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VALIDATION OF THE MCNP5 MODEL OF THE BEAM PORT FACILITY AT THE PSBR

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ABSTRACT

The Radiation Science and Engineering Center facilities at the Pennsylvania State University (PSU) include the Penn State Breazeale Reactor (PSBR), gamma irradiation facilities, and various radiation detection and measurement laboratories. The PSBR is a 1 MW, TRIGA with moveable core with pulsing capabilities.

Due to inherited design issues with the current arrangement of beam ports and reactor core-moderator assembly, the development of innovative experimental facilities utilizing neutron beams is extremely limited. Therefore, a new core-moderator location in PSBR pool and beam port geometry must be developed. A study is underway with the support of DOE-INIE funds to examine the existing beam ports for neutron output and to investigate possible new moderator and beam-port designs to produce more useful neutron beams.

Two different methodologies have been developed at PSU. First methodology, Approach 1, uses a diffusion code as the source model for the beam port calculations. The MCNP model consists of the D_2O tank, graphite reflector block, and beam tube with their surroundings. This methodology along with some preliminary results was presented at the PHYSOR-2004 conference. In the second methodology, Approach 2, not only beam port calculations but also the core calculations were performed with MCNP. The same beam port models that are used in Approach 1 are also used in Approach 2 with the exception of the source terms.

The results of the both PSU packages show good agreement with both the experimentally measured data and with each other.

Key Words: MCNP, Penn State, beam port design, TRIGA, spectrum.

1 INTRODUCTION

The Radiation Science and Engineering Center (RSEC) facilities at The Pennsylvania State University (PSU) include the Penn State Breazeale Reactor (PSBR), gamma irradiation facilities, and various radiation detection and measurement laboratories. The PSBR is the nation's longest continuously operating reactor that went critical in 1955. The PSBR is a 1 MW, TRIGA with moveable core in a large pool and with pulsing capabilities. The core is located in a pool of de-mineralized water. When the reactor core is placed next to a D_2O tank and graphite reflector assembly near the beam port (BP) locations, thermal neutron beams become available for neutron transmission and neutron radiography measurement from two of the seven existing beam ports.

When the PSBR reactor was built, MTR type fuel elements with active length of 24” were used. With the MTR fuel the beam port arrangement did not limit the maximum neutron output.

However, in 1965, the original 200 KW reactor core and the control system were replaced by advanced General Atomics TRIGA core with an active fuel length of 15” and analog control system. The new core is capable of operation at a steady-state power level of 1000 KW with pulsing capabilities up to 2000 MW for short (milliseconds) period of time. In 1991, the reactor console system was upgraded to an AECL/Gamma-Metrics dual digital/analog control system.

With TRIGA fuel, only one beam port is at the centerline of the core active area, four beam ports are five inches below the centerline and two are eleven inches below the centerline (below the active fuel region). The PSBR beam port layout is shown in Figure 1. With the current D_2O/Graphite coupling, only two beam ports are currently being used (beam ports shown as red in Figure 1). BP #4, which is located axially at the centerline of the reactor core, is used for research, primarily neutron radiography and radioscopy, and BP #7 with its lower neutron flux level is used for service activities involving neutron transmission measurements. Due to inherited design issues with the current arrangement of beam ports and reactor core-moderator assembly, the development of innovative experimental facilities utilizing neutron beams is extremely limited. Therefore, a new core-moderator location in PSBR pool and beam port geometry is needed. A study is ongoing with the support of DOE-INIE funds to examine the existing beam ports for neutron output and to investigate new moderator and beam-port designs to produce more useful neutron beams.

2 DESCRIPTION OF WORK

Two different methodologies for neutronic modeling of the PSBR have been developed at PSU. The first methodology, Approach 1, uses a diffusion code as the source model for the beam port calculations. In this methodology, core calculations were performed using a three-dimensional nodal diffusion code ADMARC-H [1], which utilizes a few-group cross-section library developed with HELIOS [2]. Next, beam port calculations are performed with the MCNP Monte Carlo code [3]. An interface program has been developed at PSU to link the diffusion code output to the neutron transport code input [4]. The MCNP model consists of the D_2O tank, graphite reflector block, and beam tube with their surroundings. A schematic view of the whole modeled system is shown in Figure 2. This methodology along with some preliminary results was presented at the PHYSOR 2004 conference [4]. The BP #4 configuration was modeled using MCNP. The output of the D_2O tank model is used as the incoming source into the BP #4 model. The results of the MCNP model were compared with the experimental data [5]. An updated plot of this comparison, amounting to better statistics, is given in Figure 3.

In the second methodology, Approach 2, the core calculations were performed with MCNP. In this paper, we report on this methodology and computational results obtained with it for the PSBR beam port configuration.

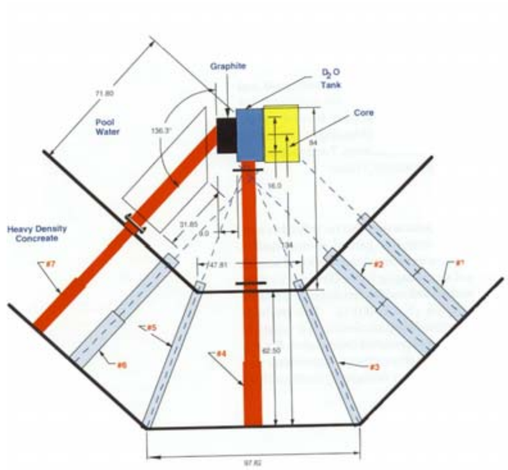

Figure 1. PSBR beam port layout with D20 tank and graphite reflector

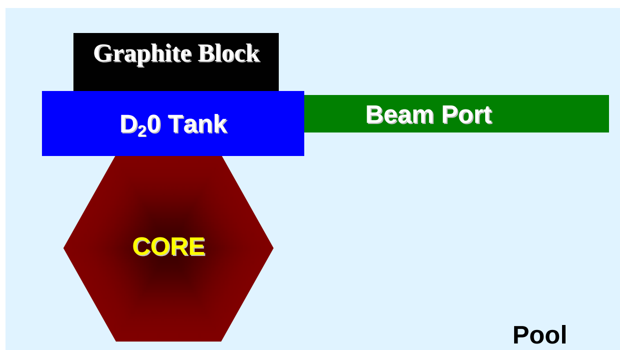

Figure 2. The schematic view of the system

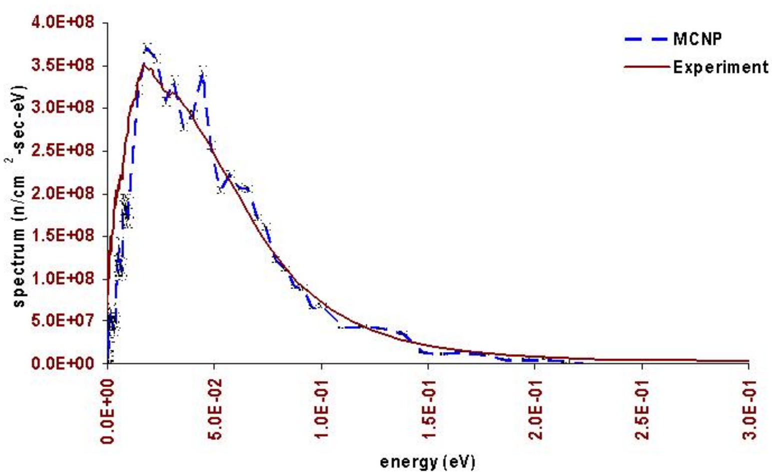

Figure 3. Comparison of BP #4 model result with the experimental data

2.1 Approach 2

The Approach 2 methodology involves MCNP models for all of the three sections of the computational model, the core model, the D_2O tank model, and the beam tube model. The same beam port models that are used in Approach 1 are also used in Approach 2 with the exception of the source terms.

2.1.1 The Core Model

In the Approach 2 methodology, the PSBR core, core loading 51, was modeled by using MCNP. First, the burnup and the fissile content of each individual fuel rod were calculated. Then, this data is combined with the core geometry to form the MCNP model. This model was verified by using the available experimentally measured data [6]. Figure 4 shows the MCNP generated plot of the core used for this study. The core model also includes the full detail D_2O tank model which also includes the graphite reflector and the beam port entry hole. Since the D_2O moderator and the graphite reflector both affect the core, we decided to include the D_2O tank model into the core calculations. The particles passing throughout the core-D_2O tank interface were tracked and printed out into an MCNP generated file.

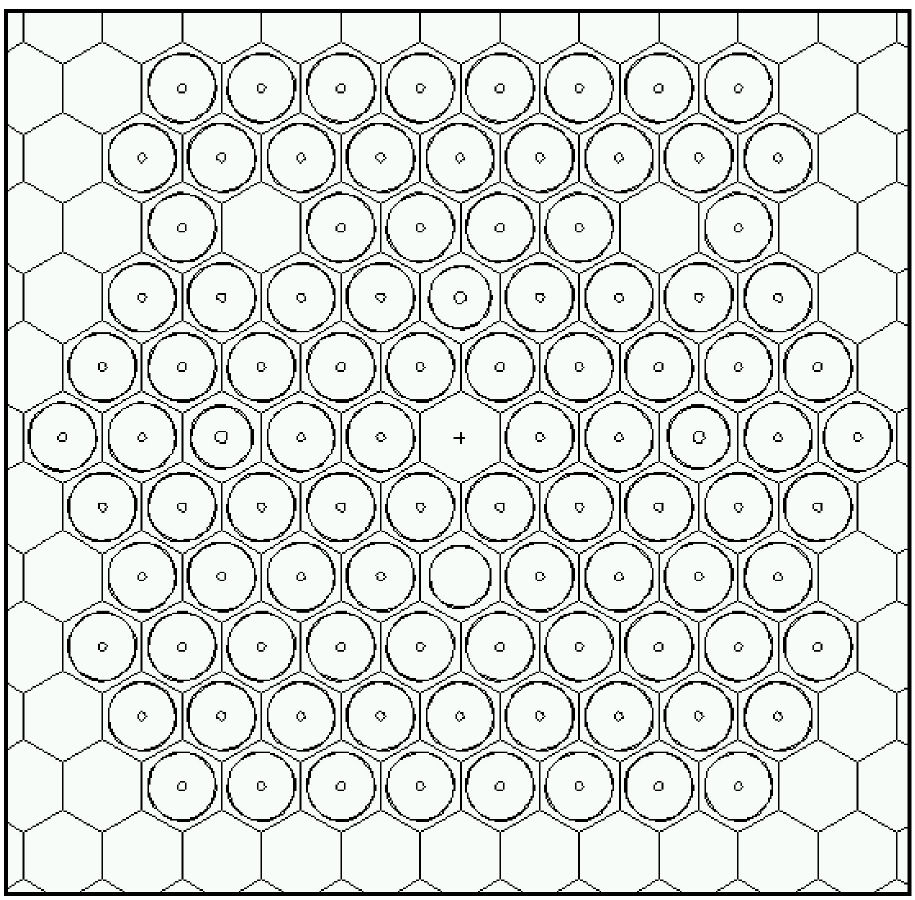

Figure 4. Core model with MCNP

2.1.2 The D_2O tank model

The same geometrical models developed for the Approach 1 methodology are also used for this study. The only difference is at the source definitions of the D_2O tank model. In the Approach 1 methodology, the user supplied tallies are used as the source term. However, in the Approach 2 methodology, the MCNP generated external source file, *wssa*, is used. The preliminary results of the Approach 2 methodology and the comparison of the two methodologies at the exit of the D_2O tank, i.e. the beam port entry hole exit, is given in Figure 5.

In the Approach 2 methodology, in addition to the neutron analysis, gamma calculations are also taken into account. The resulting tally plot and the gamma spectrum at the same location as Figure 5, are given in Figures 6 and 7, respectively.

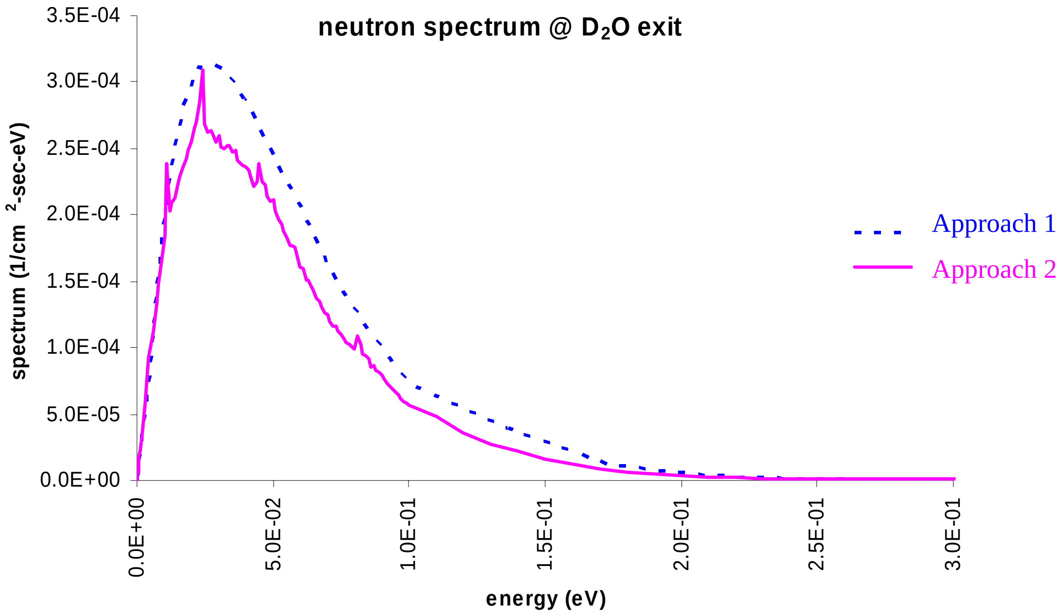

Figure 5. Neutron spectrum at the end of the beam port entry hole for both methodologies.

2.1.3 The beam tube model

The same beam port model developed for the Approach 1 methodology was used in this study [4]. The only difference is in the source definition as in the case of D_2O tank models mentioned in the previous section. The combined model is shown in Figure 8.

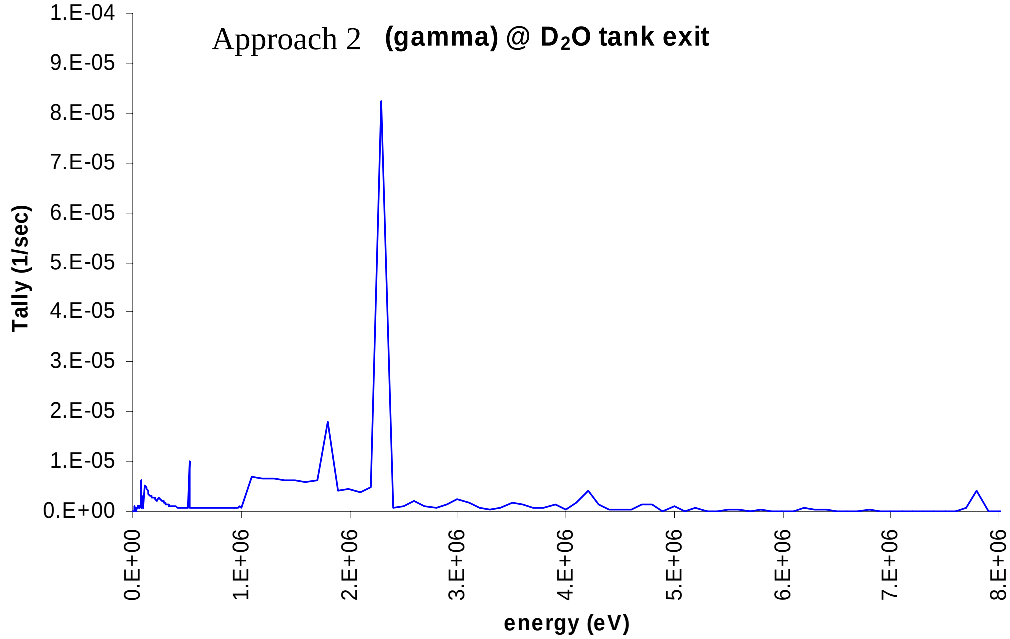

Figure 6. Gamma tally at the end of the beam port entry hole for Approach 2.

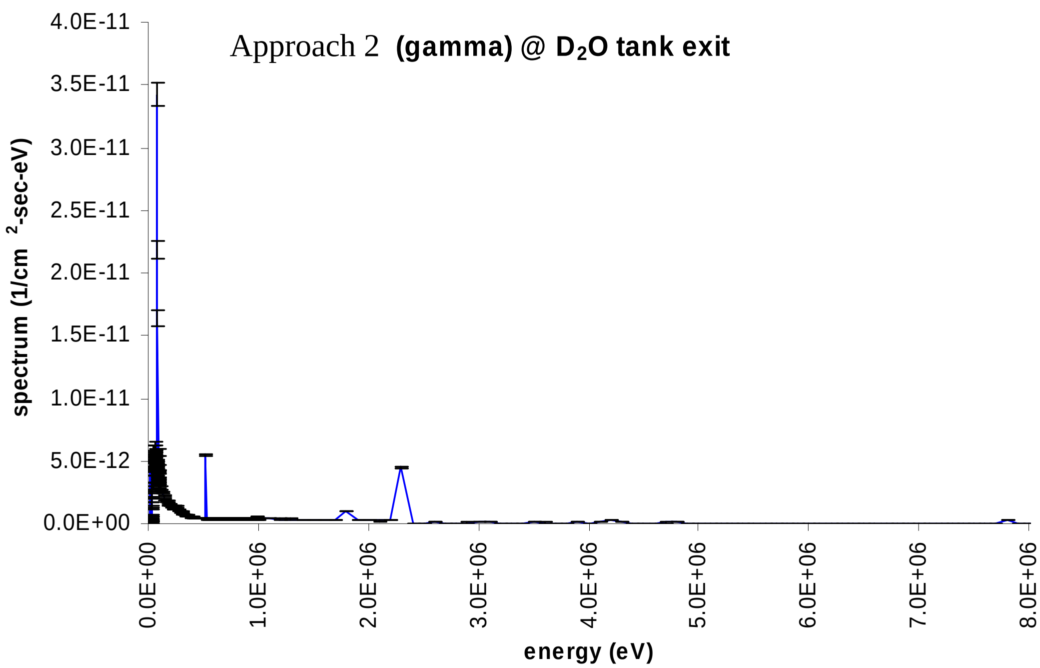

Figure 7. Gamma spectrum at the end of the beam port entry hole for Approach 2.

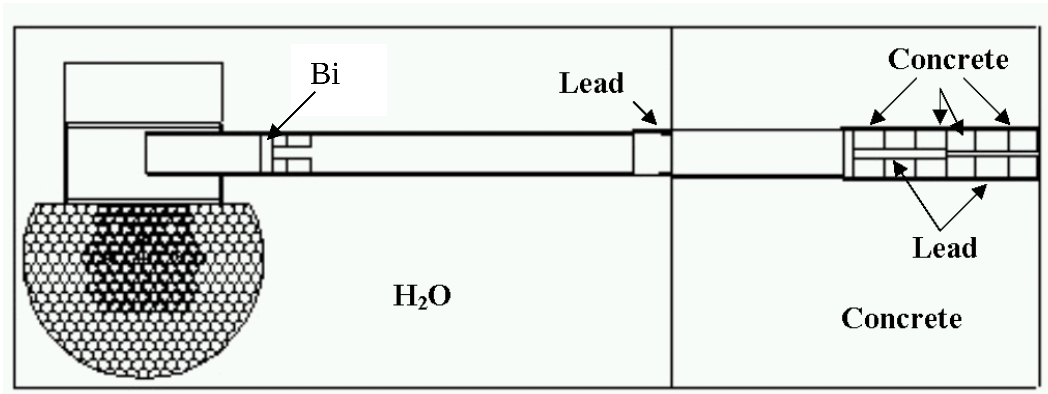

Figure 8. Combined model of core, D_2O and beam port

To observe the neutron collision points in D_2O tank and around D_2O tank, VISed MCNP is used. The result is shown in Figure 9. The number of tracked histories is increasing from left to right in this figure. It is observed that there are many collisions in the H_2O surrounding the D_2O tank. This leads to 2.23 MeV prompt hydrogen gamma rays that may stream down the beam tube. This observation will be useful to the future design of the new beam ports.

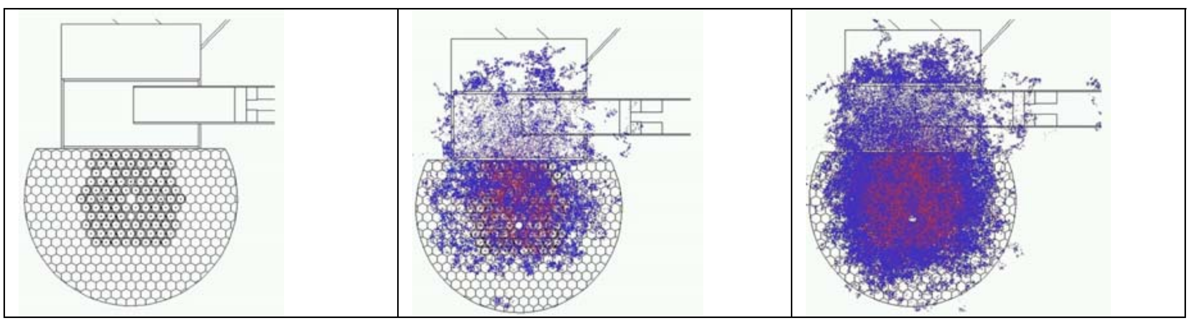

Figure 9. Neutron collision points in the combined model

Since the beam tube model is very large, the neutron spectrum at the exit has not been simulated yet. Some variance reduction techniques have been tested to achieve better statistics in the computed results at a reasonable computational cost.

In the computational models, the location of the beam port entry into the D_2O tank was changed to observe the location's influence. The original location of the beam port is demonstrated in Figure 8. Axis of the beam port was changed with respect to this original location. Figure 10 shows that the neutron flux increases monotonically as the beam port gets closer to reactor core. The neutron spectrum was calculated before bismuth insertion (see Figure 8).

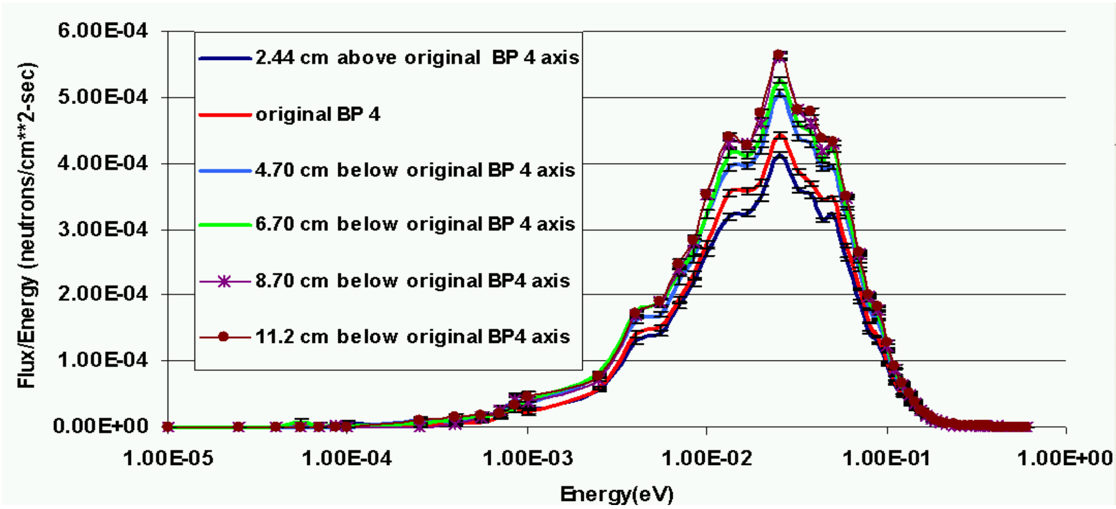

Figure 10. Neutron spectrum variance with changing the location of beam port 4

Beam port seven is added to combined model as seen in Figure 11. Because of the very deep structure of beam port seven, some variance reduction techniques have been tested. The neutron spectrum at the exit is not simulated yet. Neutron spectrum at the entrance of the beam port 7 is shown in Figure 12.

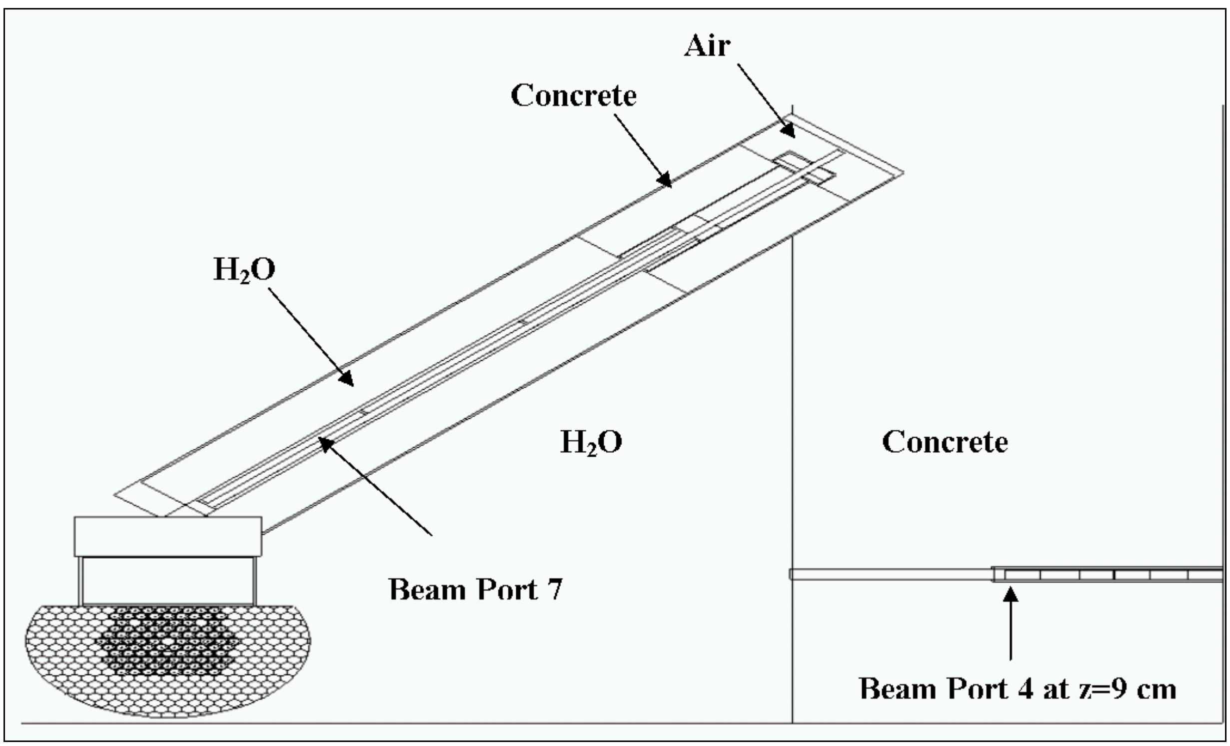

Figure 11. Beam port seven in the combined model

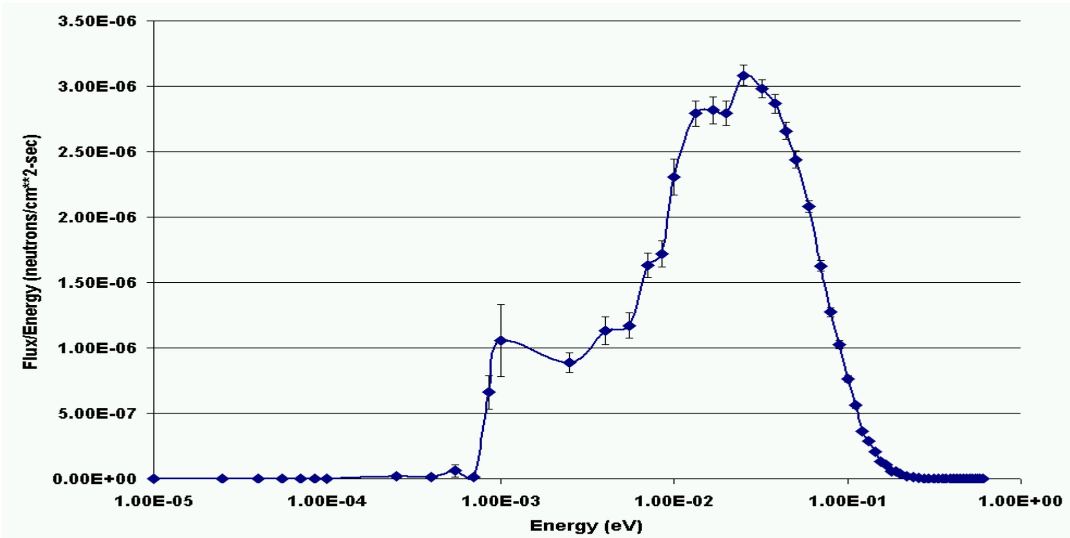

Figure 12. Neutron spectrum at the entrance of the beam port 7

3 CONCLUSIONS

The comparison of the PSU Computational Package with the experimental data, Figure 3, and the comparison of the two methodologies used, Figure 5, show that the computer models for the combined core and beam-port calculations give good agreement with both experimental data and with each other. In the Approach 1 methodology, even though the number of histories performed (nps) for this study reached to the current limit of the MCNP5 version 1.14, the statistical error, especially in the D_2O tank calculations, is still higher compared to the Approach 2 methodology results. The advantage of the Approach 2 methodology over the Approach 1 methodology is, once the core conditions are fixed, one doesn't need to run the core model for every sensitivity study. The user can use the same source file generated with the fixed core conditions. The other advantage of the Approach 2 methodology is with the runtime of the calculations. Since Approach 2 uses a more accurately defined source term in terms of the particle information, the required cpu time for the Approach 2 methodology is 30-50% less than that of the Approach 1 methodology to reach the same statistical error level. Hence, we decided to continue with Approach 2 for the further calculations and computations.

Although the statistical error associated with the beam port side calculations is relatively lower, since the D_2O tank results are used as input in the beam port calculations, the error in D_2O tank calculations is carried into the beam port calculations.

4 ONGOING AND FUTURE WORK

Beam port #7, shown in Figure 1, is also being studied by using the same methodology and the computational tools.

The optimization of the beam port entry hole location for BP #4 is still continuing. The main goal of this optimization study is to find the best location of the beam port entry position in the D_2O tank in terms of the maximum thermal flux.

The D_2O tank model for the Approach 2 methodology is still being run to reduce the statistical error and increase the number of particle tracks in the source term that will be used for the beam tube calculations. Once the D_2O tank model run is completed, the beam tube model will be run by using the same methodology described in section 2.1.3

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