport of the secondary particles in the media is basic to calculate the number of neutrons escaping from the target, its energy and angular distribution, the energy deposited in the target and the spallation products. These calculations are accomplished with Monte Carlo simulation of the space transport of those secondary particles. Among several codes, there are LAHET, developed by Los Alamos [7], and FLUKA [8], developed by CERN.

Recently the code MCNPX 2.5 [4], was developed by Los Alamos National Laboratory, being internationally one of the most used code to realize this type of calculation, and it is the one used by us to perform target calculation..

The cost of the proton accelerator is an important parameter when designing a neutron spallation source to have a comparative, or to evaluate a merit figure, an interesting parameter is the "neutron value", which is defined as the number of produced neutrons normalized to the unit beam energy per incident particle. Figure 4 illustrate such parameter

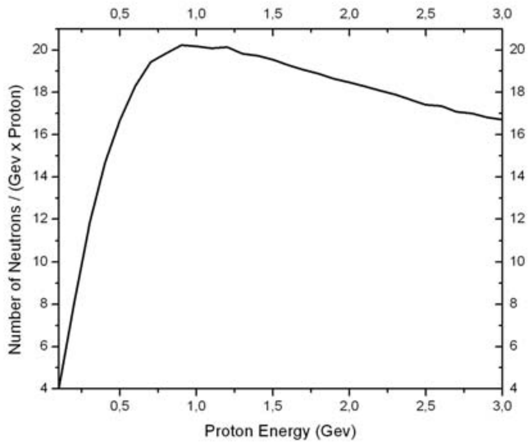

Figure 4. Average neutron multiplicity per unit energy (in GeV) and per incident proton as a beam energy.

From these results we notice that a maximum occurs in the range of energy of 0.8-1.2 GeV, therefore this is the range of energy of the protons that gives a maximum "neutron value", defining the optimum conditions, as far economy is considered.

3.1. Neutron Multiplicity (n/p)

One of the most important parameters of Spallation target is the neutron production per incident proton, once the power of an ADS is proportional to this parameter. Therefore we want to compare MCNPX prediction of the neutron production in some irradiated target. We considered a cylindrical target of 10 cm radius made of Pb irradiated in range 0.4-2.5 Gev protons beam. The results were compared with experimental data Letourneau [9], with show in figure 5.

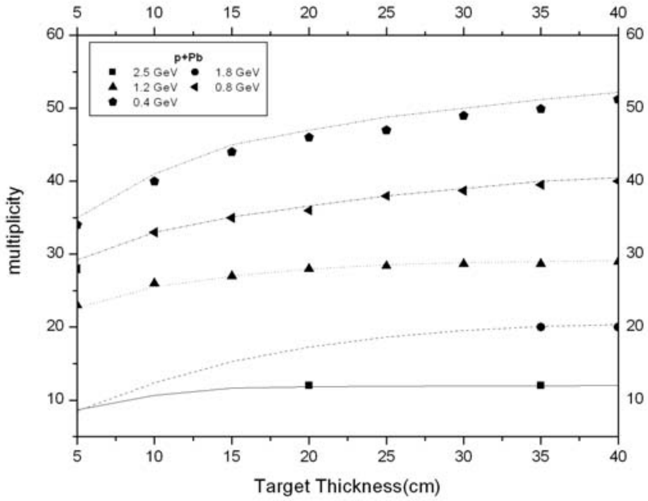

Figure 5. Average neutron multiplicity per nuclear reaction as a function of target thickness in a Pb target by an 0.4, 0.8, 1.2, 1.8 and 2.5 GeV proton beam for a 15 cm in diameter Pb target.

To compare with the experimental data (symbols in figure 5 are experimental data gotten for Letourneau [9]) for neutron production per incident proton, we noticed that the result of the simulation supplies us a larger number of produced neutrons, this may be attributed to the fact that in the simulation all neutrons are counted, already in the experiment the detectors don't measure all the neutrons.

3.3. Spallation products

Other important parameter to be tested in this study is the spallation products predicted with MCNPX. We estimated the residual nuclei prediction over the cylindrical target of 20 cm radius and 30 cm thickness made of Pb. We compared the prediction accomplished by the different available intra nuclear cascade (INC) models in MCNPX : Bertini, Isabel and CEN. Some results are shown in the Fig 6.

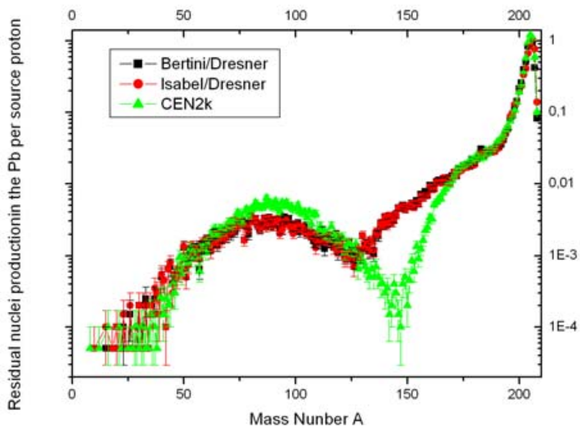

Figure 6. Residual nuclei production in a Pb target by an 1 GeV proton beam.

We can see in Fig.6 that the residual nuclei production estimated by these models are a bit different. In the fission area both models are in good agreement, already in the spallation area we noticed great disagreements, what is due to the fact of they be different models. The model CEN is the one which gives a great difference due to it residues because it is a model structurally different.

At this state of the present work, it was not possible to infer on the efficiency in the predictions of the models for residual nuclei production, such stage this being accomplished and comparisons with experiments [10] are being accomplished.

4. CONCLUSIONS

We notice that MCNPX 2.5 provides reasonable results either for thick targets of low energy nuclear reactions, as well as for high energy hadrons, being an useful toll to be used in target design. Also we emphasize that our results are preliminary, and since we are participate in the Analytical Benchmark, we intend to calculate the thick target proposed in the CRP in order to compare with the international community, and validate target calculation methodology in the IPEN.

ACKNOWLEDGMENTS

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