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TARGET DESIGN FOR THE ISODAR NEUTRINO EXPERIMENT

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Abstract

This paper focuses on the design of a high-intensity antineutrino source from the production and subsequent decay of ^{8}Li. The Geant4 code is used to calculate the anti-neutrino flux that can be obtained along with the production of undesirable contaminants. We present in this paper the optimised design for the target, moderators, reflector and shielding. Engineering issues associated with this design are also discussed in this paper.

INTRODUCTION

IsoDAR (Isotopes-Decay-At-Rest) is a novel, high intensity source of electron antineutrinos which aims for searches for physics beyond standard model [1]. The goal is to produce 1.29×10^{23} electron antineutrinos per year with a mean energy of 6.4 MeV. IsoDAR consists of an ion source, a cyclotron accelerating the protons to 60 MeV which impinge on a Be target placed next to a kiloton-scale scintillator detector. The IsoDAR experiment requires an accelerator able to deliver 10 mA proton beam at 60 MeV on the target. The solution to provide such a high current is to accelerate 5 mA beam of H_2^+ ions using the DAEDALUS injector cyclotron as a driver [2–4]. As a results of the inelastic interactions of low energy protons or deuterons with the Be target ^{8}Li isotopes are produced which then decay producing electron antineutrinos. Apart from the ^{8}Li isotopes produced in the target, additional ^{8}Li is produced in the surrounding materials by secondary neutrons. Electron antineutrinos are detected by the inverse-beta decay (IBD) process in a detector with large amounts of free protons like multi-kiloton-scale water-Cherenkov or liquid scintillator detectors. Therefore a possible choice for detector is KamLAND in the Kamioka mine in Japan. Another option is to pair IsoDAR with the US-based WATCHMAN detector. It is assumed that the large antineutrino flux from ^{8}Li beta decay can result in the collection of over 8×10^5 IBD interactions in a five-year run [5]. The Geant4 code was used in the simulations with the new charged-particle-hp package. This uses the evaluated nuclear databases from ENDF or TNDL libraries which refer to the total cross sections, inelastic channel cross sections, double differential spectra of outgoing particles and gamma emission due to nuclear level transitions for protons, deuterons, tritium, ^{3}He, alpha and gamma projectiles. The ENDF cross sections are used for protons and neutrons and TENDL calculated cross sections are used for all particle types. The package is used for interactions in the range 0 -

200 MeV. The new model has been successfully debugged, tested and validated against available data.

PREVIOUS TARGET DESIGN

Design considerations refers firstly to a high antineutrino flux and a low background but the target should also pose a low technical risk and be designed for underground operations. The previous target design consisted of a beryllium disc of radius 100 mm and 20 mm thickness followed by 30 mm of carbon and 200 mm of beryllium. The carbon layer was inserted at the Bragg peak location to dissipate the heat deposition [6]. The surrounding FLiBe sleeve had a ^{7}Li purity of 99.99%. The sleeve had a radius of 500 mm and a length of 1100 mm. With this design and considering 60 MeV incident protons the total ^{8}Li production was 0.015 ^{8}Li/p. For 80 MeV deuterons (40 MeV/amu) and considering the same FLiBe sleeve, the ^{8}Li production was 0.026 ^{8}Li/d. The neutron flux out of the reflector is presented in Fig. 1.

Shielding Calculations

In order to fit into the Kamland control room which will provide the space for the target and the surrounding components, the graphite reflector had to be reduced to (1100×1100×2500) mm. The Kamland room is 2.25 m high and minor excavation of the walls will be allowed, therefore in this design the shield is a container box of (500×500×500) mm. Accurate estimates of the neutrons coming out of the shielding into the surrounding cave walls are required for safety reasons. The characteristics of the materials used is a major factor in determining the shielding efficiency. The effectiveness of various shielding materials was simulated for two options: borated concrete (99.99% concrete and 0.01% borax) and borated polyethylene (95% polyethylene and 5% boron). Figures 2 and 3 show the number of neutrons per mm^2 escaping the 500 mm thick shielding normalised to the incoming protons for these two materials. It can be seen that both materials reduce the neutron flux above 10 MeV to $\approx 10^{-12}$ neutrons/proton/mm^2. Below 10 MeV the concrete is less efficient than polyethylene. Peaks and valleys can be observed in both spectra with peaks corresponding to 90 degrees as well as to the forward and backward directions with respect to the beam and valleys corresponding to the corners of the shielding box where more material is present in the neutrons path escaping the shielding.

Simulations have shown a similar neutron flux out of the reflector for deuterons as was for protons. The neutron flux was simulated for 500 mm borated concrete, borated
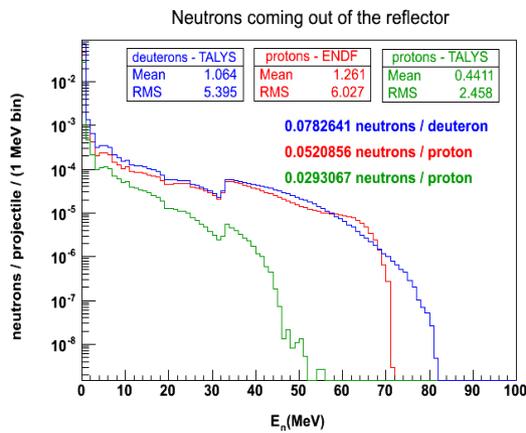
Figure 1: Comparison between the neutron spectra out of the graphite reflector for protons and deuterons projectiles. For protons, the cross sections were calculated with both experimental data and theoretical models.
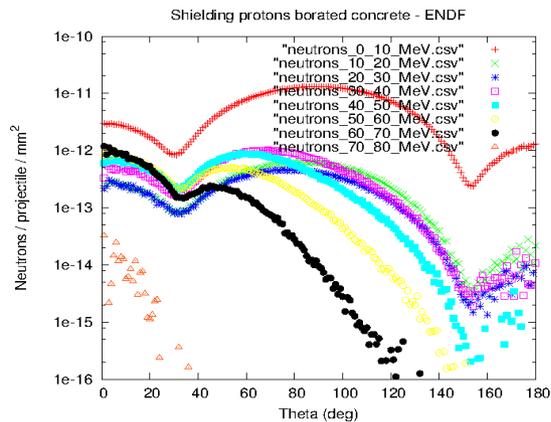
Figure 2: The number of neutrons per mm^2 escaping the 500 mm thickness shielding normalised to the incoming protons. The material used in this calculation is borated concrete.
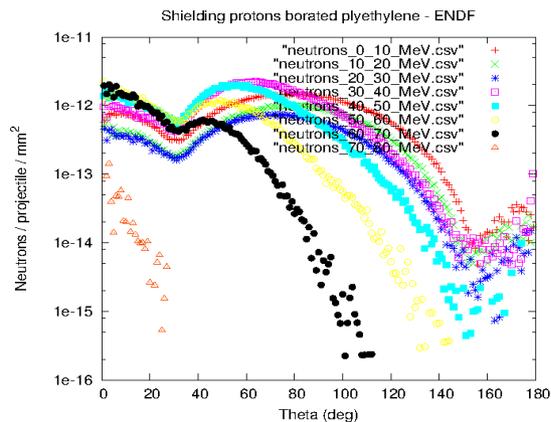
Figure 3: The number of neutrons per mm^2 escaping the 500 mm thickness shielding normalised to the incoming protons. The material used in this calculation is borated polyethylene.

polyethylene and Gd polyethylene and above 10 MeV, the flux was reduced to also $\approx 10^{-12}$ neutrons/deuteron/mm^2. Borated polyethylene and Gd polyethylene gave very similar results.

Although the new particle-hp model which uses ENDF data for protons showed a similar ^{8}Li isotope production rate as with standard Geant4, the predicted neutron flux was much higher. Since the TENDL calculations for protons proved to underestimate the neutron flux compared to what is obtained with experimental cross sections (Fig. 1) we assume that the same happens for deuterons. The neutron flux for deuterons is expected to be higher than the TENDL calculations predict.

CURRENT TARGET DESIGN

For the current target design, the 30 mm carbon disk in the previous target setup was removed and a cooling system was added, while beryllium was replaced with FLiBe in the following 200 mm disk to increase the ^{8}Li production. Also the radius of the Be vessel has changed from 100 mm to 125 mm (Fig. 4). Making the target disk integral eliminates a seal and greatly enhances the heat transfer. The cooling system consists of a central pipe which brings the heavy water in to remove the heat from the upstream end of the Be vessel surrounded by four lateral pipes which leads the heavy water away. With this design a significant amount of heat will be transported around the edges of the target disk and swept away by the water flow. The pipes are made of beryllium for the parts that are inside the FLiBe sleeve to allow neutrons to pass through and steel for the parts that are in contact with the reflector and shielding. The joints shown are either brazed or electron beam welded. The whole system is embedded in a FLiBe sleeve with an enriched 99.995% ^{7}Li and having dimensions of 1900 mm length with a radius of 500 mm. For enhanced production the sleeve is surrounded by a graphite reflector acting as a neutron reflector with a radius of 550 mm and length 2500 mm. Currently, the shield is made of borated concrete and has dimensions $(2100 \times 2100 \times 3500)$ mm.
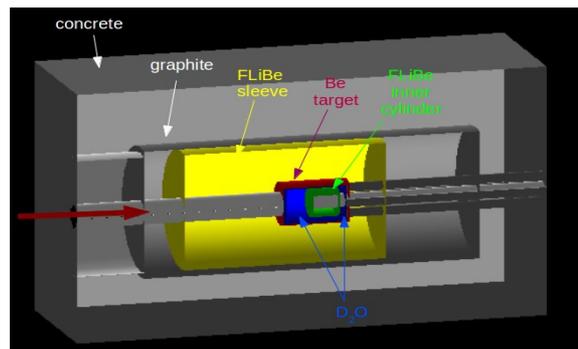
Figure 4: Current design of the ISODAR target with the surrounding components (moderator, sleeve, reflector and shielding).

The beam line module at the upstream end for insertion into the target weighs 178 lbs and it will need a rail system to guide it into the opening. The beam raster magnets that exist in the hole in the concrete need to be removed to replace this module. The target module weighs 609 lbs and it needs to be retracted into a coffin for disposal. It will also need a rail system for guidance. The target module is encapsulated in beryllium for parts in contact with sleeve, steel for parts not in contact with water and stainless steel for water pipes.

Using this design with 60 MeV protons on target the total ^{8}Li production was 0.015 ^{8}Li/p (Fig. 5).
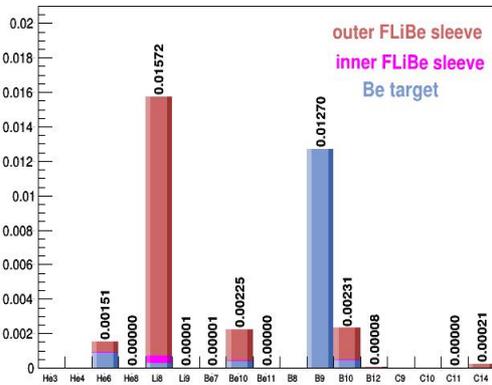
Figure 5: Total isotopes production in the Be vessel and FLiBe components. Different colours represent the contribution to the isotope yield from target, inner FLiBe disk and FLiBe sleeve.
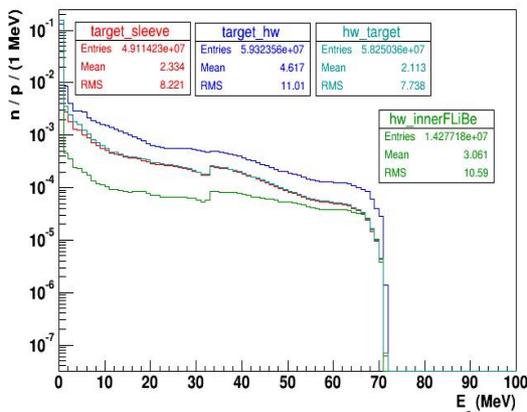
Figure 6: Neutron spectra for neutrons crossing the barrier components.

Studies have shown that there are no significant neutron losses in the heavy water moderator as many neutrons pass through the Be vessel walls and reach the outer FLiBe sleeve (see Fig. 6). From the total number of secondary neutrons

that enter the moderator (5.93×10^7) a large fraction of neutrons are back scattered into the target. A small fraction reaches the inner FLiBe cylinder and a part of them are also scattered back into the moderator. There are back scattered neutrons going down the proton beam pipe but, as expected, the majority will hit the beam pipe walls, the number of neutrons down the beam pipe having a strong dependence on the distance from the target. Based on an analysis of 320×10^6 incident protons, at 71 cm from the target down the beam pipe which represents the front end of the FLiBe sleeve, the recorded number of back scattered neutrons was 3.04×10^{-3} neutrons/proton. Simulation work to specify the exact geometry, dimensions and materials for shielding the neutrons coming out the reflector is ongoing.

CONCLUSION

In the current IsoDAR target design, the carbon disk placed at the Bragg peak location has been removed and replaced with heavy water for cooling brought in and out through water pipes. The following 200 mm beryllium disk has been replaced with FLiBe for neutron production enhancement. The current design gives the same rate for ^{8}Li isotope (0.015 ^{8}Li/p) as the previous design. The target structure has been divided up into pieces for easier assemble and replacement in the underground mine. A target cooling system has been designed and a detailed energy deposition map will be done next for thermal and stress calculation. A quick analysis of how much internal water pressure the Be vessel could stand showed that at 1000 psi (68 bar) the vessel is right at the yield strength of beryllium. An optimisation of the geometry, dimensions and shielding materials is ongoing.

REFERENCES

[1] J.M. Conrad, M.H. Shaevitz, I. Shimizu, J. Spitz, M.Toups and L. Winslow, "Precision anti-ν_e-electron scattering measurements with IsoDAR to search for new physics", Phys.Rev.D 89, 072010, 2014.

[2] L. Calabretta, J.Spitz, "High current cyclotrons for neutrino experiments", Proceeding of Science, XV Workshop on Neutrino Telescopes, Venice, Italy, 2013.

[3] D.Campo et al., "High intensity compact cyclotron for IsoDAR experiment" , Proceedings of Cyclotrons, Vancouver, Canada, 2013, WEPPT030.

[4] F. Labrecque et al, "Cyclotron injection tests of high intensity H2+ beam", Proceedings of Cyclotrons, Vancouver, Canada, 2013, WEPPT026.

[5] A.Bungau et al., PRL 109, 141802, 2012.

[6] A.Bungau et al., "Optimisation studies of a high intensity electron antineutrino source", Procceedings of IPAC 2013, Shanghai, China, MOPFI073.