TARGET ASSEMBLY AND NEUTRONICS DESIGN STUDY FOR THE INDIAN SPALLATION NEUTRON SOURCE USING NMTC/JAM CODE*

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Abstract

Target-moderator-reflector assembly (TMRA) design studies for the best neutronics performance of the proposed Indian Spallation Neutron Source (ISNS) have been carried out using high energy particle transport code NMTC/JAM. The issues relevant for TMRA design like selection of target material, effect of target shape and dimensions and placement of moderator, suitable material for reflector its size have been addressed using the code calculations. Code calculations have shown that the neutron yield per proton for thick Pb target and for varying target lengths are in good agreement within the error limit with the results reported by the experimental group and matching with the results of JAERI code calculations (JAERI –Data/code 2001-07). Different geometrical configurations for TMRA were attempted and resulted tallies for track-length, surface crossing, nuclide yield, heat deposition, and time for the neutrons have been calculated. It has been observed that wing type structure of moderator position with respect to the target is suitable for optimum neutron yield in the pulsed mode.

INTRODUCTION

Raja Ramanna Centre for Advanced Technology (RRCAT) is planning to establish a 1 GeV proton beam rapid cycling synchrotron (RCS) accelerator facility at Indore. The proton beam from the RCS will be directed towards the spallation target station which will produce intense pulsed neutrons as a complementary probing tool compared to x-rays from the synchrotron radiation source. Internationally, few such facilities are operational and efforts are being made towards development of advanced neutron sources that will revolutionize the future prospects in the basic science, material science, biology and new technologies. As next generation neutron sources are under advanced stages of construction at ORNL and JPARC which will exceed the neutron intensity level in the pulsed mode by nearly 1-2 orders of magnitude higher than the highest intensity available till date by the high flux nuclear power reactors (ILL). The neutron scattering experiments will be carried out at much higher resolution and efficiency level and in the wider range of wavelength and momentum to cover applications in almost all branches of science be it chemistry, physics, biology or material science. In the present study related to design of Indian Spallation Neutron Source (ISNS) the high energy proton beam interaction with the high atomic number solid targets have been performed using the NMTC/JAM code developed by the JAERI [1]. The TMRA design study involves evaluating best neutronics performance by selecting suitable target material its dimensions, position of moderators, reflector material its size and thermal energy deposition and related parameters that will be suitable for ISNS.

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PROPOSED ISNS PARAMETERS

The conceptual design of the spallation neutron source is based on the 1 GeV proton beam extracted out of the RCS. Typical parameters of the system are as below:

RFQ Injection Energy (keV)	50 keV
DTL Injection	4.5 MeV
RCS Injection Energy (MeV)	100 MeV
Beam Energy on Target	1.0 GeV
RCS Repetition Rate	25 Hz
Average Beam Current	100 μA

NMTC/JAM CODE CALCULATIONS

NMTC/JAM can simulate transport of nucleons, mesons, baryons, leptons as well as their anti-particles through a given medium using Monte Carlo technique. It allows any target nucleus to be used for the material in the medium except the light ions like He^3 and α and heavy ions.

Maximum energy of the particle transporting in a medium is limited to 200 GeV for all transport particles, while the minimum energy is restricted to 20 MeV for neutrons and 0.1 MeV for other particles. The cut-off neutrons below the limit of nuclear models can be stored along with phase space information data of each such neutrons can be stored in a file for subsequent transport calculations using the MCNP4A code. A user supplied source routine is required to read the phase information data of individual cut off neutrons and photons in the MCNP4A code.

In order to check the validity and accuracy of various models used in the NMTC/JAM code, we have performed the simulations of a proton beam (12 GeV energy) interactions with the cylindrical lead target with 20 and 10 cm diameter and 60 cm length. These parameters were chosen so that it can be compared with the experimental results obtained at KEK using the Mn-bath moderation method. Neutron yields data are derived experimentally by changing the target length in steps of 10 cm. First we tried to study the variation of neutron spectrum generated by the 12 GeV proton beam inside cylindrical Pb target of different dimensions ranging from 10 cm dia and 10 cm length to 20 cm dia and 60 cm length as shown in the Figure 1. It is noticed that the flux of neutrons along the length of the target in a given target volume will be highest for 10 x 10 cm cylinder and lowest for the 20x60 cm cylinder due to higher level of scatterings in larger volume and with pencil beam of proton being used to produce the spallation neutrons along the cylinder axis.

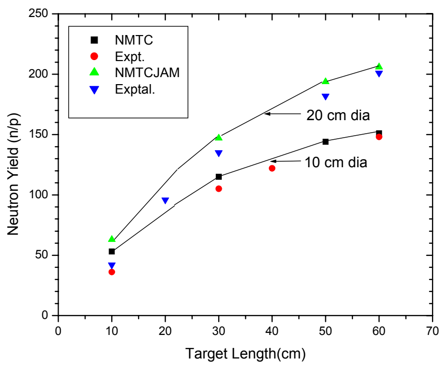


Figure 1: The neutron yields from lead target with 12 GeV protons striking the cylindrical target in units of neutrons per proton as a function of target length. The red symbols (10 cm diameter case) and blue symbols (20 cm diameter case) are experimental results and solid lines are the results of NMTC/JAM.

Then we compared the results of neutron yield from Pb cylindrical target of 10 and 20 cm diameter with length variation from 10cm to 60 cm, generated by 12 GeV proton beam and compared with experimental values. It is noticed that the neutron yield steadily increases with cylinder length and reaches a maximum value at 60 cm length. The experimental values are in close agreement with the NMTC/JAM code calculation values with in the error limit. The small difference in the calculation values is mainly due to the fact that the transport of neutrons below 20 MeV energy could not be carried out due to the non-availability of source code patch file for MCNP4A code.

Neutron production and leakage from the target

The neutron yield from the high-energy proton interaction with the target nuclei depends on the material type as well as its size for a given incident particle energy [2-4]. For practical purpose it is the number of neutrons obtained per incident proton. The axial distribution of leakage neutrons from the target depends on the target-moderator coupling (the best moderator position relative to the target). For thin target the cascade part of the spectrum can reach up to the energy of incident particle. It becomes strongly anisotropic with higher energies emerging mainly in the forward direction as expected from collision. The number of leakage neutrons from the cylindrical surface of a target depends on the target radius. Initially the number increases with increasing radius and then decreases.

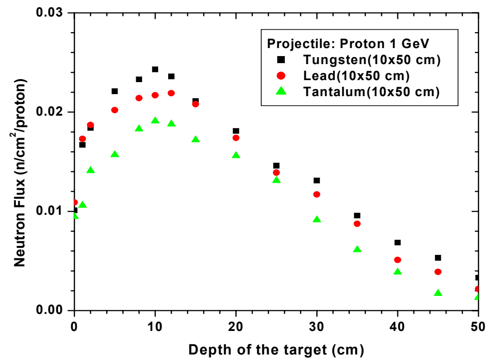


Figure 2: Neutron flux leakage from the tungsten, lead and tantalum targets (cylindrical with dia and length of 10 x 50 cm) as a function of target depth is shown for 1 GeV incident proton beam with Gaussian shape. Neutron flux consists of fast neutrons and has been obtained using NMTC/JAM code calculations.

This is due to the fact that probability of absorption of source neutron increases in the target. Therefore the 10 cm diameter is sufficient for optimum leakage of neutrons then the dependence on length of the cylinder has been calculated using the NMTC/JAM. As illustrated in Figure 2, the peak neutron flux is noticed near 10 cm depth of the target from the entrance surface of the target and this is the most suitable position for placement of the moderators in order to optimize the epithermal and cold neutron flux through the moderators. Further the neutron flux is higher for tungsten target compared to the lead and tantalum targets for 1GeV proton beam energy hence tungsten is chosen as a spallation target material.

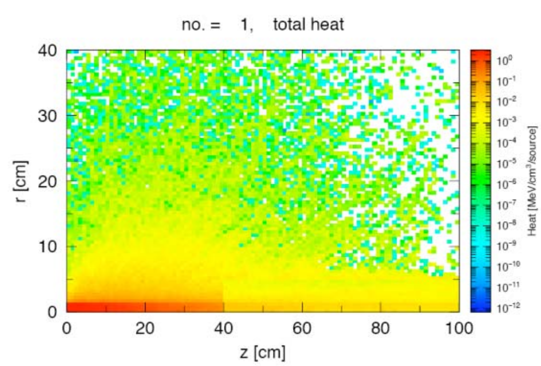


Figure 3: The heat deposition in bare tungsten target of cylindrical geometry by proton beam of 1 GeV energy with 7 cm diameter cylindrical shape.

For a cylindrical shape target the heat deposited in tungsten target is calculated for 1 GeV proton beam as shown in the Figure 3 gives a maximum value of 0.388 kW/cm^3. In the present studies we have performed using Tungsten as target, light water as moderator and Lead /Iron as reflector material. We have tried to study the TMRA configuration from neutronics point of view. We performed the NMTC code calculations for fast neutrons that are emitted from the target are allowed to diffuse through the moderator and reflector materials. The arrangement of the TMRA is shown in the Figure 4.

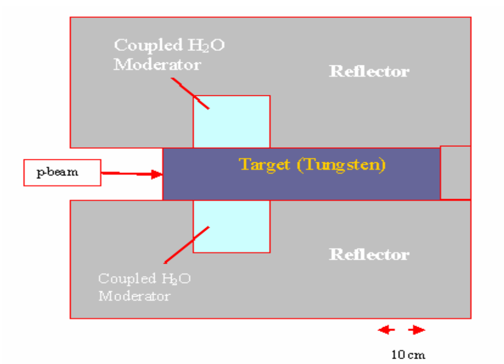
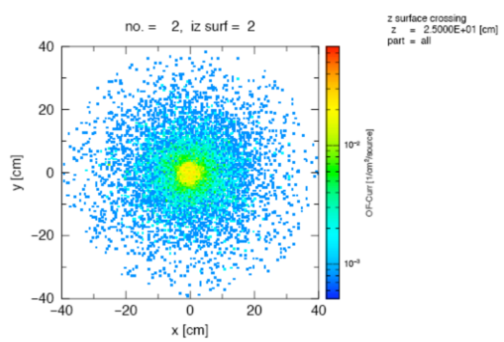
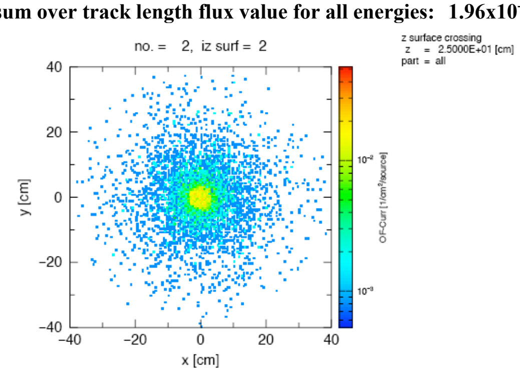


Figure 4: Target position near the centre of the reflector box is most suitable to obtain high neutron flux through the moderator. From the NMTC/JAM code calculations it appears that Pb can serve as a better reflector material compared to Fe.



sum over track length flux value for all energies: 1.96x10^{-3}



sum over track length flux value for all energies: 1.42x10^{-3}

Figure 5: Comparison of surface cross over current for the case of Tungsten (upper) and Pb (lower) target material through light water moderator at same z position suggest higher yield for tungsten target compared to Pb target.

The comparison of tungsten and lead target suggests that the surface cross over current is higher in case of tungsten target over the light water moderator surface than lead target case with sum over track length value for all energy bins of 1.96 x 10^{-3} for W compared to the value of 1.42 x10^{-3} for Pb target, as shown in the Figure 5. Nearly similar comparison exists in the 3rd surface cross over current. The time profile of cut off neutron (20 MeV) obtained with NMTC/JAM shows that Pb can give better neutron yield of neutrons below 20 MeV energies compare to Fe as a reflector material. The escape neutron time profile also suggest that there are less number of escape neutrons in case of Pb reflector compared to Fe reflector case.

CONCLUSION

NMTC/JAM code calculations performed for the ISNS design studies of TMRA for 1GeV proton beam interaction with the heavy metal targets like W, Pb and Ta suggest tungsten to be the most suitable material. Further studies have shown that an elliptical cylinder target shape is suitable for the optimum neutron leakage from the surface of the target. The placement of moderator at a position around 10 cm from the start of the target surface gives maximum neutron flux with moderator at the top of the target in a wing type geometry suitable for better neutronics performance. The track length and surface cross over from the tungsten and Pb targets suggest that tungsten can give better neutron yield. The comparison of Pb and Fe as a reflector material shows that Pb offers superior properties in terms of the neutron time pulse profile giving higher numbers of cut off neutrons and lower number of escape neutrons. In order to make a detailed study of cold and epithermal neutrons generated in the pulsed mode from the TMRA the treatment of low energy neutrons below the energy of 20 MeV would be necessary.

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