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Neutron Multiplicity Measurements for the AFCI Program Quarterly Progress Report June-August 2004

Denis Beller
University of Nevada, Las Vegas

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UNLV Transmutation Research Project
Principle Investigator: Denis Beller, Ph.D.

Purpose and Problem Statement

The U.S. Advanced Fuel Cycle Initiative (AFCI) is a program to develop economic and environmental methods to reduce the impact of waste from commercial nuclear fuel cycles. One concept for near-complete destruction of waste isotopes from used nuclear fuel is accelerator-driven transmutation. High-power accelerators would be used to produce high-energy charged particles, which then collide with heavy metal targets to create a cascade of neutrons. These neutrons then cause a nuclear chain reaction in subcritical systems. Fission neutrons then transmute fissile waste isotopes as well as other problematic isotopes such as technetium-99 and iodine-129. To design these systems, complex reactor physics computer codes and highly detailed data libraries are used to compute the reactivity of systems, reaction rates, destruction rates, and nuclear-induced damage rates to materials. In this project, we will use a Russian-built detector system to make measurements of neutrons generated in a central target by a variety of accelerators. We will also use the most advanced high-energy radiation transport code, MCNPX, to model the experiments. Experimental results will be compared to computational predictions and discrepancies will be investigated. We will conduct experiments using a 70-MeV proton cyclotron at the Crocker Nuclear Laboratory at the University of California at Davis and/or a 20 to 40 MeV electron linac (linear accelerator) at the Idaho Accelerator Center (IAC) at Idaho State University (ISU). Finally, we will use the 800-MeV linac at the Los Alamos Neutron Science Center at Los Alamos National Laboratory.

Personnel

Principle Investigator: Dr. Denis Beller (UNLV Mechanical Engineering)
Students: Mr. Dean Curtis, Undergraduate Student (Computer Science); was absent from the project during the summer. Mr. Timothy Beller, Undergraduate Student (Mechanical Engineering) worked full time during the summer to perform MCNPX calculations and conduct experiments using accelerator-generated neutrons at the IAC. Shruti Patil, a graduate student, was hired at the end of the quarter to plan and conduct an experiment with the NMDS at the Los Alamos Neutron Science Center (LANSCE) or at Brookhaven National Laboratory (BNL). Ms. Patil is majoring in computer engineering at UNLV. She will also upgrade the capabilities of the NMDS and improve data acquisition and analysis software.
National Laboratory Collaborators: Dr. Eric Pitcher (AFCI Experiments, LANSCE-12, Los Alamos National Laboratory); Dr. Stephen Wender (LANSCE-3 Group Leader, Los Alamos National Laboratory); and Dr. Michael Todosow (Brookhaven National Laboratory)
DOE Collaborator: Dr. Thomas Ward (UNLV Russian Collaboration Science Adviser, TechSource, Inc.)

Completion Percentage

June: 48%
July: 55%
Aug.: 60%

Management Issues:

Personnel: None

Budget Issues: None

Summary Report

The NMDS was used in conjunction with an accelerator at the IAC to determine it's performance. This involved disassembling the system, packing it in its shipping crates, transporting it to ISU, reassembling it, and conducting a series of accelerator-driven experiments. After the experiments were completed, the system was returned to UNLV and reassembled there.

ISU-IAC Experiments

In preparation for experiments at the Idaho State University (ISU) Idaho Accelerator Center (IAC), several different configurations were designed to determine how the detectors would perform: three cubic configurations—BCube (see Figure 1), BCube2 and BCube3—and two rectangular accelerator target configurations—AT-1 and AT-2. All five configurations were modeled in MCNPX prior to the experiments. The AT-1 and AT-2 configurations were created in anticipation of conducting neutron multiplicity experiments on the 800 MeV proton linear accelerator (linac) at the Los Alamos Neutron Science Center.

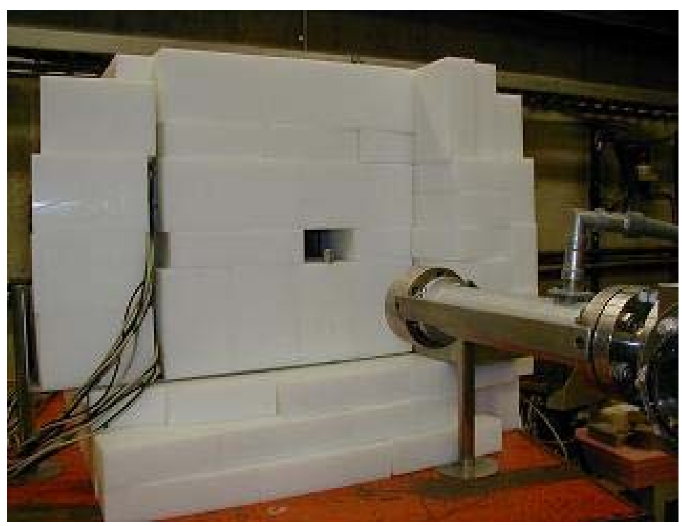


Figure 1. Front of Bcube. The AmBe source can be seen in the opening. The beam height had not been adjusted in this photograph.

The system was transported to the IAC, where a linear accelerator (linac) was used to place an electron beam on the front face of the Pb. Initial background readings at the IAC showed that, overall, the system was still performing properly after being transported. The average background reading was less than 1 count/s inside the IAC, which is shielded from cosmic radiation by several feet of earth.

NMDS Performance

An AmBe source with a neutron production rate of 2500 ±10% n/s was placed against the face of the Pb in all 5 configurations to measure the overall efficiency of the system. The system measured an average of 88 counts/s from all configurations, giving us an average efficiency of 3.5%.

Testing commenced with the electron beam using the BCube configuration. During this time, the beam was adjusted so that it worked within the boundaries of the detectors. The system was tested with frequencies of 15, 30, and 120 Hz. At 120 Hz, the dead time of the detectors caused the system to acquire data for only 20-25% of the pulses. After the initial test runs, the frequencies were restricted to 15 Hz and 30 Hz for data acquisition, which allowed date to be acquired for 82-99% of the pulses received from the accelerator. All beam results presented herein are from a 15 MeV beam at a frequency of 15 Hz, a current of ~200 μA, and a pulse width of ~2 ns.

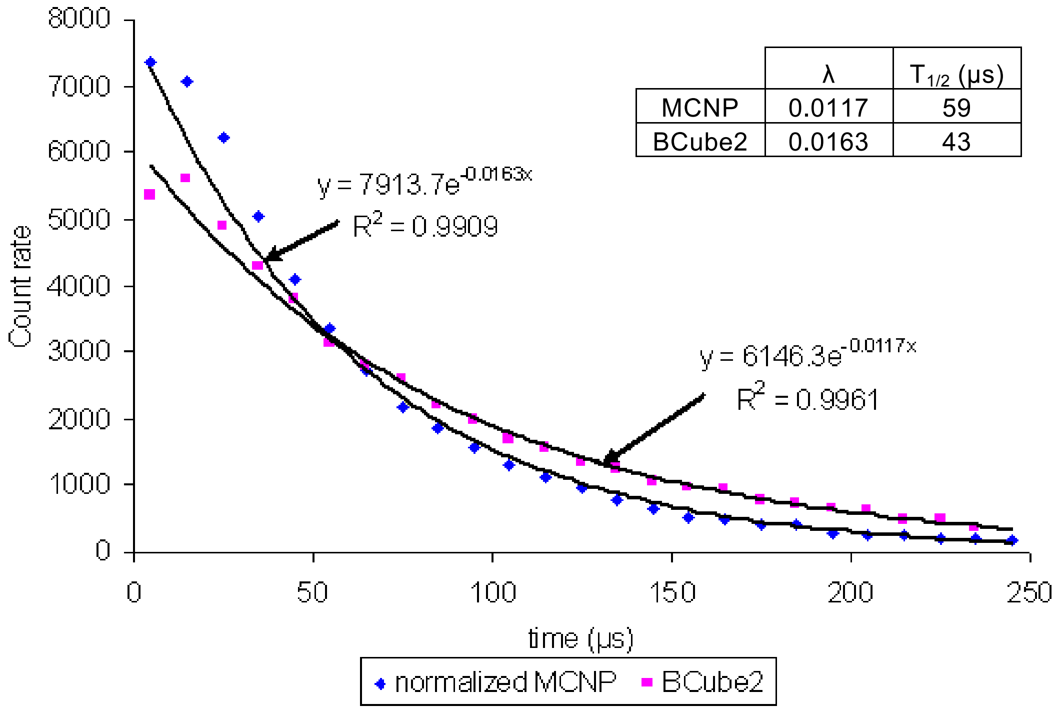
Several parameters and results are examined and compared to radiation transport predictions in these studies. These parameters include the neutron absorption time or lifetime, efficiencies of the systems and individual detectors, and multiplicity distributions. All results from the ISU-IAC accelerator-driven experiments were influenced by a count-rate limitation that is inherent in the NMDS hardware and software.

Efficiency: Calculations using MCNPX produced far greater efficiencies than were generated in the experiments. Efficiencies for BCube, BCube2, and BCube3 in MCNPX were 17%, 19% and 27%, respectively, while experimental efficiencies were 2.9%, 1.3% and 3.2%. These values are similar to the low efficiency measured with the AmBe source, and about an order of magnitude less than that measured with a ^{252}Cf source at UNLV.

Neutron Lifetime: In the BCube configuration, the average lifetime for absorbed neutrons was 71 μs. MCNPX modeling for this configuration produced average lifetimes of 44 μs. Lifetimes were lower in BCube2 (see Figure 2) because the electron beam contacted the Pb in the center of the configuration. This caused the neutrons to reach the detectors more quickly, with an average lifetime of 59 μs experimentally and 43 μs in MCNPX. In BCube3, there were a total of 23 detectors that were moved 5 cm closer to the Pb and were no longer blocked by a layer of polyethylene. As expected, the lifetimes further decreased to around 55 μs experimentally and 39 μs in MCNPX.

Neutron Multiplicity Distribution: Neutron multiplicity distribution were corrupted because of the 256-μs data acquisition window of the NMDS. We determined that "events" with few counts were recorded that should have been part of the immediately previous event. This produced a skewed multiplicity distribution. We are investigating manipulating the data to combine multiple events into one, which may also impact the calculated neutron lifetimes.

Individual Detector Performance: A comparison of the measured versus predicted count rates in the AT-1 configuration is illustrative of detector performance. Fig. 3 shows the measured and predicted fraction of total neutrons absorbed by each detector. The fraction of total neutrons absorbed in the left-side detectors (43-54) was very close to that of the right-side detectors (13-24). The same was true for a comparison between the top (1-12) and bottom (31-42) detectors. In the experiment the bottom and top detectors performed nearly the same, with the bottom counts being slightly lower because at the bottom neutrons are reflected from the steel frame. MCNPX calculations, however, had more extreme variations. While the left and right sides were very similar in the experiments, in MCNPX the top and bottom absorptions were not. In MCNPX calculations, the top row of detectors absorbed a much greater fraction of neutrons than the bottom row. For example, detector 3 on the top row absorbed 7.7% of the total neutrons, but detector 33, which occupies the same position on the bottom row, only absorbed 4.9%.



	λ	$T_{1/2}$ (µs)
MCNP	0.0117	59
BCube2	0.0163	43

Figure 2. BCube2 Lifetime. A numerical fit of neutron capture times for BCube2. Calculated lifetimes from experimental data and from MCNPX are also shown.

It was also noted that the ratio between absorptions in the inside detectors and their corresponding outside detectors was much larger in MCNPX than in the experiments. For example, in MCNP, detectors 31 and 32 measured 4.6% and 2.0%, respectively, a ratio of 2.3. Experimentally, they measured 5.0% and 4.2%, a ratio of only 1.2. This was true for all of the detectors at the front of the system (nearest the beam impact point). Due to the length of the Pb in this configuration, counts at the back of the system are so low and the statistics so poor that comparisons are only qualitative.

Other Issues

Another issue we encountered was that our counting system would “lock up” at random times. We determined that it was caused by an option in the detector settings that we could turn off without affecting our ability to use the system for accelerator target experiments. It does not seem to be related to counting rates, and may simply be a MS Windows failure. Our computer crashed and had to be recovered.

Conclusions and Future Plans

The experiments conducted at the ISU IAC provided a much better understanding of the capabilities and limitations of the NMDS. The system is severely limited by source rate. At moderate frequencies, the percentage of events recorded begins to decrease significantly. During the analysis of the data from ISU, it was also noted that the 256 μs data acquisition window is not sufficient to record all of the neutrons in the system. Attempts will be made to alter the software to provide a longer timeframe for recording counts.

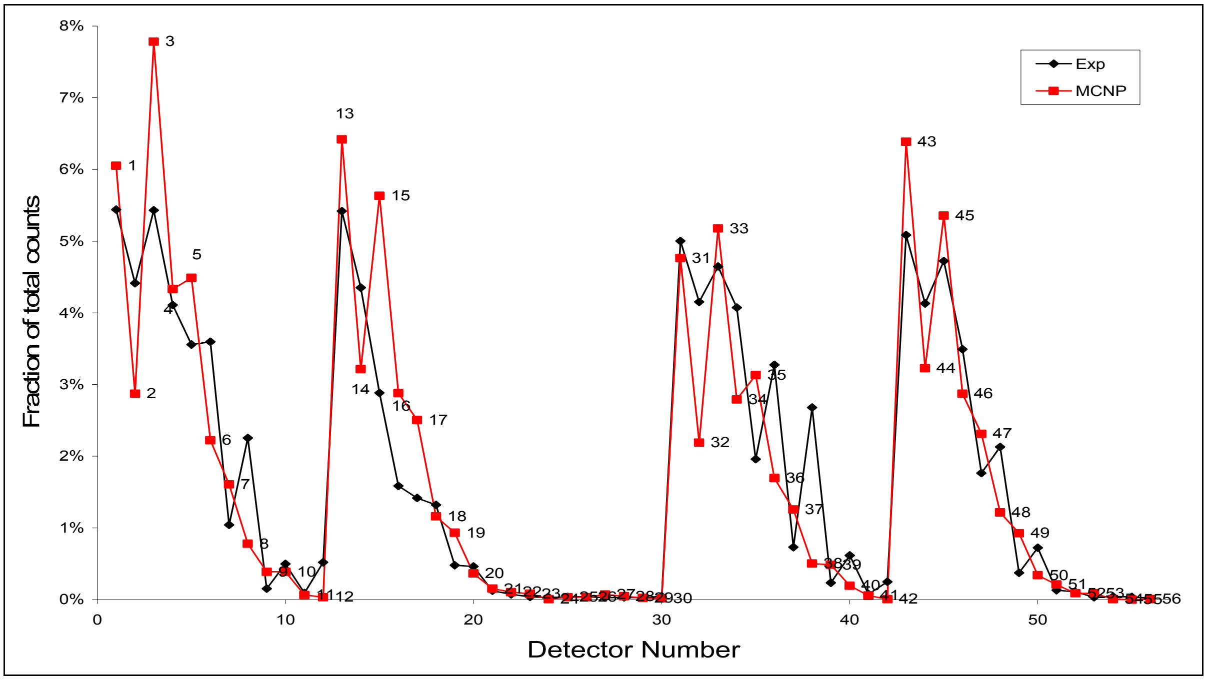


Figure 3. AT-1, Fraction of Total Counts by Detector Number, MCNPX vs. Experiment. Side detectors are 13-24 and 31-42, top detectors are 1-12, bottom detectors are 31-42.

The NMDS is also limited by dead time. In the future, we will attempt to develop the capability to calculate an accurate value for the average dead time in the system. Once the effect it has on the results is determined, then progress can be made on reducing it. We believe that the 15 MeV electron beam was too strong relative to the current dead time. If the dead time can be decreased, better results may be seen with the same beam. Future plans include using the NMDS to measure neutron multiplicity with an 800 MeV proton beam.

Other

A paper and a poster titled "The UNLV Neutron Multiplicity Detector System" were drafted for presentation to the Eighth Information Exchange Meeting on Actinide and Fission Product Partitioning & Transmutation, 9-11 November 2004, Las Vegas, Nevada.