# Abstract

Spallation neutron sources are new generation of neutron sources which offers higher neutron fluxes over currently available sources [1].

In spallation process a heavy material target is bombarded by very high energy particles. Each atoms of the target splits into several fragments with several output neutrons [2].

This research is an improvement to a previous research [3] for using a non-fissile material in the target of spallation neutron sources.

The spallation source of Rutherford Laboratory has been taken as a sample of calculations [4]. In this research, some changes has been made to the geometry of the spallation source to increase its neutron flux production and to improve its performance. These changes are allowed because of using a non-fissile material in the target instead of depleted uranium. Tungsten and Tantalum has been tested as a fuel in the target. Neutron production from these materials have been found to be very close to that produced from depleted uranium target after changing the composition of the target and geometry of the source.

The high energy transport code HETC [5,6,7] and Morse-H [8] code were used to calculate all nuclear interactions in the spallation process and neutron transport inside and out from the spallation source.

# Introduction

In a spallation neutron source, neutrons are produced by bombarding heavy material target by very high energy heavy particles like protons [1]. All spallation neutron sources have the same essential components, which are shown diagrammatically in figure [1]. The spallation neutron target of Rutherford Laboratory (which has depleted uranium fuel) is bombarded by 800 MeV high intensity protons from a synchrotron accelerator in pulses of $2.5*10^{13}$ proton per pulse at 50 pulse per second. Moderators close to the target embedded in a reflector slow down the energy of the output neutrons to the desired energies. Then the moderated neutrons pass through channels to the neutron scattering experiments.

There are many problems of using fissile materials as a fuel in spallation neutron sources [4]. The main problems are swelling, growth inside the fissile material and delayed neutrons which contribute as a constant time independent background [4] in the output flux of neutrons. These problems and others [4] could be reduced or eliminated by using a non-fissile fuel in the target.

Tungsten and tantalum are the attractive materials that could replace uranium in spallation neutron sources due to their very good and well known characteristics, beside they have very high neutrons production per incident protons which reaches 13.9 for tungsten, and 13.7 for tantalum compared with 20 neutrons per proton for depleted uranium fuel [1].

# Calculation Details

Two designs have been considered for a new geometry to the Rutherford spallation neutron source. These designs are shown diagrammatically in figures 2c and 2d. figure 2c shows that the moderators positions have been moved with reducing the target radius. But a constant distance has been kept between them and the target. This distance is the place of cooling wings volume outside the target which for this design has been kept constant.

In the second design, in addition to the changes of the first design, the cooling wings volume outside the target has been reduced with decreasing the coolant quantity so that a variable distance for the cooling wings volume have been considered.

Those changes in the original geometry of the Rutherford spallation neutron source are allowed since tungsten and tantalum fuel can work in much higher temperatures than depleted uranium [4]. Figure 2a shows a diagram of the original geometry, while figure 2b is a diagram of a front cross section of the spallation source.

The target is represented as a homogeneous mixture of fuel, heavy water coolant and cladding. The volume fractions of these components has been varied in steps to increase the neutron production from the target. Light water has been tested as an alternative coolant.

Each individual case that has been considered in the calculations for any changes in the geometry or target composition were performed by using two computer codes. These codes are HETC and MORSE-H.

The High Energy Transport Code (HETC) treats all the atomic and nuclear interactions that occurred due to the collision of the incident high energy protons with the target. It includes ionization, excitation and coulomb scattering. It uses standard formulas and procedures like Bethe-

Block formula for ionization and numerical integration for calculating the ranges of particles.

The energy of particles from these interactions extends up to the energy of the incident protons which is 800 MeV.

From these calculations the neutron spectra of energies below 15 MeV were taken and used as a source in the Monte Carlo transport code Morse-H, which solves the integro-differential multidimensional Boltzman transport equation for neutrons through the target and other parts of the assembly.

The main factors that describes the performance of the spallation neutron source are the neutron flux in the moderators and the neutrons leakage from them. Which are calculated by Morse-H code, and plotted in figures 3-8.

## Results and Discussion

First design:-

In this design a constant distance has been kept between the target and moderators. This is shown in figure 2c. The results of these calculations are represented in figure 3,4,5 and 6. Figures 3 and 4 show the effect of changing the target radius for tungsten and tantalum fuels on their performance. Figures 5 and 6 show the effect of changing the target composition and radius on its performance for a tungsten fuel only.

Figures 3a and 3b represent the average neutron flux in the moderators for tungsten and tantalum fuels. The target radius in these calculations was varied in steps of 0.5cm from 2.5cm to 4.5cm. These figures show a great effect of changing the target radius. The target performance increase with reducing its radius until 3.0cm radius, where it reaches a maximum, beyond this radius the performance decreases. It was found that the average neutron flux in the moderators of a tungsten fuel target reaches 86% of that of a depleted uranium target for similar target compositions of 77% fuel, 18% heavy water coolant and 5% Zircoloy cladding. While it was only 78% for a tantalum target compared with that achieved from a depleted uranium target. Figure 3c represent the case of using a depleted uranium fuel at a constant radius of 4.5cm for the sake of comparison.

Figures 4a, 4b and 4c show the average leakage of neutrons for the moderators for similar cases of 3a, 3b and 3c respectively. They show that the average neutrons leakage from the moderators was 84% for the tungsten fuel and 76% for the tantalum fuel compared with a depleted uranium fuel in the target.

Figures 5 and 6 show the performance of a tungsten fuel for different target compositions and radiuses. These figures show that the best performance for the average neutrons leakage from the moderators was found to be 90.5% of that of depleted uranium target. It was at a target composition of 85% fuel, 10% heavy water and 5% Zircoloy cladding, and at a target radius of 3.0cm. While the average neutrons flux in the moderators was found to be 89.5% of that of the depleted uranium target for the same target radius and composition mentioned above.

These results are represented in figures 5d and 6d respectively. The results of using light water as a coolant in the target are also represented in figures 5 and 6. The best results of using this coolant are shown in figures 5c and 6c, which indicates a performance only 3% less than that achieved from using heavy water coolant for both calculations of the average neutron flux in the moderators and the neutrons leakage from them.

Figures 5e and 6e were plotted for the sake of comparison, for the case that uses depleted uranium as a fuel in the target at 4.5cm radius only.

Second design:-

In this design the volume of the cooling wings outside the target is reduced while decreasing the coolant quantity inside the target.

Interesting results of the tungsten fuel target have been achieved from the first design, such that the target performance reaches the performance of the depleted uranium target of the existing Rutherford source.

The reason for such increase in the performance is due to an increase in the reflecting material surrounding the target since it will take place of the removed volume of the cooling wings as shown in figure 2d.

The results of calculations are shown in figures 7 and 8. The best target performance was found at 3.0cm target radius for a composition of 90% fuel, 5% $D_2O$ coolant and 5% Zr cladding. The average neutron flux in the moderators is shown in figure 7f. It is 97% of that achieved from a depleted uranium target, while the average leakage of neutrons from the moderators are slightly higher than that achieved from the depleted uranium target, as can be seen in figure 8f (3% higher).

Using light water as a coolant for similar target compositions gave a neutron production from the moderators only 3% less than that achieved from the depleted uranium target. These results are shown in figures 7d and 8d.

These results are very encouraging for the use of a non-fissile fuel in the target (like tungsten) for the future development of the Rutherford source, or if a new spallation neutron source station is to be considered in any place.