Summer Research 2014 - Final Report

Radiation Shielding - HEP Lab A - Florida Institute of Technology

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Testing Performed: 6/24/14 - 7/7/14

Report Submitted: 7/25/14

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Abstract

In order to test various GEM detectors with x-ray radiation for commissioning there must be a safe environment in which to produce such radiation. In these radiation safety testing trials, a Geiger counter was used to take 5 min total count data at 56 different positions at multiple orientations around a 1/16 in. thick lead-sheet-metal-lined radiation shielding box. For each different position/orientation background data was collected and then compared to data that was collected while an AMP TEK Mini-X Gold X-Ray Tube, producing up to 50 keV x-rays with an uncollimated and unfiltered 120° irradiation cone, was operated inside the box. All 56 positions were tested twice: once with the Mini-X staying stationary in a normal operating position (NOP) and again with the Mini-X moving around the inside of the box to do point blank irradiations from ~1 ft. away from the shielding walls. All total number of counts collected for all NOP and point blank positions were found to be within their and their background's absolute errors with the means of the NOP and point blank testing configurations' normalized percent differences being -0.18% and +0.73%, respectfully. This resulted in an average of all percent deviations from background being very close to 0%. Additionally, the theoretical normalized 0% differences were within propagated relative error for all positions in both testing configurations, so the safety of the radiation shielding box was confirmed. Overall, radiation testing and shielding box commissioning was successful. Under proper use and care the shielding box should provide a safe environment for GEM detector testing for years to come.

Contents

Objectives

With 0.0625 in. (1/16 in.) thick lead sheet metal calculated to attenuate >99.99% of incoming x-rays' (up to 50 keV) intensities, the objective of this radiation testing was to make sure that the newly constructed large lead box (LLB) did not let unsafe levels radiation leak out as a result of its construction process. Sub-objectives included making sure the Mini-X's interlock system worked properly and that the final construction state of the LLB would be fit for normal and safe use.

Equipment

Radalert Inspector Nuclear Radiation Monitor (Geiger counter)

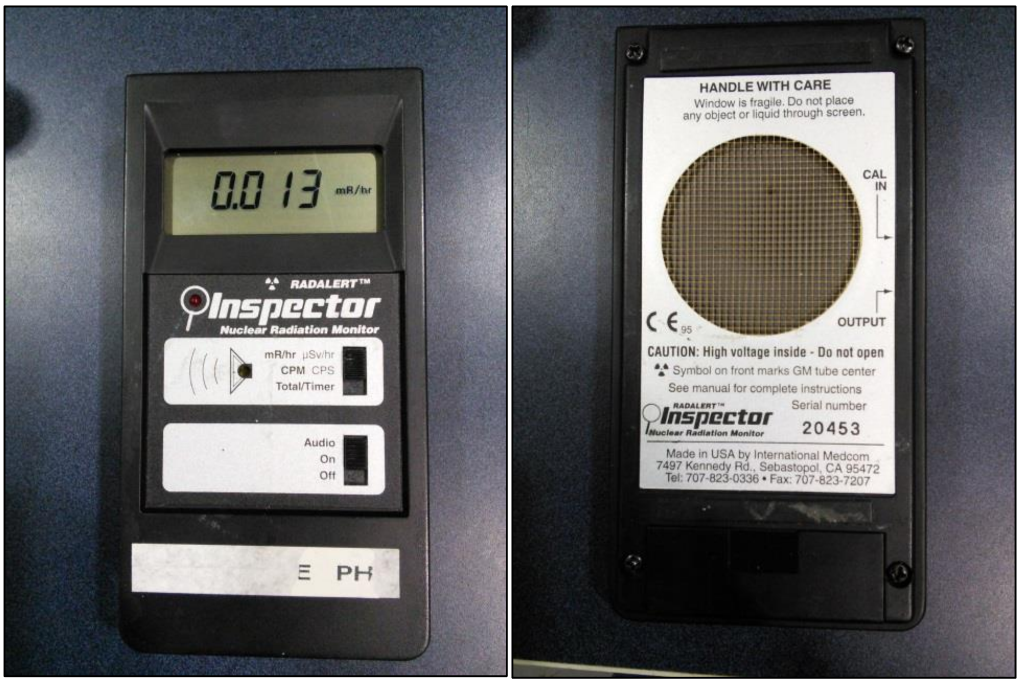

Figure 1: Radalert Inspector Nuclear Radiation Monitor. (Left) The measurement/settings readout side. The Audio/On/Off switch was set to 'Audio' for all safety checks and regular testing. (Right) The detector-side.

AMP TEK Mini-X Gold (Au) X-Ray Tube

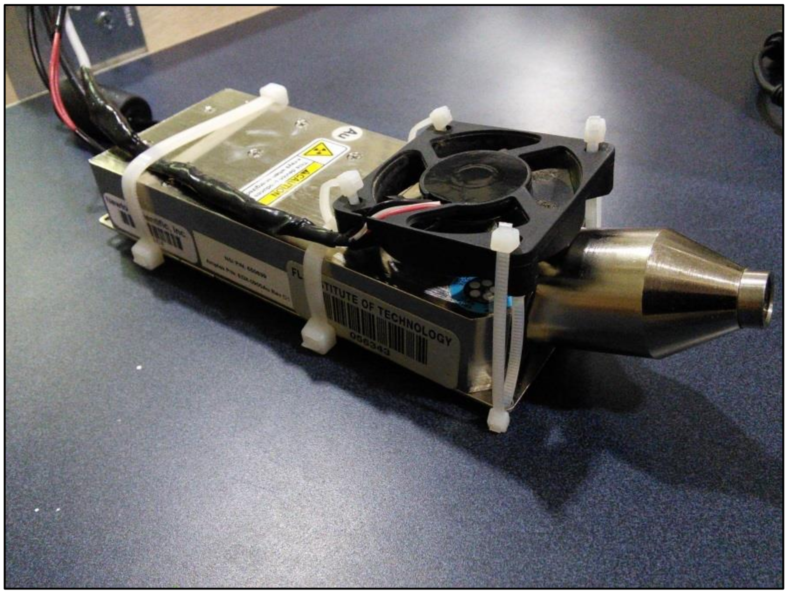

Figure 2: Mini-X gold x-ray tube with separate 12 V cooling fan attached. The tip of the source is pictured here un-collimated and unfiltered just as it was for all testing.

Mini-X Controller Software

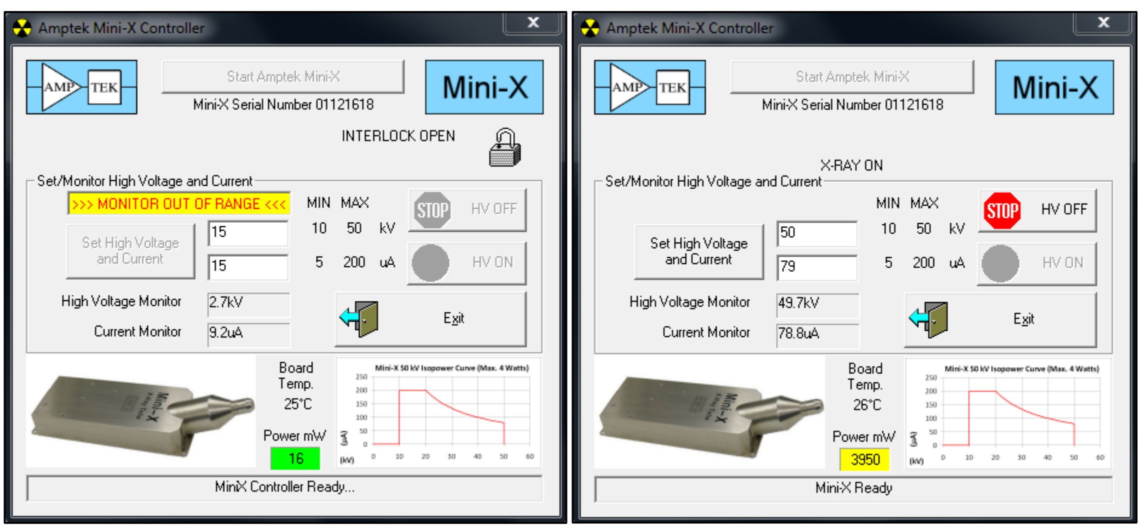

Figure 3: Screenshot of the Mini-X controller software in two modes. (Left) The interlock for the Mini-X is open so the source will not turn on. (Right) The interlock is restored and the source is operating at its fully powered ~4 W state of ~50 kV and ~80 uA; all testing occurred at this power output.

Large Lead Box – An Overview

As the actual object of testing, an extensive overview of the LLB and its safety features follow here. All interior shielding was achieved by attaching 1/16 in. thick lead sheet metal to the inside of a 0.75 in. (3/4 in.) thick plywood superstructure via polyurethane construction adhesive. The wooden superstructure is assembled through the use of metal square-brackets and screws (short enough to not damage soft lead sheets when completely drilled in). The entire LLB is able to be disassembled if necessary, but is also equipped to by carried as-is by 4+ people with its 12 chest handles.

Figure 4: The LLB fully closed and ready for operation.

Table 1: Some physical specifications of the LLB.

	Height	Width	Length	Volume	Weight
Imperial	2.5 ft.	5 ft.	7 ft.	87.5 ft^3	~600 lbs.
Metric	0.762 m	1.524 m	2.134 m	2.478 m^3	~270 kg

Permanent Shielding Features

Figure 5: The LLB with both lid doors open. Each lid weighs around 50 lbs. and has a metal kickstand to hold it open and safety cables to prevent it from slamming shut.

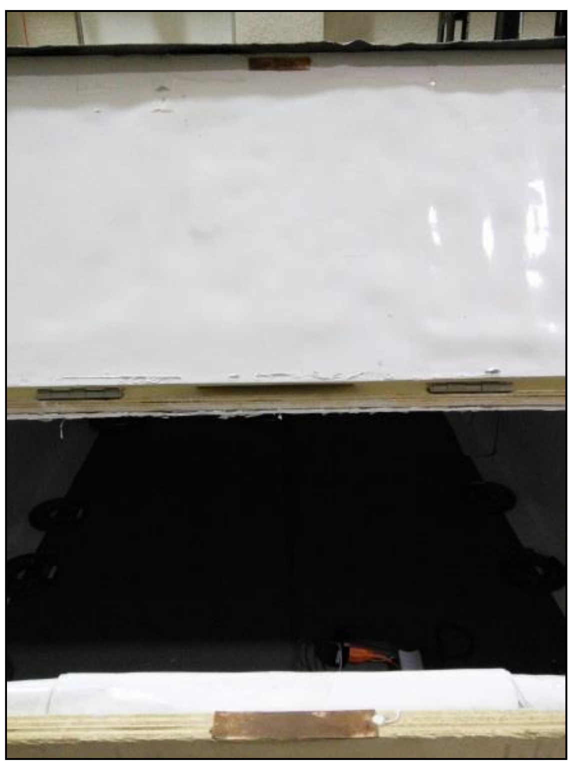

Figure 6: A close-up of the copper interlock plates on one lid door. When both lid doors are closed the interlock circuit is complete the x-ray source can be turned on.

Figure 7: Close-ups of exterior top-edge seals on and round the lid doors. These seals were added as response to radiation leaking from separation between the lid and tops of the sides of the LLB.

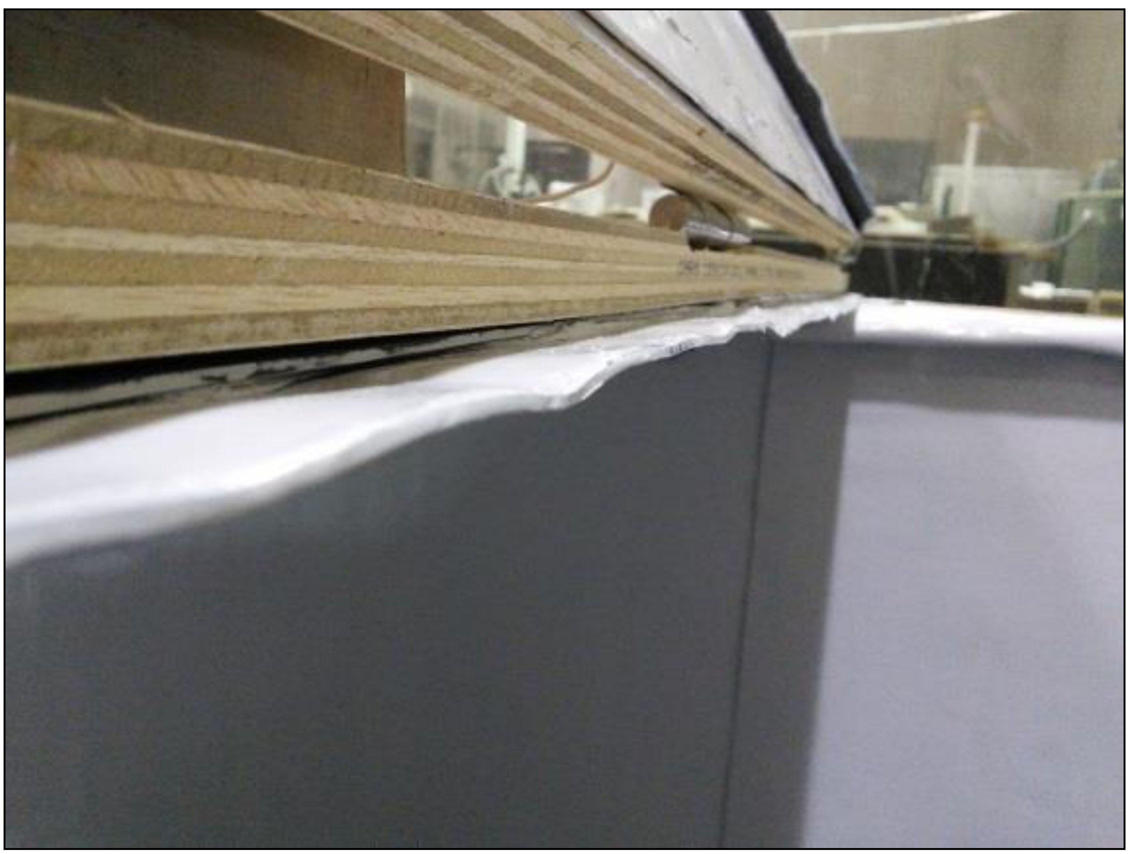

Figure 8: A close-up of a seam-sealing strip of lead along a hinged gap on the lid of the LLB.

Figure 9: (Left) Overlapping seam-sealers on the inside of the LLB. (Right) The 3 aluminum support bars that keep the lid from bowing under its own weight. The 3 pieces of the lid weigh a total of ~200 lbs.

Adjustable Shielding Features

While the overwhelming majority of the shielding in the LLB is fixed and permanent, there are several features that are adjustable so the LLB can be used in many different configurations.

The most obvious adjustable shielding features of the LLB are the 8 access ports around the bottom of its outside that allow for various feed-throughs (power cables, tubing, etc...) to exist for testing applications. Each port is 5 in. x 3.5 in., opens on a hinge and is sealed with a latch when not in use. The inside of each port, when not in use, is completely covered with a separate sheet of lead attached via Velcro as seen in Figure 10.

Figure 10: Velcro-attached inside seal of a closed access port. Underneath the solid Velco-attached seal, but not visible here, is a square 'picture frame' seam-sealer that is permenately glued around the cut in the large side panel's lead.

Figure 11: Outside view of access port #2 in its closed position.

Figure 12: Outside view of access port #2 in its open position. The back of the Velcro-attached solid seal from Fig. 10, as well as the inside lips of the ‘picture frame’ seam-sealer, are shown too. Notice the inside of the hinged wood piece is also covered in its own lead paneling.

Figures 10-12 showed how a not-in-use access port is sealed, but since ports are designed to be opened shielding adjustments must be made on a case-by-case basis. Below, Figures 13-16 show how the port used to let in the source’s power and controller cables (#8) was made safe for use despite it being partially open.

Figure 13: Two views of how port #8 was partially open while being used for radiation testing.

Leaving the port like Fig. 13 with no additional shielding led to large radiation leaks during safety check testing and so had to be improved before actual 5 min testing runs took place. Since port #8 was the only port not completely sealed for this testing, the 17 in. x 17 in. x 0.25 in. thick sheet of lead shown in Figure 14 was used as necessary external shielding.

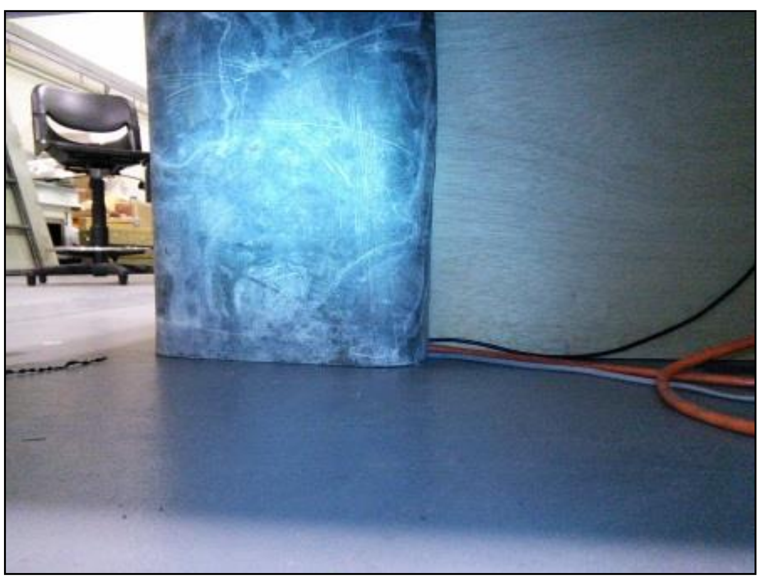

Figure 14: The 0.25 in. thick external lead sheet used to protect the partially open port #8. Where the cables exit from the sheet’s protection is ~6 in. away from the closest side of port #8 and the bottom of the sheet is flush with the ground.

The 0.25 in. thick external sheet was also bent around the corner of the LLB and had its top gap covered by other pieces of regular 1/16 in. thick lead sheet for complete protection.

Figure 15: Different views of the external shielding including the 3 pieces of 1/16 in. thick lead sheet placed on top of the 0.25 in. thick sheet.

On the inside of port #8 the Velcro-attached inside seal was placed over the cables as best as possible and was complimented by a final piece of additional 1/16 in. thick lead shielding as shown in Figure 16.

Figure 16: Interior shielding of the partially open access port #8.

Finally, the last adjustable shielding features of the LLB are weights as shown in Figures 17 & 18. These weights were put in place to bring down radiation levels that were > 15% over background for 5 min trials. The extra weight reduced separation between the lead and the ground or lead and other lead to reduce leaks. All weights were labeled as “DO NOT REMOVE.”

Figure 17: Various 5 lb. and 10 lb. weights used to reduce leaks on the inside of the box.

Figure 18: Additional weight (1 of 2) on the lid of the box to reduce separation between pressed lead sheets and thus stop radiation leaks.

With all of the permanent and adjustable shielding features outlined for the LLB as it was tested here, it must be noted that the arrangements of the features are designed to change as needed for different applications. As such, **the shielding of the LLB must be accordingly safety-checked on a configuration-to-configuration basis.** This would include changes to which access ports are being used, where the box is located in the High Bay (or elsewhere), where weights need to be moved for new hardware to fit into the LLB, damages occurred to or maintenances performed on the wood or structural supports, etc...

<u>Additional Features</u>

Figure 19: A copy of the Mini-X's radiation machine registration is on display on top of the LLB at all times.

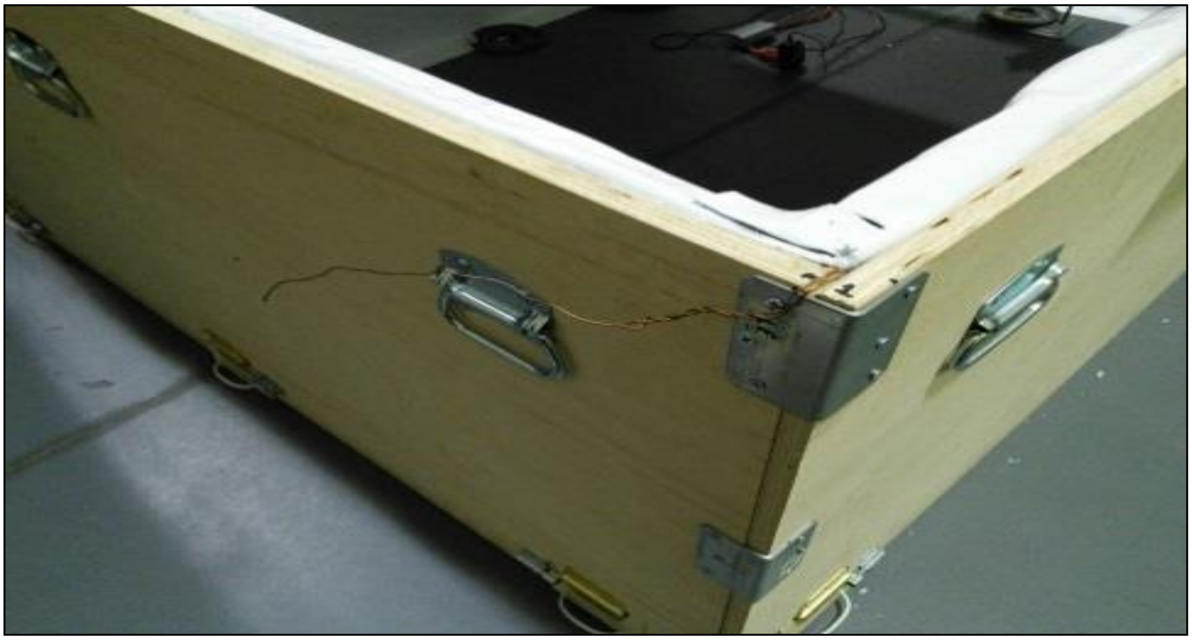

Figure 20: A solid copper grounding wire that is connected to the glued side of each large lead side panel. The wires all connect at this point, but do not complete a circuit in any way.

When ready to operate, this is the general configuration of the x-ray source and the detector.

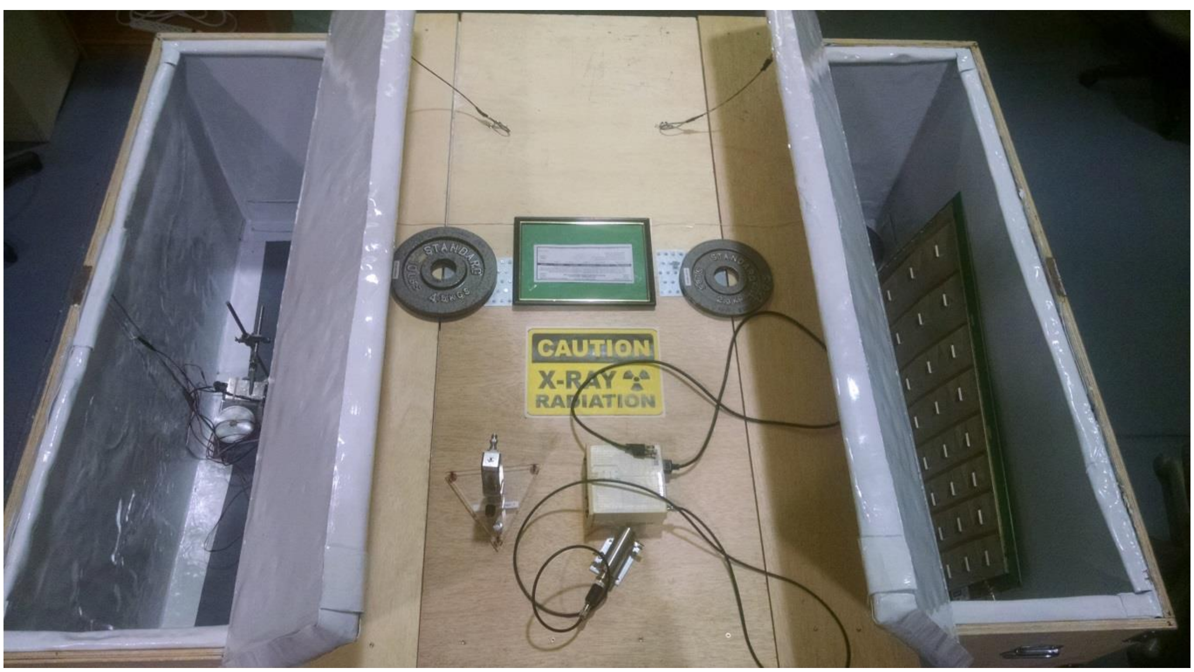

Figure 21: A final overview of the box with x-ray source and detector in respective testing locations.

Procedures

<u>IMPORTANT:</u> Before ANY official 5min. testing was done, preliminary safety checks were done at lower voltages (10 kV – 50 kV increasing in ~10 kV increments) to check for large leaks for every new position/configuration. During these checks, the Geiger counter was held at the end of a rod away from the tester and set to its mR/hr rate. When observed and listened-to from afar, if the Geiger counter read anything over 0.025 mR/hr or started clicking very rapidly, the source was immediately shut off and adjustments to the LLB's shielding was made. Until this general safety check was passed for each location tested, normal testing did not proceed.

General

All background and live-radiation testing was done with the Geiger counter's Total Timer mode set for 5 min. The following rules applied to the orientation of the Geiger counter at each position:

1. When testing at an access port, a flat-top or flat-side face position, and edges at bottom, middle, or top position, the Geiger counter's detector-face was always parallel to the plane of the wood of the face being tested. This is shown in Figure 28.

2. When testing at top corners, the Geiger counter was oriented to have its detector-face normal to the apex of the corner. This is also shown in Figure 28.

3. When testing at bottom corners, the Geiger counter was oriented like bottom edges described above.

4. Testing one portion of a larger feature that is uniform throughout, such as the middle of a 7 ft. side panel or a long lid seam-sealer, was used as data for the entire feature.

<u>Geiger Counter Testing Position Designations</u>

Each of the 56 locations tested on the LLB was given a number as shown in the following figures. The 8 hinged access ports around the bottom of the LLB are given the additional identification numbers #1-#8 as the first diagram, Fig. 22, will show. The title of each diagram after the first represents which way that side is facing.

Each diagram should be interpreted as a face-on view of each respective side. The 4 rectangles around the main diagram give an orientation based off of the Cartesian coordinate system local to the High Bay experimental hall in which testing took place. The designation diagrams are then followed by some (not all) actual examples of the Geiger counter in testing positions.

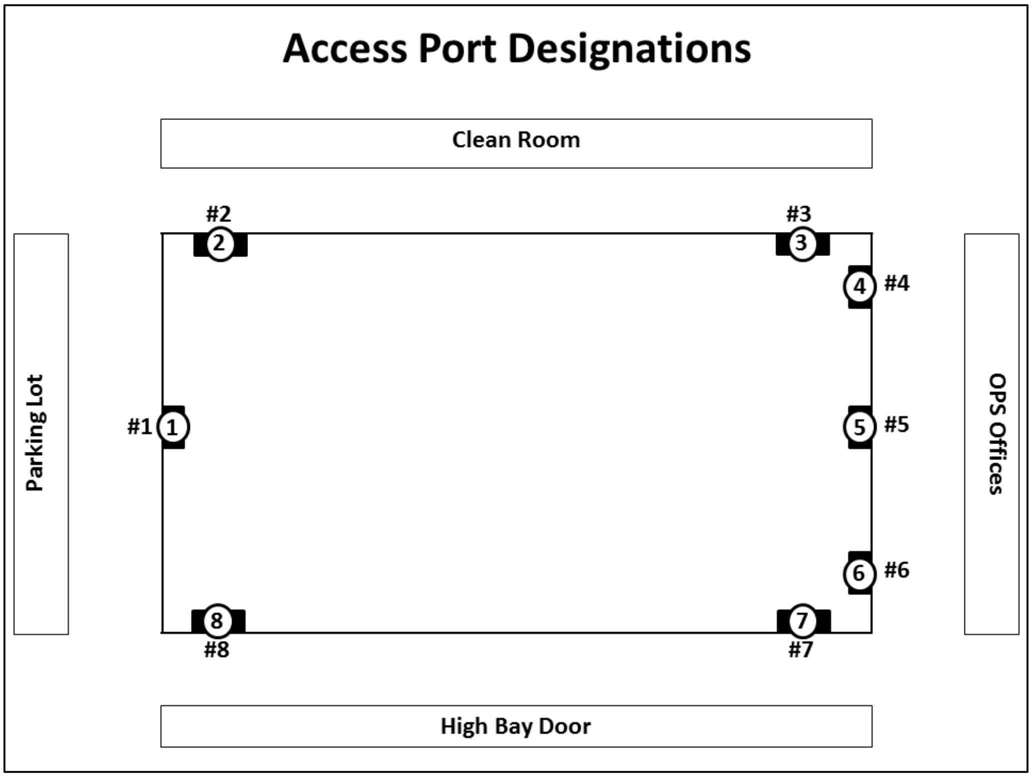

Figure 22: Testing positions 1-8 from a top-down view. These positions are also access ports #1 - #8.

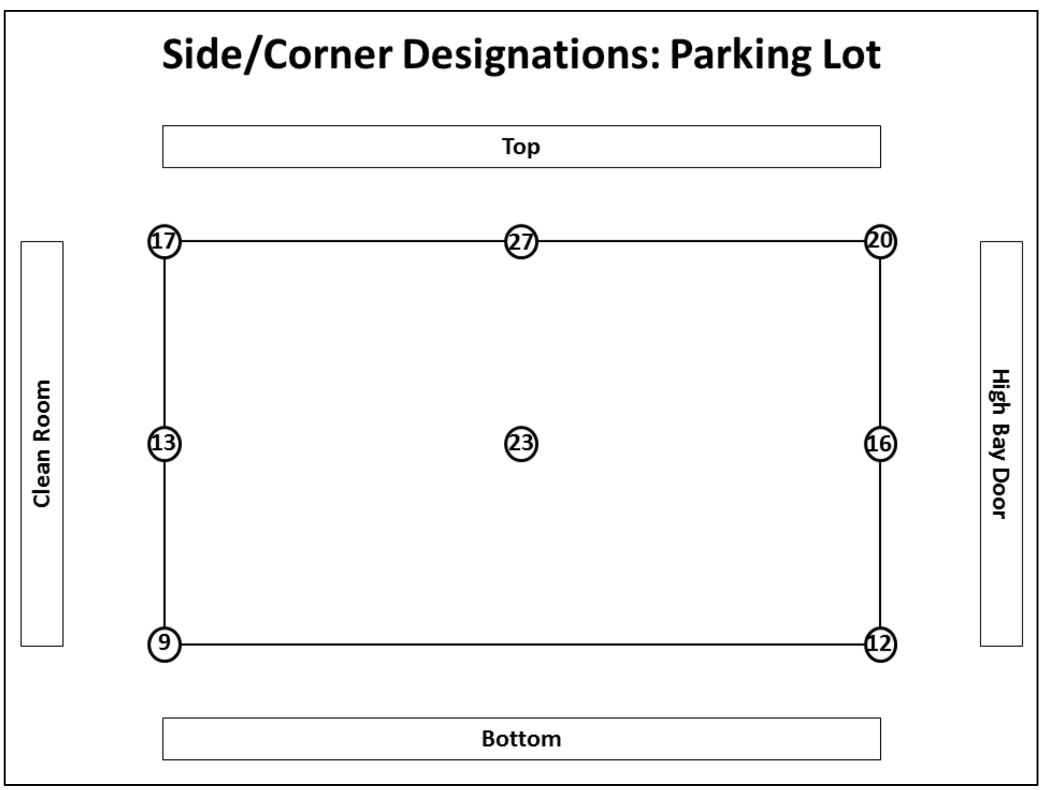

Figure 23: Testing position numbers on the parking lot side of the LLB.

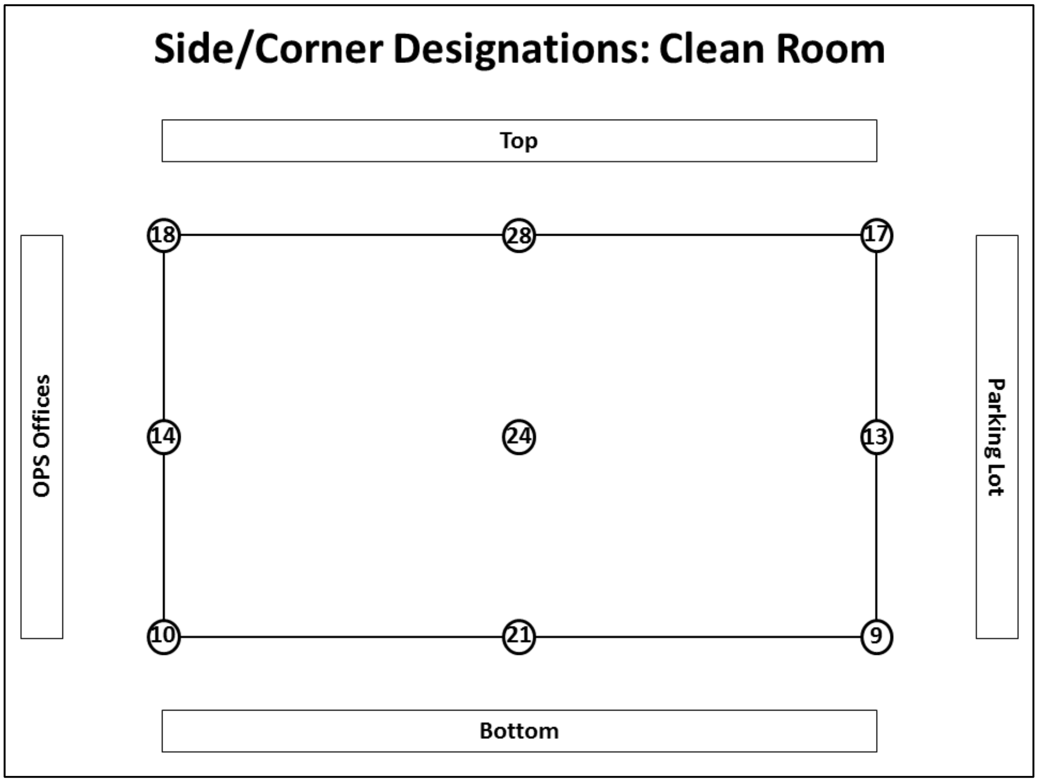

Figure 24: Testing position numbers on the clean room side of the LLB.

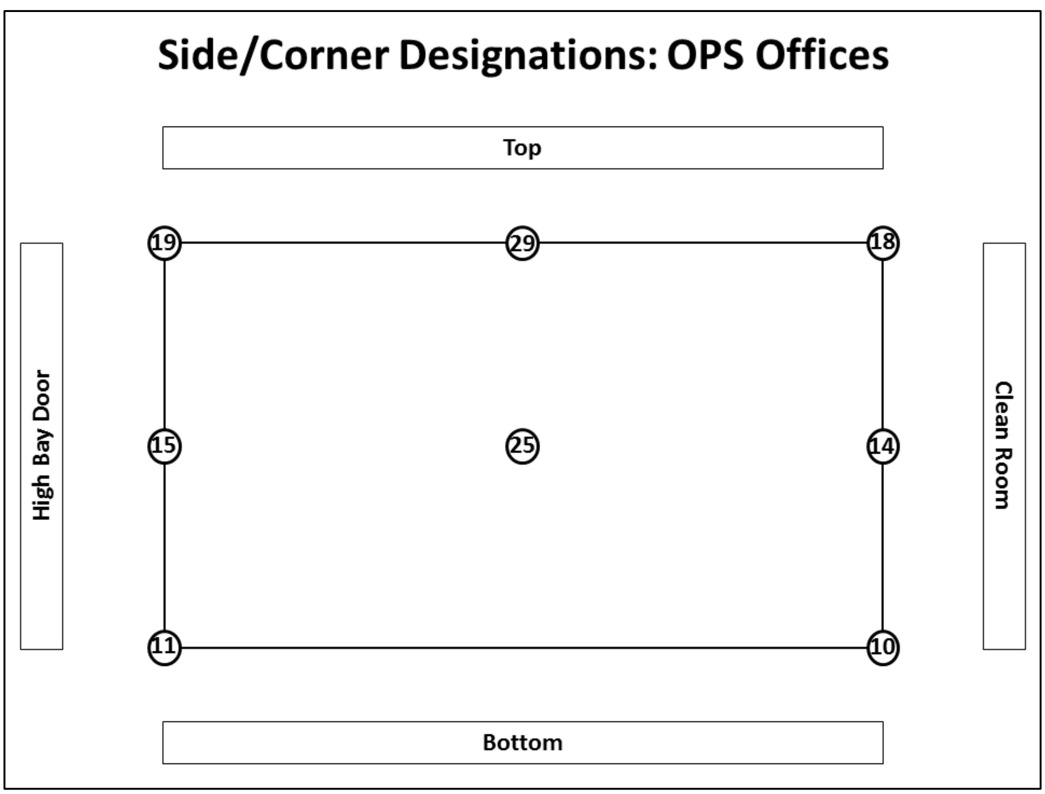

Figure 25: Testing position numbers on the Olin Physical Sciences (OPS) side of the LLB.

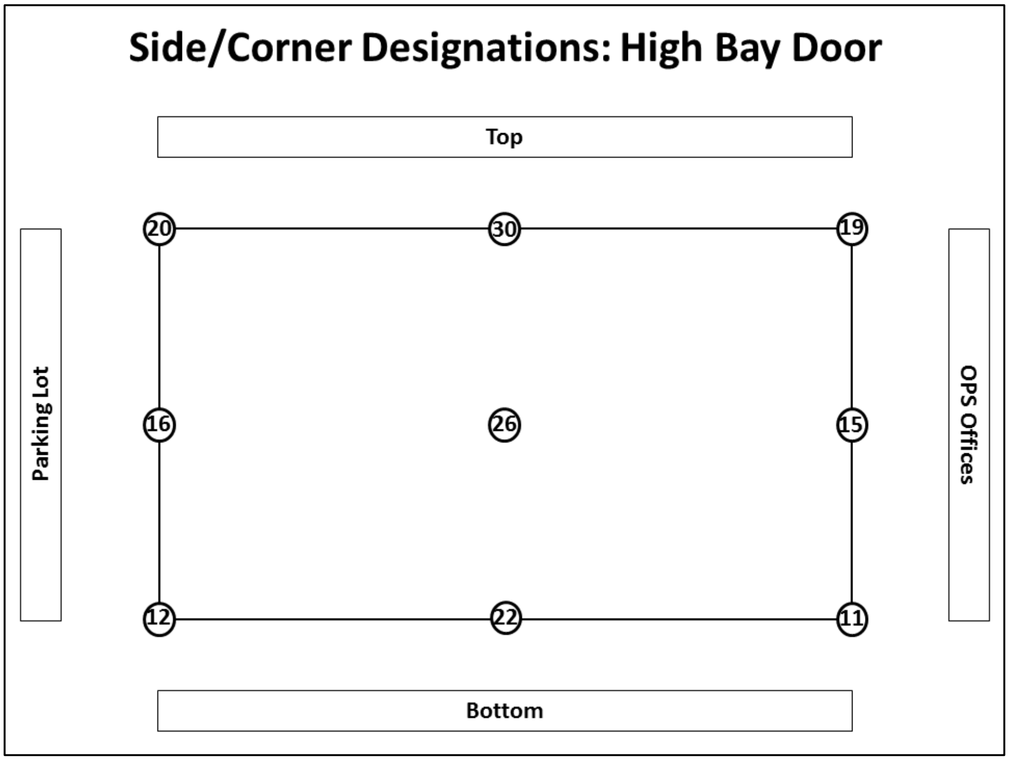

Figure 26: Testing position numbers on the main High Bay door side of the LLB.

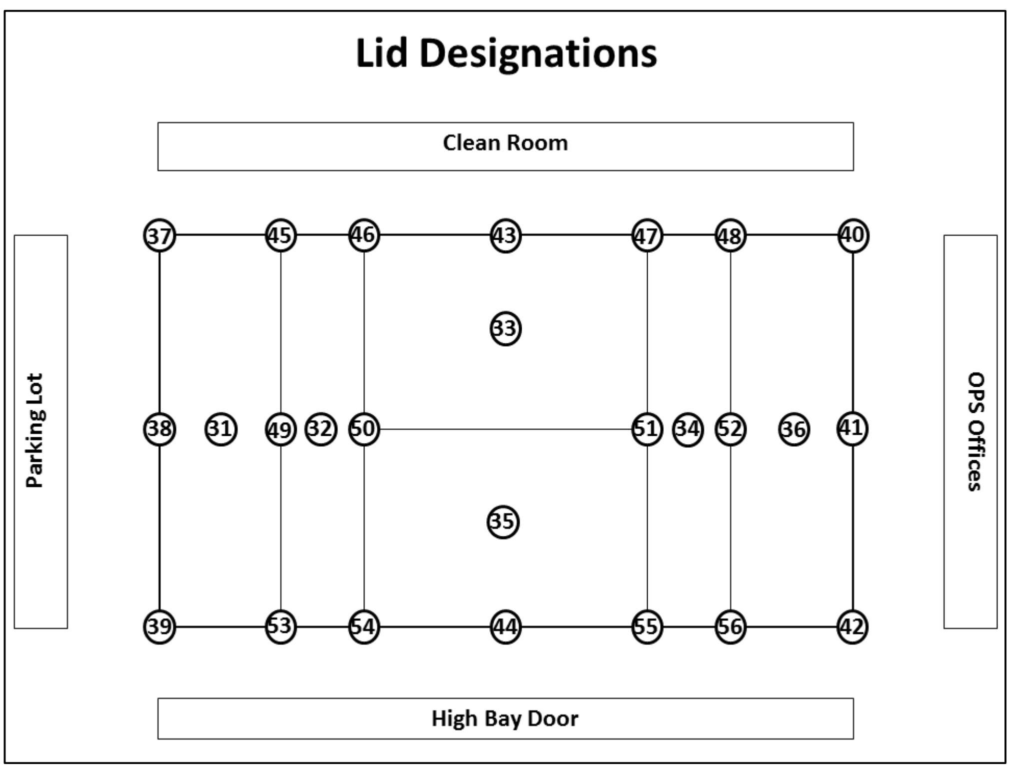

Figure 27: Testing position numbers on the lid of the LLB from a top-down view. Lines show plywood joints that make up the different pieces of the lid.

Additionally, Table 2 gives each numbered testing position a name:

Table 2: All names of Geiger counter testing positions and their corresponding numbers.

Position Name	Position Number
Access Port #1	1
Access Port #2	2
Access Port #3	3
Access Port #4	4
Access Port #5	5
Access Port #6	6
Access Port #7	7
Access Port #8	8
Corner Clean-Parking Bot	9
Corner Clean-Office Bot	10
Corner Door-Office Bot	11
Corner Door-Parking Bot	12
Corner Clean-Parking Mid	13
Corner Clean-Office Mid	14
Corner Door-Office Mid	15
Corner Door-Parking Mid	16
Corner Clean-Parking Top	17
Corner Clean-Office Top	18
Corner Door-Office Top	19
Corner Door-Parking Top	20
Side Panel Clean Bot	21
Side Panel Door Bot	22
Side Panel Parking Mid	23
Side Panel Clean Mid	24
Side Panel Office Mid	25
Side Panel Door Mid	26
Side Panel Parking Top	27
Side Panel Clean Top	28
Side Panel Office Top	29
Side Panel Door Top	30
Lid Panel Parking	31
Lid Panel Mid-Parking	32
Lid Panel Mid-Clean	33
Lid Panel Mid-Office	34
Lid Panel Mid-Door	35
Lid Panel Office	36
Lid Edge Clean-Parking	37
Lid Edge Parking	38

Lid Edge Door-Parking	39
Lid Edge Clean-Office	40
Lid Edge Office	41
Lid Edge Door-Office	42
Lid Edge Mid-Clean Panel	43
Lid Edge Mid-Door Panel	44
Lid Hinges Clean-Parking	45
Lid Seal Clean-Parking	46
Lid Seal Clean-Office	47
Lid Hinges Clean-Office	48
Lid Hinges Mid-Parking	49
Lid Seal Mid-Parking	50
Lid Seal Mid-Office	51
Lid Hinges Mid-Office	52
Lid Hinges Door-Parking	53
Lid Seal Door-Parking	54
Lid Seal Door-Office	55
Lid Hinges Door-Office	56

Finally, Figure 28 shows some example orientations of the Geiger counter.

Figure 28: Examples of the Geiger counter in some actual testing positions. (Top Left) Access Port #2; position number 2. (Top Right) Side Panel Clean Mid; position number 24. (Bottom Left) Corner Clean-Parking Top; position number 17. (Bottom Right) Lid Panel Parking; position number 31.

Normal Operating Position Testing

NOP testing was done with the source remaining stationary at a ‘general operations’ or ‘full irradiation’ position as shown below in Figures 29-31.

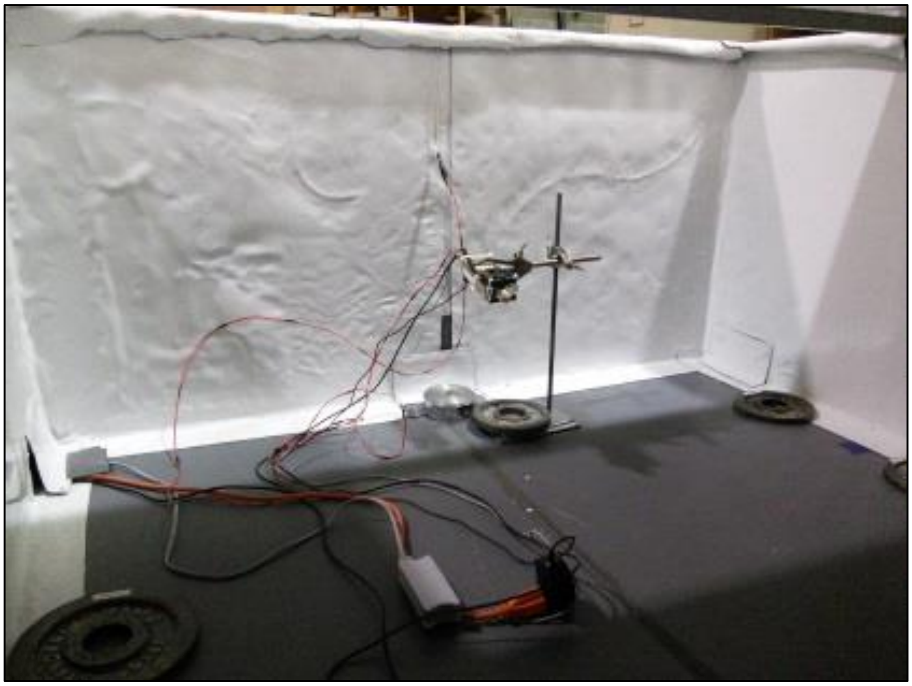

Figure 29: The normal operating position viewed from the inside of the box.

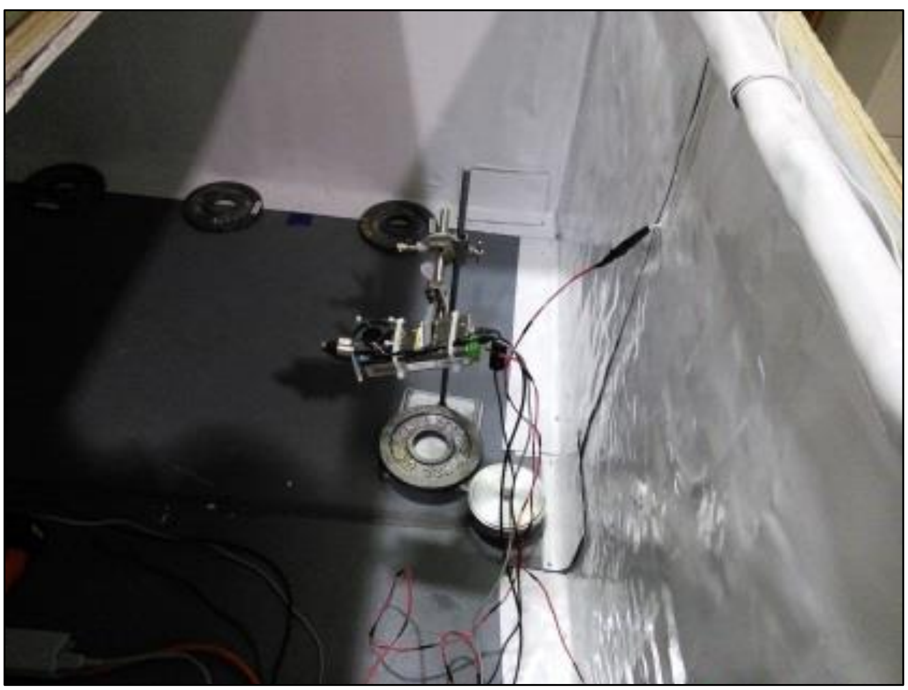

Figure 30: The normal operating position viewed from a side angle.

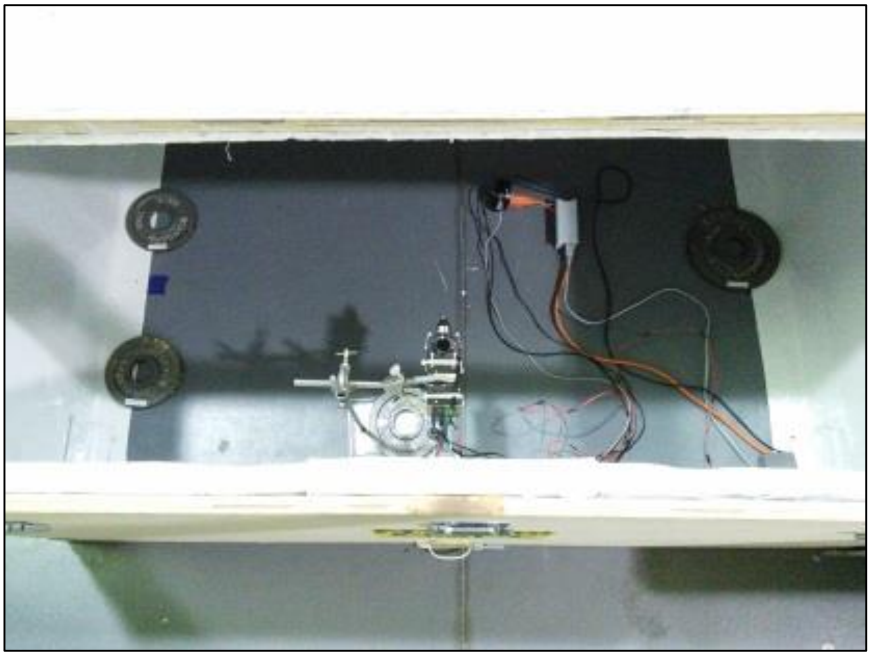

Figure 31: The normal operating position viewed from the top.

Point Blank Testing

Point blank testing was done with the Geiger counter in the same positions tested during NOP testing, but instead of the source staying still it moved around and was directed to irradiate each spot from a distance of ~1 ft.

Figure 32: The Mini-X in its point blank testing position for Access Port #2.

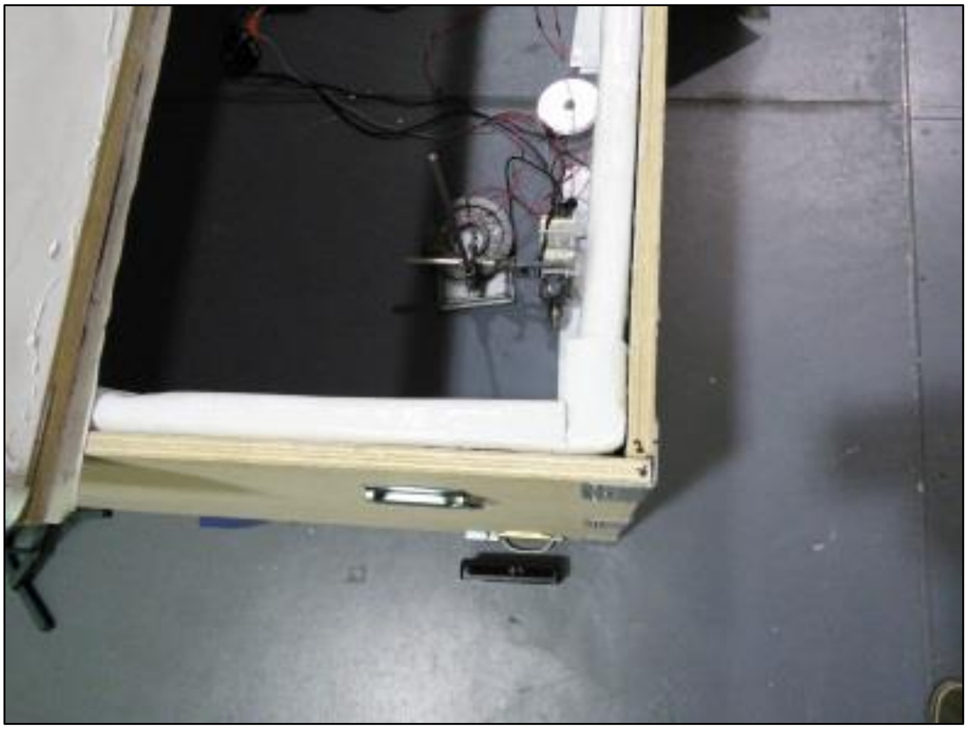

Figure 33: A view of both the Geiger counter and the Mini-X positioned to point-blank-test port #2.

Figure 34: A view of both the Geiger counter and the Mini-X positioned to point-blank-test a top corner.

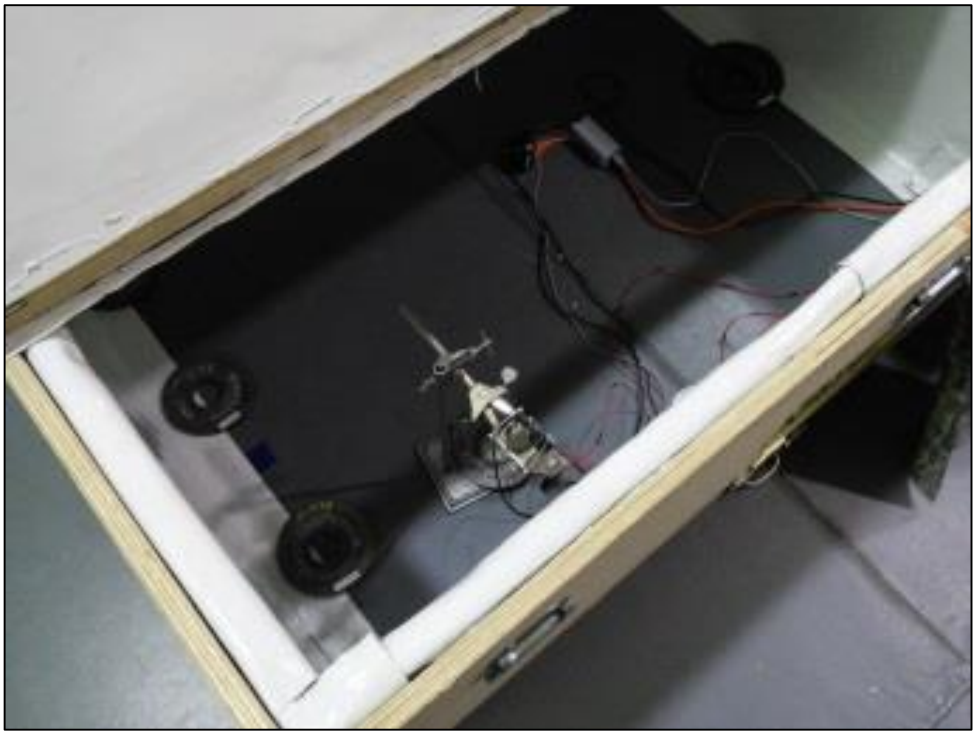

Figure 35: The Mini-X positioned to fire straight up at the lid for a point blank test.

Data, Analysis, and Results

All total count data was collected in 5min runs where the absolute error in a single trial's counts was given by Equation 1:

(1) $$\sigma_{abs} = \sqrt{n}$$

Where n is the total number of counts gathered in a 5 min trial. All other relative and calculation-based errors were propagated by standard methods.

Background trials were collected first by completing a 5 min total count Geiger counter run with the Mini-X powered off for each detector orientation that would be tested. Next, all the NOP positions were tested and finally the point blank tests.

All Positions – Raw Graphs

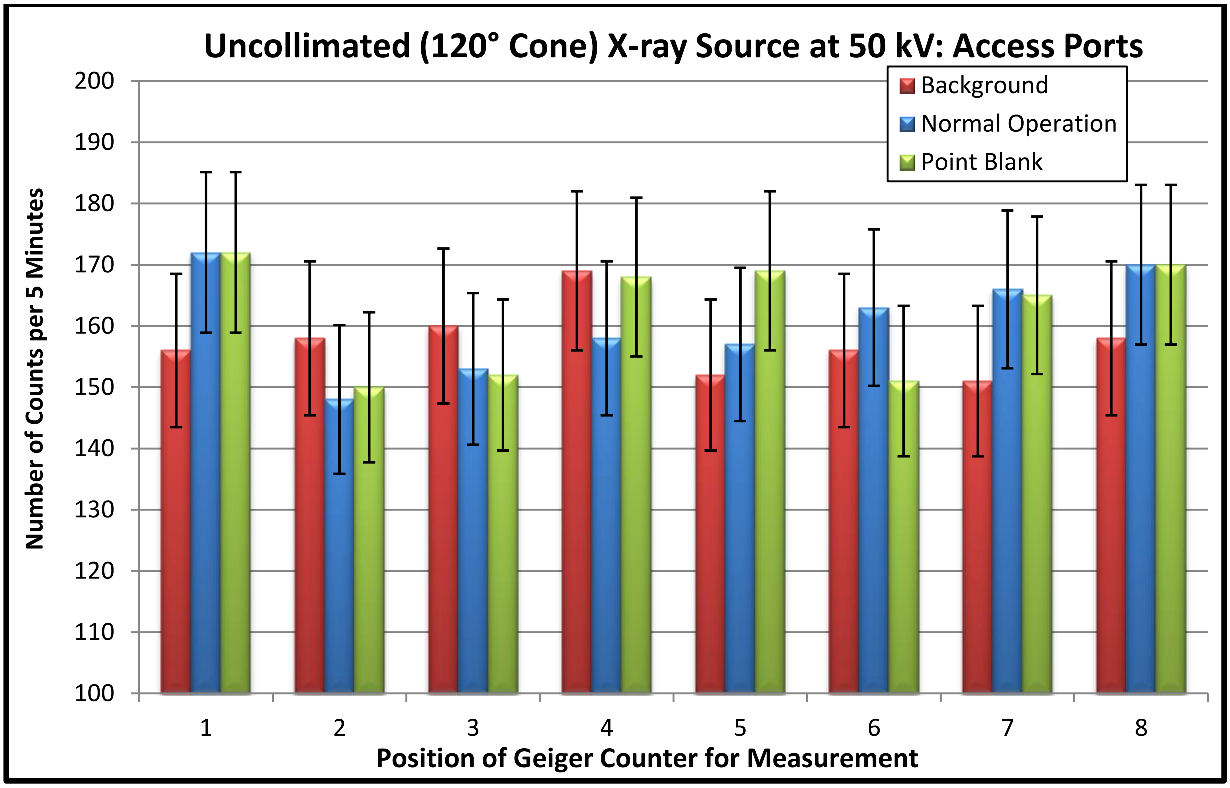

Figure 36: All raw data for Geiger counter positions 1-8 (access ports).

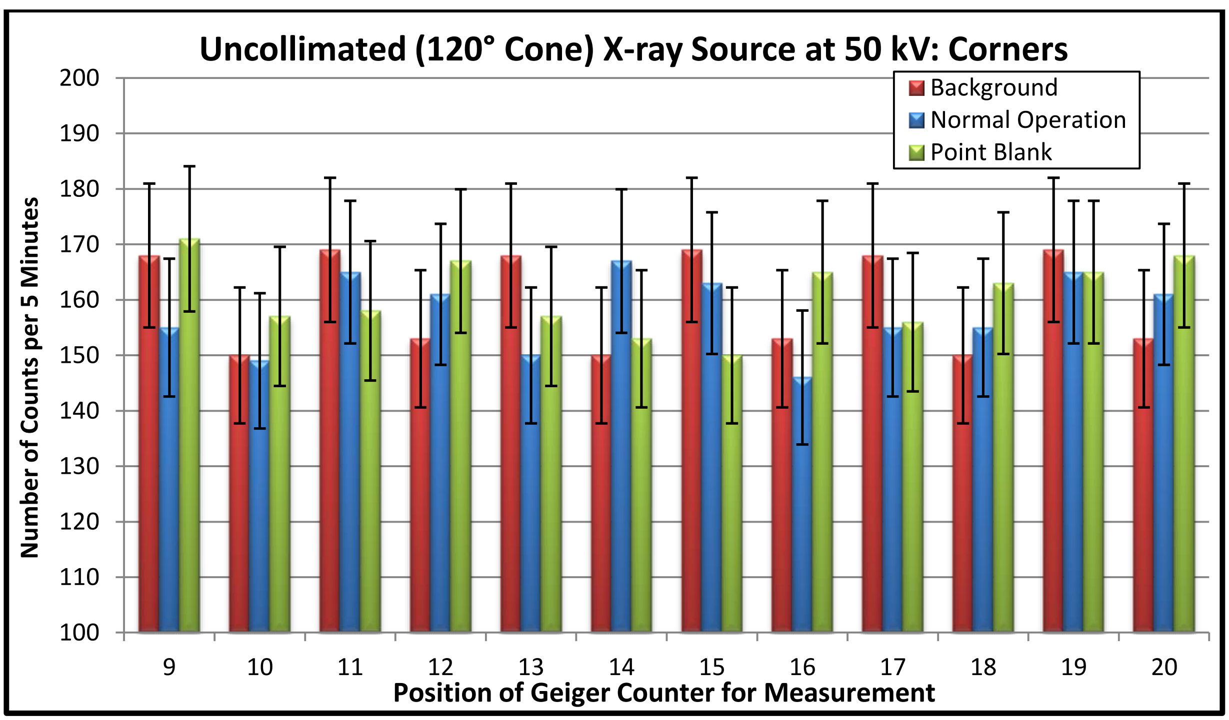

Figure 37: All raw data for Geiger counter positions 9-20 (corners).

All Positions - Raw Graphs Cont...

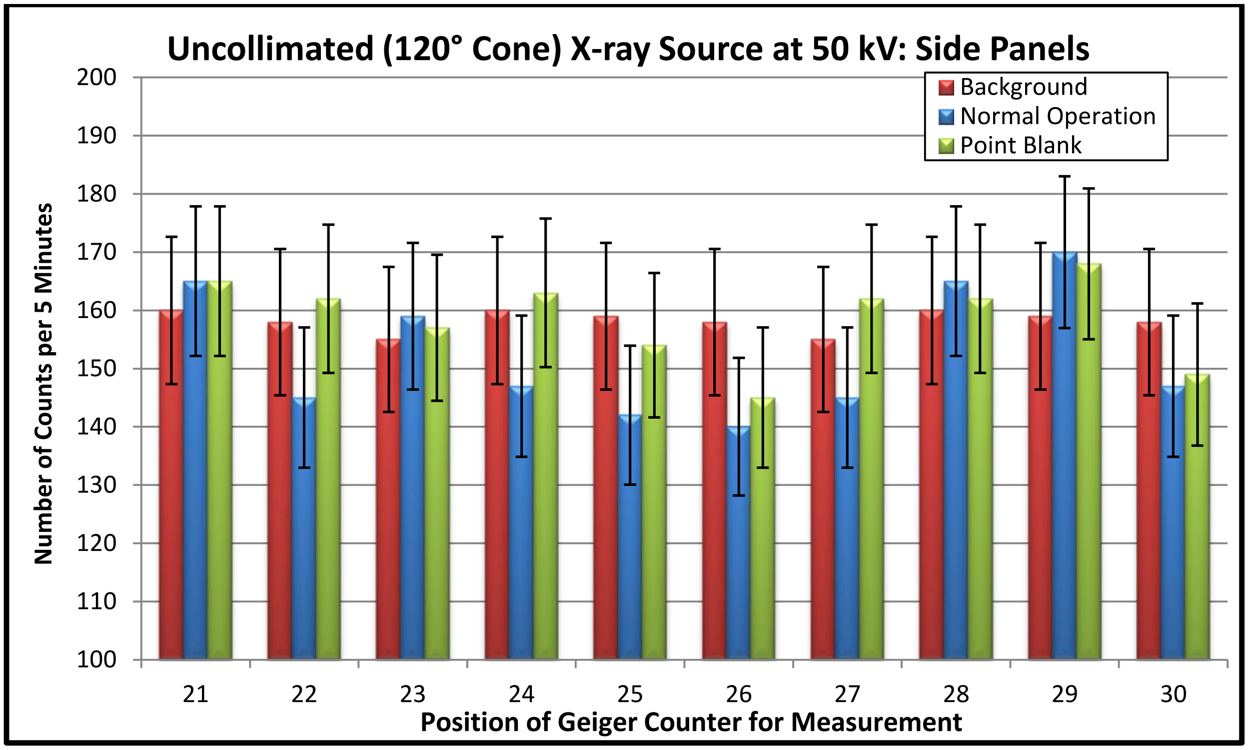

Figure 38: All raw data for Geiger counter positions 21-30 (side panels).

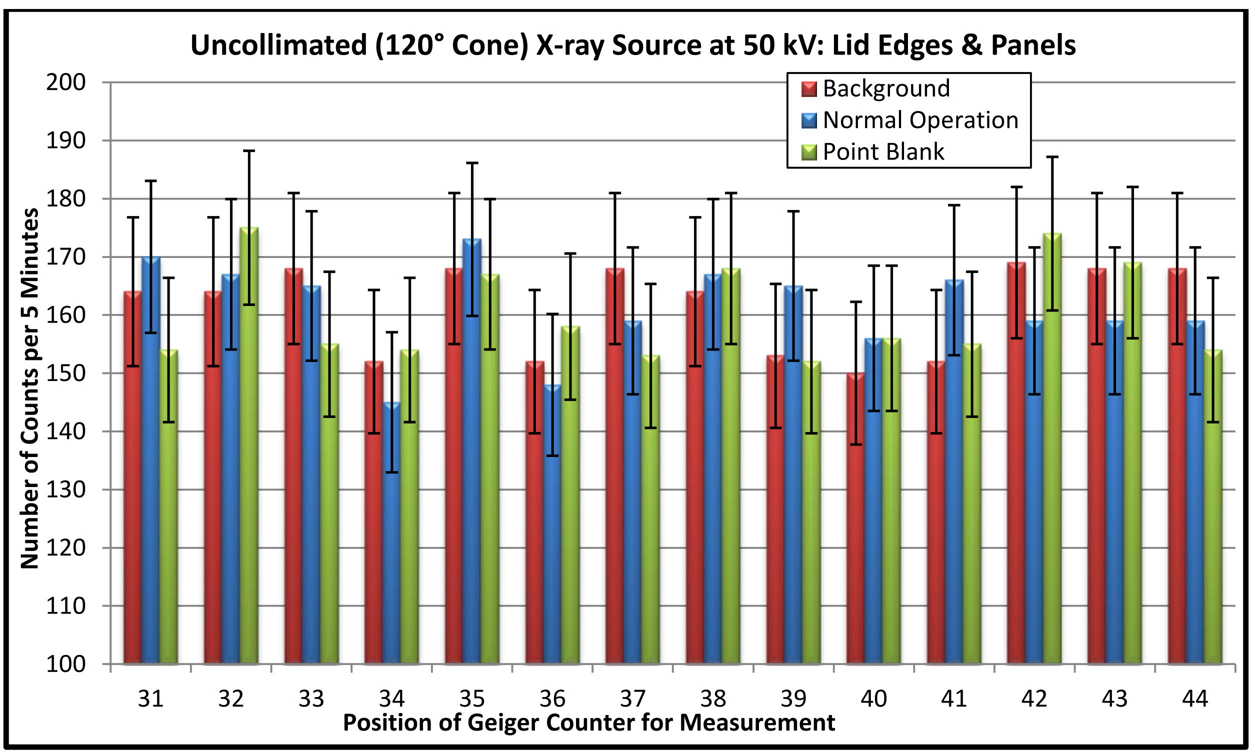

Figure 39: All raw data for Geiger counter positions 31-44 (lid edges & panels).

All Positions - Raw Graphs Cont...

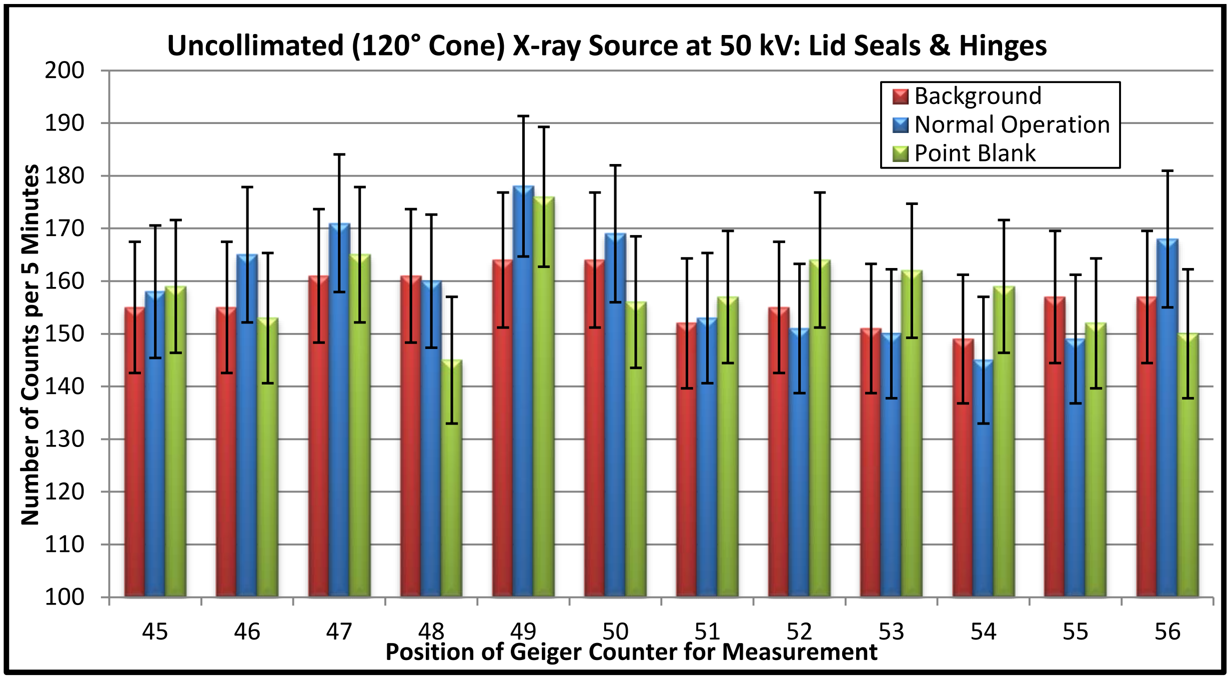

Figure 40: All raw data for Geiger counter positions 45-56 (lid seals & hinges).

As Figures 36-40 show, all total number of counts collected for all NOP and point blank positions were within their and their background's absolute error; therefore, no statistically significant amounts of radiation was found to be leaking from the LLB.

The next two sections that follow provide summaries of the two testing configurations via both normalized and distributed views of the above raw data in Figures 41-44. With the means of the NOP and point blank testing configurations' normalized percent differences being -0.18% and +0.73%, respectfully, the average of all percent deviations from background is very close to 0%. Also, 0% difference was within propagated relative error for all positions in both testing configurations, so the safety of the LLB was proven once again.

Normal Operating Position Summary

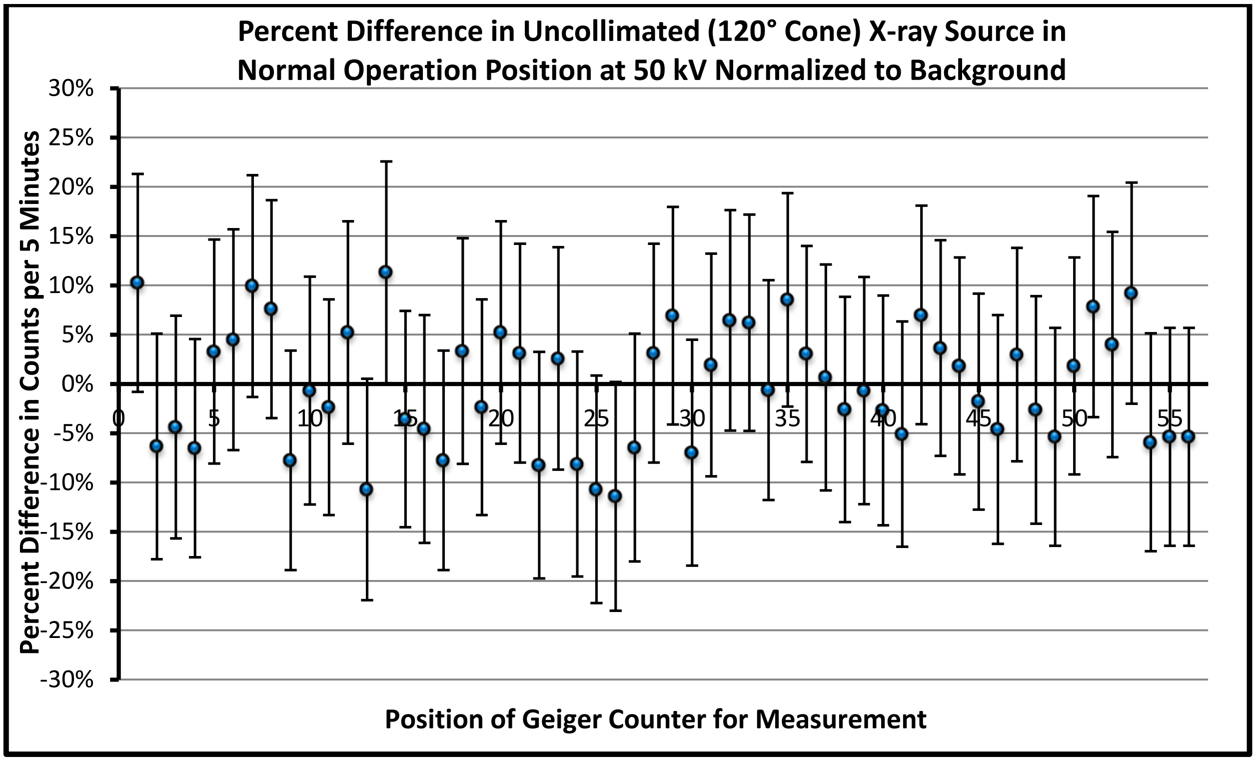

Figure 41: Normalized percent differences from background for all 56 NOP test positions.

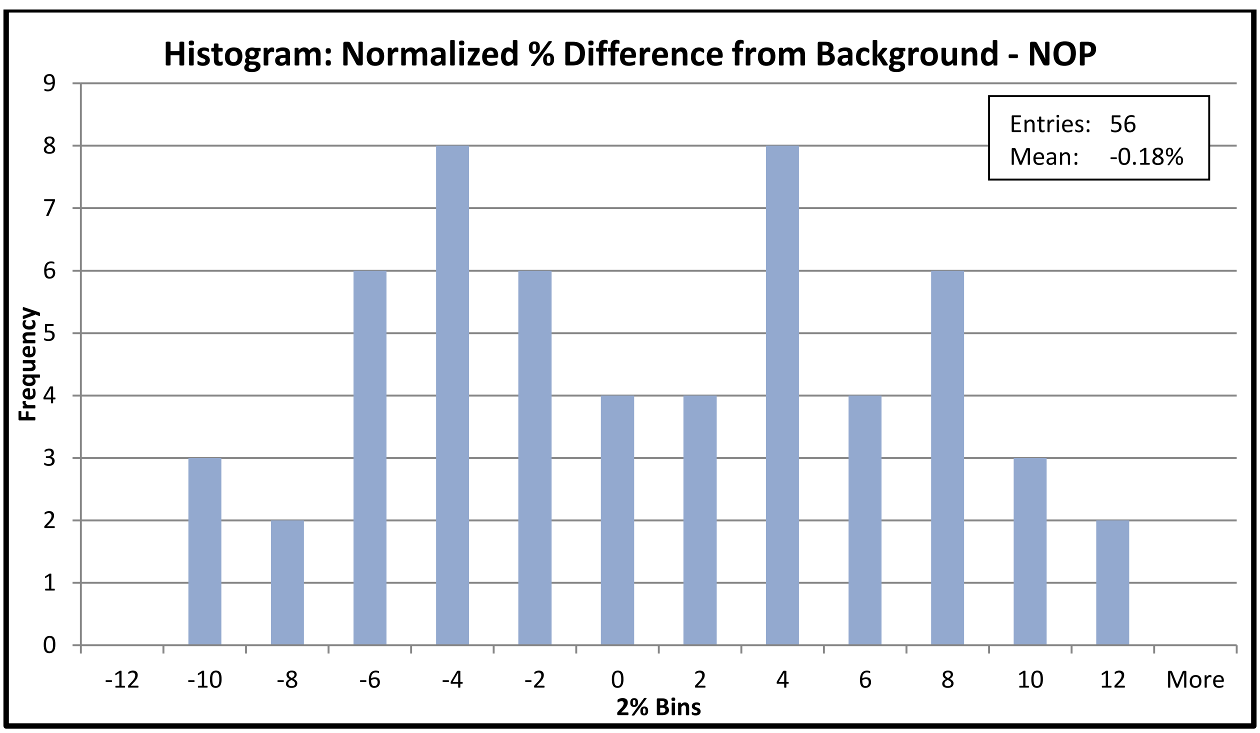

Figure 42: Distribution of NOP test positions' normalized percent differences from background.

Point Blank Positions Summaries

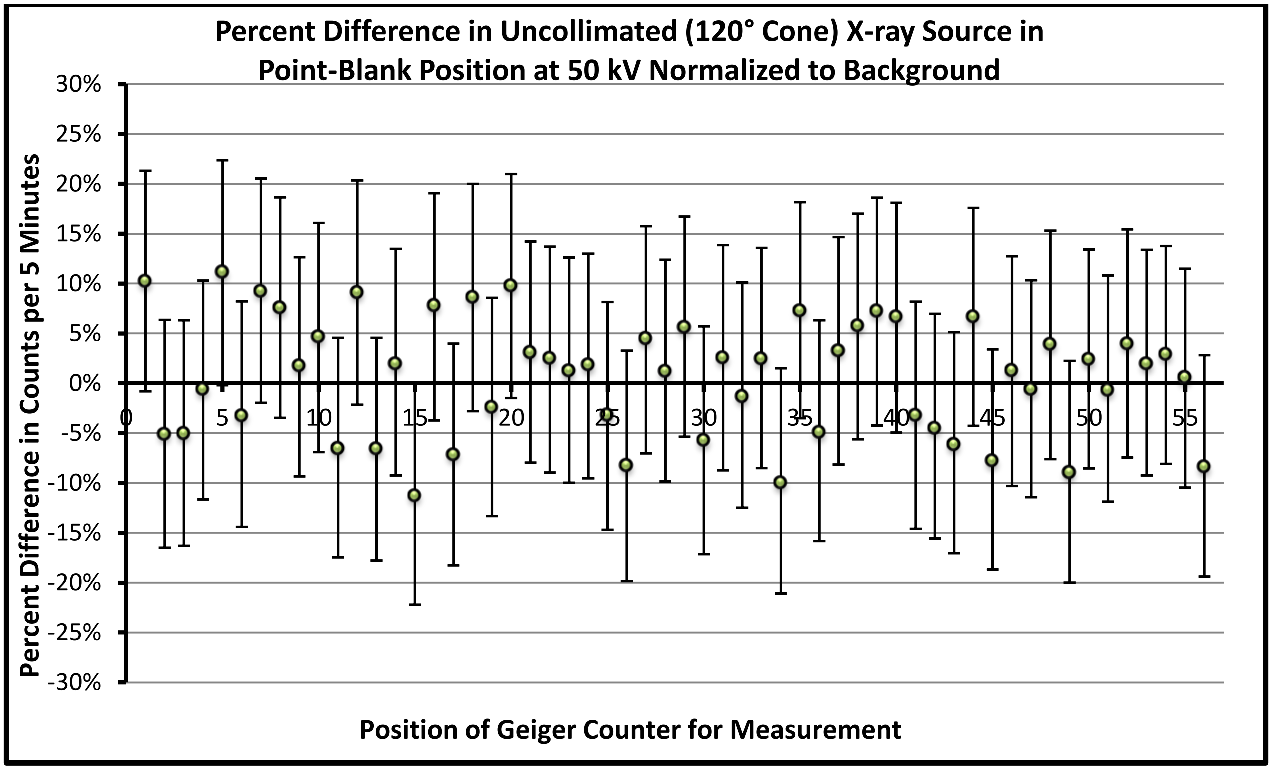

Figure 43: Normalized percent differences from background for all 56 point blank test positions.

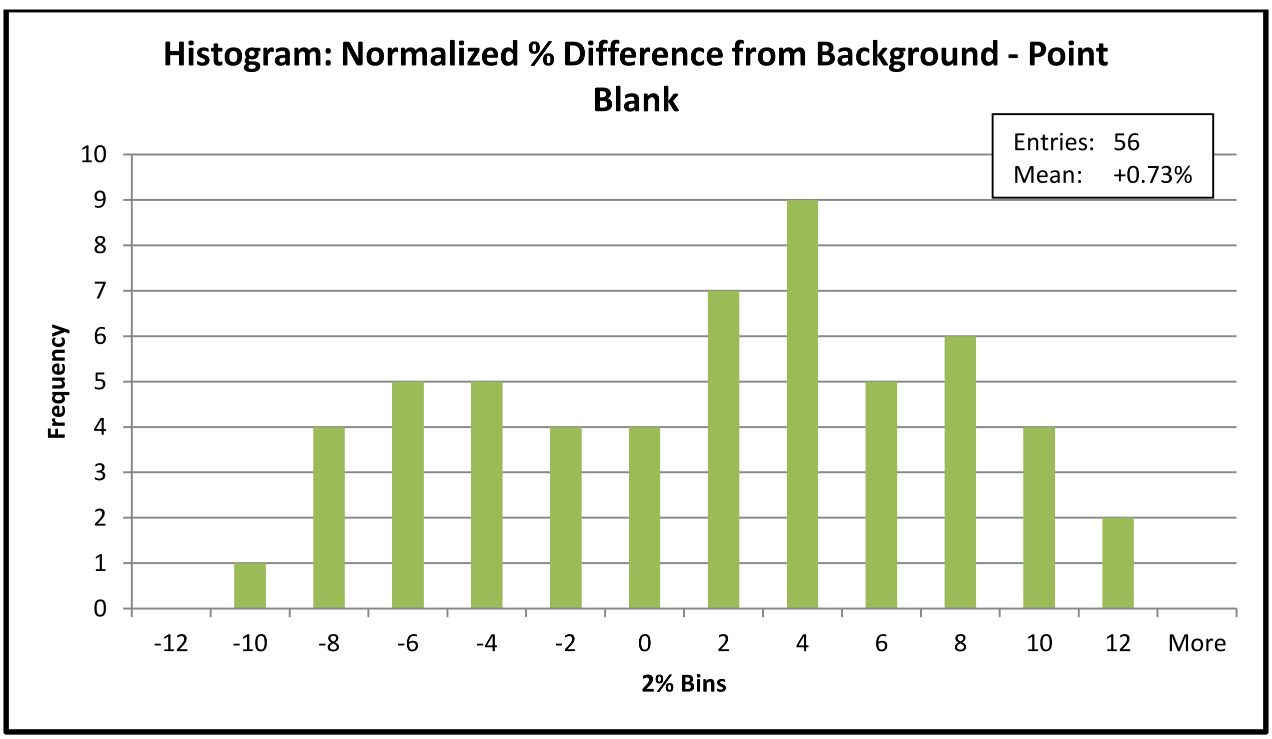

Figure 44: Distribution of point blank test positions’ normalized percent differences from background.

Summary and Conclusions

With all total number of counts collected for all NOP and point blank positions within their and their background's absolute errors, the LLB is fully commissioned and ready to use in its current setup configuration. Also, the means of the NOP and point blank testing configurations' normalized percent differences were found to be -0.18% and +0.73%, respectfully. This average of all percent deviations from background is very close to 0% - an excellent standard for radiation shielding. While these results met the goals this testing had at its start, it must again be stressed that for every new setup configuration of the LLB's shielding features additional safety-check and total count testing must take place before any radiation source is turned on.

Overall, radiation testing and LLB commissioning was successful. Under proper use and care the LLB should provide radiation shielding for years of experimentation to come.