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# LANL Plutonium Assessment

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# Plutonium Assessment

MCE 401 Final Design Report


performed by

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sponsored by

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## Abstract

At the Los Alamos National Laboratory (LANL), low level nuclear waste (LLW) is processed for disposal at the Waste Isolation Pilot Plant. This waste is processed in a glovebox and then placed into a 55 gallon drum and sent to a nondestructive assay (NDA) laboratory to determine if the waste within the drum's reactivity is below 100nCi/g stipulated by the regulation held by the Enviromental Protection Agency (EPA). In several cases every year, the reactivity of the drum is exceeded, thus requiring a costly and dangerous procedural deviation to divide the contents of the drum to reach an acceptable level of radioactivity. To avoid this problem, an in-line waste assay system must be developed to measure specifically plutonium-240 but also must give a possibility of measuring other types of radioactive materials such as Uranium-235. This product must have the ability to be applied to gloveboxes globally. This will require that the device has the capability of assaying a fully loaded 55-gallon drum that is inserted into the glovebox through a penetration in the floor of the glovebox before movement to the NDA laboratory. This assay must be completed within an hour, while maintaining an ergonomically efficient design. To satisfy these requirements, the goal was to take a neutron counting system available on the market and develop a mechanized collar to hold these devices while it assays the drum's waste underneath the glovebox.

The neutron counter that will be applied to the design is Canberra Industries' model JCC-71,72, and 73 [2] accompanied with the JR-14 shift register [3] and neutron counting software [4]. The main aspect of the design will be the development of a mechanized collar operating underneath the glovebox around the floor penetration to safely assay the waste in 2-3 sections on the drum. This will require the collar to have a vertical drive mechanism, a controls component and the construction of a holding rack for the counting slabs. The design will accompany the 6 He-3 slabs fashioned around the drum with one of the holding positions having the ability to accompany a passive or active slab depending on the application desired. The design will include a minimal amount of areas with hard to clean spaces. This design will accomplish all of the specifications explained above and hope to make the operations at nuclear processing facilities more efficient.

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# List of Acronyms

**ALARA** As Low As Reasonably Achievable

**AmLi** Americium-Lithium

**CAD** Computer-Aided Design

**CBRN** Chemical Biological Radiological and Nuclear

**DOE** Department of Energy

**EPA** Enviromental Protection Agency

**FDET** Fork Detection Irradiation Fuel Measuring System

**FOS** Factor of Safety

**GRS** Gamma Ray Spectrometer

**HLNC** High Level Nuclear Coincidence Counter

**IAEA** International Atomic Energy Agency

**INVS** Inventory Sample Counter

**LANL** Los Alamos National Laboratories

**LED** Light-Emitting Diode

**LLW** Low-Level Nuclear Waste

**NDA** Non Destructive Assay

**OHSEC** Office of Homeland Security and Emergency Coordinations

**PSMC** Plutonium Scrape Multiplicity Counter

**QFD** Quality Function Deployment

**SOP** Standard Operating Procedure

**URI** The University of Rhode Island

**VPUs** Vertical Pipe Units

**WCAS** Waste Crate Assay System

**WDAS** Waste Drum Assay

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# 1 Introduction

Team 8 is the Plutonium Assessment Team also known as "Pu Smells," the team consists of four members; Andrew Elloso, Ryan P. Murphy, Robert Simpson, and Thomas Sullivan. All four are senior Mechanical Engineering Students at the University of Rhode Island and plan on graduating this May. The four are also all pursuing a minor in Nuclear Engineering, which will be beneficial to the capstone assignment. The team has a variety of backgrounds in engineering work outside of the classroom. Andrew has spent three years interning with Saint-Gobain Research and Development Center, where he helped design experiments to solve industry related problems. Ryan has worked for Cape Cod Docks, where he has assisted in the construction of heavy sea retaining structures. Robert worked with General Dynamic Electric Boat as a student technical assistant where he became fluent with several computer software programs. Thomas has been in the Army for 3 years and has been through several CBRN courses (chemical, biological, radiological and nuclear) and has knowledge of safeguards for those threats. The combination of all of these unique backgrounds creates a team with a wide variety of skills that plans on solving the problem statement.

The problem proposed by LANL is the one of several in a group called Safeguards by Design. Safeguards by Design is a series of challenges that LANL has created to test college level students across the country on their ingenuity and ability to solve complex real world engineering problems. LANL has partnered with the International Atomic Energy Agency (IAEA) and universities around the country in hopes of finding a group capable of solving any of their seven problems. Team 8 was assigned the problems "Plutonium Waste Item Measurement System."

The LLW is moved down the glovebox line and into a 55-gallon drum. The radiation of the drum is then taken to a different room to be measured, and if the limit of 100nCi/g is exceeded a process deviation must be declared. What this means is that workers have to halt the current progress, dawn full body protective suits, and manually unload the drum. This is a dangerous process that greatly increases worker's exposure and costs the company up to $150,000. The intended end state of this problem would be to eliminate the need for this process deviation entirely. It happens on average five times a year and costs the company up to $800,000. Funding clearly is not a large issue due the fact that a solution to this problem could save the company millions of dollars and would pay for itself almost instantly. The funding, if approved, would be provided by the Department of Energy (DOE).

The problem statement is to design a method for determining the nuclear material content of waste items before they are placed into a drum and moved to the non-destructive assay lab. When the team first saw this problem statement everyone immediately began to research nuclear detection systems and various waste assay methods. The entire first half of the semester was dedicated to learning as much as possible about these systems and processes. When it came time to begin the conceptual designs the entire team focused on how and where to place different types of sensors with the glove box where the process would be happening. After a regular bi-weekly meeting with the sponsor from LANL, Jennifer Alwin, the team learned that the intended solution was more focused on a mechanical application to be implied universally.

During this meeting the team and Alwin discussed what the desired outcome should be like and reestablished the intended outcome. The clarification conveyed the need to not create a new product, but to use an existing technology and incorporate it into the in-line system currently in use. Basically, design a mechanical application that can house multiple interchangeable assay methods. At this point a new approach to the problem statement was taken.

Even though the focus of the problem changed, the requirement still remained the same. Los Alamos National Laboratories requires an in-line system that would maintain safety and keep radiation exposure within ALARA regulations. The deviation from the current process must also be minimized and the new technology requires an easy standard operating procedure. With all of this in mind the team moved forward to create the final concept.

The proposed idea is a trapdoor based slab system that will sit underneath the glove box. Waste will be loaded into the sealable bags currently in use and dropped down into the drum where different waste assaying devices will measure the contents at several different heights to gain an accurate reading. This entire process will take less than an hour and maintains a high level of safety and efficiency.

## 2 Project Plan

The project plan for the Plutonium Assessment project was modeled after the flowchart [5] in Figure 58 of Appendix A. This was used to ensure an organized process could be followed and the final goal was always kept in mind. Using the flowchart, the main milestones of the project were assessed and identified as: the problem definition, concept generation, preliminary design, build, testing, and final design. With these sorted out, roles of each team member could be assigned and the smaller tasks to reach the final goal could be divvied up.

The strengths of each member were taken into account and the roles were set up. Robert Simpson and Ryan Murphy are both design engineers in charge of computer-aided design (CAD) drawings and calculations. Thomas Sullivan serves as the main research engineer prioritizing in selecting the products used and design. Andrew Elloso is the team captain, in charge of project planning and scheduling while maintaining the team binder/portfolio. These main roles served as a guideline for the team, but each member worked together and helped in every single area possible.

To further organize the project, a schedule was created as a Gantt Chart on Microsoft Project. Figures 1 and 2 represent the fall semesters project plan, while figure 3 and 4 represent the spring semesters plan. This chart was extremely helpful as it also defined which tasks were to be completed by each team member and how much time was left until each deadline. The chart also aided in when to start each assignment, as there were sometimes multiple tasks to be completed at a single time.

As a team, a specific weekly meeting time was not set due to constantly changing schedules. The team also concluded that a single weekly meeting would not be enough as there was always a lot to work on and more communication was necessary. Consequently, several meetings were created throughout the week to discuss progress and any current work that needed to be completed. These meetings were always announced ahead of time to ensure each member could be in attendance. However, bi-weekly meetings with the team sponsor (LANL) were always scheduled ahead of time as they were planned out in the beginning of the semester.

It was in these meetings that the LANL representative, Jennifer Alwin, was updated on the progress of the team and any problems were addressed. These meeting were mostly completed via WebEx, however some were done over the phone. This and email were the best ways to keep in touch with the sponsor as the main location for LANL is in New Mexico. This made it especially hard to communicate as the entire process of the problem statement was expressed verbally and in whichever pictures could be released.

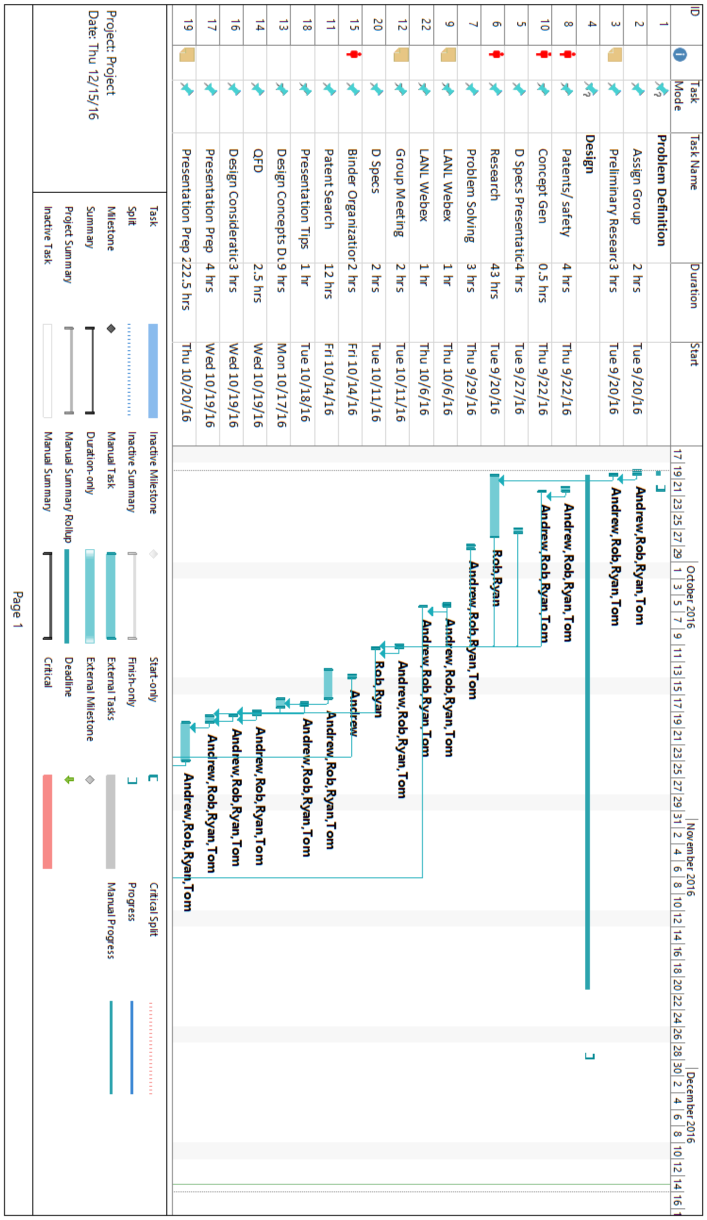



Figure 1: Fall Project Plan, Page 1

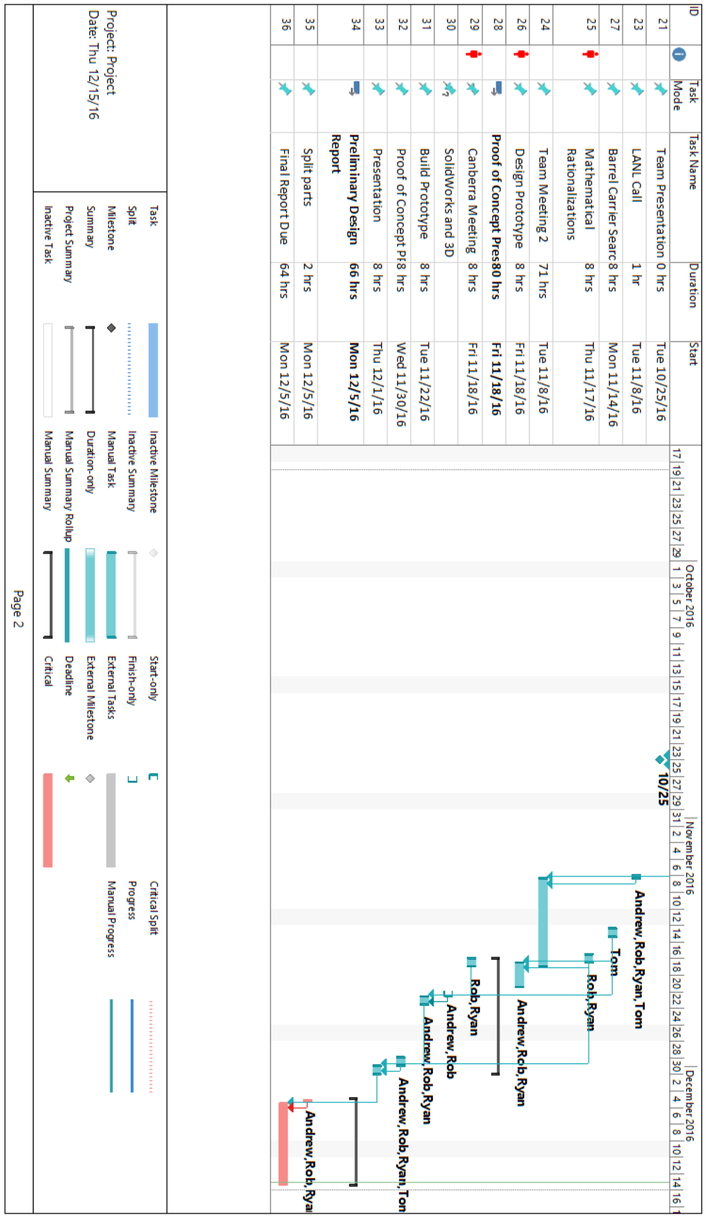



Figure 2: Fall Project Plan, Page 2

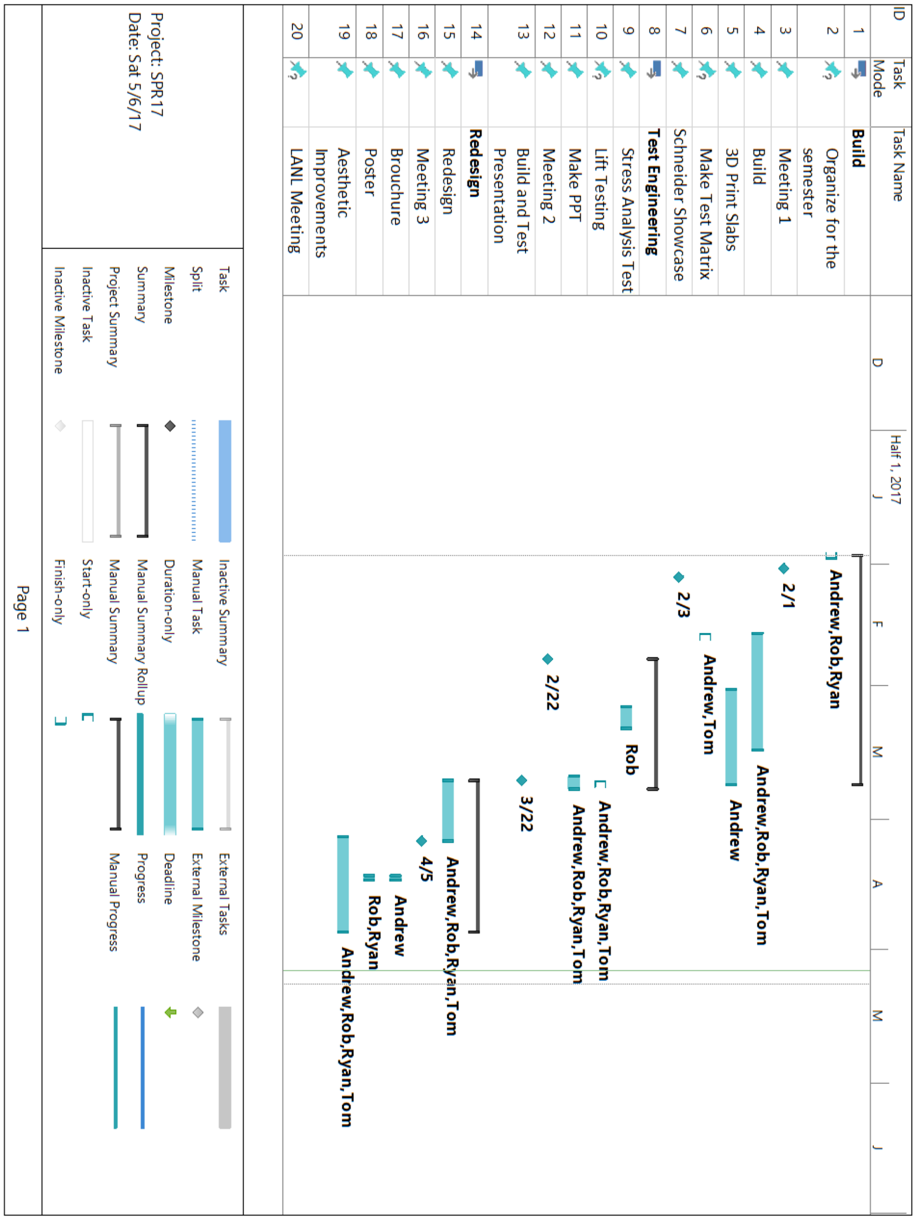



Figure 3: Spring Project Plan, Page 1

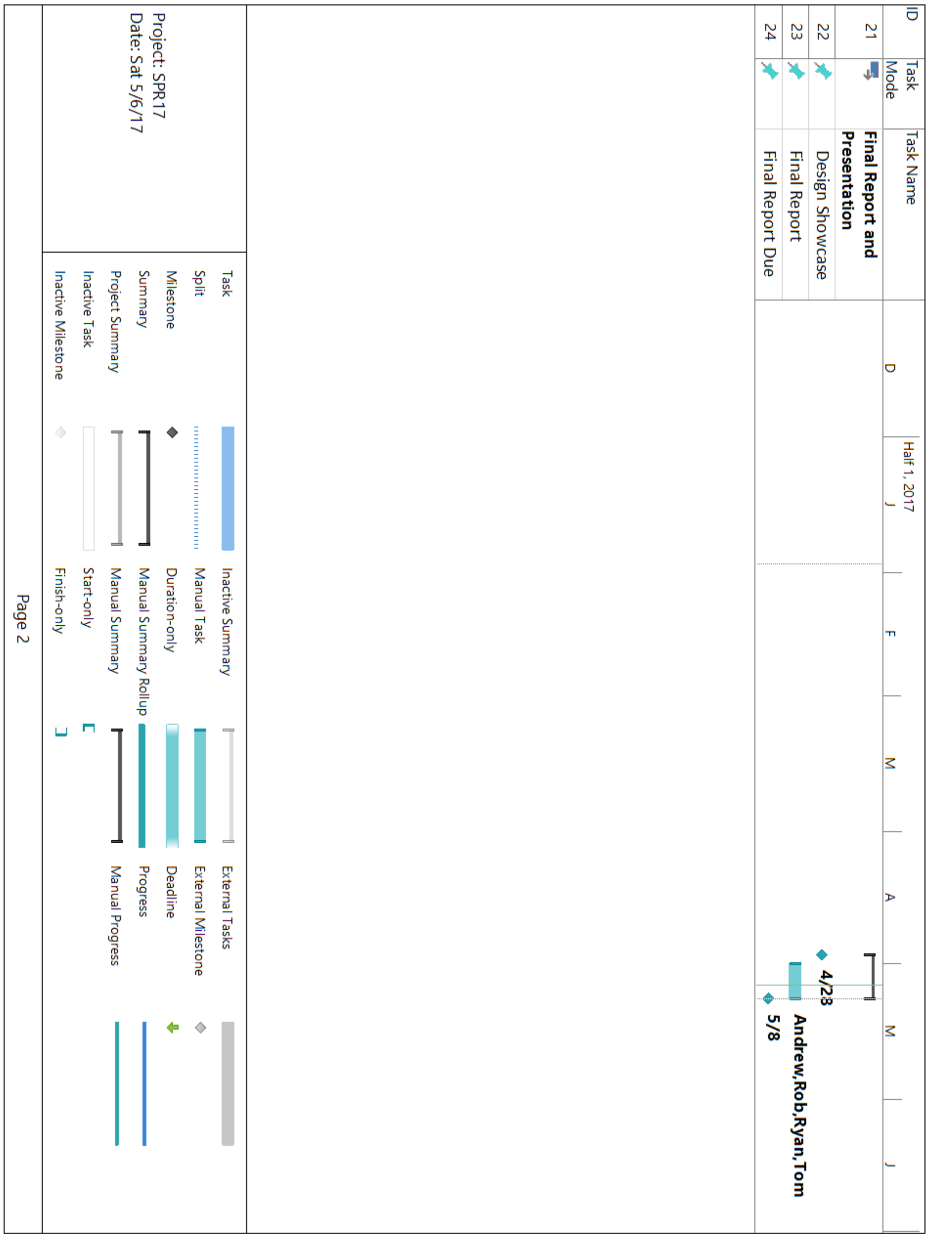



Figure 4: Spring Project Plan, Page 2

## 2.1 Problem Definition

The problem statement consisted of searching for a nuclear waste assay that could be applied to the gloveboxes in the facility at LANL. This device had to be in-line and capable of measuring the waste in a timely manner. The assay had to take quantitative measurements in order to assess the total radiation levels of the waste. The first step of this was to research the unfamiliar process and learn about current measuring practices. After this, patent searches were completed in order to find any and all materials and devices that could be useful. Each member completed their own, individual patent search and the results of the team were compared in order to find the best and most beneficial finds. The results of the final patent search can be viewed in 'Section 4: Patent Searches.'

The initial understanding of the problem statement involved a multitude of nuclear and radiation calculations, but this changed several weeks in. The new statement involved using a similar assay, but one that could measure both passive and active radiation, and also constructing a system that applied the assay to the process. This change drastically altered the project plan as a new mechanical system was to be created. This system had to be easily repeatable and adaptable for the measurement of both types of radiation. It was here where the Canberra JCC models 71, 72, and 73 were selected to take on the job. This entire project is to be approved by the Department of Energy in order to achieve a budget.

## 2.2 Concept Generation

Each member of the team also completed a concept generation study. This consisted of 30 different ideas, provided by every team member. The ideas were all to be different, but applicable to the problem given to the group. When each member completed the concept generations, a meeting was scheduled and every single idea was discussed. The assay was determined first, and then the design for the support system was created based on the needs of the sponsor.

The Canberra JCC assay featured three different models. Each model capable of different task, but all combined to fill to needs of the problem definition. The assays needed to be interchangeable based on the needs of the user. It was determined that a 55-gallon drum was the most common was to temporarily store and transport the nuclear waste in the LANL facility, so the system was to be designed around this feature.

## 2.3 Preliminary Design

In order for the Canberra assay to take a radiation measurement on the drum, a few changes were made to the advertised design. Instead of the typical four assays, six were needed to fit around the circumference of the drum. The assays also are not tall enough to take a full measurement on the 55-gallon drum, so three quantitative measurements were to be required. This required a new structure to be created. The materials of the structure were determined based on the 'radiation proof' quality the system needs to have. The structure was designed and tested on SolidWorks. The results and an in-depth detail is provided in 'Section 11: Detailed Product Design.' Along with the CAD drawings, a physical prototype was created for the Critical Design Review Presentation. The prototype is further discussed in 'Section 13: Proof of Concept.' This prototype served as a brilliant demonstration tool, and was also helpful in working out some minor design and construction issues.

## 2.4 Build

To begin the build, the initial budget was assessed in order to define the limitations. Upon receiving said budget, a half scale model constructed of wood was to be made. This took the team about a month to construct and was based on the Solidworks design made. Instead of a power screw lift, a TV lift was purchased online to serve as a basis for testing the lifting process. This was due to the limited budget constraints.

## 2.5 Testing

Before constructing the half scale prototype, the design was first tested on Solidworks. These tests included stress and displacement modeling based on both the full and half scale models. This was done to ensure a successful construction of the prototype.

After the build, several tests based on the design specifications were created in the test matrix. These included raising and lowering, along with weight constraints, and ergonomics based tests. The results of the tests can be viewed in 'Section 15: Testing.' In order to add the needed weight, the 'slabs' were 3-D printed as containers to bear sand as added weight.

## 2.6 Final Design

A few changes were made to the initial design that were recorded in the redesign period. These mostly include aesthetic changes such as using spackle to fill in any gaps and painting the entire model gray. This made a huge difference for the showcase as it was much more attractive to the eye.

The only major redesign was extending the front bracket several inches to close a gap in the mechanism. The gap was due to a last minute hinge and latch swap that left a very noticeable gap, that would have made the model unusable. A 'glovebox' was added to the top of the model in-order to simulate the in-line process during the capstone showcase.

The full scale model will be constructed out of aluminum, and will require a much bigger lifting system. The CAD drawings for this will be submitted along with the feedback received from LANL.

# 3 Financial Analysis

## 3.1 Full size Model Cost

The basis of the cost analysis of this device is derived from extensive inquiry into the projected costs of necessary raw materials, the cost of product assembly and installation, the cost of neutron counting system and the cost of other devices deemed necessary. A breakdown of the projected costs and descriptions will be listed below followed by a final estimation of cost.

1. Cost of Raw materials

   The cost incorporating into the raw materials includes the raw materials required in building of the full sized neutron coincidence collar without the inclusion of the nuclear waste assay systems the product is the collar is designed for. This includes the frame, supports and lifting mechanism. The product is made out of aluminum when possible to reduce the weight and radioactive disturbances. The carriage block, upon talking with the distributor, would be included with the sale of the pillow blocks. There is a possibility of a student discount for the linear motion system by PBC Linear and Lee Linear (PBC Linear and Lee Linear became one company [6]). The lifting mechanism is an assembly of parts made by Lee Linear and Transmotec [7].

Table 1: Cost of Raw Materials

| QTY | Product | Cost Per Unit ($) | Total Cost ($) | Source of Estimate |
|---|---|---|---|---|
| 4 | Multipurpose 6061 Aluminum Angle | 38.37 | 155.00 | McMaster Carr |
| 2 | Mortise Mount Hinge | 20.51 | 41.02 | McMaster Car |
| 100 | 12-24 Stainless Steel Philips Flat Head | .11 | 11.23 | McMaster Carr |
| 100 | Low-Strength Steel Thin Nylon-Insert Locknuts | .07 | 7.20 | McMaste Carr |
| 2 | Base Shaft Alloy Steel | 71.06 | 143.12 | Lee Linear |
| 4 | Open Pillow Block | 186.80 | 747.20 | Lee Linear |
| 1 | Carriage Block | - | - | Lee Linear |
| 2 | Grab Latch | 6.67 | 13.34 | McMaster Carr |
| 1 | Ball Screw | 42.67 | 42.67 | McMaster Carr |
| 4 | Support Block | 48.24 | 193.00 | Lee Linear |
| 5 | Multpurpose 6061 Aluminum Bar Stock | 8.01 | 40.05 | McMaster Carr |
| 1 | DMA Linear Actuator | 840.50 | 840.50 | Transmotec |

2. Product Assembly and Installation

   The professional assembly and installation of the product will account for a substantial cost in this project. The first thing that would need to be done is the cutting and set up of the material. The average cost of a skilled machinist per hour is $ 19 per hour and would need about 16 hours of labor to complete the job. This would lead to a cost of $ 304 for this individual. Based on what could be determined, the cost for welding is around 45 dollars per hour. With this information and an estimated weld time of 8 hours would give a total weld cost of $ 360 given that the collar is set-up in an optimum way. The installation would most likely take two laborers a full day to complete and the wage for a laborer is around 15 dollars per hour so the cost for installation would be around $ 240. This brings the estimated total cost of installation to 904 dollars.

3. Design Cost and Time Breakdown

The time distribution of the team is mainly distributed into five sections of research, communication/outreach, administrative duties, product design, prototype construction, acquiring raw materials and meetings. It is estimated that each group member spent around 7-12 hours per week on the project. The total estimated time the group spent on the project in the first term is 950 hours and if that is transferred into a cost for labor of an estimated $29.34 per hour [8] the cost of the labor would be $27,875 for the semester. This payment is just an estimate that will not be included in the budget because as students, the team will not be paid for the work undertaken. The research section included the time looking into neutron coincidence counting information, the patent searches, regulations of nuclear waste systems, machinery options and other pertinent information. The communication and outreach references the interaction of both on the phone and through email the team members had with LANL, Canberra Industries, Progressive Automations and the URI faculty. The vast majority of the time in this section was taken up by the bi-weekly meeting the team had with Jennifer Alwin and the consistent email communication. The administrative duties included the updating of the project plan, submission of weekly progress reports and planning group actions of the week. The product design portion of the time is roughly on the magnitude of the research portion of the lab and has dominated the groups time in the past month. This includes the CAD drawings, engineering analysis and comparative analysis of the concepts created. The prototype construction took up most of the time of this project and this included the construction of the mechanical system and the collar itself. The acquiring of raw materials included going to Arnold Lumber and ordering piece online. The final task was the regular team meetings held. This includes the meetings that lasted about for around 20 minutes per week. These meetings proved to be helpful in working out plans for the week ahead, dividing responsibilities, and addressing problems quickly to develop a solution.

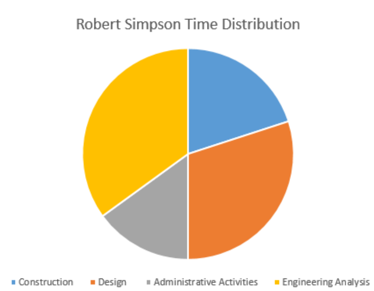



Figure 5: Robert Simpson Time Distribution

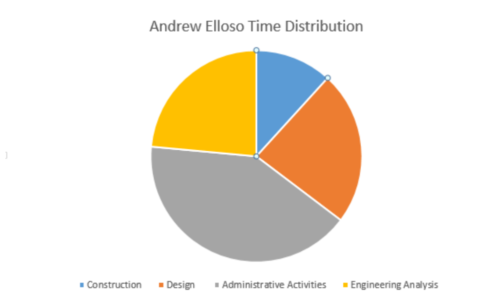



Figure 6: Andrew Elloso Time Distribution

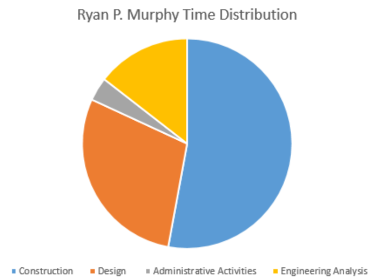



Figure 7: Ryan Murphy Time Distribution

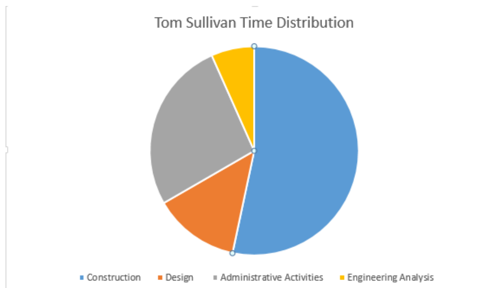



Figure 8: Tom Sullivan Time Distribution

4. Time Breakdown of the Los Alamos National Laboratory Faculty

   This design challenge's sponsor of LANL and more specifically the group's mentor Jennifer Alwin have spent a generous amount of time with the team working to answer questions as they arose during the semester, guiding the teams direction or providing information for the group to gain a good background what is expected from the team. Jennifer Alwin has spent an estimated 10 hours or more out of her busy schedule on helping the team with the tasks described above. It is difficult to estimate what to include in the budget for her time. The group is grateful for her assistance to the effort and this project would be vastly more difficult without the vested interest of LANL and Jennifer Alwin.

5. Time Breakdown of Canberra Industries

   This design challenge was aided tremendously by the team's outreach to Canberra industries technical representative. Canberra Industries produces the JCC-71, 72, 73 product line as well as the JR-14 shift register and the NDA 2000 software that is being planned on implementing into the design. Sasha Philips specifically helped the team formulate ideas for the product that is being developed now. Without even being the sponsor to our project, Sasha Philips helped an estimated two hour to the team in the design process, helping the team understand the technology and the cost of the assay equipment. The estimates for the neutron assay equipment is based on the estimates given by Canberra Industries.

6. Time Breakdown of PBC Linear

   The team reached out to the east coast sales representative of Pacific Bearing Company named Tom Ouellette. This was helpful in determining the necessary type of mechanism would best meet the requirements determined. The total time of communication was around a half hour conversation on the phone that greatly helped the group get pricing for the pieces for the lifting of the collar.

7. Time Breakdown of URI faculty

   The time of URI staff has helped the design team to hurdle challenges quick and avoid problems before they became major issue and helped with the building of the prototype. Dr. Nassersharif specifically helped the team with the selection of the type of neutron assay to use both with his discussion with the students in a private discussion for around 20 minutes and providing the students with a specialized book on radioactive detection. The group will also like to thank David Ferreria with his help with the group in assembling the prototype. This help gave the students great direction in finding solutions to the problems at hand and staying on track.

8. Project Cost of the Neutron Waste Assay System

   The neutron waste assay system is based on a system already developed by Canberra Industries. The design portion of the team's design will incorporate Canberras design into an automated system that will offer the option for the assay of waste before leaving the glovebox confinement. The cost of the neutron waste assay system does have the option to offer different paths that could be explored by the LANL that will adjust the cost greatly. The team has decided to focus on the development of the mechanical system that will house the neutron counting system, it is important that the estimated cost of this equipment is included into the projected cost of the system. This will be critical to calculate the return on investment the full product will have to help justify the purchase of the collar system that is developed.

Table 2: Assay Option One

| Task | Product | Option 1 | Price |
|---|---|---|---|
| 6 Passive Neutron Counting Slabs | (36) He-3 Tubes | Acquire from Private Sector | $144,000 |
| Neutron Analysis Shift Register | JSR-14 | Acquire from Canberra Industries | $15,000 |
| NDA Software | | Canberra NDA 2000 | $10,000 |
| One Active Neutron Source Slab | Neutron Source Material | Americium | 1,500/g |

Table 3: Assay Option Two

| Task | Product | Option 2 | Price |
|---|---|---|---|
| 6 Passive Neutron Counting Slabs | (36) He-3 Tubes | Acquire Direct from Gov't | $54,000 |
| Neutron Analysis Shift Register | JSR-14 | | |
| NDA Software | | INCC Software | N/A |
| One Active Neutron Source Slab | Neutron Source Material | Californium | $60/microgram |

9. Total Projected Costs

   The total projected cost of the device will include the cost of the collar and an estimate of the cost for a neutron coincidence counter acquired directly from the private sector. The total cost for the raw materials to build the collar is $2,235.33. The total cost for the labor would be $904. The cost of the passive neutron counting system would around be $169,000. With a high estimated customer acquisition cost of an estimated $1000 the final cost of the device would be $173,139. So it was decided that the full system would be sold for around $250,000. This would allow for a solid profit margin and a excellent return to the company.

## 3.2 Manufacture Cost and Marketability

The manufacturing cost of the design will greatly decrease with the increase in the demand for this design. This product would create a niche market, small now, but could increase greatly with the increase in the decommissioning of nuclear power plants and the expansion by other countries of reactors. If this were to increase sharply, the cost of manufacturing would decrease but it is not foreseen that the product will have the demand to justify a mass production system tailor to it. The manufacturing costs of the final product will be fairly similar to the costs that are determined by the team due to the fact that the major costs to the final project is the neutron counting system already developed from Canberra Industries. This product could dominate a small portion of the market due to the lack of competition in the application pursued by the team.

This product will be extremely attractive to the facilities that experience the same "muda" LANL experiences. With the cost of an average of $150,000 cost for a process deviation and around five process deviations per year this product, no matter how the final cost of the neutron assay system and mobile collar, will pay itself back well within a year and most likely much faster than that. If other nuclear waste processing facilities experience the same kind of waste that LANL experiences, then this product should be able to reduce their costs with relatively little upfront capital. The market strategy pursued by the team is to eventually sell the idea to Canberra Industries to allow the well-connected and vast organization use the product developed to open new market share to sell more neutron counting systems. This device would be sold as an attachment to the JCC 71, 72, 73 system and would help the company allow for one device to be applied into a new application thus helping to expand their market.

## 3.3 Future Technology and Revisions

With regard to the future technology, the collar design offers a flexible platform for the advent of new technology. With a development by Canberra Industries of a new waste assay system, the design we developed would be easily adapted to new shapes of the assay devices. The simplicity of the design offers the ability for new technologies to be easily integrated in the device including but not limited to new neutron coincidence counters. The design at this point does maximize the use of known technology and allows for optimal performance.

## 3.4 Prototype

The vast majority of time in the design work in the second semester was spent constructing a prototype. The budget for the project was provided by Dr. Bahram Nassersharif and the University of Rhode Island. The budget that the group worked off of was a generous $700 and managed to stay below budget while delivering a finished model by the end of the semester. The group had to make some decisions quickly to cut the cost of the model while still proving that the prototype would model a finished product. First the group decided to cut the model down to a half scale and make it out of wood. This cut costs immensely by eliminating the need for skilled labor and expensive material. Then the group replaced the mechanical lift system with a re-purposed television lift. This also help cut the expensive cost of the lift system and cut time in building the working system. These decisions early in the semester allowed to group to get right to work. In table four there is a breakdown of the cost to construct the prototype outlined clearly. The total cost of the prototype was a $537.96 bringing the project well below budget allowing that the group members did not receive wages.

Table 4: Prototype Cost Breakdown

| **QTY** | **Name** | **Dimension** | **Source** | **Cost per Unit ($)** | **Cost ($)** |
|---|---|---|---|---|---|
| 1 | Plywood | 4'x8'-1/4" | Arnold Lumber | 31.01 | 31.01 |
| 2 | Wood Screws | 3/8" | McMaster-Carr | 1.85 | 3.70 |
| 1 | Wood Glue | Quart | Amazon | 4.34 | 4.34 |
| 1 | Hinge | 1/2 | Arnold Lumber | 4.14 | 4.14 |
| 1 | Television Lift | N/A | Amazon | 359.99 | 359.99 |
| 6 | SS Cap Screw | 5/16x1 | Arnold Lumber | 0.54 | 3.24 |
| 6 | SS Flat Washer | 3/8 | Arnold Lumber | 0.25 | 1.50 |
| 6 | SS Hex Nut | 5/16-18 | Arnold Lumber | 0.21 | 1.26 |
| 6 | Cap Screw | 1/4x1-1/2 | Arnold Lumber | 0.15 | 0.90 |
| 6 | Cap Screw | 1/4x1 | Arnold Lumber | 0.11 | 0.66 |
| 1 | XL-FX PHIL WS | 12x1 | Arnold Lumber | 3.26 | 3.26 |
| 1 | Spruce Lumber | 2"x4"-12' | Arnold Lumber | 4.48 | 4.48 |
| 1 | Putty Knife | 1-1/2" | Arnold Lumber | 3.08 | 3.08 |
| 1 | Spackle | Quart | Arnold Lumber | 9.26 | 9.26 |
| 2 | Gray Spray Paint | Can | Arnold Lumber | 5.26 | 10.52 |
| 1 | Aluminum Sliders | 4 pack | Amazon | .22.99 | 22.99 |
| 2 | Aluminum Rods | 30" | Amazon | 44.95 | 44.95 |
| 2 | Linear Rail Support | 2 pack | Amazon | 14.37 | 28.74 |

# 4 Patent Searches

Before the team began to design any sort of nuclear waste assaying device they needed to do a patent search in order to see what type of technology already existed in this field. Most of the other teams conducted this search so that they would know not to design an already existing product and to avoid any sort of intellectual property theft. Unlike those groups, Team 8 needed to know what products already exist because the project involves incorporating a device into a mechanical design. Once the team established what technology was needed to assay waste and what technology already existed this search quickly became more of a shopping trip to find the ideal device. However, the purpose of this search was not just to see what type of assaying devices existed, the team also had to learn about the mechanical installation of said devices. Once the focus on the problem statement shifted from a nuclear aspect to a mechanical aspect, the goal of the search became less focused on the actual nuclear assaying device and more on the installation of it. This shift meant that the searches went from using keywords such as ”assaying” and ”nuclear” to ”drum” and ”hydraulic-lift” Of all the searches conducted the following patents proved to be the most beneficial to the project.

1. Patent Number: 8,729,488
   Patent Name: Assaying of Waste
   Date Patented: 20 May 2014
   Inventor: Wilson, Mark
   Patent Description: This patent was most relevant to the team’s project because the goal of this problem is to create a safer and more efficient way to assay waste. With very limited background in nuclear engineering and no substantial prior knowledge as to what waste assaying really is, this patent contained plenty of information to get a basic understanding. What this patent taught the group is that assaying is measuring the specific volume of nuclear material and the multiple methods possible for conducting the measurements. One of the biggest takeaways was that in most assay systems there are usually two or more detectors present which could measuring several different methods. The team’s final design is able to utilize both passive and active assays and that design specification is primarily due to the knowledge gained from this patent. In regards of finding a device that is related to what the team proposed as their final design, this patent did have some but not much relevance. After the focus shift the team had to keep in mind the waste assaying devices but focus more on the mechanical aspect, which this patent did little to help with. Overall, it was a good initial learning resource but did little to assist in the actual design.

2. Patent Number: 7,227,152
   Patent Name: Device to Measure a Radiation Dose
   Date Patented: 05 June 2007
   Inventors: Brabec, Christoph and Hoheisel, Martin
   Patent Description: This invention is intended to pick up radiation dose rates from a source and display this data on a monitor. It is primarily intended for medical use where a source is radiating and the device is intended to determine how much radiation is being released and where from. The team is intrigued by this patent because it fits into the original problem statement very well in the sense that it determines quantities of radiation which is exactly what needs to be achieved in the final design. Not only does this invention do the function that the team is trying to create it also explains the setup of equipment and where to position key devices. The first patent gave the team a solid understanding of how reading waste works, this patent was beneficial for a very different reason. Where the first

patent was more of a theoretical background, this patent began to describe the physical set up of such a device. When designing the final product the team had to consider the limited space that working in a glove box offered. Also, when adding additional parts outside of the box, positioning of particular parts of the scanner becomes critical. This patent provided insight on to which parts had to be in exact locations and which could be placed more freely. This knowledge became very important after the problem statement shifted.

3. Patent Number: 8993,827
   Patent Name: Method for Stabilization and Removal of Radioactive Waste and Non-hazardous Waste Contained in Buried Objects
   Date Patented: 31 March 2015
   Inventors: Soyfer, Boris, Halliwell Steve, and Stone, Kieth
   Patent Description: This invention is created to help remove vertical pipe units (VPUs) from the ground. A VPU consists of several 55 gallon drums containing low level radioactive waste stacked vertically and buried beneath the earth. The removal is necessary because certain VPUs have been known to have a breach after so many years beneath the earth and have toxins seep into the soil around them thus poising the environment. This patent is about a device that is able to remove the entire VPU at once and allow fresh soil to take its place. While this invention is not one that the team plans on using in its design it does contain a certain function that the team is considering utilizing in theirs. This device is intended to raise and lower several 55-gallon drums which is a mechanical portion that the team's final design also has to do. Although this design happens on a much larger scale the same principals could be broken down and applied to a small scale system. In the end, while the exact patent may not be used it definitely helped inspire the team to design something that will be.

The patent searches that the team conducted were first intended to give everyone a baseline knowledge on the subject of nuclear waste assaying. It then gave the group several ideas on how to design an actual assay to include the physical set up. As the group underwent this design process certain problems arose that led the team to look at other patents and see if any more information could be gained. Certain problems, such as how to raise and lower a 55-gallon drum or the positioning of certain pieces of a waste assay device were usually solved by researching how other patents have solved this issue and referencing these for help.

# 5 Evaluation of the Competition

While the product described in this report is designed for a specific application within the LANL facility, there is potential that this product can be applied to the nuclear processing gloveboxes in not only other national laboratories but nuclear reactors across the world. There are around 450 nuclear reactors operating around the world. According to the IAEA, a 1000 MWe nuclear power plant produces on average 100 cubic meters a year of low level nuclear waste [9].

The low-level waste at LANL is processed in the glovebox, placed into a 55-gallon drum, verified and finally buried. If a barrel is over the stated limit of 100nCi/g at the verification lab, a procedure deviation must be instituted that costs LANL around $750,000 per year. This cost is substantial and one could only infer that other facilities experience this "muda" in their operations.

This opens up the opportunity for the implementation of the neutron coincidence counting device that would ensure the radioactive waste was safe for burial before it leaves the glovebox. This would vastly decrease the likelihood of performing a process deviation and putting workers in danger. The marketing plan envisioned by the team is to first create a full scale working model of the neutron counting collar specifically designed for the plutonium processing glovebox. The design will require a partnership with Canberra Industries.

The goal of the team is to show the different parties the advantages of the design. To the sponsor at LANL, the designs goal is to show an innovative idea that will fill the specific requirements stated for the design challenge. This will show the device able to save the facility time and effort while offering a quick payback period. To the nuclear facilities workers, for whom will be working alongside this device on a day to day basis, it will demonstrate an easy process addition that will help ensure ALARA guideline are met. Finally to Canberra Industries, the plan is to offer the product as an add-on for the JCC-71, 72, 73 coincidence counting series. This will allow for Canberra industries product to be offered to assay a 55-gallon drum of radioactive waste while it remains within a glovebox.

The collar positioning device will be integrated into an already developed counting system and with the high cost of mistakes made in these processes, it will make the selling this add on attractive to the Canberra sales force looking to open up a new market for a product that is not offered at this date. It is expected that the product would be pleasing to all parties. With both the seemingly absence of direct competition and the ability for the product to measure different types of nuclear waste, the first step of the expansion of the product will be more to applications to different glovebox configurations within the facility. Once the product is shown to work in other applications and a patent was completed, the hope would be to sell the idea to Canberra Industries as an addition on their JCC-71, 72, 73 products.

# 6 Specifications Definition

Design specifications is necessary for a product that is desired to meet particular requirements. This provides regulations that the developers need to accomplish. These design specifications were created from initial requests by LANL which can be broken up into two components: nuclear assay device and mechanical system. The design being developed is a mechanical system that employs already existing nuclear devices where both need to meet requirements. The list will provide guidelines when solving the initial problem for LANL.

## 6.1 Nuclear System

The design for mechanical system would be difficult without specifications for the nuclear device. It important to know which nuclear assay device to incorporate in order to build an appropriate mechanical system. The requirements were directly given by LANL to ensure the product would solve the problem for the company and possibly others.

Table 5: Nuclear Specifications

| # | LANL Requirement | Engineering Specifications |
|---|---|---|
| 1 | NDA | Neutron coincidence counting |
| 2 | Measure variety of waste | Active and passive assay |
| 3 | Acceptable efficiency | Active assay: 5% or greater<br>Passive assay: 5% or greater |
| 4 | Time efficient | 1 hour or less |
| 5 | Drums reactivity level | Less than 100 nCi/g |
| 6 | User-friendly | JSR 14 Shift Register<br>NDA 2000 Software |

The first nuclear specification given by LANL was that the device should be NDA. After researching current NDA devices, Neutron Coincidence Counting is found to be a common way for measuring radioactive material. This type of assay has the ability to measure a multitude of radioactive material.

The next requirement for the nuclear product was for it to measure a variety of waste. This is accomplished with the prior engineering specifications as well as an active and passive assay device. While researching these devices, active assay and passive assay measure different radioactive material but can be combined into one system.

Acceptable efficiency is another specification made by LANL. The efficiency of neutron coincidence counting products has a wide range from less than 2% to over 40% for the high efficiency devices. The higher the mass of radioactive waste present the less efficient the machine needs to be. The device necessary to solving the problem for LANL is said to not need a high efficiency. The engineering specification for efficiency was then set to 5% or greater for both active assay and passive assay.

The time of the assay should be completed in an acceptable manner. The device should not cost the workers time that could be better spent doing something else. The fastest assay that was come across achieved the task in thirty seconds, however, it is more common to find devices that take ten to twenty minutes as the efficiency increases. The time of the assay of an entire drum should yield is an hour or less.

The drums cannot exceed a certain level of radioactivity set by Office of Homeland Security and Emergency Coordination (OHSEC). This limit is set for environmental and safety protection. The maximum radioactive waste the drum can contain is 100 nCi/g.

The last request is the NDA device provide a user-friendly interface for the workers. This is done by implementing the JSR-14 shift register and NDA 2000 software. These are universal computer programs that collect the neutron coincidence data and are the most common and user-friendly systems provided from Canberra.

## 6.2 Mechanical System

The requirements for the mechanical system derived from constraints in LANL processes and the desire to make a useful product. The major problem is implementing a mechanical system that is consistent with the majority of the current process for LANL. The product is focused on simplifying the assay of nuclear waste in the glovebox.

Table 6: Mechanical Specifications

| # | LANL Requirement | Engineering Specifications |
|---|---|---|
| 1 | In-line system | Glovebox Dimensions: 150” long, 60” wide, 100 tall<br>Underneath: 39” tall |
| 2 | NDA holders | 3.60” wide, 9.25” long, 20.35” tall |
| 3 | Universal system | Interchangeable between active and passive assay |
| 4 | Ergonomics | Install movement system |
| 5 | Vertical movement | Lift 200 lbs or greater<br>Distance of 20” |
| 6 | Motor | Torque of 4000 lbs*in |
| 7 | Rising time | 5 to 10 seconds |
| 8 | Sturdy structure | Frame holds 150 lbs or greater |
| 9 | Ability to assay drum | 23.50” diameter |
| 10 | User-Friendly | SOP Provided |

The first constraint for the mechanical system is the size of the glovebox. It is imperative for the device to fit in the glovebox line. The glovebox has a length of 150 inches, a width of 60 inches and a height of 100 inches. The height underneath the glovebox is thirty-nine inches for if a system is implicated underneath. These dimensions constrain the size of the mechanical device in order to fit.

The mechanical system must contain an area for the NDA device. Based on the device selected for this process the holders should have the dimensions of 3.60 inches wide, 9.25 inches long and 20.35 inches tall. The dimensions are 0.05 inches greater than the device to enable easy placement and removal without too much leeway.

Another request by LANL was to make the system universal. The device can be made universal by maximizing the amount it can accomplish. This is achieved by having a nuclear device that can assay a variety of waste as described in Section 6.1. The device chosen needs to a way to switch between active assay and passive assay. In order to accomplish this the mechanical system created needs to be interchangeable.

Ergonomics with the mechanical system is a priority. This is translated into the engineering specifications by the necessity to install a movement system into the product. This will cut down the heavy lifting or uncomfortable lifting done by workers.

The system that needs to be applied to the mechanical design is a vertical movement device. This device has some limits it should achieve. The total weight of the nuclear device and the mechanical product is approximately 150 pounds. The vertical movement should be able to lift 200 pounds or greater for a factor of safety. The system should also drive the system to a height of 20 inches off the ground. This is necessary to assay the entire drum.

The motor has an important requirement to allow the product to function. The torque of the motor should be at least 4000 pound inches. The mechanical system is lengthy which requires more torque for the motor. This specification has a factor of safety built in to prevent the motor from working it's maximum.

The vertical movement of the mechanical product should rise and lower in an appropriate amount of time. The time that the product should take from the top to the bottom should be 5 to 10 seconds. This time a reasonable and easily accomplished specification.

The frame itself should be sturdy. The total weight of the devices is approximately 120 pounds. The frame should be able to hold 150 pounds or more to ensure a factor of safety. This will be easily accomplished with the use of aluminum alloy and welding.

The mechanical system needs to be able to assay a loaded drum of radioactive material. This requires the system to fully fit around the standard 55 gallon drum. The mechanical system has a necessity to be 23.5 inches or greater in diameter to fit around the drum.

The final request of the mechanical system is the same as one for the nuclear system. The mechanical system should be user-friendly. This will be solved by implementing a SOP to the mechanical product.

The nuclear specifications and mechanical specifications were combined to complete the design specifications for the product. These specifications can be seen in Table 7.

Table 7: Design Specifications

| # | LANL Requirement | Engineering Specifications |
|---|---|---|
| 1 | NDA | Neutron coincidence counting |
| 2 | Measure variety of waste | Active and passive assay |
| 3 | Acceptable efficiency | Active assay: 5% or greater<br>Passive assay: 5% or greater |
| 4 | Time efficient | 1 hour or less |
| 5 | Drums reactivity level | Less than 100 nCi/g |
| 6 | User-friendly | JSR 14 Shift Register<br>NDA 2000 Software |
| 7 | In-line system | Glovebox Dimensions: 150" long, 60" wide, 100" tall<br>Underneath: 39" tall |
| 8 | NDA holders | 3.60" wide, 9.25" long, 20.35" tall |
| 9 | Universal system | Interchangeable between active and passive assay |
| 10 | Ergonomics | Install movement system |
| 11 | Vertical movement | Lift 200 lbs or greater<br>Distance of 20 |
| 12 | Motor | Torque of 4000 lbs*in |
| 13 | Rising time | 5 to 10 seconds |
| 14 | Sturdy structure | Frame holds 150 lbs or greater |
| 15 | Ability to assay drum | 23.50" diameter |
| 16 | User-Friendly | SOP Provided |

# 7 Conceptual Design

When the team was first given their problem statement and told to create 30 general concept designs, everyone began working with the idea of ways to record and track the assaying of the materials. The general consensus was to find the best way to assay the waste in line while not disrupting the current standard operating procedures. This mentality was used all the way up to and during the presentation for our 3 preliminary designs. After speaking with the representative at LANL, a new problem statement was defined.

The original thought was that a team was needed to create a nuclear counting tool and find the best way to install it. Instead, after much discussion we learned to create a mechanical tool that would allow for several different types of nuclear assaying and to focus on the creation of that system instead of the nuclear aspect itself. Learning this so late in the semester caused for a shift in what our design would be and is therefore not located in any of the 120 designs below. However, there are certain parts of each design that are being utilized together in the final proposed solution.

## 7.1 Thomas Sullivan's 30 Concepts:

1. Hand held operating Geiger counter like the light used in a dentist office. Allows for hands free use in the glove box but is still easily movable.

   **Analysis:** A Geiger counter would not perform the exact assaying intended for this problem statement. Also, the installation of such a device would only hinder future operations.

2. Remote controlled Geiger counter, this will introduce a robotic aspect of the design and reduce the need for actual gloves and/or physical movement.

   **Analysis:** A Geiger counter would not perform the exact assaying intended for this problem statement. Robotic aspect is being taken into consideration.

3. Waste is counted then sorted by quantity per item and moved into 3 separate storage spaces. One for a small amount, medium, and large. Then x small items +y medium items + z large items will fit into 1 drum.

   **Analysis:**This automated process would require more room than the glove box has to offer and doesnt exactly answer the problem being asked. The materials being assayed are having their quantity of radiation measured not their volume.

4. Digital Progress Bar shows real time quantity, the user records the counter readings and updates the bar as necessary

   **Analysis:**This software is included in the proposed solution. It is incorporated into the go or no go testing in the assaying drum.

5. Incorporation of a notification system that activates when landmarks of capacity are hit i.e. 50%. 75%, 95%

   **Analysis:** A similar software feature is in the proposed solution where the drum is assayed and given a go or no go status.

6. Have an automatic trigger that activates when one drum is overfilled. The excess spills over into an emergency backup drum. This drum will remain below the current one until it is almost filled

   **Analysis:**There is not enough room for two drums to sit below the glove box. The idea of putting one below is in the proposed solution, the idea of it being overfilled is being taken into consideration.

7. The waste material enters a small disposable box where it is then measured again to reduce inaccuracy due to any residual radiation in the glove box

   **Analysis:**There is likely very little or no inaccuracy and therefore no benefit gained from assaying the material a second time. If the radiation is going to be picked up, moving it somewhere else inside the box wont change that.

8. Waste material is recorded and moved into a storage box before entering a drum to verify that amount is under the limit prior to entering the drum

   **Analysis:**This concept would require the in-line system to be interrupted for the installation of a secondary box. While in theory this solution would work, the installation process would hinder the overall systems ability to operate.

9. Drum is loaded inside of the glove box and has an auto sealing system that activates when the limit is met.

   **Analysis:** An automatic sealing system would require that the system is constantly operating in order to track progress. The drum is filled up over several days of loading and would therefore require more power than preferred.

10. Waste is filled into an 11-gallon middle drum then measured for accuracy when filled. Once verified it is moved to the 55-gallon drum, repeat four more times then, measure again to confirm accuracy.

    **Analysis:**This method is not only timely and non-cost effective but it's also based upon the presumption that the same amount of waste will be entered into the preliminary each time.

11. Install a conveyor belt system that allows the waste to be easily moved from one scanning station to the next.

    **Analysis:** This proposed idea would help the workers move waste within the glove box but it does not directly answer the problem of loading the drums and is therefore unhelpful.

12. Have multiple glove boxes lined up to test the waste multiple times to insure accuracy. Use the average amount and add to the total before sealing the final drum.

    **Analysis:**Running the same test several times in a row is very likely to result in the same answer. If there were errors in such readings then it would be due to an equipment failure.

13. Attach a Geiger counter to the outside of the glove box that is able to scan through the glass. Makes handling the counter much easier due to the lack of need for gloves to operate

    **Analysis:**A Geiger counter is not the desired assayer for this solution and had it been this would have proved to be an ineffective method for recording the radiation.

14. Do not move the waste from the glove box after it has been measured. Instead continue to move in new waste and scan the total pile again until the max value of waste has been met. Then move all of the waste at once into the drum

**Analysis:**Safety is the biggest reason not to use this idea. While it is possible it increases the amount of time workers would be near the waste and keeping the exposure ALARA is a key part of this problem.

15. Waste is filled into a test 55-gallon drum and measured once to confirm that it is under the max limit. Once confirmed it is then moved to the real drum for sealing.

    **Analysis:**The primary test drum serves no purpose. It is simply a filler step in the system and would only prove to not be beneficial.

16. A counter system is installed over the hole/entrance into the drum and records the progress. The system tracks the progress and displays numbers for the user to see.

    **Analysis:**This idea is possible but does not answer how or where the drum will be inserted during this system. Also, constant tracking requires a lot of energy that could be better used elsewhere.

17. Roller bearings are installed in between the glovebox rooms to facilitate movement/transportation of the waste.

    **Analysis:**While likely to improve the movement of waste through the glove box, this solution does little to answer the proposed problem. It has no effect on the loading of the drum itself.

18. A back up counter will be installed on the inside of the drum lid. Then when the drum is closed this will trigger the counter which at this point will read out whether the limit is surpassed or not

    **Analysis:**It is not financially possible to load each drum with their own counters. This would simply add an unnecessary cost to an already expensive problem.

19. A rail system is installed into the glove box to improve transportation and if need be reverse the direction of movement inside the glove box.

    **Analysis:**This solution would allow for a more easily transportable system but does little to help the loading of the drum and hardly answers the proposed problem.

20. Glove box installs lead lined doors that drop down during measurements to block out any residual radiation from previous waste material.

    **Analysis:**The mechanical installation of these doors would take countless hours just to design and then the physical installation would take even longer. This would greatly hinder progress and require an immense amount of input for a very small output in terms of efficiency.

21. Install a micro NDA in the final chamber to confirm count prior to drum being sealed

    **Analysis:**While an NDA is the correct type of counter to be used in this problem it does not say how or where it will be located in proximity to the drum. It also does not say where the drum itself will be located.

22. Install a micro NDA in the 55-gallon drum to confirm the count after the drum is sealed

    **Analysis:**The cost of installing a micro NDA into every single drum that gets sealed with waste would be massive, the idea is not financially possible. It also does not say how the assayer is going to provide data to the workers.

23. Install a trap door mechanism to drop waste onto a belt below the glove box to store all waste out of the way until the limit is met.

    **Analysis:**The idea of using a trapdoor is being proposed in the final solution. However, the conveyer belt would take up too much space and require too much time and money for installation.

24. Make the glove box entirely out of glass or as close to as possible to improve visibility and help with movement.

    **Analysis:**Not only would safety be lowered by a large amount through this idea, it also does not address the problem statement. Visibility and mobility are issues but not the intended ones for this problem.

25. Have the user side glass face on a track system that is able to move while still holding a seal. This allows for the user to move about the actual gloves and does not limit them to one fixed position.

    **Analysis:**This proposed solution would require an immense amount of analysis just to determine if it is feasible. At which point if it is proven feasible it does not seem like it would benefit the workers or system in any serious way.

26. Install a tray inside the glove box that is able to move around with an external joystick to increase waste mobility inside of the glove box.

    **Analysis:**This solution would make mobility within the glove box much easier but it would do little to nothing to benefit the drum loading process. It would also limit what can and cannot enter the glove box due to its need to have items smaller than the tray.

27. Install a Geiger counter into the base or roof of the glove box able to scan the entire box at once, then clear the entire box and bring in new waste.

    **Analysis:**A Geiger counter is not the counter that should be used for this system and if it were it would need to be very big to scan the entire box at once.

28. Mount the Geiger counter on a dual rail and chain system similar to those in a claw machine in order to get more exact control over the system as it measures,

    **Analysis:**While this system provides a way to have more control over your system as you measure the waste, it is still the wrong type of counter intended for this system.

29. Remove the gloves entirely and make the glass windows as large as possible. Then utilize robots and drones to move and measure waste for you to reduce human exposure.

    **Analysis:**The addition of robots and drones to this system could solve the problem and reduce human exposure. It will however come with a large number of other problems from maintenance to cleaning that deems this solution not worth the effort.

30. Install a Geiger counter into the inside of the glove itself to form a gauntlet like system able to measure any item picked up by the user.

    **Analysis:**This solution gives the workers more control over the measurements but does not assist in the loading process. Also, no such device exists right now and the design of one would be very complex and potentially not worth the time.

## 7.2 Robert Simpson's 30 Concepts:

1. Neutron Coincidence Counter attached to the top inside glovebox: This would be a device that reads the material moved under it. The materials will be passed through the glovebox the same way it is now. The device will count the neutron coincidence and moved into the waste drum.

   **Analysis:**This is a good theoretical solution but it lacks certain specifications such as if the material is going to be isolated prior to counting and what to do if the glove box is too high for it to read smaller materials.

2. Neutron Coincidence Counter attached to glass: The device would have sensitivity to read the radioactive material through the glass. Being attached to the glass would allow the user to be hand free. This would give a reading of the material in front of the device.

   **Analysis:**This idea is based upon the presumption that the coincidence counter is able to accurately read the material in the box from the outside. With the need to still move the material would prove that this process would not be hands free, even if the device would be.

3. Neutron Coincidence Counter that adds previous readings: This will be a reader that records the radioactivity of materials. The device will have a continuous total while recording the current radioactive material. Once the limit hits the device will alert the user. The device will have a reset button for each drum.

   **Analysis:**This solution introduces a tracking method that needs to stay running while the drum is being filled, which will require constant power. It also doesnt say where or how the scanner will be installed.

4. Automatic feeder: The glovebox will have a conveyer belt moving along the radioactive material. There will be a device counting the radioactive material as it passes. The device will add the radioactivity as the materials pass by. The device will stop automatically when the maximum is hit.

   **Analysis:**The installation of a conveyer belt would limit what can and cannot pass through the glove box based upon its physical requirements. It also acts under the impression that there is a constant feed of material, which is not always the case.

5. Manual feeder: The conveyer belt will only move when the button it is controlled by is pressed. This will allow for the moving of radiation to go slowly and controlled better. The device reading the radiation will count the total and give an alert when it is close to being full.

   **Analysis:**This idea is superior than the previously proposed conveyer belt because it gives the user total control over the system. Both however do not talk about the actual loading of the drum just the recording process.

6. Ring on 55 gallon drum: The ring will track the radioactivity to enter the drum. This is based off the passive neutron coincidence counter. The device will give a warning when the drum has almost hit the limit. The ring can be kept in place allowing the drum being filled to attach to it and detach to it when filled.

   **Analysis:**This idea lead the group to propose a drum collar solution to help record the material fill progression. First the idea had to be combined with that of the trap door to create one solid idea.

7. Monitor outside glovebox connected to a device inside: The monitor outside will allow for better viewing of the reading of the material. This can assure the workers arent reading through the glass or having difficulty reading the recordings.

   **Analysis:**This is one of the solutions that the team has decided to bring to its final design. Regardless of what system was implemented, having the screen outside is the logical choice.

8. Control pad outside glovebox connected to a device inside: The control pad outside the box will allow easy access to commands. This will prevent handling the device inside with gloves that would make it difficult. The control pad can have a reset button for counting or it can allow to re-calibrate the device.

   **Analysis:**In general, this solution is vague and does not go into enough detail to be considered seriously. The idea is based upon using a remote control of sorts but doesnt say what for or how.

9. Reader imbedded to the bottom of glovebox: The radioactivity will be read as it is passed over the device in the glovebox. This will be similar to a scanner. This device will record the total and alert the workers if they will exceed the drum limits with the current waste.

   **Analysis:**This solution works similar to that of a grocery store checkout, where the item passes over the scanner. It could be taken into consideration, providing it come with an easy way to load the drum.

10. Well-Detector inside glovebox: A well-detector is a passive coincidence counter. The dimensions of the device will allow it to fit in the glovebox. The radioactive material can be placed in the detector and recorded. An image is displayed as Figure 9.

    Figure 9: Rob Idea 10 [10]

    **Analysis:**This idea is the closest to the final design that the team proposed. That being that it also is an assaying method where the materials are surrounded by the scanner. The final design is not actually a well but operates in a similar physical fashion.

11. Drums with HLNC on top: HLNC is a passive high level neutron counter used on drums currently. Implementing this device to the glovebox line would allow for the radioactive material in the drums to

be counted. Since the HLNC would be on top of the drum, the drum would need to have a slit on the side to place the nuclear waste inside (Figure 10).


Figure 10: Rob Idea 11 [11]

**Analysis:**This solution incorporates this scanner onto the drum itself and does not stay in the glovebox. While it could work, it does expose the workers to a higher risk which is not what this problem wants.

12. HLNC in glovebox: Make a compartment in the glovebox for the high level neutron counter. This would allow for the reading of the material before entering the drum. Once read the material can be moved to the drum. The compartment would need to be hooked up to a computer to record the information.

    **Analysis:**Moving the high-level neutron counter into the glove box is a safer approach than leaving it separate. However, the addition of this new compartment would upset the already inline system due to physical constraints of the surrounding area.

13. Add a lead divider to glovebox: This can be a hinge lead frame in the middle of the glovebox. The divider can separate sides of the radioactive material. This would be done for lower level neutron coincidence counters. The hinged door can be put into place either manually or automatically.

    **Analysis:**If high level neutron counters are an option then why would we need to make specific accommodations for low level counters? While yes it would increase accuracy due to the lead shielding it just seems unnecessary.

14. INVS (Inventory Sample Counter) small compartment: The inventory sample counter is used for small plutonium samples with much less plutonium than HLNC. Make a small compartment or bucket in the glovebox where INVS can be run. Run analysis on small samples of plutonium at a time until the maximum content in a drum is met.

    **Analysis:**As stated above the incorporation of an additional compartment is unlikely due to the proximity of other glove boxes. Also, the obvious flaw in this design is what to do if a large sample arrives that this device cannot accurately measure.

15. INVS incorporate into drum: The inventory sample counter is used for small plutonium samples with much less plutonium than HLNC. The device will measure samples of plutonium like designed. The device will also add up plutonium levels from previous readings of the current drum. The bottom will open dumping the radioactive waste into the drum as long as it wont exceed the drums limits.

    **Analysis:**The trapdoor idea for the glove box is being used in the final design, still however the small-scale scanner is flawed due to its inability to read large samples.

16. WDAS in line: WDAS [?] is the waste crate assay system that measures high and low radioactivity levels in waste. The system is a passive neutron coincidence counter. Using the system in line with the glovebox will cut down time.

    Figure 11: Rob Idea 16

    **Analysis:**This is a very accurate device that would definitely be able to read the radioactivity on the materials provided. The problem with it is that it is too large to incorporate into the in-line system.

17. Apply the WDAS to the glovebox: Use the system for the waste drum assay system to make it applicable to the glovebox. Place a waste container in the glovebox to be used as the measuring container. Measure out how much waste is in that drum and if it does not exceed the 55 gallon limit dump it into the drum and continue until the maximum is made.

    **Analysis:**This device is too large to easily incorporate it into the glove box and even if it were added then the problem of loading and unloading arises.

18. Flat-squared counter attached to glovebox: The flat-squared counter is a small neutron coincidence counter therefore it can fit in the glovebox. The material can be analyzed in the glovebox then placed into the drum.

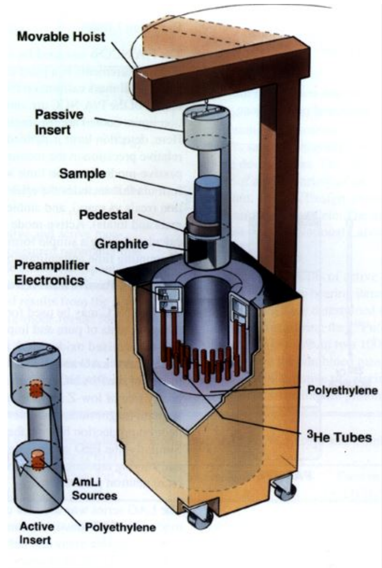



Figure 12: Rob Idea 18 [13]

**Analysis:**Using a smaller scale counter inside the glove box limits the workers exposure and does not disrupt the in-line system. If paired with a drum loading procedure this idea could work well.

19. Make a compartment with similar style of flat-squared counter: The flat-squared counter is surrounded by neutron detectors, graded liner, and moderators. The device also has a high voltage junction box. This device can try to be replicated in a glovebox to increase the amount of material that can be analyzed. This would also make it easier to move the waste throughout the glovebox.

    **Analysis:**This idea is to replicate an already existing device to install it into the glove box. What would be easier, this design or actually installing the original device, in other words, is it worth it?

20. Passive assay instead of active assay: There are two different ways to record plutonium waste through neutron coincidence counting. Passive assay is a detection and measurement of the neutrons from an isotope that undergoes spontaneous fission. Active assay is using neutrons to induce fission on a material and counting the neutrons emitted from that material. Passive assay is said to be more accurate than active assay.

    **Analysis:**This is another idea that is being considered for the final design. Active versus passive assaying is something to consider when choosing the final product that the team will use.

21. Combining both passive and active assay: There are previous devices that have a combination of both passive and active assay. Creating a device like this to incorporate in the glovebox would ensure an accurate answer.

    **Analysis:**The teams final design is able to do both active and passive assays due to its ability to have interchangeable slabs that can do several different measurements.

22. FDET detector head sealed in the glovebox: The Fork detector irradiated fuel measuring system detects gamma rays and neutrons. The system has a detector head, an extension pipe, a gamma ray and neutron detector electronics unit and a portable computer. The computer can have a station

outside the glovebox for readings. Nuclear waste would be moved to the detector had, read and the placed in the drum accordingly.

**Analysis:**This measuring system, while possible, is not one that the problem specifically is looking for. Let it be known though that the monitor outside of the glove box will be used in the final design.

23. Two different signals inside the glovebox: The first signal will detect one or more types of emissions from the material. The second signal will be a detection of the cosmic rays. Having the signals set up in the glovebox will allow for a more accurate reading of the radioactive material.

    **Analysis:**As stated above the idea of having multiple counting and detecting methods went into consideration when planning the final design.

24. Neutron scintillating wall: Neutron absorbing scintillating particles in plastic is a known neutron detector method. If there is a wall in the glovebox made for this, the neutrons can be counted by being attracted to the wall. The detector imbedded will read the neutrons. The detector can also select particles from the range of alpha to triton.

    **Analysis:**This is a very possible but costly design method. It would take a lot of time and money to replace a wall in all of the glove boxes. Even if the idea allows for a more complex array of counting methods.

25. Lithiated glass waved across the nuclear material: Have a piece of lithiated glass with scintillating particles is waved over the material. This will attract the neutrons from the radioactive material. The neutrons will be detected using this method.

    **Analysis:**This proposal does not give any details on how it will operate. Does the worker scan the glass or a machine? What happens if its drop and where is it stored?

26. Ionization chamber in glovebox: A low electric field current is caused by the creation of an ion pair (an ion and an electron). The ion chambers are preferred for high radiation doses. Implementing this into the glovebox would an accurate overall dose reading with an ability to read high radiation doses. The chamber would be in the glovebox with a door that opens to move radioactive material in or out.

    **Analysis:**Installing an ionization chamber inside of a glovebox seems a bit complex. Then once its installed inside how easily could it be operated by a worker?

27. Gas Proportional Detector in glovebox: This is similar to the ionization chamber by using ion pairs but this operates at a higher voltage. The device works well with a large area of flat arrays. This can be used in the glovebox if the waste material is spread out. The detector measures energy of radiation and can discriminate between alpha and beta particles.

    **Analysis:**Similar to the ionization chamber, this seems like a lot of work for a method that may not be the best option. Although, the use of a flat arrays was presented in our 3 design concepts presentation.

28. Solution neutron coincidence counter on its side in glovebox: This is for the radioactive waste that is too bulky or contain too much fission for gamma-ray counting. The device has an inlet and outlet tube which would work to send it from one side of the glovebox to the other side. The assay chamber is 1 liter in volume which will mean the container can be dropped into the 55 gallon drum.

    **Analysis:**This idea could potentially work but a system would need to be designed to get the tube in and out of the drum as well as what to do if an item is too large or small for the tube.

29. Smaller active and passive neutron crate counter: The active and passive neutron crate counter can measure a variety of waste boxes of plutonium or uranium waste. Place the machine in the middle of two gloveboxes to create a confined space. The waste can be measured in smaller boxes and added up for each drum. The smaller boxes will be dumped into the drum with a known total of how much waste is in the drum. The boxes can be reused or added to the waste.

    **Analysis:**The idea of using disposable counters means that there is a need to constantly purchase more of them. Not only does this idea have a consistent cost with it but it also creates more waste in the process.

30. Multiple checkpoints of the drums using scrambler: This would be a glovebox with a waste drum in the middle and a waste drum at the end. Place the scrambler attached to the first waste in order to take the readings of that drum. This will be used as a test point for the waste added. More waste can be added or some can be taking out depending on the reading given.

    **Analysis:**This idea of having a test drum is plausible but a loading and unloading mechanism would need to be created as well as a plan for when the drum is above capacity.

### 7.3 Andrew Elloso's 30 Concepts:

1. Use a window type structure equipped with sensors on the border to measure the level of radiation coming off of the specimen. Incorporate a light-emitting diode (LED) light progress bar measuring the total amount of radiation that has passed through and that quantity that is allowed until the limit is reached. See sketch below (Figure 13).

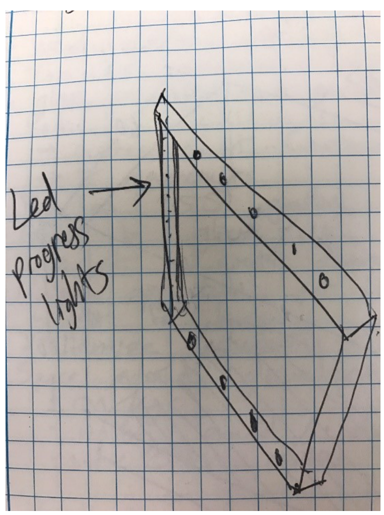



Figure 13: Andrew Idea 1

    **Analysis:** This idea seems relatively simple except the workers may want to know more information that just what LED lights can provide. Also, does not go into detail about the loading of the drum.

2. Instead of an LED lit bar, include a digital readout of current radiation and how much is left until it is full. This can either be displayed inside the glovebox, or outside, wherever is best for the operator.

    **Analysis:** This is a better solution than the use of LED lights. The team agrees that the monitor should be located outside of the glove box to provide easy visibility to the workers.

3. Place a sensor and shield around the 55-gallon drum displaying the readout as specimen are put into the drum for disposal. The display can be put wherever convenient for the operator.

   **Analysis:** The idea of a collar scanner and separate monitor was one that the team used in their 3-concept presentation. While a good idea for this presentation, it does not assist with the mechanical aspect of the new problem statement.

4. Create a pad using sensors similar to that of a grocery store scanner. The operator will place the specimen on top and hit a button on command for a readout. The sensors will be placed in the bottom of the pad and will include gamma and neutron radiation detectors. An LED light will display when the specimen is being measure and when it is safe to remove.

   **Analysis:** This scanner is a bit more complex than those previously mentioned, while in theory it could work, it does not go into details about the loading of the drum itself.

5. Incorporate idea 4 with a digital display and tally count of how much neutron and gamma radiation is left to go until the limit is reached.

   **Analysis:** What real benefit would adding a tally counter bring to this design? Again, like idea 4, still doesnt mention the physical loading of the drum.

6. Incorporate a Geiger counter type tube into the glove box design and use the current to display results either digitally or analogue.

   **Analysis:** A Geiger counter tube would require design work in nuclear engineering that we as a team do not yet posses. To consider this idea feasible would require more man hours of research than realistically possible.

7. Use a scintillation counter for neutrons and gamma radiation. This is to be placed onto one of the sensors.

   **Analysis:** This bulky device is a possible counter that we could use. However, the process of installing it onto a sensor does not seem realistic and the idea doesnt mention the loading of the drum at all.

8. Use handheld radiation detectors inside the glove box and manually enter the readout into a computer program. This can also be a Geiger counter type device.

   **Analysis:** Having a hand-held system inside the glove box and also manually entering the data into a separate program would require the worker to go back and forth between two stations, thus altering the in-line system greatly. It doesnt meet the intended goal for this problem statement.

9. Place an array of sensors above the drum in a lid type fashion (see Figure 14). This will provide an active readout when the contaminants are placed into the drum and will provide an external measurement on a screen.

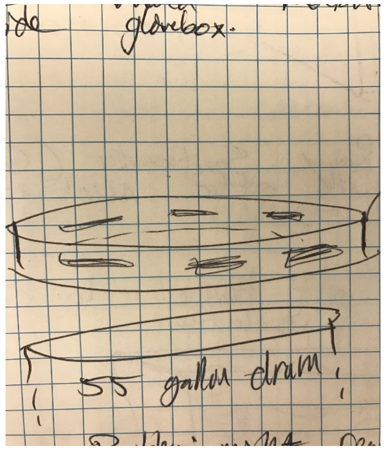



Figure 14: Andrew Idea 9

**Analysis:** This idea reflects that of a drum collar which is similar to an idea that the team presented in our final 3 design presentation. If pared with a drum loading mechanism, this idea could potentially work.

10. Use a spatially resolving radiation detector and incorporate this onto the sensor methods.

    **Analysis:** This idea exists only theoretically and has a patent created for it. For the team to physically create or at least design one would take legal actions and plenty of research. While it could potentially work, it would take a tremendous amount of man hours.

11. Use a shield for radiation blocking to keep the contaminant isolated. This shield will also have sensors underneath the lid and provide a readout on an external screen. See Figure 15 below.

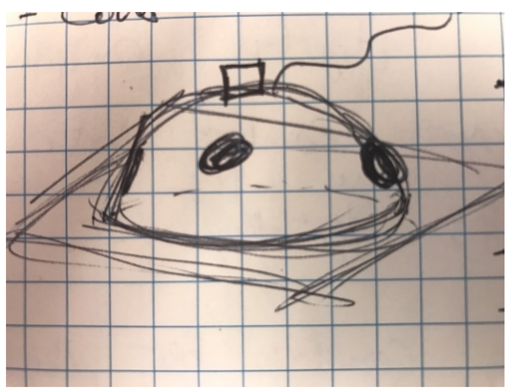


Figure 15: Andrew Idea 11

**Analysis:** If an isolation chamber such as this were to work it would need to be cleaned after every test to remove any residual radiation. This process would actually slow down the entire system, even if it means getting more accurate results it is not worth it in the long run.

12. Place the specimen in a microwave type device incorporated with sensors and shields to keep out external radiation. A screen will display the results.

    **Analysis:** A microwave type device, physically speaking, resembles that of a well detector. This is an idea that the team planned on using and is still somewhat in use for their final concept.

13. Use a gamma ray spectrometer (GRS) and combine this with a neutron detector to measure the radiation levels.

    **Analysis:** As a group of undergraduate students with limited nuclear engineering background, combining a gamma ray spectrometer with a neutron detector seems a bit too complex for the team. Maybe if we had some professional help to assist us this would be possible, but for now we need to look for a simpler answer.

14. Push the specimen through a tunnel equipped with sensors to measure the radiation. The tunnel will also have shields to help isolate the contaminant.

    **Analysis:** The idea of an isolation chamber implies that the entire glove box would need to be cleaned after each test to remove any residual radiation. This process would take far too much time and effort for the workers and would actually slow down the entire system.

15. Include a switch or button board with the ideas to control when the measurement is taken, when the sensor will be zeroed with the ambient radiation, and when to stop taking the reading. This can also omit the most recent sample if the radiation limit is too high. Numbers could also be used as a reference to the specific contaminants.

    **Analysis:** This idea seems like it's using a lot of words to simply say that there needs to be a control monitor to make sure that the workers have total control over the system. This is an obvious yet important plan to keep in mind throughout the design process.

16. Use a series of Geiger-muller tubes in a pad (Figure 16) to measure the contaminants. The tubes will be placed in rows and the highest reading on the tubes will be taken. See image below.

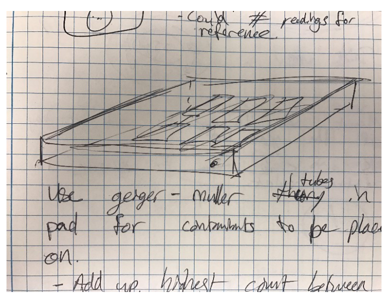



Figure 16: Andrew Idea 16

    **Analysis:** Using several tubes to record data and then only using one result of those tubes seems like a waste of equipment. If all of the tubes are measuring the same specimen and giving vastly different results due to minimal initial positioning, then that would most likely be due to faulty devices.

17. Use a dual motorized sensor to analyze the contaminant. The specimen will be placed on a designated area and the sensors will move when instructed by the operator. See Figure 17.

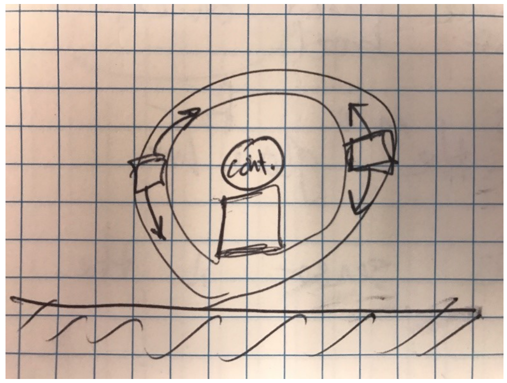



Figure 17: Andrew Idea 17

**Analysis:** This idea is vaguely describing a method of assaying the material from all angles to ensure a proper reading. This is exactly what our teams final design is based upon.

18. Use a motorized scanner similar to that of the airport security devices. See image below (Figure 18). This will scan the entire drum when instructed to by the operator and provide a readout.

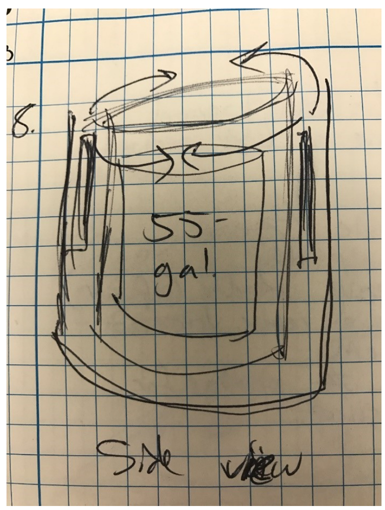



Figure 18: Andrew Idea 18

**Analysis:** This is the closest idea to our final design that will be found out of these 120 conceptual designs. Getting a 360-degree reading around the entire drum, combined with a trap door mechanism to load the drum, is exactly what our final concept is.

19. Mount idea 16 on the side or top of the glove box and equip the other sides with radiation shields.

    **Analysis:** When installing other devices or compartments onto the glove box, the bottom of it is the best chance, due to large amount of open space. There is very little room on the sides or above due to other equipment.

20. Use an analogue scale to measure the current radiation levels and include the limit. This is to be zeroed with the ambient radiation every time before use.

**Analysis:** If you keep zeroing your reader to compensate for residual radiation over time your device will slowly become more inaccurate and could affect each new reading.

21. Put a sensor pad underneath the 55-gallon drum and display the active readout externally.

    **Analysis:** This idea could potentially work but then the problem becomes how to load and unload the drum itself if it sits on the scanner. Also, loading the waste material is not addressed.

22. Put the sensors into four poles and in a designated area of the glove box.

    **Analysis:** This design shows little to no effort and makes minimal sense.

23. Place one or two Kromek DS3 sensors in the glove box and display the readout on a larger screen. Incorporate a control device where both can be operated at once.

    **Analysis:** The idea of putting multiple of the same device in the glove box to improve accuracy is a trivial notion. It is basically telling the product manufacturer that you dont believe that their device is accurate.

24. Use a motorized conveyer belt to carry the items through the sensor structure instead of pushing them through manually. This will provide a more consistent reading.

    **Analysis:** The installation of some sort material transportation device will improve mobility inside the glove box, but only for certain materials. It will also provide no benefit to assaying and loading of the drum.

25. Use a wand type device to measure the radiation levels. The results can be displayed on screen externally.

    **Analysis:** This describes how a standard Geiger counter works, it uses a wand to read direct materials and give the user audio based feedback. This is not the type of counter best suited for this problem.

26. Use a sensor on the top of the glove box that resembles a ceiling fan. This is to be placed in vertical tube shielding with an opening on the side for the specimen to enter the apparatus.

    **Analysis:** What benefit does turning the counter into a fan device give to the system? The vertical tube idea seems to resemble that of an isolation chamber, which again is not what the problem specs can accommodate.

27. Place bar sensors in the corners of the glove box or at the top and bottom.

    **Analysis:** A slab sensor, similar to that of a bar sensor, was one of the three design that the team presented originally prior to the problem statement changing.

28. Display the results from idea 25 on the side of the wand that is not used to measuring the radiation.

    **Analysis:** The wand is based upon emitting a detection system in all directions. It is not probable or beneficial for such a device to be created. It would also mean that the monitor for output reading is located inside the glove box, a design that is not wanted.

29. Use a half box shape, similar to that of a laptop, and have the results displayed where the screen would be and the sensors in the bottom and side.

    **Analysis:** This design has the monitor located inside the glove box and does not say how or where the sensor would operate with respect to the material.

30. Place sensors on a bowl-shaped structure and line the bowl with radiation shields. The readout can be displayed on the side of the bowl.

    **Analysis:** The bowl-shaped device is an interesting idea that could be possible, provided more time to research the idea. However, having the output monitor located on the outside of the bowl doesnt only seems unnecessary it in fact might hinder the workers ability to operate the device.

### 7.4 Ryan Murphy's 30 Concepts:

1. A hand held neutron monitor that is adapted to be used by operator in the by the operator to measure radiation inside the glove box. This would measure and count the radiation before disposal in a specified area in the glove box.

   **Analysis:** The problem with a hand-held detector is that it can only read material near the worker and allows for limited mobility.

2. hand held neutron monitor that is adapted to be used from the outside of the glove box to be used through the window or port of the glove box.

   **Analysis:** As stated above a hand detector limits the users ability to a localized area also passing a detector through a port would cause for more problems such as how would it transmit the data collected.

3. The IAEA neutron coincidence counting computer program to be paired with the neutron counting devices.

   **Analysis:** This is a more likely solution where an external monitor is to be used with a detecting system. This concept is used in the teams final design presentation.

4. HLNC that is adapted to be the size of a 55-gal drum inside the glove box. This would be loaded manually, then the count would be reached, then the waste would be manually unloaded.

   **Analysis:** The problem with this concept is that the loading and unloading of the drum inside the glove box would require more mobility than a standard worker is given. This is why the final design has the assaying chamber below the glove box.

5. HLNC sized to match the size of a 55-gal drum with the waste movement system styled to be removed with a trash bag style removal system.

   **Analysis:** The idea of a trash bag removal system is being implemented in our final design. We feel that it allows for easy disposal of all low-level waste.

6. HLNC sized up to the shape of a 55-gal drum and positioned on its side and have two doors on each side. This would allow for easier movement of the waste in a pass-through system in the glove box.

   **Analysis:** Attaching devices to the side of the glove box can be potentially problematic due to limited space. It is for this reason also that the final design is located underneath the box.

7. HLNC sized up to the shape of a 55-gal drum and positioned on its side with one door. The waste would be manually slid into the device, counted, and then slid out to proceed onto waste disposal.

   **Analysis:** Attaching devices to the side of the glove box can be potentially problematic due to limited space. It is for this reason also that the final design is located underneath the box.

8. HLNC sized up to shape of a 55-gal drum and positioned upright. This would be outfitted with a mechanical system for easy loading and unloading.

   **Analysis:** This style and positioning of a device is being used with the trapdoor mechanism to create our final product. The placement of the device is what sets this concept above others.

9. A waste crate assay system (WCAS) would be adapted for use in glove box (sized down). The waste would be loaded manually into the crate in small batches, the radiation would be counted then placed into disposal drums.

   **Analysis:** Installment of any sort of crate system or smaller box within the glove box would only hinder the in-line system as it gets in the way of the manual movement of waste.

10. WCAS would be adapted for use in glove box. The movement system of the waste would be aided by the implementation of a roller system.

    **Analysis:** The use of a roller system in the glove box would improve the mobility of the waste. However, it could possibly interfere with the loading and unloading of the drum.

11. WCAS would be adapted for use in glove box. The waste movement system would be aided by the use of an automated belt system.

    **Analysis:** The installation of a belt system inside the glove box would limit what waste can and cannot be moved due to physical constraints. Although it would assist in the mobility of smaller waste.

12. An INVS to be bought and adapted for use in the glove box. This will be done by counting small samples of waste and counting them separately.

    **Analysis:** This idea is good in theory but the problem with small level detectors is that if a larger piece of waste were to enter the glove box and this device is not powerful enough to accurately measure it.

13. INVS would be sized to be loaded to a size of 27.5 gal. This would only allow a maximum of two batches of counting and loading or unloading.

    **Analysis:** This concept does not specify where the drum will be located or how it will be loaded. The idea of breaking it down into two separate batches only works if the batches contain the exact same amount of waste which is unlikely.

14. INVS would be sized to be the size of a 55 gal. This would allow for one batch of counting to be done at a time and to fill them to fit into a 55-gal drum and stay under the allowed radiation level.

    **Analysis:** This concept is better suited than the two smaller batch ideas however it also does not specify the loading and unloading process for the drum.

15. INVS's waste movement system would mirror a "trash bag" for easier movement of the radioactive material inside the glove box. This would limit the movements that would need to be done by workers.

    **Analysis:** The idea of using a trash bag system is being utilized in the teams final concept. However, in that idea the trash bag is used underneath the glove box and not inside of it.

16. INVS to be implemented with a mechanism to move the device onto its side so the loading and unloading would be easier. The INVS would be rotated on its side, loaded, rotated to an upright position the lowered again for easier unloading.

**Analysis:** This sort of mechanism inside the glovebox only works for specific scenarios. The problem statement is intended to keep the glove box system the same so multiple different processes can utilize the same glove box at different times.

17. INVS to be positions on its side and to be used as a station to pass the waste through so a count could be recorded. This would resemble a check out at a grocery store type idea.

    **Analysis:** This idea is feasible however puts heavy requirements on the worker's ability to maneuver the waste properly. It also fails to mention how the waste will be loaded into the drum.

18. INVS to be positioned on its side with two doors on either end. This would make the manual loading and unloading easier and accurate counts still could be recorded.

    **Analysis:** This method would improve the ease of the loading the assaying system. However, it does not mention how it will be loaded into the drum.

19. Audible alarm system to alert the operator when the radiation limit is reached. Different tones would be used when the limit is being approached, reached and overfilled.

    **Analysis:** The idea of having a monitor track the waste's progress as it fills the drum is being utilized in the team's final design. Whether or not audible alarms will be used or a simple monitor is yet to be determined.

20. Flashing lights to alert the worker of the status of the radiation limits in the batch destined for storage in the same 55-gal drum.

    **Analysis:** As stated above, there is not a finalized idea yet as to how the worker will be notified about the status of the drum in question.

21. Plutonium scrap multiplicity counter (PSMC) to be adjusted for use in the glove box. This would be used to count the radiation in relatively small batches.

    **Analysis:** The problem with any sort of counter that is based around using smaller batches is that if a larger piece of waste that cannot be broken down enters the box then the device instantly becomes ineffective.

22. PSMC that would be installed into the glove box and the sized would be upgraded to 55 gal or 27.5 gal. This would help to cut down the amount of batches the worker would have to move.

    **Analysis:** Utilizing one or two batch methods is based upon the presumption that the batch in question will not go over the limit of the drum. If the limit is reached and superseded, then the original problem still occurs.

23. PSMC that would be outfitted with a trash bag system. This would ensure the radiation count would be accurate and minimize the loading and unloading times.

    **Analysis:** As stated before the use of a trash bag system is being used in the team's final design. It allows for easy control and more accurate reading of the waste.

24. PSMC that would be outfitted with mechanical system that would allow for the device to rotate. This would allow for the easier and faster loading and unloading of the waste for counting.

**Analysis:** The idea of rotation while counting is used to achieve a reading that is 360 degrees wide. This idea has been considered and proved to be the most accurate method and will be used in the final design.

25. PSMC positioned on its side and being a pass-through system for the waste that would count the radiation of each piece that is passed through. This would keep track of the radiation count until a barrel was filled and the count would restart afterward.

    **Analysis:** Tracking the amount of waste that enters the drum is one of the primary focuses of this problem and this is the type of solution that the team plans on using.

26. Fork detector irradiated fuel measuring system (FDET) that would be positioned as an 'arch' in the glove box. This would be used as a pass-through point of the waste and would count the neutrons detected.

    **Analysis:** Ideas such as this one are excellent in that they are able to count all of the waste and have an accurate reading. Again, they are a physical installment inside of the glove box that can affect other systems.

27. FDET that would use rollers to move the waste through the arch to make the movement of the waste much easier and more constant. This would allow for a higher accuracy measurement.

    **Analysis:** Ideas such as this one are excellent in that they are able to count all of the waste and have an accurate reading. Again, they are a physical installment inside of the glove box that can affect other systems.

28. FDET that would use an automated belt system to move the waste through the arch at a constant rate.

    **Analysis:** Ideas such as this one are excellent in that they are able to count all of the waste and have an accurate reading. Again, they are a physical installment inside of the glove box that can affect other systems.

29. FDET that would be installed directly above the loading of the drum to count the radiation as the waste is dropped into the disposal drum.

    **Analysis:** Ideas such as this one are excellent in that they are able to count all of the waste and have an accurate reading. Again, they are a physical installment inside of the glove box that can affect other systems.

30. A layer of steel to be installed over any device to be used. This will act a shield to cosmic radiation to ensure there is an accurate measurement of the plutonium placed into each drum.

    **Analysis:** Shielding is always considered when designing a device to record waste. The design of such a shield has to be precise so that waste can be measured without having any interference.

In conclusion, after analyzing all 120 of the original ideas the team established three ideas to act as preliminary designs. Shortly after we realized that these would not meet the intended problem statement. It was at this point that we had to regroup and sort through all of the original ideas to find the inspiration for our new final concept. As stated originally the exact design that is being presented isn't one sole idea in the list above. It is instead a combination of several of them that we feel would work best to solve the problem statement.

# 8 QFD

The quality function deployment (QFD) is a process to transfer customer requirements into specific product plans. The main portion in the QFD is known as the "house of quality" which acquires its name from the resemblance of a house. The sections of the house of quality include demanded quality, quality characteristics, relation matrix between demanded quality and quality characteristics, difficulty to complete quality characteristics, interaction between quality characteristics, weight importance, and competitive analysis. The first step to completing the QFD is listing the desires of the customer associated with the weight of importance for each under demanded quality. The following step is to decide on the characteristics the product will encompass and how difficult it is to achieve. After both lists are filled out, each quality characteristics will be defined by how they correlate to each demanded quality. Once this is done the weight of importance for each quality characteristic can be calculated by the weight of the demand and how strong it correlates to it. Evaluating the interaction of each quality in the top of the "house of quality" is the next step in order to see how each will affect one another. The final step of the QFD is to compare each product idea in order to analyze which will be the best product. The entire QFD can be observed in Figure 19 below.

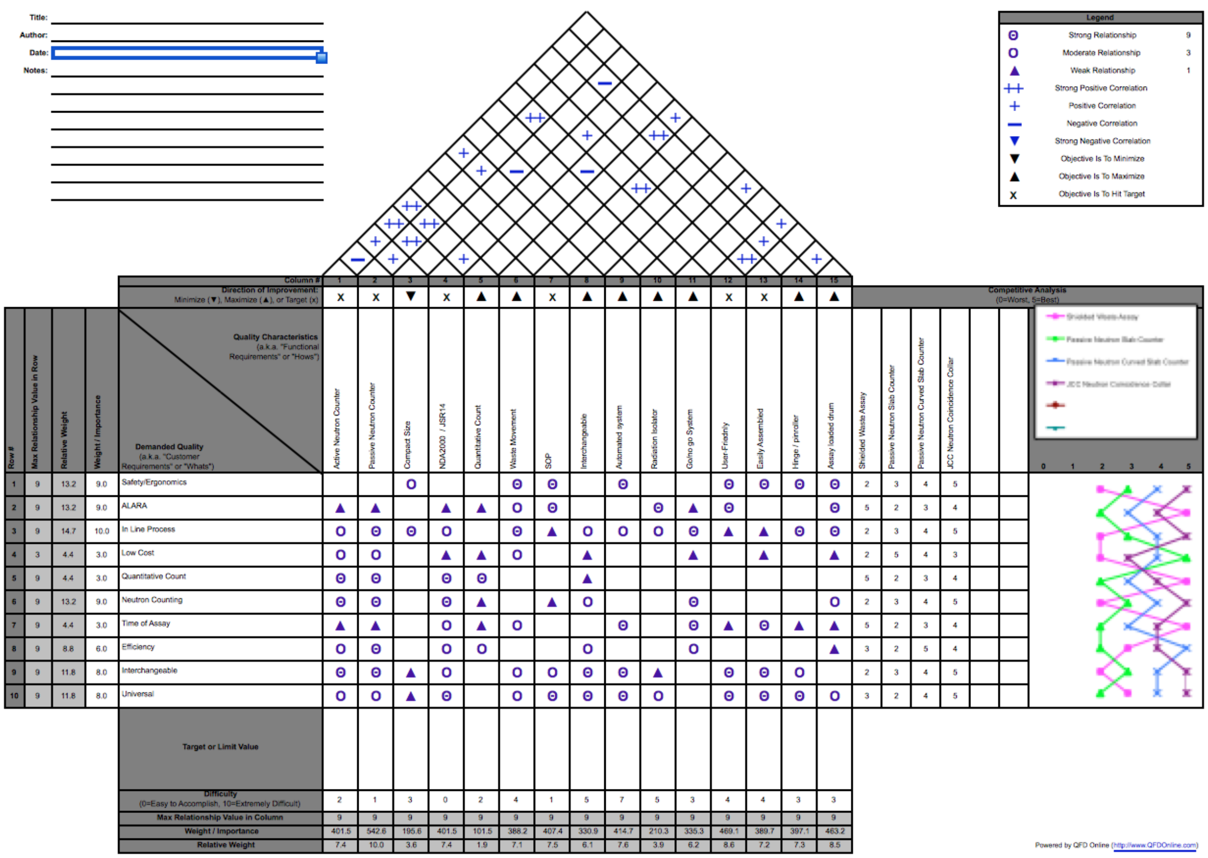



Figure 19: QFD

## 8.1 Demanded Quality

The desires of the customer are translated into a list under the demanded quality. This is an important part of the process because the needs of the customer have to be accomplished. This is located on the left side of the QFD and known as the "What's." In this section each quality is given a rating for importance to correctly evaluate the quality characteristics. The ratings given are between one and ten with ten being the greatest importance. From these ratings, the relative rates are calculated to demonstrate the importance of the quality in retrospect to others. The list of demanded qualities and their importance can be seen in Figure 20.

| Row # | Max Relationship Value in Row | Relative Weight | Weight / Importance | Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") |
|---|---|---|---|---|
| 1 | 9 | 13.2 | 9.0 | Safety/Ergonomics |
| 2 | 9 | 13.2 | 9.0 | ALARA |
| 3 | 9 | 14.7 | 10.0 | In Line Process |
| 4 | 3 | 4.4 | 3.0 | Low Cost |
| 5 | 9 | 4.4 | 3.0 | Quantitative Count |
| 6 | 9 | 13.2 | 9.0 | Neutron Counting |
| 7 | 9 | 4.4 | 3.0 | Time of Assay |
| 8 | 9 | 8.8 | 6.0 | Efficiency |
| 9 | 9 | 11.8 | 8.0 | Interchangeable |
| 10 | 9 | 11.8 | 8.0 | Universal |

Figure 20: Demanded Quality

The first quality desired from LANL was safety and ergonomics. This was given an importance rating of nine since the physical safety of their workers is very imperative for this company. This can be achieved by limiting the necessity for the workers to do any of the following: lift heavy objects, over extend their arms in the glovebox, or using second level of gloves which requires a ladder.

The next request was similar to the first but strictly deals with the radioactivity. As low as reasonably acceptable (ALARA) describes the need to minimize the exposure to radioactive material. The importance rating for this quality was a nine in order to demonstrate the significance of it and again the safety of the workers. This is already incorporated to their system with the glovebox and 55 gallon steel drum.

The highest rating (out of ten) was given to the desire of having the product be in the glovebox line. This is a major problem for LANL and essentially the reason for requiring a new product. There are currently no NDA devices that can fit some of the bulky materials in the glovebox.

For the majority of the time, a customer wants a low cost of the product. This was given a low rating of three, however, seeing it is not a major issue. The amount the company will save with this product will pay for itself in no time.

Los Alamos has the desire for the product to have a quantitative count in order to give a numerical reading of the radioactivity. This was not a major importance, receiving a rating of three, since there are devices that assay whether the waste is under the radioactive limit without a quantitative count. These systems are known as go/no-go systems which will be mentioned in the quality characteristics.

The next request from LANL for the product was to be a neutron coincidence counting device. This measurement technique is a commonly used type of NDA. The initial request was for the product to be a NDA but later narrowed down to being a neutron coincidence counting device. Since it is important for the device to be NDA the importance rating for neutron coincidence counting is given nine.

The time of assay received a rating of three for importance for this LANL product. The request is on the list since the company does not want the product to take hours to assay but it is not an issue if the assay takes a reasonable amount of time. The first point of the product is to solve this major problem for the company.

The following need for the product was that it must have an acceptable efficiency. This is similar to the time of assay with the efficiency as not being a major issue if it is low, but the higher the efficiency the better. This resulted in the quality receiving an importance rating of six.

The product being interchangeable was a desire asked for by LANL. The system being interchangeable allows for the measurement of different radioactive materials. This would allow for versatility in the product which is the reason the quality was given an eight for importance rating.

The need for the product to be universal was a major demand. This was expressed as important in order to have the system incorporated by other gloveboxes or even other companies. The rating of importance for this was an eight since the product does not need to be unique to just one area.

## 8.2 Quality Characteristics and difficulty

Quality characteristics is the next piece of the QFD located under the roof and known as the "How's." This is the fundamental requirements of the product necessary to meet the demands of the customer. The list of Quality Characteristics and how it appears in the QFD is shown in Figure 21. These requirements are each evaluated to comprehend how they correlate with each of the customer requirements. The direction of improvement is located above the quality characteristics in Figure 21 to demonstrate the objective. This is shown with symbols that are to maximize minimize or hit the target of the quality characteristic. The difficulty to accomplish the characteristic is ranked from zero to ten with zero being easy to accomplish and ten being extremely difficult which can be seen in Figure 24.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | X | ▼ | X | ▲ | ▲ | X | ▲ | ▲ | ▲ | ▲ | X | X | ▲ | ▲ |
| Active Neutron Counter | Passive Neutron Counter | Compact Size | NDA2000 / JSR14 | Quantitative Count | Waste Movement | SOP | Interchangeable | Automated system | Radiation Isolator | Go/no go System | User-Friednly | Easily Assembled | Hinge / pinroller | Assay loaded drum |

Figure 21: Quality Characteristics

The first two fundamental requirements are active assay and passive assay. These are both types of neutron coincidence counting that allow for measurement of different radioactive waste. The active assay can be set up similar to the passive with a quick change of one of the pieces. These systems can both be incorporated in the glovebox line which a major demand quality. The efficiency and relatively low cost of these type of assays make these important requirements.

The next characteristic is for the product to have a compact size. The system should be able to fit within the constraints of the glovebox or underneath the glovebox. This requires the size to be smaller than 160" long, 60" wide and 100" tall or under 39" tall for underneath the glovebox. This seems very large but relative to current NDA devices this requires a compact size.

The following two requirements are NDA2000 and JSR14 software and quantitative count. This is software that allows for the collection of neutron coincidence data. This enables the universal use of the device and the ability to receive a quantitative count. The quantitative count correlates with the neutron counting and efficiency of the device.

Waste movement is a fundamental feature to helping workers move waste through the glovebox more efficiency. Currently, workers push and pull waste through the glovebox and also use pushing sticks to extend farther in the glovebox. The waste movement has a strong correlation safety/ergonomics and in-line process.

Standard operating procedure (SOP) and User-friendly features are other characteristics. Both of these characteristics allow for safety, ALARA and universal use. This is due to the fact the SOP will give instructions how to use the system correctly and the user-friendly will make it easy for the workers to operate.

The next fundamental requirement of the system is that it be interchangeable. This is an important feature in order to assay different radioactive materials. The system being interchangeable enables the system to be universal because it broadens the waste that can be measured.

The following two features are automated system and hinge/pin-roller. These fundamental requirements provide safety to the workers by lessen the necessary work and simplifying the process. These both allow the system to be utilized universally with the simplification.

The next quality characteristic is the radiation isolator. This is a required feature due to the fact that it will correspond with ALARA. The need to accomplish ALARA can driving factor in some features.

The go/no-go assay system is a type of measurement system for assays. This type of system is used for neutron counting already and can be implemented in-line. The go/no-go system would decrease time of the assay.

The necessity for the product to be easily assembled is a quality characteristic. This will provide less headaches over the product if it is easily assembled. This characteristic strongly correlates with safety and universal use.

The assay of a loaded drum is the final fundamental requirement. This allows the drum to be filled with the waste and the measurement to be read before the drum is removed the glovebox. This requirement is important because the steel drum completes ALARA requirements, it will continue to be an in-line process and the since the process will remain similar the safety of the workers will be accomplished.

## 8.3 Relationship Matrix and Weight Importance

The relationship matrix is the correlation between the demanded quality and the quality characteristics also known as the "what's versus how's." This is meant to demonstrate how each quality characteristic corresponds to each demanded quality. The way that the connections are displayed is by a variety of symbols in the main part of the QFD. There are four type of interactions: the first is a strong correlation which is a numerical value of nine, the second is a moderate correlation which is a numerical value of three, the third is a weak correlation with a numerical value of one, and the last is no correlation with a numerical value of zero. The symbols can be viewed in Figure 22 The connection between the demanded quality and the quality characteristics can be seen in Figure 23 and are also discussed in Section 8.2 Quality Characteristics and Difficulty.

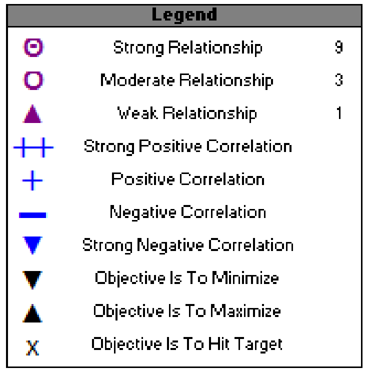



Figure 22: QFD Key

| Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats") | Active Neutron Counter | Passive Neutron Counter | Compact Size | NDA2000 / JSR14 | Quantitative Count | Waste Movement | SOP | Interchangeable | Automated system | Radiation Isolator | Go/no go System | User Friednly | Easily Assembled | Hinge / pinroller | Assay loaded drum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Safety/Ergonomics | | | O | | | Θ | Θ | | Θ | | | Θ | Θ | Θ | Θ |
| ALARA | ▲ | ▲ | | ▲ | ▲ | O | Θ | | | Θ | ▲ | Θ | | | Θ |
| In Line Process | O | Θ | Θ | O | | Θ | ▲ | O | O | O | Θ | ▲ | ▲ | Θ | Θ |
| Low Cost | O | O | | ▲ | ▲ | O | | ▲ | | | ▲ | | ▲ | | ▲ |
| Quantitative Count | Θ | Θ | | Θ | Θ | | | ▲ | | | | | | | |
| Neutron Counting | Θ | Θ | | Θ | ▲ | | ▲ | O | | | Θ | | | | O |
| Time of Assay | ▲ | ▲ | | O | ▲ | O | | | Θ | | Θ | ▲ | Θ | ▲ | ▲ |
| Efficiency | O | Θ | | O | O | | | O | | | O | | | | ▲ |
| Interchangeable | Θ | Θ | ▲ | O | | O | O | Θ | Θ | ▲ | | Θ | Θ | O | |
| Universal | O | O | ▲ | Θ | | O | Θ | Θ | Θ | O | | Θ | Θ | Θ | O |

Figure 23: Relationship Matrix

The significance of each quality characteristic on the system is analyzed by the weight importance calculations. The Weight Importance is calculated for each quality characteristics by multiplying the weight of the demanded quality by the strength of correlation to that demanded quality. The total importance of each quality characteristic is the addition of all the demanded qualities for that quality characteristic. After the total importance is calculated for each quality characteristic, the relative importance is recorded for each with the division of the total importance for one quality over the summation of the total importance for all the qualities. The top three important quality characteristics for the QFD are passive assay (10%), user friendly (8.6%), and assay of loaded drum (8.5%). After the top three the remainder are listed in descending order: automated system (7.6%), SOP (7.5%), active assay (7.4%), JSR14 and NDA 2000 software (7.4%), hinge (7.3%), easily assembled (7.2%), waste movement (7.1%), go/no-go system (6.2%), interchangeable (6.1%), radiation isolator (3.9%), compact size (3.6%) and quantitative count (1.9%). These numbers can be viewed in Figure 24 lining up with the associated Quality Characteristic displayed in Figure 21 or Figure 23.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Difficulty (0=Easy to Accomplish, 10=Extremely | 2 | 1 | 3 | 0 | 2 | 4 | 1 | 5 | 7 | 5 | 3 | 4 | 4 | 3 | 3 |
| Max Relationship Value in Column | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Weight / Importance | 401.5 | 542.6 | 195.6 | 401.5 | 101.5 | 388.2 | 407.4 | 330.9 | 414.7 | 210.3 | 335.3 | 469.1 | 389.7 | 397.1 | 463.2 |
| Relative Weight | 7.4 | 10.0 | 3.6 | 7.4 | 1.9 | 7.1 | 7.5 | 6.1 | 7.6 | 3.9 | 6.2 | 8.6 | 7.2 | 7.3 | 8.5 |

Figure 24: Relative Importance of each Quality Characteristic

## 8.4 Interaction Between Quality Characteristics

The interaction between quality characteristics demonstrates how each quality relates to the others. This is located at the top of the QFD. The correlation between each quality is displayed by symbols which mean strong positive correlation, positive correlation, negative correlation and strong negative correlation. These symbols are acknowledged in Figure 22. If there is no correlation between the qualities the spot is let blank.

Active neutron counter has a negative correlation with passive neutron counter. This is essential because these are two different ways of assaying radioactive waste. However, these neutron counters have a strong correlation with interchangeable because the active neutron counter can easily be switched to passive neutron counter and vice-versa. There strong positive correlation for both active neutron counter and passive neutron counter with the JSR14 and NDA 2000 software since the software can be utilized for both types of assay. Both neutron counters have a strong positive interaction with quantitative since the software allows quantitative count. The passive neutron counter has a strong positive correlation with go/no-go system because the devices are known to achieve it.

The compact size has negative correlations with automated system and hinge. Automating the system will increase the size of the product slightly with more circuits or devices as well as the hinge since it will open taking up more space. The quality of compact size has strong correlation with both active neutron counting and passive neutron counting because there are current devices that have a small footprint.

NDA 2000 and JSR 14 software has a positive correlation with quantitative count since the software calculates it while running. User-friendly is a positive correlation with the software also since it is a simple interface.

Waste movement has a strong positive correlation with having a hinge. The reason for this is being able to open and close the device allows for easy access to the waste. Waste movement also has a positive correlation with assaying a loaded drum because the drum can be placed on a wheeling cart in order to move easily.

User-friendly has strong positive correlations with SOP and easily assembled while a positive correlation with the system having a hinge. The SOP will provide instructions to help the user easily achieve the job at hand. The device being easily assembled and having a hinge will limit problems the workers may come across.

Radiation isolator, user-friendly, and requiring a hinge are all positive correlations to assay of a loaded drum. The radiation isolator is a positive correlation because the current process is loading the drums which would be changed if there was too much radiation exposure. This is user-friendly since it would be keeping the majority of their process constant. The hinge is a positive correlation since it allows the drum to be completely surrounded for the assay while being easily removable.

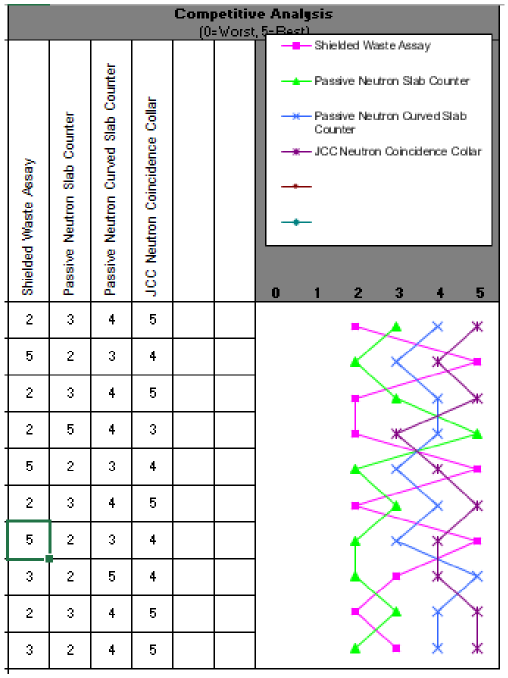
## 8.5 Competitive Analysis and Trade-off Analysis

The competitive analysis is completed to evaluate how the current LANL devices compare to their competitions. On the right side of the QFD, the competitor's devices are analyzed using the demanded qualities by the customer. Los Alamos, however, is a member of the IAEA which work together to solve nuclear waste problems such as this. The design necessary to solve the problem is a unique system which has no current competition. There are actively no devices in use that are able to solve the current problem for LANL.

The trade-off analysis evaluates the design ideas in comparison to each other. The ideas being compared are the shielded waste assay system, passive neutron slab counter, passive neutron curved slab counter, and JCC neutron coincidence collar. The way the trade off analysis is presented in the QFD can be viewed in Figure 25 as well as the trade-off analysis graph.

The shielded waste assay was considered for its time of assay quantitative count and ALARA considerations. This device had the best time of assay by far at 30 seconds. The product was also best at quantitative count and ALARA given there is a protection of radioactive shielding. The device was, however, too difficult to incorporate in the glovebox line and could only do the one type of assay.

The passive neutron slab was evaluated to have barely any advantages over the other devices. The only advantage the passive neutron slab had is the cost of the device which was low importance in the demanded




| Shielded Waste Assay | Passive Neutron Slab Counter | Passive Neutron Curved Slab Counter | JCC Neutron Coincidence Collar | | |
|---|---|---|---|---|---|
| 2 | 3 | 4 | 5 | | |
| 5 | 2 | 3 | 4 | | |
| 2 | 3 | 4 | 5 | | |
| 2 | 5 | 4 | 3 | | |
| 5 | 2 | 3 | 4 | | |
| 2 | 3 | 4 | 5 | | |
| 5 | 2 | 3 | 4 | | |
| 3 | 2 | 5 | 4 | | |
| 2 | 3 | 4 | 5 | | |
| 3 | 2 | 4 | 5 | | |

Figure 25: Trade-off Analysis

quality. The device was the lowest in universal, efficiency and ALARA considerations.

The passive neutron curved slab was eliminated after careful analyzation. The device has the highest efficiency of those evaluated. The device would also work the second best in the glovebox line, have the second lowest cost, be interchangeable and universal. This was, however, eliminated because there was a better device to fit the criteria.

The JCC neutron coincidence collar ranked the best in the trade-off analysis. The device fits will in the glovebox line and attributes to safety and ergonomics. This is the best device to make universal and interchangeable because it incorporates both active and passive assay. The only flaw in the device is it will have a decent cost to it but will meet all other expectations.

# 9 Design for X

## 9.1 Design for Safety

The most important aspect to consider when disposing of nuclear waste is safety. This includes the safety of the workers handing the radioactive materials and the safety of the environment where the waste will be stored. When the LLW is loaded into the drums, the total level of radiation is not to exceed 100nCi/g. When this level is exceeded, the LANL workers must transport the barrels to another site in order to split the waste into multiple barrels to meet the regulation. This process exposes the workers to higher levels of radiation, and is a concern when trying to keep radiation levels ALARA. The new design being created is aimed to eliminate this process and lower the overall radiation exposure to the LANL workers.

When creating the mechanical system, several safety concerns were considered. These include the stability and reliability of the device, along with the cleaning process. To make sure the Pu Assessment system will not fall apart and possible cause injury, a stress analysis was completed (Section 12: Engineering Analysis). This ensures the quality of the product. Equipment that deals with radioactive waste must stay relatively free of radiation. In order to comply with this, disposable plastic sleeves will be added to all 'beam' like structures. To aid in physical cleaning, the structure will be smooth and will contain the least amount of grooves and edges as possible.

## 9.2 Design for Ergonomics

The design for an in-line system was heavily stressed in the problem statement. The system designed by Team 8 was not to interfere with the process already instated by LANL. The process created involves using already incorporated techniques and only adds the time it takes to assay the waste. The waste is already being disposed of into the 55-gallon drums in a similar manner and adding on the assay will keep the procedure very time-efficient.

The biggest issue ergonomically will be placing the 55-gallon drums into assay. This will require the drum be attached to a dolly, however, this is already installed in the LANL facility.

Along with the Canberra JCC 71,72, and 73 meeting all of the requirements for the assay, another reason it was chosen is due to its user friendly interface and software. The assay uses the JSR 14 shift-register paired with NDA 2000 software. According to Canberra, this is the best and easiest product combination they offer.

## 9.3 Design for Performance

This project needed an interchangeable passive and active assay capable of measuring gamma and neutron radiation. This also had to be a coincidence counter capable of taking quantitative measurements. All of these issues have been solved by incorporating the Canberra JCC 71, 72, and 73 into the LANL low-level waste disposal process. This system is designed to measure objects as small as radioactive items and as large as a 55-gallon drum. The process defined by Team 8 involves measuring the barrel last, and testing to see if the radiation levels are too high.

There were three Canberra models selected due to their different qualities. The JCC 71 is a passive measuring system, which meets the first requirement. The JCC 72 and 73 models are active assays, both with different efficiencies that will be specific by the user. These three different assays are what make this system adaptable to the user's preference. All three systems meet LANL's requirements of an efficiency greater than 5% (Refer to Section 10.1).

The six slabs that will be incorporated into the design only cover one-third of the height of the 55-gallon barrel. The first measurement taken will only cover the bottom third. The motor selected will then carry the frame up to the middle and top levels. This allows the total radiation level to be compiled and a reading to be prompted to the user.

### 9.4 Design for Cost

The main concern of this project is to minimize costs. Whenever he LANL workers have to re-organize the LLW it costs the company upwards of $150,000. This occurs an average of five times a year, and totals $750,000. The solution proposed by Team 8 will cost around $175,000, which will pay off almost immediately. This cost is mostly spent on the assays, which is further analyzed in the Financial Analysis section (Section 3).This funding will be received pending approval from LANL. The design will then be passed on to the DOE, who would ultimately be providing the funds.

### 9.5 Design for Manufacturability

Part of the problem statement was to make a system capable of passive and active assay for anyone that requires it. This means that this system could potentially be used by anyone all over the world. This requires that the construction of the mechanical mechanism needs to be easily repeatable and allow for interchangeable parts.

To combat this, the frame was designed based using common materials (6061 Al and basic hinges/bolts) and an assay that is readily available through Canberra. The aluminum frame is to be welded together, which does require special equipment as it is not the same system as one would use for steel, but this system is still readily available for purchase and the method between the two is the same. All parts can be purchased through the vendors mentioned previously, and they assembly and user process will be thoroughly described in the final SOP.

# 10 Project Specific Details and Analysis

The Project Specific Details and Analysis is information that applies directly to the design. This is divided into two sections: the nuclear device chosen to build the design around and the motor to drive the linear motion system. These define and constrain the system requirements and affect how it is designed and fabricated.

## 10.1 JCC 71, 72 and 73

The NDA product chosen to help solve the problem has a significance impact on the mechanical system that will be implemented. This product is selected based on the criteria seen in section 6 Specifications Definition. This product exceeds the specifications set and is able to be implemented into a mechanical system. The NDA is actually three similar Canberra products called JCC 71, 72, and 73. LANL already employs these items to do certain assays. The data sheets for this product and it's accessories can be found in Appendices D. The JCC 71, 72 and 73 is a passive and active neutron coincidence collar. This accomplishes the first two design requirements with being a neutron coincidence counter and having the capability of doing both passive and active assaying. Passive assay is a way of measuring radioactive material by recording spontaneous fissions. Plutonium is the most common atom to be passively assayed. Active assay uses a neutron source such as Americium Lithium (AmLi) to induce fission in the radioactive material. This type of assay is common in measuring Uranium-235. In order to incorporate both types of assay, the JCC 71, 72 and 73 operates with He3 tubes to measure radioactivity. The current device uses four slabs made of aluminum cladding that contain six He-3 tubes each surrounding the radioactive material for the passive assay. The dimensions of the slabs are 3.55 inches wide, 9.20 inches long and 20.3 inches tall with a weight of 21 pounds or 9.5 kilograms each. The plan is to incorporate six slabs in the design which would equal approximately 126 pounds total in weight of the neutron device. The assay can be can be transformed from passive to active by exchanging a He3 slab for an active source such as AmLi integrated in these devices. The AmLi source is surrounded by a high density polyethylene.

The efficiency of the neutron coincidence counters is an essential to the product. The amount of neutrons the device detects for the number of neutrons emitted from the radioactivity material is essentially the efficiency of the machine. This is demonstrated from a simple nuclear engineering calculation. The probability of neutrons detected is calculated from the following equation:

$$P = \frac{n!}{(n-k)! * k!} * \epsilon^k * (1-\epsilon)^k \tag{1}$$

Where k is the neutrons detected from the amount of neutrons emitted, n, using the efficiency of the machines, $\epsilon$. The equation is plotted for the percentage of neutrons detected from 0 to 100 for the efficiency of each machine. The number of neutrons used in the calculation is found from the maximum activity of 100 nCi/g that the drum may contain. This is converted to 3700 decays per second per gram from a conversion factor then assumed there exists one gram of radioactivity for each plot. Even though the odds of detecting a neutron are low, this is for only one second and the probability will increase by a multiplication factor of the number of seconds. These plots demonstrate that the highest odds of detecting a neutron is a bell-curve around where the percentage of neutrons detected is equal to the efficiency of the machine.

When talking to Canberra, it was acknowledged that the efficiency of the device is directly proportional to the amount of He3 tubes. The efficiency is also dependent on how close the slabs are positioned to each

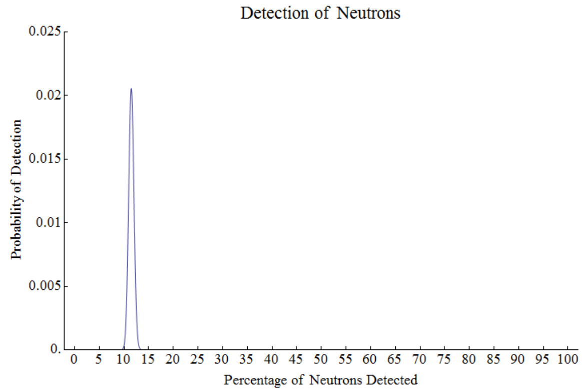



Figure 26: The Passive Efficiency of JCC 71

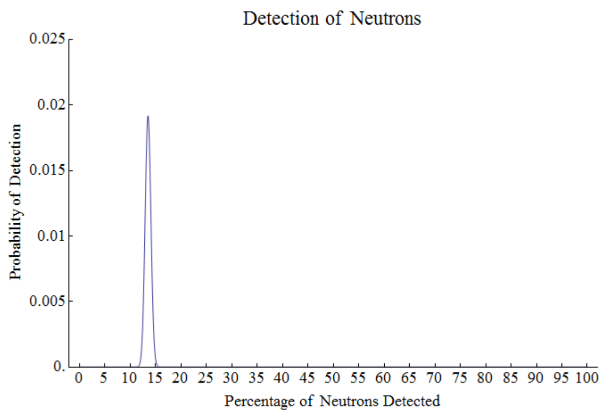



Figure 27: The Active Efficiency of JCC 72

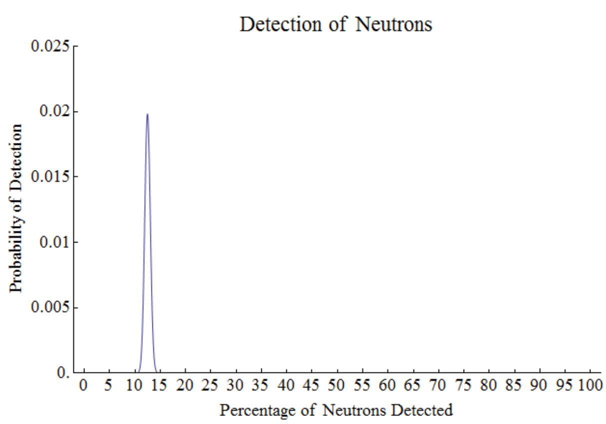



Figure 28: The Active Efficiency of JCC 73

other even they have the ability to be spread out in order to surround the nuclear material. The JCC 71 has a passive efficiency of 11.5%, the JCC 72 has an active efficiency of 13.5% and the JCC-73 has an active efficiency of 12.5%. These are the current theoretical efficiencies of the product, however the real efficiency is unknown for how the devices with be placed in the mechanical device. The efficiency will increase due to adding two more slabs but will decrease from the space between the slabs.

The JCC 71, 72, and 73 utilizes a computer software called JSR-14 and NDA 2000 that simplify the device. The JSR-14 is a Canberra product known as a neutron analysis shift register based. The device combines traditional coincidence counting with multiplicity coincidence capabilities. The fully computer controlled product has an easy to learn supplied control software for setup and acquisition. This product has three different high voltage modes for portable and facility installed neutron counting applications with a battery backed storage of system setting and 3000 data runs. The NDA 2000 is another Canberra product called Non-Destructive Assay software. Neutron counters and gamma-ray systems can both operate with this software which is supportive of all of Canberra safeguards. The product provides full control of data acquisition and controls automated assay system operations. This system is user-friendly with its menu structure and editable report format. The passive assay and active assay both use the MGA/MGAU Isotopics Analysis.

## 10.2 Actuator

For the linear motion device, the actuator that fits for the major requirements of the design was the DMA-12-40-B-610-POT-IP65. This would allow for the full range of motion for the device with 24” stroke. The large gear reduction in the design does slow the velocity of the lifting slightly but this consideration falls low on the list of major considerations and will not affect the total assay time enough for reconsidering the motor. The total thrust the device can output is 1563 lbs with a far higher static holding force. This gives the actuator more than enough force to lift the collar. This actuator comes with a potentiometer that allows the control of the positioning within a margin of less than a tenth of an inch. The life of the motor is a total of around 3300 process cycles. The full data sheet on the actuator is located in Appendix G. With these parameters met to a great satisfaction, it was determined that this product would fit well into the system.

# 11 Detailed Product Design

The detail product design is where the conceptual design is refined to include plans, specifications and estimates. This phase contains bill of materials and three dimensional drawings for the product. The final design concept was decided upon with careful consideration of the problem using design specifications and quality function deployment. The design specification set limits and goals for the product to reach while the QFD encompasses comparison analysis between the conceptual designs and the needs of the customer in relationship to the requirements of the product. The design consists of a mechanical system to assay nuclear waste in the glovebox line with the implementation of already existing NDA devices.

## 11.1 Full Scale Design

The full scale design is the system that will be applied to the glovebox system upon approval. This section discusses the materials, building process and three-dimensional drawings for the final product. The bill of materials displays the raw materials and amount necessary to complete the design while the Sub-Assembly section considers the manufacturing of the product. The drawings provide dimensions and a clear picture if the building of the product moves forward. However, the full scale design was unable to be completed this semester. The half scale prototype built this semester is explained in section 11.2.

### 11.1.1 Bill of Materials

The bill of materials is a list of raw materials, parts, quantities and sub-assemblies needed to manufacture the final system. It is necessary to plan how much raw material will be required to produce the design to avoid over or under ordering. Materials are properly considered to evaluate whether they can be applied to the final design. The raw material list is seen in table 8.

Table 8: Bill of Materials for Full Scale Model

| QTY | Raw Material | Dimension | Supplier | Part # | Assembly # |
|---|---|---|---|---|---|
| 4 | 6061 Aluminum Angle Stock | 8' L by 2" W by 0.125" T | McMaster-Carr | 8982K14 | 1,3 |
| 1 | 6061 Aluminum Angle Stock | 4' L by 2" W by 0.25" T | McMaster-Carr | 8982K36 | 2 |
| 2 | Mortise-Mount hinge w/ bearing & removable pin | 4" leaf height 4" W | McMaster-Carr | 1502A52 | 5 |
| 100 | 12-24 Stainless Steel Philips Flat Head Screws | 5/8" L 12-24 thread | McMaster-Carr | 91771A293 | 5 |
| 100 | Low-Strength Steel Thin Nylon-Insert Locknuts | 12-24 thread | McMaster-Carr | 90633A011 | 5 |
| 8 | Multipurpose 6061 Aluminum Bar Stock | 24" L by 2" W by 0.25" T | McMaster-Carr | 9015T131 | 4 |
| 2 | Grab-Latch | 1 7/8" W by 5/8" L | McMaster-Carr | 1659A7 | 5 |
| 2 | Base Shaft Alloy Steel | 1.5" | Lee Linear | Custom | 6 |
| 4 | Open Pillow Block | Ball Bearing Single Roller | Lee Linear | SPB240PB | 6 |
| 1 | Carriage Plate | 13"L by 13"W | Lee Linear | T150 | 6 |
| 1 | Ball Screw | 1" OD by 1" pitch by 24" L | McMaster-Carr | 5966K31 | 6 |
| 4 | Support Block | 1.5" OD | Lee Linear | SB24 | 6 |
| 1 | DMA Linear Actuator | 24.02" range 787 lbs thrust | Transmotec | 11014138 | 6 |

The first two materials on the list are different thicknesses of 6061 aluminum angle stock. The material of the angle stock is very important because of the desire for the material to have a relatively high yield strength without having an excessive weight. Stainless steel and zinc alloy could not be considered due to the negative influence it can have on the efficiency of the neutron coincidence counter. Aluminum has a relatively high ultimate tensile strength and yield strength especially for its low density. The machinability and weldability of aluminum is included in the decision to incorporate it in the design.

The angle stock provides an important feature to the design. The ability to create a custom dimensioned U-channel by machining the angle brackets parallel to each other is important. The inside of the channel needs to be a proper size to correctly fit the nuclear devices. One angle bracket can be ground down to within the tolerances that would properly constrain the neutron coincidence counters. The angle brackets can then be bead welded along the groove to ensure the strength of the system.

The sizes of the angle stock are 2 inches by 2 inches wide and 8 feet long for the thickness of both 1/8 inch and 1/4 inch. Since the majority of the product will be built with 1/8 inch thick angle stock, it was calculated to need four of these pieces. The estimated amount material for the product is from the dimensions of the final drawings on SolidWorks. Essentially the entire structure will be made with the 1/8 thick aluminum angle stock in order to minimize the weight and cost of the structure. The 1/4 inch angle stock is larger in thickness to support the structure on the free ends on the side with the hinges.

There will be two Mortise Mount hinges with bearings and removable pins applied to attach the two halves. Each hinge has a load capacity of 125 pounds. The dull-chrome plated steel hinges have a leaf height of 4 inches, a width of 4 inches and eight holes for number twelve screws. The screws were then chosen to be number 12-24 stainless steel Philips flat head screws to work with the hinges. These machined screws are

5/8 inches long with a yield strength of 80 ksi and will be applied to other areas of the design because of their versatility. The nuts that correspond with these 24 threads per inch screws are low-strength steel thin nylon-insert locknuts.

The 6061 aluminum bar stock is 2 inches wide and 0.25 inches long for support of the system. The first four bars will be for the inside prop of the top bracket to prevent bending. The bars should have thickness to prevent bending and a height of 20.3 inches to allow the nuclear devices clearance. The next four bars will be welded to the back face of the fixed half of the hexagon. These will be from the bottom to the top of the system with a height of 20.6 inches to allow for an area for attachment of a linear motion device.

The final material necessary to building the hexagon slab holder is two grab latches. These will help secure the system on the mirror side of the hinges. The grab latches will attach to both halves of the hexagon to prevent it from swinging open. This will allow for a safe system while the drum is being assayed.

A pivotal piece to the end product is the ability to measure the entirety of the drum's height. In order to enable this the hexagon slab holder will need to be attached to a linear motion system. These next six parts are essential for the vertical movement of the device. The first raw material needed is two custom height alloy steel base shafts. These 39 inch shafts will allow for the system to be secure at different levels while taking measurements. The shafts will be the support for the linear motion system. The four support blocks will secure these shafts to the ground and to the glovebox. These support blocks will fix the shaft in a vertical position to prevent movement.

The next three materials are essential to the movement along the shaft. The pillow blocks are sliding along the shaft driven by the ball screw. Each shaft will have two pillow blocks to lift the entire weight of the structure. These pillow blocks are associated with a carriage plates to attach to the hexagon slab holder. The 13 by 13 inch carriage plate is chosen to best fit the size of the system. The ball screw will attach to the carriage plate in order to lift the system. The ball screw is the driving mechanism in the linear motion.

The linear actuator is the motor putting work on the system. This was difficult to find a linear actuator with enough torque to lift the device. The torque required was about 2500 pounds inches. The motor has a thrust of 787 pounds which is enough to drive the system with a factor of safety. The machine selected is described in section 10.2.

#### 11.1.2 Sub-Assembly

The product being built is complex and difficult to combine without sub-assemblies. These sub-assemblies will be manufactured and accumulated to create the final product. For simplicity reasons, the parts were broken down as to how they will apply to the building of the product seen in Table 9 and Figure 29.

Table 9: Sub-Assembly List

| Assembly # | Sub-Assembly | QTY | Part # involved | Description |
|---|---|---|---|---|
| 1 | Bottom U-Channel | 2 | 8982K14 | Cross Section of Hexagon |
| 2 | Inside Support Bars | 4 | 9015T191 | |
| 3 | Top Bracket | 2 | 8982K14 | |
| 4 | Hinge Support | 2 | 8982K36 | |
| 5 | Drive System Support | 4 | 9015T131 | Area to attach vertical drive system |
| 6 | Hinge | 2 | 1502A52<br>91771A293<br>90633A011<br>1659A7 | Connection of two halves of Hexagon |
| 7 | Vertical Drive System | 1 | Custom<br>SPB24PB<br>59666K31<br>SB24<br>11014138 | Allows for vertical movement of the system |

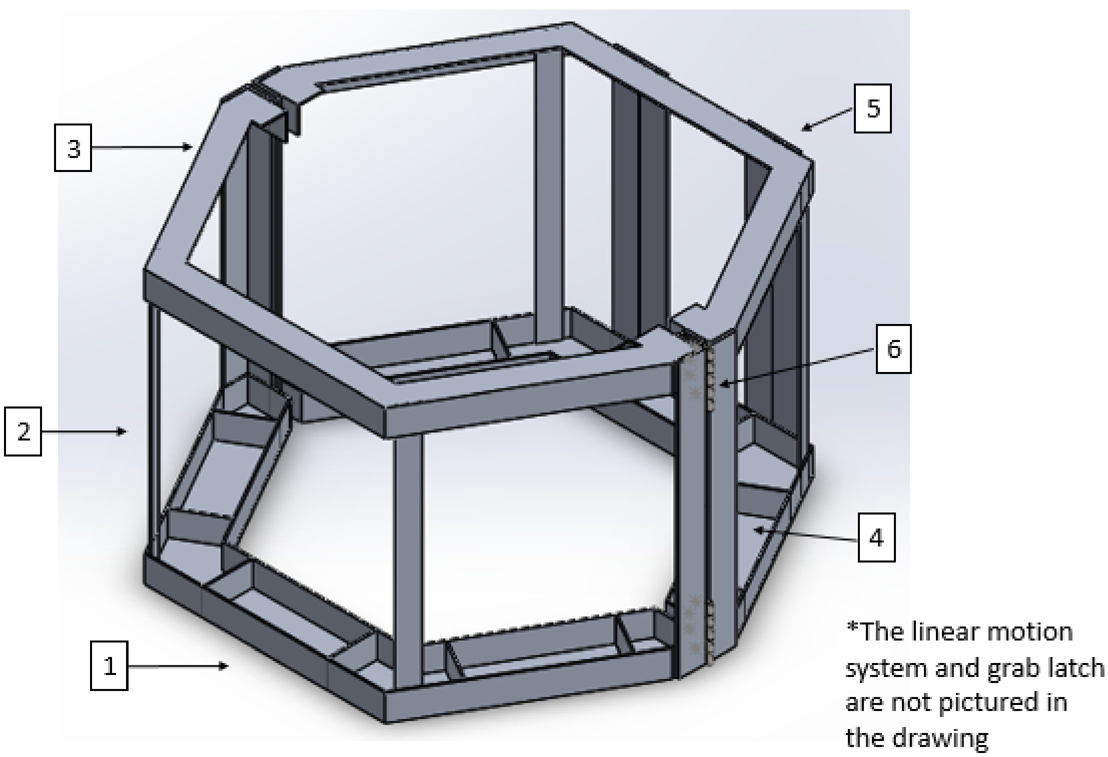



Figure 29: Sub-Assembly List

The first piece assembled is the bottom U-channel made from 1/8 inch aluminum angle stock. This section will be half of the complete hexagon built by welding three pieces together. Each individual piece is already bead welded to create a U-channel the width of 3.60 inches and cut to the correct length for the inside and outside diameter. These dimensions are displayed in the drawings in section 11.3 Two 1/8 inch stock will be welded to each prior to the sub-assembly in order to generate a 9.25 inch long pocket for the neutron coincidence counters. There will be two of these bottom U-channels manufactured to create the final product.

Once both of the bottom halves of the hexagon are built, it becomes time to begin construction up. The first step is by welding 20.35 inch aluminum bars to the inside vertexes of each U-channel. The top bracket will be welded together using the dimensions seen in section 11.3 and then welded to the support bars to connect the top and the bottom. The final step to creating both halves of the hexagon is to weld the angle stock support bar to the adjacent free ends that will be connected by the hinge.

The drive system support is welded to the cross section that will ultimately be fixed. This support is two pairs of bars, where the paired bars are adjacent, with the necessary distance for the carriage plate and evenly spread out from the edge.These welded bars allow for area to interrogate a linear motion system.

The hexagon design is assembled by using the two hinges, Philips flat head screws, and locknuts. There will be one hinge coincident with the bottom of the system and the other hinge coincident with the top. There will be 0.23 inch holes drilled through each half where the screws will be inserted. There will be a total of 16 flat head screws and 16 locknuts to attach both halves of the mechanical design.

The next sub-assembly is the linear motion system. The two shafts will be applied to the glovebox using the support blocks. The support blocks will fasten to both the ground and the glovebox to stabilize the shafts. The pillow blocks are concentric to the shafts to be able to slide along them. The shafts will have two pillow blocks each that hold a 13 by 13 carriage pillow. This carriage pillow will be screwed into the hexagon slab counter to enable the vertical movement of the system. The carriage pillow will also have the ball screw through it to drive the entire system. The linear actuator will be connected to the ball screw to motorize the system. Linear movement in the system will be guided by the ball screw which is powered by the linear actuator.

#### 11.1.3 Three-Dimensional Drawings

The product being built needs to be applicable to the glovebox line at LANL. This means the glovebox dimensions have a great constraint on what can be applied to solve this problem. As mentioned before, the dimensions of the glovebox are 160 inches long by 60 inches wide by 100 inches tall with a clearance of 39 inches underneath. These are all rough approximations considering the exact dimensions are classified. In order to better picture this, there is a three view drawing of the glovebox below with tolerances of 1 inch since the dimensions are only estimates (Figure 30).

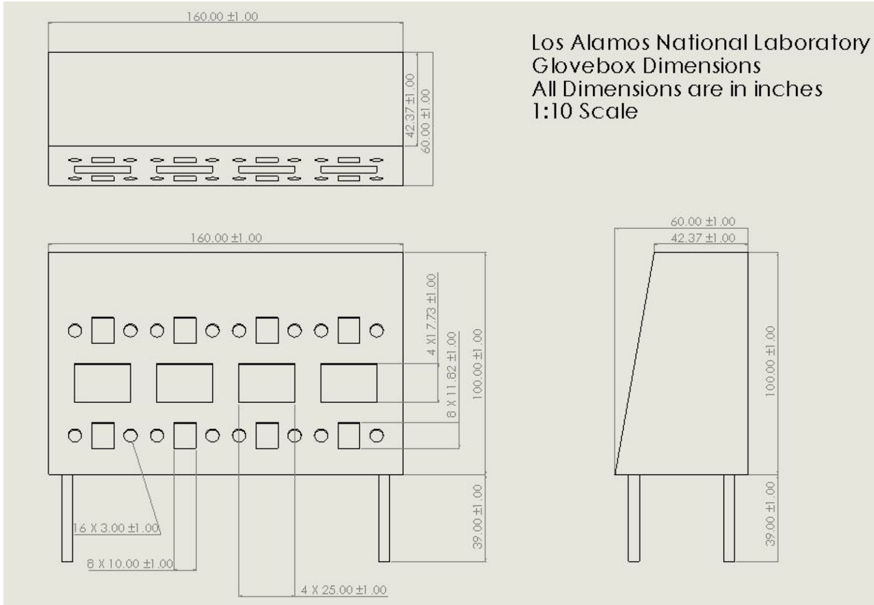



Figure 30: Dimensions of the LANL Glovebox

The devices decided upon for the radioactive waste assay has a substantial impact on the mechanical system. The products are Canberra neutron coincidence counter chosen to accomplish the essentials of LANL described in-depth in Section 10. As described before, these products, the JCC 71, 72 and 73, are 9.20 inches long, 3.55 inches wide and 20.3 inches tall. The design incorporates six of these devices to counteract the efficiency lost by the spacing of the device. The mechanical design is a hexagon shape to enable a neutron coincidence counter or source to fit on each side while still being able to surround the drum. The bottom of the system has an area representing a pocket for each device to securely fit. These pockets are 9.25 inches long and 3.60 inches wide with a height of approximately 2 inches to enclose the product. The inside of the hexagon has a diameter of at least 24 inches to install around a standard 55 gallon drum. A 3-D drawing of the dimensions and tolerances of the bottom of the structure is shown in the Figure 31.

The hexagon design is split in half perpendicular to two of the vertexes. The reason for splitting the device is to allow it to be opened and closed. Applying hinges to the top and bottom is the most efficient way to consistently open and close the system. The bottom of the product supports a top hexagon bracket that is 20.35 inches above. There are four 0.25 inch thick and 2 inch long supports offset from mirroring corners to help hold the top. The top is well supported with 2 inch long and 0.25 inch wide angle brackets from top to bottom on the ends of each half with the hinges. These angle brackets allow for more surface area to bolt the hinge. The cross section of the hexagon or half of the hexagon assembly can be seen in drawings in the Appendices.

This top bracket is set to be the same outside diameter of the bottom hexagon with a 2 inch overhung inwards. The function of the top bracket it to better secure the nuclear products from tipping over when the system is opened. The system is only 20.60 inches tall which is the reason for a vertical movement requirement. SolidWorks Drawings are provided in the figures below for a visual understanding of the design (Figures 32, 33, and 34).

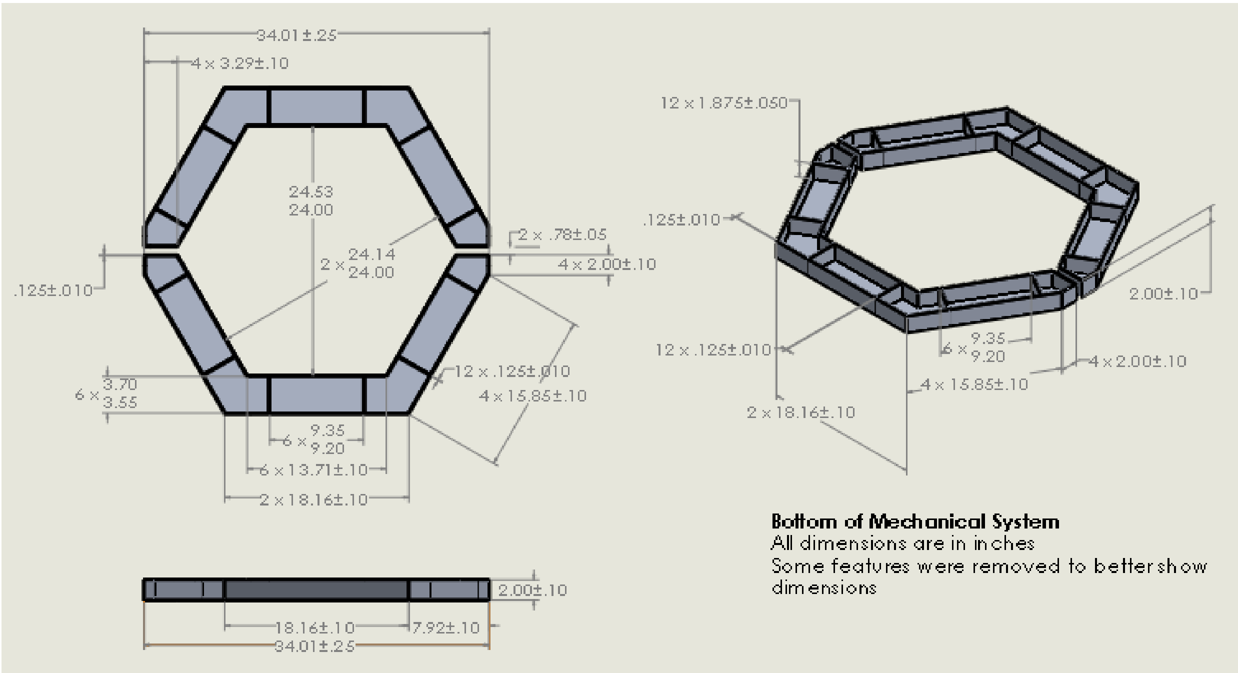



Figure 31: Dimensions of the Bottom of the System

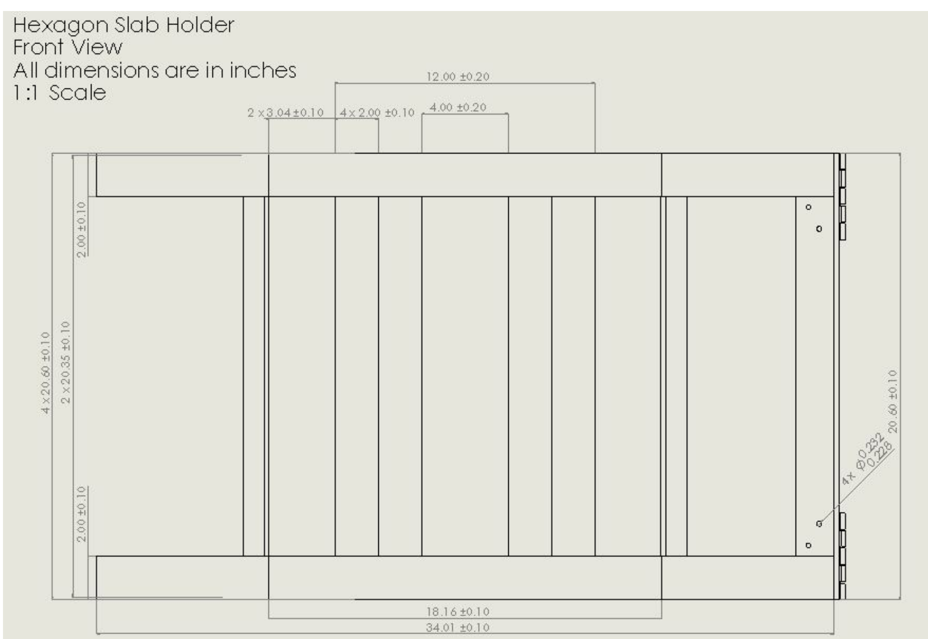



Figure 32: Front View of the Hexagon Slab Holder

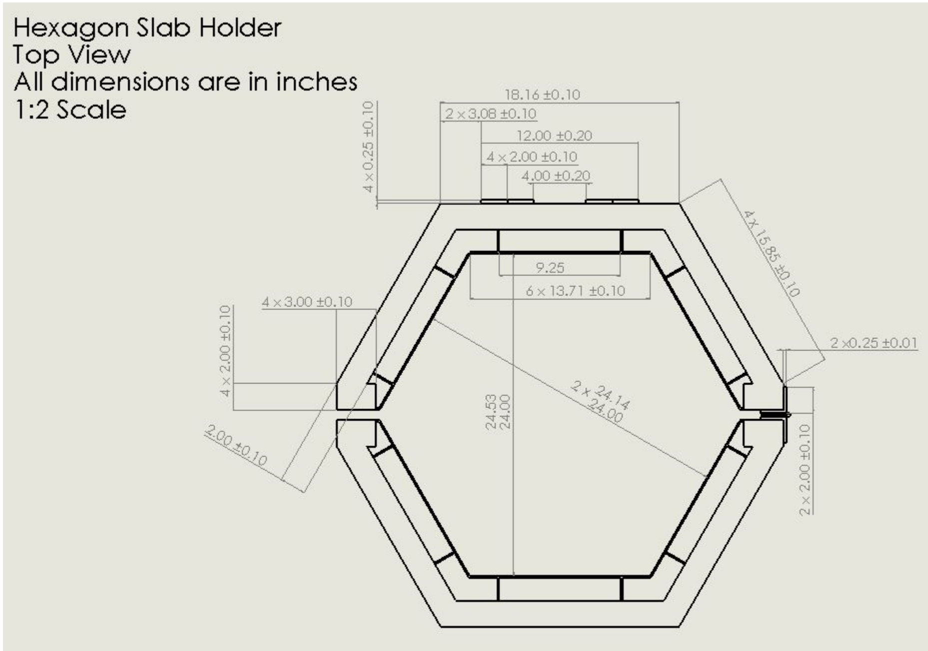



Figure 33: Top View of the Hexagon Slab Holder

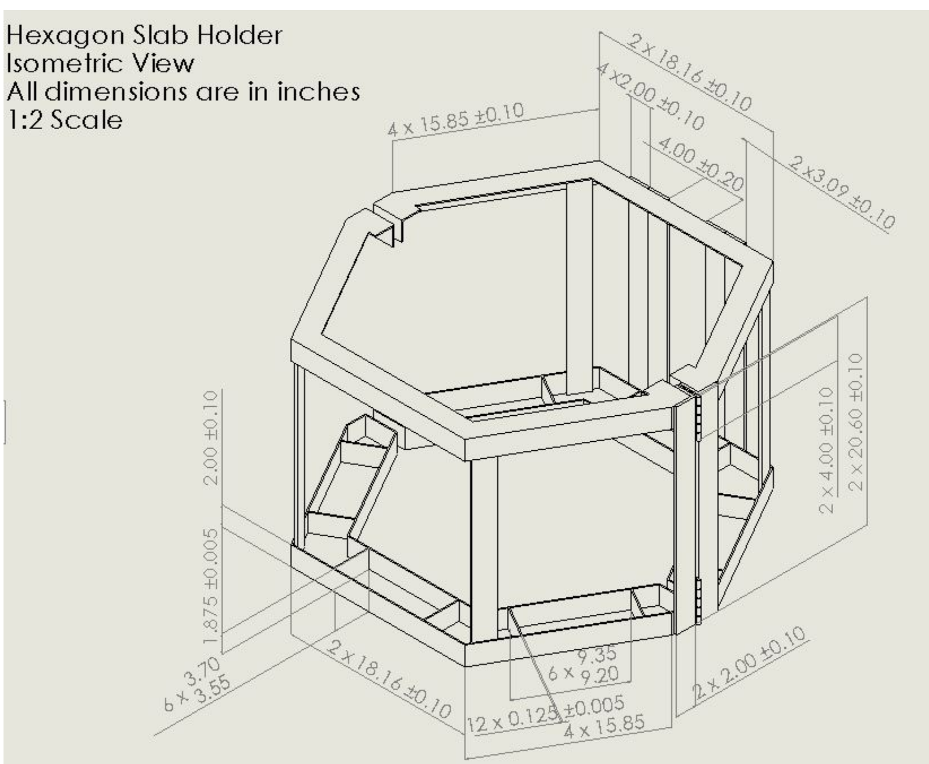



Figure 34: Isometric View of the Hexagon Slab Holder

## 11.2 Half Scale Prototype

The half scale prototype was developed this semester to evaluate the legitimacy of the design. The prototype, however, incorporated many different materials than the full scale model. The design altered slightly with dimensions but for the most part was a half scale representation. These changes required a new bill of materials and more three-dimensional drawings for the scaled down model. The building of the design is discussed in Section 14.

### 11.2.1 Bill of Materials

The raw materials that contributed to the manufacturing of the prototype were chosen due to the lower cost and easier manufacturability with the current resources. The main distributors for the materials were Arnold Lumber, Amazon, and McCaster-Carr. The bill of materials for the half scale design can be seen in Table 10. Even though these supplies were utilized to build the prototype, it is still expected the full scale design to be constructed with the materials in Table 8.

Table 10: Bill of Material for Prototype

| QTY | Name | Dimension | Source | Part # |
|---|---|---|---|---|
| 1 | Plywood | 4'x8'-1/4" | Arnold Lumber | N/A |
| 2 | Wood Screws | 3/8" | McMaster-Carr | 90031A108 |
| 1 | Wood Glue | Quart | Amazon | 6205001 |
| 1 | Hinge | 1/2 | Arnold Lumber | 5031176 |
| 1 | Television Lift | N/A | Amazon | B01K1SG220 |
| 6 | SS Cap Screw | 5/16x1 | Arnold Lumber | C84139 |
| 6 | SS Flat Washer | 3/8 | Arnold Lumber | C84121 |
| 6 | SS Hex Nut | 5/16-18 | Arnold Lumber | C84115 |
| 6 | Cap Screw | 1/4x1-1/2 | Arnold Lumber | C80189 |
| 6 | Cap Screw | 1/4x1 | Arnold Lumber | C80185 |
| 1 | XL-FX PHIL WS | 12x1 | Arnold Lumber | C40850 |
| 1 | Spruce Lumber | 2"x4"-12' | Arnold Lumber | 2412KDS |
| 1 | Putty Knife | 1-1/2" | Arnold Lumber | 443600 |
| 1 | Spackle | Quart | Arnold Lumber | 7172 |
| 2 | Gray Spray Paint | Can | Arnold Lumber | 441622 |
| 1 | Aluminum Sliders | 4 pack | Amazon | xudhc8264 |
| 2 | Aluminum Rods | 30" | Amazon | BC20762-2 |
| 2 | Linear Rail Support | 2 pack | Amazon | a15120700ux0413 |

The structure was built using  inch plywood. The amount of plywood bought was a four foot by eight foot sheet which provided some excess after completion. The wood for the whole structure was significantly cheaper than the aluminum for the full scale structure. The wood was able to be dimensioned and cut using the band saw and table saw. Easy construction and assembly was another upside of using plywood.

The structure was connected with the help of wood glue and 3/8 inches long wood screws. The wood is first assembled into the appropriate connections with the wood glue before eventually screwing the pieces together for an added security. Neither the quart of wood glue nor the hundred wood screws were fully used in the half scale prototype.

The hinge packet from Arnold Lumber came with two  inch hinges with appropriate screws. The hinges were used on one side of the structure to attach the two halves. This enables the device to open and close with ease.

The lifting mechanism of the half scale prototype was a repurposed television lift from Amazon. The mechanical lift system in the full scale model was not necessary for the half scale model since the weight and moment of the system both significantly decreased. This was because of the half scale as well as the significantly lower density of plywood compared to aluminum. The television lift has a load capacity of 135 pounds which provides a factor of safety of over 2 for the designed weight. The device also has a built in control system to lift the structure to the maximum height in under ten seconds.

Bolts, nuts and washers were needed in order to connect the structure to lift. Six SS Cap Screws, six SS Hex nuts, and six flat washers were bought from Arnold Lumber for this purpose, however, only four of each were needed in the connection. The structure was mounted to the frame of the lift by adding two bars the height of the structure to allow for proper assembly.

The next set of screws attached the television lift to a wood base. This purpose is to stabilize the lift on a stand with a bigger surface area. The bigger surface area on the ground would limit the possibility of the whole system tipping over.

The spruce lumber and package of Philips head screws were used to better our design. The half scale structure is already being held in the air when connected to the television lift. The full scale mechanical lift system raises the structure from the bottom of the floor to the bottom of the glovebox. The spruce lumber along with extra plywood and the wood screws created a mock floor and bottom of the glovebox for the structure. This gave an appeal that the scaled down system was operating as designed for the full scale system.

The putty knife, spackle, and spray paint aesthetically improved the wood structure. The manufacturing using wood proved to be challenging for cutting appropriate angles. The spackle was spread using the putty knife in order to help cover any errors in the building process. The spray paint gave the structure a uniform gray color to project as the designed material of aluminum.

The last items on the bill of materials are the two 30 aluminum rods, four sliders and four rail shaft support systems. These are linked to the structure on the side fixed to the lift to add support to the mechanical lift. The sliders are attached to a wood bar that ranges the full height of the structure on either side. The sliding system is installed from the mock floor to the bottom of the mock glovebox. The rod is kept in place by the rail shaft support systems. This system counteracts the moment on the structure due to the weight of the nuclear devices and gravity.

### 11.2.2 Three-Dimensional Drawings

Three-dimensional drawings are necessary for the easy dimensioning in the building of the prototype. The design is the same layout as the full scale model set. Almost all the dimensions are half of the original design. The major difference is the full scale model has a thickness of 1/8” while the half scale has a thickness of double that at 1/4”. The design has a different layout with two extra bars on one half to allow for the slider system to be connected.

The isometric view of the design best demonstrates the structure. This can be seen in figure 35.

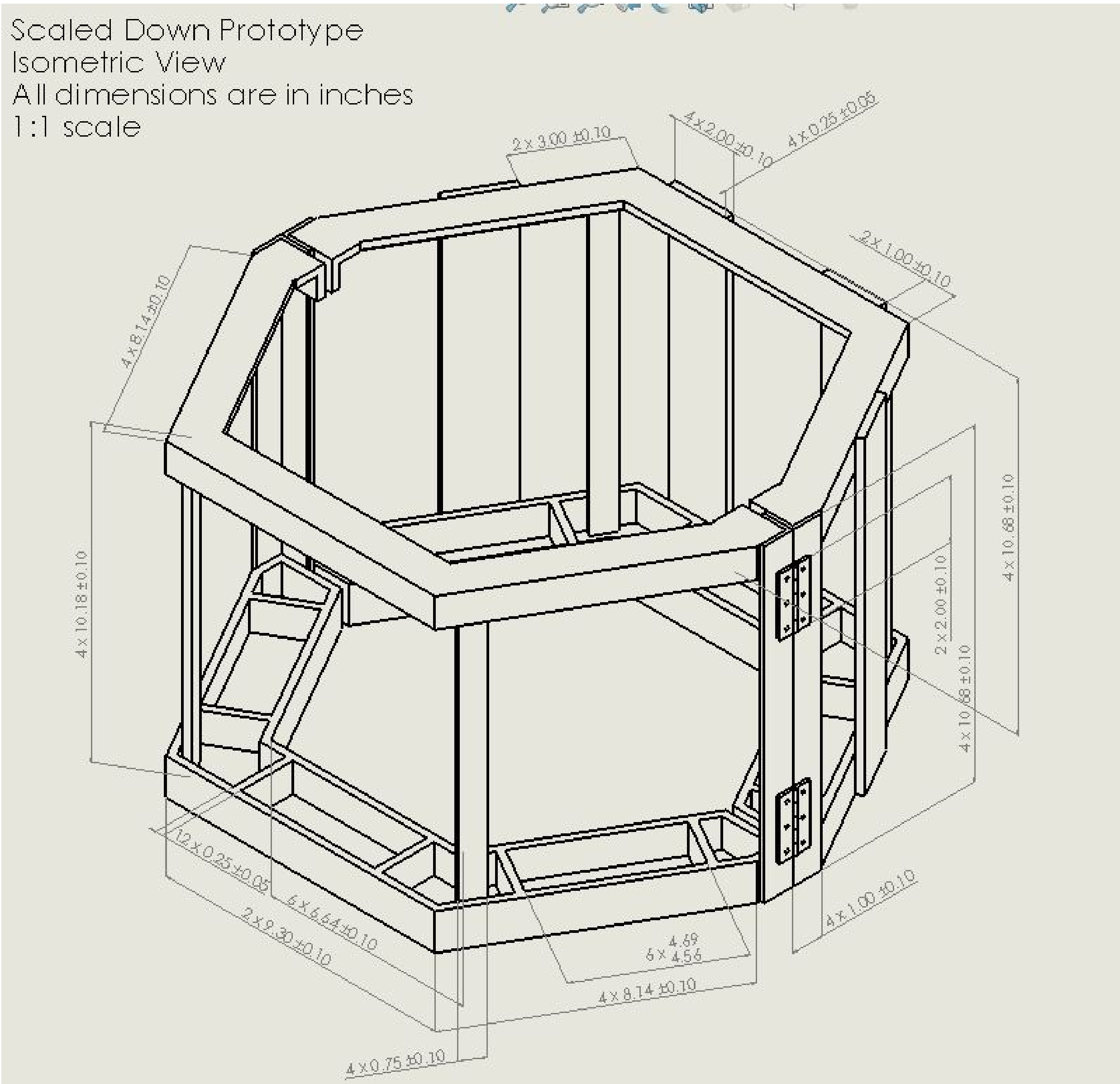



Figure 35: Isometric view of the half scale prototype

The bottom of the the structure gives a clear picture of the slots designed for the nuclear system. The dimensions of the bottom are shown in Figure 36.

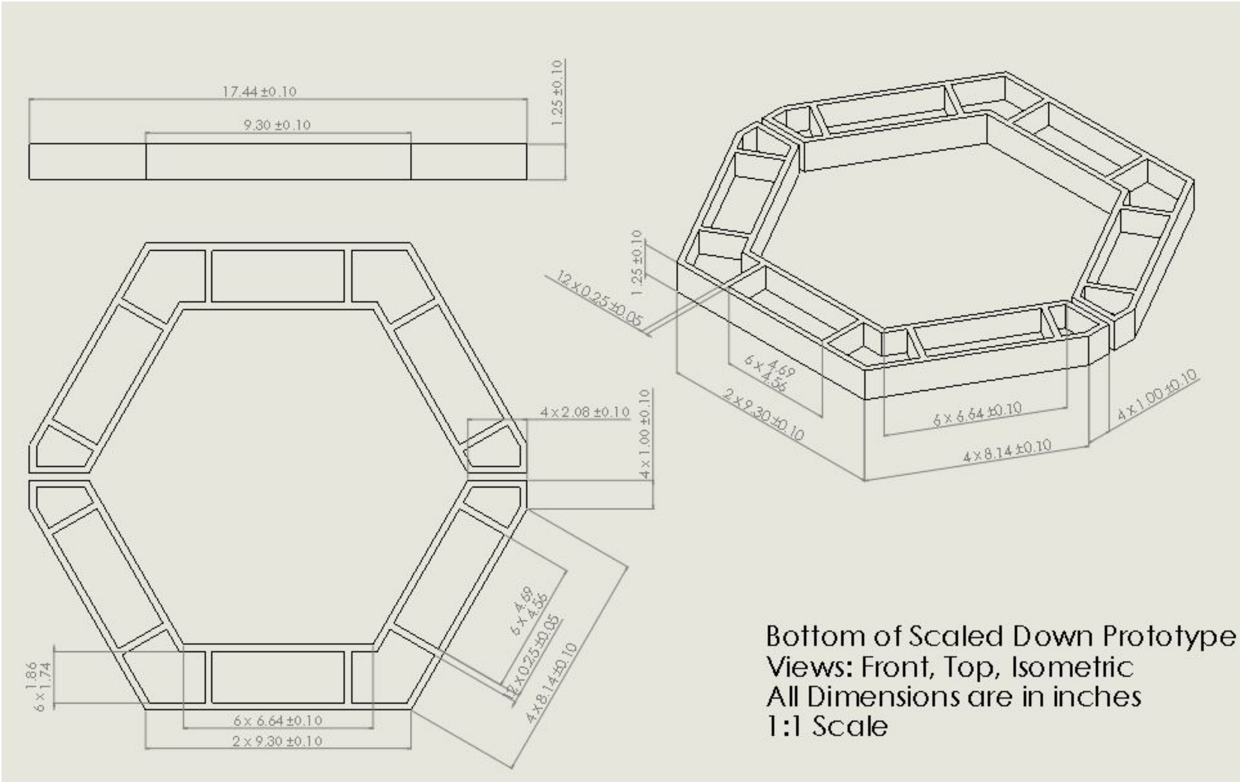



Figure 36: Bottom of the half scale prototype

The top and back view of the structure were dimensioned as well. These can be seen in appendices 23.3. The top view is figure 62 while the back view is figure 63.

# 12 Engineering Analysis

The engineering analysis completed in tis section is for the full scale model. The system designed is a hexagon that is symmetric along it's center in two directions. The hexagon is symmetric along it's width, the z-plane, and along it's length, the x-plane, as shown in Figure 37 with it's datum. The system will be driven by a ball screw and linear actuator on the back on the hexagon. Since the system is symmetric along both planes the moments will cancel each other out. This results in the system acting similar to a cantilever beam as seen in Figure 38. The forces on the beam will be acting at the center of mass of the hexagon which is 6.77 inches above the ground. This is determined because the bottom of the hexagon has double the material as the top therefore the center of mass is one third of the height from the bottom.

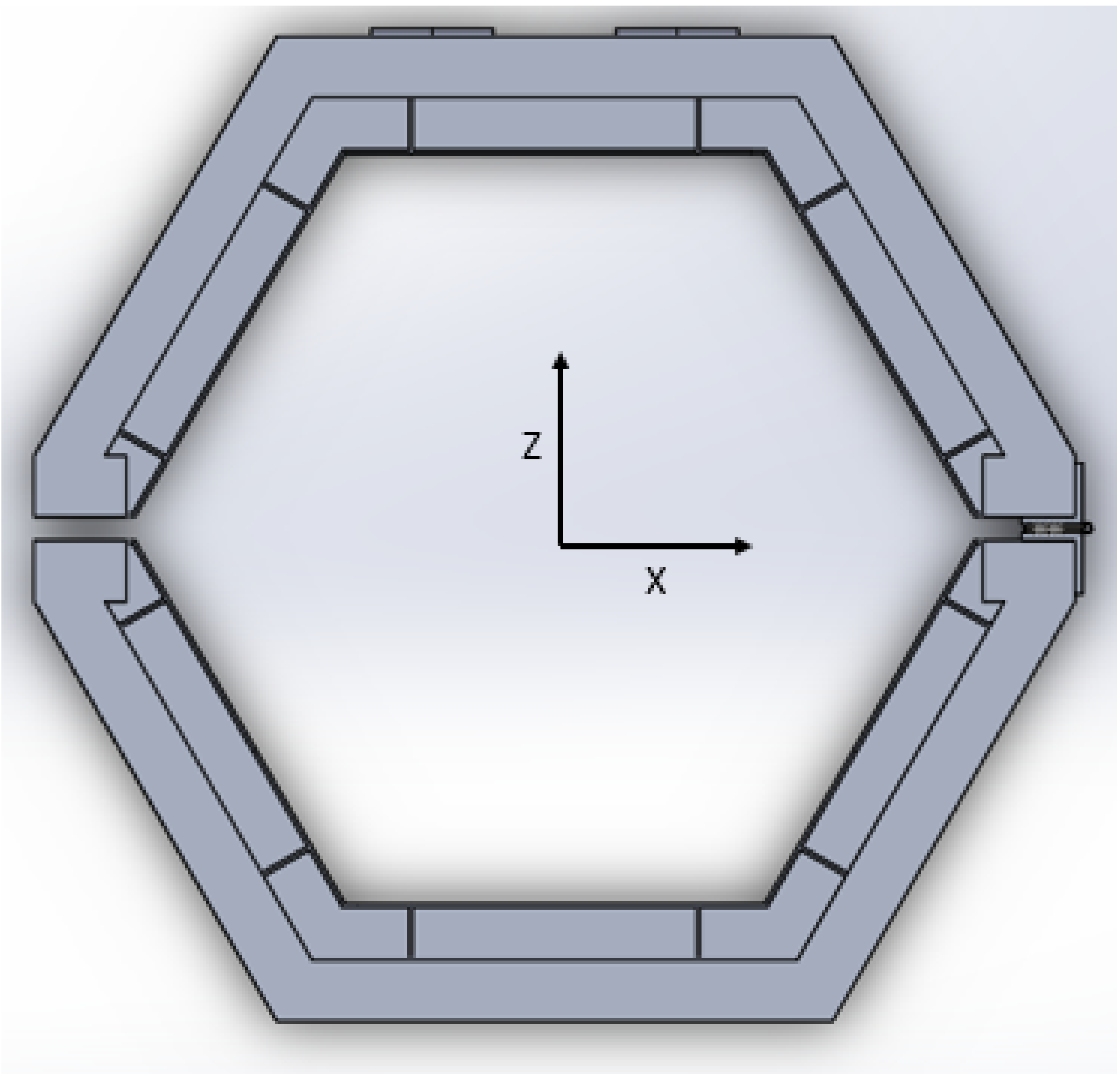



Figure 37: Definition of Coordinates of the Assembly

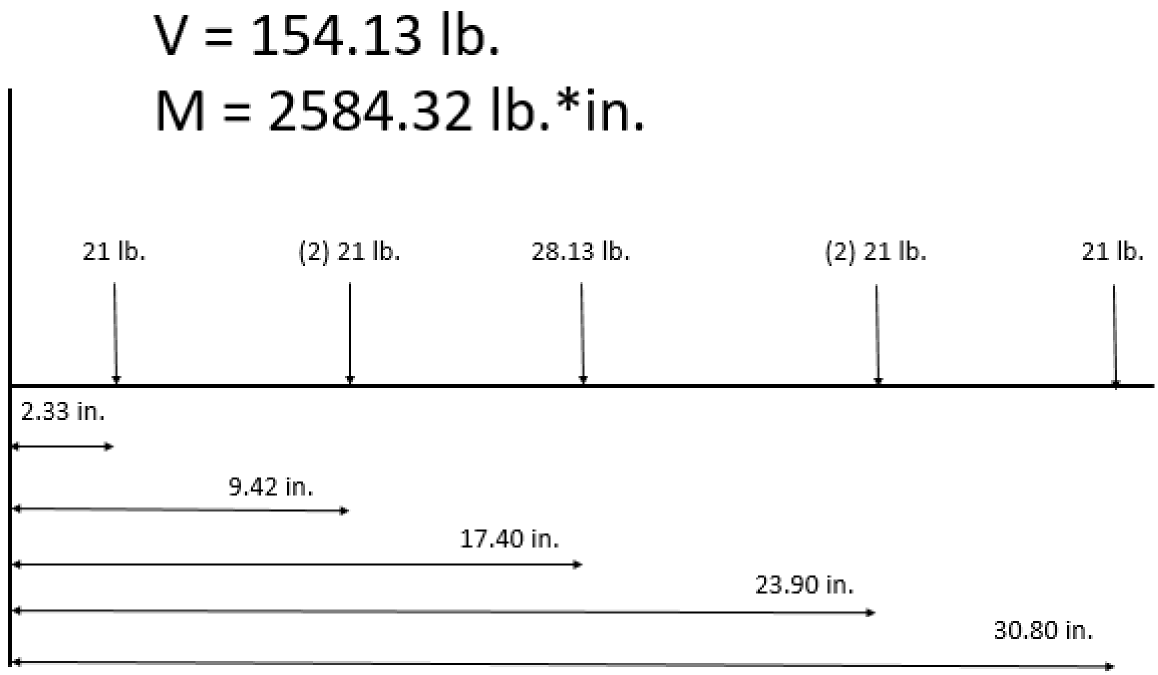



Figure 38: Forces on the Hexagon Slab Holder

The shear force, V, and moment, M, on the beam can be calculated from this diagram. The 21 pounds represent the force from each slab and the distance from the fixed point is displayed underneath the beam in inches. The two in front of the 21 pounds is when two slabs are positioned in the same distance away from the fixed point. The weight of the system is 28.13 pounds, recorded from SolidWorks, directly through the center. The moment of the fixed point is found from the force multiplied by the distance from the fixed point. The calculations can be seen below.

$$V = 21 + (2 * 21) + 28.13 + (2 * 21) + 21 = 154.13 lb.$$

$$M = (21 * 2.33) + (2 * 21 * 9.42) + (28.13 * 17.40) + (2 * 21 * 23.90) + (21 * 30.80) = 2584.32 lb. * in.$$

## 12.1 Carriage Plate Bolts

The carriage plate will secure the system while it is off the ground. There are eight bolts that will be fastened to the hexagon slab holder. The stress on the bolts needs to be tested to ensure the bolts will not yield. The centroid of the bolts is the direct center of the carriage block since the bolts are evenly spaced. The dimensions of the carriage block, the set-up of the bolts, and the distance the bolts are from the centroid can be seen in Figure 39.

The first stress on the bolt evaluation is the nominal stress from the moment. The bolts on the top are being pulled while the bolts on the bottom are being compressed. The force is not applied by a point load but instead by the downward moment. The force on the bolt is recorded from the distance the bolt is from the moment which is the center of the carriage block. The bolt shares the force with the amount of bolts in the same line. This is the equation used to find the nominal force on each bolt:

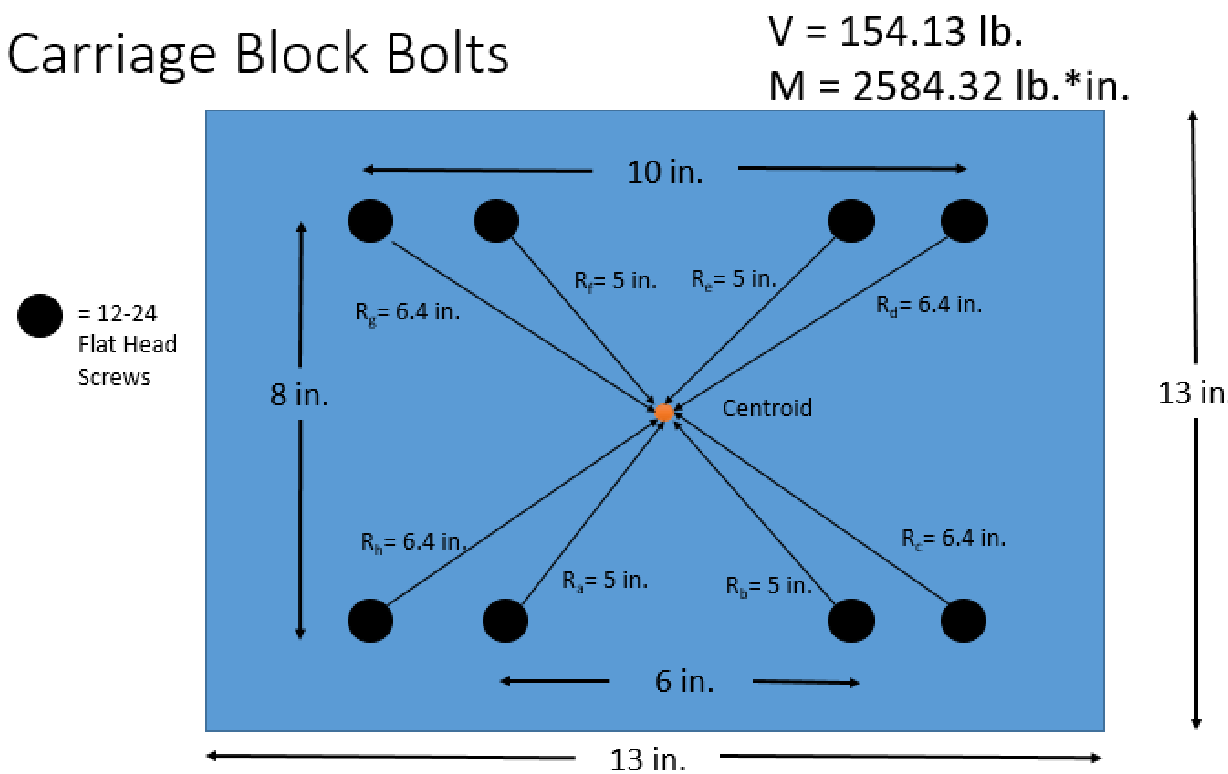



Figure 39: Screws on the Carriage Block

$$P = \frac{M}{y * N} \tag{2}$$

Where M is the moment, y is the distance from the center of mass of the hexagon and N is the number of bolts the force is applied to. In this case the moment is 2584.32 pounds inches, the distance is 4 inches since the carriage plate will be located at the center of mass, and there are four bolts taking the load.

The force causes the top bolts to be in tension which is represented by positive stress while the bottom bolts are in compression which is shown with negative stress. The stress is computed from the force and the area of the bolt. Each bolt has a major diameter of 0.215 inches which results in an area of 0.0363 inches squared. The nominal stress is calculated from the following:

$$\sigma = \frac{P}{A} \tag{3}$$

Where P is the nominal force and A is the area of the bolt.

The bolts undergo stress from shear as well. This shear stress is broken up into primary shear from the direct force and the secondary shear from the moment. The primary shear force is perpendicular to the object and distributed upon all the bolts shown by the following equation:

$$V' = \frac{V_{total}}{N} \tag{4}$$

that N is the number of bolts influenced by the total shear force, $V_{total}$. The primary shear stress is found similar to nominal stress. The primary shear force found in equation 4 is divided by the area of the bolt:

$$\tau' = \frac{V'}{A} \tag{5}$$

Where V' is the primary shear and A is the area of the bolt.

The secondary shear force is more involved than the primary shear. This shear is a resultant of the moment and the distance the bolt is from the centroid:

$$V" = \frac{M * r_h}{r_a^2 + r_b^2 + r_c^2 + r_d^2 + r_e^2 + r_f^2 + r_g^2} \tag{6}$$

Since $r_h$ is subjective, the distance of any bolt from the centroid can be multiplied by the moment, M, and divided by the summation of the remaining bolts' distances squared from the centroid expressed as $r_a, r_b, r_c$... and on. The secondary shear force is divided by the bolt area to find the secondary shear stressed displayed in equation 7

$$\tau" = \frac{V"}{A} \tag{7}$$

.

The primary shear stress and secondary shear stress are then combined from the following equation:

$$\tau = \sqrt[2]{\tau'^2 + \tau"^2} \tag{8}$$

Illustrating Pythagorean Theorem to compute the overall shear stress. The overall shear stress is thus evaluated from both the moment on a fixed object and the perpendicular force to the same object.

The Von Mises stress is the prediction of the yielding of materials influenced by from different loading conditions. This equation:

$$\sigma_v = \sqrt[2]{\sigma^2 + 3 * \tau^2} \tag{9}$$

Combines the nominal stress, $\sigma$ and the total shear stress, $\tau$, on the bolts. This stress is important since it acknowledges when the material will begin to fail. The materials yield strength, $\sigma_y$ can be divided by the Von Mises stress, $\sigma_x$:

$$FOS = \frac{\sigma_y}{\sigma_v} \tag{10}$$

To determine the load carrying capacity beyond the actual loads of the bolts. This is known as the factor of safety (FOS) determined from the yield strength of 80 ksi of the bolts.

Each bolt in the carriage block was evaluated for nominal stress, shear stress, and Von Mises stress and then given a FOS. The bolts are labeled in Figure 39 and the results are presented in Table 11. The calculations for the maximum stressed bolt is demonstrated in the Appendices. The bolts that experience the maximum stress are the bolts farthest away from the centroid.

Table 11: Carriage Block Bolts

| Bolt | $\sigma$ (ksi) | $\tau$ (ksi) | $\sigma_v$ (ksi) | FOS (-) |
|---|---|---|---|---|
| a | -4.45 | 1.58 | 5.22 | 15.31 |
| b | -4.45 | 1.58 | 5.22 | 15.31 |
| c | -4.45 | 2.11 | 5.76 | 13.89 |
| d | 4.45 | 2.11 | 5.76 | 13.89 |
| e | 4.45 | 1.58 | 5.22 | 15.31 |
| f | 4.45 | 1.58 | 5.22 | 15.31 |
| g | 4.45 | 2.11 | 5.76 | 13.89 |
| h | -4.45 | 2.11 | 5.76 | 13.89 |

## 12.2 Hinge Bolts

The bolts on the hinges will be subjected to stress while the device is in the air. The stresses on the bolts need to be analyzed to determine if the bolts can withstand the amount of force applied to them. This evaluation will be similar to how the bolts were simulated in section 12.1. However, there are three slight differences: the bolts for the hinges are in a different location than the carriage block bolts, the bolts on the hinges will only be exposed to forces on half of the design but will induce a moment in multiple directions, and the direct shear force on bolts is from the three slabs of 21 pounds and half of the weight of the entire system as shown below.

$$V = 21 + 21 + 21 + \frac{28.13}{2} = 77.07lbs$$

The first moment the bolts face is pulling from the distance the forces are in the width or z-plane. This is force from the left when facing parallel to the length of hinge. The moment is determined from the slab that is 14.20 inches away, the other two slabs that are both 7.30 inches away and the weight of the object that is 9.60 inches away all in the same direction as described before.

$$M_z = (21 * 7.30) + (21 * 14.20) + (\frac{28.32}{2} * 9.60) + (21 * 7.30) = 740.80lbs * in$$

The moment of 740.80 pounds inches applies the nominal stress on the bolts. Therefore the force is the division of the moment divided by the number of bolts in the same line and the difference in height from the center of mass of the hexagon shown in equation 2. From this nominal force, the nominal stress is assessed using equation 3. This is involved in the secondary shear of the bolts as well as the second moment applied to the bolts. This moment is applied parallel to the length of the hinges also known as the x-plane. The moment is driving this half downward parallel to the other half. This moment is determined from the 21 pound slabs, 4.40 inches, 16.35 inches, and 28.30 inches away from the bolts in this direction as well as the weight 17.40 inches away from the bolts.

$$M_x = (21 * 4.40) + (21 * 16.35) + (\frac{28.32}{2} * 17.40) + (21 * 28.30) = 1275.70lbs * in$$

The moment in the x-direction, 1275.70 pounds inches, only pertains to shear stress. The secondary shear of the moment in the x-direction and z-direction are calculated from equation 6 using the distances in Figure 40.

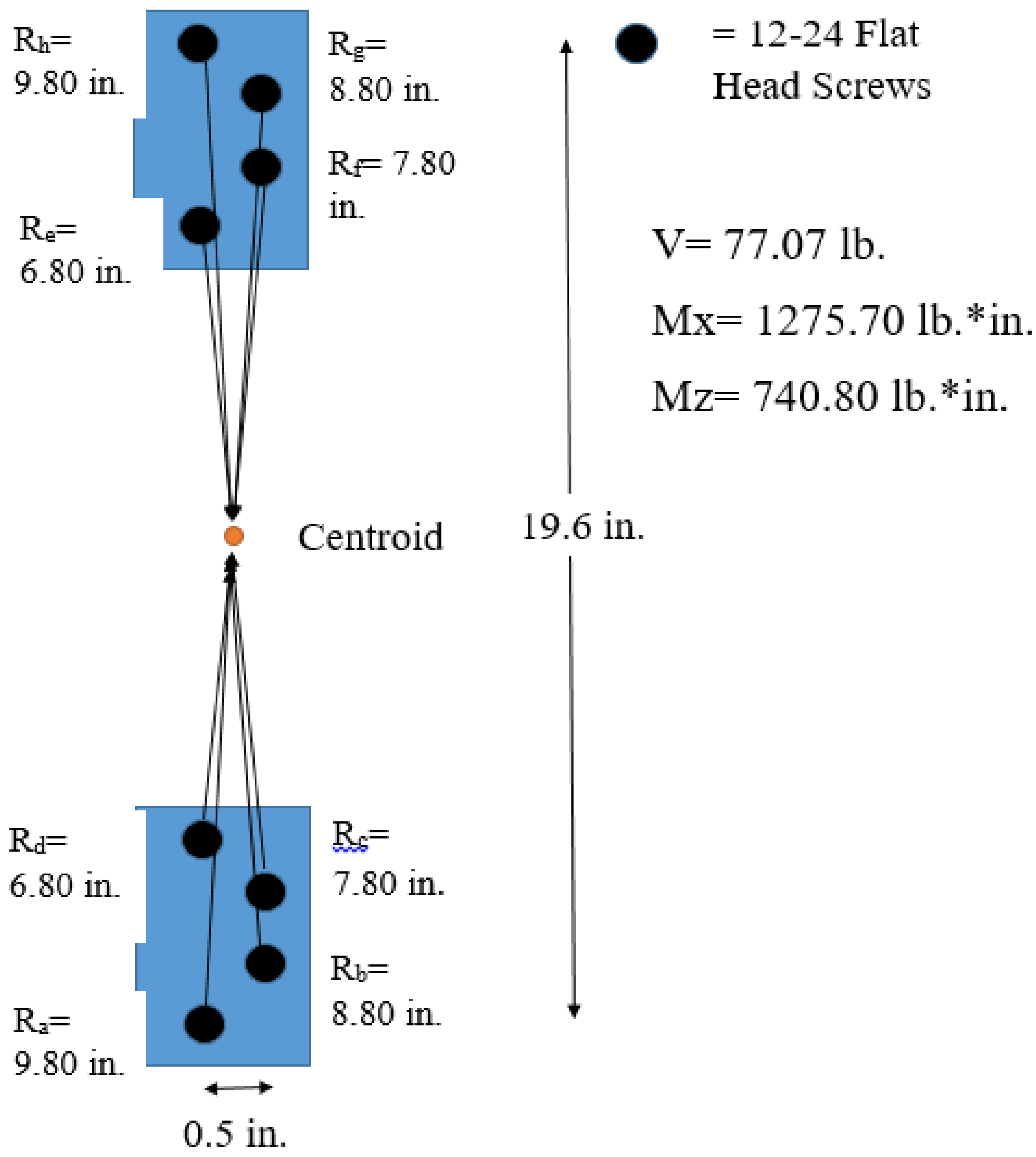



Figure 40: Bolts on the Hinges

The shear stress of the bolts is evaluated from the following equation:

$$\tau = \sqrt[2]{\tau'^2 + \tau_z"^2 + +\tau_x"^2} \tag{11}$$

Where the primary shear is combined with the shear from both the x-direction and z-direction. This shear stress is employed with the nominal stress to analyze the Von Mises Stress on the bolts. The stresses for each bolt is revealed in Table 12 with the FOS. The maximum stress of the bolts in the hinges are the closest to the center of mass and the calculations for the maximum stress is displayed in the Appendices.

Table 12: Hinge Bolts

| Bolt | Sigma (ksi) | Tau (ksi) | Von Mises (ksi) | FOS (-) |
|---|---|---|---|---|
| a | -3.54 | 0.90 | 3.86 | 20.71 |
| b | -4.28 | 0.79 | 4.49 | 17.82 |
| c | -5.41 | 0.69 | 5.54 | 14.44 |
| d | -7.37 | 0.60 | 7.44 | 10.75 |
| e | 1.88 | 0.60 | 2.15 | 37.20 |
| f | 1.72 | 0.69 | 2.09 | 38.18 |
| g | 1.59 | 0.79 | 2.10 | 38.22 |
| h | 1.48 | 0.90 | 2.14 | 37.35 |

## 12.3 Linear Motion Device

For the design that is being pursued by the team, it was required to develop a lifting device that could allow for both linear lifting and the holding of the collar. This portion of the design breaks down into two main sections; the motor requirements and slider assembly. After extensive research it was determined that a ball screw assembly with a few adjustments would be the ideal fit for the mechanism envisioned.

The requirements for the motor that would be selected are described below and they include the calculation of load inertia, required speed, required force and required torque. The load inertia is the motors resistance to change of speed or change of inertia. This was acquired from the equation.

$$J_L = J_W + J_S \tag{12}$$

Where $J_W$ is the inertia based on the weight of the load and can be calculated by the equation

$$J_W = W \times (P_B \div 2\pi)^2 \tag{13}$$

Where W is the weight and $P_B$ is the pitch of the ball screw. Using these values the weight inertia was determined to be 5.07 lb*in$^2$. Then the screw inertia must be calculated using equation

$$J_S = \frac{\pi}{32} * \rho * P_B * D_B^4 \tag{14}$$

Where $\rho$ is the density of steel which is .2856 $lbs/ib^3$, $L_B$ is the length of the ball bar which is 24". The diameter of the ball screw ($D_B$) is 1" and using these factors the screw inertia is .6725 lbs*in$^2$. Given these inertia, the total load inertia for this system is 5.744 lbs*in$^2$. This is just one aspect of the motor calculations used to determine the motor choice. The next aspect is the speed required for the motor. This requirement is more of a minor consideration but it must still be considered to allow for the assay time to stay under one hour. In considering this, it was deemed that the speed that would be used is to raise the collar at 1 in/sec. So to determine the speed of the motor needed to operated, the equation

$$V_M = V_1(60/P_B) \tag{15}$$

Where $V_1$ is the desired velocity, $V_m$ is the velocity of the motor. This requires that the motor speed must be 60 RPM. The most critical calculation for the motor sizing is the required torque. In order to determine this, the force required to move the collar must be determined. The only force that was acting against the collar is the weight of the device itself. The force was estimated to be 150 lbf and using the equation

$$T_L = (((F * P_B) * 1.1) + T_B)(1/\nu \times 0.01) \tag{16}$$

Where $T_B$ is the breakaway torque and this was determined to be 2582 lbs*in. $\nu$ is the efficiency of the ball screw which can range from 95% to 80%. To stay on the safe side, the efficiency was given a conservative estimate of 80%. The final load torque was calculated to be 3220 lbs*in. Finally, to determine the required torque, the load torque was multiplied by a factor of safety of 1.5. This gives a required torque of 4830 lbs*in. The factor of safety was used in accordance to industry norms discovered from research into motor design. These calculations were aided by the use of the online motor sizing calculator provided by oriental motor [14] and the inputs can be seen in Appendix G.

## 12.4 Bending Stresses

The sliding shaft would experience a substantial force requiring the need for calculations on the bending to be precise. The magnitude and slope of the deflection will need to be minimized to allow for the pillow block to slide seamlessly. The maximum bending stress on the shaft would be 2021.5 psi, the maximum deflection would be .694" and the maximum slope of bending would be 8.07 degrees. These fall well under the maximum bending that the pillow block can operate at with the factor of safety for stress being at approximately 40. These calculations were assisted by the use of an online calculator [15] using the fixed support. The full analysis of the data acquired and the inputs are listed in Appendix H with the exception of the bending diagrams listed below.

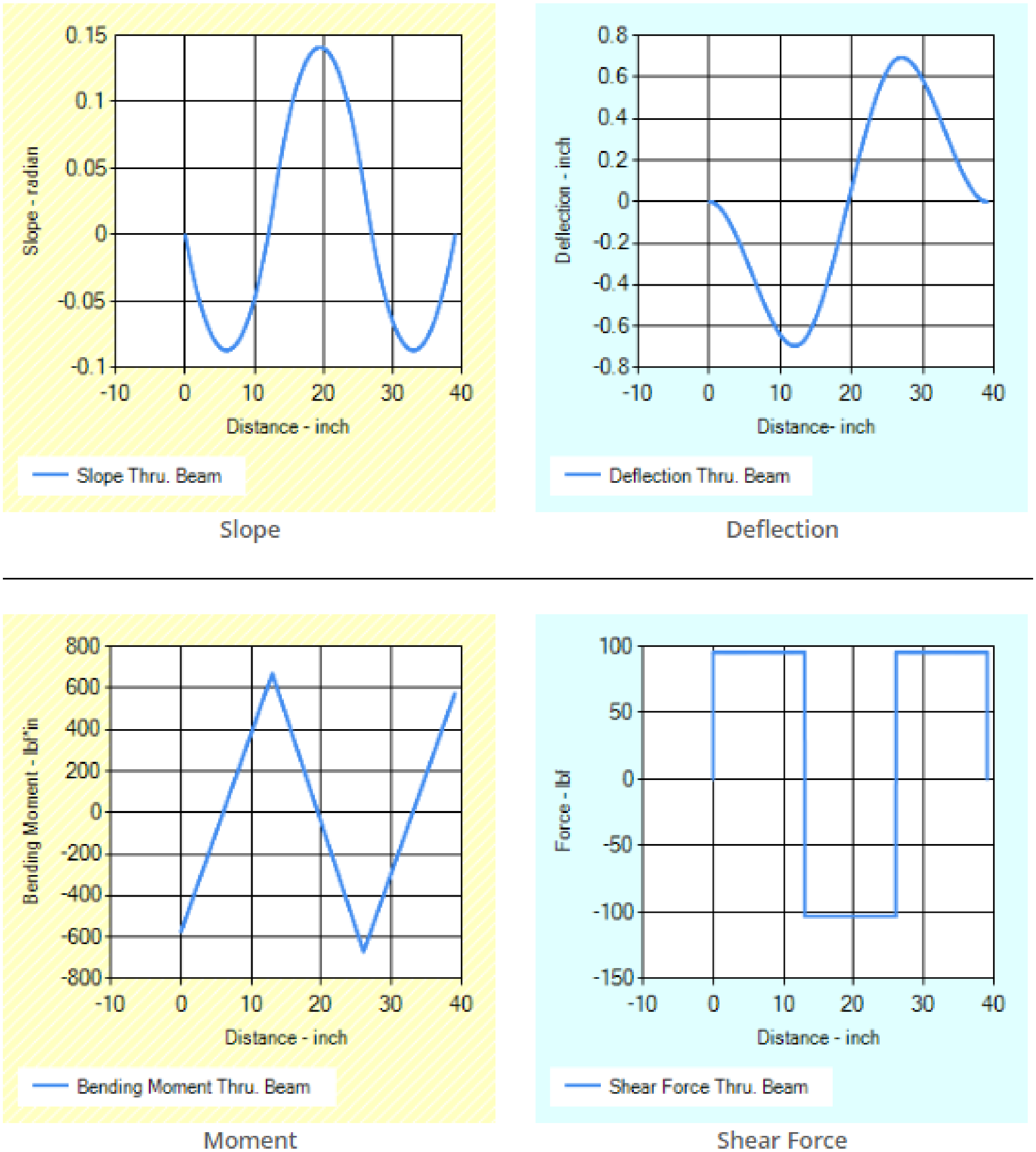



Figure 41: Bending Diagrams

## 12.5 Weld Stress on Linear Support

The linear support is the four bars that will be welded to the hexagon in order to attach the linear motion system. These bars will be butt welded to the top and bottom of the system. These bars will face the same moment and shear as the carriage block bolts.

The bending stress is evenly distributed throughout the four bars. There will be a primary bending and secondary bending on the welded joints similar to the bolts. Since each bar will be welded on both the top and the bottom the shear force will be divided by 8. The throat area of the weld is determined by:

$$A = 0.707h(b + 2d) \tag{17}$$

where h is weld throat, d is the length of the welds adjacent to the height and b is the length of the weld coincident with the top or bottom. The throat weld for this circumstance is 0.0039 inches, while b is 2 inches and d is 2 inches for each bar. The equation for the throat area is from the bar being welded on three adjacent sides. For each bar, the throat area is calculated to be 0.017 $in^2$. The primary bending stress is calculated by using the following equation:

$$\tau = \frac{V}{A} \tag{18}$$

Where V is the shear force and A is the throat area.

The secondary bending stress on the weld is determined from:

$$\tau" = \frac{M * c}{I} \tag{19}$$

Where M is the moment applied to the weld, c is the distance to point of rotation, and I is the area of inertia of the weld. The area moment of inertia for these welds are calculated from:

$$I_u = \frac{2d^3}{3} - 2 * d^2 * \overline{y} + (b + 2 * d) * \overline{y}^2 \tag{20}$$

Where $\overline{y}$ is $\frac{d^2}{b+2*d}$ and 0.67 inches for each bar. The area of inertia for the weld of each bar is 2.67 $in^3$ and the distance to the point of rotation is from the center of gravity to $\overline{y}$. The bending stress will be greater on the top than the bottom since it is farther away from the center of gravity. The permissible stress on the weld for the material is:

$$\sigma_p = 0.60 * S_y \tag{21}$$

Where $S_y$ is the yield strength, 35 ksi, of the aluminum bars. The resultant permissible stress is 21 ksi for the bars. The stress on the welds is insignificant compared to yield strength of the weld as seen in 13.

Table 13: Weld Stress of Bars

| Weld | $\tau'$ (ksi) | $\tau"$ (ksi) | $\tau$ (ksi) | Permissible Stress (ksi) |
|---|---|---|---|---|
| Top | 1.17 | 3.30 | 3.51 | 21.00 |
| Bottom | 1.17 | 1.37 | 1.80 | 21.00 |

# 13 Proof of Concept

After all of the design work and stress analysis was performed throughout the semester, a small-scale prototype was created. This prototype served as a great demonstration tool and also helped eliminate some minor functionality problems and aesthetic issues.

The first step was to determine how to implement the new design into LANL's glovebox waste disposal system. To tackle this issue, the glovebox and waste container (55-gallon drum) were designed on SolidWorks and 3-D printed to serve as a physical model (Figure 42). The print also included the original assay that was to be used, a collar design also provided by Canberra. This model was helpful as it determined that the assay was to be placed underneath the glovebox due to space and accessibility issues if it were to be placed inside. This helped the team to tackle some ergonomic problems that arose during the early design process.

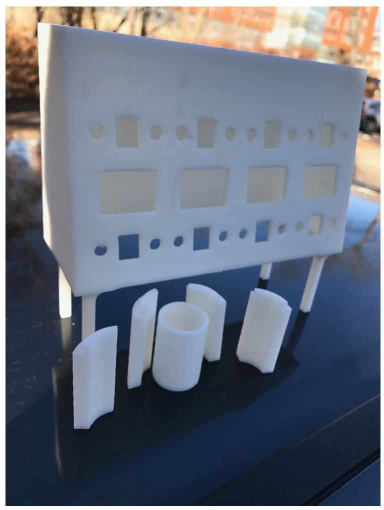


Figure 42: Glovebox 3-D Print

When the new assay was selected due to the change in problem statement, a new 3-D print was not made. However a CAD drawing was produced in SolidWorks which was discussed in a previous section (Section 11: Detailed Product Design). This drawing was run through the simulation program on SolidWorks and a thorough stress analysis was completed, see Figure 43. To get a better understanding of the system that was to be created, a small-scale model was created (Figure 44a).

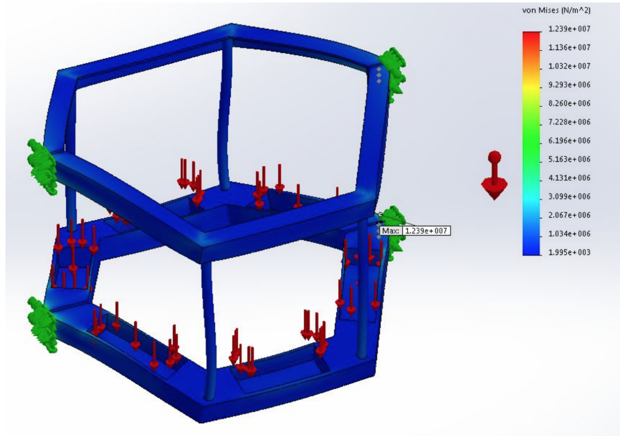



Figure 43: SolidWorks Stress Analysis

The project results for the changed system will yield similar results as to what is displayed in Figure 43. It is hard to tell, but the maximum stress concentration is located at the hinge.

(a) Side View (b) Top View

Figure 44: Small-Scale Prototype

To create the prototype, materials were purchased based on needs of the model not the actual needs of the design. Many of the materials used for the demonstration was found from past projects and other products found by the team members. The materials used for the prototype are not the final materials that will be used.

The prototype does not reflect the size of the design, it is there to explain the process. The top wooden board represents the top of the glovebox and the assay system will rest below. There will be a trapdoor/hole leading into the 55-gallon drum which will sit right inside the metal apparatus (Figure 44b). The nuclear waste will be disposed of through the hole and into the drum. The metal apparatus holds the six slabs, the type of slab will vary depending on the user's preference. The white slab represents the slab that can be changed out to an active assay.

Once the drum is loaded via trapdoor, the user will start the assay process. This will start the 17 minute long measurements of the top, middle, and bottom of the drum. To raise the mechanism, a motor will be attached to the frame of the system. This motor was determined by calculating the weight and speed needed for the movements (Refer to Section 10.2: Linear Motion). The goal is to raise the apparatus to each different level in five seconds. The raising of the frame is demonstrated in Figure 45.

Figure 45: Motor Demonstration

The three separate assays will take about 17 minutes each, or 51 minutes total. This keeps the total time under the allotted slot of one hour. Once this process is complete, the results of the assay will be displayed on the user interface. If any waste is needed to be removed, it will be done so. If not, the front half of the assembly will be opened by the user and the barrel is able to be removed to further disposal (See Figure 46).

Figure 46: Hinge Demonstration

# 14 Build/Manufacture

The prototype, Figure 47, that the team produced for the showcase was only a mock-up of what the final design would be. Due to budget limitation, different materials had to be used instead of what would be proposed. The frame was constructed out of plywood and the lift was replaced with a television mount to simulate the proposed lifting mechanism. Also, due to the scanners high cost of several thousand dollars, they were left out of the design and replaced with 3D printed slabs. These slabs, while not able to detect anything, allowed the team to test the mechanical properties of the frame as the slab weight was still to scale. The prototype was constructed in three main steps, frame construction and assembly, external parts, and attaching to the glovebox and lift.

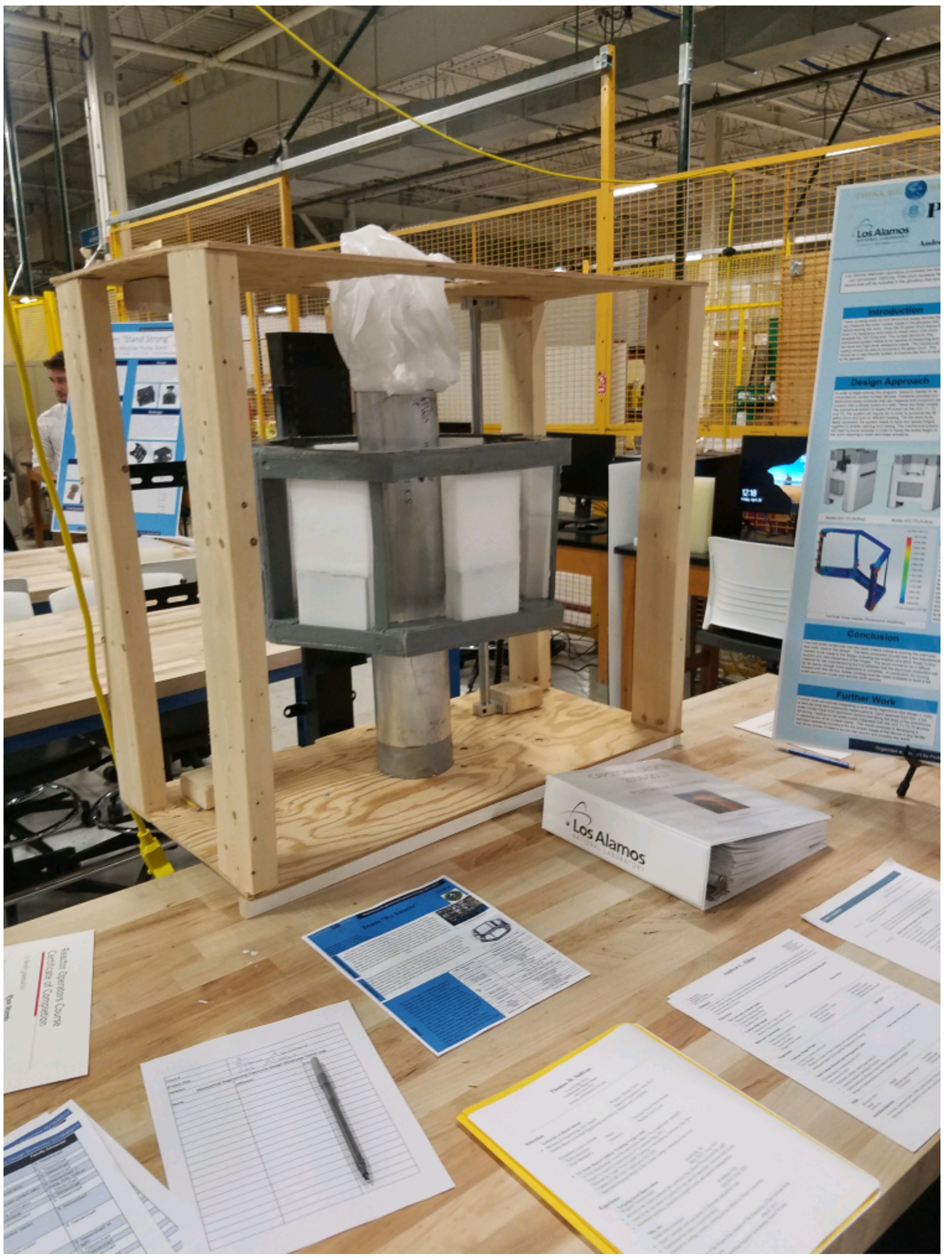



Figure 47: Half Scale Prototype

Being that the frame was constructed from plywood, the team had to cut and shape each individual part via ban saw. Once each smaller part was cut, the six upper and lower sides of the frame were glued together using wood glue and small wood screws. Being that these limbs were fabricated by hand and not by machine several needed to be re-cut during the redesign portion due to not matching the opposite limb. After several days of cutting, gluing, and waiting, the hexagon frame was constructed, which meant the team could now add on the external parts. These parts consisted of the hinges on one side, the locking mechanism on the opposite, as well as the parts to mount the frame on the television lift and the sliders to ride on the support rails. During the initial build and redesign of the frame the team noticed that as the frame needed to change so did the hinges. After several trials the right type of hinge and positon was achieved. The locking mechanism was a simple pin and hole mechanism that would keep the frame closed in use. The television mounting device and rail sliders were also simple add-ons. Both were screwed and glued into the devices frame and mounted easily. While all of this was happening six slabs were being printed and fitted into the wooden frame to simulate the real scanner slabs. When placed in their individual wells on each limb the prototype is completed.

The proposed design will be made from aluminum instead of plywood, the frame will then be welded together. Aluminum will be strong enough to hold up the actual weight of the slab with little to no bending on the unsupported side and is relatively cheap to purchase. The frame will still have the six wells for the slabs to allow for easy installation and change between active and passive assaying models. Being made out of metal allows all of the external parts to be welded on as well. The hinges and locking mechanism will have to be tougher than what was used in the prototype but once attached will be fine. Lastly, instead of the originally used television lift the frame will be welded to a lifting mechanism and guide rails. Again, with the implementation of the six slabs concludes the fabrication of the prototype.

Being that the proposed design is a high value device, as well as being in a niche market, there is little chance that it will ever be mass produced. The initial design is based off of the specifications Los Alamos gave the team. The design is made to be used at any facility processing nuclear waste.

# 15 Testing

Testing is important for the design and development of a new product. The purpose is to verify design uncertainties, manufacturing and variations in the prototype. Products can fail due to many reasons including design problems, excess stress, and errors. This ensures the design will have reliability and durability in its performance in the planned environments. The tests were performed on the full scale design and half scale design for stress and displacement analysis. However, the remaining tests were applied to only the half scale prototype due to the necessity for a physical representation.

## 15.1 Standards

ASTM does not have any standards regarding the prototype of the design. However, the ASTM standards for the materials will need to be followed for the full scale manufacturing. This includes includes Section B769, Shear Testing of Aluminum Alloys, and Section A370, Mechanical Testing of Steel Products. The Engineering Standards Manual for Los Alamos should also be followed when testing the full scale system.

## 15.2 Procedure

The design must be analyzed to guarantee that the product can handle the nuclear devices without failure. This test requires the use Solidworks simulation. The results will determine if the aluminum material is acceptable for the application and if the design needs altering. The analysis is run for each half of the structure using the conditions in which each half will be fixed. Both halves will have a force of gravity applied to the system as well as a distributed mass of 21 pounds applied to the locations for each of the nuclear slabs. The Von Mises stress will be the first information taken into consideration to ensure the stress does not exceed the yield strength of aluminum 1060. Displacement of the material will be recorded as well to provide sufficient detail of the testing.

In order to run the analysis on either side of the structure, testing must be completed on the hinges. The calculations on the bolts have been finalized in the Engineering Analysis, section 12.2. The simulation on the hinges were subject to the same forces seen in Figure 40. This will be able to conclude whether the hinges are able to handle the stress in the system. The tests on the hinges were evaluated for both a two hinge system and a three hinge system. The results can help better determine how many hinges are necessary for the structure.

Similarly, to the full scale model, Solidworks analysis is necessary for the half scale prototype. This is due to the scaling, the thickness changes and most importantly the material changes of the model. The tests are done to assure the design and material can handle the expected conditions. The analysis is again run for each half of the structure using the force of gravity and the conditions in which it will be fixed. However, the distributed mass is scaled down by half to 10.5 pounds for each of the nuclear slab locations. The results taking from the analysis are the Von Mises stress and displacement for the same reasons as the full scale model.

The manufacturing testing will be done by using three-dimensional printed nuclear slabs. These nuclear slabs will be scaled down exactly half to test the building of the half scale model. The slabs should tightly fit in the designation slots. They should be able to be easily removed but not allow too much space where they will fall out.

An important piece in the design is the structure needs to be able to open and close. This is to allow the 55-gallon drum to be easily replaced with a new one. The test is simple but necessary for the success of the device. The premise of the test is the device must open large enough to easily move the drum in or out while close to fully surround the entire drum.

The mechanical lift should be able to raise and lower the structure built to hold the nuclear device. This is important to test prior to adding the weight of the nuclear device. This test is precautionary in case the mechanical lift has a problem with the structure. This would prevent more damage to the motor or the highly expensive nuclear devices if something went wrong.

There is a time limit in the design specifications for the raising and lowering of the structure. The limit is to ensure it does not take unnecessary time waiting for the device to reach to top or bottom since the assaying of nuclear waste is already time consuming. The maximum time the mechanical lift should take to reach the maximum height is ten seconds.

The next test involves using the weight of the nuclear slabs on the scaled down model. In order to assay the entire drum, the mechanical system needs to raise the structure and the nuclear devices. This test is to determine if there is any problems with the mechanical lift or the structure holding the nuclear devices. The test was performed on the scaled down system with a quarter of the weight that will be subjected to the full scale model. This is for numerous reasons including: not wanting to subject the television lift to that much torque, the half scale model being made out of wood and the way the structure was assembled.

The following test is necessary to testing the durability of the structure. This is to ensure the structure can hold the nuclear devices at the designed heights properly while assaying the drum. The length of time for the test was determined to be thirty minutes since it takes the nuclear devices under twenty minutes to record the reactivity. The purpose of the test is to conclude whether the structure requires more support or has to be altered to better handle the weight of the nuclear devices. This test was also performed with a quarter of the weight subjected to the full scale model for the same reasons.

Reliability testing creates a mistake proof design. The first test involved not enabling the device to be opened when the assay of the waste is being processed. This was to prevent incorrect data or damage to the structure if the device is off the ground. The next test was to mistake proof the structure for easy cleaning. The design has many curves and crevices which will be hard to clean properly without creating a 'poke yoke.'

The final test is the system needs to be able to work underneath the glovebox. This is important because the design has essentially zero purpose if it is incapable of working in the glovebox line. The mock glovebox is built around the half scale prototype to conclude the test.

## 15.3 Testing Results

The results for the stress and displacement analysis on the full scale aluminum structure proved to be acceptable. The side of the structure which endures the most stress is shown in Figure 48. This is the side that will be supported by only the hinges and the latch on the opposite of the hinges. The factor of safety for the structure is 5.98 which is above the threshold of 2 set in the design specifications. The same half of the structure experienced the most displacement at 0.06 millimeters, seen in Figure 49 which leaves no concern over the structure. The other half of the structure is supported by the lifting mechanism. This half faced far less stress and displacement seen in the Section 23.9.

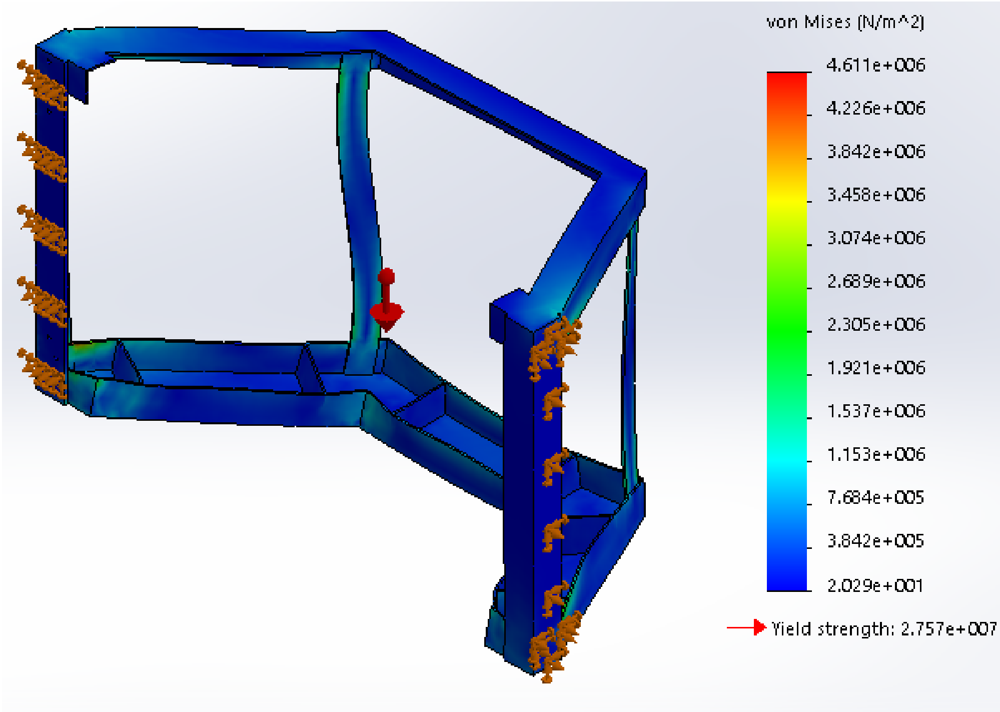



Figure 48: Stress of the Full Scale Structure

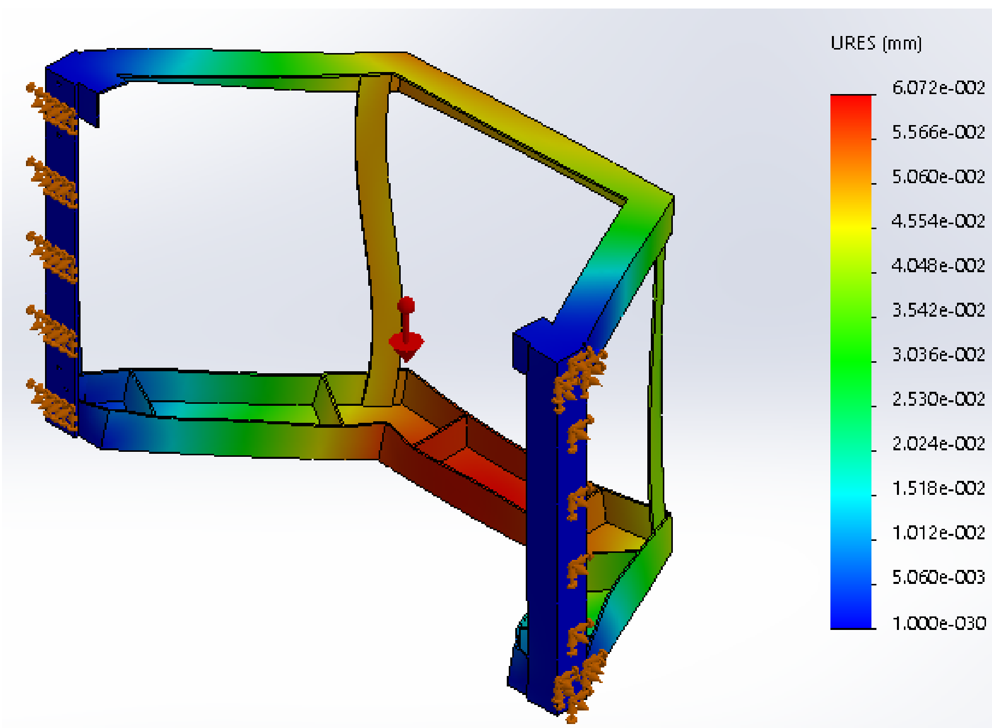
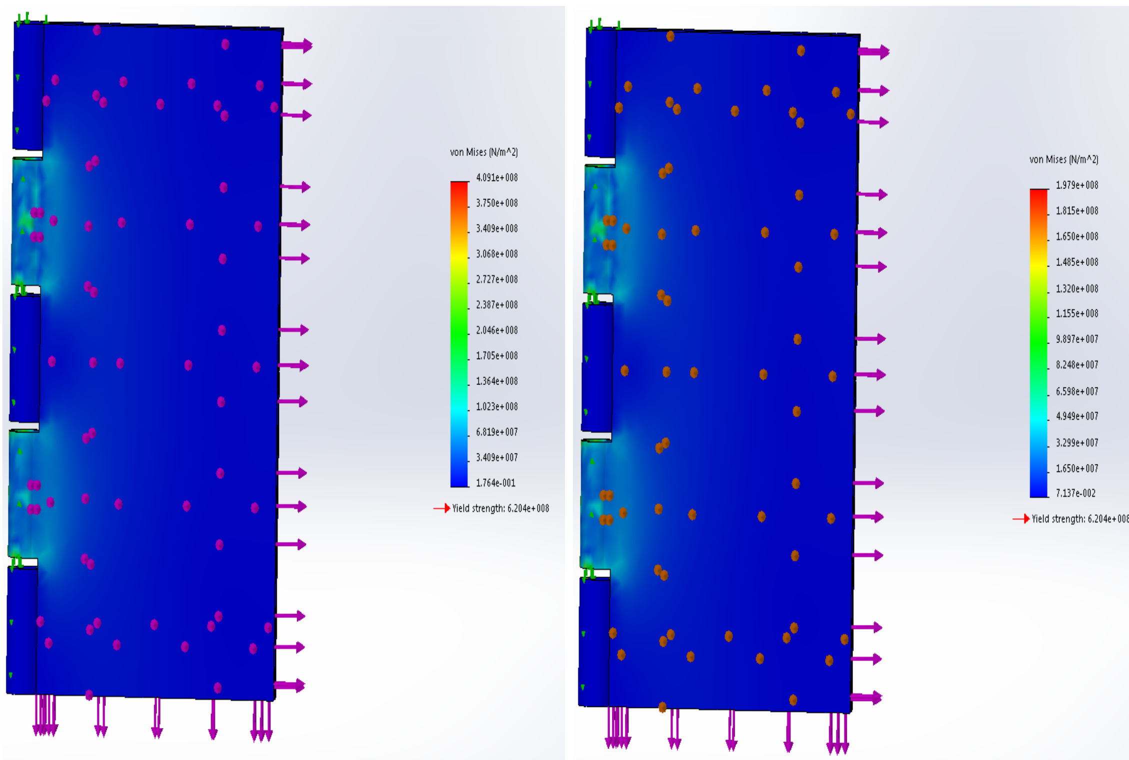



Figure 49: Displacement of the Full Scale Structure

A major concern for the structure was the stress on the hinges. As previously discussed, the bolt calculations were calculated in Section 12.2 to ensure they would withstand the stresses. The hinges were analyzed to determine whether two or three were necessary for the structure. Seen in Figure 50, the hinge subject to forces if there were two hinges (left) faces stress of 409 MPa while the hinge subject to forces if there were three hinges (right) endures only 198 MPa. The hinges would have a factor of safety of 3.13 with three hinges on the structure but only a factor of safety of 1.52 with two hinges on the structure. This is further discussed in Section 16.




(a) Stress with Two Hinges

(b) Stress with Three Hinges

Figure 50: Testing Stresses on the Hinges

The results on the simulation of the half scale prototype were similar to the full scale model. This was important to guarantee there would be no abnormally large stresses with the use of plywood. The same half as the full scale structure encountered the maximum stress (Figure 51) and maximum displacement (Figure 52). The plywood half scale prototype result for factor of safety was 6.59 which is greater than that of the full scale aluminum. The displacement of the half scale model is more than the full scale structure at 0.0929 millimeters. The half of the structure that faced far less stress and displacement can be seen in the Section 23.9.

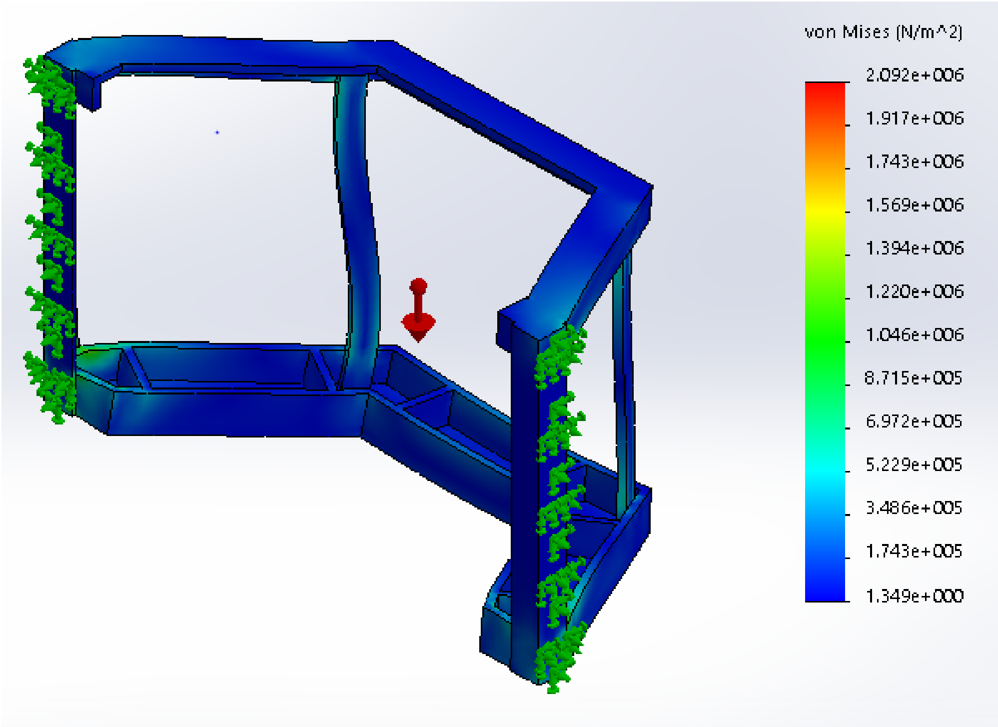



Figure 51: Stress of the Half Scale Structure

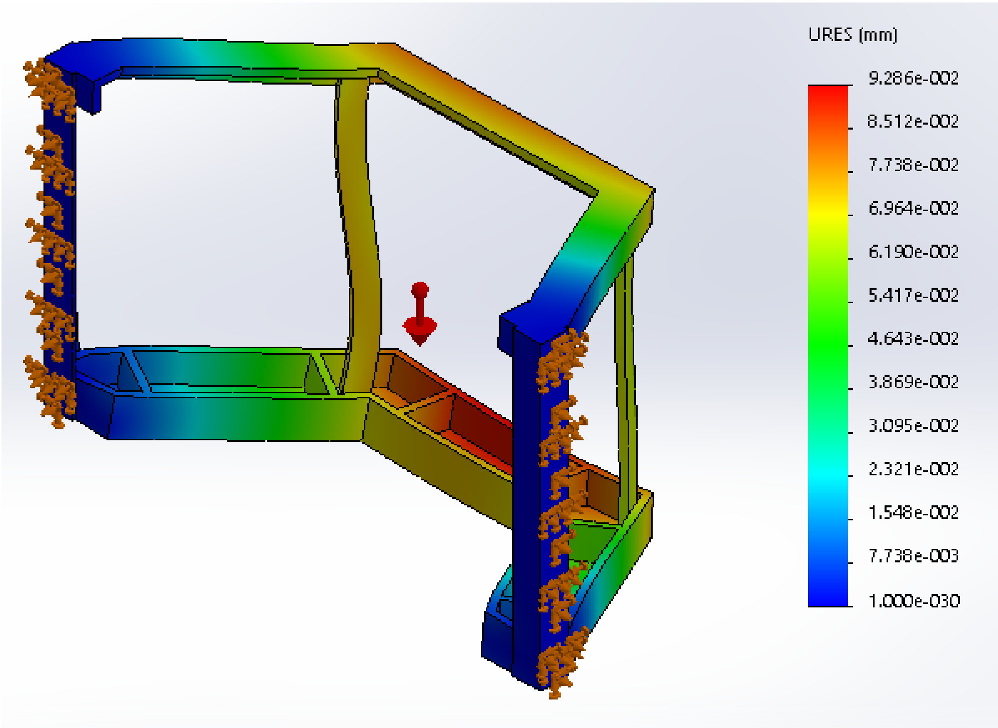



Figure 52: Displacement of the Half Scale Structure

The first test on the design that was completed was checking the manufacturing. This test verified the dimensions of the slots for the nuclear devices by using half scale plastic versions. All six designed areas succeeded in the test.

The next test was to determine if the prototype would open and close properly. The prototype has a wide range of motion when opening. This would allow a half scale 55 gallon drum to be easily replaced. The problem was the prototype had approximately a four inch gap between halves when fully closed which can be seen in Figure 53. This issue could result in a lower efficiency than intended for nuclear devices. Since the problem could negatively impact the system, the design needed to undergo a redesign discussed in Section 16.

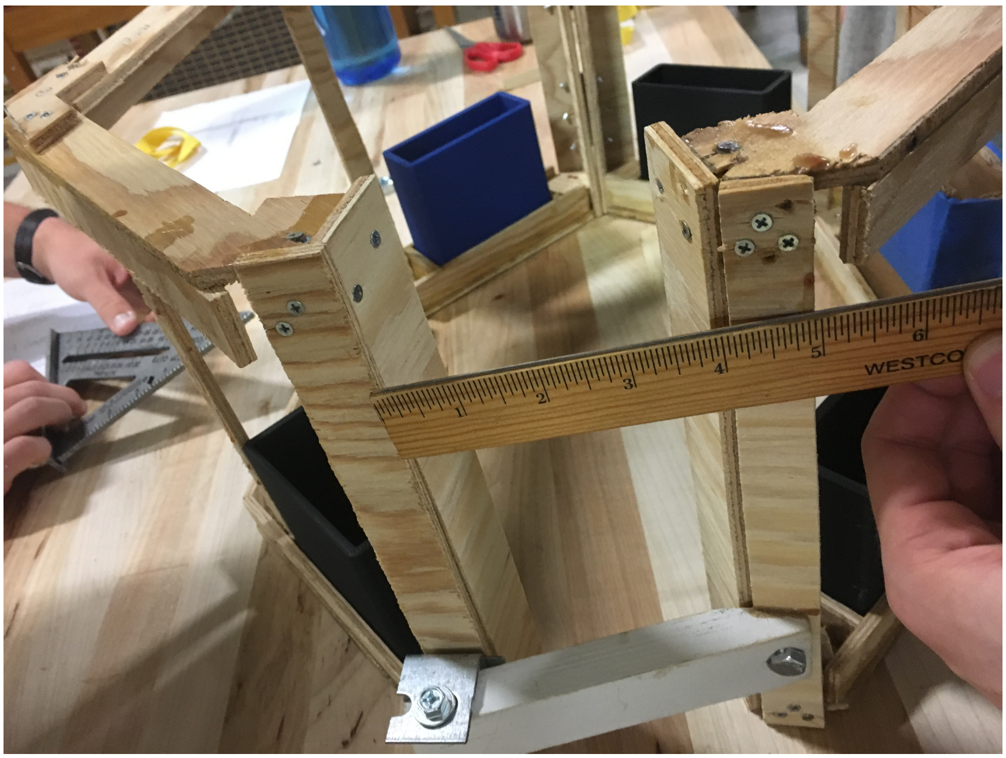



Figure 53: Prototype Fully Closed

The mechanical lift accomplished the first two required examinations. The first was to lift the structure without the weight of the nuclear devices. This was seemingly done with ease by the television lift. The time recorded for the lift to reach the desired maximum height was consistently ten seconds. This was on the lower scale for time on the design specifications but it did fit within the necessary range.

The following tests involved the weight of the nuclear devices. The mechanical system was able to lift the quarter scaled weight but there was some trouble. The bending of the structure was noticeable due to the weight. However, this is due to the flexibility of the plywood. The aluminum used in the final design would not deflect as much. A redesign was required before the durability test of supporting the weight for thirty minutes at the designed measuring levels. The improvement to the structure is discussed in Section 16. Once the design was altered, the system was able to perform the test adequately.

Both of the mistake proofing created for the design was developed during redesign process. The first prevents the structure from being opened when the assaying process is in progress. The other provides an easy method for being able to clean and sanitize the system. These poke yokes are examined more in Section

16.

The final test performed was to verify if the system would work within the glovebox line constraints. The mechanical structure rested underneath the design glovebox without problems. The design was able to still be opened and closed with no hinders to the vertical movement either.

## 15.4 Test Matrix

A test matrix is an important part of testing the design. The test matrix is not just a list of everything being tested. The plan will include why each test is being performed and how each test will be conducted. Also, incorporated is the results of the test and the planned resolutions for any problems. There are two test matrices below which both contain the same tests and parameters. However, in Table 14, not all the tests were performed before the first set of redesigns. The parts that failed in the first test matrix were corrected before the testing continued. In Table 15, the results that failed were re-evaluated and deemed worthy of success. The only two failures in the second test matrix were improved as well. The solutions will be discussed in depth in the next section, 16.

Table 14: Test Matrix 1

| | **Test** | **Test Parameters** | **Results** | **Solutions** |
|---|---|---|---|---|
| Full Scale Frame | Stress Analysis | Factor of safety of at least 2 | Pass | |
| Full Scale Frame | Displacement | Less than 1 mm of displacement | Fail | Add a latch to opposite side of hinge |
| Hinges | Stress Analysis | Factor of safety of at least 2 | Fail | Add a third hinge |
| Half Scale Frame | Stress Analysis | Factor of safety of at least 2 | Pass | |
| Half Scale Frame | Displacement | Less than 1 mm of displacement | Fail | Add latch to opposite side of hinge |
| Half Scale Frame | Manufacturing | Open and close around a 12" diameter barrell | Fail | Re-machine a side of the structure |
| Half Scale Frame | Manufacturing | Properly fit scaled down nuclear devices | Pass | |
| Lift | Vertical Movement | Raise and lower the frame | Pass | |
| Lift | Time | Reach max. height in less than 10 seconds | Pass | |
| Lift | Vertical Movement | Lift weight of frame and nuclear devices | N/A | |
| System | Durability | Hold nuclear devices in air for 30 minutes | N/A | |
| System | Manufucturing | Work underneath glovebox | N/A | |

Table 15: Test Matrix 2

| | **Test** | **Test Parameters** | **Results** | **Solutions** |
|---|---|---|---|---|
| Full Scale Frame | Stress Analysis | Factor of safety of at least 2 | Pass | |
| Full Scale Frame | Displacement | Less than 1 mm of displacement | Pass | |
| Hinges | Stress Analysis | Factor of safety of at least 2 | Pass | |
| Half Scale Frame | Stress Analysis | Factor of safety of at least 2 | Pass | |
| Half Scale Frame | Displacement | Less than 1 mm of displacement | Pass | |
| Half Scale Frame | Manufacturing | Open and close around a 12" diameter barrell | Pass | |
| Half Scale Frame | Manufacturing | Properly fit scaled down nuclear devices | Pass | |
| Lift | Vertical Movement | Raise and lower the frame | Pass | |
| Lift | Time | Reach max. height in less than 10 seconds | Pass | |
| Lift | Vertical Movement | Lift weight of frame and nuclear devices | Fail | Add vertical slider system |
| System | Durability | Hold nuclear devices in air for 30 minutes | Fail | Add vertical slider system |
| System | Manufucturing | Work underneath glovebox | Pass | |

# 16 Redesign

Redesign is an important part of creating a new product. Designs are constantly being improved to make the product better, safer, and more cost efficient. The first major redesign was manufacturing the structure out of plywood and utilizes a television lift for the vertical movement system. This alteration for the prototype was strictly for cost saving purposes. The remainder of the improvements of the structure and system were developed from testing results. Through the testing of the product, flaws in the original design were exhibited.

## 16.1 Manufacturing Redesign

The first improvement on the prototype was to better manufacture the structure after it failed to fully close. The original construction created approximately a four inch gap when the structure was fully closed. This can be seen in the picture below Figure 54. The structure needed to be modified to reduce or eliminate the gap. One of the six sides was completely disconnected and re-machined. This allowed for the mapping of the new side using the existing pieces to ensure the structure will fully close. After the piece was machined and connected, the structure accomplished the intended goal.

Figure 54: Prior to Redesign

## 16.2 Displacement Redesign

There was a flaw in the design when the simulation of one of the halves of the structures was first analyzed. The half was only fixed by the hinges on one side leaving the other side free. This resulted in too much displacement for the structure shown in Figure 55. The half scale prototype experiences a displacement of over 2.7 millimeters. This resulted in the requirement to fix the opposite side of the hinge. The simplest way in doing so without hindering the ability to open and close is to add a support latch from the side of the structure. This redesign is for both the full scale model and half scale model as the testing results improved with two fixed ends. Those results were displayed in the analysis in Section 15.

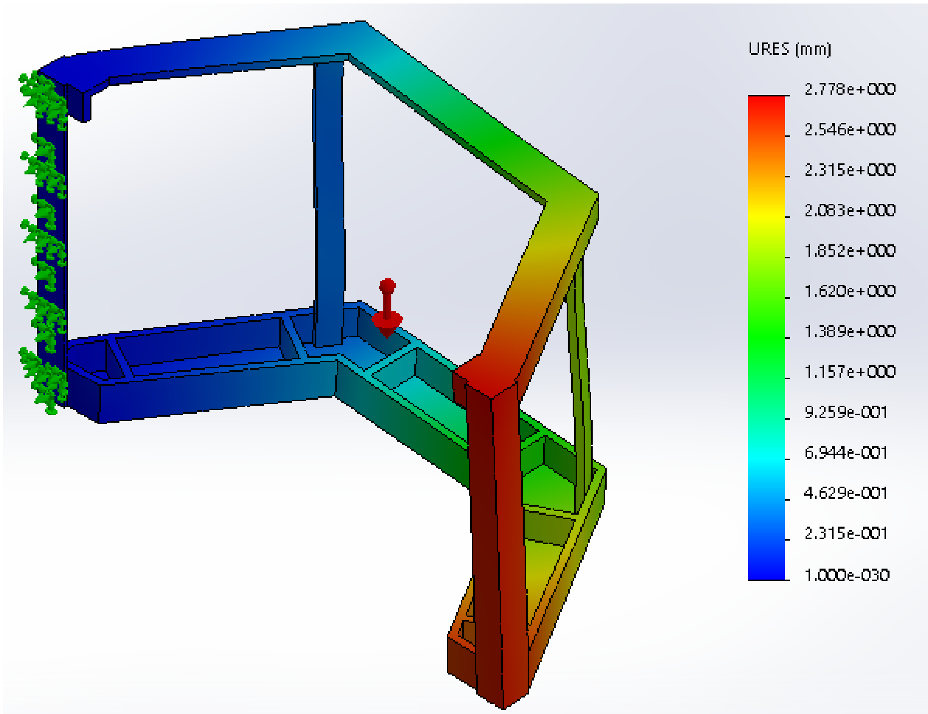



Figure 55: Half Scale Displacement without a Latch

## 16.3 Hinge Redesign

The hinge was an important part of the design to test. The original design of the structure included only two hinges. However, when the analysis was run with forces of the full scale model on the two hinges the factor of safety was only 1.5. The factor of safety for the design should be above 2 for extra security. This was achieved when the analysis was completed for the forces of the full scale model distributed on three hinges. This resulted in a redesign to add a third hinge in the middle of the other two hinges.

## 16.4 Vertical Slider Redesign

The mechanical lift struggled when lifting and holding the the structure with the weight of the nuclear devices. This was due to the bending moment created by the weight on the opposite end of the lift. In order to counteract the moment, vertical sliders were attached to the fixed half of the structure. The vertical rod for the sliders was supported by the linear rail supports connected to the floor created for the device and the mock glovebox. This can be seen on the design in Figure 56. This redesign would be applied to the full scale model to help support the structure and mechanical lift.

Figure 56: Vertical Slider System

### 16.5 Poke Yoke Redesign

The mistake proofing of the design was accomplished during the redesign process. A major problem was to prevent the structure from being opened while the waste is being assayed. This is achieved using the support latch discussed in Section 16.2. A pin will be placed in the latch to lock the structure closed when assaying the drum. This will prevent any error in data or any unnecessary damage to the nuclear devices.

The next redesign was to enable easier cleaning for the structure. This was accomplished by adding covers to areas of the design that would be hard to clean. These areas were the corners of the hexagon where the nuclear devices would not be placed. In the full scale model, plastic sleeves would be employed to cover these areas. This would allow the structure to be wiped down quickly and efficiently preventing any cleaning mistakes.

### 16.6 Aesthetic Redesign

Aesthetic redesign was necessary for the half scale prototype. This redesign is solely for the prototype. The purpose is to improve the appearance due to the manufacturing errors and necessary connection methods. In order to connect each side, an additional piece of plywood is needed to act as a bridge to the sides. This was hidden on the bottom with the covers for easy cleaning purposes. On the top, a second layer was created to give the appeal the structure was only two pieces or the two halves. The screws from the hinges extended out of the wood maintaining an unfinished look. These were subsequently hidden to establish a clean look.

Spackle was eventually applied to the structure to fix gaps created from manufacturing errors. The spackle created a solidified look for each of the halves. The final adjustment to improve the aesthetics of the structure was spray painting the plywood. Gray spray paint was applied to reflect the color of aluminum which would be utilized for the full scale model. The paint gave the structure a finished look seen in Figure 57.

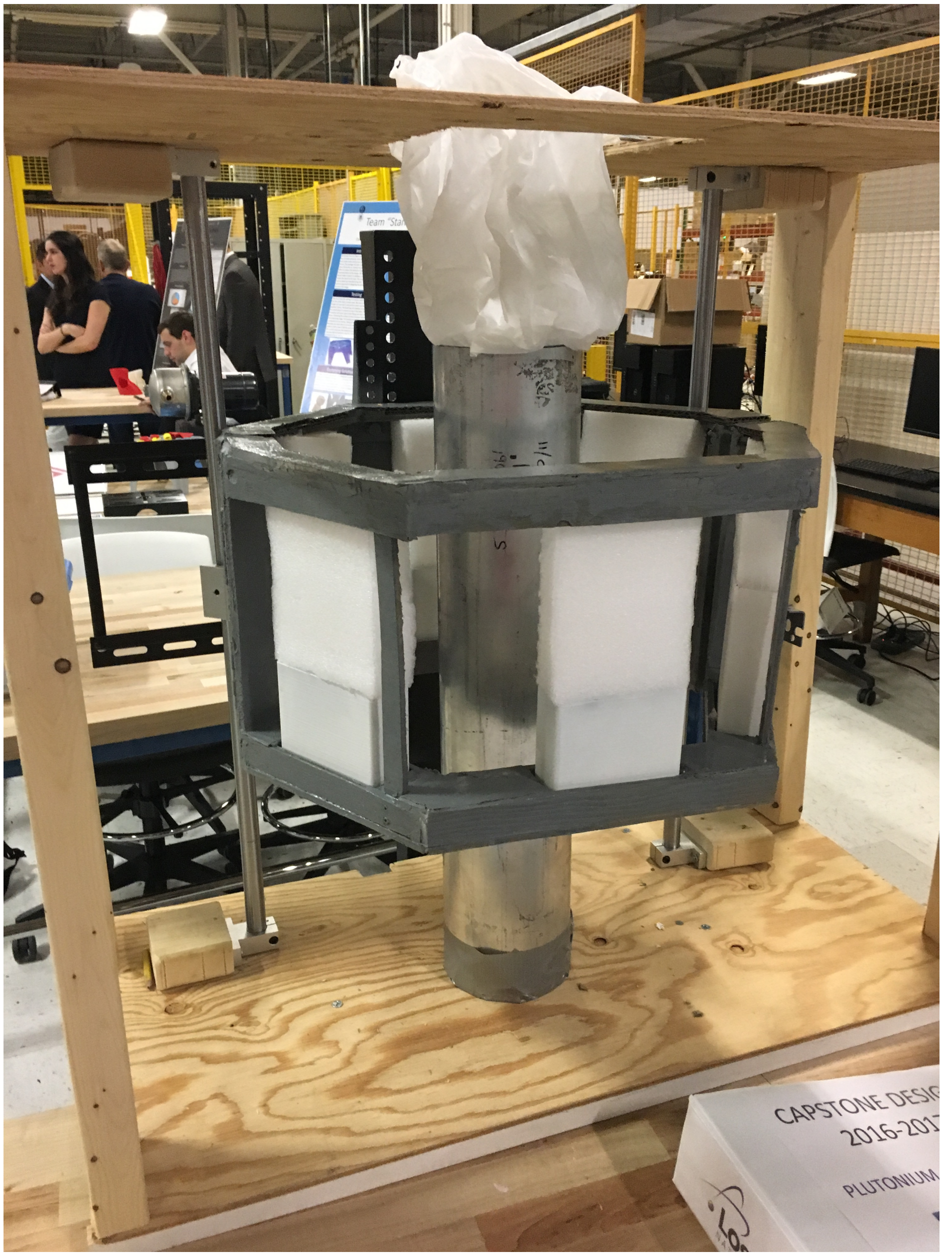



Figure 57: The Finished Prototype

# 17 Operation

One of the critical requirements set by Los Alamos National Labs is that the implemented mechanism remain in line with their current system. Once installed, the device will remain under a glove box to be used at any time. As the waste moves down the line it will enter through a trap door mechanism into the drum below the glove box. Then, either after each object enters the drum, or at chronologically set points an operator can use the device to measure the drums contents. The JCC scanners are not large enough to measure the entire drum in one sweep so the first scan will be taken when the operator runs the software for the slabs. Next, he or she activates the linear actuator to bring the scanners to their second position and again activate the software. Lastly, they are risen once more to their third position and conduct their final scan. At this point the scanners are lowered back down to their resting position and their readings are totaled. Based upon these readings three things can occur; the drum will be ready to be removed, the drum is over the allowed amount and needs to be emptied, or it will continue to be filled.

If the drum is ready to be removed a drum dolly is brought up to the glove box and the mechanism is opened. The drum is then loaded onto the dolly and brought to its next destination. If the drum is not at its limit yet and will continue to be filled up then no further actions is needed. The final possibility that the drum is overfilled is the catalyst for the problem statement that birthed this project. If the drum ever reaches this level with this design in place means that scans are not being taken frequently enough or too much waste is entering at a time. However, the solution to this problem is that because the drum is still under the glovebox in a sealed state than the waste can simply be removed back up through the trap door into the glovebox. At this point the drum can be rescanned to determine if more waste needs to be removed or the drum is safe to transport.

# 18 Maintenance

## 18.1 Cleaning

To ensure that any contaminants, whether physical or radiation based, could be cleaned off of the NDA, several considerations were taken into effect. Any sharp edges that could possibly hinder wiping down the device were eliminated. Additionally, to avoid wiping the mechanism down completely, the entire design is able to be covered in plastic wrap to avoid contaminants. The cleaning process will occur as according to the LANL standards.

## 18.2 Repairs

Any physical damage to the aluminum frame of the design will just simply be repaired as needed. Additional welding may be needed if it is severely damaged, or even just replacement of parts. This is all based on the given need at the time.

Any damage or faults with the NDA slabs should be taken forth with Canberra, the providing company. The product may be under warranty depending on the conditions provided by Canberra. This also applies to the motor, hinges, and sliders.

# 19 Additional Considerations

With any project dealing in the nuclear domain, there must be many questions on the impact of the proposed change. In the world today, the public has very little understanding about nuclear systems and it is hard to discern fact from fiction without a good knowledge base. This is not helped by the general negative connotation toward nuclear technology in the media. This tends to drown out the experts and the remarkable safety record for the industry as a whole not to mention the extraordinary benefits the technology gives to society. To address these concerns for this project, below will discuss the economic, environmental, societal, political, ethic, and health and safety impact and the sustainability of the project.

## 19.1 Economic Impact

The impact to the economy of this device could be considerable in the nuclear technology sector. This device would allow for a far more streamlined processing of nuclear waste not only in the LANL facility but to nuclear facilities across the world. The device is designed to assay waste produced in any facility like rags and tools that come in contact with radioactive material. With Los Alamos saving hundreds of thousands of dollars with this device they will be able to spend more money on research and testing. This device will not change the economy on the whole but could allow for more JCC 71,72, and 73 devices to be sold for it opens a new application. Overall, it is believe that this device can eliminate muda in nuclear waste processing.

## 19.2 Enviromental Impact

The enviromental impact of this device has it ups and downs. The upside of this device is the ensurence that high level nuclear waste is dangerously buried at the Waste Isolation Pilot Plant. This site does have many safeguards to ensure this will that there will be no contamination but the device does add a layer of security. The advantage of the device is the ability to remove waste before it leaves the glovebox. The drawbacks with regard to the enviroment is the need for He-3 for the product. Although this element is the second most abundent in the universe, it is extremely rare on this planet. It is produced with the enviromentaly damaging process of natural gas production. It is a by-product of the drilling and if not capured imediately the helium escapes into space. This device will increase the need for the element thus contributing to depleting this precious resource further. On the whole, the device still does less damage than it can protect against but the depletion of a critical resouce is something that needs to be considered with care.

## 19.3 Political and Societal Impact

This device does open a current discussion for the consideration in disposing of nuclear waste. The device would be the first step of the waste on its way to the Waste Isolation Pilot Plant, which is a controversal way to dispose of low level waste. This is a politically charged issue that has successed in closing the proposed Yucca Mountain site and stands consistantly in the way of solving a resonable approche to the safe perminent storage of nuclear waste products. The device that was developed does make the processing of waste products more safe and if the process was made resonably transparent. This would help to ease the collective conscience of the society. This device put one more level of security before the waste is buried. It is doubted this one difference will make a large impact on the society but with small changes and transparency will allow for experts to be trusted. Nuclear waste has been produced but a decision on what to do with it once it is done is still up for debate. The fact of the matter is it needs to go somewhere and must be done in a safe manner. Understanding this may clear the fog in the debate over waste disposal and allow for good hearted discussion on the best route forward.

## 19.4 Ethical Impact

With any device in the nuclear field, a great deal of ethical consideration is taken and this is the same with this product. The consideration that would be the most important is the abiltiy for this product to perfort the task it is design for. This would ensure the saftey of the workers in the facility and the public on the whole. In order to upkeep the quality, each device needs to be tested and calabrated upon installation. This product does ensure that nuclear waste is safe for burial so it is important to make the device correctly and use it in the way it is intended.

## 19.5 Health, Saftey and Ergonomic Impact

One of the main purposes of this device is the saftey of nuclear workers in handling dangerous material every day. This device allows for the nuclear material to stay in glovebox area while it is being assayed thus helping in increase the ALARA standards. It also protects the nuclear workers, whom job it is to remove material if it exceeds the limit, from radiation in the way of elimiating this deviation from happening. This will stop workers from handling the dangerous waste. This will increase both health and saftey of workers. The ergonomics of the process will decrease because of the constrained area below the glovebox. It will not be markedly different but will make the work area a bit more constrained. If the device signals that the activity of the drum is too high, than attempting to remove the material from the drum within the glovebox would be fairly difficult but the cost of process out of the glovebox does justify this difficultly. Overall, this is a very safey product that protects the workers properly from the dangerous materials.

## 19.6 Substainability

This product does offer a fairly substainable design that offers a flexible solution for the problem. The design offers a flexible platform if other devices are developed similar to the JCC 71, 72, and 73 products. The collar is made with readly available materials and technology. The neutron coincidence counter is the device that is not all that substainable because of the scarcety of He-3 in the world. To help substain the resource it should be reused for new products and saved at the time when the counter excedes its lifespan.

# 20 Conclusions

The construction of the prototype has been a success. The prototype made was a half scale model due to budget constraints. The model was however tested under similar conditions that the actual device would face. The model was made out of plywood instead of aluminum, and greatly served its purpose as to demonstrate the in-line procedure and confirm the design. When designing the prototype the team had to make sure that it met all of LANL's specified requirements. The three categories that the team focus on primarily were the nuclear requirements, the mechanical requirements, and the financial requirements.

## 20.1 Nuclear Requirements

While the focus on this design was not to create a brand new non-destructive assay, the team still had to research and select one that would meet the lab's given specifications. The NDA that the team selected is a neutron coincidence counter that is able to measure in both active and passive assays. The lab wanted to have this flexibility so that they did not have to limit this design to just one process. They also had a desire for the design to have an acceptable efficiency greater than 5 percent. Obviously, the device needs to be efficient or else it would not be used and both the active and passive assay processes that were selected meet this standard. When adding a new process to the system it cannot take up too much time or else it would only become a hindrance. The proposed solution can run its tests at all three heights in under one hour, a time that the lab finds suitable. The accepted level of radiation is to have no more than 100 nano-curies per gram in the drum, and this measurement is to be taken at an efficiency of greater than 5%. The device is more than accurate enough to get a reading this low. Lastly the system has to be user friendly, the representative from Canberra assured that this systems software is very user friendly and easy to operate. Each specification given to the team was considered and met when designing the final solution.

## 20.2 Mechanical Requirements

Los Alamos also gave the team a list of requirements that the design had to meet in regards to the mechanical aspect. The first and most important is that the design maintain the in-line process that currently exists. They do not want any major changes to the layout they currently use, so the team decided to install the device beneath the glove box where there is currently nothing but empty space. With the need to have multiple types of readers means that there needs to be an easy process for changing them. The final design has a simple removable portion that can be swapped out for a different device in just a few minutes. The motor has to be able to move the entire system vertically the entire length of the drum. The one selected operates with 4000 pounds per inch torque and should have no trouble with the basic function of raising the scanner. When designing the frame of the device the team had to consider how sturdy it needed to be. After several calculations, it was determined that the frame needs to hold 150 pounds. This knowledge came into consideration when determining what materials were to be used. The actual drum that is being measured may not always be a 55-gallon drum and therefore the device has to be adaptable enough to measure several different drums. The maximum diameter than can be entered into the system is 23.5 inches which is large enough to handle any container needed. Lastly, just like in the nuclear requirements, the device needs to be user friendly. Prior to completion of this project the team will create a Standard Operating Procedure on how to use the device. In theory, it should only require a couple buttons that when clearly labeled will be self-explanatory.

## 20.3 Financial Requirements

The entire purpose of this project is to prevent the number of or even eliminate the need for process deviations. This problem costs the company 150,000 dollars per process deviation and happens approximately 5 times a year. At an average of 750,000 dollars a year the solution to this problem could save the company millions of dollars. Also, the initial cost and annual costs of this solution will come nowhere near as much. The team broke down the costs into two main categories, mechanical and nuclear materials. The mechanical portion is what the team plans on constructing and is relatively inexpensive at only a couple hundred dollars. The nuclear materials are the physical devices that need to be installed. This cost is approximately 175,000 dollars and would be paid for by the DOE if they choose to use the proposed solution. Even though this sounds like a lot for a senior design project, if it can solve a million-dollar problem then the cost should be no concern.

## 20.4 Summary

After doing all of the analysis, planning, and designing, the team feels that this device meets all of the requirements set by LANL. After further testing of the half scale model, all physical requirements have been met and the construction was ruled a success. The next step is the build the full scale model, made of aluminum, and order the NDAs from Canberra. After this is pieced together the system will then be fully functional in the Los Alamos Lab. The group sponsor, Jennifer Alwin, thinks that project went very well and met all standards previously set.

# 21 Acknowledgments

Pu Smells would like to thank the faculty of the University of Rhode Island especially Professor Bahram Nassersharif for meeting with the team during his office hours and providing the team with resources. The team would like to thank David Ferreira for the help provided in the fabrication of the prototype. The team owes a special degree of thanks to Los Alamos National Laboratory and Jennifer Alwin specifically for her continuous investment in the success of the design challenge. Thomas Oulette and Sasha Philips from PBC Linear and Canberra Industries respectively took generous ammounts of took time out of their days to help the team understand some problems that needed to be overcome. The team is very thankful for all the help that was received and looks forward to continuing the work into the new year.

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# 23 Appendices

## 23.1 Appendix A: Project Planning

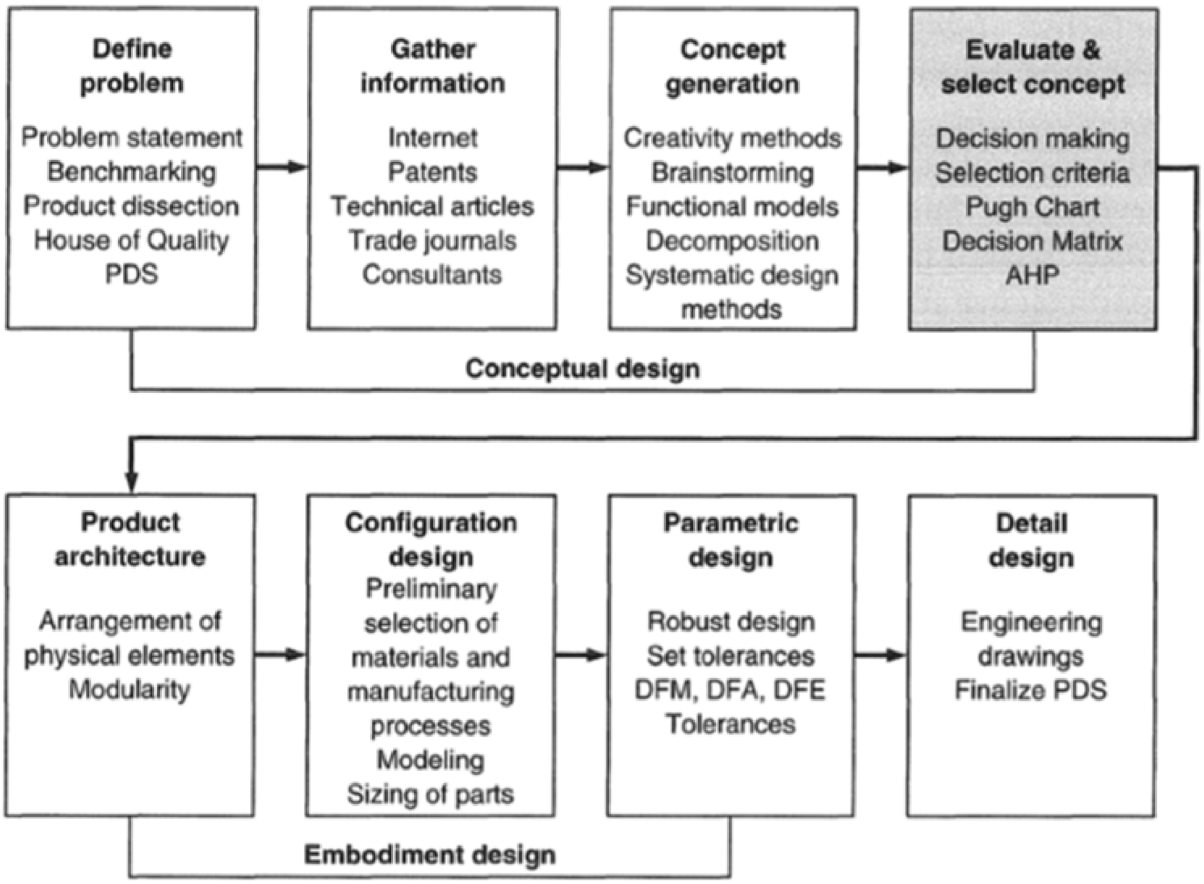



Figure 58: Design Process

## 23.2 Appendix B: Product Design

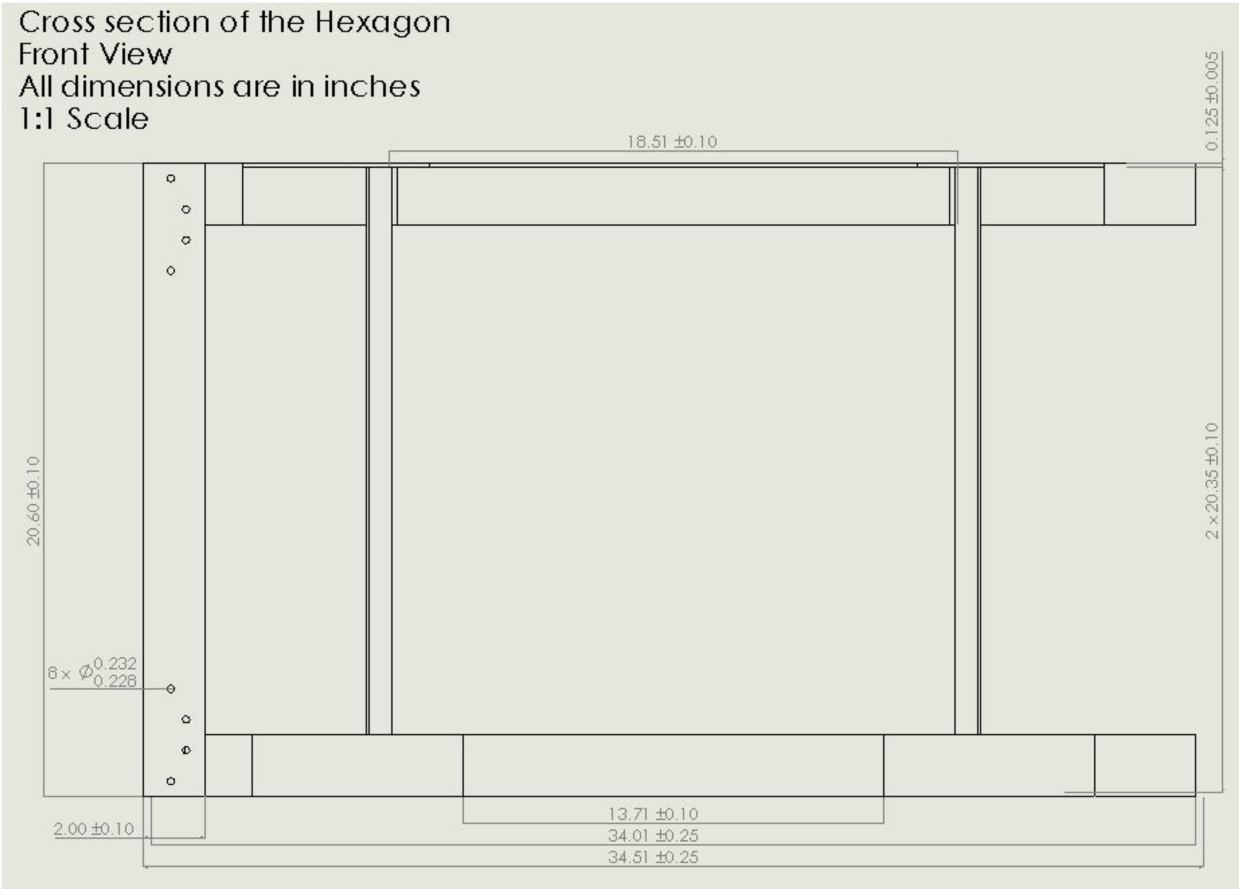



Figure 59: Front View of the Cross Section Hexagon Slab Holder

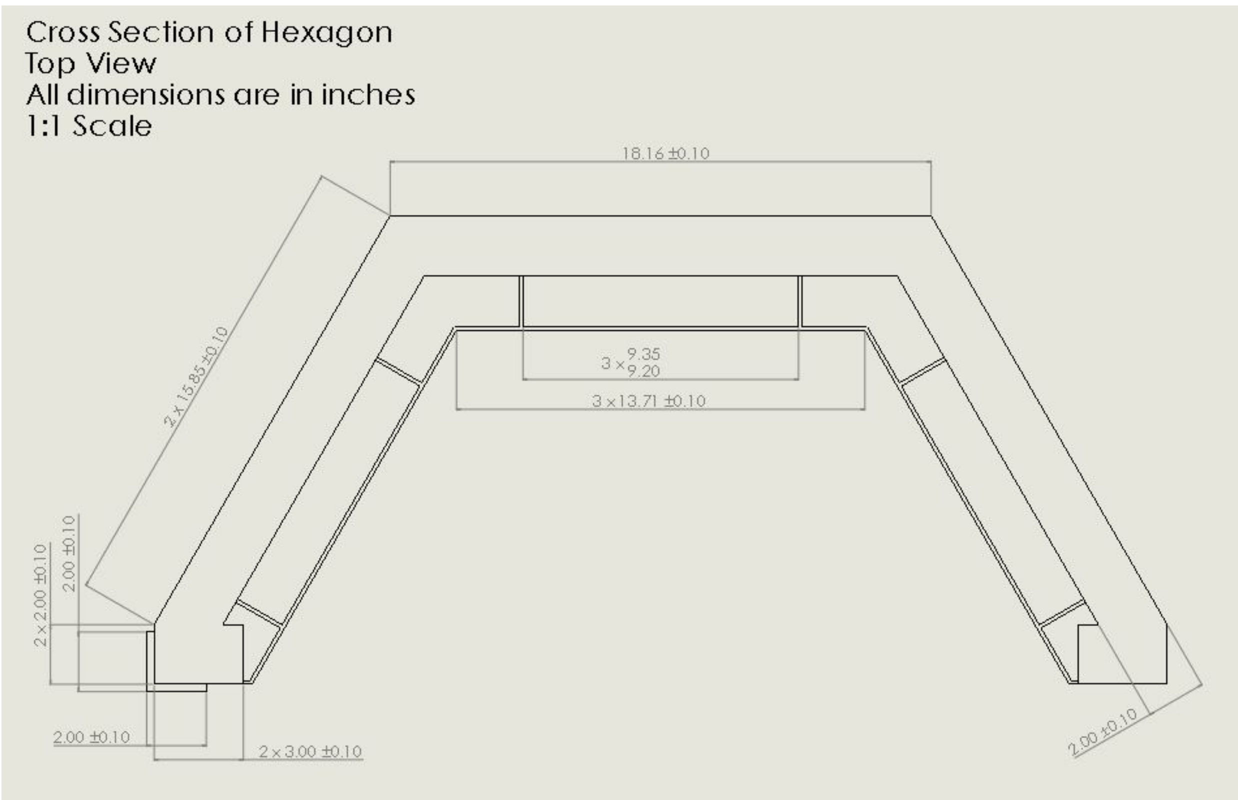



Figure 60: Top View of the Cross Section Hexagon Slab Holder

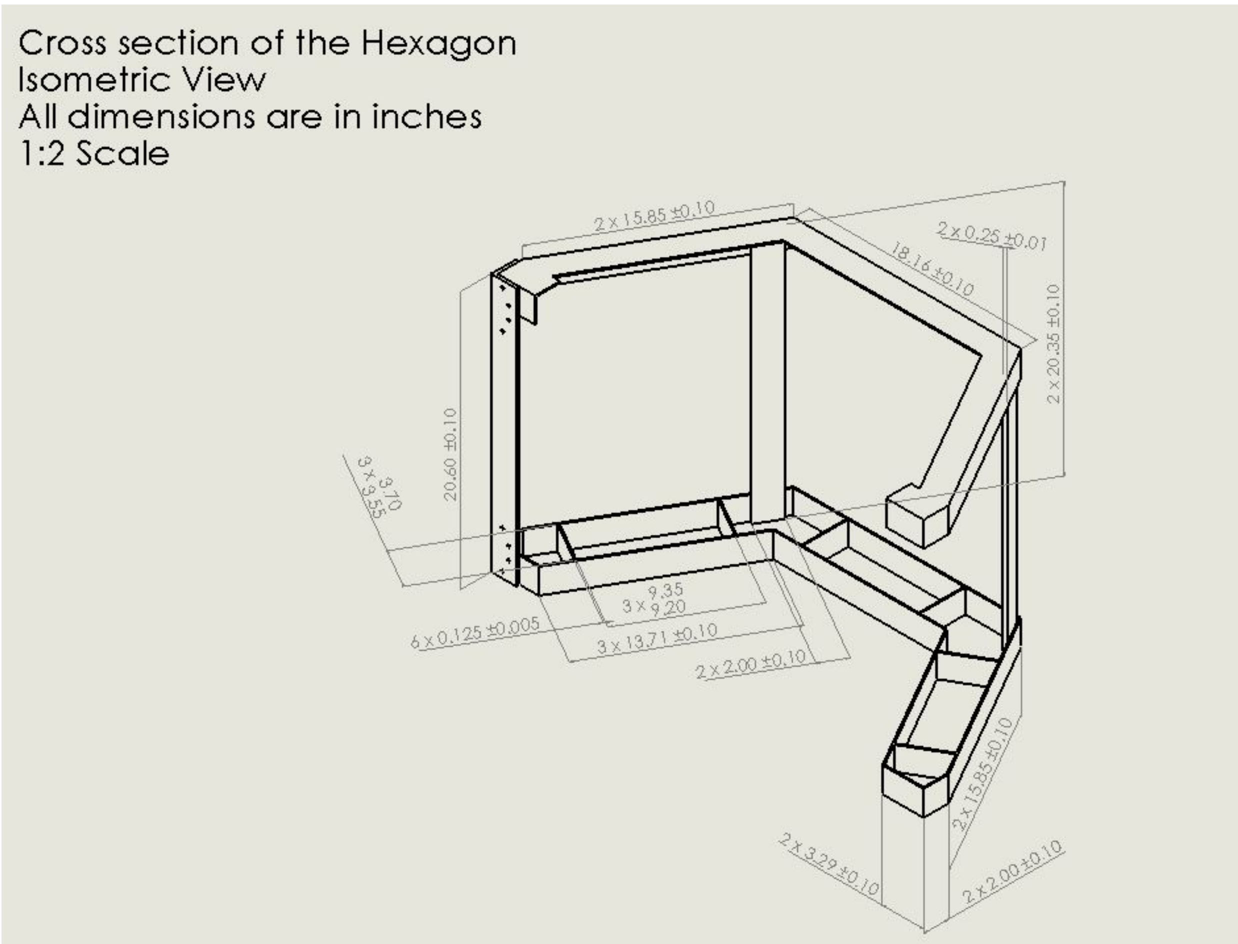



Figure 61: Isometric View of the Cross Section Hexagon Slab Holder

### 23.3 Appendix C: Half Scale Prototype

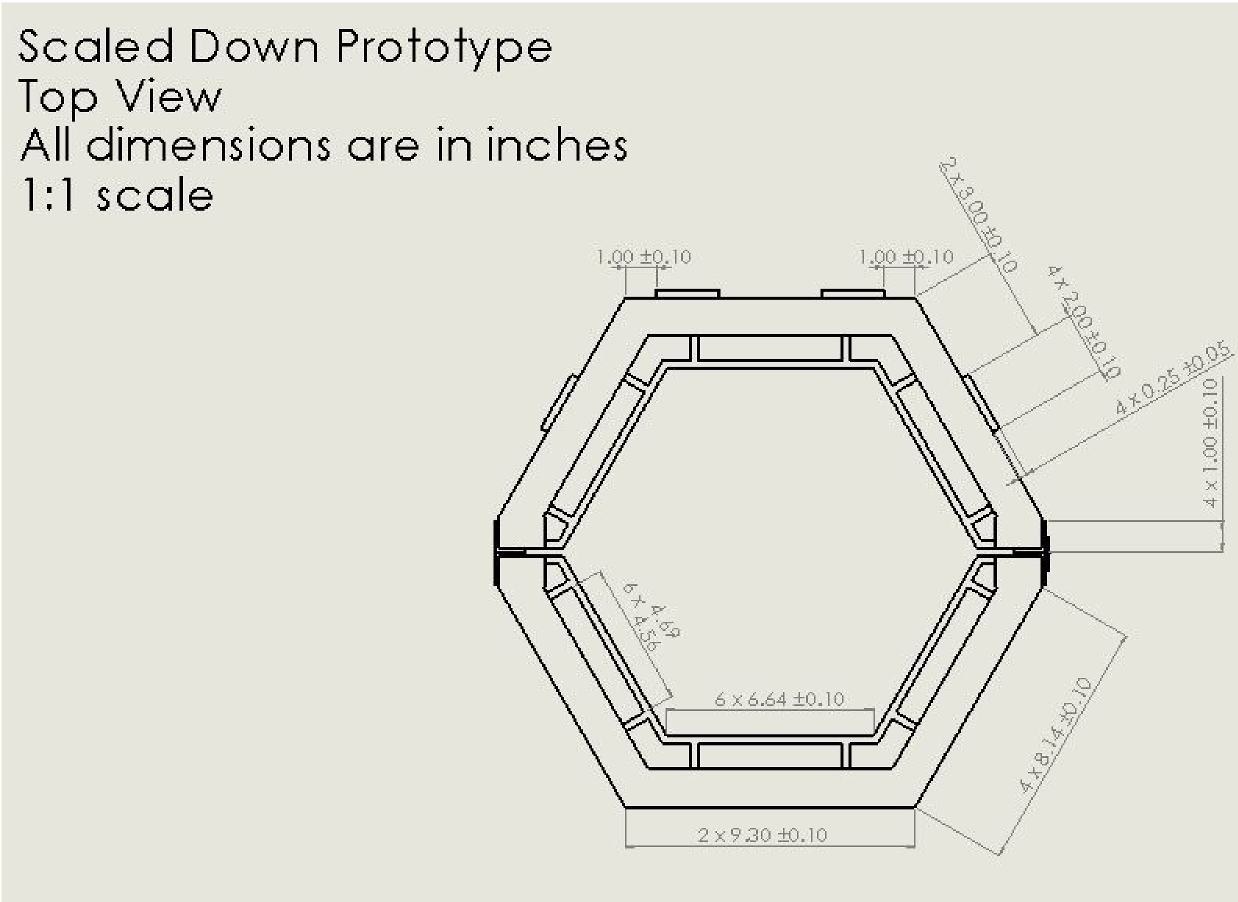



Figure 62: Top view of the half scale prototype

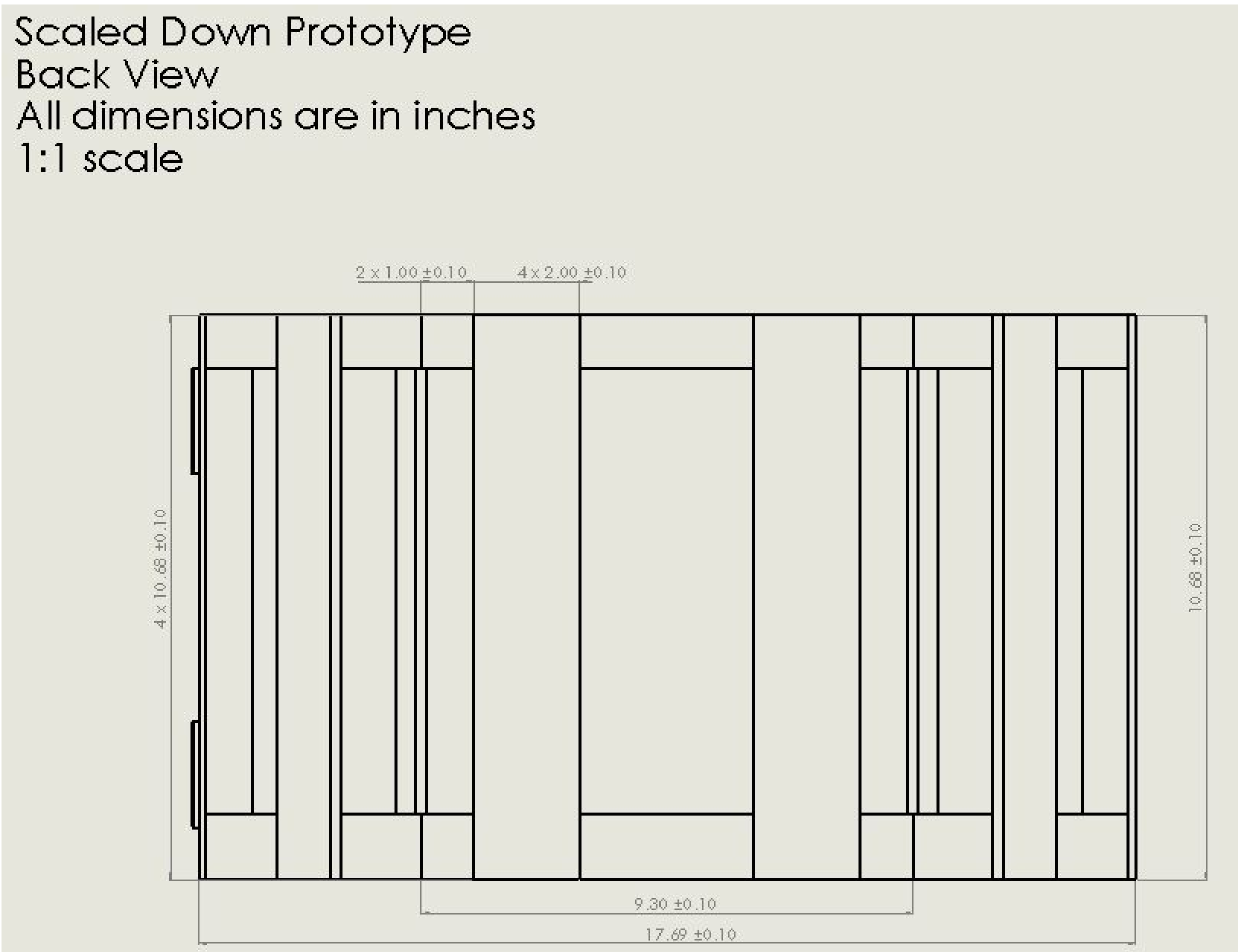



Figure 63: Back view of the half scale prototype

## 23.4 Appendix D: Data Sheets

CANBERRA

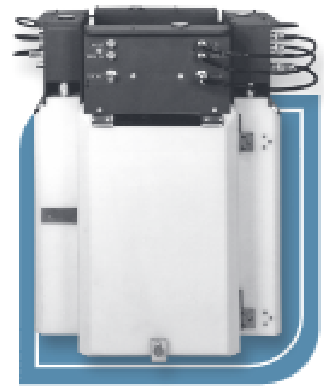
### Features

- Designed for neutron coincidence measurement of uranium in PWR, BWR and CANDU fuel assemblies, or plutonium in MOX fuel assemblies
- Variable sample cavity size (Model JCC-71)
- Fast Amptek® electronics
- $^{3}He$ detectors
- Transportable
- Optional transport container
- Authorized for routine inspection use by the International Atomic Energy Agency (IAEA) as the Uranium Neutron Collar (UNCL and UNCL II)

# Model JCC-71, 72 and 73 Neutron Coincidence Collars

### Description

The Model JCC-71 Neutron Coincidence Collar is a passive/active neutron counter for the measurement of the $^{235}U$ content per unit length in fresh PWR, BWR and CANDU fuel assemblies. The JCC-71 can also be used to measure the plutonium content of MOX fuel. The system design is based on technology transfer from the Los Alamos National Laboratory.

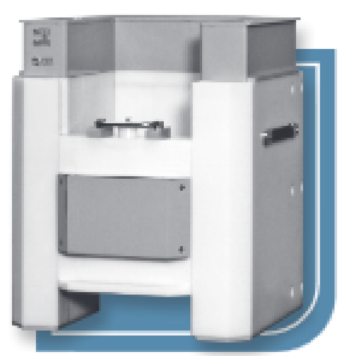


Model JCC-71 (Passive)

The JCC-71 is made up of four counter banks, each composed of high-density polyethylene for the moderation of the fission neutrons. Each bank contains several $^{3}He$ detectors for the detection of neutrons. The counter can operate in both an active mode and a passive mode. For the passive mode, all four counter banks are used around the fuel assembly. If operated in the active mode, one bank of detectors is replaced with a polyethylene bank containing only an Americium-Lithium (AmLi) interrogating source. (The AmLi source must be ordered separately.)

Model JCC-72 (Active)

In the active mode, the AmLi source is required to interrogate the fuel, and coincidence counting of the induced fission neutrons from $^{235}U$ is performed. The AmLi source is contained in a tungsten source bottle and placed inside the polyethylene bank. The AmLi neutrons are thermalized in the polyethylene and induce fission in the $^{235}U$. The average energy from the induced fission is higher than the moderated AmLi neutrons and gives fast neutron multiplication which allows the measurement to penetrate into the interior of the fuel assemblies. For HEU fuel, cadmium liners can be added to improve neutron penetrability.



Model JCC-73 (Active)

Figure 64: JCC 71, 72, 73 Data Sheets

# Model JCC-71, 72 and 73 Neutron Coincidence Collars

To measure the $^{238}U$ content, the bank with the AmLi source is replaced by the fourth bank of $^{3}He$ detectors, and the counter is operated in a passive mode, counting the coincidence neutrons from spontaneous fission of $^{238}U$. The collar measures the $^{235}U$ and $^{238}U$ content along the axis of the assembly, not the enrichment. Since the $^{235}U$ content is of primary interest for safeguard purposes, only the active measurement is typically necessary. Pu-containing fuel rods are measured in the passive mode because of the relatively high spontaneous fission rate.

The JCC-71 Neutron Coincidence Collar is designed to allow modification of the geometry to closely couple the detectors with the fuel type. For the smaller BWR fuel, the side detector banks are moved into the inner screw-hole position. The fourth bank of $^{3}He$ detectors (used in passive mode) is hinged in order to facilitate placing the counter around fuel assemblies.

The Neutron Coincidence Collar is designed to be insensitive to parameters such as open channels for control rods, enrichments, angular orientation of the fuel in the Collar, fuel pellet density, and any protective bagging. Cladding type (zinc alloy or stainless steel), different fuel pellet diameters, and neutron absorbers (Gd2O3) can affect the measurement.

A Neutron Coincidence Analyzer (or shift register), a computer, and analysis software are required for coincidence counting and must be purchased separately from the JCC-71.

The increased use of neutron collars at various facilities for measuring designated fuel types (BWR or PWR), led to two additional designs by Los Alamos National Laboratory. The two additional neutron collar counters are the JCC-72 for BWR and CANDU fuel assemblies, and the JCC-73 for PWR fuel assemblies.

## Specifications

### PERFORMANCE

- HV Setting – 1680 V.
- Required AmLi Source Strength – JCC-71, 5 x $10^4$ n/s; JCC-72 and JCC-73, 1 x $10^5$ n/s. (not included with counter).
- Gate Setting – 64 µs.
- Efficiency – JCC-71 (Passive, PWR Configuration), 11.5% ±10%; JCC-72 (Active), 13.5% ±10%; JCC-73 (Active) 12.5% ±10%.
- Sensitivity (JCC-71)[1,2] – 2.2 rods for iron substitution; 2.8 rods for empty substitution.

2. Sensitivity is defined as the minimum number of rods that can be substituted and detected in a 1000 second count at a confidence level of 2 sigma.

### PHYSICAL

- Weight – JCC-71, 38 kg (84 lb).
- Sample Cavity Size
  - PWR Assemblies – 41.4 x 23.4 x 23.4 cm (16.30 x 9.21 x 9.21 in.) H x L x W.
  - BWR/CANDU Assemblies – 41.4 x 16.5 x 23.4 cm (16.30 x 6.5 x 9.21 in.) H x L x W.
- $^{3}He$ Tubes
  - JCC-71 (Passive Mode) – 24.
  - JCC-71 (Active Mode) – 18.
  - JCC-72 (Active Mode) – 16.
  - JCC-73 (Active Mode) – 20.
- $^{3}He$ Active Length – 33 x 2.54 cm (13 x 1 in.) L x Dia.
- Cladding – Aluminum.

### OPTIONS

- Passive fourth bank for JCC-72 and JCC-73.
- $^{252}Cf$ neutron source for verifying proper operation.
- Cart to vary the vertical and horizontal position of the counter.

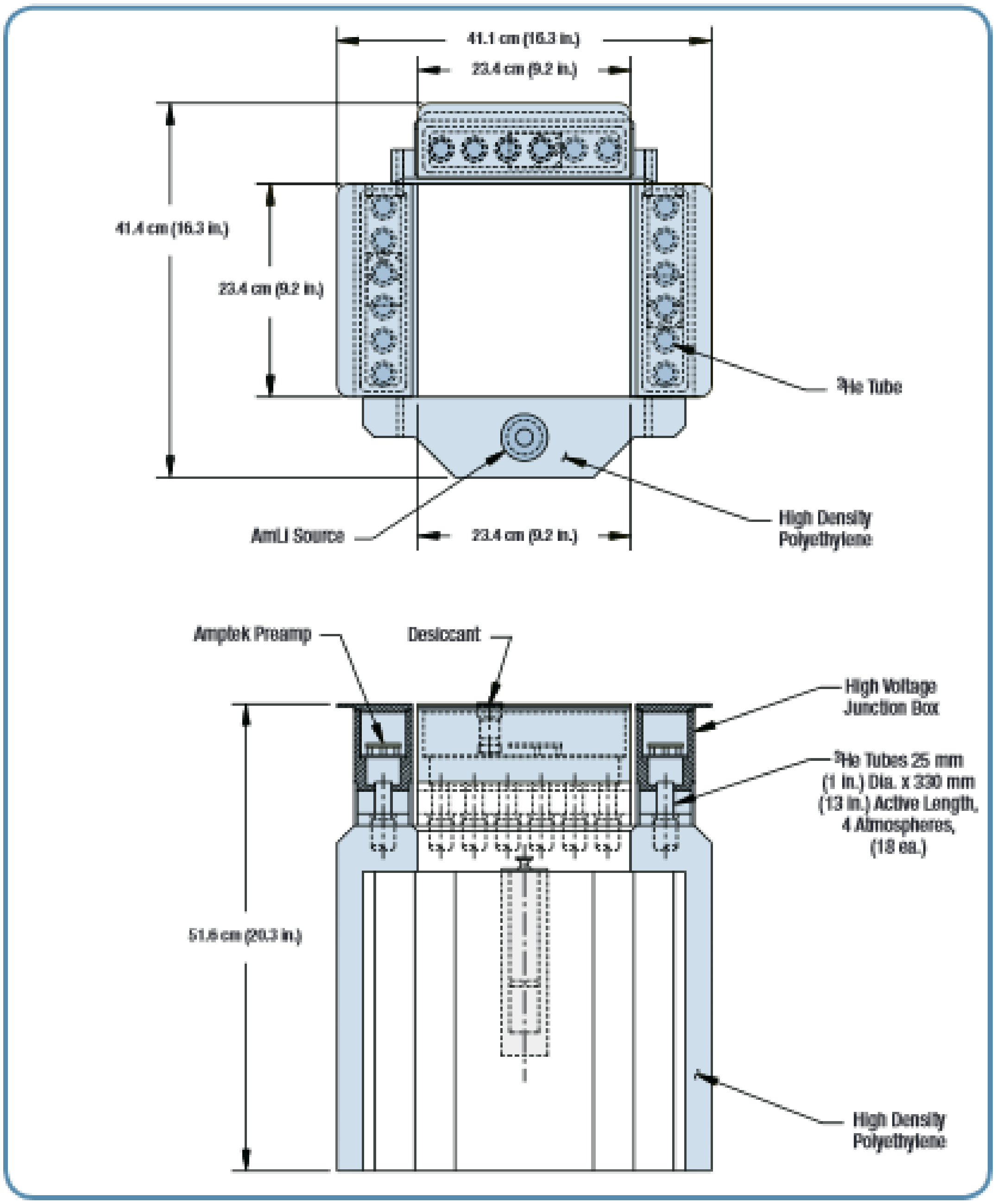
### REFERENCES

1. Menlove, Howard A. (1981). Description and Performance Characteristics for the Neutron Coincidence Collar for the Verification of Reactor Fuel Assemblies. *Los Alamos National Laboratory Report LA-8939-MS*. Los Alamos, New Mexico.

ISO 9001 SYSTEM CERTIFIED

Figure 65: JCC 71, 72, 73 Data Sheets

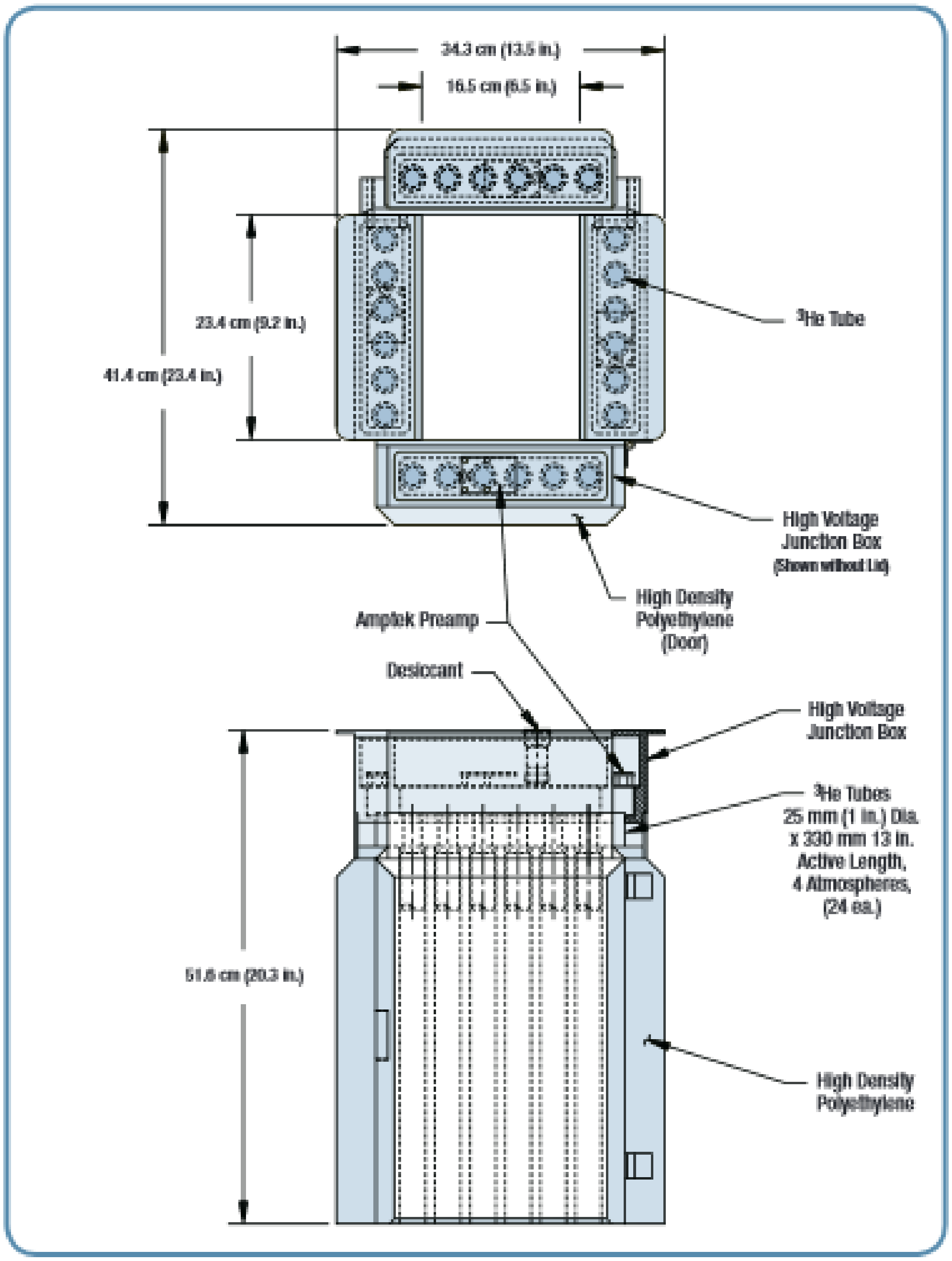
# Model JCC-71, 72 and 73 Neutron Coincidence Collars




JCC-71, PWR Active Configuration

Figure 66: JCC 71, 72, 73 Data Sheets

# Model JCC-71, 72 and 73 Neutron Coincidence Collars




JCC-71, PWR Passive Configuration

Figure 67: JCC 71, 72, 73 Data Sheets

CANBERRA

## Features

- Combines multiplicity capabilities with traditional coincidence counting at one low price
- Operates in selectable JSR-12 or Multiplicity mode (CANBERRA 2150)
- Is fully computer controlled
- Similar to the CANBERRA InSpector™ in form factor
- Based on the Los Alamos design
- Like for like replacement of JSR-12 when operating in the JSR-12 mode
- Uses same JSR-12 battery backed RAM for storage of data points and systems settings
- Supplied control software used for setup and acquisition is easy to learn, based in Visual Basic®, and is compatible with Windows® 95 and NT® operating systems
- Can operate from facility mains with battery in reserve or with batteries in "Ping Pong" mode
- Configurable to operate with high voltage operative after power is lost and restored without rebooting system software
- Selectable long delay of 1 or 4 ms provides optimal counting conditions for both coincidence or multiplicity applications
- Battery operation, small size and light weight makes it ideal for portable applications
- Special features allow for installed operation as well

# Model JSR-14 Neutron Analysis Shift Register

## Description

The JSR-14 Neutron Analysis Shift Register is a portable, fully computer controlled neutron analyzer that provides both neutron coincidence and multiplicity capability that is selectable through use of the provided setup software. The JSR-14 functions as a direct replacement of the CANBERRA JSR-12 Neutron Coincidence Analyzer and the 2150 Multiplicity Module. The JSR-14 is based on a Los Alamos specification and shares the same chassis and form factor of the CANBERRA InSpector Multi-Channel Analyzer. The JSR-14 is fully compatible with existing software operating with either the JSR-12 or CANBERRA 2150 Multiplicity Module. The JSR-14 supports the same JSR-12 battery backed storage of system settings and 3000 data runs with time and date stamping of all data points by the system real-time clock. Also, the JSR-14 has the ability to operate in one of three different high voltage modes for portable and facility installed neutron counting applications. In addition, the JSR-14 can be powered with an ac charger/adapter using facility provided ac power, or operated with the unique "Ping Pong" camcorder battery system found on the CANBERRA InSpector. When using ac power, the JSR-14 is protected from power loss for three hours by the use of a battery in the spare battery port. The memory buffer and hardware settings are protected by a lithium battery that is designed to operate for five years and easily replaced. Another feature is a programmable long delay of 1 and 4 milliseconds providing compatibility with 2150 multiplicity and JSR-12 coincidence settings.

### ELECTRONICS

All JSR-14 front end electronics are programmable. The JSR-14 features signal input, two auxiliary scalers, gate input, gate output (TTL output level configurable in JSR-12 or 2150 Multiplicity mode), RS-232 serial interface, and a High Voltage output. In addition, the JSR-14 has sufficient +5 V dc output to power ten JAB-01 Preamp/Discriminator boards. Full computer control of the front end eliminates physical switching of modules or jumpers. Functions such as changing the detector bias are totally computer controlled. The user will never have to initiate changes in operating parameters.

### USER INTERFACE

The user interface is provided through a notebook or other suitable computer. A status display panel on the acquisition unit displays all vital information to its user. Brightly colored, well positioned status LEDs provide battery state and instrument status information. A total of four LEDs cover the critical status of the instrument – the two battery states, the acquisition status, and the high voltage status.

Figure 68: JSR 14 Data Sheets

# Model JSR-14 Neutron Analysis Shift Register

**SOFTWARE**

The JSR-14 comes with a neutron setup and acquisition software package that is based in Visual Basic and is compatible with Windows 95 and NT. It allows the operator to quickly define the operating modes, set up the counting parameters, and manually collect coincidence and multiplicity data. This software package displays the Reals plus Accidentals (R+A), Accidentals (A) and Totals (T) data during acquisition in real time for both coincidence and multiplicity modes. In multiplicity mode, the individual multiplicity channels are available for inspection after the acquisition is completed. All system configuration and hardware settings are stored in non-volatile memory, available in the event of power loss.

MODE CONFIGURATION – System configuration information is contained within the system bootstrap. Any changes in mode settings require a reboot of the JSR-14. The following mode selections are available from the software:

UNIT MODE – User selects operation in either JSR-12 (coincidence) or CANBERRA 2150 (multiplicity) modes.

POWER MANAGEMENT MODE – User selects the primary power source as ac mains or batteries.

HIGH VOLTAGE MODE – User selects to operate JSR-14 high voltage control in manual, installed or portable modes.

BAUD RATE – Configured from factory for initial system startup in autoranging mode, user may select new rate.

HARDWARE CONFIGURATION – In the hardware setup portion of the software, the user may select the gate width, predelay, high voltage, count times, and counting recycle configurations. The system acquisition screen informs the user of the system settings and counting data during acquisition.

**DATA ACQUISITION**

The JSR-14 internal clock rate is 4 MHz, with a pulse pair resolution of 50 ns. Internal diagnostics continuously monitor the state of the data acquisition, providing internal flagging of under and over flows whenever they occur. A second and third totals counter is provided for an additional channel input. They can be operated in synchronization with the regular input or as a totally separate counter.

**POWER MANAGEMENT**

A unique feature of the JSR-14 is the dual battery design with programmable power management. There are two power management modes, AC Mains Mode and Battery Mode that are selectable using the JSR-14 set up and acquisition software. Instrument power is always derived from one of the two power ports, whether it is from the ac power supply or a battery. Two front panel LEDs provide a complete picture of the battery's operation and status. The port currently in use is indicated by a blinking green LED. An ac power adapter accepts multivoltages rated from 110 to 220 V ac at 50 to 60 Hz.

BATTERY MODE– In battery mode, the system monitors both batteries, switching to draw power from the port with the lowest power available. As this battery cycles through its discharge curve, the system will detect a "battery low" condition and change the LED color to a blinking red. This indication is a prelude to an automatic battery switchover. Continuous operation of the instrument will be assured if the battery in reserve is charged and ready to go as indicated by the green LED status. At switchover, the now depleted battery is indicated by a constant red LED color, while the new battery LED assumes a blinking green status. Uninterrupted continuous operation can be maintained indefinitely by changing the discharged battery as the power manager switches from old to new.

AC MAINS MODE – In ac mains mode, the system is set up for power supplied from port "A" where the AC Power Adapter is connected. A battery is then connected to port "B", acting as a backup. An automatic switchover to the alternate battery port will occur if ac power is lost. In this way, the instrument is essentially set up for battery backed ac operation. The LEDs indicate system power status as described above in "Battery Mode".

**HIGH VOLTAGE**

Three separate high voltage modes are available to the user.

MANUAL MODE – High voltage is turned ON independent of setting the high voltage magnitude value.

INSTALLED MODE – High voltage operates in conjunction with the main power switch. This feature is designed to provide support for unattended neutron counting systems. High voltage is made available to detectors after power is lost and restored without rebooting system software. The system operates by storing the status of the voltage internally. When the power is shut down, and brought back again, the system automatically provides its original high voltage value.

PORTABLE MODE – High voltage can be set and operated in an implied fashion using a single set-voltage command or in a similar manner to the Manual Mode, using two separate commands.

Figure 69: JSR 14 Data Sheets

# Model JSR-14 Neutron Analysis Shift Register

### PACKAGING

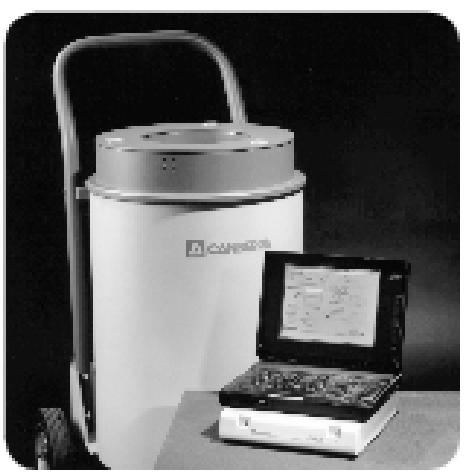
JSR-14 batteries are commercially available Sony® compatible camcorder type. They are 5 cm (2 in.) long and 3.8 cm (1.5 in.) thick, and allow approximately four hours of operation with ten JAB-01 preamplifier boards. Replacements are readily available in most camera stores, and are expected to be supported by industry for a very long period of time. The battery ports are external, with easy access. Dual batteries ensure uninterrupted operation as the user can change one while the other maintains power to the instrument.

### CARRYING AND STORAGE

Carrying the instrument is similar to carrying an executive style notebook PC. A soft-sided carrying case suitable for the JSR-14, notebook PC, and accessories are included. The instrument can be conveniently carried in an attaché case.

### APPLICATIONS

The JSR-14 is a data acquisition and analysis electronics package used in the measurement of plutonium and uranium (high and low enriched) materials. The added flexibility of coincidence and multiplicity counting ability, provides the user with analysis capability for a broad range of material configurations. These configurations include: Pu pellets, powder, solutions, Mixed Oxides, MOX fuel pellets, Pu fuel assemblies, HEU and LEU in metals, oxides, powders, fuel pellets and rods, as well as uranium hexaflouride ($UF_6$) samples. The multiplicity analysis capability is very useful for measurement of scrap and other waste materials. The JSR-14 can also be used in various gross neutron counting applications such as those found in facility installed process systems.



**Small size and battery operation make the JSR-14 ideal for portable applications**

NUCLEAR SAFEGUARDS – Nuclear safeguards applications prevent unauthorized diversion of nuclear material. Regulatory Agencies routinely make *in situ* measurements during inspection trips at various nuclear sites. Data collection times are often short, and sometimes they must be conducted in hostile environments.

PORTABLE APPLICATIONS – The JSR-14 is designed to facilitate travel, allowing for quick setup and disassembly. Such measurements are performed at a site for extended periods, often in harsh industrial environments. The JSR-14 enclosure is very rugged, absorbing shock due to minor impacts. The JSR-14 configured battery mode, allows full day continuous operation using the CANBERRA JCC-12/13 (INVS) from batteries alone, while an AWCC or HLNC can be operated for about seven hours. If required, the user can replenish batteries without interrupting data acquisition, providing indefinite counting capability, as long as there are charged batteries on hand.

INSTALLED APPLICATIONS – The JSR-14 portability does not compromise any of its installed applications' abilities. Operating from the ac mains, a battery in reserve, and high voltage configured in the "Installed Mode"; the JSR-14 is ideal for an installed neutron counting system, operating in attended or continuous unattended safeguard applications. The JSR-14 operates with any software already running JSR-12 or the 2150 multiplicity modes, making it a drop-in replacement for already installed systems.

## Specifications

### CONNECTORS

- SIGNAL – Rear panel BNC connector accepts TTL compatible pulses for standard shift register counting or multiplicity operation; pulse width >30 ns.
- AUX 1 – Rear panel BNC connector accepts TTL compatible pulses for 1st totals scaler; pulse width >30 ns.
- EXTERNAL – Rear panel 9-pin female D-style connector; pins 1, 6, 7 and 8 are ground; pin 9 is not connected.
  - Pin 2: Aux 2 – TTL compatible input for second totals scaler; pulse width >30 ns.
  - Pin 3: Index – TTL compatible input used to trigger a cycle.
  - Pin 4: Gate Out – TTL compatible output; Low when counting and High when Idle.
  - Pin 5: Gate In – TTL compatible input; High suspends counting and Low for normal operation.
- +5 V – Rear panel BNC connector providing a +5 V dc output; ±1%; 700 mA max; short circuit protected.
- HV – Rear panel SHV connector (isolated from chassis ground by 47 Ω resistor) providing +500 to 2500 V dc with 100 µA output current capability; programmable resolution of 1 part in 2048.
- RS-232 – Rear panel 9-pin male D-type connector; EIA RS-232 interface to host personal computer. Supports baud rates of 300, 600, 1200, 2400, 4800, 9600, and 19.2 k.

Figure 70: JSR 14 Data Sheets

# Model JSR-14 Neutron Analysis Shift Register

## CONTROLS

- ON/OFF: OFF – No power is consumed. ON – Batteries continually tested and status displayed using front panel LEDs.

## INDICATORS

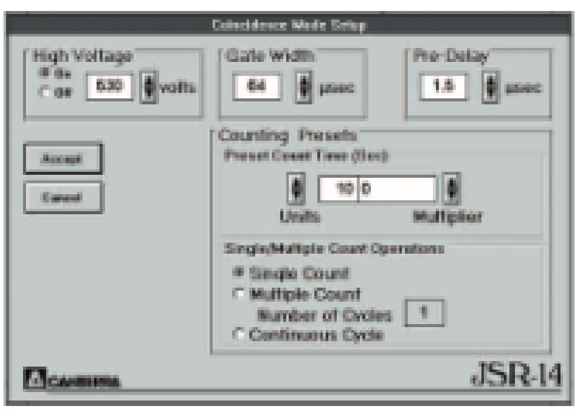
- BATTERY STATUS – A, B – Red/Green LEDs indicate the following:
  - OFF – Battery not installed.
  - BLINKING GREEN – Battery good and in use.
  - STEADY GREEN – Battery good and available.
  - BLINKING RED – Battery low warning and in use.
  - STEADY RED – Battery low warning or discharged.
- BATTERY CAPACITY – LED array indicators standard on Sony Battery Pack Model NP-80D, or equivalent.
- HV – Yellow LED to indicate the presence of HV at the rear panel SHV connector.
- ACQ – Green LED to indicate that a count is in progress.

## POWER SUBSYSTEM

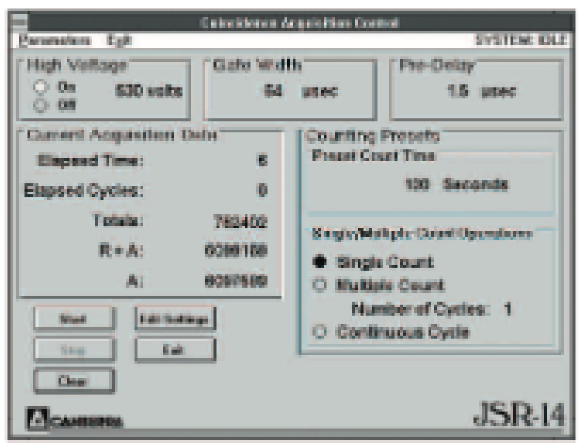
- BATTERY PACK – Dual 6 V NiMH battery packs; standard Sony Model NP-80D Battery Pack, or equivalent, such as Duracell DR-11 (ICN 95200440).
- BATTERY LIFE – Approximately four hours of counting for two batteries when connected to a Neutron Counter containing ten JAB-01 Preamp/Disc boards.
- POWER RESERVE – Battery cartridges may be changed, one at a time, without interrupting instrument operation.
- FAST CHARGER – Separate charger for standalone batteries; charge time: approximately three and one half hours; standard Sony AC-V16 (ICN 95200436) or equivalent.
- AC ADAPTER – 110/220 V ac powered external supply connected to the instrument in place of Battery A. Battery B can be used to supply power to the instrument if mains (ac) power is lost.
- BATTERY BACKUP – Battery backup used to run the Real Time Clock and 3000 run storage.
- LOW BATTERY SENSOR – When both batteries packs become fully discharged, the instrument will automatically enter the OFF state, disconnecting the batteries to prevent damage due to deep discharge.
- POWER MANAGEMENT – Power Management allows setting of ac or lowest battery first and automatic battery switch over.
- SYSTEM POWER CONTROL – No System Power Control from host computer; always full power.

## HVPS

- MULTI-RANGE – Programmable +500 to +2500 V dc; resolution to within 1 part in 2048.
- LOAD CURRENT – 100 µA.
- NON-LINEARITY – <±0.6% of full scale.
- RIPPLE AND NOISE – ≤50 mV peak to peak at rated load current.
- TEMP COEFFICIENT – ≤±50 PPM/°C after a 30 minute warm up.
- REGULATION – ≤0.02% variation in output voltage over the load range at constant ambient temperature.
- OVERLOAD PROTECTION – Power supply will withstand any overload, including a short circuit, for an indefinite period.
- CURRENT LIMIT – 350 µA maximum.
- SETTLING TIME – < 100 V/s, turn ON or OFF.




Setup of the JSR-14 is easy using the included setup software




Performing coincidence or multiplicity measurements is fast and easy with the JSR-14

Figure 71: JSR 14 Data Sheets

# Model JSR-14 Neutron Analysis Shift Register

## SHIFT REGISTER

- COUNTING REGISTERS:
  - REAL+ACCIDENTAL – 48 bits deep; internally clocked at 4 MHz.
  - ACCIDENTAL – 48 bits deep; internally clocked at 4 MHz.
  - TOTALS – 36 bits deep; internally clocked at 4 MHz.
- DERANDOMIZING BUFFER – 16-event deep buffer on signal input; random input capture rate; synchronized output rate at 4 MHz.
- PULSE PAIR RESOLUTION – 50 ns.
- DATA STORAGE – Storage of last 3000 runs in battery backed RAM.

## MULTIPLICITY SCALERS

- SCALERS – 256 channels; 32 bits deep.
- DATA STORAGE – Internal histogram memory with storage of the last multiplicity data run in battery backed RAM.

## AUXILIARY SCALERS

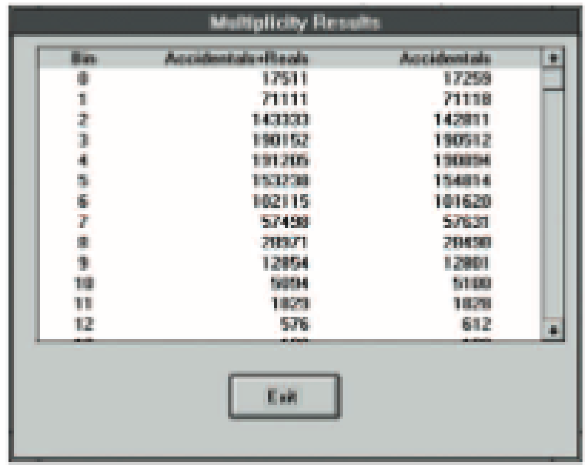
- SCALERS – Two scalers AUX1 and AUX2; 40 bits deep each; 2-event deep buffer; random input capture rate; synchronized output rate at 16 MHz.
- PULSE PAIR RESOLUTION – 50 ns.
- DATASTORAGE– No storage of data in battery backed RAM.

## PROGRAMMABLE PARAMETERS

- AUX COUNTER CONTROL – Independent start/stop of auxiliary counters.
- HVPS SETTING – +500 V dc to +2500 V dc; resolution to within 1 part in 2048.
- TIME AND DATE – Real time clock/calendar with seconds, minutes, hours, day, date, month, and year with leap year compensation. 24 hr mode. Accuracy of ±1 minute per month at 25 °C. Five years of operation with a lithium battery if no power is applied.

## JSR-12 PROGRAMMABLE PARAMETERS

- GATE WIDTH – 1 to 250 µs in 1 µs steps.
- PREDELAY – 0.5 to 7.5 µs in 0.5 µs steps.
- PRESET – 0.1 to 9.9 x $10^9$ s.
- MULTIPLERUN – Continuous cycles or preset for 1-99 cycles.




Multiplicity results are readily available once data acquisition is complete

## 2150 PROGRAMMABLE PARAMETERS

- GATE WIDTH – 0.25 µs to 1024 µs in steps of 250 ns.
- PREDELAY – 0 to 1023.75 µs in steps of 250 ns.
- PRESET – 0.1 to 1.67 x $10^8$ s.
- MULTIPLE RUN – Continuous counting cycles retaining data from the previous count cycle only.

## PHYSICAL

- SIZE – 26.9 x 27.2 x 4.8 cm (10.6 x 10.7 x 1.9 in.) width x depth x height.
- WEIGHT – 3.2 kg (7.0 lb) with batteries.
- OPERATING TEMPERATURE – 0 to 45 °C.
- RELATIVE HUMIDITY – 8 to 80%, non-condensing.

## ENVIRONMENTAL

- OPERATING TEMPERATURE – 0 to 50 °C.
- OPERATING HUMIDITY – Up to 95%, non-condensing. Tested to the environmental conditions specified by EN 61010, Installation Category I, Pollution Degree 2.

## OPTIONS

- Model 1212 Cigarette Lighter Adapter.

Figure 72: JSR 14 Data Sheets

CANBERRA

# NDA 2000
# Non-Destructive Assay Software

## Features

- Supports all CANBERRA safeguards and waste assay systems
- Supports neutron and gamma-ray assay systems
- Based on the CANBERRA's Genie™ 2000 platform
- Provides full control of data acquisition electronics
- Controls automated assay system operation
- Menu structure for ease of operation
- Customer editable report formats
- Multi-level password control
- Compliant with ISO 9001 and IEEE 730 requirements
- Developed in compliance with the requirements of ISO 9001 and the requirements of CAO QAPP, Document number CAO-94-1012, Rev 3, which specifies the WIPP quality program to be ASME NQA-1-1989, and ASME NQA-2-1990, Part 2.7
- Operates under Microsoft® Windows NT®, Windows® 2000 and Windows XP

## Description


CANBERRA's NDA 2000 software is designed to be a complete acquisition, analysis and archival package for use with all CANBERRA neutron counters and gamma-ray systems. NDA 2000 offers fully integrated neutron and gamma-ray analysis for either combined or sequential assay operations. NDA 2000 is based on CANBERRA's Genie 2000 format providing the ease and flexibility of operation found in our popular gamma-ray spectroscopy applications. Various counter arrangements, detector arrangements, analysis sequences, hardware control, and reports can be generated from the standard software. This provides the advantage that as the customer's assay requirements change, the software can be easily adapted to handle the new requirements.

### Analysis Modes

NDA 2000 supports a variety of analysis types to provide flexibility in sample assay. With the Genie 2000 Analysis Sequence Editor it is possible to select which type or types of analysis is to be performed for a given sample.
A selection of the system and analysis types supported by NDA 2000 are given in Table 1 on the following page.

### Set Up

NDA 2000 offers Simplified Start Up through the use of a wizard to step the user through the setup of a neutron or gamma-ray based assay system. For most standard system configurations, default counter profiles exist to facilitate initial system startup.

The user can select an existing counter or create a new one. The wizard then leads the user through the counter setup. The set-up wizard simplifies definition of new container and sample types as well as isotopic and mass reference files.

Figure 73: NDA 2000 Data Sheets

# NDA 2000 Non-Destructive Assay Software

**Table 1**
**Analysis Options and System Types Supported by NDA 2000.**

| |
|---|
| Quantitative Gamma-Ray Spectroscopy<br>– Segmented Gamma-Scanning<br>– Tomographic Segmented Gamma-Scanning<br>– Multi-Detector Analysis (Q2)<br>– Transmission Correction<br>– Differential Peak Attenuation Correction |
| MGA/MGAU Isotopics Analysis |
| Passive Neutron Counting<br>– Totals Neutron Counting<br>– Passive Multiplicity Analysis<br>– Add-A-Source Matrix Correction |
| Active Neutron Counting<br>– Differential Die-Away<br>– Cf-252 Shuffler Support (future release)<br>– Active Well Coincidence<br>– Active Neutron Collars |
| Simultaneous Neutron-Gamma Assay<br>– On-Site Laboratory Counters<br>– Integrated Waste Assay System |
| Automated Drum Handling |
| Gamma-Ray Box Counting |
| PNCC Waste Crate Assay System |
| Automated Waste Assay (AWA) Review |

NDA 2000 provides complete and flexible control of the assay system and its configuration. For example, the software supports Multiple detector geometries allowing (for those systems with the applicable hardware requirements):

- Automated detector positioning.
- Automated attenuator selection and setting.
- Automated selection of configuration specific calibration.
- Container specific efficiency calibrations.
- Support of multiple dosimeters for drum exposure rate measurements.

**Operations**
Following setup, operation can be as simple as a single click of the mouse where a full assay sequence is launched requiring little or no operator intervention.

The software accommodates neutron, gamma and integrated data acquisition systems. Integrated gamma-neutron assay sequences can acquire this data simultaneously, sequentially or independently. Following completion of both measurements, the neutron and gamma-ray assay results can be combined automatically even if the measurements were performed days apart.

The Genie 2000 Quality Assurance software, required with NDA 2000, provides daily measurement checks on the system performance. The software can be configured to enforce the use of the quality control checks and ensure that system operating parameters such as efficiency, resolution, or background levels are within the desired bounds.

**Mechanism Control**
The NDA 2000 software communicates with CANBERRA's Model 2445 line of GE/Fanuc PLC controllers (support for other PLC models can be provided at additional cost). These are used to control the mechanism and automation function on all recent CANBERRA waste systems. A standard command format in the applications software allows one set of commands in the NDA 2000 software to perform a variety of mechanical functions based on the programming of the PLC control system.

For systems incorporating a PLC control mechanism control is provided for optional equipment such as:

- Transmission Source Shutters.
- Load Cells for weight measurement.
- Variable attenuator assembly.
- Dosimeters for surface exposure measurements.
- Material handling systems.

**Genie 2000 Based**
The heart of the NDA 2000 software is CANBERRA's Genie 2000 Spectroscopy software package. The NDA 2000 software can utilize all of the features of the Genie 2000 software including:

- The Editors – Nuclide library editor, analysis sequence editor, certificate file editor and MCA input definition editor.
- All Genie 2000 Analysis Algorithms – Peak search and peak locate algorithms, library driven search and analysis algorithms, area correction algorithms, calibration algorithms, nuclide identification algorithms, MDA algorithms, etc.
- All Genie 2000 QA trending and plotting capabilities.
- All CANBERRA Instrument Control Bus (ICB) NIM setup, adjustment, and status commands.
- Full storage of all data, setup parameters, calibration parameters, and analysis results in a file structure that facilitates review of data or reanalysis of questionable results.

Figure 74: NDA 2000 Data Sheets

# NDA 2000 Non-Destructive Assay Software

### Multi-Detector Gamma-Ray System Support

NDA 2000 supports the operation and analysis of multi-detector systems such as the Q2 and Auto-Q2. NDA 2000 allows the following functionality:

- Acquire data from multi-detector assay systems with simultaneous start/stop of all detectors.
- Analyze spectra from each detector individually.
- Analyze the summed spectra for greater sensitivity.
- Attenuation correction using weight based density measurement.
- Attenuation correction using gamma-ray transmission measurements.
- Efficiency calibrations using ISOCS.

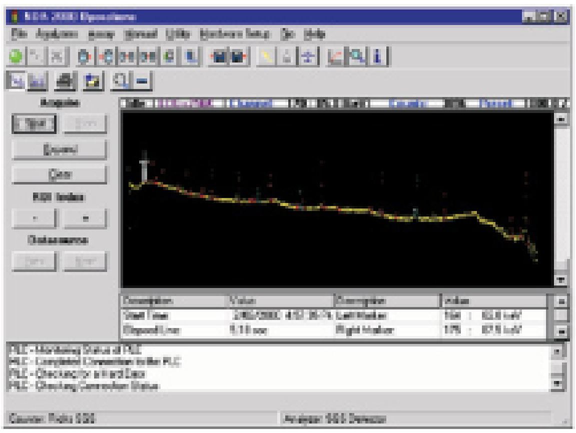


**Figure 2**
**Genie 2000 capabilities for live display and analysis of gamma-ray spectra.**

### Reports

A variety of standard reports have been created for the standard waste system configurations at CANBERRA. However, a special feature of Genie 2000 and the NDA 2000 software is the capability for the customer to edit existing or create new report templates which will fit particular site requirements. All report structures can be easily edited in a standard ASCII editor. Any parameter which is stored in the CAM file can be included in a report. In addition, results can be scaled or combined using the basic arithmetic operations of addition, subtraction, multiplication or division.

### Log Book

The NDA 2000 software allows storage of key assay results into a Microsoft Access database. Access reports are provided and data reports can be modified from Access. (Note that Microsoft Access is not required but is recommended in order to take full advantage of the software's capabilities).

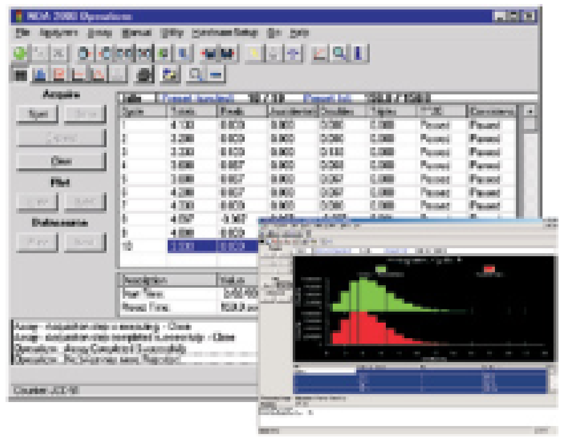


**Figure 3**
**Neutron data may be examined live in tabular or graphical form.**

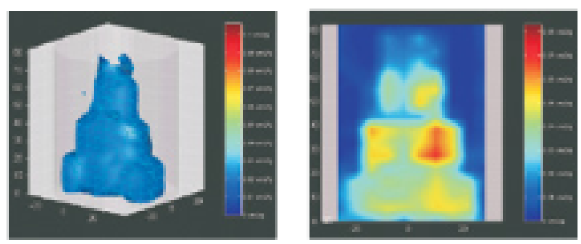


**Figure 4**
**NDA 2000 provides full support for CANBERRA's Tomographic Gamma System. The TGS viewer provides false color transmission and emission images of the drum contents to facilitate interpretation of results from complex waste streams.**

### Reanalysis

Analysis is performed automatically during and following completion of the assay. The data may also be completely reanalyzed using the Data Review menus. Data storage utilizes the Genie CAM file format. Not only are all raw data and results stored but also the parameters used in the analysis. Reanalysis allows the modification of all calibration parameters to provide a powerful tool for expert review of the data. Data files may be reanalyzed one at a time or if many assay results require the same parameter correction, a batch reanalysis capability is provided.

Figure 75: NDA 2000 Data Sheets

# NDA 2000 Non-Destructive Assay Software

**Total Measurement Uncertainty (TMU)**
NDA 2000 calculates a total measurement uncertainty for each assay based on the measured and entered data for the container. The TMU analysis includes error sources such as calibration errors, counting statistics, matrix effects, non-uniform source distribution, non-uniform matrix distribution, self shielding, and multiplication effects. The TMU approach is consistent with that required for waste characterization of drums destined for the WIPP facility.

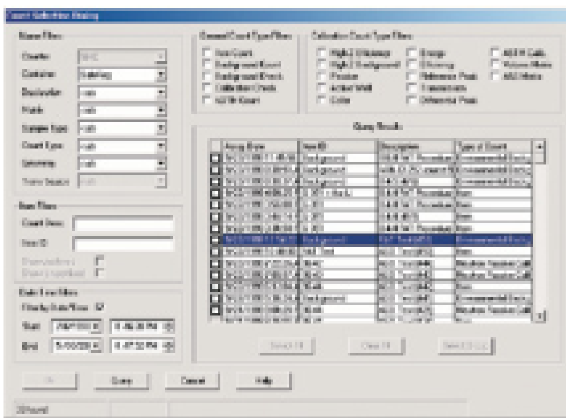


**Figure 5**
**Full re-analysis capability is provided. NDA 2000 provides capabilities for reanalysis of individual assay results or large groups of files using the batch reanalysis feature.**

## Specifications

**MINIMUM COMPUTER REQUIREMENTS**

The following are the minimum recommended computer requirements.

Operation can be greatly enhanced by using faster processors and additional memory:

- Pentium® II Processor with 200 MHz clock speed.
- 64 MB of memory.
- Windows NT Operating System.
- 2 GB of hard disk capacity.

**ORDERING REFERENCES**

NDA 2000 is normally sold in a package with all other required CANBERRA software. The package is dependent to some extent on the intended use of the software (e.g., neutron only).

- NEUTRON ACQUISITION ONLY
  - S529 – NDA 2000 Non-Destructive Assay Software.
  - S500 – Genie 2000 Basic Spectroscopy Package.
  - S505 – Genie 2000 Quality Assurance Software.
- GAMMA-RAY ACQUISITION AND INTEGRATED SYSTEMS
  - S529 – NDA 2000 Non-Destructive Assay Software.
  - S500 – Genie 2000 Basic Spectroscopy Package.
  - S501 – Genie 2000 Gamma Analysis.
  - S505 – Genie 2000 Quality Assurance Software.
  - S507 – MGAU Software (Optional).
  - S508 – MGA Software (Optional).
  - S573 – ISOCS.

ISO 9001 SYSTEM CERTIFIED

Figure 76: NDA 2000 Data Sheets

### 23.5 Appendix E: Carriage Plate Bolt Calculations

$$P = \frac{2584.32}{4 * 4} = 161.52lb.$$

$$\sigma = \frac{161.52 * 4}{\pi * 0.215^2} = 4.45ksi$$

$$V' = \frac{154.13}{8} = 19.27lb.$$

$$\tau' = \frac{4 * 19.27}{\pi * 0.215^2} = 0.53psi.$$

$$V" = \frac{2584.32 * 6.4}{(4 * 5^2) + (3 * 6.4^2)} = 74.2lbs.$$

$$\tau" = \frac{4 * 74.2}{\pi * 0.215^2} = 2.04ksi$$

$$\tau = \sqrt[2]{0.53^2 + 2.11^2} = 2.11ksi$$

$$\sigma_v = \sqrt[2]{3.88^2 + 3 * 1.79^2} = 5.76ksi$$

$$FOS = \frac{80}{5.76} = 13.89$$

## 23.6 Appendix F: Hinge Bolt Calculations

$$P = \frac{740.80}{-2.77} = -267.40lb.$$

$$\sigma = \frac{-267.40 * 4}{\pi * 0.215^2} = -7.37ksi$$

$$V' = \frac{77.07}{8} = 9.63lb.$$

$$\tau' = \frac{4 * 9.63}{\pi * 0.215^2} = 0.27ksi.$$

$$V_x" = \frac{1245.52 * 6.80}{(2 * 7.80^2) + (2 * 8.80^2) + (2 * 9.80^2) + 7.80} = 16.85lbs.$$

$$\tau" = \frac{4 * 16.85}{\pi * 0.215^2} = 0.46psi$$

$$V_z" = \frac{740.8 * 6.80}{(2 * 7.80^2) + (2 * 8.80^2) + (2 * 9.80^2) + 6.80} = 9.78lbs.$$

$$\tau" = \frac{4 * 14.67}{\pi * 0.23^2} = 0.27ksi$$

$$\tau = \sqrt[2]{0.27^2 + 0.46^2 + 0.27^2} = 0.60ksi$$

$$\sigma_v = \sqrt[2]{-7.37^2 + 0.60^2} = 7.44ksi$$

$$FOS = \frac{80}{7.44} = 10.75$$

## 23.7 Appendix G: Motor Information

**Orientalmotor** *Call 1-800-GO-VEXTA(468-3982) or 1-847-871-5931* Print

- given information -

**Load and linear guide**

| | | | | |
|---|---|---|---|---|
| Total weight of loads and table | W | = | 150 | [lb] |
| Friction coefficient of the guide | μ | = | 0.1 | |

**Ball/Lead screw specifications**

| | | | | | |
|---|---|---|---|---|---|
| Diameter | | $D_B$ | = | 1 | [in] |
| Total length | | $L_B$ | = | 24 | [in] |
| Lead (ptich) | | $P_B$ | = | 1 | [in/rev] |
| Efficiency | | η | = | 80 | [%] |
| Material | Steel | ρ | = | 4.57 | [oz/in$^3$] |
| Breakaway torque of the screw | | $T_B$ | = | 2550 | [lb·in] |

**External force**

$F_A$ = 0 [lb]

**Transmission belt and pulleys or gears**

| | Primary pulley (gear) | | | | Secondary pulley (gear) | | | |
|---|---|---|---|---|---|---|---|---|
| pitch circle diameter (PCD) | $D_{p1}$ | = | | [in] | $D_{p2}$ | = | | [in] |
| weight | $W_{p1}$ | = | | [lb] | $W_{p2}$ | = | | [lb] |
| thickness | $L_{p1}$ | = | | [in] | $L_{p2}$ | = | | [in] |
| material | ρ | = | | [oz/in$^3$] | ρ | = | | [oz/in$^3$] |

**Mechanism Placement**

Mechanism angle α = 90 [°]

Figure 77: Motor Calculation Input

- calculated result -

**Load Inertia**

$J_W = W \times 16 \times (P_B / 2\pi)^2$

$= 150 \times 16 \times (1 / (2 \times 3.14))^2 = 60.85$ [oz·in²]

$J_S = (\pi / 32)\, \rho\, L_B\, D_B^4$

$= (3.14 / 32) \times 4.57 \times 24 \times 1^4 = 10.76$ [oz·in²]

$J_L = J_W + J_S$

$= (60.85 + 10.76) = 71.62$ [oz·in²]

**Required Speed**

$V_m = V_1\,(60 / P_B)$

$= 1 \times (60 / 1) = 60.00$ [r/min]

**Required Torque**

$T = (T_a + T_L)$ (Safety Factor)

$= (0.000 + 3220) \times 1.5 = 4831$ [lb·in]

$= 7.729e+4$ [oz·in]

**Load Torque**

$F = F_A + W(\sin\alpha + \mu\cos\alpha)$

$= 0 + 150\,(\sin 90 + 0.1 \times \cos 90) = 150.0$ [lb]

$T_L = ((((F\, P_B) / 2\pi) \times 1.1) + T_B)\,(1 / (\eta \times 0.01))$

$= ((((150.0 \times 1) / (2 \times 3.14)) \times 1.1) + 2550) \times (1 / (80 \times 0.01)) = 3220$ [lb·in]

$= 5.153e+4$ [oz·in]

**Required Stopping Accuracy**

$\Delta\theta = \Delta l\,(360° / P_B)$

$= .1 \times (360 / 1) = 36.00$ [deg]

Figure 78: Motor Calculations

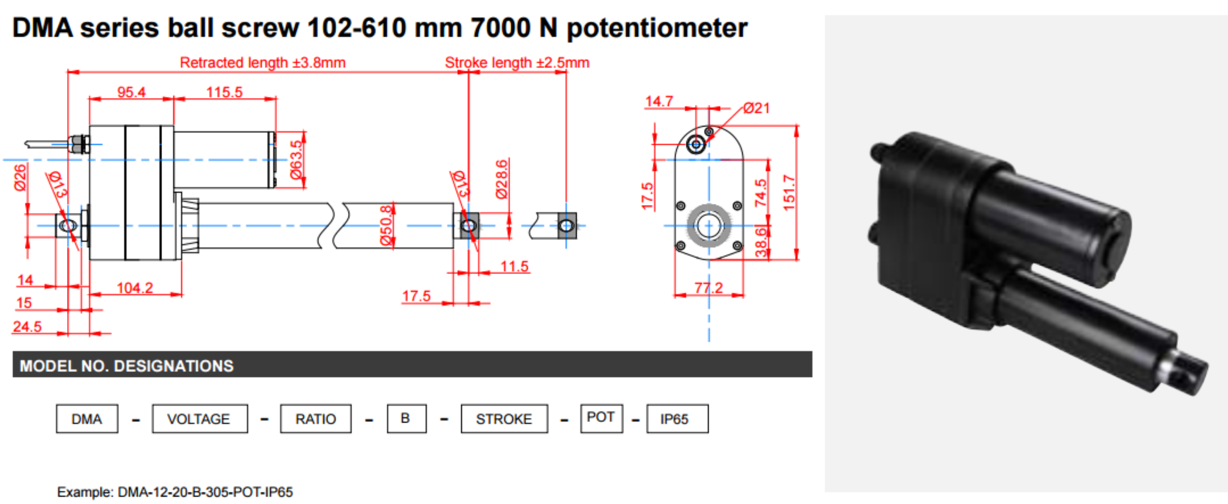



Figure 79: Motor Data 1

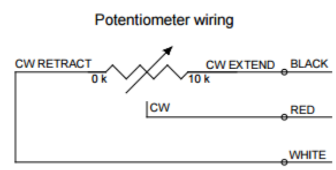
| ACTUATOR DATA | | | | | |
|---|---|---|---|---|---|
| Reduction | 5 | 10 | 20 | 30 | 40 |
| Voltage (VDC) | 12/24 | 12/24 | 12/24 | 12/24 | 12/24 |
| Current at max. thrust (A) | 28/14 | 18/9 | 13/7 | 13/7 | 11/5.5 |
| Max. thrust (N) | 2600 | 3500 | 4500 | 6000 | 7000 |
| Max Static force (N) | 13600 | 13600 | 13600 | 13600 | 13600 |
| Speed at max. thrust (mm/s) | 47 | 23 | 13 | 9 | 5 |
| Max. speed | 67 | 35 | 17 | 12 | 7 |

| ACTUATOR STROKE DATA | | | | | | |
|---|---|---|---|---|---|---|
| Stroke length and version (mm) | 102 | 153 | 203 | 305 | 457 | 610 |
| Retracted length (mm) | 342 | 393 | 444 | 546 | 775 | 928 |
| Feedback (ohm/mm) | 100 | 67 | 50 | 33 | 22 | 17 |
| Life time number single strokes | 39.000 | 26.000 | 20.000 | 13.000 | 8.700 | 6.500 |
| Weight (g) | 4.3 | 4.6 | 4.9 | 5.4 | 6.2 | 7.8 |

Figure 80: Motor Data 2

| ACTUATOR FEATURES AND STANDARD DATA | STANDARD | CUSTOMIZATION OPTIONS |
|---|---|---|
| Type | Electric linear actuator | |
| Motor type | Brush PM dc motor | |
| Cable | Flying wire 250 mm | Yes |
| Voltage | 12 or 24 volt dc | 36 or 48 volt dc |
| Screw type | Ball screw | |
| Noise level | < 60 db (A) | Yes |
| Life time | 4 million mm total stroke | |
| Limit switches | N/A | |
| Overload protection | By clutch | |
| Direction movement | By reversing voltage polarity | |
| Stroke tolerance | ±3 mm | ±2 mm |
| Duty cycle | 25% | |
| Max. duty operational time | 1 min. max. thrust | |
| Protection class | IP65 | |
| Insulation class | F | |
| Max. motor winding temp. | 155 °C | |
| EMC | EN55014 IEC61000 | |
| Gear box | Metal spur gears | |
| Gear box material | Aluminum alloy | |
| Rod and house material | Steel 12L14 STKM11A | |
| Feedback | Potentiometer | |
| Operating and storage temperature | -26°C~+65°C | |
| Manufacturing quality standards | ISO 9001:2008 | |
| RoHS | Yes | |
| CE label | Yes | |
| UL approval | No | Yes |

| POTENTIOMETER DATA | |
|---|---|
| Type | Wire wound |
| Resistance | 0.3 - 9.7 Kohm |
| Resolution | 0.025% |
| Resistance toleance | ±5% |
| Linearity | ±0.25% |
| Cable | 3+2 leads 250 mm |



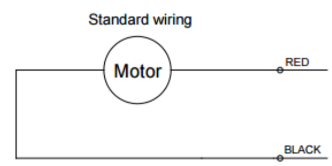




Figure 81: Motor Data 3

## 23.8 Appendix H: Bending Analysis

**INPUT LOADING TO FIXED BEAM**

POINT LOADS

| No. | Location | Magnitude |
|---|---|---|
| 1 | 13 inch | 198.7 lbf |
| 2 | 26 inch | -198.7 lbf |

CONCENTRATED MOMENTS

| No. | Location | Magnitude |
|---|---|---|

DISTRIBUTED LOADS

| No. | Start Location | Magnitude | End Location | Magnitude |
|---|---|---|---|---|

**RESULTS**

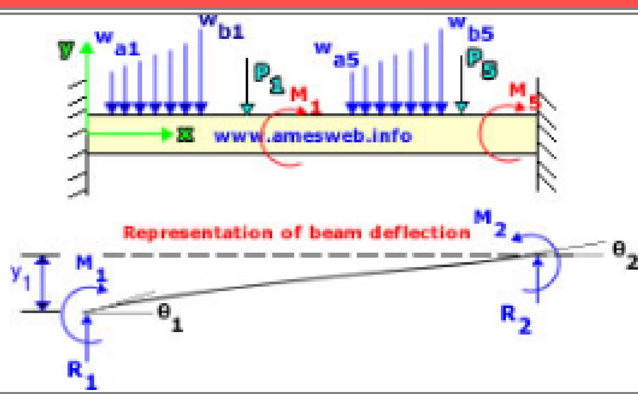



Figure 82: Bending analysis

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Reaction Force 1 | $R_1$ | 95.7 | lbf |
| Reaction Force 2 | $R_2$ | -95.7 | |
| Transverse Shear Force @ distance x | $V_x$ | -103.0 | |
| Maximum Transverse Shear Force | $V_{max}$ | -103.0 | |
| Reaction Moment 1 | $M_1$ | -574.0 | lbf*in |
| Reaction Moment 2 | $M_2$ | 574.0 | |
| Moment @ distance x | $M_x$ | 257.6 | |
| Maximum Moment | $M_{max}$ | -668.4 | |
| Slope 1 | $\theta_1$ | 0.000 | radian |
| Slope 2 | $\theta_2$ | 0.000 | |
| Slope @ distance x | $\theta_x$ | 0.125 | |
| Maximum Slope | $\theta_{max}$ | 0.141 | |
| End Deflection 1 | $y_1$ | 0.000 | inch |
| End Deflection 2 | $y_2$ | 0.000 | |
| Deflection @ distance x | $y_x$ | -0.339 | |
| Maximum Deflection | $y_{max}$ | 0.694 | |
| Bending Stress @ distance x | $\sigma_x$ | 779.0 | psi |
| Maximum Bending Stress | $\sigma_{max}$ | 2021.5 | |

Figure 83: Bending analysis

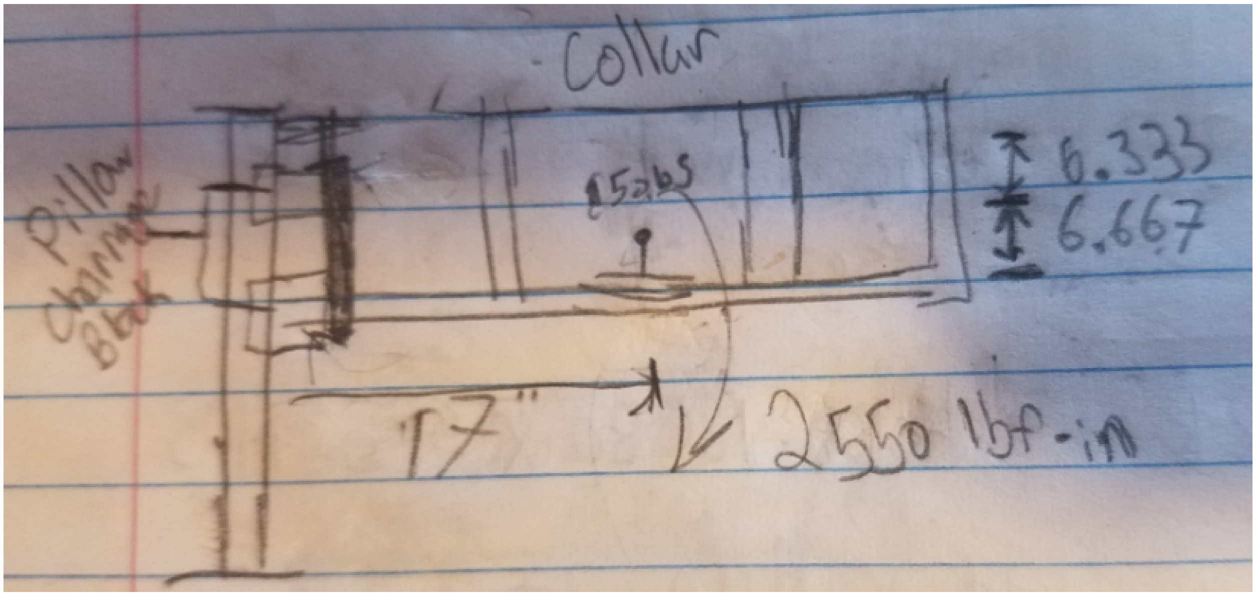



Figure 84: Free Body Diagram

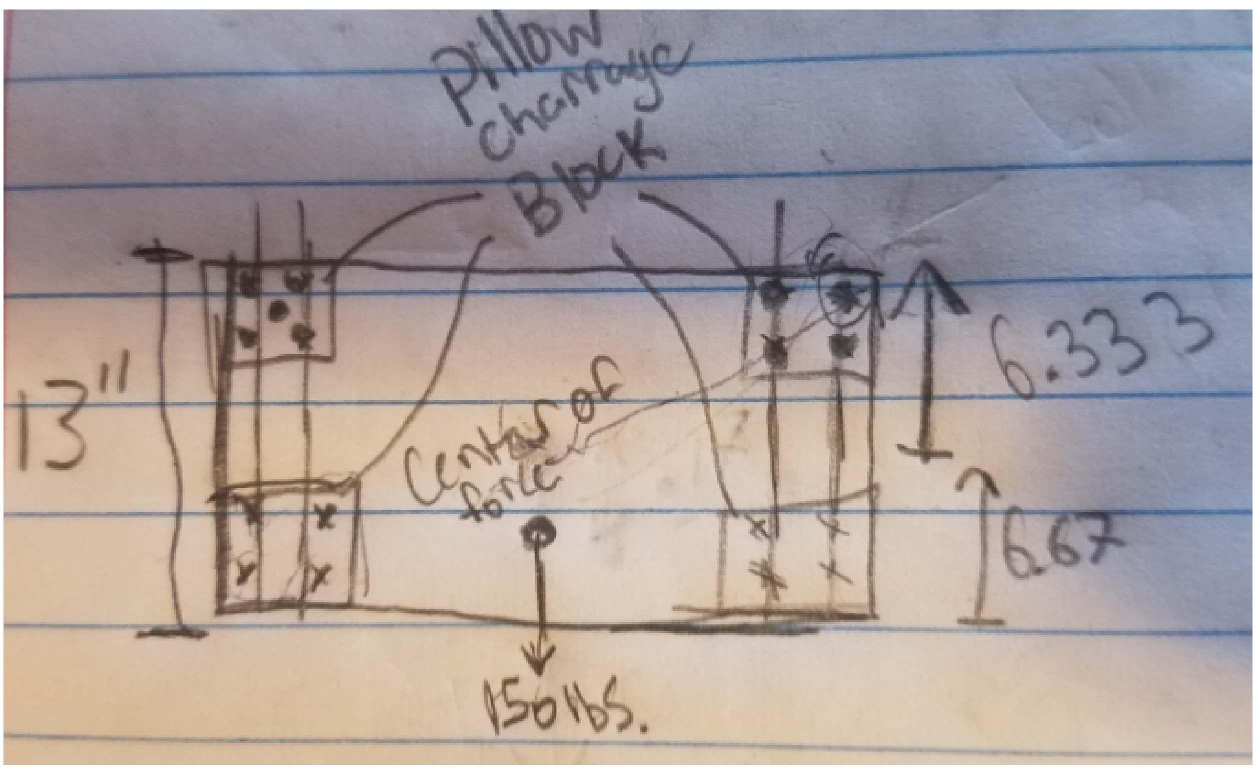



Figure 85: Free Body Diagram

## 23.9 Appendix J: Testing Results

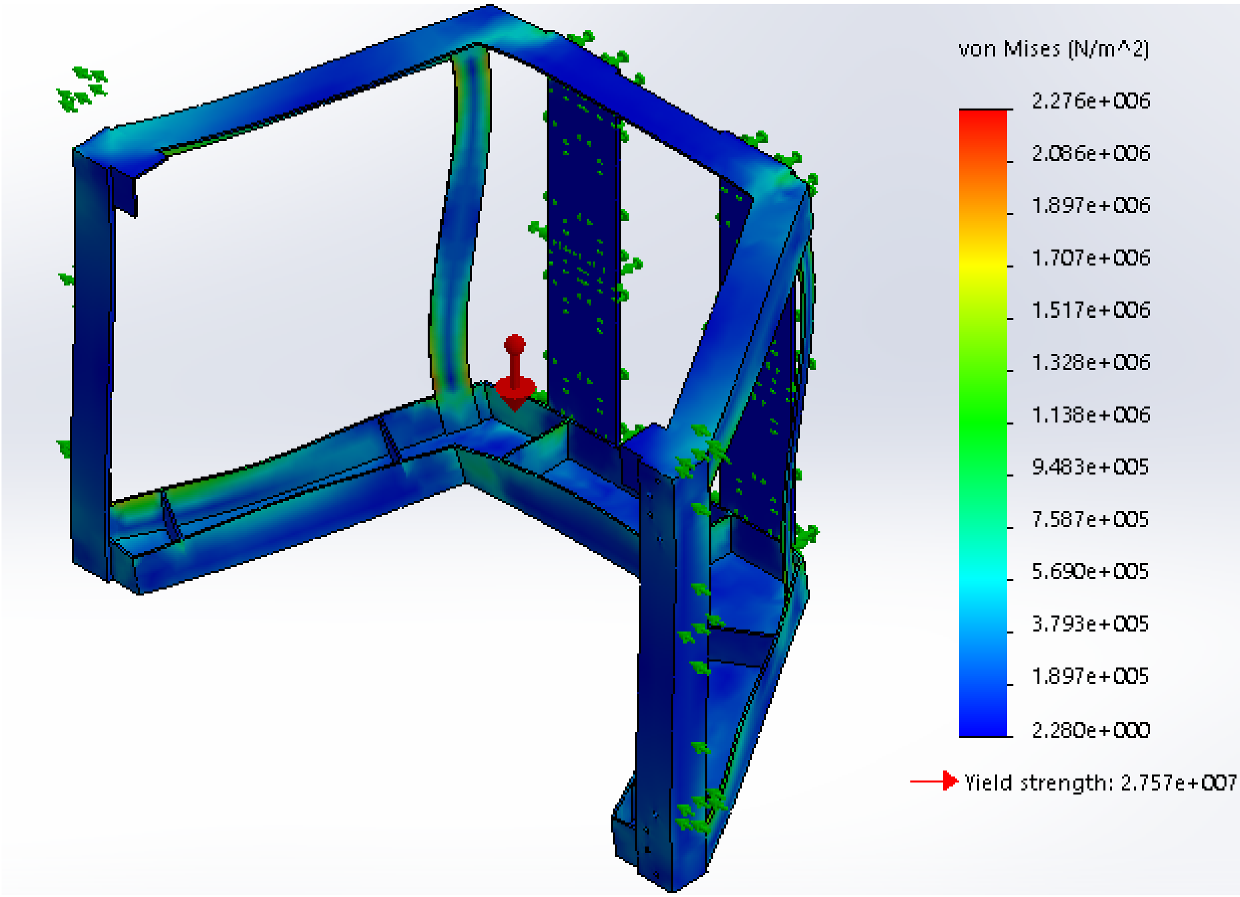



Figure 86: Stress of the Full Scale Structure

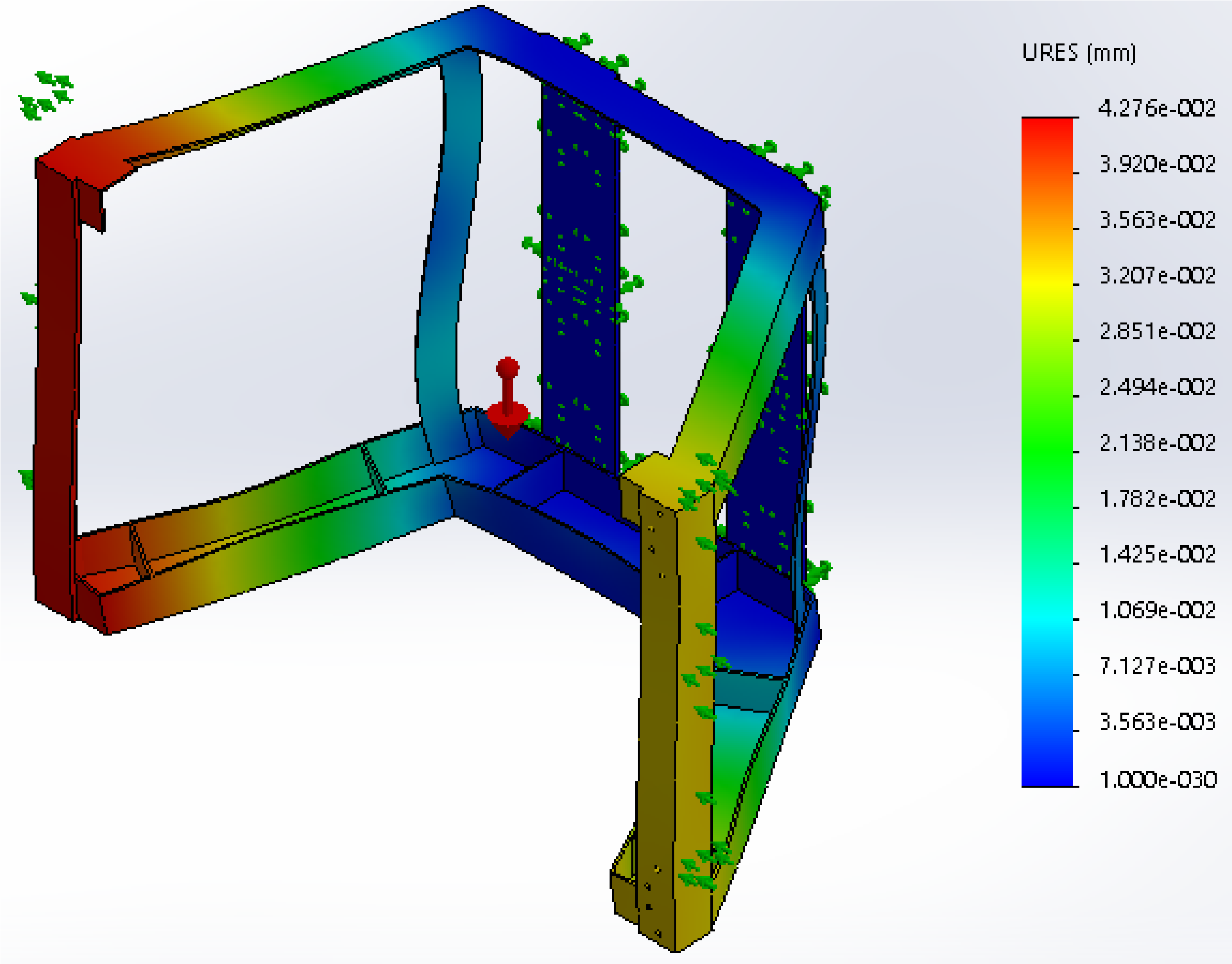



Figure 87: Displacement of the Full Scale Structure

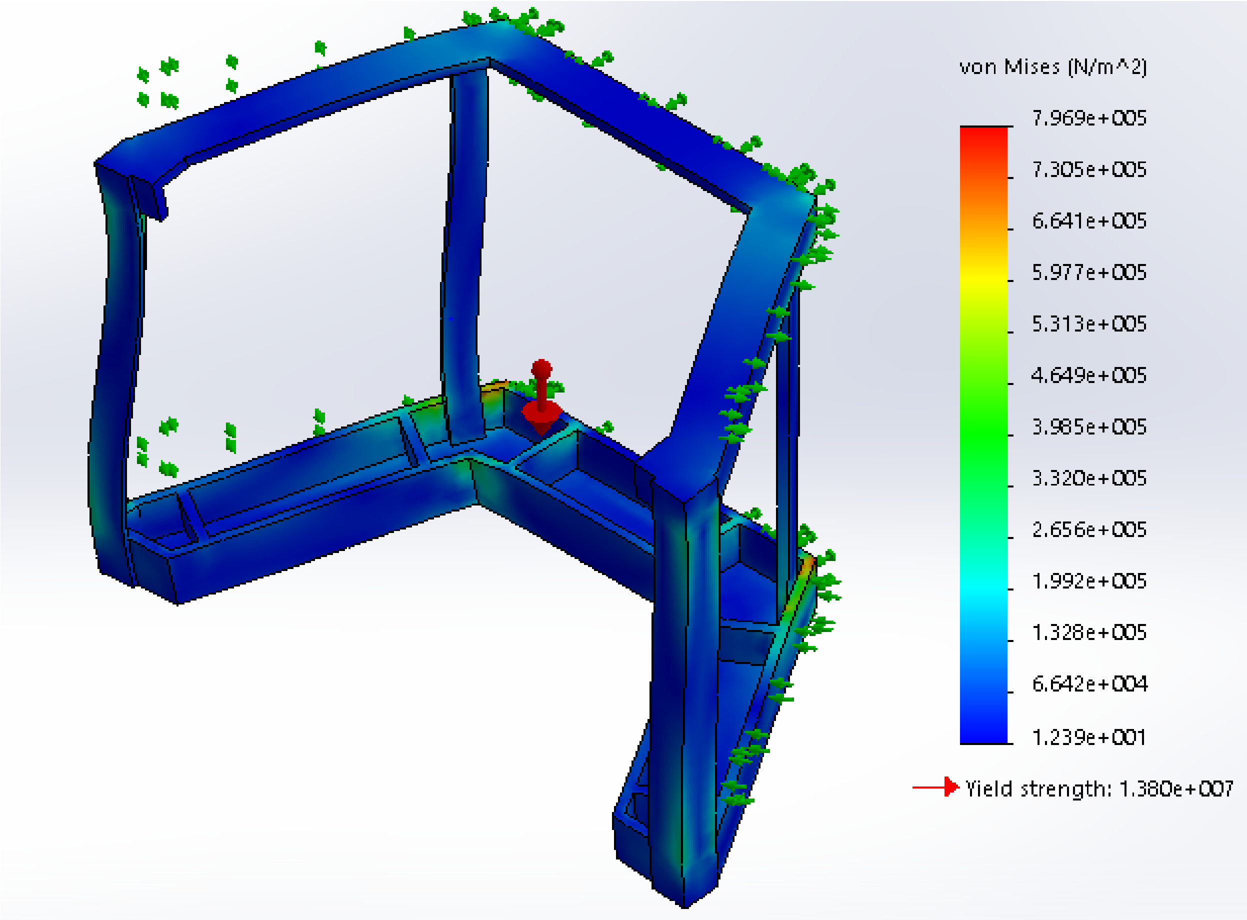



Figure 88: Stress of the Half Scale Structure

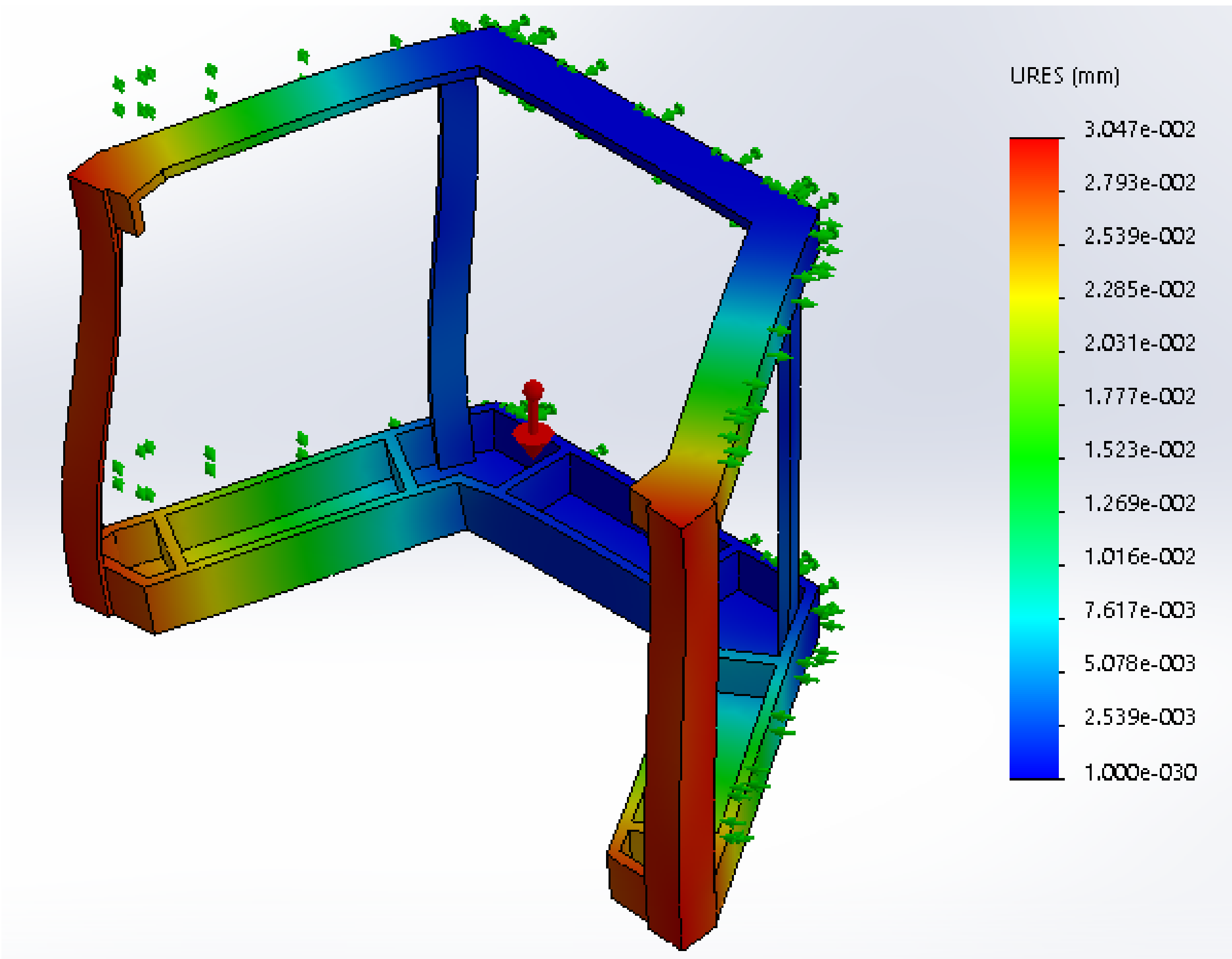



Figure 89: Displacement of the Half Scale Structure