THE UNLV NEUTRON MULTIPLICITY DETECTOR SYSTEM

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Abstract

Efficiency, accuracy, and limitations of the UNLV Neutron Multiplicity Detector System (NMDS), a modular ^{3}He detector system, were tested with a pulsed 15 MeV electron beam from a linear accelerator at the Idaho Accelerator Center (Idaho State University). We conducted experiments with five different NMDS configurations. Each configuration was modeled with the MCNPX radiation transport code to predict neutron lifetime and detector response. Results and comparisons are reported herein. MCNPX results indicated that efficiencies should be an order of magnitude greater than measured. In addition, predicted neutron lifetimes were around 70% of measured lifetimes. The discrepancies are likely a result of count-rate limitations (dead time) in the NMDS, but evaluation continues.

Introduction

The University of Nevada, Las Vegas (UNLV) Neutron Multiplicity Detector System (NMDS) is a modular system made up of 64 individual counting tubes. The detectors are 40 cm long by 5 cm square. Each detector contains a tube measuring 28.5 cm long and 1.55 cm in diameter that is filled with a mixture of Helium-3 (^{3}He) and Argon (Ar) at a pressure of 4 atm. Each detector also contains a preamplifier which sends a signal to a high-voltage box when a neutron is captured. The high voltage boxes are controlled by a special computer which records data and sends it to a standard PC. The data acquisition program is controlled through *Windows* and allows the user to customize the parameters of the data received. When a neutron count is registered in any detector, it is given a time-bin of 0 and the entire system begins counting neutrons. The absorption times and locations are recorded for 256 microseconds and then the system is reset. A complete description of the system and explanation of its operation are included in a previous paper.[1] The NMDS system was built by the V. G. Khlopin Radium Institute in St. Petersburg, Russia.

Validation of the NMDS at UNLV

The NMDS system in the cubic configuration was tested at UNLV to ensure accuracy of all detectors and the reliability of the system as a whole. A configuration made up of 60 detectors surrounding a 30 cm by 30 cm by 30 cm cube of lead (Pb) bricks (Fig. 1) was utilized. We began acquiring data with varying amounts of Pb ranging from zero to six layers. Results from these tests were compared to determine the performance of each individual detector. All detectors performed as expected for the amount of Pb in the center and their relative position in the system. Fig. 2 shows an example of the percentage of total counts by detector position for 44 of the 60 detectors used in this cubic configuration with 6 layers of Pb. Each detector compares favorably with the detector that mirrors its position. The percentage of total counts increases slightly toward the top of the system because the bottom detectors rest below a steel frame, which reflects some neutrons back up into the system. The 16 detectors not shown in Fig. 2 are on the front and back faces of the Pb; comparisons for those detectors produced similar results.

Figure 1. **Front View of NMDS at UNLV:** Front detectors and steel support frame can be seen. The Pb is completely enclosed.

Neutron lifetimes were calculated using the time of absorption. The lifetimes are a numerical fit of the neutron capture times within the system. As the amount of Pb was increased in the center of the cube, the measured neutron lifetime decreased from 66 μs with no Pb to 62 μs with 6 layers of Pb. In previous MCNPX[2] calculations, the lifetime in this system was 62 μs. The measured count rate increased steadily from 3.1 counts/s with no Pb to 6.6 counts/s with 6 layers of Pb. These trends led to the conclusion that the system was working properly and could be used for more rigorous tests.

Figure 2. **Percentage of Total Counts by Detector Position: 44 of 60 detectors shown**

	1.1	1.4	2.0	1.8	2.3	2.1	1.5	1.1	
1.1	1.8	2.0					2.2	1.6	0.8
1.2	2.4							2.3	1.5
1.7									1.3
1.7				**Pb**					1.8
2.0									2.1
1.9									1.9
1.1	1.9							2.1	1.3
0.5	1.3	2.0					2.0	1.4	1.0
	0.9	1.2	1.7	1.6	1.8	1.7	1.3	1.0	

Idaho State University Idaho Accelerator Center

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. Also of interest was how the efficiency of the system would be affected by simply changing the shape of the system and the locations of the detectors relative to the Pb and the beam. Three cubic configurations were designed, named BCube, BCube2 and BCube3 and two rectangular accelerator target configurations, named 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.

All MCNPX calculations were done using an f8 tally to count the total number of neutrons captured by the ^{3}He tubes. The captured value was compared to the total neutron production in order to get the efficiency of the system. The individual detector absorptions in fractions of total neutrons absorbed was also observed. These values were compared to the experimental results to determine whether the trends seen in the system were also seen in MCNPX. For example, if the fraction of total absorptions significantly decreased toward the rear wall of the experimental system, it was of interest to know if MCNPX would show us the same trend. Additionally, the f4 tally was used with time bins to calculate average neutron lifetimes and compare them to calculations made using data obtained from the experiments.

The system was transported to the IAC, where a 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. An Americium-Beryllium (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%.

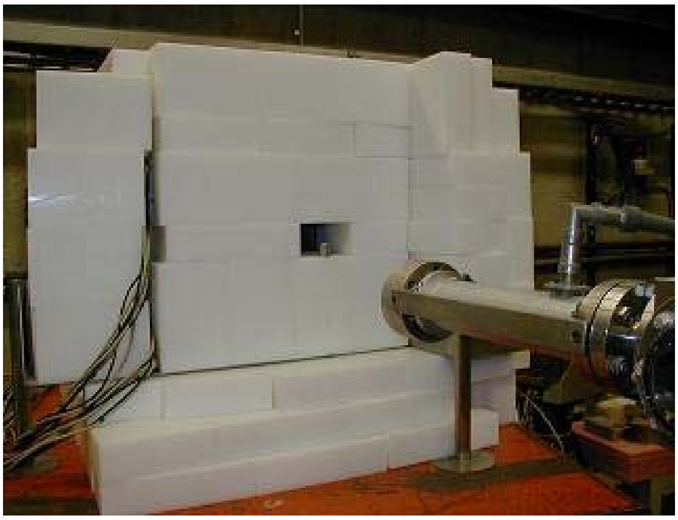


Figure 3. **Front of BCube:** The AmBe source can be seen sitting inside the opening. The beam height had not been adjusted in this photograph.

Testing commenced with the electron beam using the BCube configuration (Figure 3). During this time, the beam was able to be 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.

BCube, BCube2 and BCube3

The three BCube configurations are made up of a 30 cm by 30 cm by 30 cm Pb center, surrounded by 59 ^{3}He detectors and polyethylene moderator. Each system had a 5 cm high by 10 cm wide hole in the system to provide a path for the beam (Figure 4). This also allowed us to place the AmBe source on the face of the Pb without losing a significant amount of neutrons through the hole. BCube is the same as the original cubic configuration that was constructed and tested at UNLV. For BCube2, the front hole was deeper to allow better penetration for the electron beam (Figure 4). BCube3 is the same as BCube2, except that all detectors that were previously separated from the Pb by polyethylene were moved so that they were in direct contact with the Pb (Figure 6).

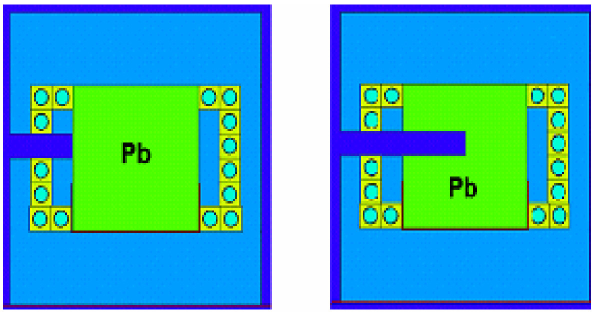


Figure 4. **Side View of BCube (left) and BCube2 (right):** BCube2 and BCube3 both allow deeper penetration for the beam.

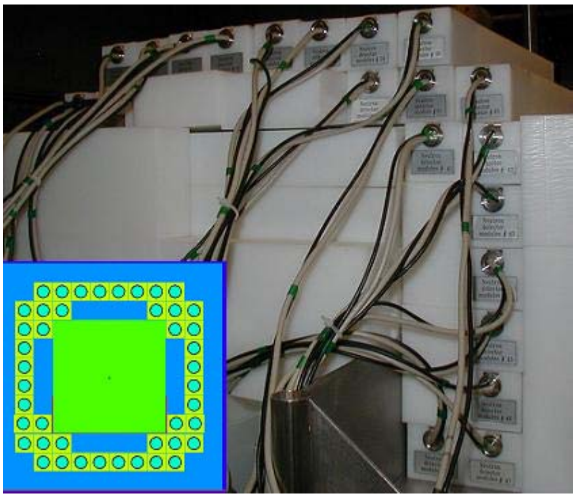


Figure 5. **Rear View of BCube and BCube2:** Top and right side detectors from the rear of the configuration. The light blue areas are high-density polyethylene.

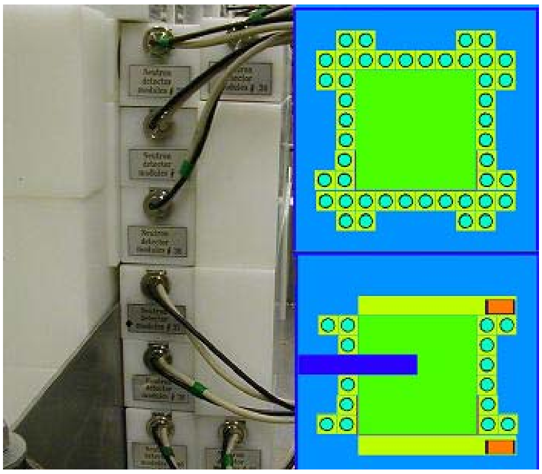
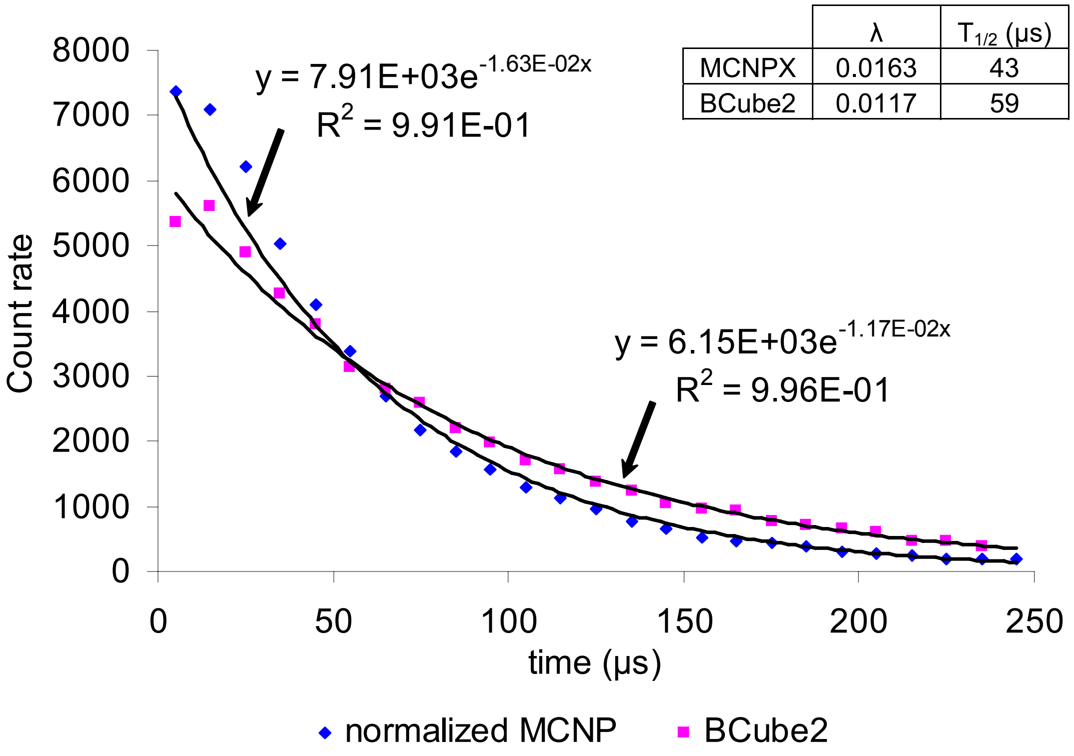


Figure 6. **BCube3:** This photograph shows the back wall. Notice that the 4 centre detectors have been moved to contact the Pb in BCube3. The detectors on all 6 faces were changed. BCube3 also allows the beam to reach the centre of the Pb.

In the BCube configuration, the average lifetime for absorbed neutrons was 71μs. MCNPX modelling for this configuration produced average lifetimes of 44μs. Lifetimes were lower in BCube2 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 (Fig. 7). 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.



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

Figure 7. **BCube2 Lifetime:** A numerical fit of neutron capture times for BCube2. Calculated lifetimes from experimental data and from MCNPX are also shown.

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%. This was probably caused by the dead time in the NMDS and a neutron production rate that was too high.

AT-1 Configuration

The AT-1 configuration was built around a 60 cm long x 20 cm high x 20 cm wide block of Pb bricks. There were 56 detectors, placed both vertically and horizontally, touching the Pb (Fig. 8). There is an additional wall of detectors behind the Pb. The detectors located along the sides and the top and bottom of the Pb are placed in double columns to allow us to measure and compare readings from the inside detectors to the outside detectors. All gaps were filled in with polyethylene.

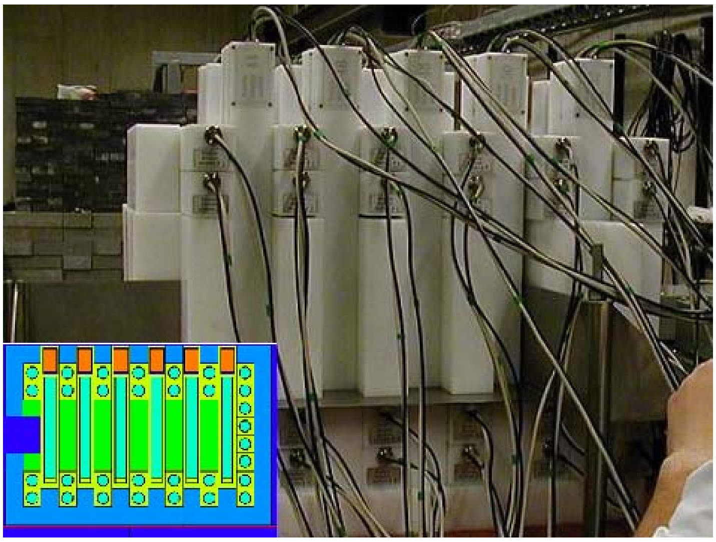


Figure 8. **Side View of AT-1:** The configuration has not yet been enclosed in polyethylene.

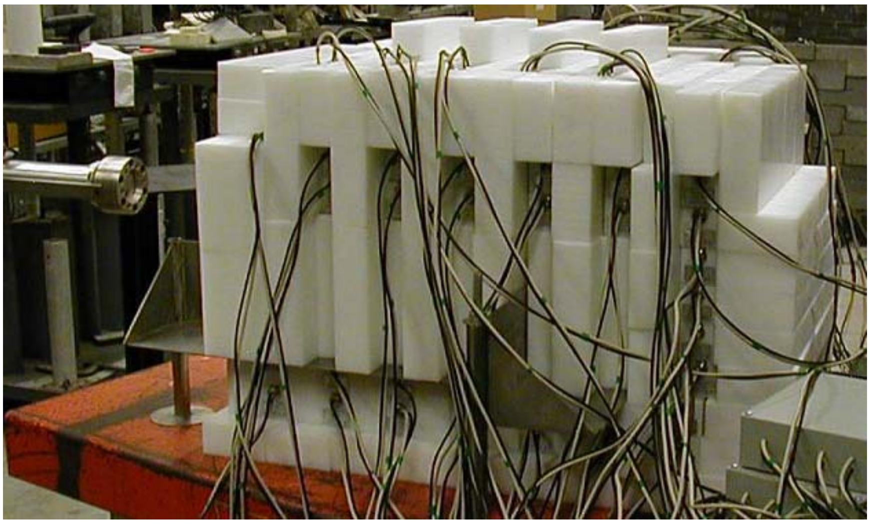


Figure 9. **Complete AT-1 at the IAC:** The steel support and the beam window can be seen on the left.

The AT-1 configuration was modeled in MCNPX to compare theoretical neutron absorptions to the experimental values. Fig. 10 shows the fraction of total neutrons absorbed by each detector. It was observed that the experimental results demonstrated that 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) rows of detectors. In the experimental results, there was very little difference between the top and bottom row of detectors, with the top values being slightly higher due to reflection from the steel frame. MCNPX calculations, however, had more extreme variations. While the left and right side detectors were very similar, the top and bottom detectors were not. In MCNPX results, 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 5.2%.

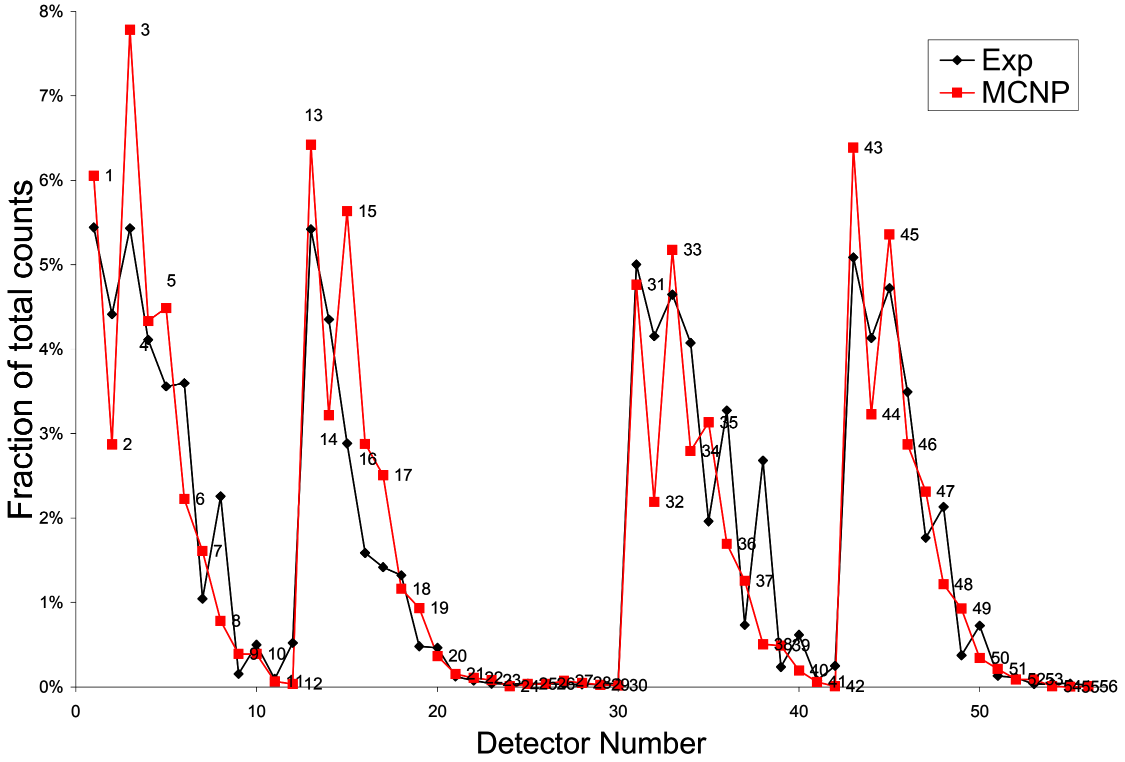


Figure 10. **AT-1, Fraction of Total Counts by Detector Number MCNPX vs. Experiment:** Side detectors are 13-24 and 31-42, top detectors are 1-12, bottom detectors are 31-42.

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 MCNPX, 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. 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. The lifetimes in this configuration were 67µs compared to 44µs in MCNPX. Overall system efficiency was 19% in MCNPX and 1.8% experimentally.

While conducting experiments with the AT-1 configuration, we found several events that appeared to be the "tails" of the previous event. The NMDS is limited to recording data for 256µs time bins. At the end of the time bin, the system resets and waits for another event before it begins counting again. If a neutron from the previous pulse has a lifetime longer than 256µs, the system will start a new time bin for that neutron. The system treats the leftover neutron as a new event. That neutron will get a "0" time bin, instead of its actual lifetime. The difference in true lifetimes causes small errors in calculated average lifetimes. Additionally, these "tails" cause significant errors in the multiplicity distribution. In Figure 11, experimental results show multiplicities of 1 to 5 to be much more frequent than expected. Multiplicities between 1 and 5 in Figure 11 represent 40% of the total. The majority of these were caused by leftover neutrons from previous events. Each data set acquired from an experiment with the 15 MeV electron beam produced similar results.

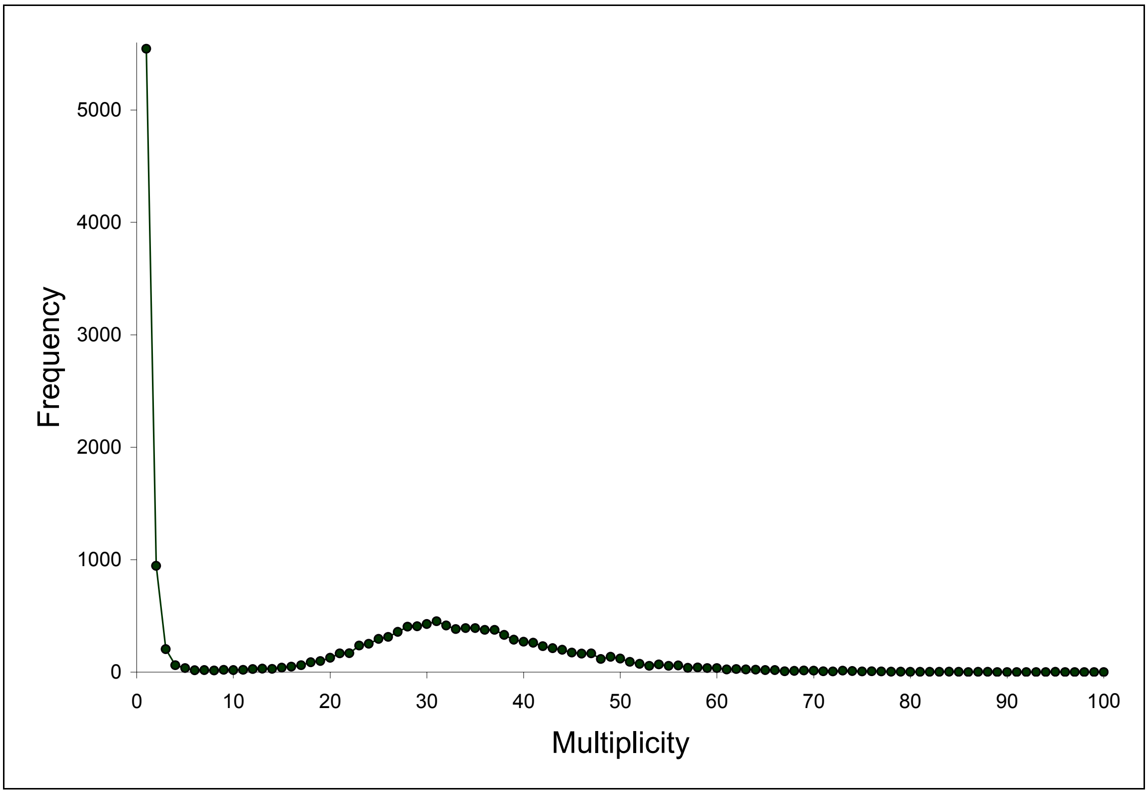


Figure 11. **Multiplicity Distribution for AT-1:** System limitations caused the frequency of multiplicities of 1 to 5 to appear much too high.

AT-2

The AT-2 configuration is built around the same shape as the AT-1, but all top and bottom detectors were moved to the sides, creating a solid wall of detectors on each side of the Pb (Fig. 12). The benefit of this configuration is that there are no gaps in the side detectors. It was of interest if there were possible changes in the behavior of the system with these gaps filled, but with the top and bottom of the Pb covered only by polyethylene. The experimental efficiency of AT-2 with the AmBe source was 3.4%, compared to 3.5% with AT-1, so the effect on efficiency was minimal. The calculated efficiency with the 15 MeV beam in MCNPX was 14% and experimentally it was 1.3%. The average neutron lifetime decreased as expected for AT-2. In MCNPX it was 42 μs compared to 56 μs experimentally.

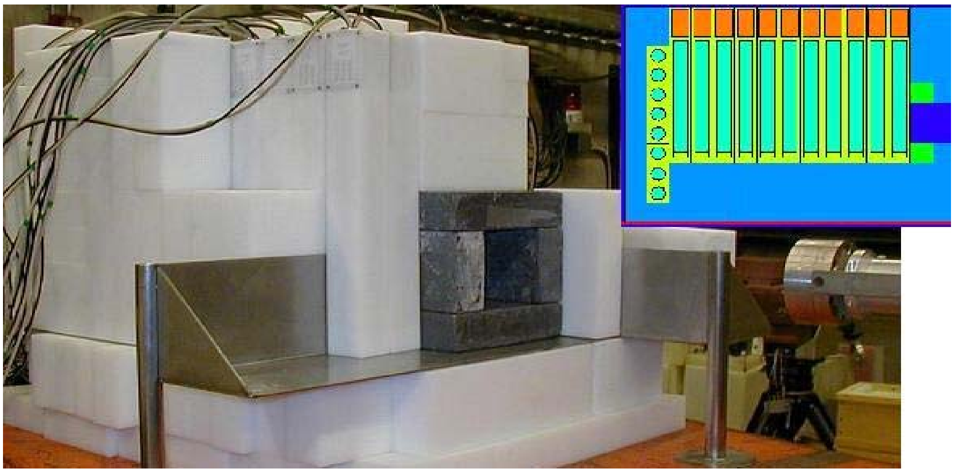
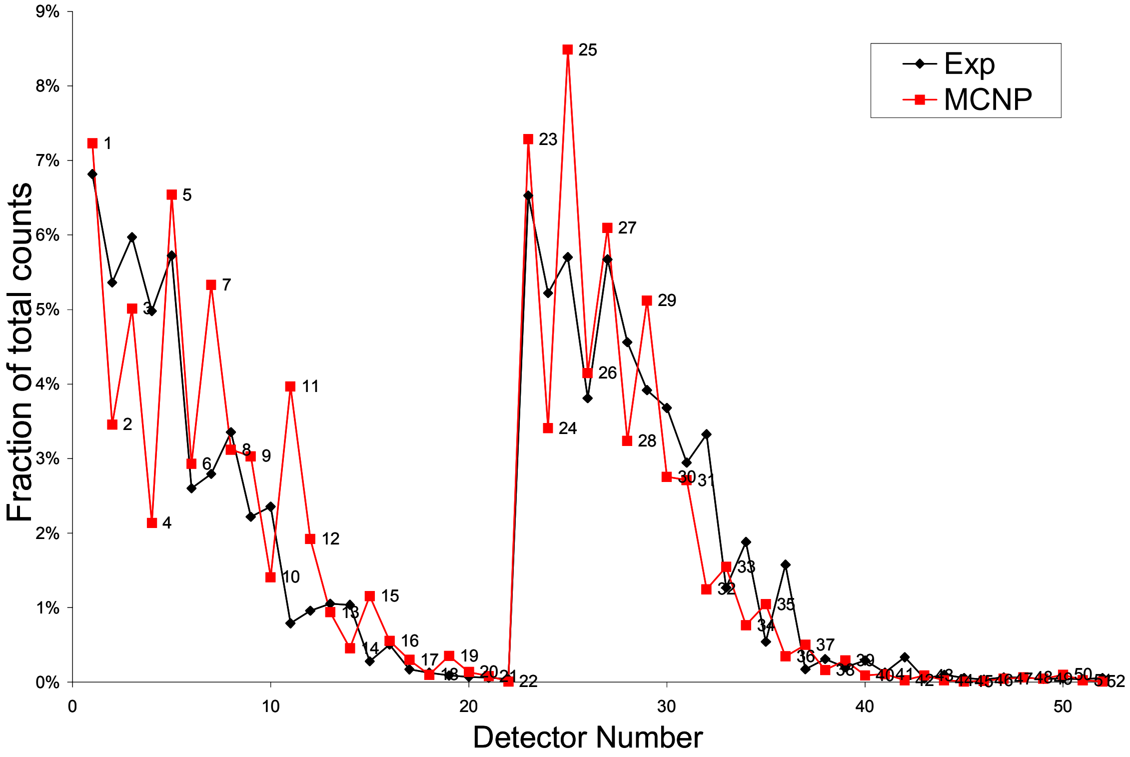


Figure 12. **AT-2 During Construction at the IAC:** AT-2 configuration prior to being enclosed in polyethylene. The double columns of detectors are visible as well as the hole for the beam and the beam window.

As in the AT-1 configuration, comparisons of relative neutron distribution in MCNPX models to the experiments produced a few anomalies (Fig. 13). The variation between counts in the inside detectors and outside detectors was again much higher in MCNPX than it was in the experiments. A ratio of 1.3 between detectors 1 and 2 was observed in the experiment, but MCNPX calculated a ratio of 2.1. This trend continued throughout the configuration.

Figure 13. **AT-2, Fraction of Total Counts by Detector Number, MCNPX vs. Experiment:** Left side detectors, 1-24; right side detectors, 23-44. Notice there is very little activity on the back wall, detectors 45-52.



Conclusions and Future Plans

The experiments conducted at the ISU IAC provided a much better understanding of the capabilities and limitations of the NMDS. It was learned that the system is severely limited by frequency. 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 256μs 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.

It was found that the NMDS is also limited by dead time. In the future, it is desired to calculate an accurate value for the average dead time in the system. Once the effect on the results is known, then progress can be made to reduce it. It is believed 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 putting an 800 MeV proton beam on the NMDS to further test its abilities.

Several anomalies were found for which work will be dedicated towards understanding. In the AT-1 and AT-2 configurations, the number of counts on the inside detectors was higher than the outside detectors at the front of the system, but lower at the back of the system. MCNPX calculations did not produce the same pattern. More testing is needed over longer time periods to investigate this further. MCNPX calculations also produced much higher efficiencies in all configurations than were able to be recorded in the experiments. It is believed that this was caused by the source strength and the dead time, but more tests will need to be run under varying conditions to produce a definitive answer.

REFERENCES

[1] "Modeling Neutron Multiplicities in a 60-element ^{3}He Detector System," Dean Curtis, Denis Beller, Carter Hull, Alexander Rimsky-Korsakov, and Thomas Ward, *Proc. of the Sixth International Meeting on Nuclear Applications of Accelerator Technology (AccApp'03*), American Nuclear Society, pp. 190-194, 2004.

[2] MCNPX Team, "MCNPX, Version 2.5.d," *Los Alamos National Laboratory report* LA-UR-03-5916 (August 2003).