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The Utilization of Crisp Code in Hybrid Reactor Studies

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One of the main applications of the Hybrid Reactors (ADS - Accelerator Driven System) is the incineration of transuranics (TRU) by fast neutrons that emerge from a spallation source in a sub critical reactor waste burner [1, 2]. For this application, an accurate description and prediction of spallation reaction is necessary, including all the characteristics concerning spatial and energetic angular distributions, spallation products and neutron multiplicity. To describe the nuclear reactions at intermediate and high energies, Monte Carlo calculations have been used. The CRISP package considers the intranuclear cascade (INC) that occurs during the spallation process in a realistic time-sequence approach in which all particles inside the nucleus can participate in the cascade and the nuclear density fluctuations are naturally taken into account during the process. The occupation number of each single particle level is considered as a function of time and a more realistic Pauli blocking mechanism can be performed. None of the existing models have effectively used all those features. The evaporation of protons and alpha particles are taken into account making possible the correct prediction of fissilities of actinides and pre-actinides [3]. Another implementation is the NN single-pion production reaction. This reaction is especially relevant if one is interested in neutron or proton multiplicities, since the creation/emission of pions is directly related with the excitation energy of the residual nucleus. We will present some results obtained with the CRISP package for proton-nucleus reaction at intermediate and high energies. This package was obtained by the coupling of the MCMC [4] and MCEF [5] codes, with the introduction of some improvements, such as better Pauli blocking mechanism, which constrains the residual nucleus energetic evolution to the Pauli Principle from the ground-state to the final compound-nucleus formed at the end of the intranuclear cascade process, and introduction of the most relevant resonant excitation and the NN single pion production channel. The results of interest for ADS development are consistent with the experimental data at different proton energies. More detailed calculations are being performed for studying other features of proton-nucleus reactions and with different targets.

I. INTRODUCTION

To overcome the need of final storage, incineration of transuranics, TRU, is being considered by using fast neutrons from a spallation source. It takes into account that the fission cross section is much higher than the capture cross section at these energies for most of TRU, and therefore transmuting long lived TRU in medium or short lived waste (fission fragments - FF). Besides the incineration of TRU and FF, a coupled system consisting of spallation source and a sub critical array of fuel, may have a positive gain of energy (net energy/energy to operate the accelerator). This system is known as ADS - Accelerator Driven System.

tect the vacuum in the accelerator tube and being, at the same time, the first barrier to the spallation target. This window is submitted continuously to the proton irradiation. Among those problems are the radioactivity induced by the spallation products, changes in the chemical composition and embrittlement (Martensitic steels has 90% of Fe).

Some radioactive spallation products are:

^{210}Po ($T_{1/2} = 138$ days) for Bismuth target,

^{194}Hg ($T_{1/2} = 520$ yr) for Mercury and Lead targets,

^{148}Gd ($T_{1/2} = 74.6$ yr) for Tungsten and Lead targets.

A. Target

One of the preferred options for an ADS target is the Lead-Bismuth Eutectic (LBE). Effects of spallation products on LBE corrosion control are one of the key problems to be investigated.

In most hybrid systems a thin window exists between the incident proton beam and the spallation source, needed to pro-

II. THE CRISP PACKAGE

The CRISP package here developed utilizes an algorithm that describes a many-body intranuclear cascade (INC) and evaporation/fission competition process, considering dynamic evaluation of the fermionic multicolisional process and the possibility of neutron, proton and alpha particle evaporation [6, 7]. Fission process can also occur and competing with the evaporation process. The INC is considered in a realistic time-

sequence approach and all particles inside the nucleus can participate in the cascade. The occupation number of each single particle level is considered as a function of time and a more realistic Pauli blocking mechanism was implemented.

III. IMPLEMENTATIONS

Another implementation is the NN direct single-pion production reactions. The channels that are present in the CRISP code are listed below:

$$\begin{aligned} p + p &\rightarrow p + n + \pi^+ \\ p + p &\rightarrow p + p + \pi^0 \\ n + p &\rightarrow n + n + \pi^+ + p + p + \pi^- \end{aligned}$$

The two-pions production occurs at about 1 GeV and is being implemented.

The level density parameters present in CRISP are the same as described in [8]:

$$\begin{aligned} a_n^{1/2} &= a^{1/2} (1 - 1.3\Theta/A), \\ a_p^{1/2} &= a^{1/2} (1 + 1.3\Theta/A), \\ a_\alpha^{1/2} &= a^{1/2} (1 - 3/2A), \\ a_f &= a_n \times r_f, \end{aligned}$$

where

$$\begin{aligned} \text{if } Z^2/A > 34.25, r_f &= 1 + 0.06(Z^2/A - 32.5), \\ \text{if } 31.5 < Z^2/A \leq 34.25, r_f &= 1 + 0.03(Z^2/A - 33.5), \\ \text{if } 22.9 < Z^2/A \leq 31.5, r_f &= 1.1 - 0.02(Z^2/A - 21.6), \\ \text{if } Z^2/A \leq 24.9, r_f &= 1, \\ \text{and } a &= A/10, \Theta = (N-Z)/A. \end{aligned}$$

IV. RESULTS

In Table 1, neutron multiplicities for proton induced reactions on Pb at different intervals of energy are given. Our model predictions agree very well with the cascade neutrons ($E \geq 20$ MeV) and the evaporation neutrons (2 – 20 MeV) [9]. Also in

Table 1 the CRISP results are compared with those obtained with other models.

During the irradiation a large amount of neutrons is generated. However, the process generates spallation products from the target material, in direct proportion to the energy of the proton beam. Their radiotoxicity is likely to exceed that of the fission products in the short term, which is relevant to operation and storage rather than final disposal. Ultimately the burning of actinides means that overall radiotoxicity is reduced greatly by 1000 years, and is less than that of the equivalent uranium ore.

Considering this, an important result is to calculate the spallation products that are generated in the target during the reactor operation. In figure 1 the spallation products resulting from a Lead target irradiated by 1 GeV protons are shown. Although the results are preliminary, the calculated data agree very well with the experimental one. Analyzing this results one can estimate how much ^{194}Hg , for example, could be generated.

In figure 2 the spallation products resulting from a Gold target irradiated by 0.8 GeV protons are shown. Although the results are also preliminary, the calculated data agree very well with the experimental one.

In both figures one can note that there are some discrepancies in the curves with higher atomic numbers and higher atomic masses. This kind of effect is related to the initial interaction and we are working on it.

V. CONCLUSIONS

The particle multiplicities calculated with CRISP code agree with the experimental data, giving results as good as, or even better than other INC/Evaporation codes. The spallation products parabolas show a good agreement with experimental data, indicating that the INC and Evaporation/fission processes are being correctly simulated. The CRISP package can be used in ADS target design contributing with the correct prediction of important quantities.

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TABLE I: Neutron multiplicities in proton-induced reaction on Pb nuclei (second column) compared with the predictions of our model (third column) and those from other models [9].

Neutron energy	Expt.	CRISP	INCL4 KHSv3p	TIERCE Cugnon	LAHET Bertini	LAHET ISABEL	LAHET Bertini-preq
Pb $E_p=800$ MeV							
0 - 2 MeV		2.9	3.3	4.9	5.61	5.13	5.37
2 - 20 MeV	6.5	6.6	6.8	6.9	8.63	6.63	7.12
> 20 MeV	1.9	2.2	2.5	2.2	1.75	1.92	2.13
Total		11.7	12.5	14.0	16.0	13.7	14.04
Pb $E_p=1200$ MeV							
0 - 2 MeV		3.3	3.4	5.8	6.35		6.02
2 - 20 MeV	8.3	7.6	8.1	8.9	11.44		9.86
> 20 MeV	2.7	2.6	3.1	2.8	2.45		2.83
Total		13.5	14.7	17.4	20.2		18.7

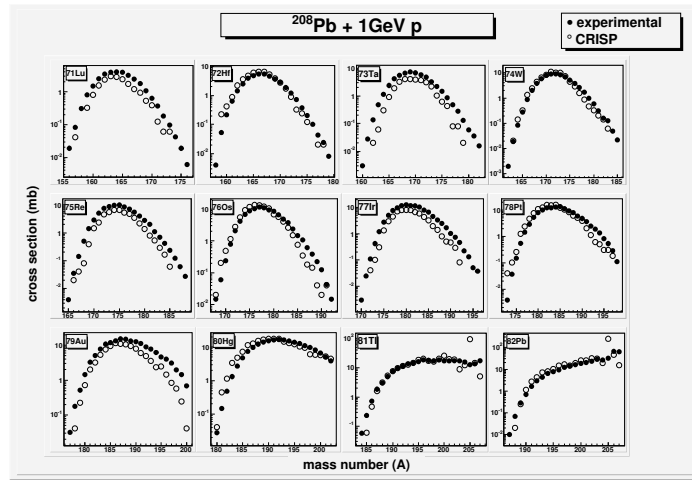


FIG. 1: Spallation products from a Lead target irradiated by 1 GeV protons. The full circles are experimental data taken from [10]. The open circles are from CRISP calculations.

