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A STUDY OF NEUTRON PRODUCTION IN PROTON REACTIONS WITH HEAVY TARGETS

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Abstract

The purpose of this work is to study the production of (pn) nuclear reactions from proton collision with different targets, Pb, W, Ni, U, Au, using proton accelerator. The bombarding energies considered in the article are: 0.5, 0.6, 0.7, 0.8, 1.0, 1.5 GeV. The calculating results are shown in diagrams.

I. INTRODUCTION

An important ingredient in the performance of accelerator driven systems for nuclear waste transmutation and other applications is the number of spallation neutrons produced per incident proton. Neutron production, angular and energy distributions are usually calculated using simulation codes based on specific models, which describe the elementary production of particles in nuclear reactions.

The accelerator driven system (ADS) is an innovative reactor which is being developed as a dedicated burner to incinerate nuclear waste. The ADS system consists of a sub-critical assembly driven by an accelerator delivering a proton beam on a target to produce neutrons by a spallation reaction. The spallation target constitutes a functional interface, situated between the accelerator and the sub-critical reactor. For this reason it is probably the most innovative component of the ADS. The design of target is a key issue to be investigated when designing ADS, and its performance is characterized by the number of neutrons emitted per incident proton, the neutron spectrum and the spallation product distribution.

Spallation reactions have attracted considerable interest due to their importance in technical applications [2,3]. However, up to now, there has not been any research on this problem. Recently, only Kaplan's working group [1] (published in 12 December 2008) have calculated for a similar process but in the low energies from 11.2 MeV to 140 MeV on isotopes of lead target element.

In our study, neutron emission spectra produced by (p,n) reactions for some spallation neutron target nuclei such as Pb, W, Ni, U, Au have been calculated by proton beam energy from 0.5 GeV to 1.5 GeV used the MATLAB program with database of JENDL-HE-2007. We use the simulation code MCNP 4C2 to model the sub-critical assembly and to calculate the neutron flux in the core.

II. THE MODEL AND CALCULATION

1. The (p, xn) reaction cross-sections

A MATLAB program has been written to calculate the (p, n) reaction cross-sections basing on the following equation:

$$\sigma_i(E,E',\mu)=\sigma(E).y_i(E).f_i(E,E',\mu) \qquad (1)$$

Where: i denotes one particular product

E is the incident energy (eV)

E' is the energy of the product emitted with cosine μ (eV)

$\sigma(E)$ is the interaction cross section (barn)

y_i is the product yield or multiplicity

f_i is the normalized distribution with units (eV unit cosine^{-1})

where
$$\int dE' \int d\mu \; f_i\left(E, E', \mu\right) = 1 \qquad (2)$$

The energy parameter is defined to vary from 0.5 GeV to 1.5GeV with targets having mass number from 58 to 238

Figures 1-12 show the neutron spectra from the (p,n) reaction on the ^{206}Pb, ^{208}Pb, ^{182}W, ^{184}W, ^{186}W, ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni, ^{235}U, ^{238}U, ^{79}Au nuclei, calculated at the proton energies of 0.5, 0.6, 0.7, 0.8, 1.0, 1.5 GeV

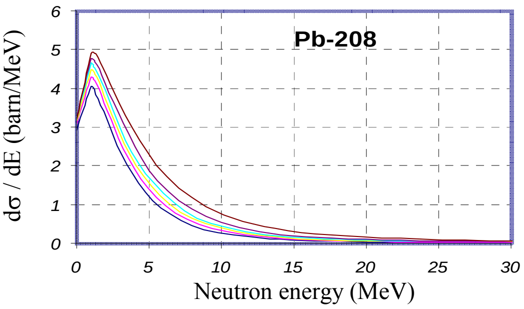

Fig.1: Neutron emission spectra of ^{208}Pb (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

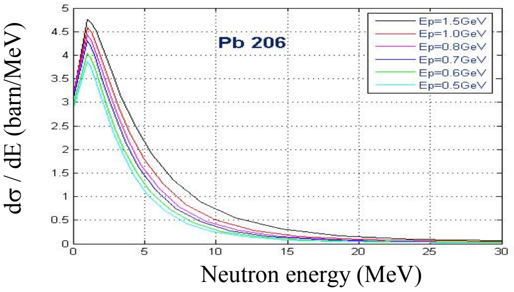

Fig.2: Neutron emission spectra of ^{206}Pb (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

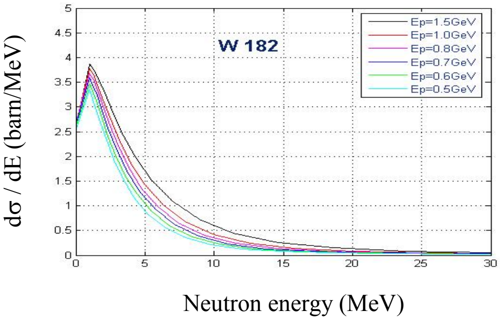

Fig.3: Neutron emission spectra of ^{182}W (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

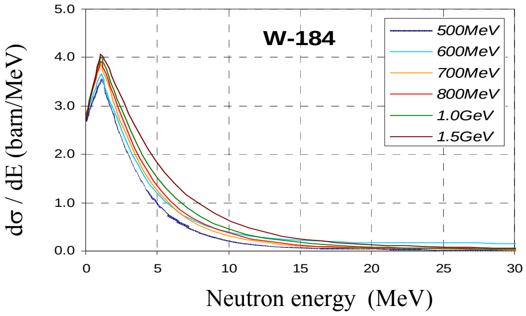

Fig.4: Neutron emission spectra of ^{184}W (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

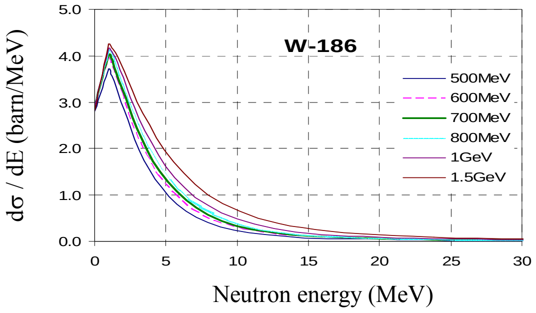

Fig.5: Neutron emission spectra of ^{186}W (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

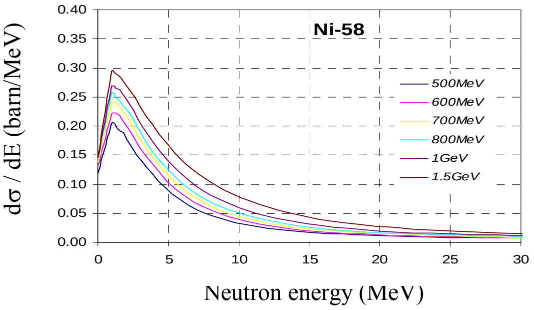

Fig.6: Neutron emission spectra of ^{58}Ni (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

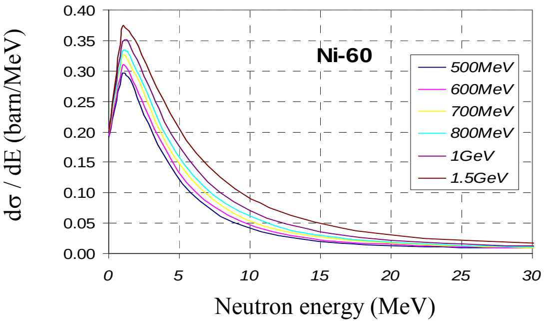

Fig.7: Neutron emission spectra of ^{60}Ni (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

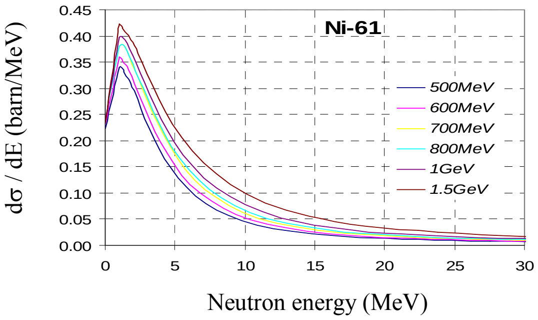

Fig.8: Neutron emission spectra of ^{61}Ni (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

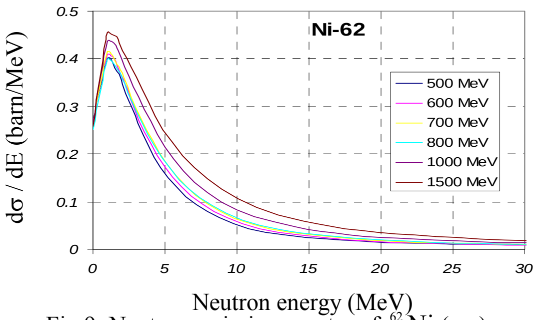

Fig.9: Neutron emission spectra of ^{62}Ni (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

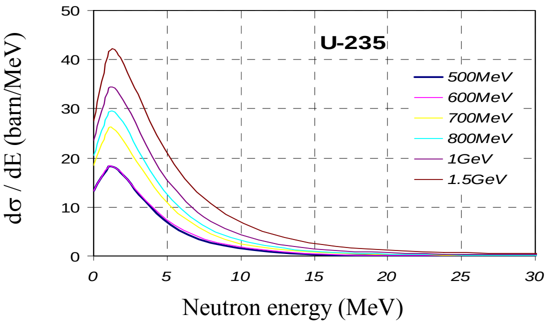

Fig.10: Neutron emission spectra of ^{235}U (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

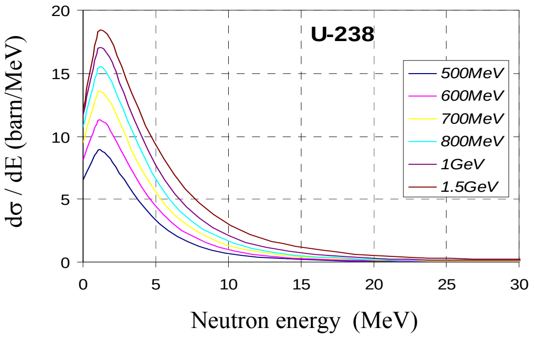

Fig.11: Neutron emission spectra of ^{238}U (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

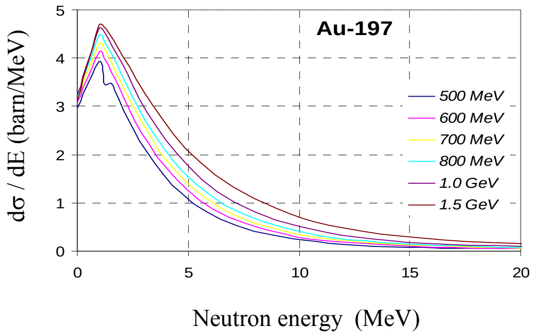

Fig.12: Neutron emission spectra of ^{197}Au (p,n) reaction at 0.5GeV to 1.5GeV incident proton energy

From figs.1 through 12, we have some remarks as follows: The neutron emission spectra produced by (p,n) reactions depend on:

- Incident proton bombarding energy
- Different target materials

The same isotope of an element, if the proton bombarding energies are highest, the neutron cross-sections will be largest.

At the same bombarding energy, neutron emission cross-sections depend on target materials. For example the (p,n) cross-section values for spallation target nucleus ^{235}U (see fig.10) are more than 400 times that by target nucleus ^{58}Ni (see fig.6).

The conclusions also agree well with the works reported in the Proceedings of the Final Meeting of a Coordinated Research Programme organized by the International Atomic Energy Agency and held in Bologna, Italy, 13-15 November 1989 of some authors.

The details of this problem will be described in the following papers which will be published in future.

2. Model parameters

In the model, the core has height 152.4cm, radius of device R = 65 cm, height of the target column is 10 cm, and radius of the target column is 30cm.

The MCNP 4C2 code system has been used in the following applications:

- Simulating geometry of the core ADS
- Calculating k_{eff}
- Calculating the neutron flux

The choice of fuel for ADS: Thorium [$^{232}ThO_2$ (+ $^{233}UO_2$)] with thermal power is 30MW.

From an MCNP 4C2 cell flux tally, modulus of neutron flux was calculated

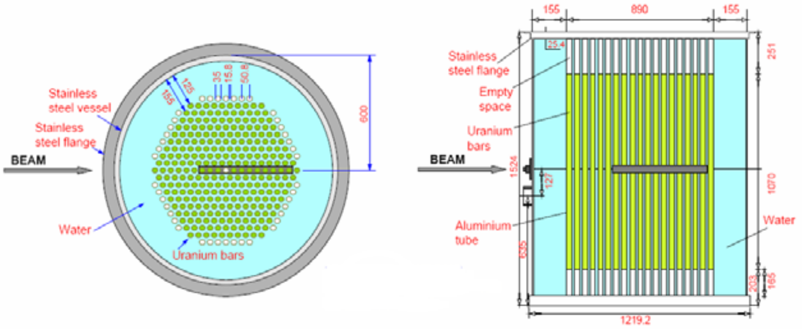

Figure 13a: Top and bottom views of the ADS assembly along the beam line from the accelerator

The test was performed with an existing sub-critical assembly of (Th + U)O_2 and water. It consists of small cylindrical rods of metal, with aluminum cladding, immersed in ordinary water which has the function of moderator.

Table 1: Neutron flux in the core of ADS at E_p= 500MeV÷1500MeV

Target	**E_p=500MeV**	**E_p=600MeV**	**E_p=700MeV**	**E_p=800MeV**	**E_p=1000MeV**	**E_p=1500MeV**
^{208}Pb	Φ_n=2.99701E+14	Φ_n =3.00230E+14	Φ_n= 3.00391E+14	Φ_n =2.99003E+14	Φ_n= 2.99026E+14	Φ_n=2.98995E+14
^{182}W	Φ_n=1.46446E+14	Φ_n =1.46864E+14	Φ_n =1.43786E+14	Φ_n =1.47484E+14	Φ_n =1.46065E+14	Φ_n=1.42975E+14
^{184}W	Φ_n=2.29556E+14	Φ_n =2.23602E+14	Φ_n =2.32186E+14	Φ_n =2.27879E+14	Φ_n =2.29301E+14	Φ_n=2.27607E+14
^{235}U	Φ_n=4.93245E+14	Φ_n =4.92332E+14	Φ_n=4.90450E+14	Φ_n = 4.94100E+14	Φ_n= 4.94187E+14	Φ_n= 4.92441E+14
^{62}Ni	Φ_n=1.58019E+14	Φ_n=1.55359E+14	Φ_n=1.58442E+14	Φ_n= 1.58672E+14	Φ_n= 1.57371E+14	Φ_n= 1.58332E+14
^{79}Au	Φ_n =1.24339E+14	Φ_n =1.23941E+14	Φ_n= 1.24498E+14	Φ_n =1.27028E+14	Φ_n= 1.23428E+14	Φ_n =1.24854E+14

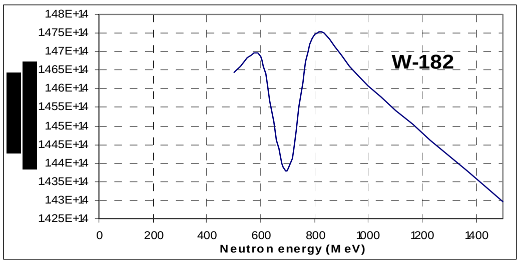

Fig.13: The neutron flux in the core ADS using ^{182}W target

Fig.14: The neutron flux in the core ADS using ^{184}W target

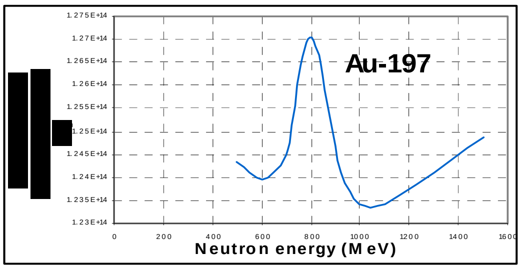

Fig.15: The neutron flux in the core ADS using ^{197}Au target

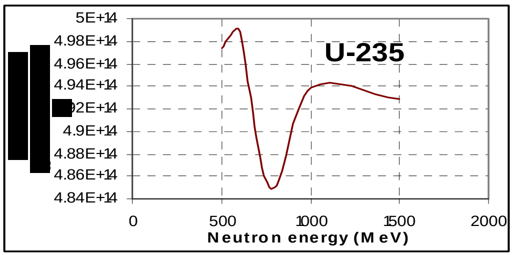

Fig.16: The neutron flux in the core ADS using ^{235}U target

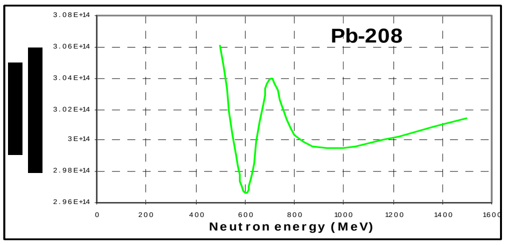

Fig.17: The neutron flux in the core ADS using ^{208}Pb target

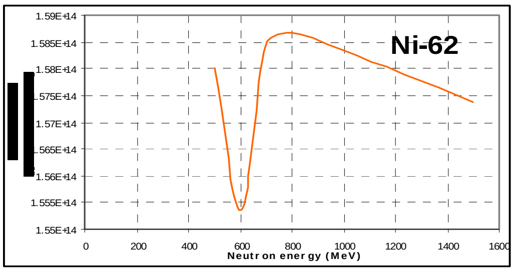

Fig.18: The neutron flux in the core ADS using ^{62}Ni target

- Using the results obtained from figs.1 through 12, we calculated neutron flux in ADS. This is a key issue to investigate in designing ADS. Figs.13 through 18 show that we can use different targets for ADS with changes on the incident proton energy. This detailed issue will be presented in another work.
- A 30MW$_{th}$ sub-critical system controlled by a 25 mA protons beam, which achieves a neutron flux of about E+14 with multiplication factor in our experiment, yields a largest figure of 0.98 on some targets, would improves reactor safety conditions.
- The result of this study can have applications in the design and operation of accelerator driven system (ADS).

Acknowledgments

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