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NOTE ON THE DEVELOPMENT, BENCHMARKING AND VALIDATION OF THE APT NEUTRONICS ENGINEERING CODE[1]

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Abstract: Tritium production modeling can be used to gain cost savings and schedule improvements. However, at present much of the predictive uncertainty is in the modeling of neutron generation and transport, and tritium production in the target. These uncertainties require engineering design margins, primarily contingencies that increase the facility cost. Much of the uncertainty associated with the codes, in the (20-30)% uncertainty range, is thought to be due to multiple scattering (leakage) of high energy neutrons and possibly protons in the radial directions of range thick targets of less than (20-30) cm diameter. It is estimated that a well carried out neutronics measurement program coupled with high-energy transport code development could reduce the predictive engineering neutronics code uncertainty to the few percent level for all local or global geometries of use in the APT engineering design. This level of precision would then be comparable to the neutronics core physics codes employed in nuclear reactor design engineering. Following the improved engineering neutronics code development the overall engineering design contingencies for APT could then be reduced from the present (50-65)% level down to the more acceptable (25-30)% level.

1. INTRODUCTION

Integral neutron production measurements on range-thick complex/composite targets are required to benchmark, test and validate the upgraded Monte Carlo High Energy Transport Codes (HETC'S) such as LAHET and TIERCE. One of the deficiencies of the earlier HET codes was the observed discrepancy in the comparison of the doubly differential high-energy cascade neutron components in the back-angle data. LAHET corrected this problem by including pre-equilibrium in the cascade process. Excellent agreement now exists between the code and measurements obtained for thin targets. The Sunnyside experiments at LAMFF, using the Mn bath integral neutron measurements with very large diameter range-thick targets, i.e., a tungsten (W) target with 20 cm diameter and surrounded by a 60 cm diameter lead collar (acting as a neutron multiplier for escaped particles) were found to be in excellent agreement with LAHET simulations, in the range of (2-5)% agreement (Ref. 1).

The first measurements of integral neutron yields produced with (0.8-4.0) GeV protons on thick Pb targets (10 cm dia by 61 cm length) were performed in 1965 at the BNL Cosmotron (Ref. 2) and later at Harwell (Ref. 3). Those results consistently disagreed with HETC calculations. The differences at 1.5 GeV proton energy between the measured and calculated yields were approximately 18%. Those measurements were made with water bath detectors using Au foil or Mn bath activation techniques. The experimental errors were quoted to be in the (5-10)% range, well below the difference between the calculated results of the HETC simulations and the measurements. More recent results measuring the neutron leakage from a 20 cm diameter by 60 cm length Pb target by the Russians at Dubna in the proton energy range of (1.0-3.7) GeV (Ref. 4) have shown major differences (27% discrepancy) in the high-energy neutron leakage when compared with LAHET/PEQ (with pre-equilibrium) calculations. General agreement (<8%) was found for the low-energy isotropic neutrons. In addition, the most recent integral neutron measurements (Ref. 5) using the Brookhaven Integral Neutron (BIN) detector

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with (800-1400) MeV protons on a 10 cm dia. By 60 cm length Pb target are in excellent agreement with all previous 10 cm dia. Target measurements made over the past 30 years. The overall least square fit to all data was within +/- 1.6% at the 95% confidence level indicating the global experimental agreement of those measurements. The new LAHET/PEQ calculations reduced the overall disagreement from 18% to the (10-12)% level.

2. DISCUSSION

The overall importance of this leakage relates to "local geometry" effects in complex/composite stopping-length targets and the location of decoupling (thermal neutron absorption) materials such as He-3 and Li-6 within the assembly. Indeed the very good agreement with the large diameter (60 cm) targets in the Sunnyside experiment points to some possible minor physics adjustments to the LAHET code system (see Ref. 6 for details). Corrections to the LAHET/PEQ code which properly takes into account these local effects should allow comparisons of measured and simulated integral neutron production to the few-percent level for the full range of complex and composite target geometries at all energies of interest. The two complementary detectors to be used in the experimental benchmarking and validation are capable of measuring the integral neutron production rates with total absolute uncertainties of a few percent or less. This unprecedented capability will allow high-precision measurements to be made that will enable one to test and validate the HETC's such as LAHET/PEQ with MCNP in complex target arrays to the few % level of uncertainty. Currently, low energy neutron transport codes such as MCNP, which are used for nuclear reactor design engineering simulation, have total absolute uncertainties in the (0.5-1.0)% range at the 95% confidence level. The use of the Los Alamos Code System, LAHET/PEQ with MCNP, validated to a high level of confidence and low uncertainty would reduce the overall cost and risk of engineering design of the various target/blanket assemblies to be considered for APT, ATW, SNS, and other accelerator based applications.

The LANL (Ref. 1) and BNL (Ref. 5) detector systems can provide complementary datasets that are well correlated at 800 MeV proton energies on elemental W and Pb targets. The LANL detector is well suited to large complex/composite target assemblies whereas the BNL detector accumulates data on an event-mode basis at a rate of several kHz and is ideal for survey experiments. Thus the LANL manganese water bath technique relics on neutron activation and subsequent gamma ray decay analysis of the manganese sulfate solution to determine the production rate of Mn-56. This activation experiment requires high beam currents with total intensities of 4E14-1E15 particles on the target or about 8-hour bombardments. The number of targets and beam energy variations are limited by the long bombardment times and the wait for Mn-56 decay to low levels. The BNL detector is a high density CH2 moderated assembly with He-3 proportional counter tubes which electronically operate as a multiplicity/correlation integral neutron counter. It is about 33% efficient, operates at count rates up to a few kHz and only requires beam intensities of a few hundred particles per se cond. It is well suited to survey experiments in which a matrix of targets, projectile energies and type can be quickly varied. However, the present small diameter of the barrel (15 on diameter) does not allow massive radial target dimensions nor is it well suited at present for scaled down complex/composite target measurements. The present BIN detector would have to be rebuilt to accommodate larger and longer targets (60 cm dia. By 150 cm length). An added advantage of this type of detector operated on a secondary beam line such as the AGS is that both proton and pion cascade neutron production can be compared in the same experimental configuration under almost identical operating conditions. Therefore, a comparison of the ratio of neutron production with the two projectile cascades when compared with the LAHET code predictions will allow a measurement of the systematic uncertainties of the code calculations (all statistical and systematic uncertainties associated with the detector cancel almost exactly). The LANL and BNL detectors are capable of being calibrated to an absolute uncertainty in the range of a few percent thus providing a correlated, consistent experimental database which we can have a high level of confidence in.

Total neutron cross section measurements were carried out several years ago at the WNR by Finlay and Rapaport (Ref. 7) and a more recent proposal by Dietrich et al. (Ref. 8) will extend those measurements. In addition, recent measurements (Ref. 9) of neutron elastic scattering cross sections have been made at the WNR on a variety of isotopes, C-12, Ca-40 and Pb-208, at energies of 52.5 MeV to 225 MeV and compared with three optical model calculations. These type of measurements are of fundamental importance for the understanding of neutron-induced reactions. In particular, total cross sections are essential in the

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development and parametrization of nuclear optical-models. These models are a key ingredient in the calculation of reaction cross sections, and they place an important constraint on the sum over all reaction channels calculated by intranuclear cascade codes such as LAHET.

3. RECOMMENDATIONS

Improvement of the neutronic production and transport code calculations of LAHET Code Systems will require a benchmarked and validated experimental databases of the following: a) measurements of neutron production on Pb and W targets (and possibly lower mass elements) of various radial dimensions (10-60) cm at proton energies of (800-2000) MeV using both the LANL and BNL detector systems, b) total neutron elastic and inelastic scattering cross section measurements in the neutron energy range of 50-200 MeV parametrized by means of c) a new optical-model potential for physics improvements in LAHET in the neutron energy range of (20-200) MeV.

REFERENCES

1. "Differential Neutron Production Cross Sections for 800-MeV Protons," W.B. Arnian, et al., Nucl. Sci. and Eng. **112**, 78-86 (1992).

2. "The AECL Study for an Intense Neutron-Generator", J.S. Fraser, et al., Physics in Canada, **21** (2) 17 (1965).

3. "Neutron Yield from Protons and Deuterons of Momenta between 0.85 and 1.7 GeV/c Totally Absorbed in Lead", D. West and E. Ward, Canadian J. Phys. **49**, 2061 (1971).

4. R.G. Vassikov, et al ICANS-XI, KEK, Tsukuba, Japan, Oct. 22-26, 1990.

5. "The BNL (N/P) Experiment", M. Zucker, et al., BNL Technical Report to Doe on APT, September 1994.

6. **"Recent Advances in Integral Neutron Measurements"**, T.E. Ward, Joint DAM/DOE Workshop on APT, September 1994 held at CEA/Bruyeres-le-Chatel.

7. R.W. Finlay, et al., Phys. Rev C47, 237 (1993).

8. F.S. Dietrich, et al., LANSCE/WNR Proposal No. 4N0095, "**Neutron Total Cross Sections in the 5-600 MeV Range**". March 1996.

9. J.H. Osborne, Jr., Ph.D. Dissertation, Univ. of California at Davis (1995), "**Measurement of Neutron Elastic Scattering Cross Sections for 12-C, 40-Ca, and 208-Pb at Energies from 52.5 MeV to 225 MeV with Angles from 7 degree to 23 degree**".