Experimental Hardware Development and Testing

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Senior Undergraduate Research Report Summer 2013
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Contents

Introduction

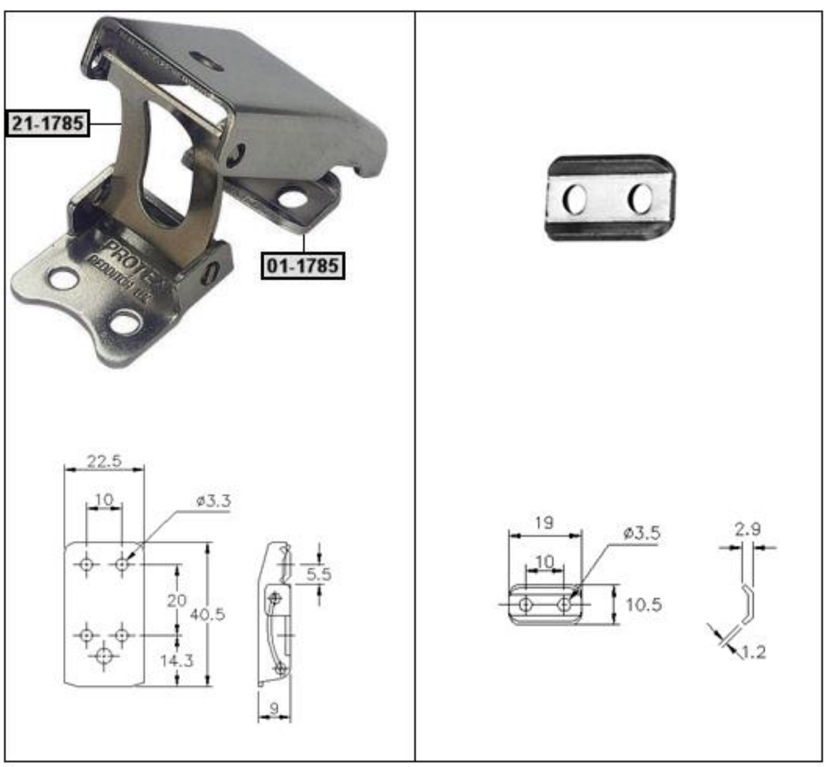
In receiving the materials needed to assemble a 1m CMS GEM detector, the need arose for the construction of hardware that would allow for 1m GEM foil and detector testing. An air-tight gas chamber for foil leakage current testing and a larger lead-lined box for x-ray testing the assembled detector were needed and constructed. Additionally, a rigid aluminum plate was deemed necessary for further 30cm x30cm S4 detector testing after seeing the S4's current read-out board was warped; other smaller hardware jobs were needed and completed on a case-by-case basis.

Work was conducted in Dr. Marcus Hohlmann's High Energy Physics Lab A, the Florida Institute of Technology Machine Shop, and Olin Physical Sciences' High Bay and its room-sized clean room.

1m Acrylic Box Commissioning

After the 1m acrylic box was initially constructed, problems arose with the lid and its Viton O-ring maintaining an air-tight seal. This was remedied by installing latches all around the edge of the box to apply more pressure for a better contact seal with a now gum-rubber O-ring.

Figure 1: Latch and catch plate diagrams as given from PROTEX's online catalogue



Raw Materials

(18) PROTEX 21-1785 latches

(18) PROTEX 01-1785 catch plates

(36) #4 – 40 hardware screws

(36) #6 – 32 hardware screws and matching nuts

(1) Stycast two-part epoxy application

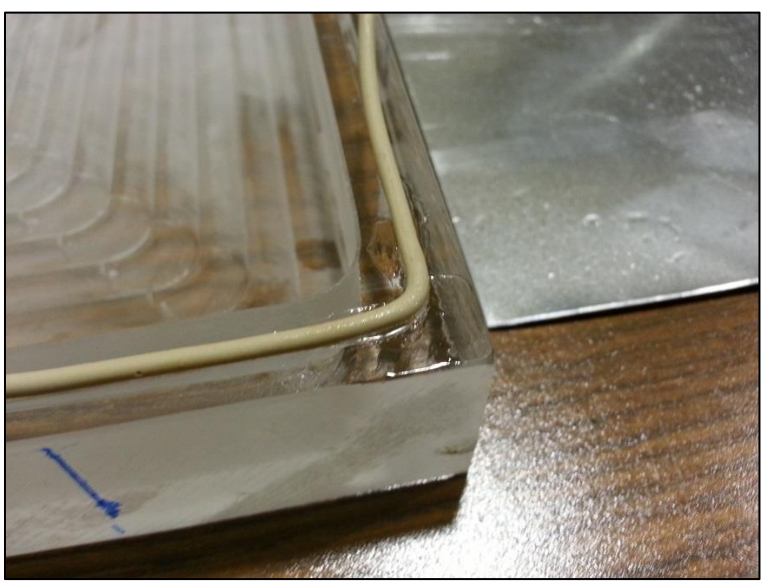
(1) Two-part O-ring superglue application (glue in small brown bottle with brush applicator, hardener catalyst in white push-button mister bottle)

Note: Drills, taps, drill bits, and drill press supplied by individuals or machine shop. All other tools/supplies supplied by HEP Lab A supplies.

O-Ring Installation

The gum-rubber O-ring was cleaned thoroughly with soap and water and the groove in the box was cleaned extensively as well with 91% isopropyl alcohol prior to installation. After cleaning, the O-ring was initially glued into place with ~1’’ segments of the two-part O-ring superglue spaced ~5’’ apart, but was then completely glued down after it fell out of placed every time the lid shifted.

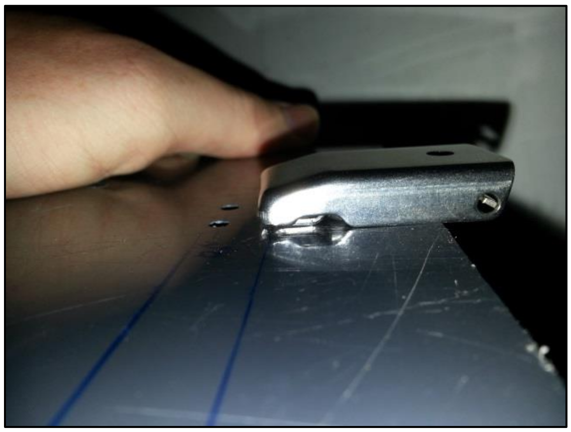
Figure 2: The gum-rubber O-ring being glued into place at a corner of the box bottom



Latch Installation

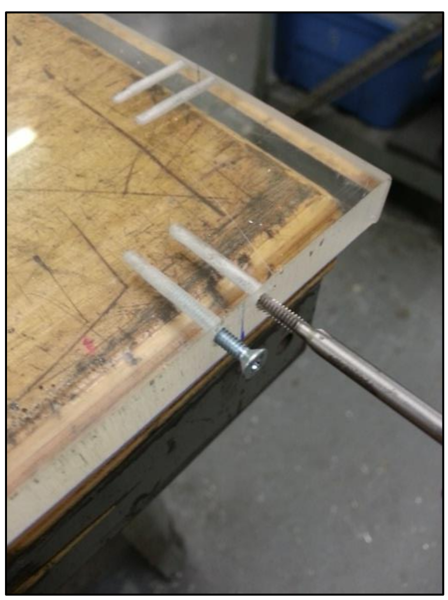
Since the thickness of the closed and sealed acrylic box restricted the possible sizes of latches that could be used, the latches from PROTEX were ordered and planned to be screwed into tapped holes in the box's lid. The tapped holes' locations restricted the possible catch plate locations, so this accordingly required the catch plates to be fastened to the bottom of the box with through-the-wall screws. Latch and catch plate fit and tapping and drilling were all tested on scrap acrylic before on the actual box.

Figure 3: First successful latch and catch plate spacing with latch closed on scrap acrylic



To have access to the proper tapping and drilling tools, practice and actual lid work was done in the Florida Tech Machine Shop. Charts in the machine shop provided the proper sizes of taps and drill bits to use for #4 – 40 hardware screws.

Figure 4: Tapping and testing holes in a fake acrylic lid in the machine shop



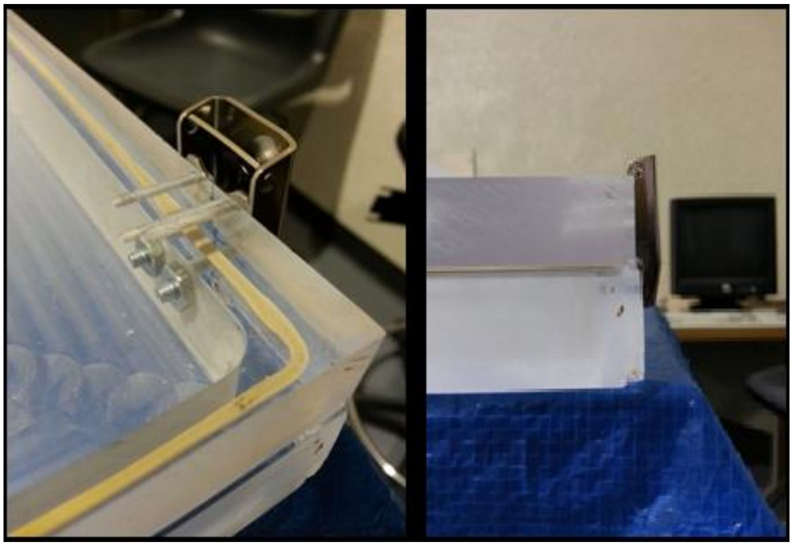
The fake lid was used in conjunction with other scrap spacing materials for approximating the positions of the catch plate holes. This spacing testing was done back in the high bay, seeing as the machine shop was very dirty and not a safe place to keep the fragile box bottom.

Figure 5: Determining the position of the catch plate holes with the completed fake lid

The process of using scrap acrylic for a dry-run of installing the latches revealed many potential material damages that could result from improper machining techniques, including: the need for drilling and tapping to take place exactly perpendicular to the acrylic surface, the extremely fragile nature of taps and drill bits and their tendency to break off inside a hole, the possibility of torqueing a screw too much and completely shearing off its head in a hole, and the property of the latches to bend and become unusable if they were forced to close with too much force. All of these errors were prevented to a much greater extent when working with the actual lid and bottom.

The dry-run was completed, so four test latches and catch plates were attached to the four corners of the box to see if the latch system would, in fact, work. The four test latches worked very well and provided excellent O-ring compression as shown in Figure 6.

Figure 6: Close up of O-ring compression during first successful closing of the four test latches



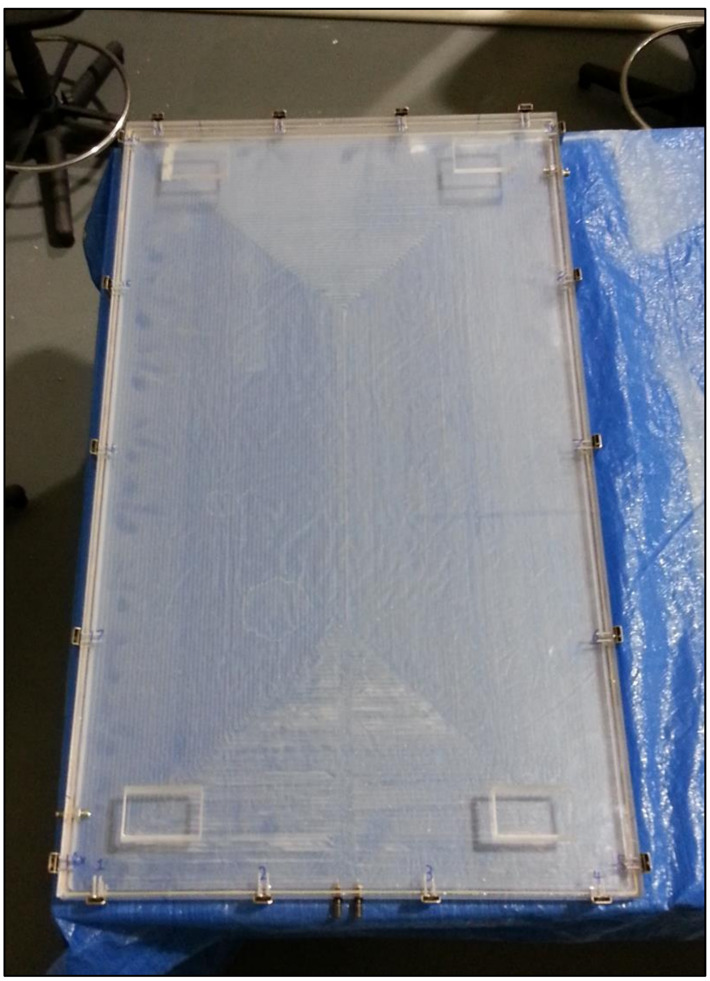
With the test latches successful, the actual lid was taken to the machine shop and drilled and tapped to specification; steps were taken to keep the lid as clean as possible for the given environment. A drill bit and tap broke off into the lid, but an additional drilled holed into the latches in question solved those problems and did not change any properties of the lid or the latches.

Figure 7: The lid in the machine shop with paper towels shielding it from the dirty table

After the lid was completed and all remaining latches were attached, the lid was placed on top of the box bottom so both holes for each catch plate could be custom marked to where the latches were after permanent installation. Holes were carefully drilled into the box's bottom and the catch plates were attached without being sealed with Stycast so their fit with the catch plates could be tested.

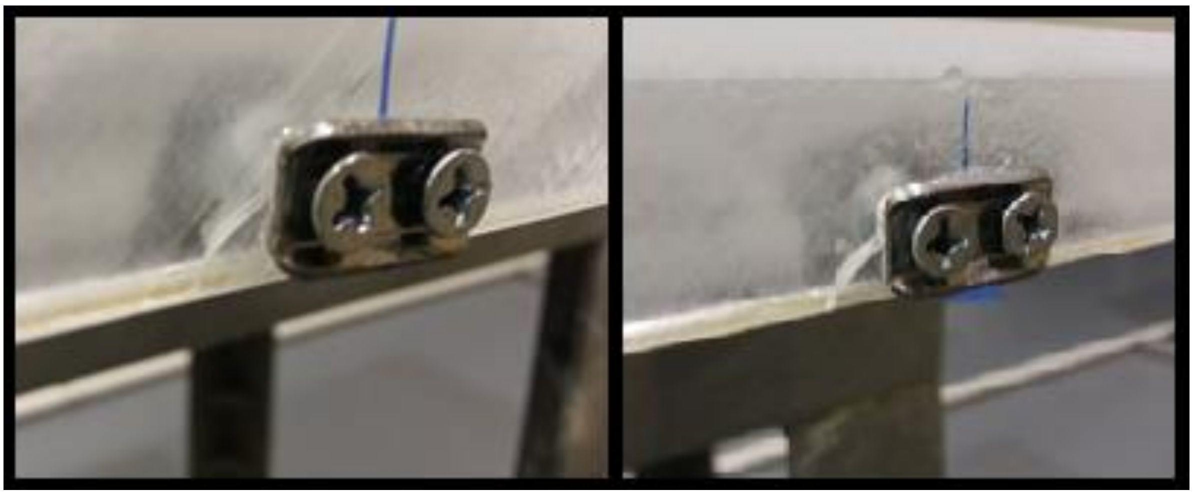
All but three latches closed securely on the first complete closure of the latches; they were too tight and the force required to close them might have damaged the box. The problem latches were taken off, and after inspection of their curved hinge-like component revealed that each was bent, they were beaten back into working order with a hammer on a wood block. This solution helped one of the three close, but the other two were still too tight to close safely, so their catch plates were removed and a drill was used to shave away the inner top of the catch plates' screws' holes. This was done gradually and carefully to prevent cracking of the acrylic. After reinstalling the latches, all latches closed properly for the first time and the O-ring was completely compressed.

Figure 8: All latches closing for the first time



Sealing the now working catch plate holes with Stycast went smoothly. Both screws for each catch plate and the inside of each through-the-wall hole was coated extensively in wet Stycast; screws were put into their holes and then had their nuts tightened to hold them in place. The latches all closed again after the epoxy fully cured for 24 hours. At this time two cracks were found by two different catch plates' now sealed holes; they were monitored from then on very carefully.

Figure 9: Small cracks found by two different catch plates



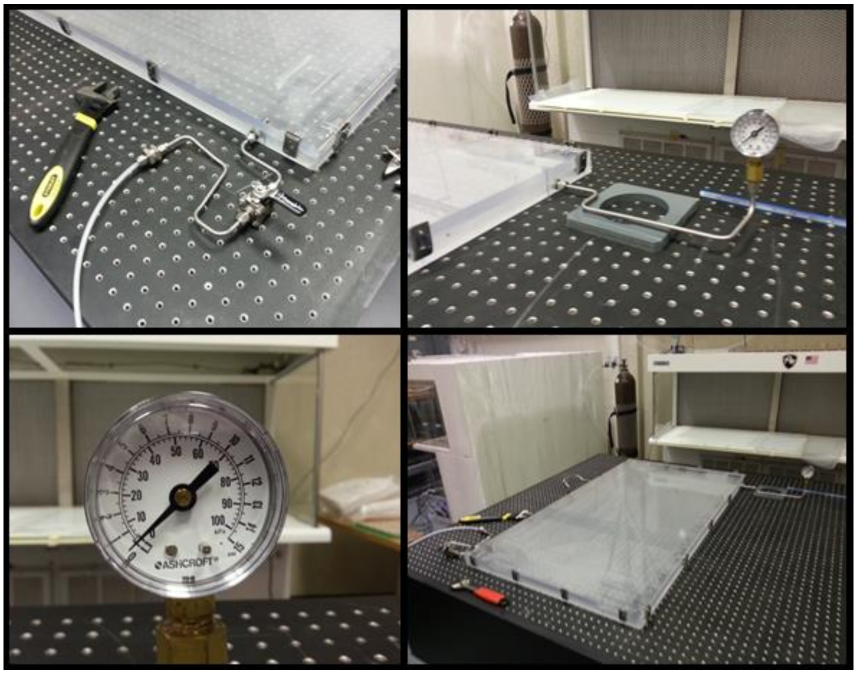
As a side note, it was observed that the aging Stycast in the lab cured very rapidly in batches that weighed as little as 30g. The Stycast also produced a large amount of heat during this rapid curing and partially melted its temporary application container; this led to the institution of the rule that Sycast should never be made in a batch (in the proper proportions as indicated by its MSDS sheet) weighing greater than 15g.

The acrylic box was thus completed, cleaned extensively, and moved into the room-sized clean room in the high bay.

Pressure Testing

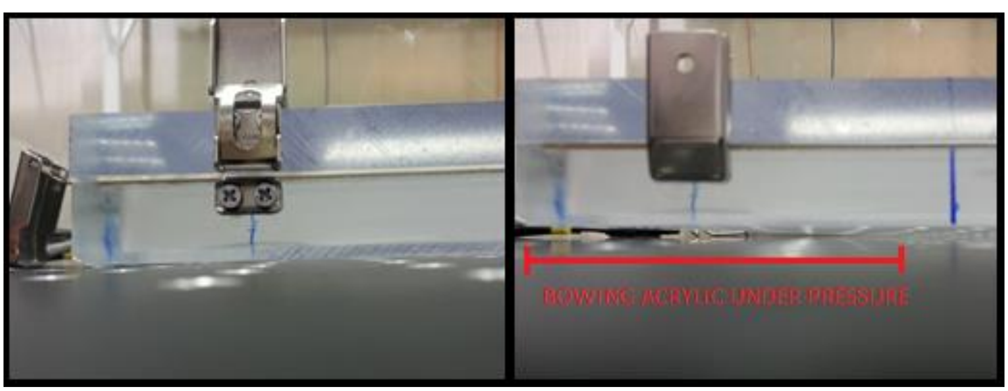
By attaching a ball valve to the gas input and pressure gauge to the gas output of the latched, sealed, and closed acrylic box, its gas tightness was to be determined.

Figure 10: Pressure testing setup



Pressure testing started around 20kPa, but soon showed problems. Even though gas was flowing into the chamber, the pressure gauge did not move past 2-3kPa. Before any kind of long term observation could take place, the box was observed to have begun inflating; the thin bottom of the box was bowing under the pressure and lifting the edges of the box up off the optic table. The nitrogen gas was shut off immediately and several minutes were allowed to pass to let the box deflate to where the lid could be taken off.

Figure 11: Left panel is the normal box, right panel is the inflated and bowing box



After taking off the lid to inspect box after its first unintentional inflation, the two small cracks that had been found previously were found to not be any larger, but pressure testing was still suspended. Since the box had held its inflated shape for several minutes after the gas was turned off, it was deemed to be air tight enough for our applications. At this time a rule was established that the acrylic box should never be sealed and pressurized if the output gas line did not vent to the outside or if it was significantly blocked in any way.

The acrylic box was then fully commissioned and started serving as a test chamber for 1m CMS GEM foils and any other related needs.

Aluminum Plate

Design and Purpose

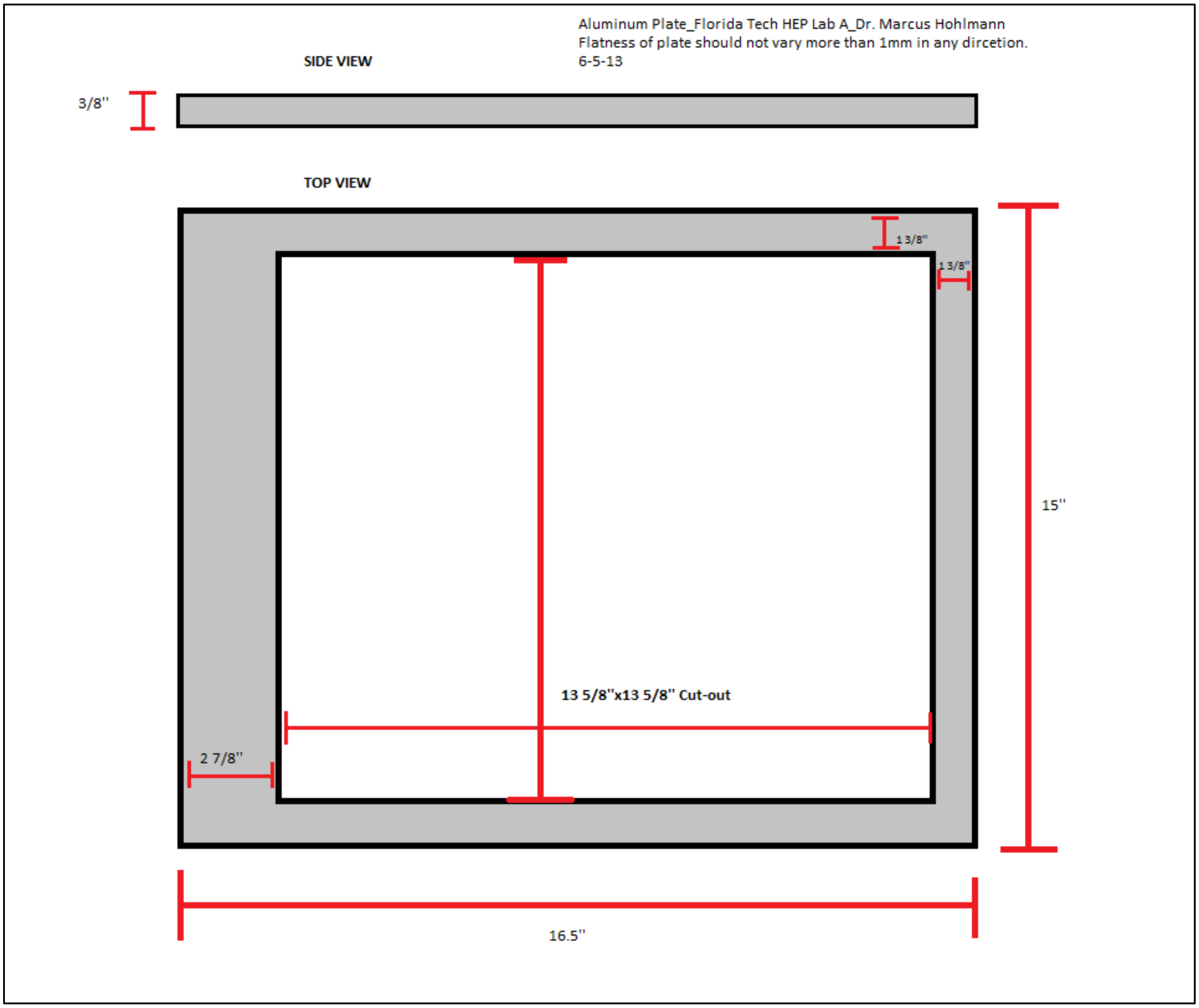
After the research group had been experiencing many problems with the self-stretched 30cm x 30cm S4 detector, it was decided some problems could have resulted from the readout board of the detector being warped several mm away from it being a completely flat board. To remedy this problem, a stiff, strong, and, most importantly, flat plate of aluminum was designed to be attached to the readout board and then tightened down with screws to force it flat.

Several pieces of scrap aluminum were obtained from the machine shop to get a feel for their rigidity and eventually a 3/8’’ thickness was decided up as the desired thickness. It was also decided that the plate would need to not vary from a perfect flatness more than 1mm in any direction. With these specifications in-hand, calls were made to different local companies and the only one that could meet our requirements was SBS Precision Sheet Metal.

Ongoing Communication with SBS Precision Sheet Metal

After talking with Don Morse on the phone about the plate’s design, a sketch was sent so he could make an official quote.

Figure 12: First sketch of the aluminum plate design submitted to SBS Precision Sheet Metal



After Don received the first sketch, he sent the below quote of $104.67.

Figure 13: Quote from SBS Precision Sheet Metal for aluminum plate fabrication

SBS
PRECISION SHEET METAL

YOUR RFQ# EH060513

PAGE 1

AS9100 / ISO 9001:2008

4324 FORTUNE PLACE, MELBOURNE, FLORIDA 32904
TELEPHONE (321) 951-7411 FAX NUMBER (321) 728-0847

DATE 6/6/2013
CUSTOMER ID HOUSE

HOUSE SALES
PROPOSAL SUBMITTED TO

ATTN:
ERIC HANSEN
PH
FAX

YOUR REQUEST: EH060513
RFQ DATE 6/6/2013

CITY, STATE, AND ZIP CODE

EMAIL DRAWING'S TO
dmorse@sbspre.net

We hereby submit specifications and estimates for the following:

ITEM ID	RFQ QTY	RFQ UM	PART NO	DESCRIPTION	REV.	PRICE EA.
1	1	EA	3/8" ALUM 15X16.5	PLATE		$104.67

FOB: MELBOURNE, FL
DELIVERY: 1 WK. ARO
TERMS: NET 30 DAYS

ONE TIME TOOLING CHARGE:
EXPIDITECHARGE:

QUOTE NOTES:

EXCLUSIONS:

FOR SBS PRECISION SHEET METAL
Authorized Signature:

PREPARED BY: **Don Morse**

Note: This proposal may be withdrawn if not accepted within 180 days. $250.00 NRE IF 1ST ARTICLE IS REQUIRED

As of 7-26-13, the group has communicated to SBS that they want them to complete the given quote, but SBS has been busy with other jobs on their machines. At the time of writing this report SBS had not confirmed they have started the job in any way, but they do know their services are greatly desired. Once SBS fabricates the aluminum plate, four holes will be drilled into the plate and the readout board so they may be attached and the board flattened as desired.

Extended Lead Box Commissioning

To be able to accommodate the larger 1m CMS GEM for x-ray testing, the 2’ x 2’ x 3’ lead shielding box was expanded to be an additional 10.5’’ longer. Using the wood scrapes from when the box was originally built, and by ordering more 1/16’’ thick lead sheet from RotoMetals, the box was expanded and therefore had to be completely retested for radiation leaks. This construction was also used as an opportunity to improve upon some of the original box’s shortcomings, such as interlock reliability.

Raw Materials

(3) 2’ x 10.5’’ x ¾ ‘’ pieces of plywood

(1) 2’ x 3’ x 1/16’’ sheet of lead (to be cut up into various sizes)

(8) Standard hardware metal bracers

(104) Standard hardware ¾’’wood screws (must fit metal bracers)

(4) Metal folding chest handles (Home Depot)

(4) Metal pull handles (Home Depot)

(2) Metal door hinges (Home Depot)

(1) Tube of polyurethane construction adhesive

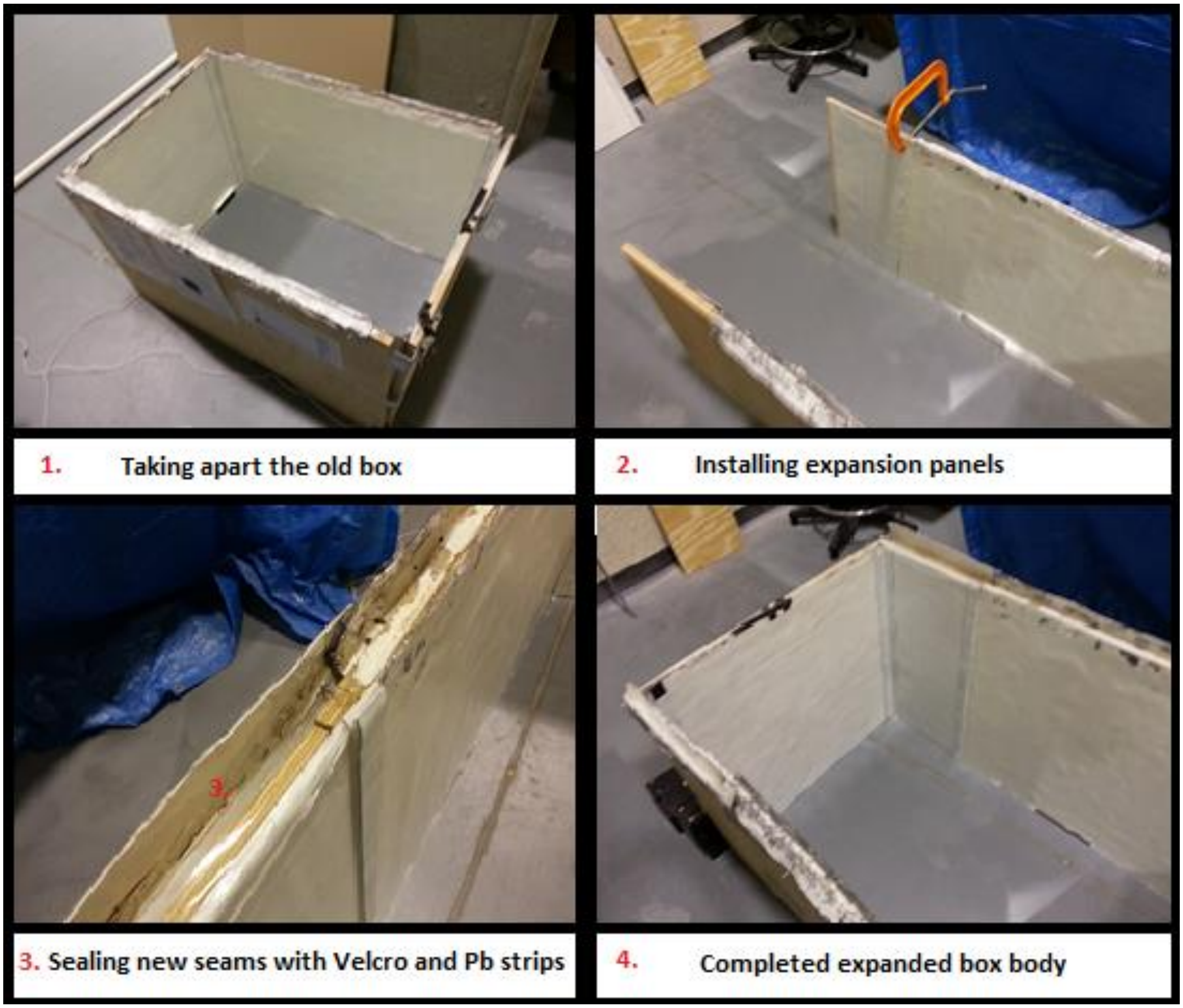
(1) Roll of packaging tape and electrical tape

Note: Drills and drill bits supplied by individuals or machine shop. All other tools/supplies supplied by HEP Lab A supplies.

Extending the Box

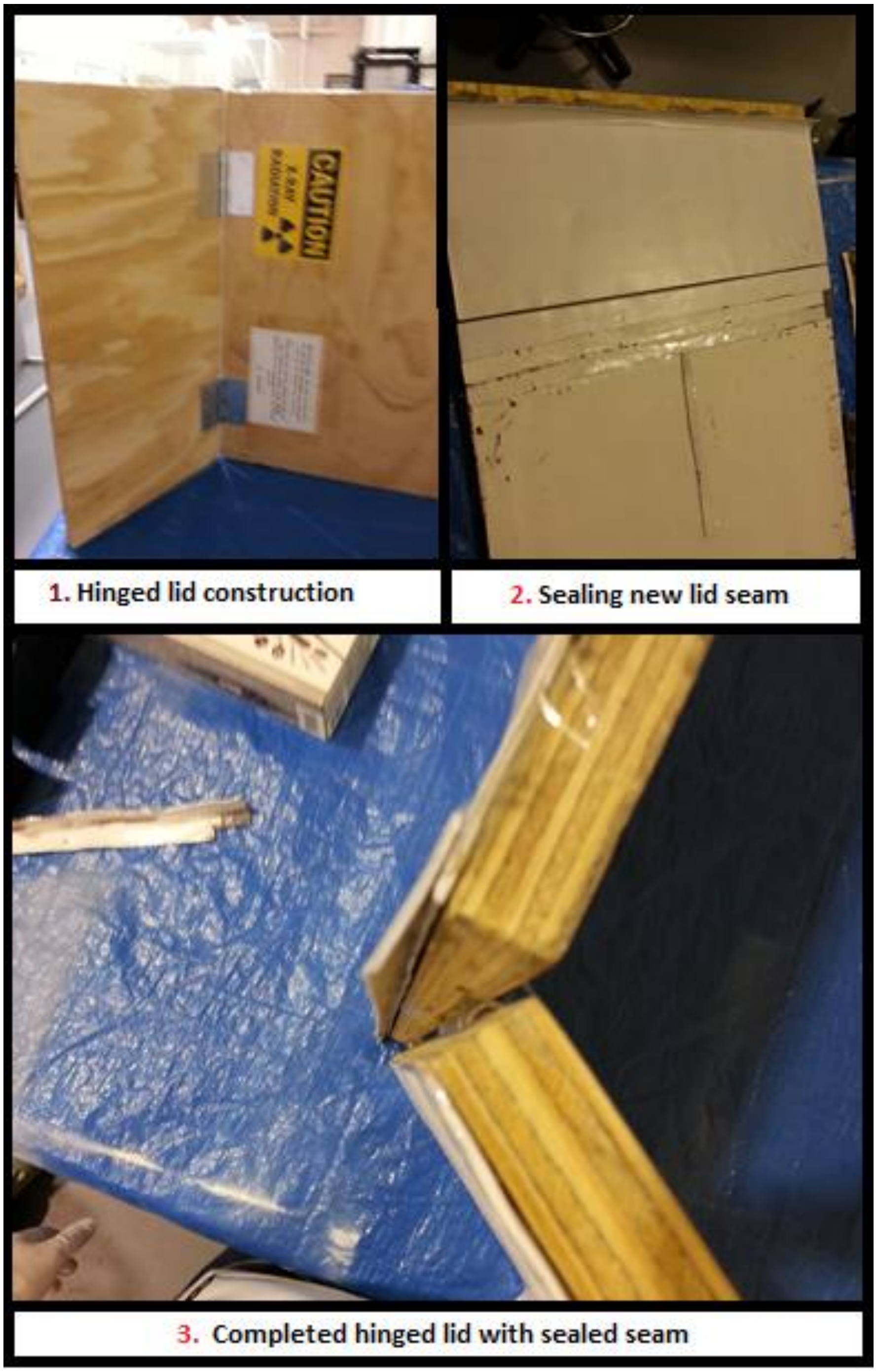
Using standard woodworking and construction techniques already used to make the first iteration of the box, the box was expanded. The lining of the ¾’’ plywood panels was completed during the Spring 2013 semester and the completed panels have been waiting to be installed for several months. The following Figures 14-18 detail the expansion process.

Figure 14: Box body expansion steps



The only tricky part about Figure 14 was gluing the lead sheets to the plywood sheets using the polyurethane construction adhesive. Since the lead was non-porous, water had to be misted over the area of the lead where adhesive was applied. The panels were then compressed and let dry for at least 24 hours. The top edge strips were nailed at their bottoms in 3-4 different places to allow them to act as flaps that will let the hinged lid move freely when needed. All other parts of this process were simply drilling and screwing repeatedly.

Figure 15: New lid construction and sealing in steps



Some wood had to be sanded away with the Dremel's sander attachment so the hinges would allow the pieces of wood to close flush. Some lead had to be glued to the inside of the lid, just as for all panels of wood. Shielding was completed along all seams.

Figure 16: Completed expanded box body and lid with installed handles

Figure 17: Panel grounding wires soldered to connect all lead sheets to a common ground

Figure 18: Completed expanded box with Interlock wires now installed (left=on, right=off)

The interlock was installed so that there is a clip on each end of the box that must make contact with a nail for the interlock circuit to be complete. The hinged door must be closed for it to work.

Radiation Leak Testing

The fully expanded lead box was tested for radiation leaks by firing the Amptek Mini-X Au X-Ray source at 35 different locations in the inside of the box outwards towards the Radalert Inspector Nuclear Radiation Monitor (Geiger counter). Hit counts over a 2 minute interval were taken three times and averaged while the Geiger counter was being observed from afar to obtain the minimum and maximum radiation levels (mR/hr) over the cumulative 6 minutes of data collection. All readings were taken at a point-blank distance (~6 in.) between the tip of the source and the sensing area of the Geiger counter. All readings were taken with the Mini-X fully set to 50kV and 20uA with a 1mm brass collimator in the tip of the source.

Figure 19: First part of the testing location key

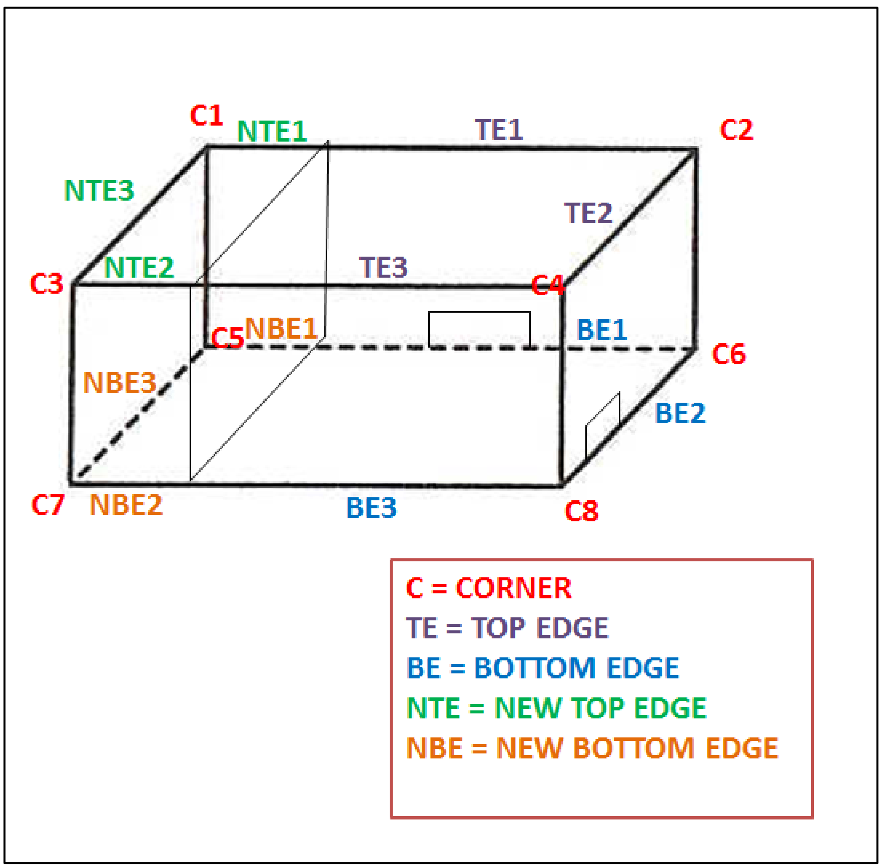


Figure 20: Second part of the testing location key

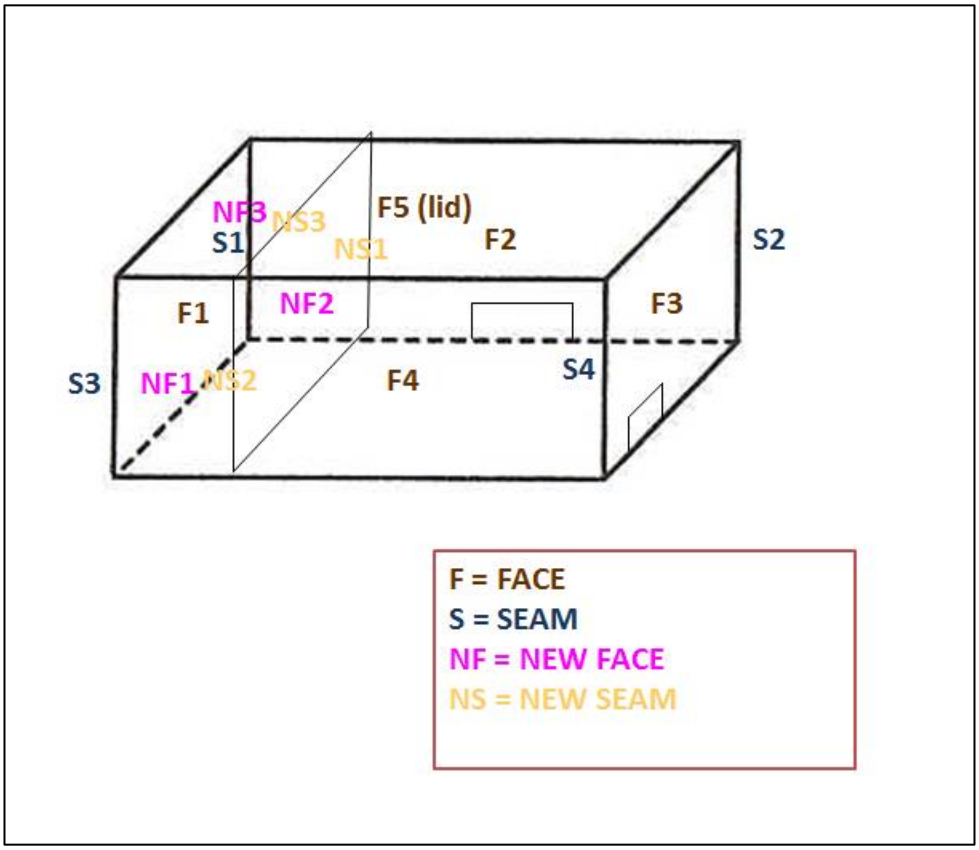


Table 1: Radiation testing of all locations

LOCATION	Average (counts/2 min)	Average (counts/s)	Min. over all trials (mR/hr)	Max. over all trials (mR/hr)
Background	70	0.58	0.005	0.018
C1	79.33	0.66	0.006	0.021
C2	153.33	1.28	0.021	0.033
C3	84	0.7	0.007	0.018
C4	92.67	0.77	0.008	0.022
C5	59.33	0.49	0.006	0.013
C6	63.33	0.53	0.005	0.016
C7	68.67	0.57	0.005	0.015
C8	66	0.55	0.006	0.027
F1	53	0.44	0.004	0.01
F2	52	0.43	0.003	0.015
F3	55.67	0.46	0.005	0.015
F4	64	0.53	0.004	0.015
F5	59.33	0.49	0.004	0.011
NF1	53.33	0.44	0.005	0.015
NF2	57.67	0.48	0.005	0.01

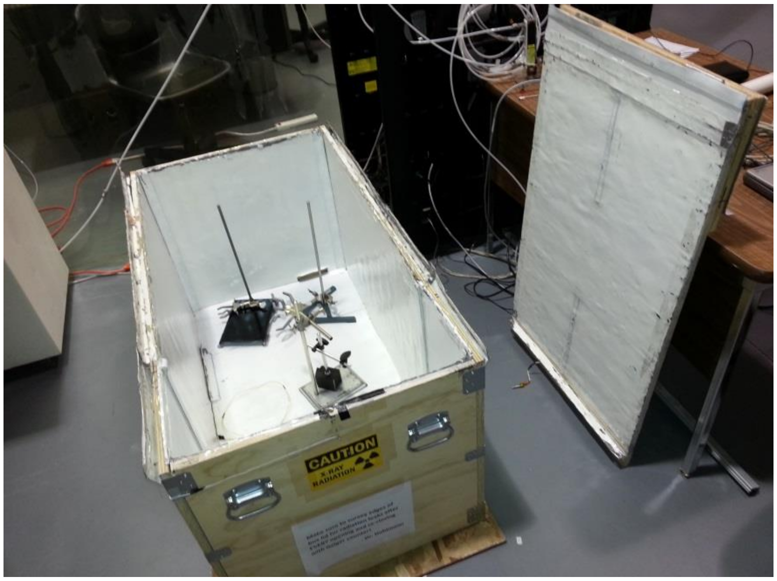
NF3	61	0.51	0.005	0.013
S1	53.67	0.45	0.003	0.011
S2	63.67	0.53	0.005	0.02
S3	61.33	0.51	0.005	0.013
S4	59.33	0.49	0.003	0.015
NS1	56.67	0.47	0.004	0.016
NS2	54	0.45	0.005	0.013
NS3	69	0.58	0.004	0.016
TE1	66	0.55	0.005	0.013
TE2	59.67	0.50	0.005	0.013
TE3	71	0.59	0.006	0.015
NTE1	62.33	0.52	0.006	0.017
NTE2	61.33	0.51	0.006	0.014
NTE3	64.67	0.54	0.007	0.016
BE1	56.67	0.47	0.002	0.015
BE2	95.67	0.80	0.006	0.022
BE3	69.33	0.58	0.004	0.019
NBE1	64.67	0.54	0.004	0.015
NBE2	52.67	0.44	0.004	0.013
NBE3	67.33	0.56	0.006	0.019

Figure 21: Radiation leak testing setup

As the data show, the corners leaked small amounts of radiation above the measured background levels, but no levels went over or even near 0.12 mR/hr (dangerous levels) for the tested locations. Not shown in Table 1, but diagramed in Figures 19 and 20 are the two rectangular holes that were used as cable feedthroughs. The only measurement taken for these holes was taken at a distance during which the Geiger counter beeped furiously and was observed to read 25+mR/hr. As soon as this measurement was observed (at an angle out of the source's cone of radiation), the Mini-X was shut off. Further testing was not safe. This one measurement was taken with the source pointed down at the hole on the 2’ wide side of the box. A rule that was already a standard was reinforced by this one data point: never point the source directly at or even near either of the box’s cable feedthrough holes.

With these successful radiation tests completed, the extended lead box was commissioned and moved back to the primary experimental area in the high bay.

Figure 22: The commissioned extended lead box ready for experimentation in the high bay



Companies Involved

RotoMetals: San Leandro, California- Lead sheet metal supplier.

Protex Fasteners Ltd.: Worcestershire, United Kingdom- Latch and catch plate supplier.

SBS Precision Sheet Metal: Melbourne, Florida- Will be doing aluminum plate manufacturing.

Future Work

In the future it will be important to keep these essential pieces of hardware up and running and safe, but also it would be nice to improve on some aspects of the boxes and or get rid of some unnecessary pieces of hardware through better design, like the need for the aluminum plate; a better readout board is the obvious solution and it is being worked on!

Until these pieces of hardware can be improved, my immediate future work will be using these items to collect data and further other areas of research in our lab that have been impossible to do without this hardware. I also plan on becoming much more familiar with the software aspect of our research experimentation. Hardware is important, but it is not everything by any means. Gaining a proficiency in Solidworks or another CAD program could be very useful too.

Conclusions

Looking at the acrylic box first, it is obvious that future work with O-rings will require large amount of compressive force just as it was needed is this application; latches are absolutely needed for future, and possibly bigger, air-tight test boxes. When working with chemicals of any kind, specifically the ingredients of Stycast, re-reading MSDS sheets is a very good idea. Even though the epoxy was ~10 years old, making a first batch of less than ~80g would have resulted in a much less dramatic exothermic curing reaction. Additionally, a valid machine shop certification and a working knowledge of how to properly use hand tools greatly expedites the process of creating completely custom hardware; it is also good to know that pressure testing fragile gas chambers should never exceed pressures of a few millibar. Custom hardware is generally expensive and breaking it is in no one's best interest.

Next, from even now being caught in a communication dead-zone with SBS precision Sheet Metal, it is painfully obvious that good communication skills are needed for a research *group* (or any group) to make any kind of progress in a reasonable amount of time. There will be difficulties, but those difficulties are much more manageable when you have a dozen minds searching for a solution. However, even good communication can't help a company you're working with ignore its main stream of revenue for a smaller custom job. It's just a fact. Collaboration makes stuff happen and I certainly would not have gotten as much done this summer if I did not have support from everyone in our group all the time.

Finally, my work with the lead box has proved that good experimentation techniques are not only important for getting sound data to build conclusions upon, but also for safety. Lots of people in our group are going to be using the lead box and it having been tested as much as it has been is the only way to consider using it. Safety comes first.

I've learned a lot this summer and I hope this report will help out many people beyond me for years to come!