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Rocky Flats Neutron Detector Testing at Valduc, France

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Auspices Statement

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1. INTRODUCTION

Recent program requirements of the US Department of Energy/NNSA have led to a need for a criticality accident alarm system to be installed at a newly activated facility. The Criticality Safety Group of the Lawrence Livermore National Laboratory (LLNL) was able to recover and store for possible future use approximately 200 neutron criticality detectors and 20 master alarm panels from the former Rocky Flats Plant in Golden, Colorado when the plant was closed. The Criticality Safety Group participated in a facility analysis and evaluation, the engineering design and review process, as well as the refurbishment, testing, and recalibration of the Rocky Flats criticality alarm system equipment to be used in the new facility.

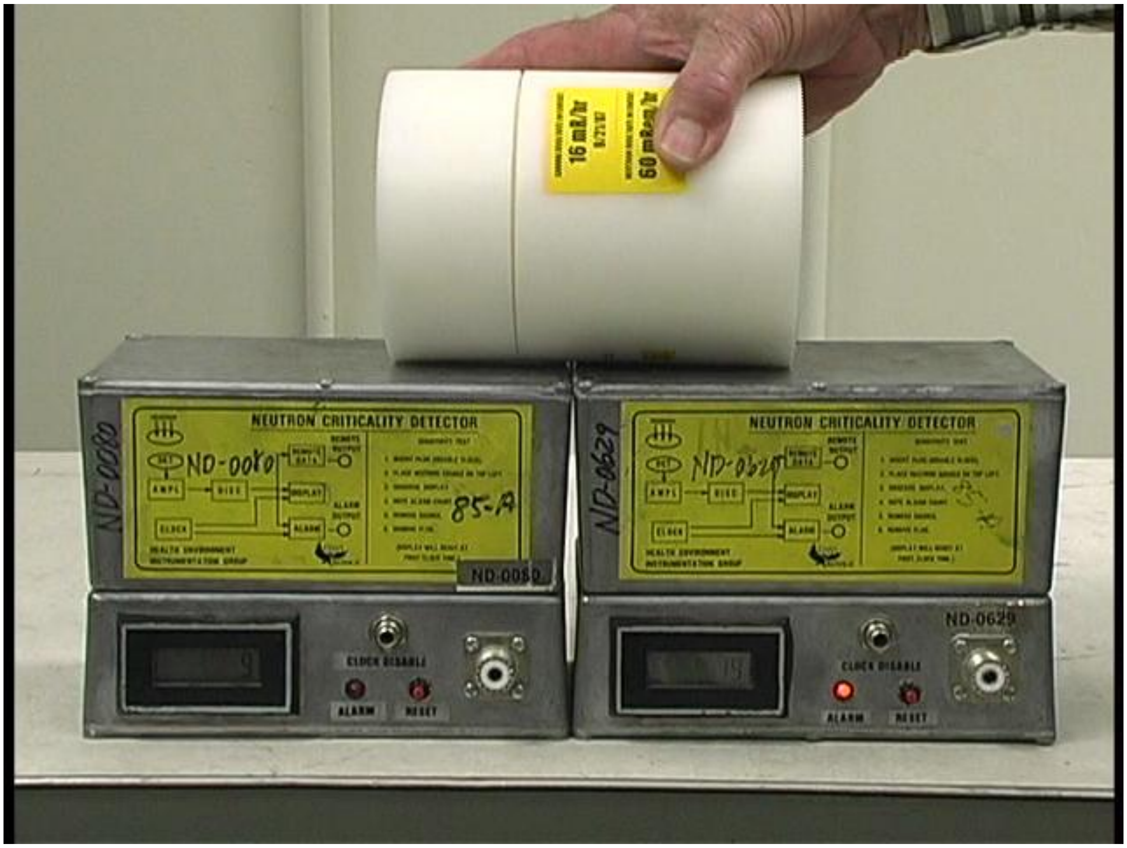
In order to demonstrate the functionality and survivability of the neutron detectors to the effects of an actual criticality accident, neutron detector testing was performed at the French CEA Valduc SILENE reactor from October 7 to October 19, 2010. The neutron detectors were exposed to three criticality events or pulses generated by the SILENE reactor. The first excursion was performed with a bare or unshielded reactor, and the second excursion was made with a lead shielded/reflected reactor, and the third excursion with a polyethylene reflected core.

These tests of the Rocky Flats neutron detectors were performed as a part of the 2010 Criticality Accident Alarm System Benchmark Measurements at the SILENE Reactor. The principal investigators for this series of experiments were Thomas M. Miller and John C. Wagner of the Oak Ridge National Laboratory, with Nicolas Authier and Nathalie Baclet of CEA Valduc. Several other organizations were also represented, including the Y-12 National Security Complex, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, CEA Saclay, and Babcock International Group.

2. DETECTORS

Several weeks prior to the experiment, a number of detectors (12) were selected from LLNL stock and processed through the alignment and calibration procedures (Reference 1) that Rocky Flats had developed and refined over approximately 15 years of experience with this basic design. The process consists of two primary phases, the first phase being electrical and mechanical bench checks including electronic adjustments and alignment of the detector subunits, and the second phase being an irradiation with a well characterized neutron source, typically a TRIGA reactor. Detector calibration at LLNL and TRIGA reactor testing procedures were videotaped in a DVD (Reference 2). Two detectors showing LCD display and LED alarm indicator, tested with a moderated californium source at LLNL are shown in Figure 1.

Figure 1. Rocky Flats Neutron Detectors.



LLNL personnel performed the initial bench checks, adjustments, and tests during the first two weeks of September, 2010. On September 17, 2010 the detectors were taken to the UC Davis McClellan Nuclear Research Center in Sacramento, California for the neutron source response tests.

Detector count rates and the thermal neutron flux for the four detectors used at Valduc are shown in Table 1.

Table 1. Detector Count Rate vs. Thermal Flux.

Detector No.	Detector ID	Detector Count rate Avg. of 3 1 minute tests (cpm)	Thermal Neutron Flux (n/cm^2-sec)	Detector Normalization Factor Count Rate / Thermal Flux
D1	ND-0028	13,261	551	24.07
D2	ND-0242	6,779	585	11.59
D3	ND-0632	4,226	549	7.70
D4	ND-0450	8,177	569	14.37

As shown in Table 1, a detector efficiency or normalization factor was derived so the counts from each detector/location pair used in the experiment could be compared on a common basis.

3. DETECTOR PLACEMENT

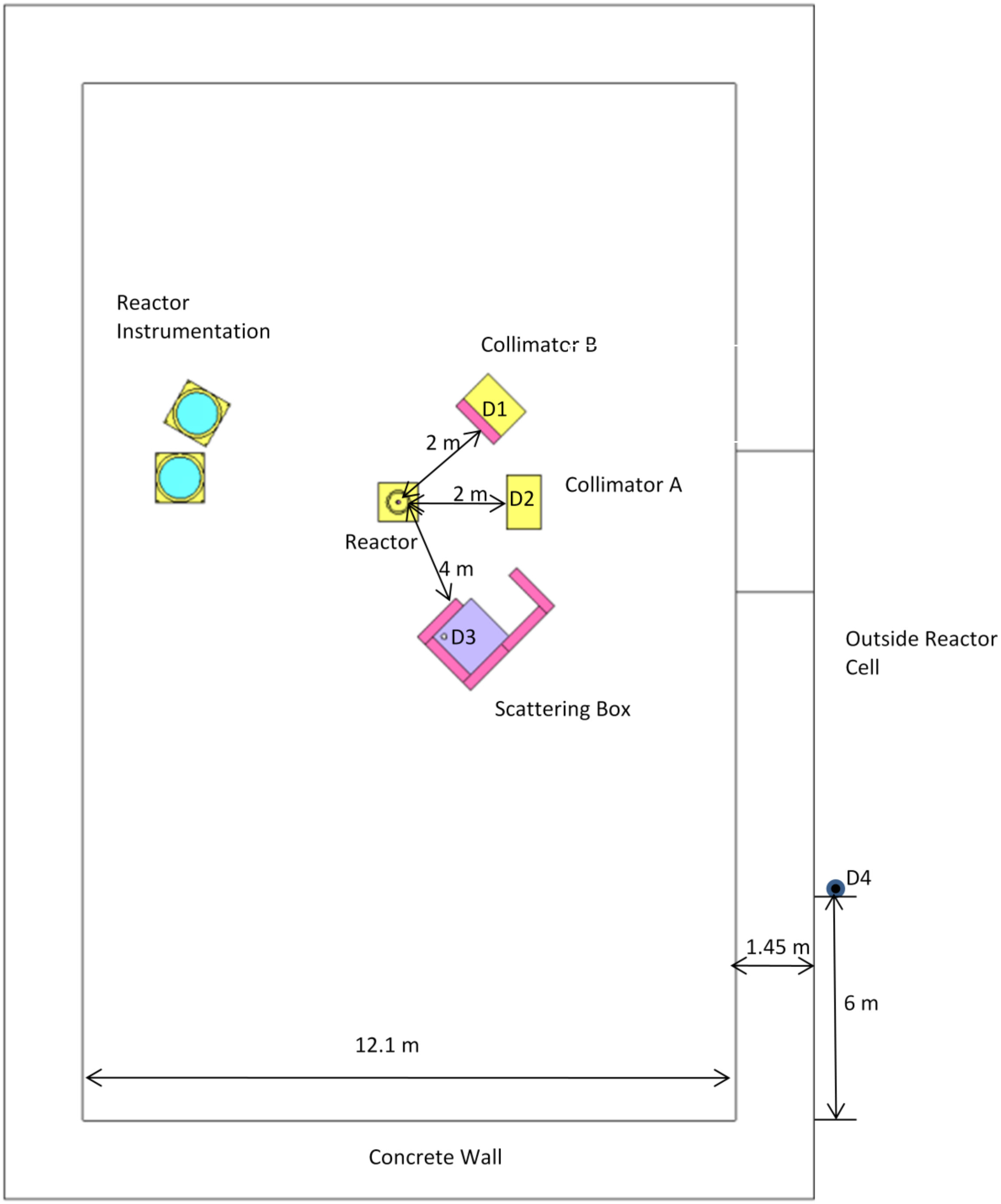
Four neutron detectors were placed in the experimental area, three inside and one outside the reactor cell (see Figure 2). Table 2 identifies the detector serial number that was placed at each of the four locations for the experiments.

Table 2. Four Detectors used in the Experiments.

Detector No.	Location	Configuration	Detector ID
D1	Collimator B	Concrete Shield	ND-0028
D2	Collimator A	Unshielded	ND-0242
D3	Scattering Box	Partially Shielded	ND-0632
D4	Outside Reactor Cell	Heavy Cell Wall Shield	ND-0450

The collimators are box-shaped structures having five solid sides with an open sixth side facing the reactor. The side of the collimator facing the reactor is 1 m x 1 m. The other dimension of the box is 0.65 m. The collimator walls are constructed of stainless steel, copper, lead, and borated polyethylene.

Figure 2. Four Detectors Placed at Collimator B, Collimator A, Scattering Box, and Outside Reactor Cell.



The purpose of the collimator box in these experiments is to effectively eliminate the contribution from particles that scatter in the walls or other equipment in the reactor cell. Detectors in the collimator box, if the collimator is shielded, will primarily measure the transmission of particles through the shielding materials. A detector inside an unshielded collimator will primarily measure direct radiation from the reactor. For these experiments, collimator A was used unshielded, and collimator B was used in a shielded configuration. The distance from the center of the reactor to Collimator A, Collimator B, and Scattering Box are 2, 2, and 4 m, respectively.

The scattering box refers to a detector placement and configuration of shielding materials such that there is no direct line of sight from the reactor to the detectors. Therefore, the majority of the measured neutron radiation will have been scattered and a majority of the measured photon radiation are secondary photons produced by neutrons.

4. EXPERIMENTAL OBSERVATIONS

During the experiments, the neutron detector LED alarm indicator was checked to verify that the detector alarmed during criticality accident situations, and the integrated counts displayed on each detector's front panel LCD display were recorded to determine the relative levels of thermal neutron fluence detected by the unit at each of the four locations. A pulse output available on the rear of each detector was connected to a data acquisition system that was setup and controlled by a laptop computer system in an area adjacent to the reactor control room. The system had an independent counter for each detector channel, and logged the data onto a micro SD data card for later analysis.

October 7, 2010 (Thursday): LLNL staff arrived at the Valduc facility with detectors and instrumentation. After arranging access, the equipment was transported to the SILENE facility. The Rocky Flats neutron detectors and other materials were unpacked and inspected for damage. No damage was evident to any of the materials. The internal batteries of the neutron detectors were given a refresh charge to bring them to full capacity. The experimental plan was reviewed and detector placement was discussed with the other experimenters and the Valduc staff.

October 8, 2010 (Friday): Four detectors were placed in the experimental reactor cell in the locations indicated in Figure 2. Due to the minimal cabling available from the reactor cell to the diagnostic area, we were not able to use a line-operated DC power supply to provide latching power for the criticality alarm LEDs as originally planned. Normally this power is provided from the criticality alarm system central panel over the common power and alarm transmission link. External battery packs with dry cell batteries were installed on each detector to power the front-panel criticality alarm indicator LED. The available cables were patched from the detector at each of the four locations and routed to the diagnostic room adjacent to the reactor control room. The detector cables were connected to a laptop computer data acquisition system to record the event pulses from each detector.

October 11, 2010 (Monday): The first pulse, a size of 1.9×10^{17} fissions, was generated in 1.7 msec by a bare reactor. Magnetite concrete with a density of 3.9 g/cm^3 and a 20 cm-thick slab was used as the shielding for Collimator B. Due to communication difficulties between the reactor control room operator and the data acquisition operator, the data collection was not triggered until briefly after the initial critical pulse had occurred. Data was recorded for 37 seconds after triggering and are summarized in Table 3.

Table 3. Integrated Counts Recorded on Laptop / Logger for Pulse #1.
t = 37 seconds

Detector No.	Location	Detector ID	Integrated Counts
D1	Collimator B	ND-0028	847,314
D2	Collimator A	ND-0242	834,028
D3	Scattering Box	ND-0632	642,368
D4	Outside Reactor Cell	ND-0450	10,187

Table 3 integrated counts were then divided by the adjustment factors in Table 1 to get the normalized counts. Table 4 summarizes these counts.

Table 4. Normalized Logged Counts for Pulse #1.
t = 37 seconds

Detector No.	Location	Detector ID	Integrated Counts	Normalization Factor	Normalized Counts
D1	Collimator B	ND-0028	847,314	24.07	35,206
D2	Collimator A	ND-0242	834,028	11.59	71,973
D3	Scattering Box	ND-0632	642,368	7.70	83,446
D4	Outside Reactor Cell	ND-0450	10,187	14.37	709

Approximately four hours after the pulse, when activation and radiation levels had decreased enough to allow safe access to the reactor cell, experimenters entered the cell to retrieve the foils and record the LCD readout displays on the criticality detectors. The counts shown on the detector LCD displays were recorded as shown in Table 5. The LCD counts for D4 were not recorded because an assigned record-keeper was in a hurry to exit the reactor area. Criticality alarm indicator LEDs were illuminated on all detectors as expected. The power was removed from the detectors after the observations were made in order to preserve the battery life.

According to Tables 4 and 5, thermal neutron fluence is highest at the detector of the scattering box, Collimator A, Collimator B, and outside reactor cell, in the descending order.

Table 5. Normalized Counts Shown on LCD for Pulse #1.
t = 37 seconds

Detector No.	Location	Detector ID	LCD Counts	Normalization Factor	Normalized Counts	Alarm LED lit?
D1	Collimator B	ND-0028	530,935	24.07	22,058	Yes
D2	Collimator A	ND-0242	907,587	11.59	78,308	Yes
D3	Scattering Box	ND-0632	967,609	7.70	125,664	Yes
D4	Outside Reactor Cell	ND-0450	*	14.37	----	Yes

*Not recorded.

October 12, 2010 (Tuesday): Preparation for the second pulse was made. To avoid the communication problems that caused the first data recording to be started late, it was decided to start recording well before the event trigger. The data acquisition software was modified to record for a longer period, which was set to correspond with a file size of 192 MB, or 8.06 minutes. Operation of the modified software was verified, and simulated inputs on all detector channels were logging correctly to the memory card. A meeting was held in the afternoon with the Valduc radiation physics and dosimetry group staff and the experimenters to discuss early dosimetry and activation analysis results of the first pulse.

October 13, 2010 (Wednesday): Prior to the second pulse, the experimenters entered the reactor cell to place the new foils and repower the criticality detectors. The voltage of the internal batteries in each of the neutron detectors was measured and found to within specification. The external battery packs which power the criticality alarm LED and latch were evaluated for condition. The external dry cell batteries on all of the detectors except for the unit in the scattering box were found to be in a discharged, low-voltage condition and were replaced.

The second pulse, a size of 2.1×10^{17} fissions, was generated by the lead reflected SILENE reactor. The concrete shielding slab for Collimator B had been changed to one constructed of regular concrete, having a density of 2.3 g/cc. The logging software was started well in advance of the reactor pulse in order to capture the initial events. An examination of the recorded data shows the initiation of the criticality as reflected by the count rates at 1.59 minutes into the data record. The data recorded by the logger is summarized in Table 6.

Table 6. Normalized Logged Counts for Pulse #2
t = 484 seconds

Detector No.	Location	Detector ID	Integrated Counts	Normalization Factor	Normalized Counts
D1	Collimator B	ND-0028	0	24.07	----
D2	Collimator A	ND-0242	1,780,150	11.59	153,594
D3	Scattering Box	ND-0632	0	7.70	----
D4	Outside Reactor Cell	ND-0450	10,751	14.37	748

Note that there was no data recorded for detector channels D1 and D3. Examination of the detectors indicated that they were functional. After the pulse, a local simulation test at the data logger showed that it was correctly logging data applied to all inputs, including channels D1 and D3. The cause of the missed data is unknown at this time.

Approximately four hours after Pulse #2 when activation and radiation levels had decreased enough to allow safe access to the reactor cell, experimenters entered the cell to retrieve the foils and record the LCD readout displays on the detectors. The counts shown on the detector LCD displays were recorded as shown in Table 7. Criticality alarm indicator LEDs were illuminated on Detectors 1, 2, and 4. According to the normalized counts, thermal neutron fluence is highest at the detector of the scattering box, Collimator A, Collimator B, and Outside Reactor Cell in the descending order.

Table 7. Normalized Counts Shown on LCD for Pulse #2
t = 484 seconds

Detector No.	Location	Detector ID	LCD Counts	Normalization Factor	Normalized Counts	Alarm LED lit?
D1	Collimator B	ND-0028	550,381	24.07	22,866	Yes
D2	Collimator A	ND-0242	737,656	11.59	63,656	Yes
D3	Scattering Box	ND-0632	892,989	7.70	115,973	No
D4	Outside Reactor Cell	ND-0450	10,358	14.37	721	Yes

No indicator was reported as lit on detector 3, located in the scattering box. The detector appears to have been functional, as the LCD was operating and indicating a reasonable number. The scattering box detector did not have new dry cells installed for this test. If the cells have a low capacity, the alarm LED will not remain illuminated.

Figures 3 and 4 show accumulated counts versus record number (time) for Pulse #2 for two time scales. These data were obtained from the laptop computer data acquisition system. As shown in the short time scale in Figure 4, initial slope on D2/counter 2 looks almost like an exponential, indicating the start of the short pulse. The accumulated counts are supposed to be saturated after the pulse, but the reason for continued increase is not known at the time of this writing.

Figure 3. Accumulated Counts up to Record Number 1951.

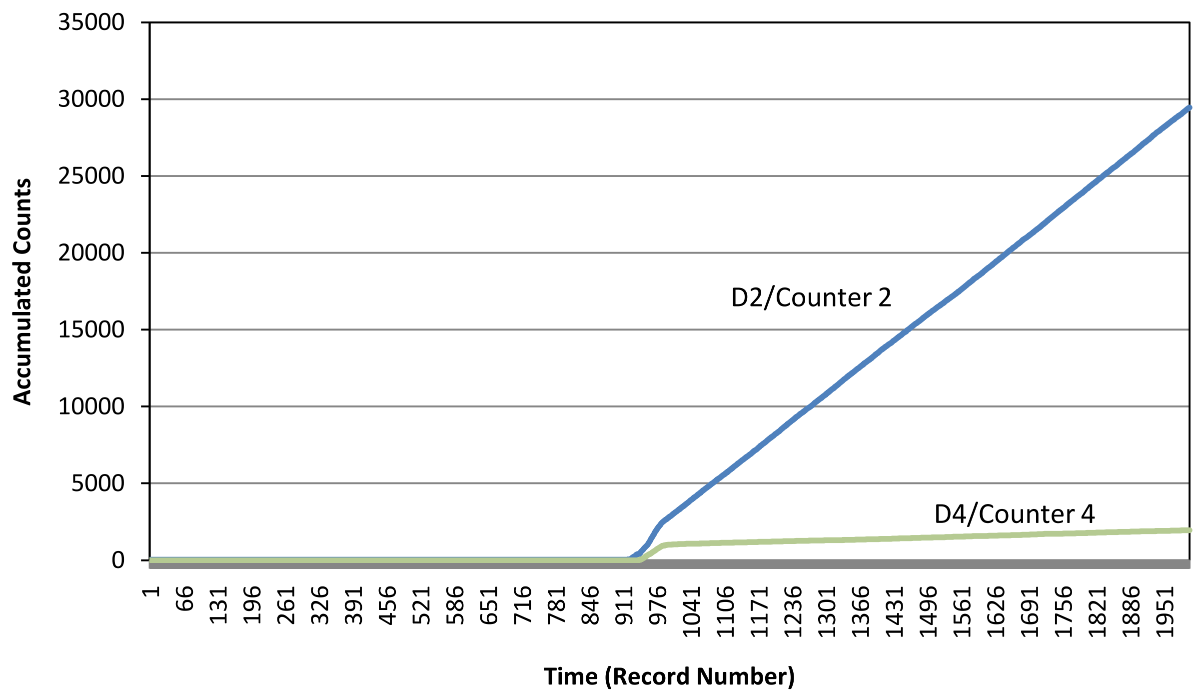
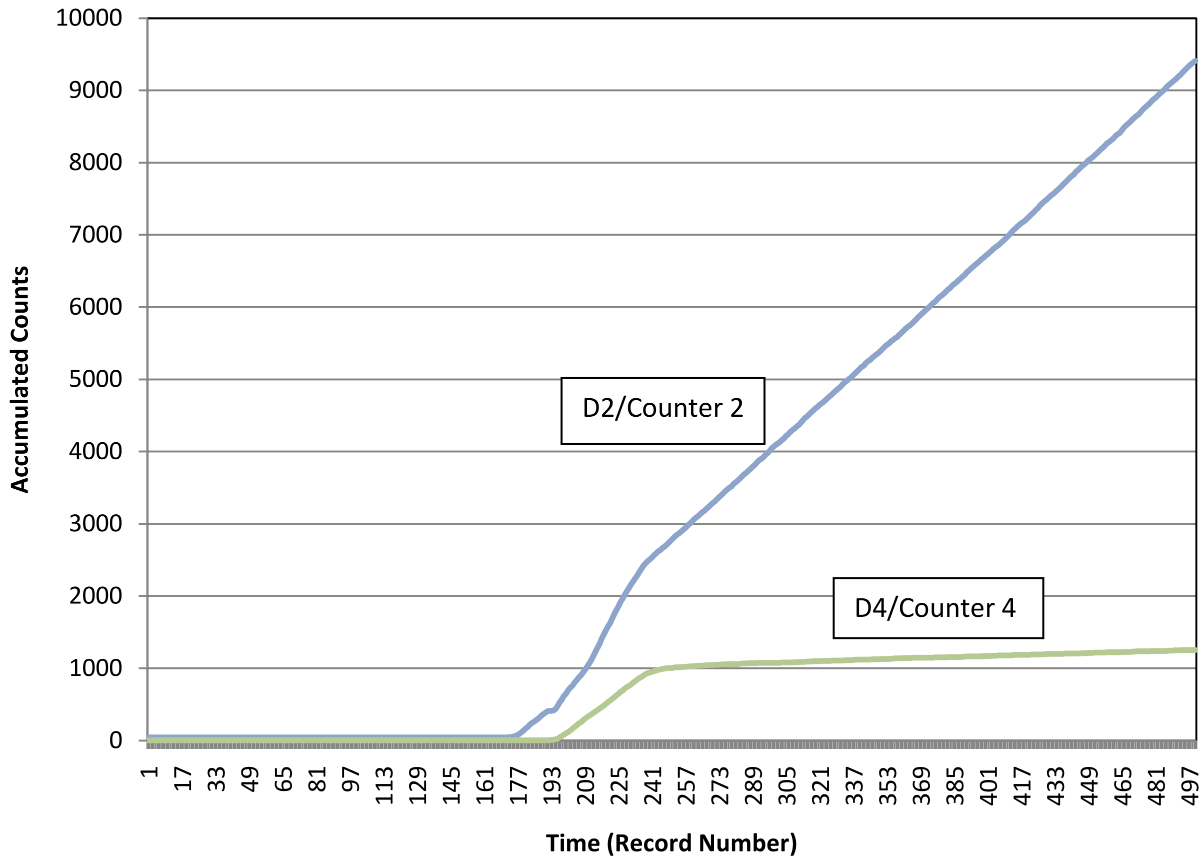


Figure 4. Accumulated Counts up to Record Number 497.



LLNL staff left Valduc on October 13, 2010, but the four detectors were left there to obtain more data for additional pulses. On January 11, 2011, Richard Hunter from Babcock International provided additional measurement data for Pulse #3. This last pulse was made by a polyethylene reflected SILENE reactor on **October 19, 2010 (Tuesday)**. Table 8 summarizes integrated and normalized counts for the four detectors. Criticality alarm indicator LEDs were illuminated on all detectors except D3 of the scattering box, and the thermal neutron fluence was highest at D2 of Collimator A instead of D3 in the scattering box.

Table 8. Normalized Counts Shown in LCD for Pulse #3.

Detector No.	Location	Detector ID	Integrated Counts	Normalization Factor	Normalized Counts	Alarm LED lit?
D1	Collimator B	ND-0028	466,532	24.07	19,382	Yes
D2	Collimator A	ND-0242	806,862	11.59	69,617	Yes
D3	Scattering Box	ND-0632	516,776	7.70	67,114	No
D4	Outside Reactor Cell	ND-0450	1658	14.37	115	Yes

5. SUMMARY

According to the experimental results, thermal neutron fluence was highest at the detector in the scattering box for Pulses #1, and #2. For Pulse #3, the thermal neutron fluence was highest at the detector of Collimator A. Criticality alarm indicator LEDs were illuminated on detectors as expected. The Rocky Flats neutron detectors appeared to have functioned as intended in an actual criticality situation.

When the detectors can be released from the SILENE radioactive material control area, they will be shipped back to LLNL. When the detectors arrive at LLNL, they will be inspected and tested according to the calibration procedure they went through prior to the experiment. Data recorded in this process will be compared to the previous data to determine if there has been any significant change in electrical parameters.

6. REFERENCES

1). Annual Calibration of Model 85A and NCD-91 Neutron Criticality Detectors, 4-16000-RI-4301, Rocky Flats Plant (December 1993).

2). Calibration of DAF Criticality Accident Alarm System, LLNL-VIDEO-402771 (March 2009).