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Online HEPA Filter Replacement

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Online HEPA Filter Replacement
Team #6 - No Filter

Team Members

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Sponsored by Los Alamos National Lab

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University of Rhode Island 2017-2018
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Abstract

High Efficiency Particulate Arrestance (HEPA) filters serve an important role in safety of nuclear facilities and can be an important tool in safeguards verification of nuclear activities. This paper describes a new design for HEPA filter housing in nuclear facilities to reduce replacement time, improve safety, reduce worker dosage, and facilitate safeguards procedures post replacement. This design must meet the criteria of staying online during filter exchanges, assisting with International Atomic Energy Agency (IAEA) sampling practices, meeting the nuclear air and gas code specifications and relevant subsections, and adhering to the principles of ALARA (as low as reasonably achievable), for maintaining low radiation levels to maximize worker safety.

Our new design focuses on improved safety while achieving an online filter exchange. Not only will an online filter exchange reduce facility downtime and save facilities money, it has the potential to offer increased worker safety, and provide easy filter access for IAEA officials who wish to conduct sampling and inspection for safeguards. It would effectively eliminate the need for a facility to shut down for filters to be replaced. In our research, we did not find any current designs on the market that can perform an online HEPA filter exchange. We also conducted research on sealing techniques to support the online system design. We have established a project relationship with Radiation Protection Systems (RPS), Inc.: a contracting company based out of Groton, Connecticut, USA which specializes in mobile HEPA filter and carbon pre-filter housings for nuclear applications. The technical information exchange and partnership with RPS may result in an actual product that could be installed in future nuclear power plants if the design can be proven to work in concept and function. It may also be possible to retrofit existing HEPA installations in some cases.

The design includes a double door bag-in, bag-out design and operational procedure to maintain worker safety and allow for zero escape of radioactive volatiles or particulates into the air external to the facility enclosure. A combination of neoprene gasket, silicone gel, and brush sealing techniques are employed in the new design with continuity of airflow during the switch in mind. This innovative design improves safety as well as operational efficiency.

The design team is cognizant of safeguards considerations and aimed the design towards facilitating access. In particular, in our new design access to HEPA filter for sampling is much easier which can potentially improve the frequency and quality of sampling during IAEA inspections. Likewise, the lower level of effort (therefore cost) in switching filters will encourage changing filters more frequently. This will lower the risk of filter failures caused by clogged or possibly faulty filters. In fact, the IAEA reported that âĂIJInvestigators from other

national laboratories have suggested that aging effects could have contributed to over 80 percent of these failures.âĂİ The prototype design features a HEPA filter train (2 HEPA filters connected by a gel-seal interface) that slide seamlessly through the housing on rollers while the nuclear facility is online, the first (old) filter being dislodged into a sealed bagging unit, and the second (new) filter being clamped into place using a cam shaft clamping mechanism. There are two areas of design innovation here that are particularly exciting. The gel-seal interface that connects the filters will provide an air tight gap between two filters while they are exchanged. The clamping system features a brush seal interface on top and bottom, to maintain airflow and mobility of the filter while facilitating a switch.

Because extended radiation exposure may alter the properties of sealants and gaskets we are investigating the use of seals that can be replaced during these quick filter changes. The design prototype is a full-scale model, capable of housing a 12x24x12 inch HEPA filter. Currently, we have completed the design of the new housing unit, created a proof of concept build, as well as conducted the preliminary engineering analysis, cost analysis, and material selection of the final prototype. Manufacturing of the final housing is proceeding and upon completion will be validated with a set of rigorous testing procedures concerning sealing and safety of the system. These tests are standard industry practices and RPS will assist in performing the tests. Namely, ASME test FC-I- 3272, a test in which aerosol particles of 20 m, which are the most penetrating particle sizes (MPPS), are sent through the housing unit and penetration is monitored during an online switch. Further testing will include colored smoke being pumped through the unit to test sealing capabilities and to identify possible particulate buildup. Provided the tests show that the design is successful in maintaining air flow and safety during the filter exchange, methods of improvement for ease of use and the automation of the exchange process,improvements to continuity of knowledge, and radiation monitoring techniques will be investigated for a comprehensive final product design.

Contents

Nomenclature

kWh	Kilowatt Hours
MWh	Megawatt Hours
ρ	Density
l	Lifetime of a radioactive isotope
$\bar{l}$	Average lifetime of a radioactive isotope
σ_y	Yield Strength
psi	Pounds Per Square Inch
F	Force
k	spring constant
x	spring extension

Acronyms

TiO_2 Titanium Dioxide.

ALARA As Low As Reasonably Achievable.

BIBO Bag-In Bag-Out.

CFM Cubic Feet Per Minute.

DOD Department of Defense.

DOE Department of Energy.

DOP Diameter of Particle.

HEPA High Efficiency Particulate Arrestance.

IAEA International Atomic Energy Agency.

LANL Los Alamos Nuclear Lab.

POC Proof of Concept.

QFD Quality Function Deployment.

RINSC Rhode Island Nuclear Science Center.

RPS Radiation Protection Systems.

USPTO United States Patent and Trademark Office.

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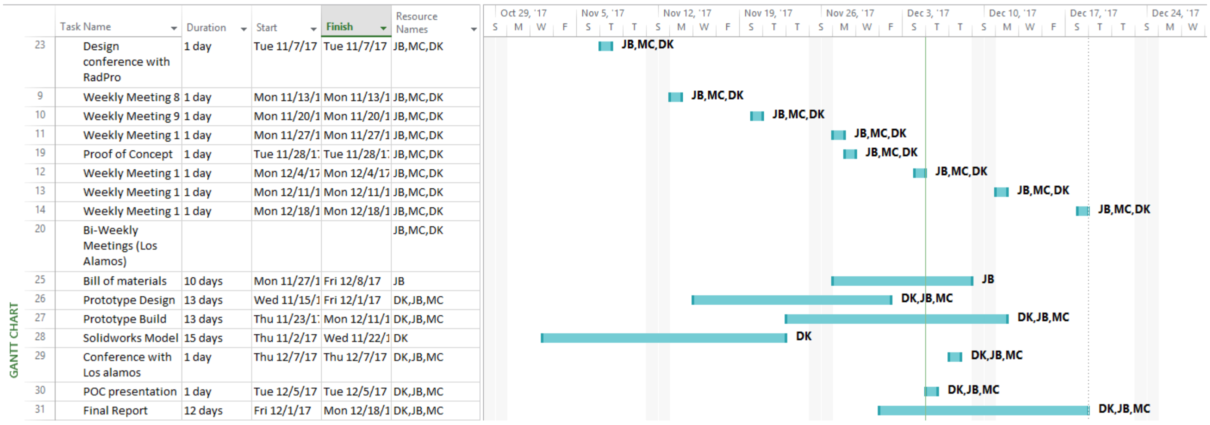
1 INTRODUCTION

The aim of our Capstone design group is to develop an automated system for online HEPA filter replacement that reduces facility downtime and limits radiation exposure to workers. Currently, HEPA filters are found throughout nuclear reactors, research facilities, and reprocessing centers. Their job is to filter irradiated air and remove dangerous particulate before the air leaves the facility. These filters must be switched out every 12-18 months for most nuclear applications. Previously, filters have been manually switched out, a process that is time consuming and most importantly requires the nuclear facility to shut down for weeks to remove the filters. We are suggesting solutions for 4 different levels of radiation, but our focus is on filters found in nuclear reactors. There are several ways in which our capstone team plans to improve the current process for HEPA filter removal. First, the system will remain sealed throughout the filter exchange, by using a neoprene gasket that is constantly compressed during the switch. We also plan to implement a disposable gel filter seal, that will provide sealing along the space in between the filters during the exchange. This allows the facility to stay online and produce power during the switch, potentially avoiding weeks of downtime. It will also assist IAEA inspectors, because they can access filters on demand for testing without significantly disrupting facility operations. Our design will also speed up the filter exchange time, while still meeting Nuclear Air and Gas Treatment requirements. We plan to utilize the same bag-in, bag-out process (Fig 1), that will contain the filters on the hot side of the reactor. Our final design requirement is to adhere to ALARA, and minimize worker exposure to radiation. We plan to implement additional sealing, including brush seals during filter entry and exit, as well as a double bag-in, bag-out procedure that would ensure zero particulate escapes the closed system. Our project sponsor, Los Alamos National Laboratory, specified that they were searching for an innovative solution that was able to offer constant sealing and meet safety requirements, but not necessarily be ready to be implement into a reactor. The scope of our project is to create the model and prove its usefulness as a solution, but not to design it for mass manufacturability, as nuclear requirements are numerous and vary by facility. Our final design will be a model HEPA filter housing that is full-scale, and meets all the design requirements specified above, and is rigorously tested to determine its validity and safety.

2 PROJECT PLANNING

Organization is essential for a team project of this scope. The team was keeping track of multiple approaching deadlines simultaneously throughout the semester so it was necessary to use an efficient system of tracking due dates and progress. Microsoft Project was used and kept up to date as the project evolved. A Gantt chart can be seen in Figure 1, this is what the team referenced to stay on schedule.



	Task Name	Duration	Start	Finish	Resource Names
23	Design conference with RadPro	1 day	Tue 11/7/17	Tue 11/7/17	JB,MC,DK
9	Weekly Meeting 8	1 day	Mon 11/13/1	Mon 11/13/1	JB,MC,DK
10	Weekly Meeting 9	1 day	Mon 11/20/1	Mon 11/20/1	JB,MC,DK
11	Weekly Meeting 1	1 day	Mon 11/27/1	Mon 11/27/1	JB,MC,DK
19	Proof of Concept	1 day	Tue 11/28/1	Tue 11/28/1	JB,MC,DK
12	Weekly Meeting 1	1 day	Mon 12/4/1	Mon 12/4/1	JB,MC,DK
13	Weekly Meeting 1	1 day	Mon 12/11/1	Mon 12/11/1	JB,MC,DK
14	Weekly Meeting 1	1 day	Mon 12/18/1	Mon 12/18/1	JB,MC,DK
20	Bi-Weekly Meetings (Los Alamos)				JB,MC,DK
25	Bill of materials	10 days	Mon 11/27/1	Fri 12/8/17	JB
26	Prototype Design	13 days	Wed 11/15/1	Fri 12/1/17	DK,JB,MC
27	Prototype Build	13 days	Thu 11/23/1	Mon 12/11/1	DK,JB,MC
28	Solidworks Model	15 days	Thu 11/2/17	Wed 11/22/1	DK
29	Conference with Los alamos	1 day	Thu 12/7/17	Thu 12/7/17	DK,JB,MC
30	POC presentation	1 day	Tue 12/5/17	Tue 12/5/17	DK,JB,MC
31	Final Report	12 days	Fri 12/1/17	Mon 12/18/1	DK,JB,MC

Figure 1: Detailed Fall Semester 2017 Gantt Chart

When the team was formed and the problem definition defined the first task on the teams list was research. Each team member did separate research and then compared findings and ideas. The most important aspect of this endeavor was learning how the ecosystem around HEPA filters operated and what standard procedures were. Each member of the team also conducted a patent search to learn about existing technologies and potentially find a useful component for the final design.

The next stage of the project was concept generation. Each team member came up with 30 unique ideas separately to prevent cross contamination. The team then went over all 90 concepts and identified the strongest and most synergistic ideas and compiled them into 3 full design concepts. At this point in the semester each team created a critical design review presentation and received feedback from the class and professor. Moving forward the team dispensed with most ideas and settled on one solid design concept.

The remainder of the fall semester was spent finalizing this design on Solidworks, creating a physical model POC, and applying engineering analysis methods to the design.

The spring semester was spent building a realistic prototype of the product. First the frame needed to be welded, then the aluminum walls of the housing were fastened to that. Intake and outtake holes were cut into the front and the back of the housing. The doors were constructed out of high density polyethylene(HDPE) that was purchased in raw bar stock form. The HDPE needed to be cut to size and was then CNC'ed into its final form. The rollers and clamp were constructed and then fastened into place within the housing. Finally, brush seals were attached in the proper places and the prototype was ready for testing. Tests were conducted at RPS as well as Schneider Electric. Once the testing was complete the remainder of the semester was spent on redesign and preparing for the final design showcase.

Throughout the course of the year a lot of time has been dedicated to the project by the team, the sponsors from LANL, consultants and the professor. The breakdown of time spent on this project can be seen in the following table.

Person	Hours
Joshua Bolt	288 hours
Matthew Carlson	288 Hours
Frank Conahan	10 Hours
David Kehoe	288 Hours
Bahram Nassersharif	40 Hours
Christy Ruggiero	50 Hours

Table 1: Person Hours

As shown in Table 1 approximately 964 man hours have been devoted to the project so far. The team arrived at this result by assuming 12 hours of work a week for 24 weeks for each of the 3 team members broken up into tasks such as research, calculations, patent searches, market analysis, design, proof of concept, engineering analysis, SolidWorks modeling, administrative work, building, and testing as divided in Table 2. In addition 40 hours of work was assumed to have been allocated by Professor Bahram Nassersharif for guidance, grading and oversight. An estimated 10 hours allocated by Frank Conahan our consultant from Radiation Protection Systems for consultation and 75 hours dedicated by our Sponsors from Los Alamos including conference calls, email correspondence, and travel.

3 FINANCIAL ANALYSIS

Mass Production Cost Analysis: For a rough estimate for a HEPA housing, the manufacturing material of 304 stainless steel was used. For the purposes of this pricing estimate, a single HEPA filter, as well as a single carbon pre-filter were considered. According to our consultant at RPS, a very rough estimate for manufacturing such a housing would cost $3000, with a profit margin of roughly 100%, equating to a market price of $6000 per unit.

Market Demand: The demand of these filters will vary from facility to facility, but for the purposes of this project the assumptions that all current reactors will retrofit their existing HEPA filter housings with the new design. From the DOE handbook, a typical PWR has approximately 5 webs of 64 HEPA filters per web, equating to 320 HEPA filters in the facility. There are about 100 reactors in operation in the U.S., so there is a large market for an on line exchange HEPA filter enclosure. Our design could also be deployed in new nuclear facilities, with little cost difference compared with a current off line HEPA filter arrangement.

Cost Savings and Return on Investment A 500MWH plant with is assumed to have a downtime of 1 week due strictly to HEPA replacements over a one year period. (See additional considerations). A reactor typically sells its electricity at a price of 2 cents per kWh. It can be estimated that the savings are over a million dollars for this two year period. The contact at RPS estimated a retail cost of 6,000 dollars for each HEPA unit, so the Facility would spend 320*6,000= 1,920,000 dollars to retrofit their current HEPA filter webs. Therefore, a return on investment could be expected after two years.

$$168 Hours * 500,000 kWh * \$0.02 = \$1,680,000 \tag{1}$$

Cost savings/manufacturing efficiencies One of the goals of the team is to change as little as possible about existing systems in order to make it easier and cheaper for a facility to incorporate our design. The current design can be incorporated without changing the current ductwork other than for local connections, blowers, air temperature, HEPA filters or disposal bags meaning the current manufacturing can still be used resulting in efficient manufacturing and cost savings.

4 LITERATURE AND PATENT SEARCHES

In order to begin the process of designing innovative solutions to the problem it was required to do in depth research of the field to determine where the frontier is and where there are existing technologies that can be implemented in new creative ways. The team began their search on the USPTO website investigating any patents with relevant key words such has "HEPA", "Enclosure", "Filter" or "Containment". The findings are listed below.

United States Patent 6,537,350
HEPA Filter Encapsulation
Abstract: A low viscosity resin is delivered into a spent HEPA Filter or other waste. The resin is introduced into the filter or other waste using a vacuum to assist in the mass transfer of the resin through the filter media or other waste.
Reason for Interest: This patent attracted the teams attention because of its potential for assisting with the disposal of HEPA filters in a safe manner and although this particular method was not selected the main ideas are implemented into the design.

United States Patent 7,378,954
Safety Indicator and Method
Abstract:A safety indicator monitors environment conditions detrimental to humans e.g., hazardous gases, air pollutants, low oxygen, radiation levels of EMF or RF and microwave, temperature, humidity and air pressure retaining a three month history to upload to a PC via infra red data interface or phone link. Contaminants are analyzed and compared to stored profiles to determine its classification and notify user of an adversity by stored voice messages from, via alarm tones and associated flashing LED, via vibrator for silent operation or via LCD. Environmental radiation sources are monitored and auto-scaled. Instantaneous radiation exposure level and exposure duration data are stored for later readout as a detector and dosimeter. Scans for EMF allow detection with auto scaling of radiation levels and exposure durations are stored for subsequent readout. Electronic bugs can be found with a high sensitivity EMF range setting. Ambient temperature measurements or humidity and barometric pressure can be made over time to predict weather changes. A PCS RF link provides wireless remote communications in a first responder military use by upload of alarm conditions, field measurements and with download of command instructions. The link supports reception of telemetry data for real time remote monitoring of personnel via the wrist band for blood pressure, temperature, pulse rate and blood oxygen levels are transmitted. Commercial uses

include remote environmental data collection and employee assignment tasking. GPS locates personnel and reporting coordinates associated with alarm occurrences and associated environmental measurements.

Reason for Interest: The team was interested in this patent because they were initially looking into solutions involving extra sensors located throughout a system to assist the IAEA but ultimately chose a different design path.

United States Patent 4,726,825

Disposable HEPA filtration device

Abstract: A sealed filtration cannister including a filtration mechanism sealed within the cannister. A prefilter and a HEPA filter entrap asbestos-containing dust within the sealed cannister. Upon usage of the filtration cannister for a predetermined number of hours, the cannister is disposed of in its entirety. The cannister is used in conjunction with a separate vacuum cleaner device having a suction hose communicating with a cannister lid removably mounted on top of the cannister. Alternatively, the cannister is used with a portable vacuum motor assembly removably mounted on top of the cannister to provide independent suction to the filtration cannister.

Reason for Interest: Although designed for asbestos applications this patent was invented within similar constraints to the project. The team made use of a disposable filtration device for one of the selected solutions.

In addition to Patent searches the team carried out an investigation into literature provided by some of the big name companies in the industry such as Camfil and RPS. One of the most useful files the team came across was Camfil's Bag-in/Bag-out Process which details the process for workers to remove filters without releasing any particulate from the system. The bag-in/bag-out process became an integral aspect of the design. One of the requirements of our project is that it complies with nuclear air and gas treatement requirements also known as AG-1. AG-1 is a critical piece of literature for the project. The team has been keeping an eye on the relevant sections of the text and has greatly benefited from the guidance provided by existing literature.

5 COMPETITIVE ANALYSIS

Although the market for HEPA filter solutions is limited, there are a couple of players with strong holds in the industry, which will be difficult to compete with. The team has researched the firms, developed a profile, and identified their strengths and weaknesses. From this the team has developed a strategy to gain market advantage over these companies.

Competitor 1 - Camfil Clean Air Solutions

Profile:

- Headquarters in Stockholm Sweden
- 3,800 employees
- Concentrated in four main areas: Comfort Air, Clean Processes, Power Systems and Safety and Protection
- 50+ years of experience
- 95% of sales done internationally
- Focus on sustainability

Analysis and Strategy:

Despite being a main player in HEPA filter housings for the nuclear industry, nuclear is far from their only venture. From the teams research, their other industries of expertise are pharmaceutical, food and beverage, and comfort air. They have developed several solutions for HEPA housing and gasket seals, boasting competitive prices and well-developed designs. They are devoted to research and development to ensure that their products do not fail. An advantage is that Team 6s product is specifically designed for a certain function in a nuclear reactor. Camfil moved into the nuclear industry because its filters share many of the same requirements as other industries. The team will argue that their company is too widespread, and not focused enough in the nuclear discipline. Not to mention, Camfil does not have any solutions for an online-HEPA filter replacement. The team will assert that our product is unique, and has been the product of many hours of specialized work and research.

The team can also address that they are an international firm, and only 5% of their sales stem from the United States. The U.S. nuclear market is therefore not a large concern of theirs.

Competitor 2- RPS: Radiation Protection Systems

RPS
RADIATION PROTECTION SYSTEMS, INC.

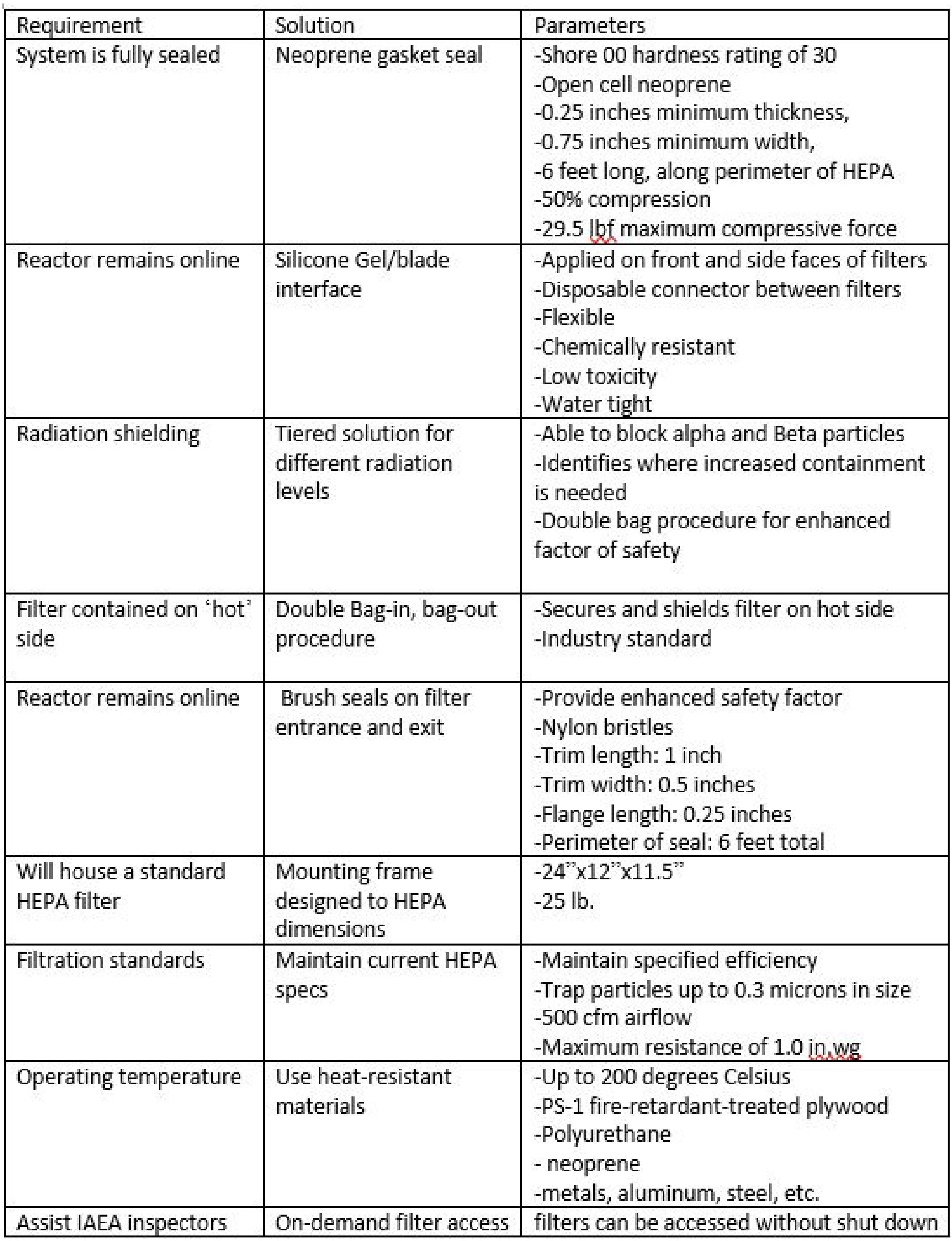
Profile:

-Based out of Groton, CT
-Small business
-Contractor to U.S. and Canadian Nuclear industry
- Clients include DOE, CDC, DOD
- Deal with radiation shielding and safety and develop engineering controls

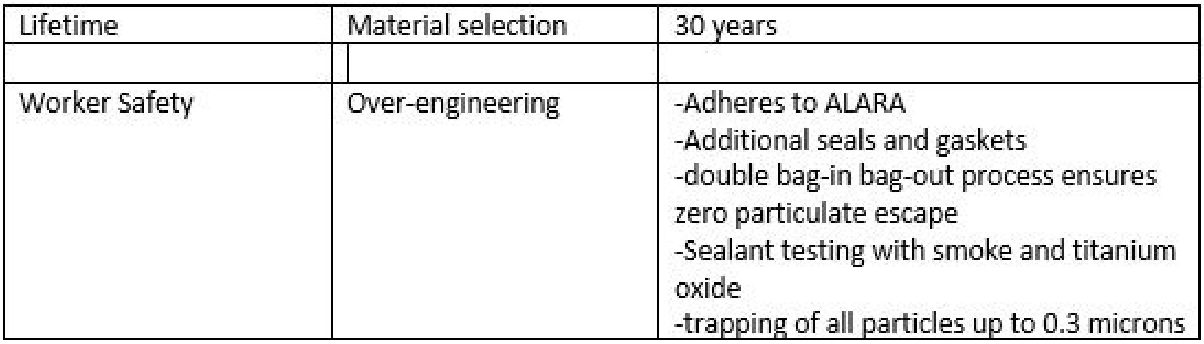
Analysis and Strategy:

RPS is a smaller, more concentrated firm. They manufacture a variety of solutions in radiation shielding and protection. Many of their units are portable, full metal casings meant for inline, highly irradiated HEPA filters. They also design the filters themselves, as well as specialized ductwork. The team had a consultation with RPS to go over our design concepts and how the team could better meet our sponsor requirements. They have a vast knowledge in these types of solutions since they are one of the only companies that specializes in this work. The team plans to capitalize on the fact that RPS typically deals mainly in temporary, highly specialized, highly protective equipment. They do not have a solution for the online replacement of filters either, so our product is unique. RPS is well respected in the industry though, and are known for their testing methods to rate filters and enclosures. If we can test our product with their methods and prove that our online sealing functions, this will be a huge step towards getting the product recognized by the DOE and DOD.

6 DESIGN SPECIFICATIONS



Requirement	Solution	Parameters
System is fully sealed	Neoprene gasket seal	-Shore 00 hardness rating of 30 -Open cell neoprene -0.25 inches minimum thickness, -0.75 inches minimum width, -6 feet long, along perimeter of HEPA -50% compression -29.5 lbf maximum compressive force
Reactor remains online	Silicone Gel/blade interface	-Applied on front and side faces of filters -Disposable connector between filters -Flexible -Chemically resistant -Low toxicity -Water tight
Radiation shielding	Tiered solution for different radiation levels	-Able to block alpha and Beta particles -Identifies where increased containment is needed -Double bag procedure for enhanced factor of safety
Filter contained on ‘hot’ side	Double Bag-in, bag-out procedure	-Secures and shields filter on hot side -Industry standard
Reactor remains online	Brush seals on filter entrance and exit	-Provide enhanced safety factor -Nylon bristles -Trim length: 1 inch -Trim width: 0.5 inches -Flange length: 0.25 inches -Perimeter of seal: 6 feet total
Will house a standard HEPA filter	Mounting frame designed to HEPA dimensions	-24”x12”x11.5” -25 lb.
Filtration standards	Maintain current HEPA specs	-Maintain specified efficiency -Trap particles up to 0.3 microns in size -500 cfm airflow -Maximum resistance of 1.0 in.wg
Operating temperature	Use heat-resistant materials	-Up to 200 degrees Celsius -PS-1 fire-retardant-treated plywood -Polyurethane - neoprene -metals, aluminum, steel, etc.
Assist IAEA inspectors	On-demand filter access	filters can be accessed without shut down



Lifetime	Material selection	30 years
Worker Safety	Over-engineering	-Adheres to ALARA -Additional seals and gaskets -double bag-in bag-out process ensures zero particulate escape -Sealant testing with smoke and titanium oxide -trapping of all particles up to 0.3 microns

To determine our design specifications, the team took our customer requirements, and requirements developed from the research and translated them into engineering terms. Perhaps the largest area of focus in this project is to create a HEPA filter exchange system that can remain sealed, and therefore online, during a filter switch. To address this, the team suggests a rolling neoprene gasket seal, with the specifications listed in the table. The seal will have a 0.25-inch thickness, the minimum required for nuclear applications. A seal with minimum thickness provides several advantages. First, it is inherently less susceptible to deformation, because less material is being compressed. It also has a lower leakage rate, because less gasket material is exposed to the fluid. Furthermore, it has higher resistance to creep, which can occur in a neoprene gasket that is under compressive force for a long period of time. Finally, it is more cost effective and has easier manufactureability. We wish to select a foamed, closed cell configuration for our neoprene gasket, because it will be easier to compress and still fulfill our needs. This is important because the maximum compressive force on the HEPA filter from the clamp does not exceed the 1400 lb. rating. Neoprene is commonly used as a seal in nuclear applications, so we know that it has been successful in the past. This concept adds the rolling component to the seal, allowing the new filter to be pushed through as the neoprene belt slides across the rollers.

It will not be enough to only seal the front face of each filter in the design. The gap between filters must also be addressed, since air will continue to flow through the ductwork during the switch. To combat this issue, we are implementing an attachable, gel/ knife blade filter attachment. This will attach to the side face of the HEPA filters, joining the two and sealing them before they are pushed through the system. We plan to use a silicone based gel for its temperature resistance, low toxicity, and inertness to a wide range of chemicals. It is possible for the silicone seal to be used again, if it is removed from the blade and allowed to rest. However, the gel will not chemically bond back together, so for safety reasons it would be best to replace it with each filter exchange (approximately every 12-18 months). The team will test the sealing capabilities of this design, as well as the neoprene gasket, using the methods discussed in the **Engineering Analysis** section. If it indeed can maintain sealing while a filter is pushed through, the team will have met our requirement to assist IAEA inspectors with the removal of filters. They could now access HEPAs simply with an online switch, instead of waiting, or forcing the facility to shutdown in order to remove their HEPAs.

Los Alamos national lab also made it clear that our design must provide adequate radiation shielding as well as adherence to ALARA, for minimizing worker exposure to radiation as much as allowable. It is prudent to first consider at which locations radiation shielding is necessary. We have proposed 4 different solutions for 4 increasing levels of radiation. However, the team's focus in on third tier, a design to be implemented in current nuclear power reactors. For this tier, a bag-in bag-out process is used, which is outlined in the âĂŸProject Specific DetailsâĂŹ. This is an industry standard practice which is very safe for workers and prevents any leakage of particulate into the facility. The team plans to increase the factor of safety for workers, while also keeping the sealing, by having a bag and bagging ring on the entrance and exit ends of the housing.

The filter must also be contained on the hot side of the reactor. This means, the filter cannot be removed and transported to a lower containment level without being properly shielded. This is an advantage of the bag-in, bag-out process and why the team chose to keep it. The filter is bagged immediately as it exits the housing unit and is completely contained by crimping the bag shut. It can then be transferred to storage or a glovebox for analysis.

One concern in maintaining online sealing during the filter exchange was the gap between the filter and the mounting frame. There cannot be any air leakage into the facility while the filters are exchanged. Therefore, the team plans to implement wire brush seals along the perimeter of the mounting frame, that extend to form a space for the filter to slide through that is slightly smaller than the HEPA itself. The stainless steel bristles at 0.5 inch thickness will be enough to stop alpha and beta particles from escaping, as well form an angled seal that redirects the air back towards the filter.

The design will also need to maintain the filtration standards required of a HEPA filter in a nuclear facility. An efficiency of 99.97% of particles under 0.3 microns in size must be trapped by the filter. Although the team is not manufacturing the filter itself, we must ensure proper sealing and setting of the filter in the mounting frame so that no leakage between the filter encasement and frame are present. We will base our mounting frame dimensions on current HEPA designs in the industry. The efficiency of our mounted filter can be tested using two different assessments; a smoke test and a titanium oxide particle test. Both methods are outlined in Engineering Analysis.

Operating temperatures in nuclear reactors, depending on the type, can reach over 300 degrees Celsius. HEPA filters are manufactured to function at temperatures of up to 200 degrees Celsius, so it is apparent that the air cools down significantly by the time it reaches a HEPA. Specific numbers on the temperature of the air at a HEPA filter was difficult to find, but the model will be engineered to work within the same temperature range as the HEPA is built for.

The team's final design requirement is not necessarily required, but was a component that LANL wanted to see in the design. Namely, automating the filter exchange. The team has researched the feasibility of automating HEPA filter exchanges, but in the end it seemed like a costly and unnecessary requirement. HEPA's are currently taken out by hand, using the bag-in, bag-out process. In theory, automating the process of pushing the filter through, would be accomplished by rollers that actuate and are powered from an electric motor. However, there would still need to be an operate present to remove the doors on either side of the housing, as well as handle the bag after the old filter is ejected. If this was a daily task, it would be more sensible to have the process be automated, but in this case filters are exchanged on a yearly basis. This also would mean the electric motor would have to function after long periods of downtime, and last for the full 30-year lifetime of our product. Any breakdowns would require maintenance, and probably require the reactor to be shutdown to be performed. One positive of automation is a decreased risk of worker exposure to radiation, but this has been addressed in our design with several other safety measures. After weighing these concerns, the team feels it is best to implement a purely mechanical system. However,if Los Alamos feels automation is the right direction the team will take steps to include it.

7 CONCEPTUAL DESIGNS

One of the most important aspects of the design process is the generation of many design concepts to be selected from. 30 concept designs were generated by each group member, allowing for 90 total design concepts. These were done independently from each other, and as such some may be redundant. The concepts were narrowed down, and the best parts were used for the final concept design.

7.1 David Kehoe's 30 Design Concepts

For the purpose of this exercise, the 30 design concepts were broken down into a few areas of interest. These were: (1) door securing, (2) door design, (3) HEPA train configurations, (4) quality testing systems, (5) containment systems, (6) automation systems, and then (7) a few housing design concepts.

At the end of each concept description in parentheses is a relevance rating from 1 through 10, 1 being the least relevant to the project, and 10 being the most relevant to the design.

1. 1.1 Push Through Filter Exchange: A new filter is to be loaded above the HEPA filter housing, with two access doors. The new filter is pushed up against the old filter, which plunges the old filter out onto the hot side of the containment system. A trap door mechanism would allow for the door to close automatically. (8)
2. 1.2 Spring Loaded Trap Door: For the bottom door of the push through filter exchange, springs acting in tension would be installed from the inside of the housing to the two trap doors. When the old filter is pushed through the system, the doors will then automatically close. (7)
3. 1.3 Internal Linear Actuator Trap Door: Under the same principals as the spring loaded trap door, linear actuators would be installed inside of the HEPA housing unit. These could then be electrically controlled from an external micro-controller, and monitored from the control room. (6)
4. 1.4 External Linear Actuator Trap Door: Almost exactly identical to the above concept, but the linear actuators are located on the outside of the trap doors, on the hot side of containment. This would reduce the exposure to the electronics and likely increase the lifetime of the parts, yet would take up more space in the facility. (4)

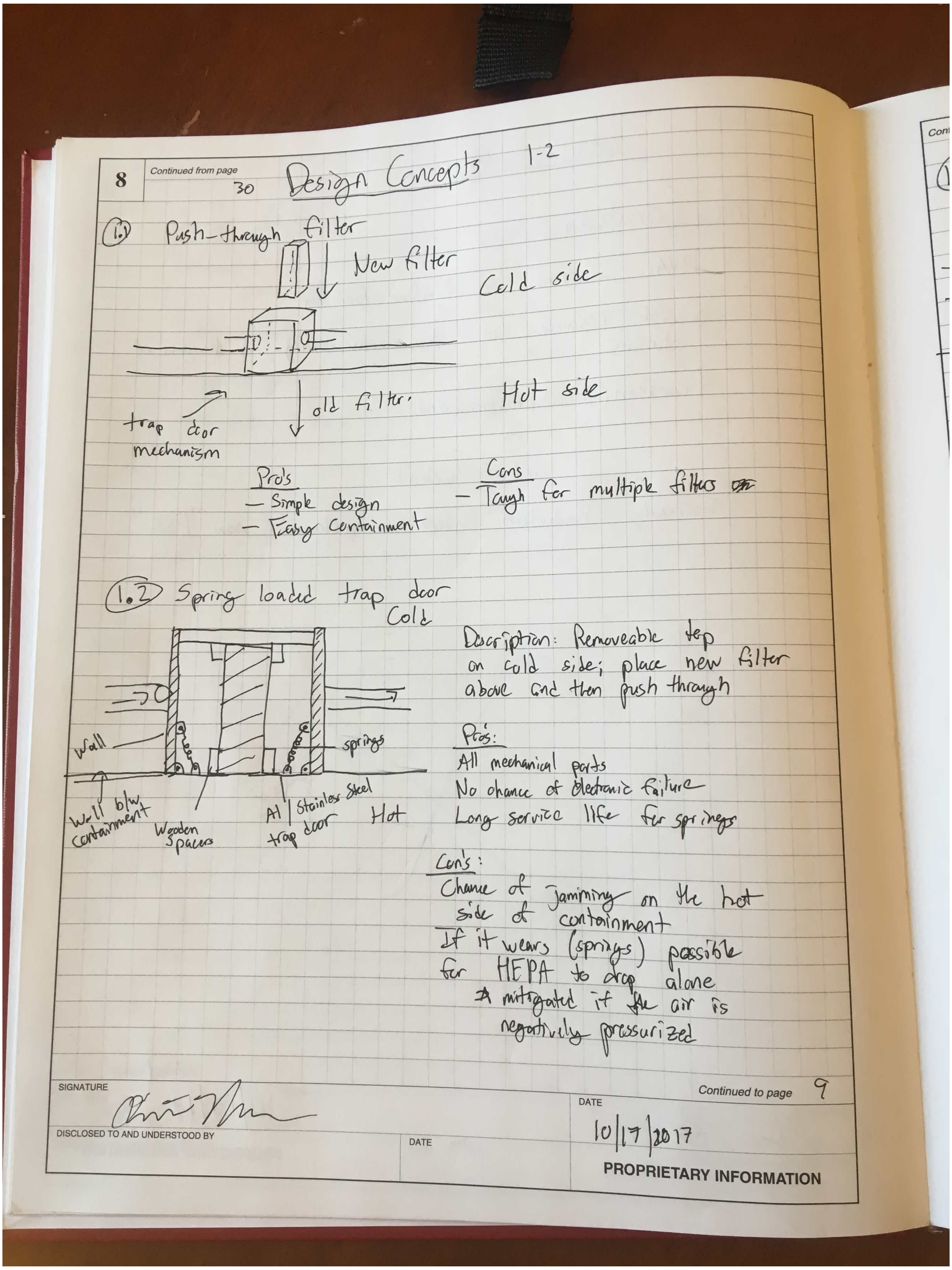
5. 2.1 Upper Door Design: The first design for the upper door is a simple swinging door design, with locking latches on the opposite corners. The door would be manually opened during filter exchange, and closed when completed. (6)
6. 2.2 Sliding Door Design: A sliding door would be just large enough to allow a tight exchange of the HEPA filter. It would be self-locking due to the pressure differential of the system. (5)
7. 2.3 Linear Actuated Rising Door Design: Four linear actuators would raise and lower the locking door and filter guide, completely removing human element in the installing of the new filter during the exchange process. (4)
8. 2.4 Gasket Seal and Latch Door Design: For the best sealing mechanism, a metal door with a rubber gasket installed on the inside would be used to seal the door. This would then be clamped, allowing the most air-tight seal possible. (8)
9. 2.5 Robotic Door Design: A door with an automated robotic arm cap, using a few linear actuators or hydraulic actuators to apply a sealing pressure on the door. This would completely remove the human element to the opening of the housing. (6)
10. 2.6 Automated Plunger Door Design: A suspended door on a linear actuator or hydraulic press to raise and lower the door to push the the new filter in. This would be a completely automated process, yet it would take up the most space. (4)
11. 3.1 Pneumatic Switch Design: Two separate HEPA trains would be used in parallel to each other, with only one actively filtering air at a time. These would then be switched between whenever the HEPA filter needs to be changed out. (10)
12. 3.2 Separate HEPA Systems: Similar to the multiple pump and reservoir systems for the pool water at $RINSC$, two separate HEPA environment systems would be installed for redundancy. Having two systems would allow for no downtime, but able to do extensive maintenance on other parts of the HVAC system. (4)
13. 4.1 Quality Testing with an Embedded Probe: A probe would be embedded within the HEPA filter to measure real-time radiation levels from within. This however could potentially compromise the fiber integrity of the filter. (5)
14. 4.2 Quality Testing with an Embedded Device: An external device would be attached to the HEPA filter, to measure radioactive activity. This would then be transmitted real-time to the control room for monitoring. (7)

15. 4.3 Quality Testing with Pre and Post Filter Sampling: There would be two sensors that would measure radioactivity installed, one just before and one after the HEPA housing unit. These would measure radioactivity as well as air speed and flow rate, allowing for the real-time integrity of the HEPA to be measured. (8)
16. 4.4 Sampling via Spent Filter Containment: Using the existing containment units from each facility, radiation monitors would be installed to allow testing of the contained filters. There would be no real-time monitoring for an installed filter. (6)
17. 5.1 Containment with a Lead Box: For highly radioactive filters, a lead box would be used to shield the radioactivity from the radiation workers. This would be a very expensive and heavy solution. (7)
18. 5.2 Containment via Trolley: This would act under the same principals as the lead box, just adding a cart system that would allow for the radiation worker to roll the spent filter around on the ground. Weight would be easier to deal with, but would still be a limited working solution. (5)
19. 5.3 Hand Truck Containment Design: A modified hand truck with 3 pivoting wheels to allow for ease of access up and down stairs. Would be a niche solution for facilities such as $RINSC$ where their irradiated HEPA filters are found on a second floor landing in a tight space. (6)
20. 5.4 Concrete Cask Containment Design: Long term containment system where a concrete cask would be installed away from the housing unit. This would provide long term spent filter storage, and would allow for radiological measuring devices to be installed to monitor the decay. (4)
21. 5.5 "Chute" Containment Design: An isolated aluminum chute, akin to a laundry chute, that would go all the way down to basement level containment. This would allow for the radiation worker to load out the HEPA and it would be sent down straight to containment. (3)
22. 6.1 Automation with a Rail System: A guide arm would be implemented for the filter, and those rails would be automated to load the filters in and out. A human element would have to still be in play to load it into the guides. (6)
23. 6.2 Automation with a Mechanical Arm: A robotic arm would be installed and then program to remove the spent filter, and replace them with a new filter. This is by far the

most costly design, and would not be reasonably scalable for larger arrays of filters. (7)

24. 6.3 Automation with a Fast Acting Valve Switch: A fast acting valve would change the flow of air to one of two HEPA trains, with a bidirectional plunger located between the two housing units. This plunger would then push the spent filter in the off system out, to be handled by a radiation worker. (9)
25. 6.4 Automation by a 2 Step HEPA Push Through System: The radiation worker would load in a new filter upstream of the old filter, and the filter would then be pushed internally to the correct position. The old filter would be removed through the second access door. (4)
26. 6.5 Automation with a Rotating HEPA Filter Switch: A new filter would be preloaded onto a radial swing arm, which would guide the new filter into place, while holding the old filter. (4)
27. 6.6 Automation with a Double Plunger System: One plunger would push a new filter in, which would in turn push the old filter out. A second plunger would then remove the old filter from the bottom of the housing. (3)
28. 7.1 General Housing Design 1: System akin to what was shown at $RINSC$ (8)
29. 7.2 General Housing Design 2: Allows for 2 filters to be loaded in series, and then pushed forward. (4)
30. 8 Extending Lifetime with a Carbon Prefilter (10)

The following 10 pages contain sketches and brief descriptions taken from the engineering logbook of David Kehoe.



8 Continued from page 30

Design Concepts 1-2

① Push-through filter

New filter

Cold side

old filter.

Hot side

trap door mechanism

Pro's
- Simple design
- Easy containment

Cons
- Taugh for multiple filters

1.2 Spring loaded trap door

Cold

Description: Removeable top on cold side; place new filter above and then push through

wall

springs

Wall b/w containment

Wooden Spacers

Al / Stainless Steel trap door

Hot

Pro's:

All mechanical parts

No chance of electronic failure

Long service life for springs

Con's:

Chance of jamming on the hot side of containment

If it wears (springs) possible for HEPA to drop alone

→ mitigated if the air is negatively pressurized

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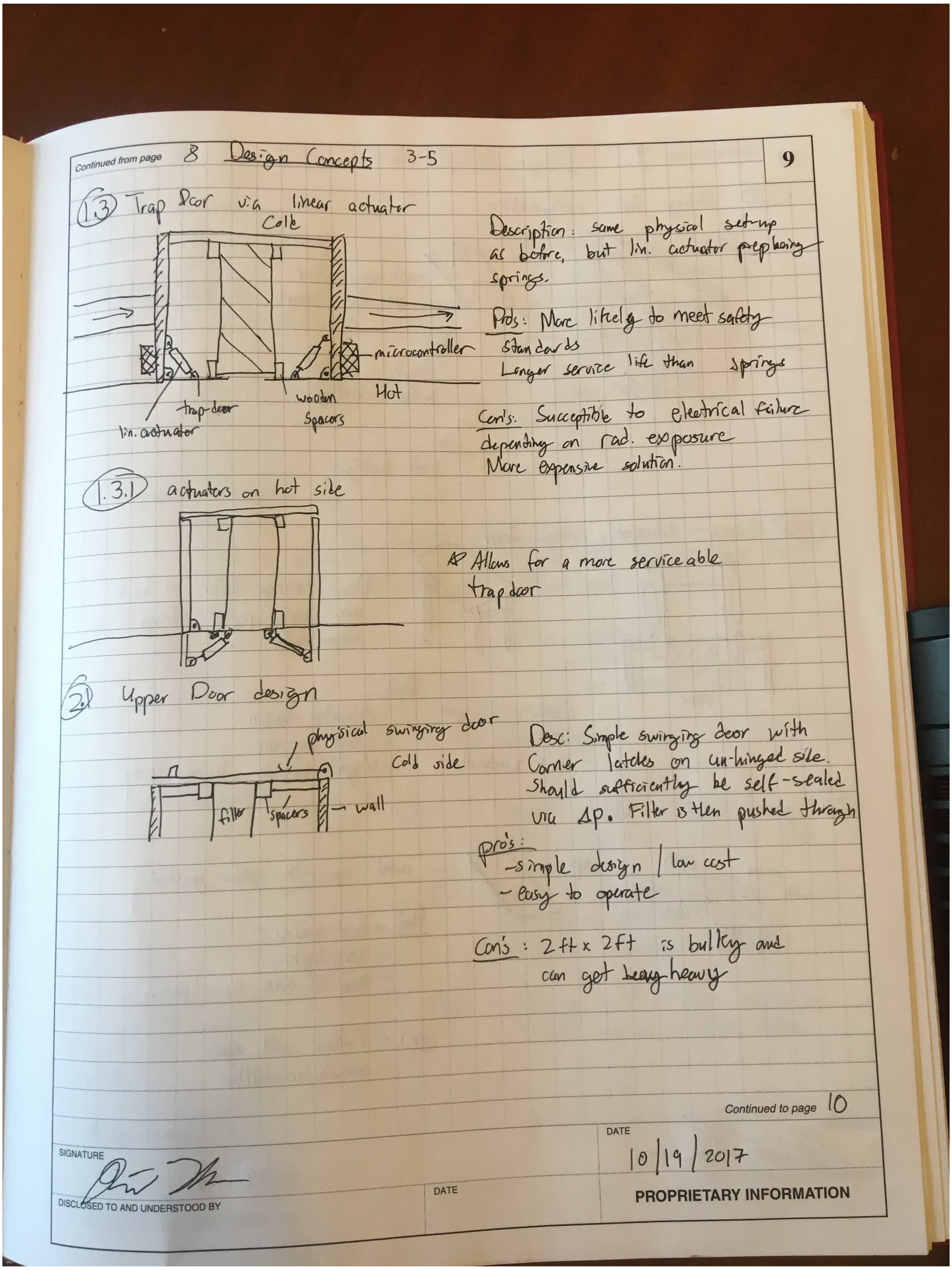

Continued from page 8 **Design Concepts** 3-5 **9**

(1.3) Trap Door via linear actuator

Description: same physical set-up as before, but lin. actuator replacing springs.

Pros: More likely to meet safety standards
Longer service life than springs

Con's: Susceptible to electrical failure depending on rad. exposure
More expensive solution.

(1.3.1) actuaters on hot side

Allows for a more serviceable trap door

(2.1) Upper Door design

Desc: Simple swinging door with Corner latches on un-hinged side. Should sufficiently be self-sealed via ΔP. Filter is then pushed through

pro's:
- simple design | low cost
- easy to operate

Con's: 2ft x 2ft is bulky and can get ~~heavy~~ heavy

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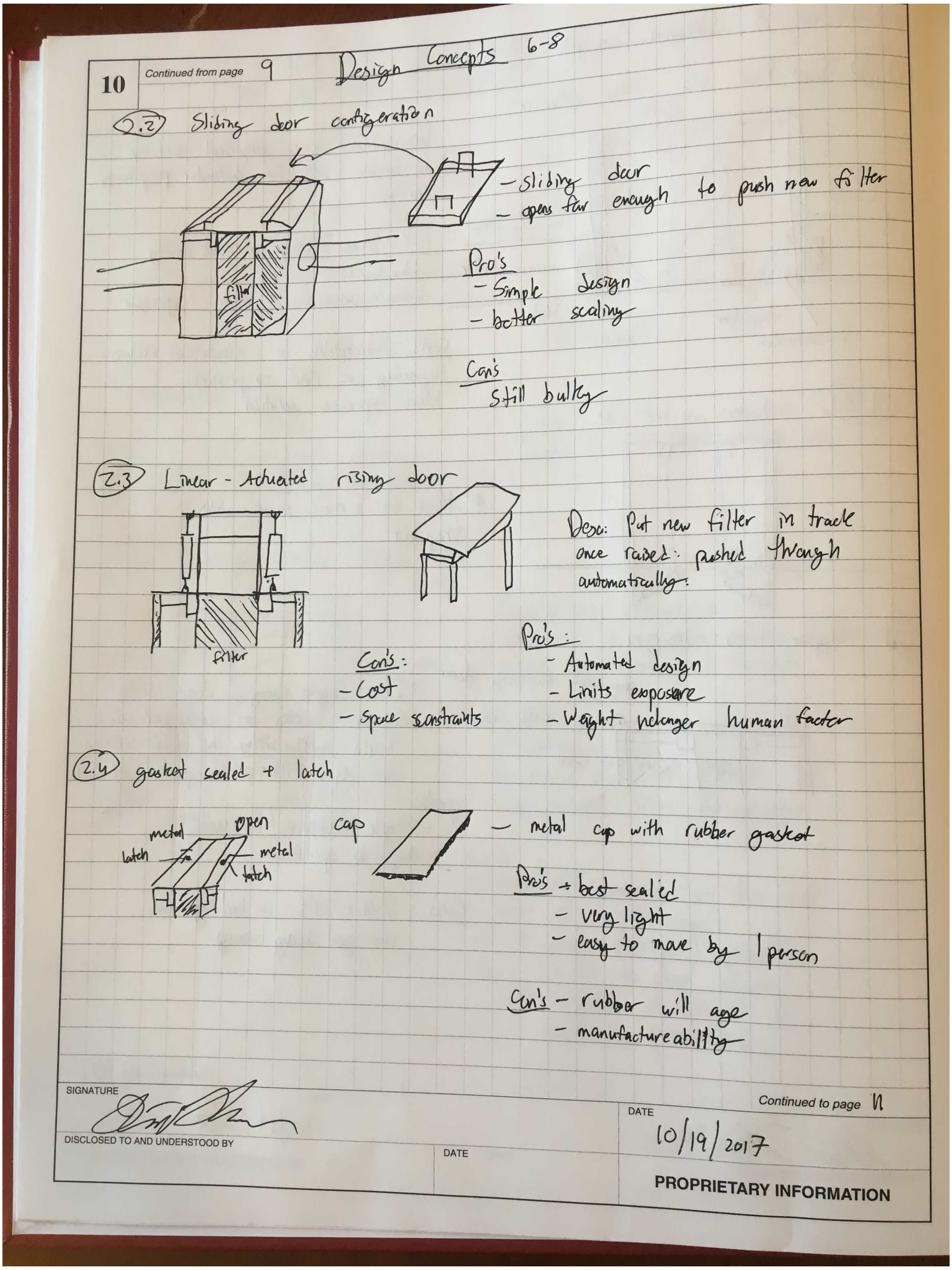

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Design Concepts 6-8

(2.2) Sliding door configuration

- sliding door
- opens far enough to push new filter

Pro's
- Simple design
- better scaling

Con's
Still bulky

(2.3) Linear - Actuated rising door

Desc: Put new filter in track once raised: pushed through automatically.

Con's:
- Cost
- Space sconstraints

Pro's:
- Automated design
- Limits exposure
- Weight nolonger human factor

(2.4) gasket sealed + latch

- metal cap with rubber gasket

Pro's - best seal'ed
- very light
- easy to move by 1 person

Con's - rubber will age
- manufacture ability

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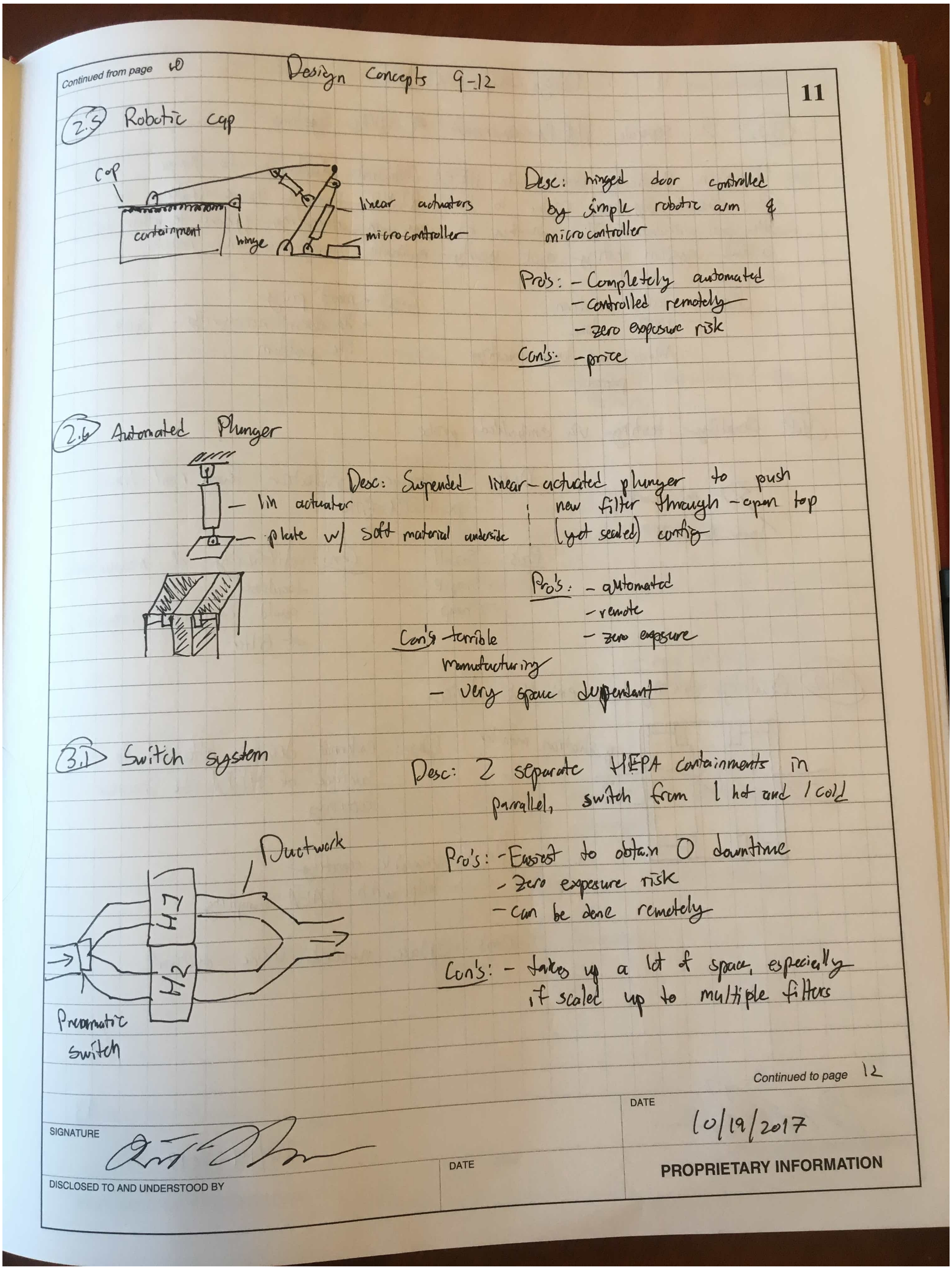

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Design Concepts 9-12

11

2.5 Robotic cap

Desc: hinged door controlled by simple robotic arm & microcontroller

Pro's: - Completely automated
- controlled remotely
- zero exposure risk

Con's: - price

2.6 Automated Plunger

Desc: Suspended linear-actuated plunger to push new filter through - open top (yet sealed) config

Pro's: - automated
- remote
- zero exposure

Con's - terrible manufacturing
- very space dependant

3.1 Switch system

Desc: 2 separate HEPA containments in parallel, switch from 1 hot and 1 cold

Pro's: - Easiest to obtain 0 downtime
- Zero exposure risk
- Can be done remotely

Con's: - takes up a lot of space, especially if scaled up to multiple filters

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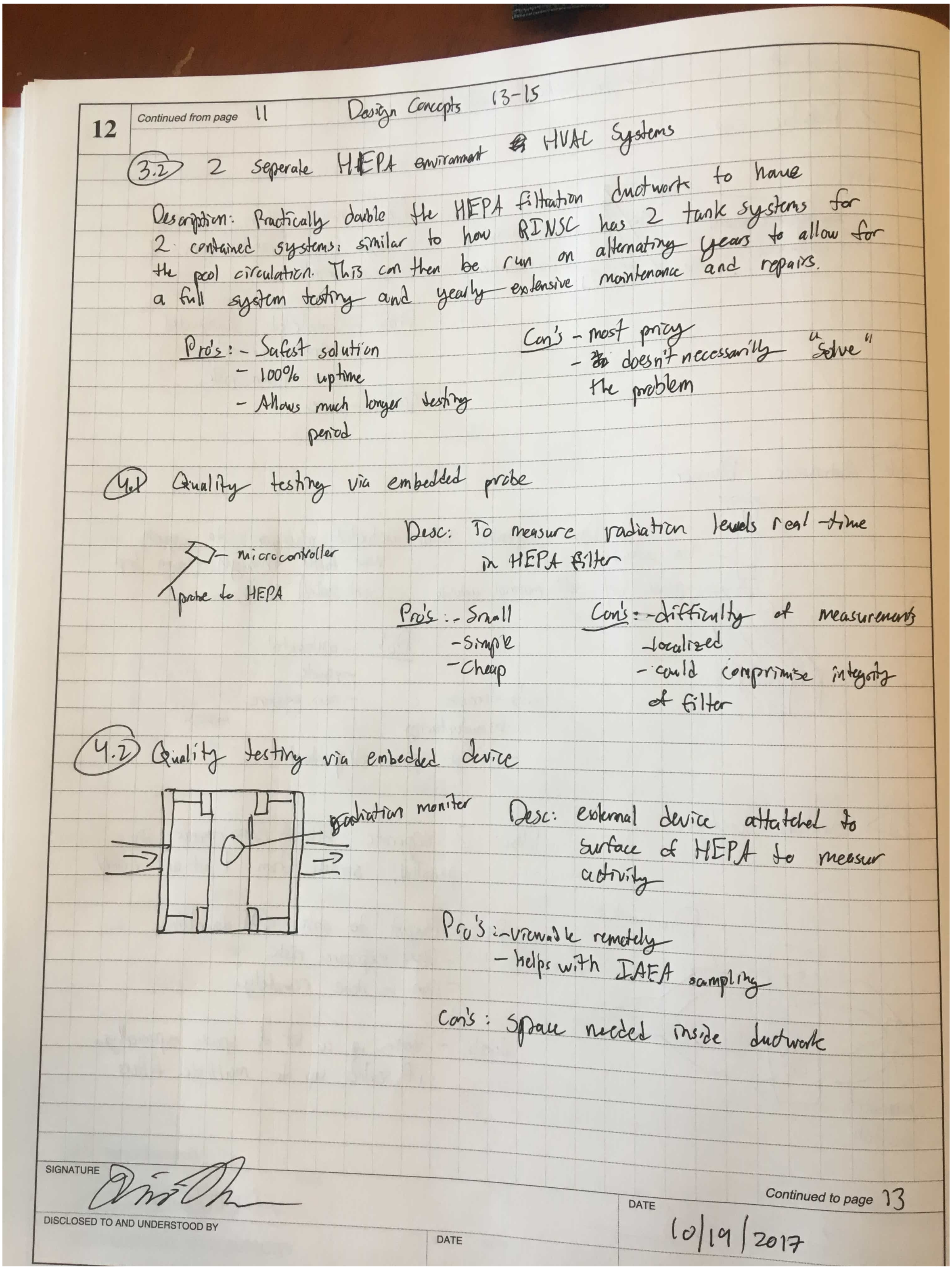

12 Continued from page 11 Design Concepts 13-15

(3.2) 2 seperate HEPA environment HVAC Systems

Description: Practically double the HEPA filtration ductwork to have 2 tank systems for 2 contained systems; similar to how RINSC has the pool circulation. This can then be run on alternating years to allow for a full system testing and yearly extensive maintenance and repairs.

Pro's:
- Safest solution
- 100% uptime
- Allows much longer testing period

Con's
- most pricy
- doesn't necessarily "solve" the problem

(4.1) Quality testing via embedded probe

Desc: To measure radiation levels real-time in HEPA filter

Pro's:
- Small
- Simple
- Cheap

Con's:
- difficulty of measurements localized
- could comprimise integrity of filter

(4.2) Quality testing via embedded device

Desc: external device attatched to surface of HEPA to measur activity

Pro's:
- viewable remotely
- helps with IAEA sampling

Con's: Space needed inside ductwork

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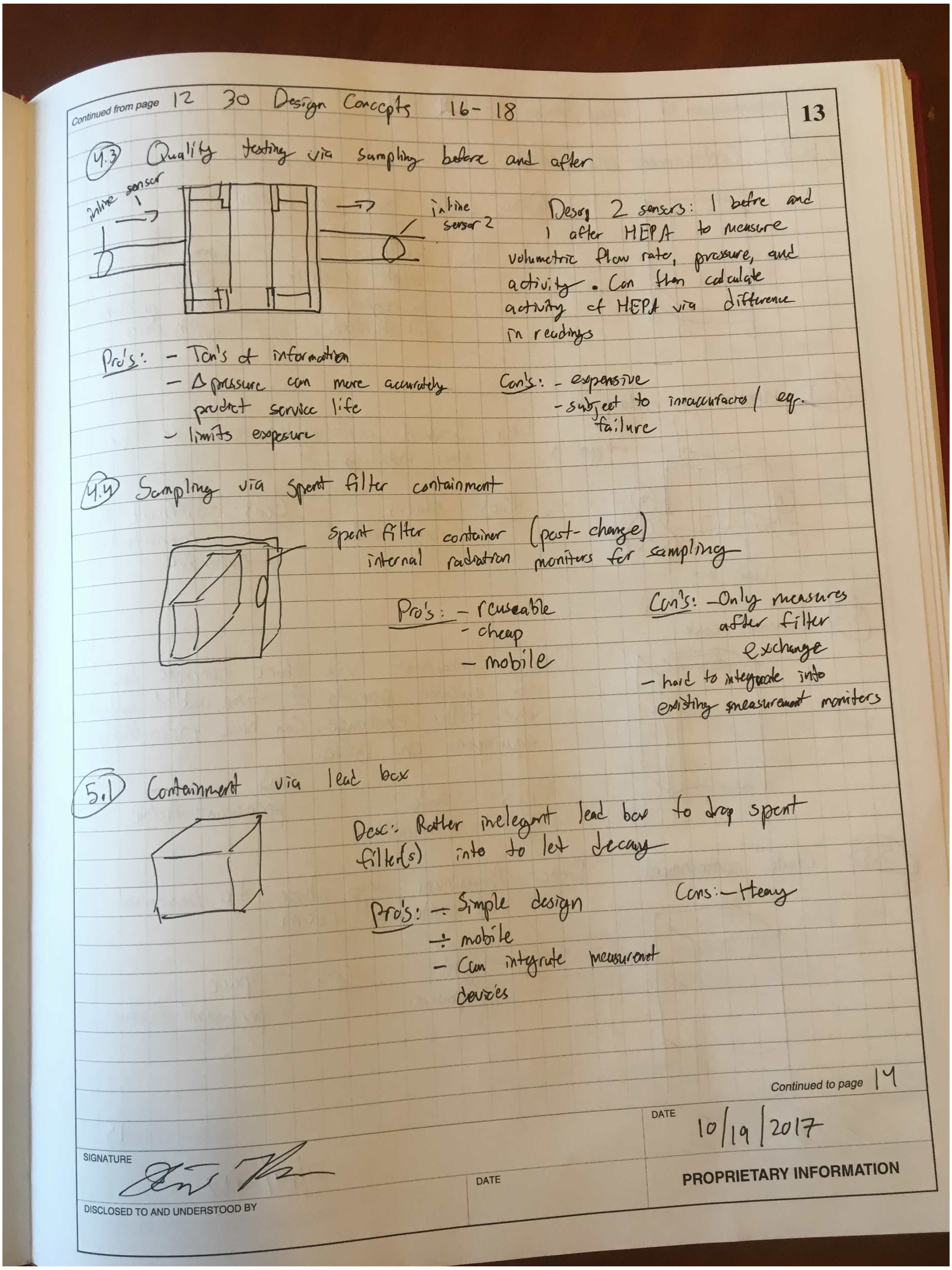

Continued from page 12 30 Design Concepts 16- 18

13

(4.3) Quality testing via sampling before and after

inline sensor 1

inline sensor 2

Desc: 2 sensors: 1 befre and 1 after HEPA to measure volumetric flow rate, pressure, and activity. Can then calculate activity of HEPA via difference in readings

Pro's:
- Ton's of information
- Δ pressure can more accurately predict service life
- limits exposure

Con's:
- expensive
- subject to innaccuracies / eq. failure

(4.4) Sampling via spent filter containment

spent filter container (post-change) internal radiation monitors for sampling

Pro's:
- reuseable
- cheap
- mobile

Con's:
- Only measures after filter exchange
- hard to integrate into existing measurement moniters

(5.1) Containment via lead box

Desc: Rather inelegant lead box to drop spent filter(s) into to let decay

Pro's:
- Simple design
- mobile
- Can integrate measurement devices

Cons: - Heavy

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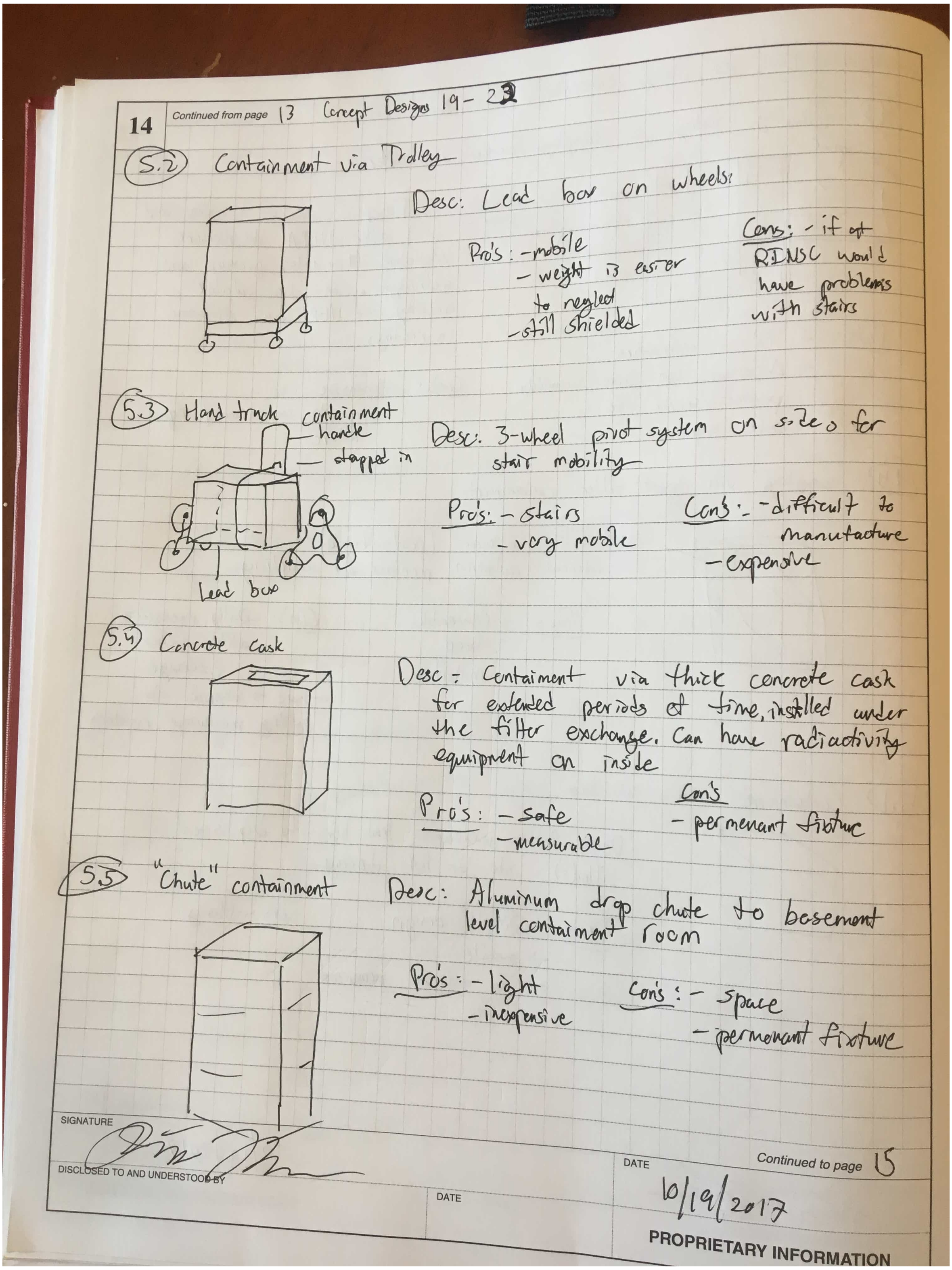

14 Continued from page 13 Concept Designs 19-22

(5.2) Containment via Trolley

Desc: Lead box on wheels:

Pro's:
- mobile
- weight is easier to neglect
- still shielded

Cons:
- if at RINSC would have problems with stairs

(5.3) Hand truck containment

handle

stapped in

Lead box

Desc: 3-wheel pivot system on side, for stair mobility

Pro's:
- stairs
- very mobile

Con's:
- difficult to manufacture
- expensive

(5.4) Concrete cask

Desc: Contaiment via thick concrete cask for extended periods of time, installed under the filter exchange. Can have radiactivity equipment on inside

Pro's:
- safe
- measurable

Con's
- permenant fixture

(5.5) "Chute" containment

Desc: Aluminum drop chute to basement level containment room

Pro's:
- light
- inexpensive

Con's:
- space
- permanent fixture

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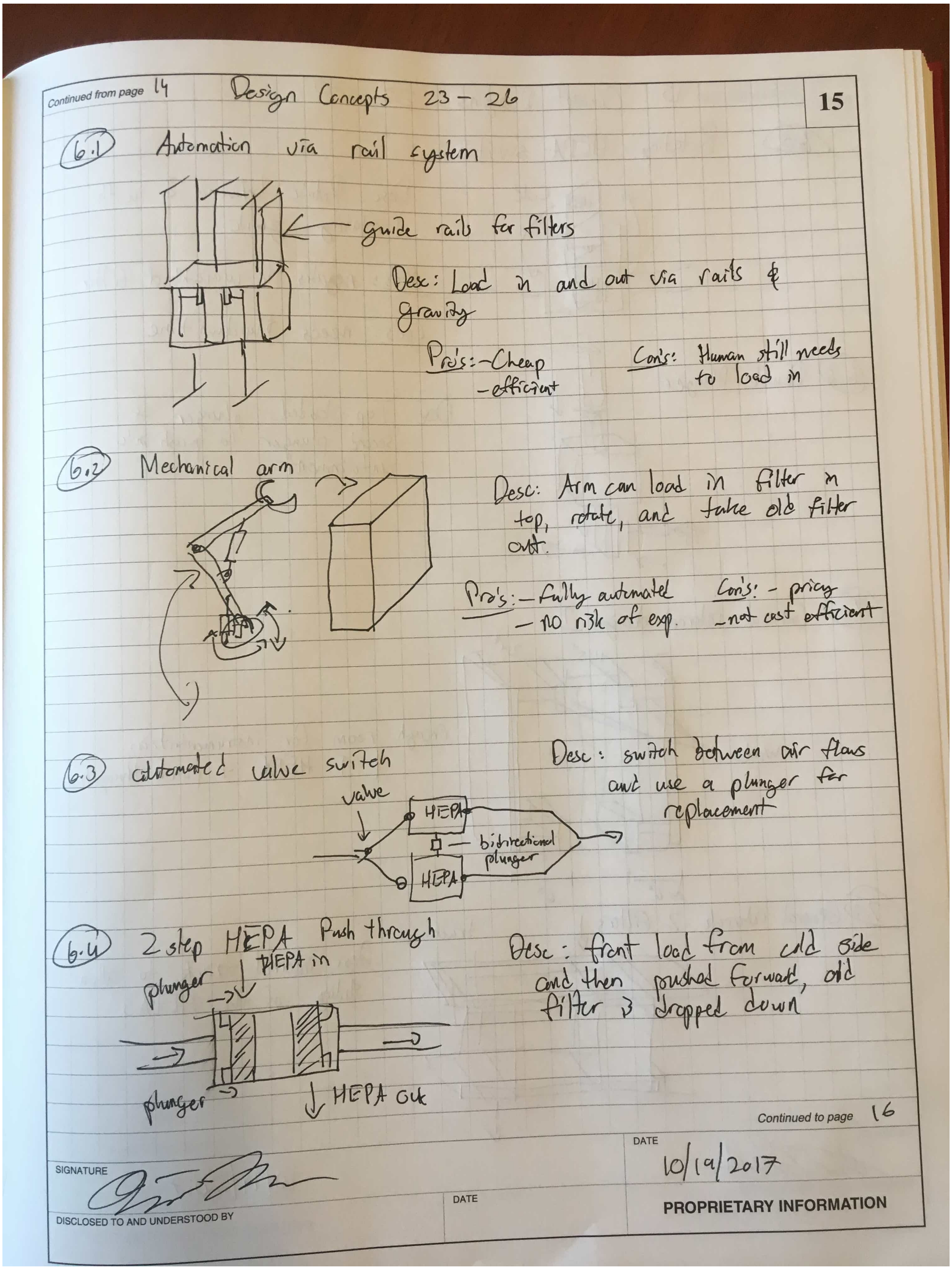

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Design Concepts 23 – 26

15

(6.1) Automation via rail system

guide rails for filters

Desc: Load in and out via rails & gravity

Pro's: -Cheap
-efficient

Con's: Human still needs to load in

(6.2) Mechanical arm

Desc: Arm can load in filter in top, rotate, and take old filter out.

Pro's: - fully automated
- no risk of exp.

Con's: - pricy
- not cost efficient

(6.3) automated valve switch

valve

HEPA

bidirectional plunger

HEPA

Desc: switch between air flows and use a plunger for replacement

(6.4) 2 step HEPA Push through

HEPA in

plunger

plunger

HEPA out

Desc: front load from old side and then pushed forward, old filter is dropped down

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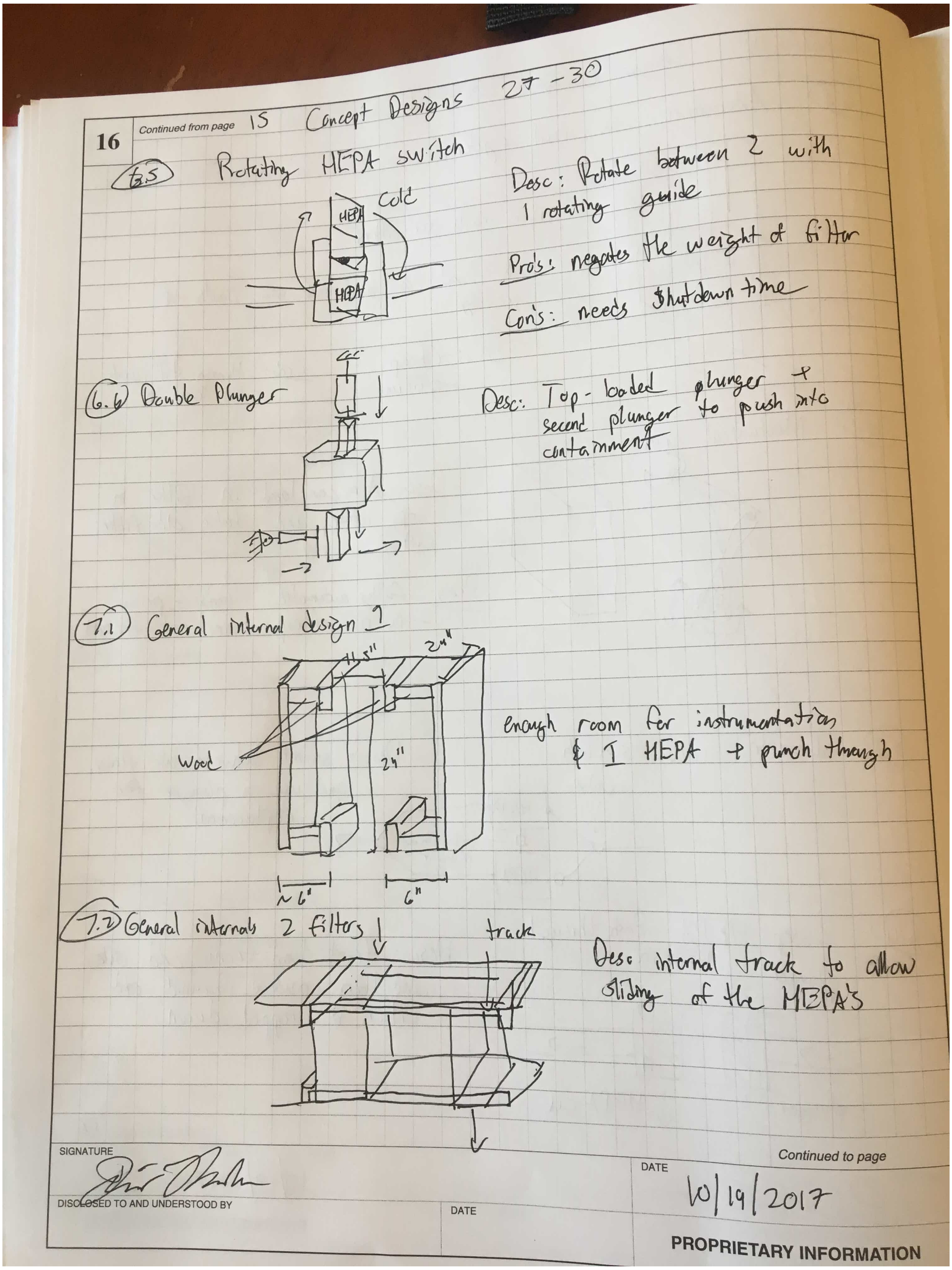

16 Continued from page 15 Concept Designs 27 – 30

6.5 Rotating HEPA switch

Desc: Rotate between 2 with 1 rotating guide

Pro's: negates the weight of filter

Con's: needs shutdown time

6.6 Double Plunger

Desc: Top-loaded plunger + second plunger to push into containment

7.1 General internal design 1

enough room for instrumentation & 1 HEPA + punch through

7.2 General internals 2 filters

Desc: internal track to allow sliding of the HEPA's

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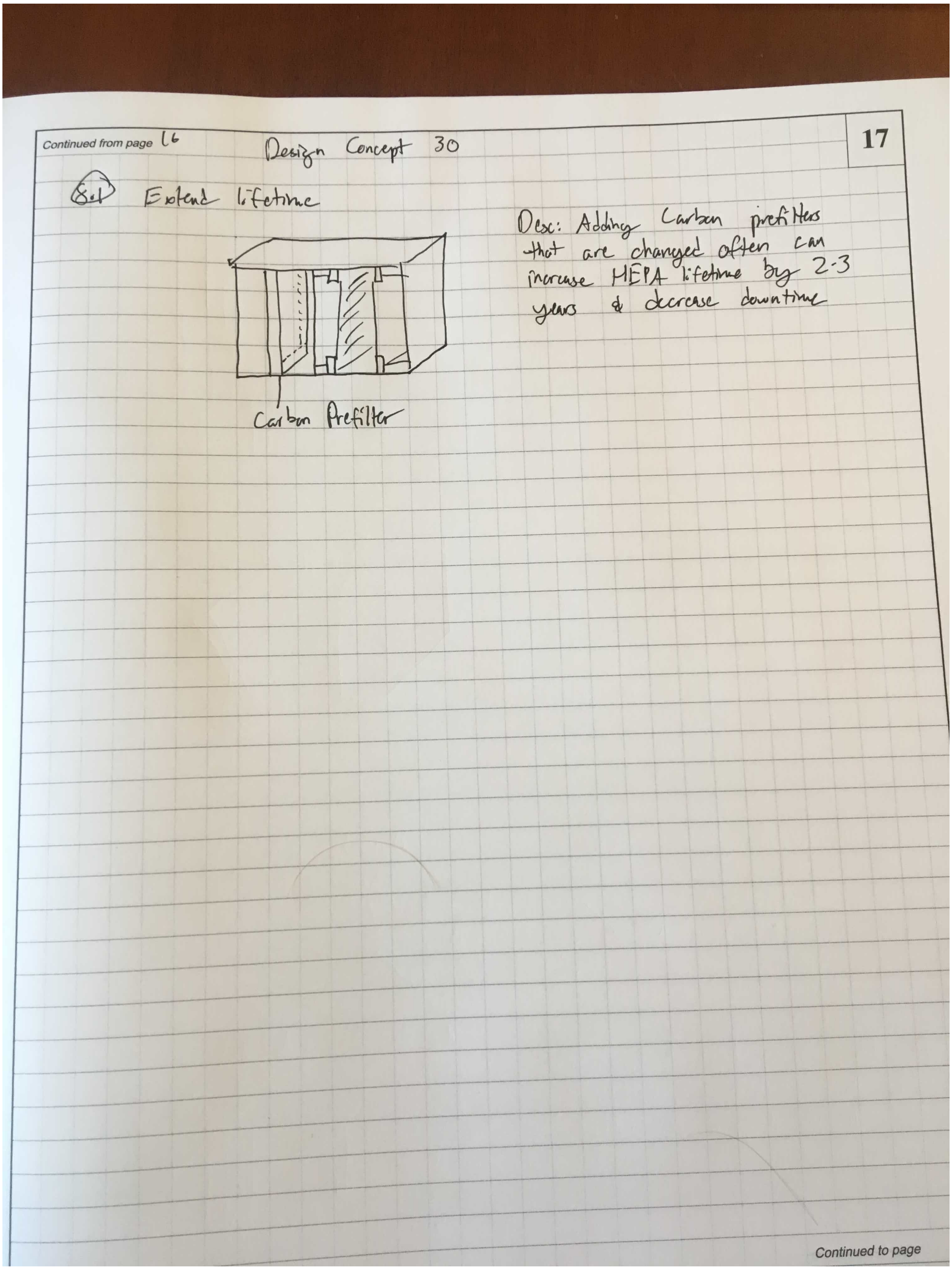

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Design Concept 30

17

8.1 Extend lifetime

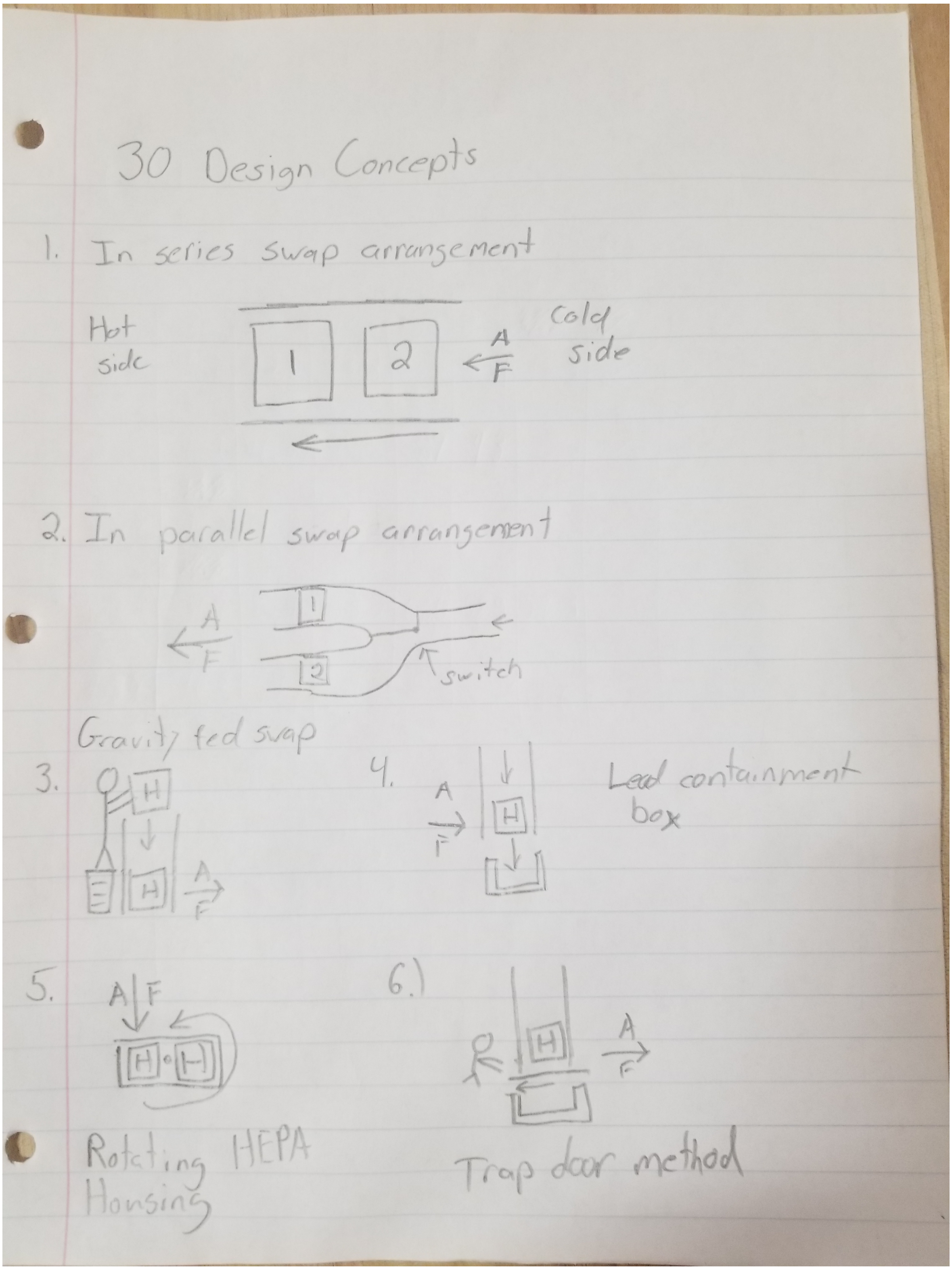
Desc: Adding Carbon prefilters that are changed often can increase HEPA lifetime by 2-3 years & decrease downtime

Continued to page

7.2 Matthew Carlson's 30 Design Concepts

1. In series swap arrangement - This concept accomplishes the goal of online swaps by always having one HEPA in the housing filtering the air.
2. In parallel swap arrangement - This concept accomplishes the goal of online swaps by switching airflow down alternating paths.
3. Gravity fed swap - The goal is to assist workers in loading filters into housings by letting gravity do the work.
4. Lead containment box - A box for spent HEPA filters to contain radiation. Would be connected to housing unit and be easily movable with a jack.
5. Rotating Housing - A housing with 2 filters but only 1 active at a time. Switch active filters by rotating quickly.
6. "Trap door" Method - Building off of concept 3 an easily activated trap door to initiate movement.
7. Wax coating method - In reference to the patent involving wax seals, an easy way to implement the method on newly removed filters.
8. Runners withing housing - Sliders and or wheels within the enclosure help workers insert and remove filters.
9. Mobile glovebox - A mobile glovebox would allow workers to do any testing they need to do onsite rather than offsite.
10. Hinged door modification - A hinged door design would save RINSC time, assuming it complies with standards.
11. Sliding door modification - A sliding door design would save RINSC time, assuming it complies with standards.
12. Radiation meter within housing - A radiation meter within the enclosure would give easy access to data that the IAEA is interested in. It would need to be tamper proof.
13. Slider insert for existing enclosures - Building off of concept 8, it would be nice if these sliders could be inserted into existing housings rather than requiring new manufacturing.

14. Spring compression for seal - A spring activated compressor to hold the filter in place and the seal tight when the housing is closed.
15. Proximity sensor - A proximity sensor built into enclosures to assure the presence of a filter would help prevent some mistakes.
16. Housing that holds 2 filters that can swap - Similar to concepts one and two but utilizing the sliders and a filter to filter seal.
17. Inclusion of brush seals - Redundant brush seals would help assure airtight seals for concept 16.
18. Disposable connection between filters - a required part for concept 16 to be viable.
19. Modified HEPA filters with edge seals - Built in gel seals would make the process of swapping simpler for workers with a downside of complicating manufacturing. This is an alternative to the previous concept.
20. Double bag in/bag out configuration - This concept would allow for a filter to be added while one is removed, probably necessary for concept 16. Downside is it would require 2 workers.
21. External lever for clamp - Builds off of the spring loaded compression concept. An external lever would be the easiest way to activate and deactivate the spring.
22. Vertical 2 filter swap - A vertical 2 filter swap would allow on line swaps and let gravity do the heavy lifting.
23. Fully modular replaceable enclosure - A fully modular replaceable enclosure could be implemented anywhere and swapped out at the facilities leisure.
24. Temporary air diversion - Temporary air diversion would give a short window during which swaps would be clean.
25. Hopper fed system - A hopper to hold a stack of filters combined with an automated swap could remove the necessity for workers for large periods of time.
26. Automatic rollers - Automatic rollers would assist with moving filters through the housing.
27. Redundant systems with clean switch - Two of these next two each other would achieve on line swaps and be very versatile,



30 Design Concepts

1. In series swap arrangement

2. In parallel swap arrangement

Gravity fed swap

3.

4.

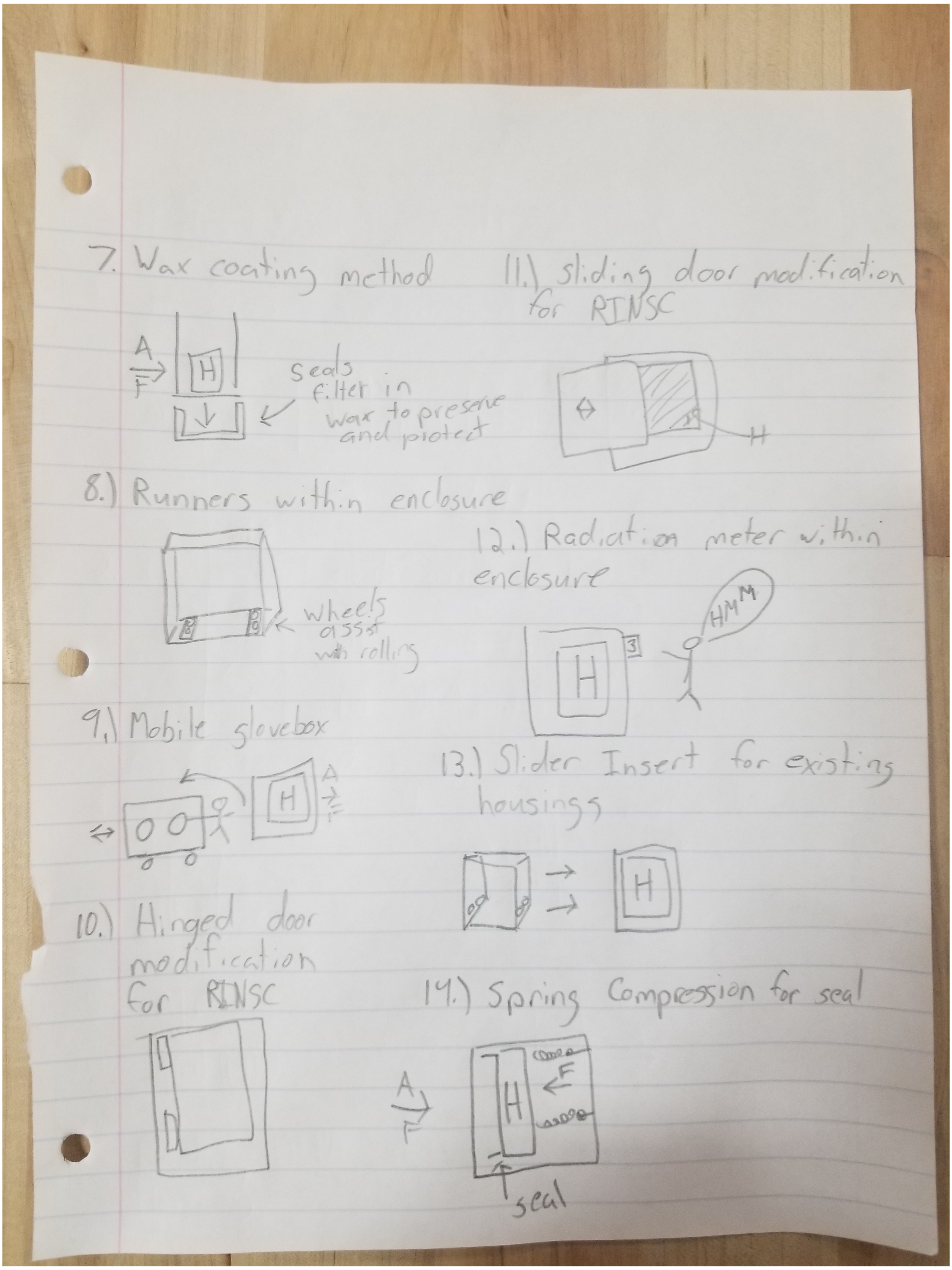
Lead containment box

5.

Rotating HEPA Housing

6.)

Trap door method



7. Wax coating method

8.) Runners within enclosure

9.) Mobile glovebox

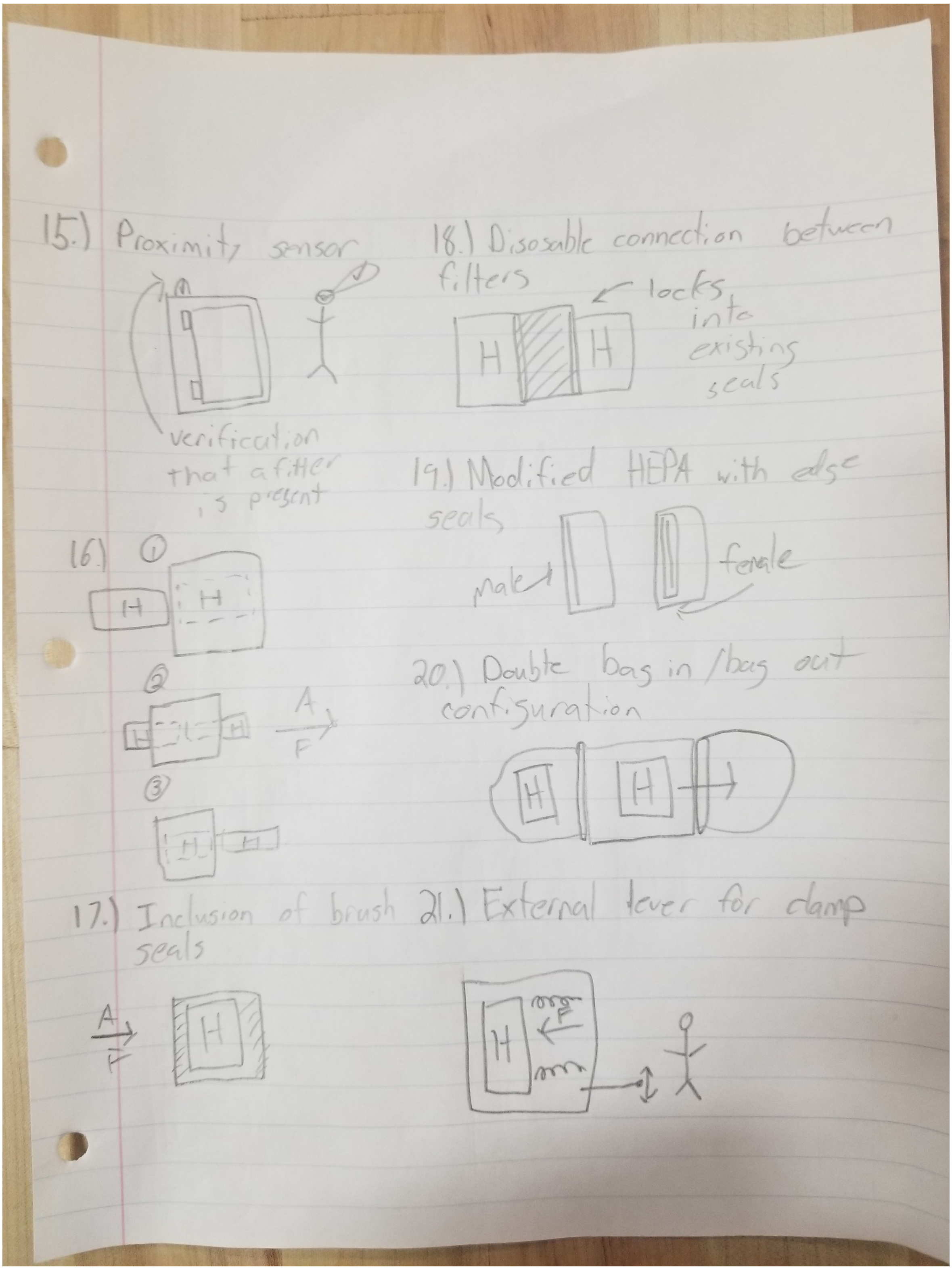
10.) Hinged door modification for RINSC

11.) sliding door modification for RINSC

12.) Radiation meter within enclosure

13.) Slider Insert for existing housings

14.) Spring Compression for seal



15.) Proximity sensor

verification that a filter is present

18.) Disosable connection between filters

locks into existing seals

19.) Modified HEPA with edge seals

male

female

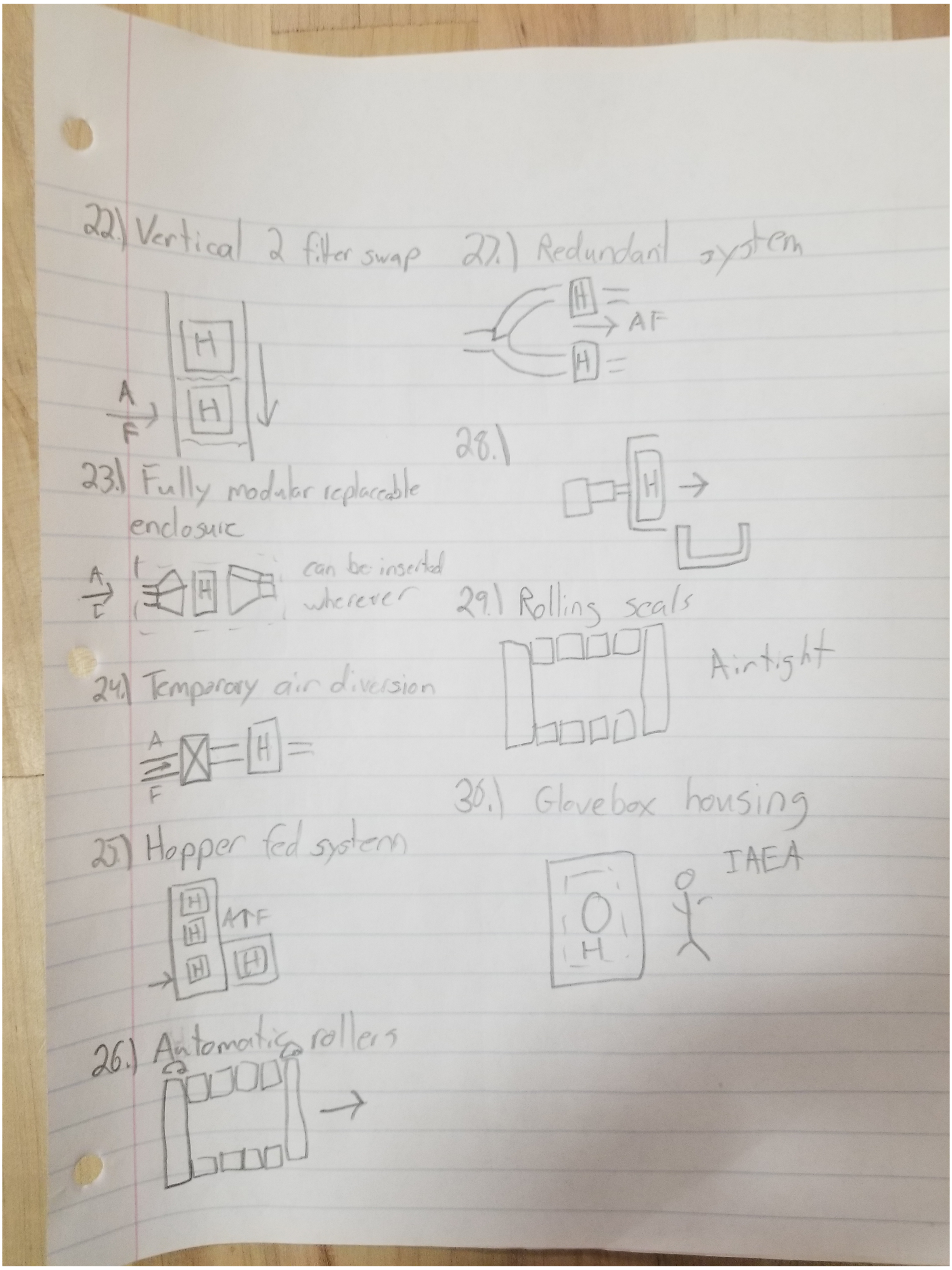
16.) ① ② ③

20.) Double bag in/bag out configuration

17.) Inclusion of brush seals

21.) External lever for clamp

28. Pneumatic removal - a pneumatic pusher could take advantage of air pressure differences and assist in removing filters.
29. Rolling seals - Rolling seals would maintain a seal for during swaps and be compatible with concept 16.
30. Glove box housing - This would give the potential to run tests on filters without removal.



22.) Vertical 2 filter swap

23.) Fully modular replaceable enclosure

can be inserted wherever

24.) Temporary air diversion

25.) Hopper fed system

26.) Automatic rollers

27.) Redundant system

28.)

29.) Rolling seals

Airtight

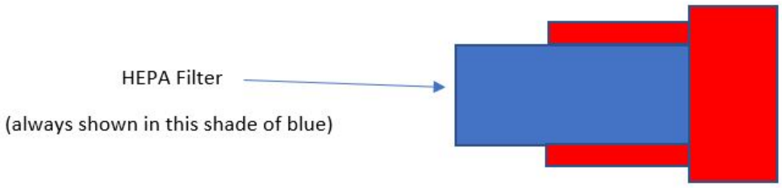
30.) Glovebox housing

IAEA

7.3 Joshua Bolt’s 30 Design Concepts

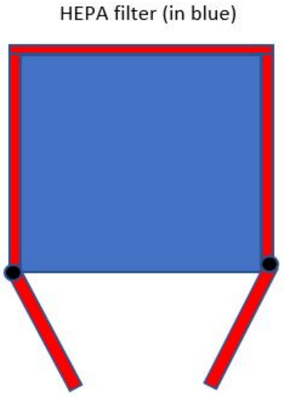
Concept #1: pneumatic gripper system

This system would make use of the air that is already flowing through the ductwork in the system. This idea comes out of the notion that if the airflow had to be redirected to change out a filter, and the rise in pressure could be used to operate the gripper. The gripper is shown in red, from a top down view, grabbing the filter width-wise, because that is the smallest dimension at 1ft. The gripper would be connected through the ductwork for its air supply. Validity 9/10



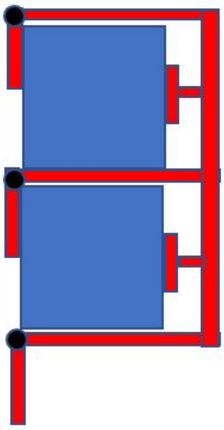
Concept #2: Trap door drop-out

This idea would utilize gravity as the main source of power. The bottom of the filter housing unit would be modified to have a door so that it could be opened and the filter just drop out into a storage container. This concept would not work if the filters are in a vertical series, as they are near the diffusion blower in the RINSC reactor. Validity 9/10



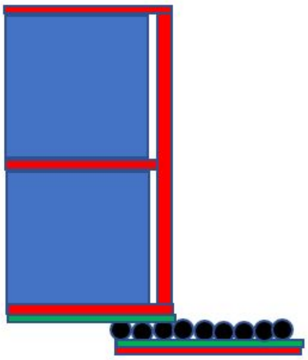
Concept #3: Side trap door

This design is like the trap door, but modified for filters that are vertically in series. There will need to be a mechanism to push the filters out from one side. This could be mechanical, or pneumatically powered. It will be set up on the inside of where the filter is housed. Validity 10/10



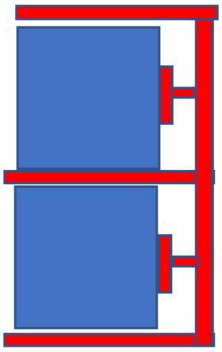
Concept #4: sliding exchange web

In this concept, a web of HEPA filters can be slid out from their housing within the ductwork, where they will drop out into a containment or transfer unit, or be transferred by hand if they are not irradiated. Validity 7/10



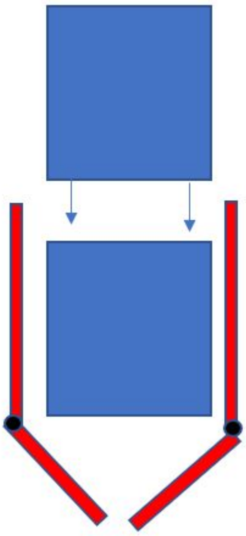
Concept #5: Filters Pneumatically discharged

The outside panel is removed, and a pneumatic pusher will eject the filters into a containment unit. Instead of having swinging doors like the trap door design, the current panel will remain, but be easier to remove, because it will be sealed shut through the vacuum instead of bolted shut. Validity 8/10



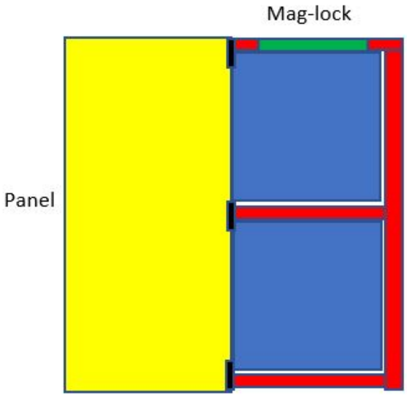
Concept #6: Top-loader system

A new filter is fed through the top of the system and the old filter is pushed out through a pressure activated trap door. The operator does not have to handle the old filter this way. The filter falls into a containment or transfer unit. Validity 8/10



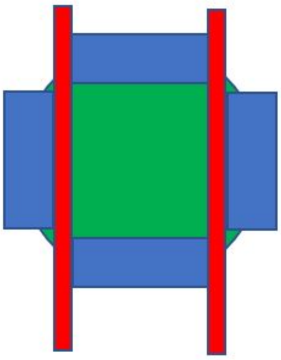
Concept 7: Manual replacement, mag-locked panel

In the current setup at RINSC, the outside panel must be removed by unscrewing several wing nuts, which takes a lot of time. This idea minimizes the amount of time, but still requires a manual replacement. This would be useful when removing filters that are not irradiated. The panel would be hinged onto the assembly. Validity 9/10



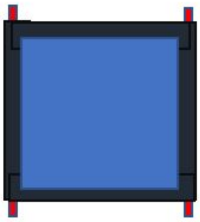
Concept #8: Filter carousel

For this concept, four filters are fitted into an assembly that can spin to change between filters. The outermost filters will be easily accessible outside the duct while the other two remain within. Validity 6/10



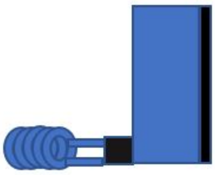
Concept #9: Gasket seal attached to rollers

This design incorporates rollers across the face of the filter that allow the filters to move freely while being switched, and be sealed by a clamp that pushes the filter up against the gasket when it is in place. In the drawing shown, the rollers are on the left and right side and are wrapped in the gasket material. Validity 9/10



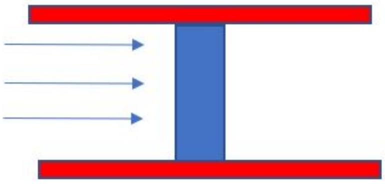
Concept #10: Spring loaded clamping device

The clamp will be able to apply enough force to the filter to push it up against a seal, which will allow the system to remain online during filter switches. This combined with a rolling design should allow for seamless filter replacement. Validity 9/10



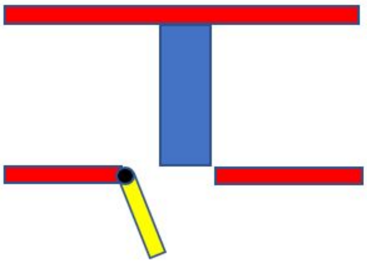
Concept #11: Filter encapsulation with resin and vacuum

This idea came through patent searches. There is already a resin that exists, that when introduced to a HEPA filter in a vacuum, coats the filter and makes it safe for disposal. The resin could be fed into the system and then absorbed once it reaches the filter. Validity 9/10



Concept #12: encapsulation with resin, hand sprayed

The same resin will be used as in concept 11, except now the outside panel will be removed and the resin will be sprayed in by hand. Validity 7/10

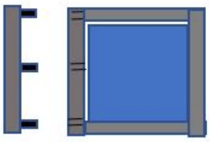


Concept #13: lead box, bolted shut

A lead box that fits the filter perfectly and can block any radiation that it contains. The box will be bolted shut, but can be later unbolted so the filter can be examined. Validity 9/10

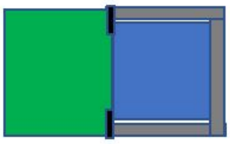
Concept #14: lead box, with pin and hole cover

Similar to concept 13, but the cover for the box is held in place with pins instead of being bolted shut. This would make for easier access to the filter, while still protecting against radiation. Validity 8/10



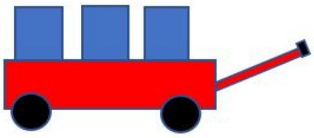
Concept #15: lead box, with hinged door

For this design, the lead box has a hinged door that can be locked into placed and easily unlocked to review the filter. Validity 8/10



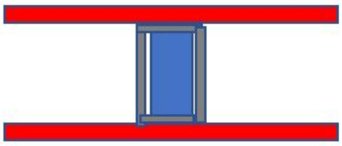
Concept #16: Transfer wagon

This concept is geared towards HEPA filters that can be manually removed, or Filters that are not highly irradiated. The filters would fall into, or be placed in a wagon to be transferred. Validity 6/10



Concept #17: in-line cannister, removable lid

This contains the entire filter and cannister within the ductwork of the facility. The cannister can be bolted shut within the system and then the entirely removed and stored, and then opened later for IAEA inspections. Validity 8/10

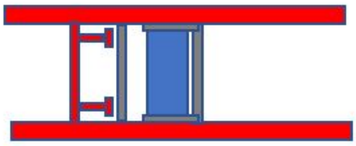


Concept #18: in-line cannister, disposable

This is the same concept as number 17, except the cannister will be made of thinner, lighter metal for easy disposal. This would apply to filters that do not need to undergo IAEA inspection Validity 7/10(See sketch above)

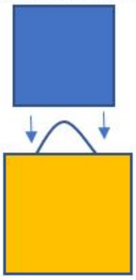
Concept #19: in-line cannister, pneumatically sealed

The cannister will have to cover pressed on pneumatically in the system. The cannister and filter are still contained within the ductwork. Validity 9/10



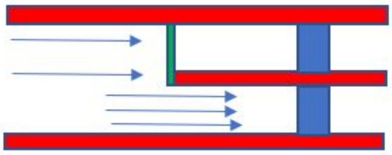
Concept #20: Transfer carrying case

This design is meant for HEPA filters that are not highly irradiated. The can simply be carried out with the case, which saves time and protects better against any radiation there may be. Validity 5/10



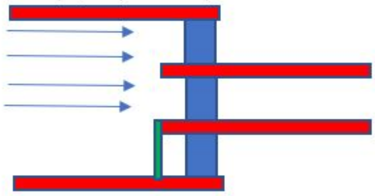
Concept #21: air redirected online, horizontal set-up

In this setup, the airflow is redirected to a different filter in the system. Switching between these filters allows one to be changed while the other is active. A lever to shut the divider between the two will be used. Validity 9/10 (top down view)



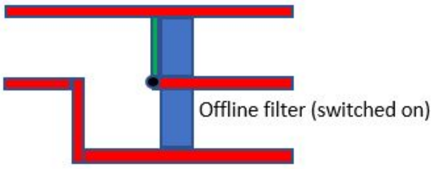
Concept #22: air redirected online, vertical set-up

The setup is modified from concept 21 to fit a vertical filter stack, like the one at RINSC. If there are three filters, the flow will be redirected to two of them, and the remaining volumetric flow used as part of a pneumatic system. Validity 9/10 (side view)



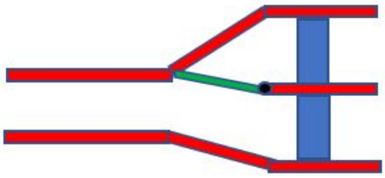
Concept #23: air redirected offline, horizontal set-up

A filter set up remains offline until a replacement is needed. The offline filter is now switched online, and the filter that was previously in use can be switched out. Validity 9/10



Concept #24: air redirected offline, vertical set-up

The design is meant for filters that are vertically in series. A barrier redirects air to a filter setup that was previously offline, in order to switch the spent filter. This helps the facility stay online during filter switches. Validity 9/10

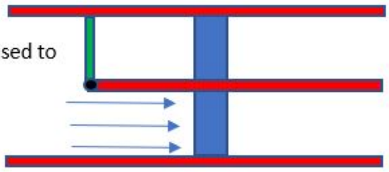


Concept #25: addition of multiple pre-filters

For this concept the facility will still have to come offline to switch filters, but they will have to do it much less often. With the addition of one or more pre-filters before the HEPA filters in the system, the life of the HEPA could be extended for many more months. Validity 6/10

Concept #26: decreased airflow, air redirected

Instead of the redirected air being used in a pneumatic system, the air flow would be decreased since the filters have a limit of 1100 cfm. This would be done in the control room of the reactor. Validity 8/10



(air flow decreased to

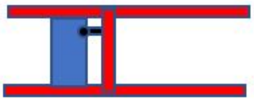
1100 cfm)

Concept #27: Multiple HEPA filters in a row

This design contains multiple HEPA filters in a row, to increase the time between replacements. This set up is currently used in extreme radiation cases to make sure the air is filtered sufficiently. Validity 7/10

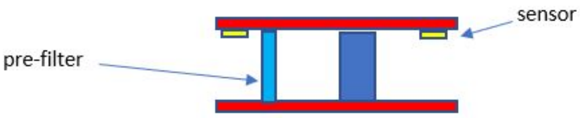
Concept #28: Hole punch sample

A small sample of the filter is punched out and then contained in a small led box, so that the rest of the filter can be disposed of. The hole puncher will be pneumatically controlled. Validity 7/10



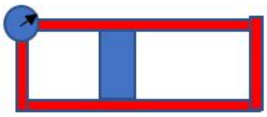
Concept #29: Sensors before and after filtration

Sensors will be attached on the inside of the ductwork to test the filtering capabilities of the HEPA and pre-filter, and provide insight into activities the nuclear material underwent. Validity 8/10



Concept #30: pressure gauge to ensure good airflow

Air pressure through the filter will be measured to ensure good flow, and show when a filter should be replaced if it is clogged. Validity 7/10



8 DESIGN FOR X

When designing a product it is inevitable that multiple different values will conflict with each other. When a conflict arises it is important to have a hierarchy of values to determine what the correct solution is. The main design considerations for this product were safety, reliability and ease of use. In order for a company to adopt a new technology it needs to improve the function of their facility. In the nuclear world ever detail needs to be planned for and predictable. Workers need to know that they are safe while properly operating the systems, those systems need to work, and they need to be as simple as possible to reduce wasted time.

8.1 Safety

When designing anything that can be used in a nuclear environment safety needs to be the first priority. Nuclear technologies are inherently dangerous if the proper precautions are not taken. Additionally nuclear technologies already have a poor reputation amongst some of the public so any potential mistakes need to be avoided. The HEPA housing allows the use of the bag-in-bag-out procedure which is industry proven to protect radiation workers and prevent accidents. The untreated air is never released into the clean areas and all air directed to the housing is filtered. All typical personal protective equipment is to be worn when interacting with the housing. Additionally the use of traditional sealing methods where applicable ensures adequate protection.

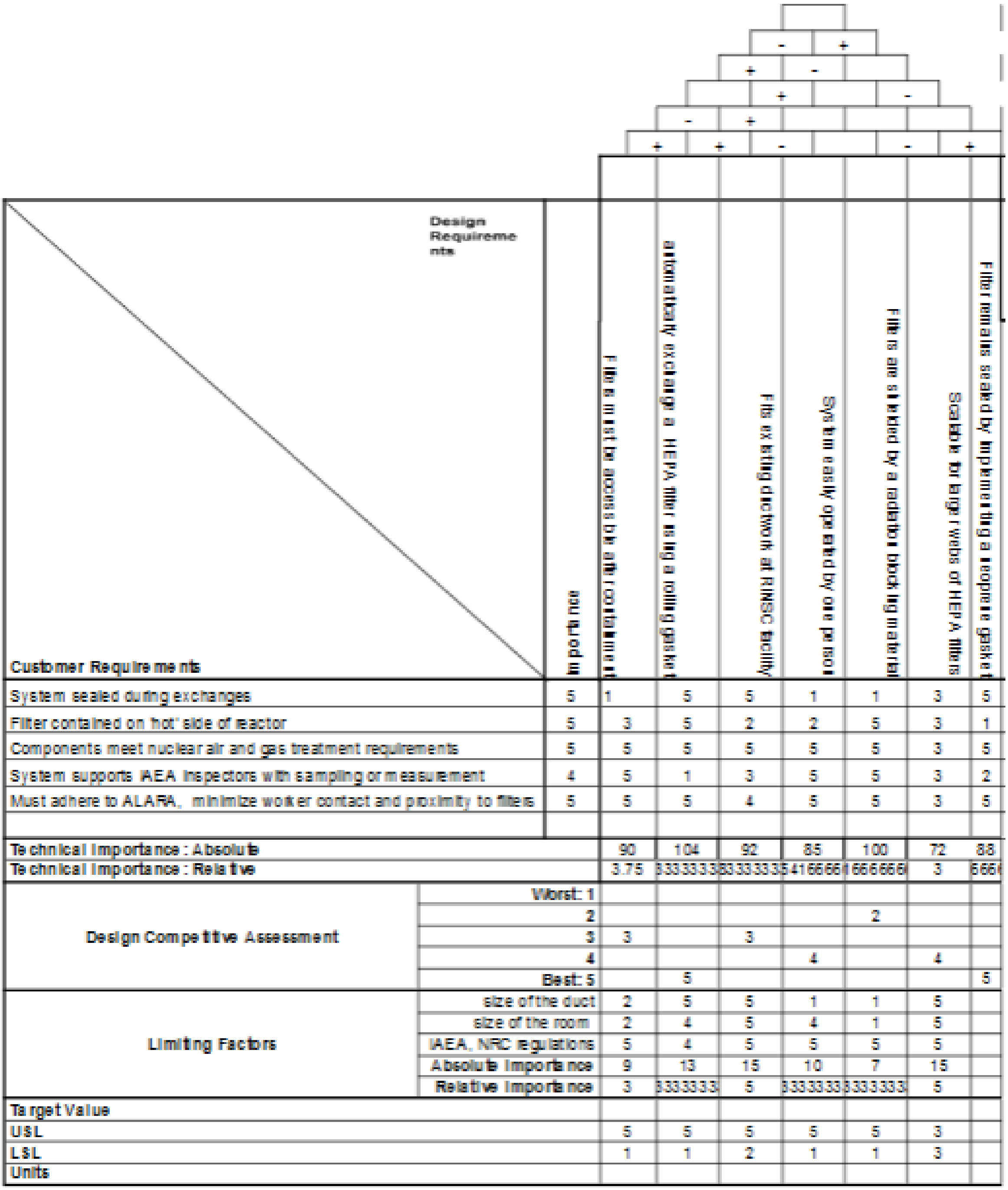
8.2 Reliability

Reliability goes hand in hand with safety. Downtime in a nuclear power plant is extremely expensive and needs to be avoided when at all possible. With the amount of different components that need to work at any given time the chance that one will fail increases. With this fact in mind it is essential that every component is reliable across its entire lifetime in order to be useful. The housing unit was designed with small tolerances so that unwanted movement within the enclosure are kept to a minimum and the swapping process can be executed the same way every time without problem. All materials were selected with a 30 year lifetime in mind meaning that failure is unlikely before decommissioning. When the product is reliable over its entire lifetime it means that undesired delays will be avoided and the facility can continue to run smoothly and to plan.

8.3 Ease of Use

The third key design feature is ease of use because a product that requires more man hours for maintenance, replacement or training will be less appealing than the existing alternatives. The procedure for filter swapping involves simply disengaging the clamping mechanism and then pushing a new filter through one side which in turn pushes the old one out the other utilizing the familiar bag in bag out system. Once the filter is removed it can be inspected and disposed of at leisure without hindering the uptime of the facility. The custom HEPA filters will have all necessary features already attached decreasing the amount of steps required to preform a HEPA filter replacement.

9 QFD



Customer Requirements	Importance	Filters must be accessible after containment	automatically exchange a HEPA filter using a rolling gasket	Fits existing ductwork at RINSC facility	System easily operated by one person	Filters are shielded by a radiation blocking material	Scalable for larger webs of HEPA filters	Filter remains sealed by implementing a neoprene gasket
System sealed during exchanges	5	1	5	5	1	1	3	5
Filter contained on 'hot' side of reactor	5	3	5	2	2	5	3	1
Components meet nuclear air and gas treatment requirements	5	5	5	5	5	5	3	5
System supports IAEA Inspectors with sampling or measurement	4	5	1	3	5	5	3	2
Must adhere to ALARA, minimize worker contact and proximity to filters	5	5	5	4	5	5	3	5
Technical Importance : Absolute		90	104	92	85	100	72	88
Technical Importance : Relative		3.75	3333333	8333333	5416666	1666666	3	6666
Design Competitive Assessment	Worst: 1							
	2					2		
	3	3		3				
	4				4		4	
	Best: 5		5					5
Limiting Factors	size of the duct	2	5	5	1	1	5	
	size of the room	2	4	5	4	1	5	
	IAEA, NRC regulations	5	4	5	5	5	5	
	Absolute Importance	9	13	15	10	7	15	
	Relative Importance	3	3333333	5	3333333	3333333	5	
Target Value								
USL		5	5	5	5	5	3	
LSL		1	1	2	1	1	3	
Units								

Figure 2: The QFD used by the team

A QFD was used to assist the team in identifying the most important aspects of the design, where trade offs were necessary and for decision making. THe QFD allow the team to take customer requirements and weight them as design requirements and then get a quantitative value of relative importance. Upon analyzing the QFD the team determined that the two most important design requirements were that the design could be scalable and that it would fit into existing duct work. The team set out to accomplish this goal.

10 PROJECT SPECIFIC DETAILS AND ANALYSIS

To account for the differences in requirements from facility to facility the team has proposed four different solutions for varying levels of radioactivity. The tiered list allows the group to recommend cheaper solution packages for facilities with less requirements while still remaining safe. The tiers and proposed solutions are presented below.

10.1 No Radioactivity

This application is slightly outside the scope of the project which is focused on nuclear applications but is important to explain for context. In a situation where a HEPA filter is required but there is no radioactivity concern the main purpose of the filter is to be picking out unwanted particles from the air. Once these particles are captured they simply need to be contained in a sealed manner without any concern for shielding. During the course of competitive analysis the team discovered a few products that already fulfill the needs of this tier. For the sake on not reinventing the wheel the team recommends a Camfil housing unit or one of the many others like it.

Figure 3: Tier 1: Basic Camfil Housing

10.2 Trace Amounts of Radioactivity

For a situation in which there is trace radioactivity the solution is similar to Tier one in the sense that there are many existing products aimed at this situation that function without issue. An additional feature that would be desired here is the ability to implement a bag in/bag out procedure. It should be noted that a facility falling into this category may opt for our Tier Three design solution because of the cost saving potential.

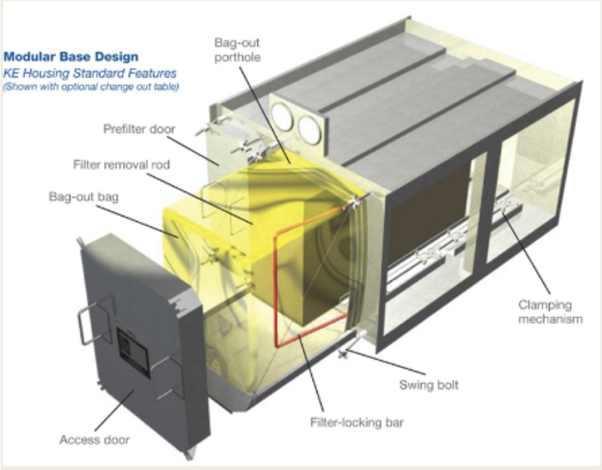


Figure 4: Tier 2 : Simple housing featuring bag system

10.3 Radioactivity in a Power Reactor

This Tier is the area in which the team identified the most room for improvement. Currently many facilities that fall under this category are nuclear power reactors. Unfortunately there is no current method of filter swaps that allows the reactor to still be running during the swap. This means lost profits for these companies as calculated in the financial analysis section. shown below is the rolling seal design that allows for live filter swaps by utilizing two bag ports and a filter to filter seal. This is the design that the team has spent most of their time on.

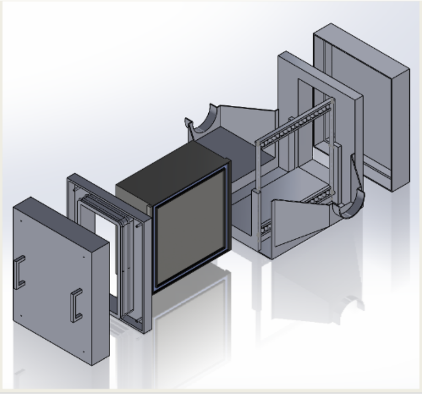


Figure 5: Tier 3 : Rolling seal design

10.4 High Amounts of =hh Radioactivity

For this tier the recommendation is an entirely disposable housing that can be swapped out when necessary. This solution is expensive but is often the easiest way to handle a housing that falls into this category. Similarly to tier one and two there are already effective products on the market for this tier like the one seen below.

Figure 6: Tier 4 : Replaceable HEPA housing

11 DETAILED PRODUCT DESIGN

For the purposes of the capstone project, the targeted area of interest is for facilities where the HEPA filters are experiencing medium level radioactivity, and could benefit from remaining online during the filter exchange. For this, a traditional single HEPA filter housing with no carbon pre-filter was designed, with a few key design modifications. The follow design criteria were considered during the design phase:

Design Parameter	Fulfillment
HEPA filter dimensions: 24" x 24" x 11.5"	Yes
Material Considerations	304 Stainless Steel
Bag-In Bag-Out Compatible Doors	2 Doors Meeting Requirements
No Space Requirements	N/A
No Price Estimate	< $10,000

Table 2: Design Specifications

To provide context for the bag-in bag-out doors, the standard procedure provided by CamFil was used for design purposes. The following abridged procedure of a single bag unit was used for design purposes, and is to be modified for the final product:

1. Store the bag in the access door when not in use
2. Remove the access door and extend the bag, using the service sleeves to move the spent filter into the bag.
3. Remove the contaminated filter from the housing unit, using a facility specific support if necessary.
4. Seal the bag with two banding ties, and sever the plastic in between the ties to create a sealed container for the spent filter.
5. Place a new filter into a new bag, and insert the bag over the housing door. Remove the old bag stub into the new bag.
6. Move the bag stub into the third glove port, seal, and cut away. Place the new HEPA filter into the housing.
7. Fold the bag and place into the door cavity, ensuring that it will not tear in the process. Replace the door and secure it tightly.

Space requirements were not specified by $LANL$, so they were not taken into account during the initial design phase. However, the product designed was made to be relatively compact, and would not be much larger than models currently available on the HEPA housing product market. In comparison to the models seen at $RINSC$, the product designed would contain a few key modifications: including a tapered zone at either end of the housing leading into the assumed 8" outer diameter ductwork, two bag-in bag-out compatible doors, and a roller system to which a neoprene track is to be attached for clamping.

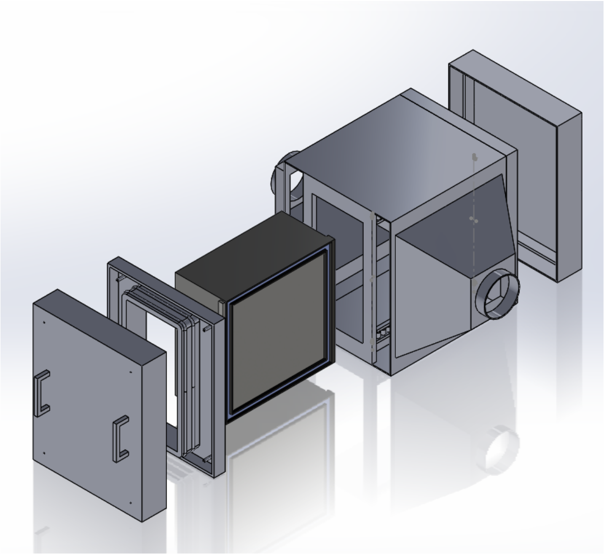


Figure 7: Exploded View of Design Assembly

As seen in Figure 7, the housing is not much larger than it needs to be, just enough to contain the HEPA filter of specified dimensions. There are two bag-in bag-out compatible doors, which allow for two HEPA filters to be handled at the same time. The cinches on which the bags are sealed have placeholder radii, as further investigation on the PVC bags is a task for the spring semester. Below is a cross section of the bagging door:

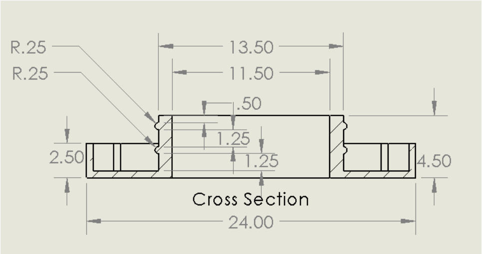


Figure 8: Cross Section of Bagging Cinches

The cinching cross section can be seen in Figure 8, with the cinching band radius of 0.25". The cinching bands are 1.25" apart, with a 0.5" gap between the first cinch and the door interface. There is a total gap of 2" between the front of the HEPA door interface and the side walls, allowing plenty of space for operators to cinch the bag onto the door. The door interface itself is just big enough to allow a standard sized HEPA filter through the door opening. As seen in Figure 9, there are four mounts for the screws, placed adequately far away from the cinches as to not pinch any hands from the operators. These mounts are to secure the door onto the housing. When produced, this would not be a standalone part, and would instead be welded directly onto the housing, and will be made from the same 304 stainless steel material.

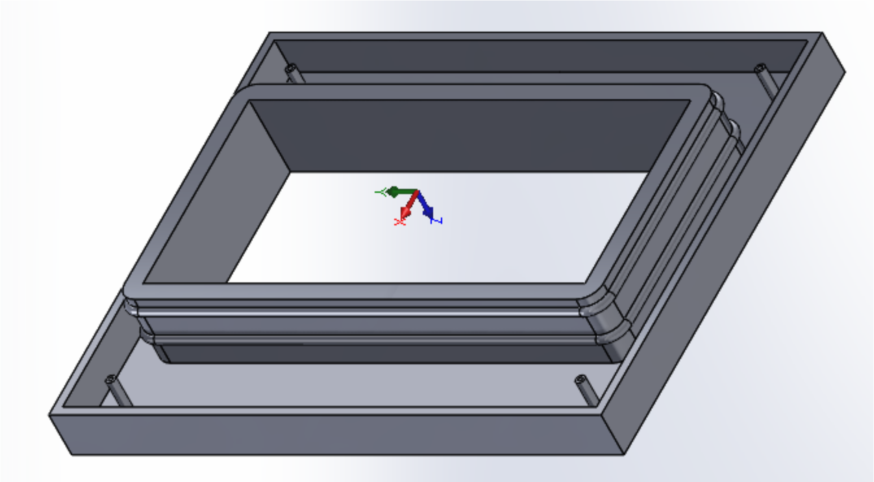


Figure 9: Isometric View of Bagging Cinches

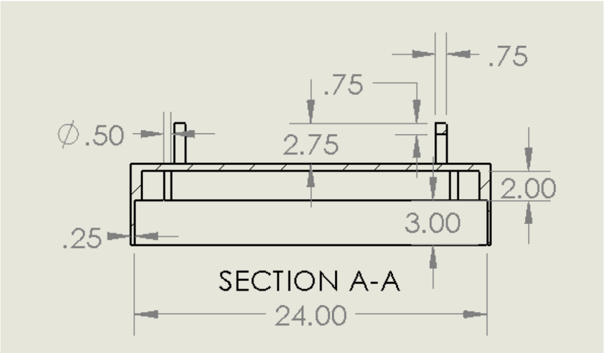


Figure 10: Cross Section of Housing Door

Seen above in Figure 10, the door meshes perfectly with the bagging cinch interface. As seen, there is a 3" gap between the very far end of the door, and the first edge. This is to allow up to 1" of clearance for the stored bag when the door is shut. The handles are just generic extruded handles, spaced out for a reactor operator to hold the door during the installation of the new filter.

The key difference in this design is the two door system. The bagging cinches and doors are nothing new in themselves, but the manufacturing of a housing with a door at either end is the inovation that the team wishes to bring to the industry.

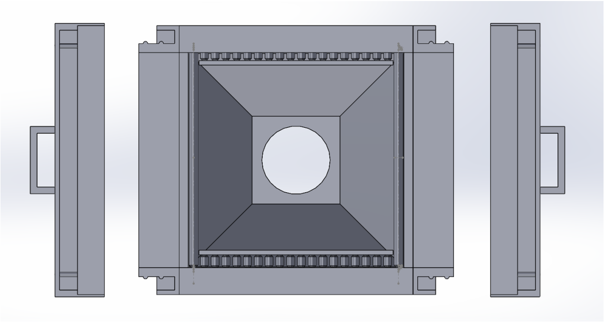


Figure 11: Cross Section of Housing Assembly

As seen above in Figure 11, there is an access door on either side, which are designed for the *BIBO* procedure. On the one side, a new filter will be loaded into a standard *BIBO* bag, attached to the provided cinches, and then the new filter will be pushed against the old filter, into the bag and hands of a reactor operator on the opposite side of the housing enclosure. This should allow for a seamless transition from one filter to another, potentially reducing, if not eliminating, filter downtime for the facility.

Figure 12: Cross Section of Modified HEPA Filter

To ensure sealing between the two filters, a modification to the standard HEPA filter was created. Pictured above in Figure 12 is a cross section of the modeled HEPA filter. Outlined in orange of the bottom of the HEPA filter is the channel in which a gel seal would be poured for a knife and gel seal. Similarly, male and female ends were attached to the left and right sides of the HEPA filter respectively. The idea of this is to pour the gel into the right edge modification of the HEPA, and a knife blade would be present on the male end of the new filter. When pushing the filter into the housing, the knife and gel seal would create a complete seal in between filters, ensuring that all air is being filtered during the filter exchange, through both filters. This was a concern for the team, as it was desired that zero unfiltered air would be allowed through the housing.

Ensuring the complete sealing of the filter to the front edge of the HEPA filter is the primary design challenge for this design process. In today's market, the two types of sealing are the knife and gel seal, and compressed neoprene seal as outlined earlier. The knife and gel seal require very little active sealing force for the same capabilities of the compressed neoprene seal. The standard for a compressed neoprene seal is up to 50% compression, with at least 1" thick and wide neoprene gaskets. This is easily achievable for a static seal.

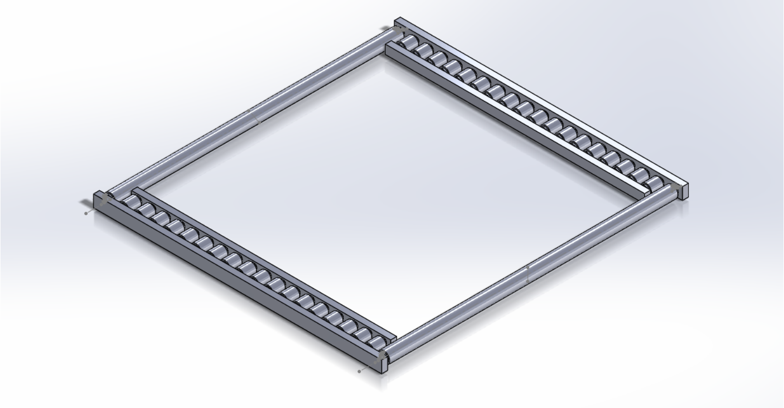


Figure 13: Proposed Roller Assembly

The proposed design includes a rolling gasket seal, which is still very much a conceptual work in progress. To obtain an equal amount of compression across the full gasket, 1" 304 stainless steal rollers (identical material to the rest of the housing) would be custom made. As seen in Figure 13, the assembly would include 2 inside and 2 outside tracks where the rollers would attach, two 24" wide 1" diameter rollers, and 18 1" wide 1" diameter rollers. These rollers would be attached on either end with plastic ball bearings (not pictured), to ensure that the rollers move smoothly, and that they would not be radioactively active. Also not pictured would be 2 neoprene rollers wrapped around the 24" rollers, and 2 long neoprene sheets that would wrap around the outside of the 24" and the 1" rollers. These sheets would be secured upon themselves using dove-tail seams, eliminating the need for an adherent that could age more quickly than the rest of the housing design. The specifics behind the the rubber gasket roller are to be investigated further and will be the primary focus for the spring of 2018. This includes the custom manufacturing and testing of the sealing system through a series of rigorous tests, in conjunction with RPS.

12 ENGINEERING ANALYSIS

12.1 Roller Gasket Seal

The following parameters are used to validate a rolling gasket seal for the cold side of the HEPA filter housing unit. The industry standards for sealing are two basic designs: a compressed neoprene gasket seal, and a gel seal. Both designs will be implemented in conjunction with each other. Namely, a gel/ knife edge seal along filter interfaces, and a neoprene gasket seal along the perimeter of the filter that will be compressed to maintain sealing.

In a future model of this enclosure, a neoprene seal will be implemented along the rollers, to stop any particulate from getting underneath the filter during the exchange. The current industry standards for a rubber gasket seal can be seen in the following table:

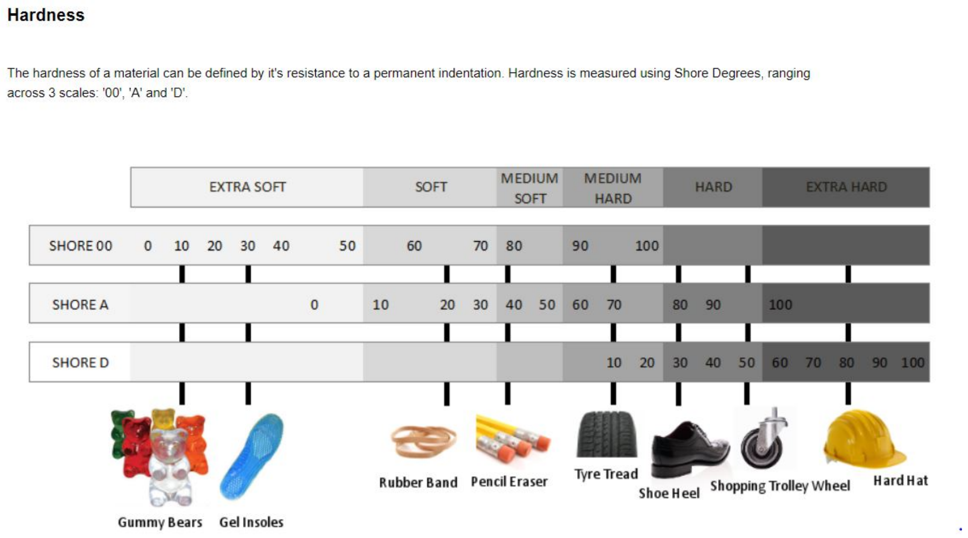
Design Parameter	Standard
Material	Synthetic Rubber (Neoprene)
Material Grade	2C3 or 2C4 of ASTM D1056
Minimum Thickness	1 inch
Compression	50%
Joint Type(s)	Dove-Tail
Shelf Life	3 Years

Table 3: HEPA Filter Gasket Standards for Nuclear Applications

12.2 Material Selection

As of right now, the material selection is based upon existing models of HEPA filters and their relative material selections. For the HEPA filters that were obtained for this project however, a different type of neoprene was implemented. It was clear that this neoprene was not up to industry standards, but would be fine to suit our testing needs. From consulting the Shore Hardness rating chart, it is obvious that the neoprene on this particular filter was an open cell type. From the Shore Hardness chart below, it was determined the neoprene on these particular HEPA's had a rating of between 20-30 Shore 00

Based on the evaluation of a 30 Shore 00 hardness rating, calculations were made to determine the amount of pressure needed on the gasket, to maintain an airtight seal during



Hardness

The hardness of a material can be defined by it's resistance to a permanent indentation. Hardness is measured using Shore Degrees, ranging across 3 scales: '00', 'A' and 'D'.

Figure 14: Shore Hardness Chart

testing. A compressive force of 1 psi is needed to compress 30 Shore 00 material to 50% of the original thickness. For the tested HEPA, there is a neoprene gasket perimeter equal to 27 square inches of material. Therefore, 27 pounds of force must be evenly distributed by the clamping unit. To satisfy this requirement, 2 springs with spring constant 29.5 lbf/inch were used, at a compression of 0.5 inches. This applies 29.5 pounds of force, enough to maintain the airtight seal. The calculations and assumptions made can be found in the appendix

12.2.1 Gasket Material

For the neoprene gasket seal, grade 2C3 or 2C4 of ASTM D1056 neoprene are being considered for the rolling gasket seals. Below are the physical properties of the two specified compounds.

Property	ASTM D-1056-00 2c3	ASTM D-1056-00 2c4
Polymer	Neoprene (CR)	Neoprene(CR)
Color	Black	Black or Grey
ASTM D-1056-67 Classification	SCE-43	SCE-44
ASTM D-1056-00 Classification	2C3	2C4
Suffix Requirements	B2, C1, F1, M	B2, C1, F1, M
ASTM D-6576-00 Type II	Grade A or B Medium	Grade A or B Medium
25% Compression Resistance [psi]	9-13	13-17

Table 4: Neoprene Physical Properties

Both of these materials are very similar in material properties. the classification number denotes most of the physical properties of interest for the scope of the project. ASTM D-1056 is the 1994 to current call for cellular materials. The classification number (number - letter - number) denotes the physical properties.

The first number is either a 1 or a 2, noting if it is open cell or close cell material. Both of the commonly used sponged materials are open cell in this case.

The letter is A-D, noting the material requirements in the specific application. A represents non-oil resistant materials (Ethylene Propylene rubber or Styrene-Butadiene rubber). B represents an oil resistant, low swell material (nitrile rubbers). C represents oil resistant, medium swell materials (Neoprene). And finally, D represents extreme temperature resistant materials (silicone based rubbers).

The last number in the classification number notes the grade of the sponge substance, ranging from 0-5. This grade refers to the compression deflection of the material, which is the force in psi required to compress the material 25% of its original thickness. For the two materials commonly used for HEPA gasket seals, grade 3 denotes 9-13 psi, and grade 4 denotes 13-17 psi.

There are a wide list of additional suffixes to the classification number, which can note any special characteristics of the polymer, for example, heat resistance, ozone resistance, or impact resistance.

12.2.2 Gel Material

Specific gel materials for a knife and gel sealant is to be determined in the spring 2018 semester as it needs more investigation. The standard for the United States, Asia, and Europe for gel seals in HEPA housing units are a silicone gel seal, although in some cases a polyurethane gel is used where temperature is not a factor. A silicone gel will likely be chosen, as it has a useful temperature range from $-58 \deg F$ to $400 \deg F$. This eliminates any concern for the adaptability to conform to a wide range of of facilities.

12.2.3 Housing Material

The material selected for the HEPA filter housing and rollers was selected to be 304 Stainless Steel. 304 stainless has the needed material properties for nuclear applications.

Physical Property	Value
Density	0.289 lb/in^3
Yield Strength	31.2 ksi

Material Components	Weight %
C	0.08 max
Cr	18-20
Fe	66.345 - 74
Mn	2 max
Ni	8-10.5
P	0.045 max
S	0.03 max
Si	1 max

Table 5: 304 Stainless Steel Material Properties [1]

This material was chosen for both it's structurally sound physical properties, and it's chemical components. Nothing stands out as being particularly dangerous if exposed to radioactive particulate. Furthermore, 304 stainless steel is already common practice for the manufacturing of HEPA filter housings.

12.3 Testing Procedures

Testing the finalized design prototype will be done in a safe environment, with no radioactive particulate present. There are no current certified radiation workers in the group who could facilitate a full scale testing procedure with hot particulate, nor would it be safe to do so with a theoretical design. As such, RPS has suggested that two tests should be performed in the spring semester, after the finalization of the sealing system, and a full-scale prototype is manufactured. The two tests are a test using Titanium Oxide as a particulate, and the second using a smoke machine, as a fine particulate baseline.

TiO_2 is a common compound with a wide variety of uses, and is non-toxic to humans. The DOP of TiO_2 is on the order of 50μm to 100μm, and will be a good baseline for the larger particulates found in a typical HEPA filter. The TiO_2 will be blasted into the HEPA filter enclosure, to be visually inspected for leaks in the housing. If there is a large concentration of powder, then it will be apparent where flaws in the system will be. This is important in testing the overall design structure.

After a preliminary TiO_2 large particulate test is rendered conclusive for the prototype, a secondary test using a smoke machine will be performed. A colored smoke machine will be placed at the inlet of the filter housing, and the housing will be powered online. This will be accurately representative of a real online HEPA enclosure, as the blower will be in a pull configuration. For nuclear air filtering purposes, most if not all HEPA filters are always in the air pull configuration to create a negative pressure environment as the containment level gets higher and higher. If there is ever a breach in the environment, it is desirable for air to rush in, instead of the air rushing out, potentially irradiating the cleaner level of containment. For comparison, clean room environments use positive pressure HEPA enclosures, to push clean air into containment.

By the end of these two experiments, there should be a rendered final product. The largest area of interest is the sealing mechanism, and the colored smoke test should provide the most important engineering analysis for the HEPA housing design. If successful, the rolling neoprene seal, in conjunction with the knife and gel seal in between HEPA filters, should prove to filter all of the colored smoke from the air being filtered, and nothing but clean air should exit the enclosure. This in turn will finalize the design for this project.

12.4 Evaluating the Compressibility of the Neoprene Gasket

From research, a neoprene material (Grade A UL-50) with the desired shore A hardness rating of 50 was found to require 9-13 psi in order to be compressed to a proper level for sealing. The perimeter along which the gasket will be configured is 8ft in length, the same as the perimeter of a HEPA filter. Since we will have a gasket of width 0.5 inches, there is a total compressible surface of 48 square inches. Assuming the maximum applied pressure of 13 psi, a total force of 624 lbf will need to be applied. This force will be applied across the perimeter of the gasket via the spring-loaded mounting frame, using four separate springs. By using the spring constant formula:

$$F = -kx \tag{2}$$

and assuming a spring extension just larger than the 11.5 inch width of the HEPA filter, it is determined that four springs of with spring constants of 13lbf/in are required for our mounting frame.

13 PROOF OF CONCEPT

The *POC* build generated during this process was to prove a few different key points. It was intended to prove that the filter exchange can be done while adhering to the design specifications provided, of which the ability to have the reactor remain online was the primary focus during the design. Meeting the other design criteria were considered in this process, and it was proved that the system will adhere to the principals of ALARA, and will be able to contain the filter on the hot side.

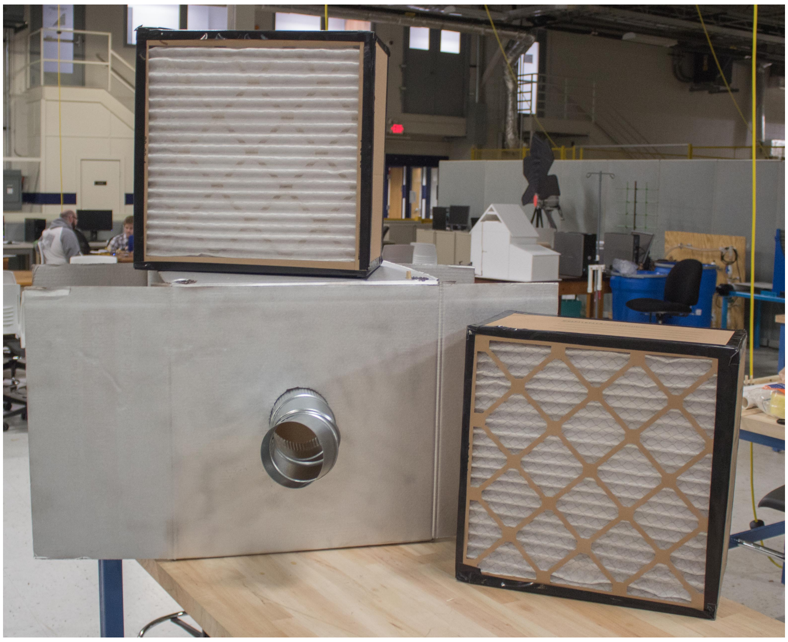


Figure 15: Proof of Concept Build

13.1 Keeping the Reactor Online During Filter Exchange

Implementing a second HEPA train to the existing system would also be a viable solution to keeping the reactor online. Fast acting pneumatic valves can have an actuation time on the order of microseconds, immediately redirecting the airflow to a second set of HEPA filters. This would allow for the air to be continuously filtered while a standard bag-in bag-out procedure is performed, minimizing the possibilities of non-containment.

13.2 Adhering to ALARA

The *POC* design minimizes the risk of exposure to the radiation workers, by implementing the standard bag-in bag-out procedure. While wearing correct personal protective equipment

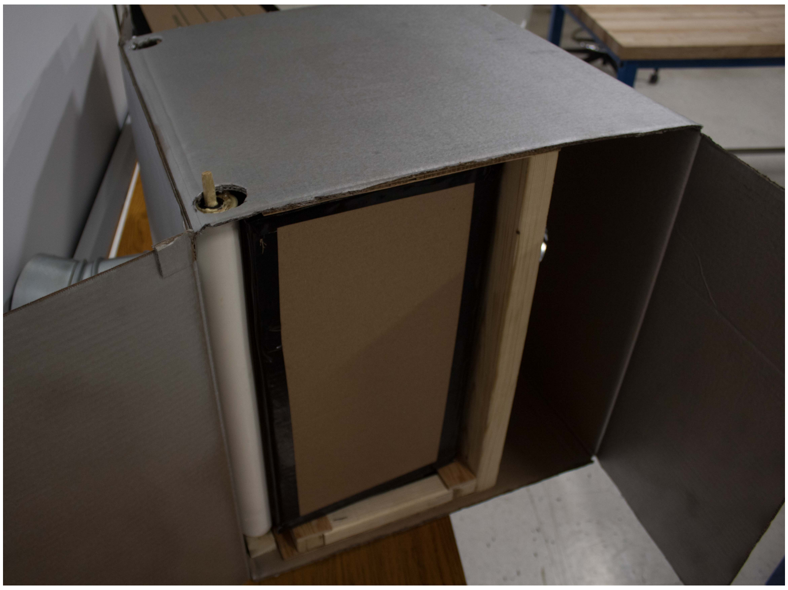


Figure 16: Roller Detail for Proof of Concept Build

based on the radiation quality of the HEPA's, radiation workers would only be facing minimal risk of exposure. The largest health hazards for spent HEPA filters are in the particulate contained within the fibrous material, which will be contained completely by the PVC bags.

13.3 Filter Containment on the Hot Side

Filter containment varies from facility to facility, but all of the procedures begin with containing the filters within the PVC bag from the removal procedure. From there, each facility uses different means of containment, ranging from carrying the bags if they are not very irradiated, to using a robotic arm to move them into a lead containment unit. These external containment procedures will not be changed, as they are a per-case basis.

13.4 System is Fully Sealed

The sealing capabilities of our initial proof of concept are impossible to determine, because it is made of wood, cardboard, and PVC, and has not yet implemented actual HEPA filters or neoprene and silicone gel seals. The team has, however, extensively researched the sealing capabilities of such materials and found a creative way to implement them in our final design. Neoprene is a gasket material that has been used in the nuclear industry to provide full seals when compressed to 50% of its total width. The team is considering a neoprene material with a Shore A hardness rating of 50, because this is more easily compressed, but still maintains an airtight seal. The silicone gel seal comes into use on the side of each HEPA unit, to form a seal between them as they are pushed through. This knife edge and gel silicone seal is a standard in the United States for sealing the front face of a HEPA filter, so the team is certain that it will do the job on the side edge. Our goal is to manufacture an attachable gel/knife seal that adheres to a common HEPA.

14 BUILD/MANUFACTURE

14.1 Test Build

During the manufacturing and build process, Team 6 had to make a few design and material compromises to meet both the deadlines and the available manufacturing techniques. For example, the door and cinching assemblies are typically casted parts to create a single airtight piece which is then welded to the rest of the housing. the team opted to machine the cinches out of High Density Polyethylene plastic. The team with the assistance of the resources provided at the University of Rhode Island was able to create a door interface with great machining tolerances at a much lower cost, at the drawback of needing to be assembled from four separate parts.

Similarly, the flanged air intakes were omitted to reduce the overall cost of materials and cost of manufacturing; to accurately created the flanges the team would have had to outsource the construction process to an external welder. The drawbacks are that the airflow will not be evenly distributed across the HEPA filter, but the team is confident that this will have minimal effect in proving the proposed concepts.

To cut both overall costs as well as need for physical manpower, the team opted for the use of aluminum in the construction of the test prototype, instead of 304 Stainless Steel. The team experienced drawbacks in lacking the ability to weld aluminum, and then opted for physical fasteners, and then the utilization of tape and caulking to ensure the housing is airtight.

The team used a mixture of 5/8" and 1" self tapping sheet metal screws for the structural fastening of the aluminum plate to the 3/4" aluminum bar stock and $HDPE$ bagging door features. The bagging door features were machined to be 1" thick around the entire door interface perimeter, and then fastened directly to the aluminum plating. The seams were then taped and caulked using duct tape, and common household quick-drying caulking. The team wanted to take every precaution in making the test housing as airtight as reasonably possible, and the smoke testing detailed in Testing section confirmed the validity of the sealing methods. Using a downstream blower of a known volumetric flow rate, and measuring the upstream flow of air, the team observed a nearly perfect airtight seal of the door.

Perhaps one of the most aggressive design build cuts that the team elected was the omission of dedicated doors for the system. The team was mostly concerned in the ability to change out the filter with the system remaining online, and to test this opted to test the system using $BIBO$ bags cinched to the door rings. This eliminated the need to manufacture the doors needed for each side. Standard gloved $BIBO\ HEPA$ housing replacement bags retail on the order of magnitude of $250 per each, so the team opted to use a lower cost alternative. Overall the compromises that the team made proved successful, and allowed the team to build and test while minimizing the need to outsource the manufacturing of the test build.

Figure 17: HEPA Filter Housing Test Build

Depicted in Figure 17, the test build features the $BIBO$ doorways at either entrance, a reduced width of only 14", with the addition of PVC rollers for operator assistance and a removable top section for our testing purposes. 8" diameter holes were cut in for the addition of standard 8" ductwork. Each seam of the build has been meticulously taped and caulked in lieu of TIG welding. The roller assembly is to be moved up, and the clamping mechanism down to accommodate the testing of filters that are differently sized than originally specified.

14.2 Manufacturing

In addition to manufacturing a test build in-house, the team took into account future design considerations were this project to progress to a larger scale fabricated part. Camfil is one of the United States' largest producers of *HEPA* filter and carbon filter housings, and *RPS* contracts out to Camfil for the larger scale production of housings. Under the guidance of *RPS*, the team was able come up with an accurate price point for a double bag-in bag-out single filter *HEPA* housing.

Two *BIBO* doors and cinches would be casted out of stainless steel, and then welded to the rest of the housing. The most common housing material is 304 stainless steel, but there are other options for the manufacturing of housings if weight is a limiting factor. The rough dollar amount on manufacturing the double door housing would be around $3500. The additional sealing methods as tested by the team would add to the cost of production, and the cost for the brush seals and gel seals between filters would not raise the cost by a significant amount. The team would put a tentative wholesale price tag of under $4000 per housing unit.

15 TESTING

15.1 Glo-germ Testing

The first testing procedure was to launch glo-germ powder into the enclosure during the filter exchange, to examine any risk areas present in an online exchange environment. The purpose of this test was to highlight the risk areas of the test build housing, and specifically the additional sealing methods that the team installed. Whether or not the housing was airtight, the overall efficiency of the filter, and the efficiency of the filter housing system were outside of the scope of this test.

The glo-germ test was conducted at 150 cfm. After introducing the system to the glo-germ powder black light was shined into the enclosure after the powder was sent through, which allowed the team to take vibrant photographs of the filter housing. The team found that the sealing methods did a good job of preventing particle penetration through to the clean air side of the filter. The housing and its various components simply reflected the light in a range of blue to purple hues, whereas the glo-germ powder glowed a bright white.

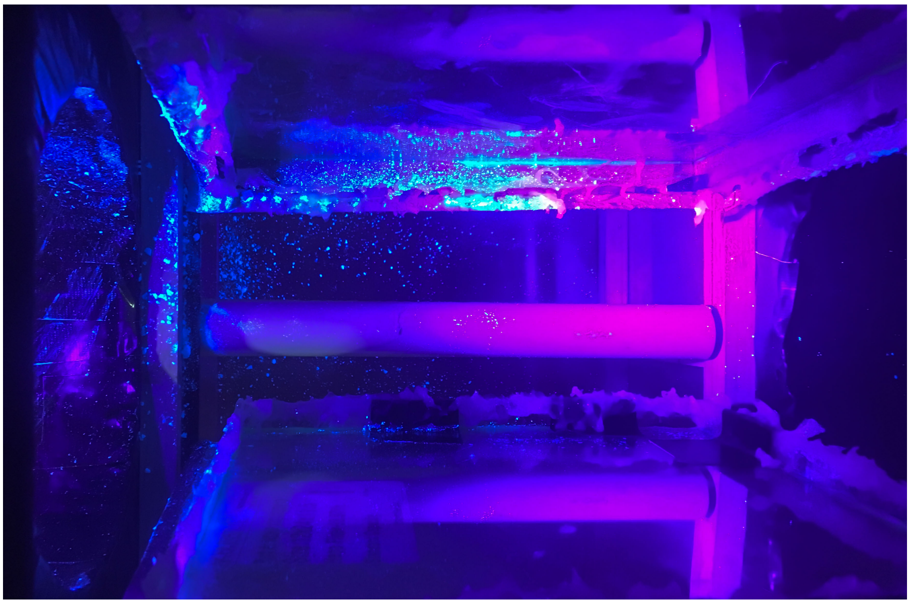


Figure 18: Gel Seal containment of particulate

As seen in Figure 18 , the gel/ knife edge interface prevented most of the particulate from penetrating from the upstream (left side) to the downstream (right side) of the enclosure. From left to right, the observed areas with the most glo-germ powder buildup were the inlet of the housing, the silicone gel half of the installed knife and gel seal between the filters, and the filter housing floor. The team observed no discernible powder on the outlet of the filter housing, and as such were able to validate the concept of using a sealing interface between the filters during a reduced capacity filter exchange.

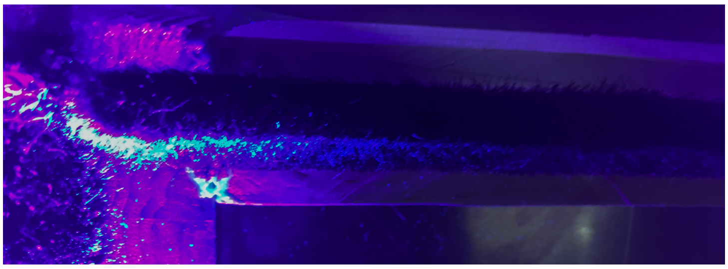


Figure 19: Brush Seal containment of particulate

As illustrated in Figure 19, the brush seals accomplished their goal of keeping the particles from penetrating through the brushes. There was an observed concentration on the bottom edge of the brush seal, which in this case was the upstream face, and the downstream face of the brush seal was clean. All of the glo-germ particulate was contained on the inside of the brush seal. However, there was noticeable particulate built up along the brush seals and gel seals: a possible risk area.

The particulate buildup on a brush seal interface could become an issue when the built up particulate can become airborne when disturbed, for example, during a filter exchange or regular maintenance. One of the primary design criteria is to keep risk of exposure as low as reasonably as possible, which makes this buildup area an primary area of concern. It is recommended that future iterations of this type of product include changeable brush seals to combat this issue. The glo-germ testing was able to validate the short-term effectiveness of brush seals in a reduced capacity filter exchange, but testing using longer test cycles to allow for the complete buildup and saturation of the brush seals is needed to draw conclusions on the overall effectiveness of brush seals in HEPA enclosures.

15.2 Smoke Testing

The second testing procedure consisted of sending a known amount of particulate through the filter from upstream. The air passed through the filter housing and then downstream to a particle counter. The goal was to meet DOE standards is to capture 99.97% of particulate in the filter, because the filter is rated for 99.97% efficiency this would mean that there are no air gaps in the sealing within a reasonable tolerance. The filter was set in a locked position and the smoke was sent through the housing. A reading was taken upstream to establish the control level and then also downstream which reads out as a percentage.

Figure 20: Testing Setup at RPS

The team transported the test build down to the *RPS* facility located in Groton, CT, and with the help of staff members used a the testing setup seen in Figure 20. The team used an upstream smoke generator that released a known concentration of a dissolved wax smoke into the 8" ductwork. The smoke then traveled through the ductwork to the filter housing. The filter was securely clamped in place within the housing during the entirety of the tests, and the doors were secured using a plastic bag alternative to the *BIBO* bags, cinched tightly to the doors. Additional 8" ductwork was attached between the upstream side of the housing, to the blower. The blower in Figure 20 was a blower designed to convert 120VAC power into three phase power, allowing for an adjustable flow rate as the frequency of the power was increased. This blower was used for the 200 CFM and 340 CFM trials, but was later changed for a 500 CFM blower for the final testing trials.

Not depicted in Figure 20 was the digital particulate monitor. The device used a sample from the upstream side and the downstream side of the ductwork, and then automatically calculated the concentration differential, to give the percent penetration of particulate in the system. Small holes were cut into the 8" ductwork to insert said probes. Each test was conducted after adjusting the smoke generator to produce $30\mu\text{g/L}$.

The scope of this specific type of smoke test was to analyze the efficiency of the system, through the calculation of the percent penetration through the system. Whether or not the housing and assembly were airtight, and the integrity of the build were all secondary variables within the scope of this test. The efficiency of the *HEPA* filter was not included during this test.

Using the known volumetric flow rate of the blower, the team was able to compare the measured flow rate at the intake to validate whether or not the build was airtight. With know significant difference in flow rate, the team validated this parameter. Similarly, the team did not observe any smoke from any of the seams or sealing areas of the test housing, which was able to validate the overall build integrity of the test housing. Penetration testing results for the smoke test can be seen in the table below.

Flow rate	200 CFM	340 CFM	500 CFM
Penetration level	8.50%	6.50%	5.50%

By the teams original expectations these are failing numbers but on closer analysis it seems that the filter was the weakest link when analyzing the effectiveness of the frame, seals, and welds. The filters that were tested had on their ratings on the frames themselves, and were rated for 99.97% filter efficiency. However, the filters purchased through a third party were likely not labeled or rated correctly. After visual inspection by the experts at *RPS*, certain signs lead the team to conclude that the filters should likely rated lower than the originally specified efficiency rating, and likely were only rated for operation at 500CFM. These signs included the wider than usual pleats in the filter membrane, the construction of the filter using particle board framing, the gasket material being both thinner and softer than the correct neoprene gaskets, and the presence of bending in the corrugation from the shipping of the parts. The filters themselves here were adequate for proving the concept of the open door procedure, but the empirical penetration test data was inconclusive on the real world effectiveness of the design.

Other areas of note were that during testing the bags got pulled into the housing by the negative pressure. The bags used for the testing were less costly alternatives to the polyvinyl chloride bags used during the $BIBO$ procedure, and the team was worried that they would fail under the testing circumstances. The $BIBO$ bags are designed to withstand the load applied by the saturated filters, and are much durable than the household plastic bags used by the team. The bags used in the testing procedure did deflate significantly, and even at the lowest flow rate tested were unwieldy to manipulate, but they remained cinched and sealed with no issues. This leads the team to believe that with the use of the proper bags, as well as the proper sized filters, that the bags have a chance of withstanding a live filter exchange procedure while remaining intact.

Overall, the testing procedures conducted in-house at URI and those conducted at RPS provided a good baseline to prove the concept of an online filter exchange. However, both the true sealing capabilities of an online filter exchange procedure and the effects of particulate buildup on the sealing methods remain inconclusive without the testing on a properly manufactured, industry ready prototype.

16 REDESIGN

The team was content with the functionality of the build and test iteration of the filter housing. The team would like to change the following design features of the housing.

16.1 Housing Inlets and Outlets

The housing inlets and outlets were simply 8" ductwork connections adhered and fully sealed onto the aluminum sheet stock as manufactured by the team. For the testing purposes, they worked perfectly, and provided an airtight and seamless connection to the smoke machine apparatus, ductwork, and blower. They were lacking however in their ability to evenly distribute air flow across the whole filter membrane.

Figure 21: Test Housing Inlet

As seen in Figure 21, the manufactured test housing flat plates, but the majority of the options on the market currently have flanged inlets and outlets. The team would like to include this in the final production design, and was already accounted for in the initial completed design. This feature was omitted for ease of manufacturing, but in the future, testing with the flanged inlets and outlets should prove to improve the penetration numbers that were observed in the testing of the filter housing.

16.2 Filter Clamping Mechanism

The team elected to use a spring clamping mechanism to achieve the desired clamping force on the filter. The clamping force was adequate for the purposes of fully sealing the filter to the inside of the housing, but the clamping force was not able to be evenly distributed across the purchased filters. The team would investigate further improving the filter clamping as a whole, in relation to attempting to keep the filter clamped as much as possible during the filter exchange.

Figure 22: Test Build Clamping Mechanism

As seen in Figure 22, the team used a few springs to apply the clamping force needed. The team later retrofitted the test housing before the tests were completed to accommodate these 12" x 24" x 11.5" *HEPA* filters, and as such the filter clamp experienced a few problems. The total surface area of the neoprene gaskets was much smaller than originally specified, and as such the clamping force was much too strong, and concentrated on just the top edge of the filter. In addition, the neoprene was less than 1" thick, and needed much less force to compress. This led to the filter clamping being uneven, and overall a detriment to the overall efficiency of the system.

If given the time to redesign the clamping filter, the team would elect to emulate the market products of Camfil to achieve the clamping in a better fashion.

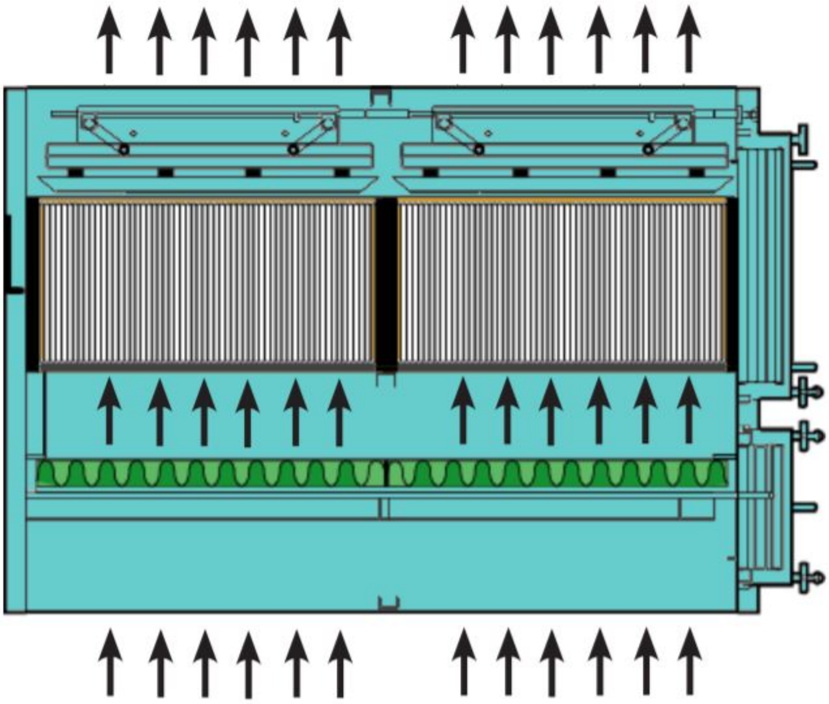


Figure 23: Camfil Clamping Mechanism Drawing

As seen in the diagram of Figure 23, the clamping surface is clamped against the filter gasket, instead of the filter being clamped against the surface. The CAMs here are externally controlled, and would allow for a quick release and exchange of the filters without the need to reach into the housing.

16.3 Housing Rollers and Ease of Accessibility

After extensive conversations with the consultant at Radiation Protection Systems, the team was in the middle on the future usage of the rollers. As of right now, the industry standard for the internal surfacing of the housing is just a flat surface that the filter can be place on. The manufacturing tolerances of the internal space of the filter housings are very tight, to allow for as little airflow and contamination buildup as possible on the exterior of the filter. If anything, the rollers could could provide a risk area in terms of particulate buildup.

Figure 24: Test Build Bagging Ring and Rollers

As seen in Figure 24, the manufactured PVC piping rollers sit about 1" above the bottom of the filter housing. This provides quite a large air pocket where the flow of air could possibly divert. The team would like to minimize risk areas as a whole, and would likely elect to omit the rollers in the future.

An alternative, yet costly solution, would be to use rotary stroke bearings as a roller alternative.

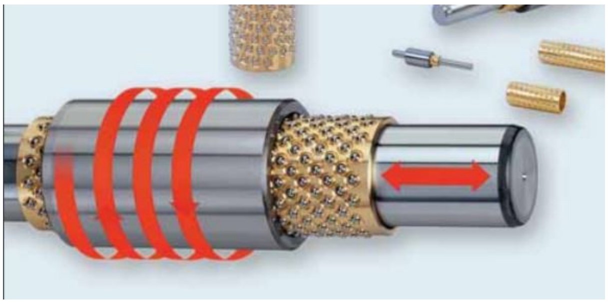


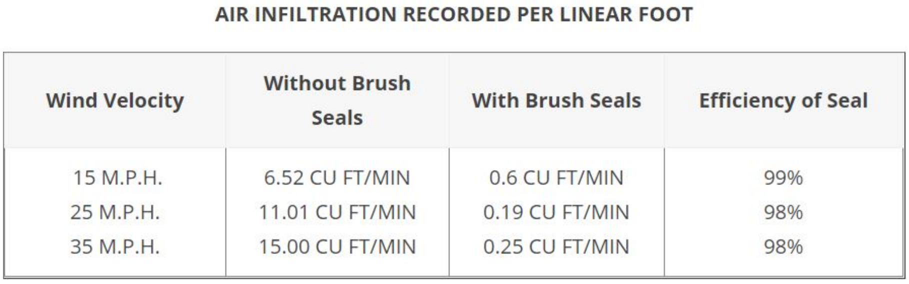
Figure 25: Rotary Stroke Bearing

The rotary stroke bearings as depicted in Figure 25 were discovered by the team while researching component alternatives. As seen in the diagram, the rotary stroke bearings would allow for rotational motion to assist the radiation workers in sliding the filters through the housing, but would also allow for lateral movement to assist with clamping. The bearings, sleeves, and shafts are customizable in geometry and with a metallic or plastic option, and would likely add to the ease of accessibility of the $HEPA$ filters. This redesign consideration would be secondary in priority, as the overall effect on the system is minimal, and would only provide minor increases in ergonomics.

16.4 Brush Seals

For the test build of the filter housing, the team used brush seals that were most readily available to add to the design. The brush seals were added on top of the clamping device as seen in Figure 22, as well as at each doorway to provide a secondary method of sealing during the filter exchange. The testing procedures proved that the brush seal mechanism had an overall positive effect on trapping the particulate. However, the longevity of the brush seals remain a future question, as testing the seals over the lifetime of the filter housing was outside of the scope of this project.

The team would recommend further investigation on the effectiveness of brush seals as a sealing mechanism as a whole.



AIR INFILTRATION RECORDED PER LINEAR FOOT

Wind Velocity	Without Brush Seals	With Brush Seals	Efficiency of Seal
15 M.P.H.	6.52 CU FT/MIN	0.6 CU FT/MIN	99%
25 M.P.H.	11.01 CU FT/MIN	0.19 CU FT/MIN	98%
35 M.P.H.	15.00 CU FT/MIN	0.25 CU FT/MIN	98%

Figure 26: Almost Airtight Nylon Brush Seal Efficiency Ratings

The team investigated the industrial applications of nylon brush seals, and used the seals and data from the manufacturing company "Almost Airtight". The efficiency of the seals dropped as the flow rate increased across the seal, and the ratings only went up to 15.00 ft^3/min. It is unclear without investigating the situation further what exactly the conditions the brush seals would undergo in a housing environment; the design constraints limited the scope of this capstone project for a single filter rated to 1000 CFM, but this is the system airflow through the housing. It is unlikely that the brush seals would undergo this airflow directly, unless the full capacity of the blower was not reduced during the filter exchange procedure.

The means of glo-germ testing the brush seals were intended to identify the potential risk areas within the filter housing, and not to provide an accurate representation of buildup on the brush seals. The smoke test was a more accurate representation of the intensity of particulate that the brush seals would be exposed to, and the target concentration used was about $3.0 * 10^{-8}$kg / L. The buildup from short duration smoke testing was insignificant for the expected lifetime of the filter housing, and as such can only be used as a proof of concept for the effectiveness of the brush seals.

17 OPERATION

17.1 Daily Operation

The day to day operation of the designed filter housing will not contain any modifications in comparison to the single door housing. The *HEPA* filter will be clamped internally to 0.5" of neoprene in accordance with the standard operating procedures. When the doors are closed, the housing will act identically to the existing options on the market.

17.2 Filter Exchange Procedure

The team took the standard *BIBO* procedure as outlined by the Camfil Bag-In Bag-Out Procedure and modified it to accommodate a second bagging door, and a simple push through filter exchange. The aim was to keep the procedure as simple as possible, while taking the necessary safety considerations to adhere to the principles of *ALARA*.

Step 0: During normal operations, the *BIBO* doors will remain shut and locked tight, with the *BIBO* bags remaining cinched on the inside of the bagging doors, and the *HEPA* filter being clamped with the appropriate sealing force.

Step 1: To initiate the filter exchange, apply all necessary personal protective equipment, load in a new *HEPA* filter into a standard *BIBO* bag, and if able reduce airflow to 20% of maximum capacity.

Step 2: Remove each door carefully, and ensure that the cinched bags are still in their proper position. If the remaining cinched bag is in place, attach the new bag and filter to the second cinch, and pull the tail of the old bag through the third glove port, isolating the old bag.

Step 3: Release the clamping mechanism to the old filter, and use the new filter to push the old filter out of place, leaving the new filter in its place. A second operator will be at the other *BIBO* bag to catch the filter once it is fully pushed through.

Step 4: Clamp the new filter into place. Once clamped, cinch the old filter into the bag, and remove from the housing area.

Step 5: Replace the housing doors, making sure the filter bags are fully enclosed. Securely fasten the doors for long-term use.

Step 6: Ramp the airflow through the $HEPA$ enclosure back up to full capacity. Manually inspect the old filter at leisure.

17.3 Inspections

Now that the filter has successfully been live exchanged, the spent filter is now available for inspections. In accordance with ANS or the $IAEA$, filters can now be tested for various reasons. The advantage of this change-out procedure is that the filter is almost immediately available for an inspection, with little to no large-scale impact to the facility.

18 MAINTENANCE

HEPA filter housings utilize materials selected for an effective lifetime of 30 years at which point it should be replaced. Within that 30 years the requirements for maintaining a HEPA Filter housing in a nuclear environment include replacing the HEPA filter every 12-18 months, monitoring air flow for anomalies, and periodically inspecting ductwork for flaws.

One of the goals of this project was to keep the maintenance required to a minimum. In keeping with that goal no additional maintenance not necessary with current models is required at any time other than during the 12-18 month swap. The procedure for replacing HEPA filters is outlined in the section above(Operation). With the current design it would be necessary to visually inspect the internal components of the housing for potential problems. A faulty roller or clamp could result in an imperfect seal and would need to be immediately replaced.

The internal brush seals that help maintain an airtight environment during filter replacements showed a tendency to catch particulate resulting in a build up of possibly harmful material around them. It would be advisable to replace these brush seals periodically with the current model. A filter to filter clamp would also need to be installed onto the new filter prior to inserting it into the housing for every replacement.

A potential solution to this additional maintenance would be the use of a custom HEPA filter with the filter to filter seals and brush seals included during manufacturing. In the case of using this custom filter, the required maintenance would would be equivalent to current models.

At the end of the products useful life the housing would most likely need to be treated as low-level radioactive waste. The process depends of the exact application of the housing but would likely involve a cooling off period in a quarantined area followed by either compacting or incineration and then landfill disposal.

19 ADDITIONAL CONSIDERATIONS

Economic Impact:
A HEPA filter enclosure capable of facilitating an online switch will have a significant economic impact for nuclear facilities. It has the potential to save weeks of shut down time, some of which is spent exchanging old filters. Some facilities may be required to shut down for IAEA inspections, so the shut down time for this may not always coincide with refueling and maintenance schedules. After a test and analysis of the new double bag-in, bag-out procedure, we figured the time savings of a filter exchange using the new system, as compared with the old system to not be significant. Assuming a shut down for filter exchange occurs twice in a two year period, and only one of those times coincides with a reactor refueling and maintenance shut down, a cost savings has been calculated to be the following:

Assumptions:

- 2 weeks of downtime eliminated by this design, for filter exchange in a two-year period, that does NOT coincide with a refueling or maintenance shut down. Equivalent to 336 hours saved
- Reactor operates at 500 Mw
- Reactor sells electricity for $0.02/KwH

Savings for a two-year period:

336 hours/2 years * 500,000 Kw-h* $0.02/Kw-h= $3,360,000/ 2 years

30 year life time of reactor= $50,400,000 total reactor lifetime savings.

The number of HEPA filters per facility varies widely, but we will take the case of a 500 Mw PWR reviewed by the NRC. Such a reactor contains 5 separate webs of 64 HEPA filters per web. If a new reactor used the new online exchange HEPA filter housing, it would require around 320 HEPA filter units. Going on the estimated cost of the new enclosure design, the facility would pay $6000 per HEPA unit, calculating to $1,920,000 for 320 units. So after retrofitting an existing reactor with these units, the operator could expect a return on investment within two years. This cost however, is not significantly different than a typical HEPA enclosure on todays market that do not feature an online exchange capability.

Environmental Impact and Sustainability Considerations:

The aim of this HEPA filter enclosure is to maintain current safety and environmental impacts that are achieved with today's HEPA filter systems. Current systems are designed to be exceptionally environmentally friendly, rated for an efficiency of 99.97% when removing carbon and other irradiated particulate. The new design raises questions in terms of achieving this same efficiency. An online filter exchange is blowing irradiated particulate through the filter and housing, as the exchange is taking place. Naturally there are more risk areas for escape. However, our testing showed that the utilization of brush seals, and a gel/ knife edge seal between filters shows promise for stopping this particulate during an online exchange. More rigorous tested would be required to determine if the efficiency would remain unchanged. Overall, the environmental impact of an online exchange is more irradiated particulate released into the air, because of the nature of such an exchange. Efficiency numbers would be affected slightly but are expected be close to the current 99.97% figure.

Societal Impact:

Society as a whole is unfamiliar and perhaps frightened by the idea of nuclear energy. The goal of Los Alamos lab, the DOE, NRC, IAEA, and other groups has been to increase safety of power reactors and facilities and improve public perception thereof. There are innumerable safety measures taken to ensure another nuclear accident does not occur. The design of this enclosure attempts to match these strict guidelines and improve upon the process of the exchange. Hopefully, as more people are educated about nuclear energy, as we have done throughout the process of our design project and showcase, the public perception will improve, allowing more reactors to be built in the United States. This would have an impact on the way citizens obtain their energy. It would likely reduce energy costs overtime, and produce more carbon-free energy, having a direct affect on the quality of life of the average person.

Political Impact:

Policy of nuclear reactors and facilities varies widely from state to state. Each state government has their own agenda, which could involve being for or against nuclear energy based on if they already have it in their state or not. Many politicians are able to use the poor public perception of nuclear energy to their advantage, claiming it to be unsafe. This has led to zero nuclear reactors being built in the past 20 years in the United States. Reactor start up costs are significant, and many governments do not give as much financial assistance to companies who would like to build nuclear reactors, as compared to a natural gas power plant, for example. Policy has begun to change in recently in some states however. In New York, the government has begun providing financial help to those companies seeking to build nuclear power reactors. It has led to two reactor proposals being made for construction in the next few years. The design of this enclosure will assist nuclear facilities financially, and increase the continuity of knowledge of the spent fuel in a reactor, which could lead to more governmental acceptance of nuclear reactors. If governments know these reactors are more profitable, and safer, it will lead to more of them being constructed.

Ethical Considerations:

The IAEA has the goal of maintaining a continuity of knowledge in nuclear facilities worldwide. They perform inspections on spent HEPA filters to determine what types of activities have been going on in the reactor. This means for example, they can determine whether a plutonium reprocessing facility has been enriching their fuel to the correct level. This is of massive ethical concern, since facilities could in theory be creating weapons grade uranium or plutonium if not kept under surveillance. The online HEPA filter enclosure has a direct impact for IAEA testing capabilities. If the IAEA could exchange a filter online, they could do completely random testing and not require the facility to shut down before they take a sample. The issue with a facility shut down is that it could possibly give a facility enough time to clean up their enclosures and make it appear like a normal operation has been taking place.

Health and Safety Considerations:

Health and safety are of utmost concern with nuclear facilities. Special considerations must be taken into account when exchanging HEPA filters because they are filled with irradiated particulate that becomes dangerous if let into the air. Currently, a bag-in, bag-out filter exchange procedure using PVC bags in done to ensure zero particulate leakage occurs. This filter enclosure recommends a similar procedure, with the difference being a double doored design with a bag on either side. This also ensures a completely airtight seal around the entrances. Operator safety would therefore not be compromised to any extent in the new filter bagging procedure. An area of concern is the irradiated air passing through the filters as the exchange is occurring. Since the filter's neoprene gasket seal is no longer clamped into place, a brush seal is relied upon to stop the penetration of particles for the time of the exchange. From the glo-germ particulate test, we saw that the brush seal did a good job of stopping particle penetration for the 30 second testing period. The gel/ knife edge seal, also used in industry as a seal in HEPA filters, also managed to stop most particles from getting between the filter to filter interface. However, to meet industry standards, a more rigorous test with 0.3 micron diameter particulate must be done to ensure these seals are capable of achieving 99.97% efficiency.

20 CONCLUSION

The team was challenged to improve the way HEPA filters are integrated into nuclear facilities. The overall goal was to develop a system for online HEPA filter replacement that reduced facility downtime and maintained worker safety. The new design required that the system remain sealed during exchanges, old filters were kept on the hot side of ventilation, all aspects comply with Nuclear Air and Gas Treatment Requirements, the design assists IAEA inspectors, and radiation exposure is kept as low as reasonably achievable. Our sealing techniques and bagging process design meets all of these requirements while keeping costs low, and without requiring a complete HVAC system overhaul for the facility.

The reactor remaining on line during exchanges is the central goal. The critical component of our design that makes this possible is the brush seal interface and rollers. The brush seal in combination with rollers that have a neoprene seal will provide an airtight seal during filter exchange. That seal combined with the filter to filter gel seal which is well tested in industry will provide a fully sealed exchange which in turn allows the facility to stay on line regardless of when swaps are scheduled or the IAEA is inspecting.

The bag-in bag-out procedure is the standard method of containing removed HEPA filters and systematically removing them without contaminating any parts of the facility. Our design makes use of this very effective system and succeeds in containing spent HEPA filters.

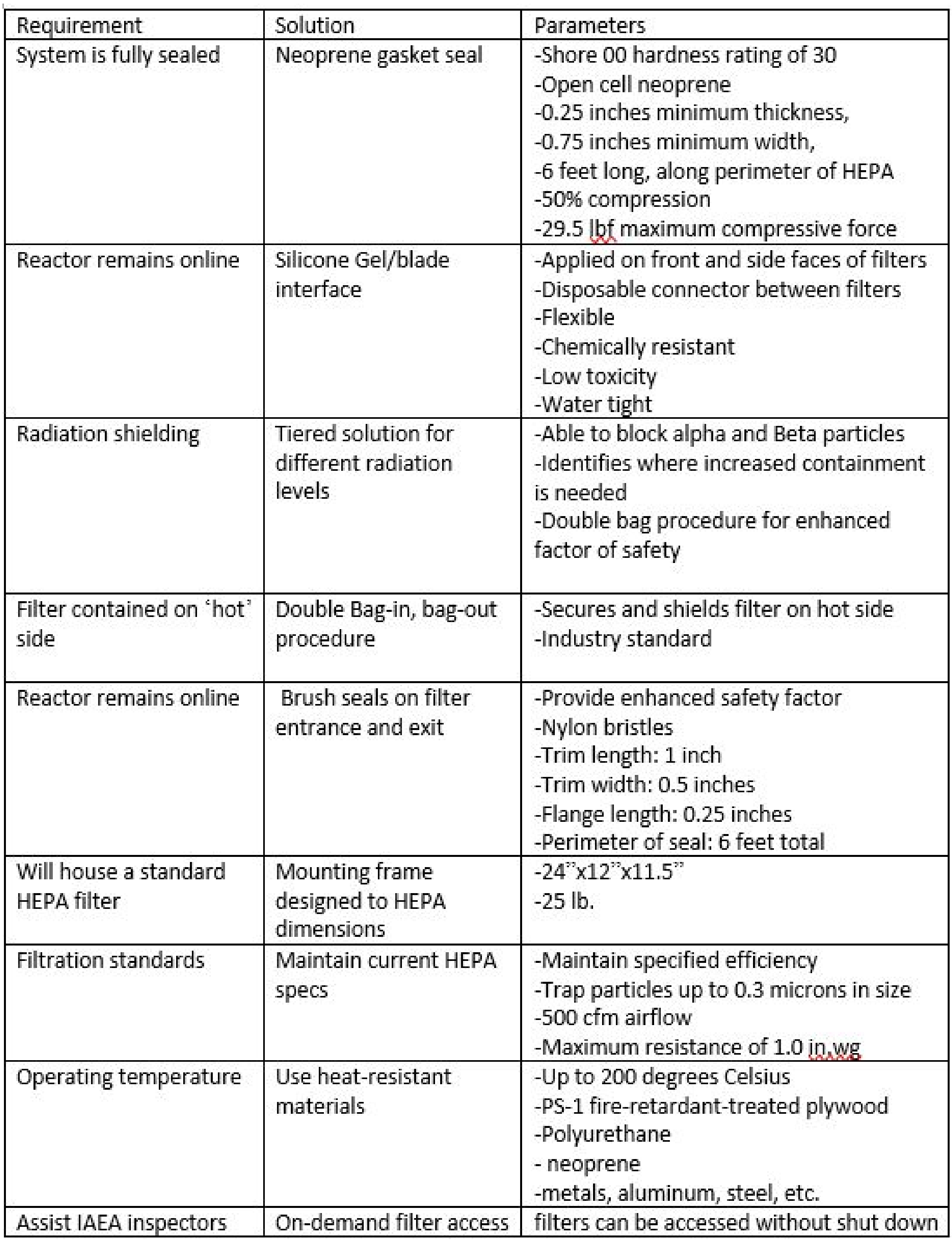
The next requirement the design is held to is that it must comply with Nuclear Air and Gas Treatment Requirements. The requirement refers to ASME's standards manual AG-1. The sections that pertain to the project are FC and HA (HEPA filters and Housings respectively). The team has been consistently referencing these sections to make sure everything is up to code during our consultations. Any testing will conform to the DOE handbook's guide on testing procedures for HEPA filter enclosures.

The IAEA is tasked with sampling HEPA filters from all around the world in order to verify safe procedures and to flag nefarious activity. This ends up being a difficult task because facilities that need to be on line to earn profits are resistant to shutting down for the IAEA to carry out its tests. An on line exchange would make complying with this regulation of negligible cost greatly assisting the IAEA with sampling or direct measurements of the filter.

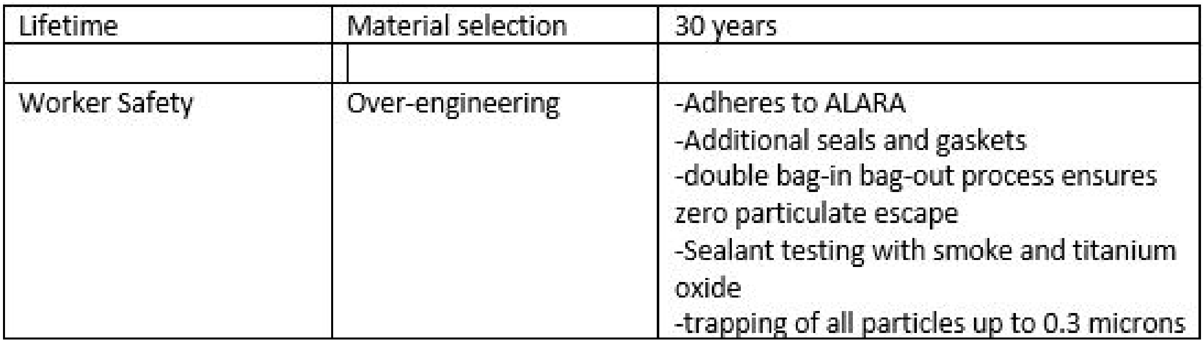
The final requirement is that the design must adhere to ALARA as do all nuclear designs. A double bag-in, bag-out process will ensure that no particulate is able to escape the enclosure during a filter exchange. Additionally the team recommends two systems in parallel for redundancy and in case of emergency. Such a system can be employed in generation IV reactors.

In conclusion the team and the design build met each of the design specifications required, and the testing procedures of the innovative design shows promise for future build iterations.

20.1 Reference Design Specification



Requirement	Solution	Parameters
System is fully sealed	Neoprene gasket seal	-Shore 00 hardness rating of 30 -Open cell neoprene -0.25 inches minimum thickness, -0.75 inches minimum width, -6 feet long, along perimeter of HEPA -50% compression -29.5 lbf maximum compressive force
Reactor remains online	Silicone Gel/blade interface	-Applied on front and side faces of filters -Disposable connector between filters -Flexible -Chemically resistant -Low toxicity -Water tight
Radiation shielding	Tiered solution for different radiation levels	-Able to block alpha and Beta particles -Identifies where increased containment is needed -Double bag procedure for enhanced factor of safety
Filter contained on 'hot' side	Double Bag-in, bag-out procedure	-Secures and shields filter on hot side -Industry standard
Reactor remains online	Brush seals on filter entrance and exit	-Provide enhanced safety factor -Nylon bristles -Trim length: 1 inch -Trim width: 0.5 inches -Flange length: 0.25 inches -Perimeter of seal: 6 feet total
Will house a standard HEPA filter	Mounting frame designed to HEPA dimensions	-24"x12"x11.5" -25 lb.
Filtration standards	Maintain current HEPA specs	-Maintain specified efficiency -Trap particles up to 0.3 microns in size -500 cfm airflow -Maximum resistance of 1.0 in.wg
Operating temperature	Use heat-resistant materials	-Up to 200 degrees Celsius -PS-1 fire-retardant-treated plywood -Polyurethane - neoprene -metals, aluminum, steel, etc.
Assist IAEA inspectors	On-demand filter access	filters can be accessed without shut down



Lifetime	Material selection	30 years
Worker Safety	Over-engineering	-Adheres to ALARA -Additional seals and gaskets -double bag-in bag-out process ensures zero particulate escape -Sealant testing with smoke and titanium oxide -trapping of all particles up to 0.3 microns

21 FURTHER WORK

The team was extremely happy with the functionality of the test build, but would like to make recommendations for the future work on the *HEPA* Housing.

The chosen clamping device failed to fully clamp the filter into place, leading to perhaps one of the larger sources of error for the team. The device was quickly retrofitted to accommodate smaller filters than originally specified, but the team would recommend switching to the industry standard of clamping mechanisms, in comparison to spring clamps. CAM based clamps would provide a more even and exact clamping force and displacement. The team could even see CAM clamps being integrated into the door mechanisms, to automatically clamp the filter as soon as the exchange is finished.

The rollers of the test build were designed and built for the ease of manufacturing the test prototype, and the team would like to make recommendations going forward for this area of design. During the research and development of components, the team found rotary stroke bearings, allowing for the filter to glide through the exchange, and be able to move laterally during the clamping process with further ease. These types of bearings are machined out of both metal and plastic, and have options to run without the need of additional lubrication, and would likely outlive the expected lifetime of the filter housing.

As a proof of concept, the team was pleased with the functionality of the brush seals as a means of providing a form of sealing during the filter exchange. As previously discussed, the brush seals provide a risk area in terms of particulate build-up. The first few filter exchanges should be flawless without the possibility of particulate leaving the brush medium. However, the team is concerned with the longevity of the brush seals that were tested, as the powder quickly built up on the inside of the brush seal medium. These specific brush seals would likely not meet the lifetime requirements of the filter housing inside of a power reactor, so a new method of sealing would be recommended. Research and development specifically designated to developing a brush seal medium that would work efficiently at high airflow would be ideal.

The smoke testing at 200 CFM, 340 CFM, and 500CFM confirmed that the filter housing itself was airtight and could withstand the minimum operating conditions expected. To further validate the test procedures proposed, the team would recommend working with a housing manufacturer to create a full-scale, industry ready prototype using the double $BIBO$ door design. The team believes that there is enough potential to recommend further investigations in this area. Long term testing is recommended; there should be enough particulate filtered to saturate the housing and filter to its expected lifetime. This should be done several times to ensure that the housing is a valid long-term solution to the filter exchange problem.

In addition to the built and tested housing design, the team would recommend the use of multiple filter housings in parallel, with the ability to divert airflow quickly and safely from one to another. This is the safest way to ensure an live filter exchange, and would do so without risking any exposure to the radiation workers.

Finally, the ability to scale the design for a variety of arrangements of HEPA filters should be completed. HEPA filter arrangements range from the single in-line filter such as our build and test design build, to webs of filters in array of up to 4 x 5 arrangements, allowing for up to 30,000 CFM of filtered airflow. Each facility is unique with its own needs for air filtration, and the use of many filter housings should be expected in any case.

22 ACKNOWLEDGEMENTS

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[5]

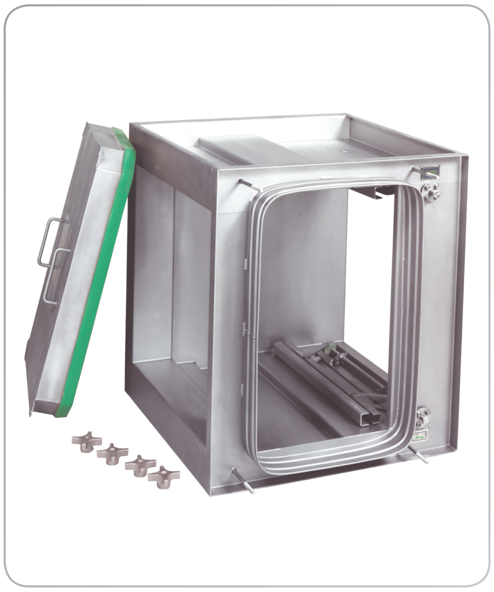
Appendix A: CamFil Bag In Bag Out Procedure

The following pages are a standard Bag In Bag Out Procedure that was useful in the modeling of the design.

camfil

CamContain™ GB Housing

Gasket Seal Bag-In/Bag-Out Air Filter Housing



Camfil CamContain GB Series Housings are designed for use in critical processes where hazardous airborne materials must be prevented from escaping to the atmosphere. Air filters may be replaced using a control barrier to protect change-out personnel from contaminants within the housing or contaminants captured by the filters.

The Camfil CamContain GB Housing minimizes exposure to harmful contaminants during filter service through the use of a PVC bag enclosure system. The entire filter changing process isolates personnel from the hazardous materials.

Although the Camfil GB Housing is available in a basic configuration various options specific to the application are available.

These housings are typically used in facilities that incorporate hazardous materials in their processes. These contaminants may include biomedical, radiological, carcinogenic or other materials of concern. Some specific applications include:

- Chemical manufacturing facilities
- Food processing
- Genetic research and biotechnology facilities
- Hospital Isolation Suites to prevent the spread of infectious diseases
- Industrial processes exhaust
- Microelectronic and semiconductor facilities
- Nuclear power plants
- Pharmaceutical facilities
- Radioisotope handling facilities
- University research laboratories
- US Department of Energy Facilities
- Veterinary research and animal disease laboratories
- Specific United States Government facilities including military and the Department of State.

1400 pounds of gasket-sealing integrity to ensure complete capture of airborne contaminants

The highest level of personnel protection.

Containment Train Components

Figure 2

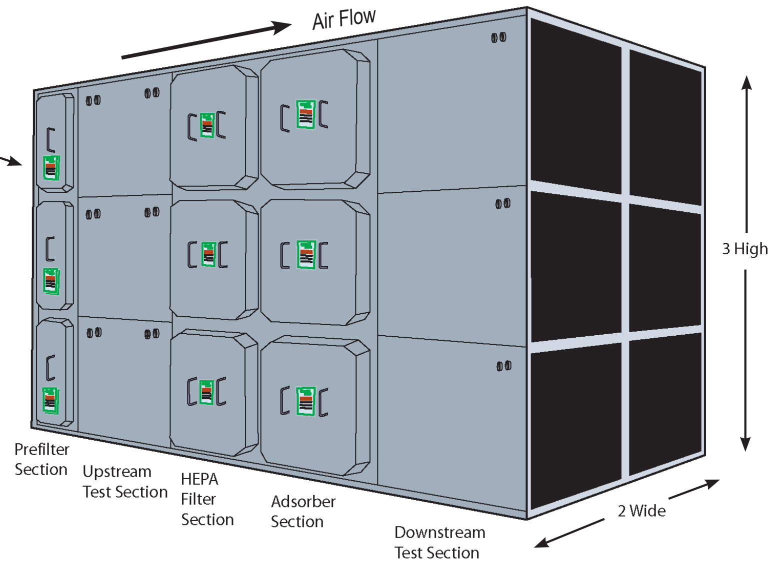


Figure 1

CamContain GB Housings are available in configurations from ½ x ½ (that include the installation of one filter 12" by 12" size) to configurations that are 1 x 3 that allow the service of up to three 24" by 24" filters from a single service door.

Units may be stacked or connected in series dependent upon the airflow requirements and contaminants of concern. The housing in Figure 1 shows a stacked unit that is 3 filters high by 2 filters wide and includes 3 stages of air filtration. Personnel in critical applications need an extra level of protection during filter service and maintenance. In many cases containment measures are required by Federal or State mandates or by recommended practices by other cognizant authorities. The details of each enclosure are clearly identified on a stainless steel label (Figure 2). The following components assure compliance with these mandates.

Prefiltration
CamContain GB Housings can incorporate a prefilter track to extend the life of the primary filters. Tracks may accommodate 2", 4", or 6" deep prefilters. Access to prefiltration may be through the same door as the final filter without disturbing final filter integrity. A separate door may also be provided for prefilter access only. Prefiltration efficiency typically ranges from a MERV 7 to a MERV 14 when evaluated under ASHRAE Filter Testing Standard 52.2.

Particulate Filters
Typically the primary filter in a containment system is a high efficiency particulate air (HEPA) filter. Camfil Absolute® filters are manufactured under strict quality control guidelines. Every filter is tested to ensure that the particulate efficiency meets or exceeds the requirements of the application. Particulate filters are available from 99.97% on particles 0.3 micron in size to 99.9995% on particles 0.12 micron in size. All Camfil HEPA filters include a unique poured-in-place seamless gasket for superior filter sealing integrity. Conventional closed-cell neoprene gaskets are also available.

Molecular Filtration
Hazardous gases may be removed from the airstream through the application of various configurations of adsorbers. Adsorbers should be selected for their affinity to the hazardous gas contaminant of concern or combination of gases involved. In some cases multiple stages of adsorbers should be applied, and in all cases adsorbers should be prefiltered. An additional stage of prefiltration may be required downstream of the adsorber to capture any particulate that may be generated by the adsorber. Consult Camfil Bulletin 3431.

Test Sections
Most installations will require an in-place filter efficiency evaluation to ensure that the system is performing to specifications. Applications that should incorporate test sections include any system where access to upstream and downstream ductwork may be restricted. In-place test sections minimize system train distance requirements that are typical for proper mixing of challenge aerosol. In most cases the entire bank of air filters is evaluated for overall efficiency. Scan test sections are also available that allow individual filter scanning for leaks. Consult Camfil Bulletin 3407.

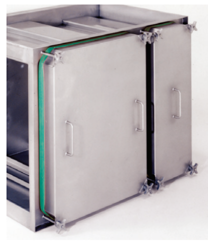
CBR Systems (Special)
A CBR system is a single filter system designed to control chemical, biological and radiological contaminants that may be generated by wartime, terrorist or industrial accident. The system usually includes prefiltration, gaseous adsorbers and post filters for particulate removal in one certified leak free module. Contact factory for assistance with CBR units.

Standard Component Construction

8-Mil Change-out Bag
Each CamContain Housing includes a translucent poly vinyl chloride bag mounted behind each access door. Standard bags include three glove sleeves to facilitate handling of the filter(s) and an elastic shock cord to seal internal components from the atmosphere during a change. Bag replacement data is engraved on the label of each housing as well as identified with a label on the shock cord supplied with the bag. Consult Camfil Bulletin 3410.

Stainless Steel Construction
Camfil GB Housings are completely factory assembled and constructed of 304L stainless steel sheet metal. There are no painted surfaces, nor cross-contamination from the use of carbon/mild steel materials. Each housing is warranted to withstand 15" w.g. positive or negative pressure without failure of the housing to ambient air seal or compromise of the overall housing integrity. Each housing is tested to this level and test reports are available on request. Camfil has the ability to custom design housing integrity to most operating conditions.

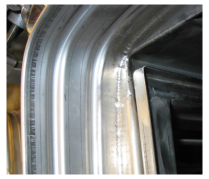
Access Door(s)



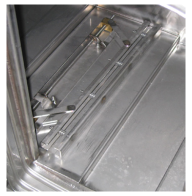
Access doors, of the same construction materials as the housing, include a built-in bagging ring cavity to store the filter change bag during system operation. Each access door includes a high-memory silicone gasket that recreates a positive housing to ambient seal after each filter change. Convenient permanent door handles are optimally placed so the doors have a natural balance during filter change.

Removable Star-Style Door Knobs
Each door is secured through the use of four threaded studs with removable star knobs. After filter change the knobs are tightened in an alternating pattern to ensure an even and secure housing seal.

Dual Ribbed Bagging Rings
Each filter access port includes a ribbed bagging ring assembly for attachment of an 8-mil changing bag of poly vinyl chloride (PVC) construction. Two ribs are included as required to facilitate the filter changing process. The bagging ring is continuously welded and hemmed to prevent damage to the bag.



Filter-Sealing Assembly
CamContain GB Housings incorporate a linkage clamping mechanism that may be operated with a standard wrench from outside of the housing.



Filter seal adjustment is accomplished by a clearly identified hexagonal cranking bolt. Up to 1400 pounds of filter seal may be applied. Leak paths from the mechanism's penetration of the housing wall are eliminated through the use of the penetrating knife edge, enabling filters to be removed. Filter change is then performed from inside the filter change out bag.

Optional Components

(see last page for standard specifications on these items)

Banding Kit

The Camfil Banding Kit includes a case/lap apron, a heavy duty tie-banding gun, PVC bag cutting shears, a 7" hook-and-loop fastener cinching strap and ten 100-lb tensile strength banding ties. The kit offers assurance that all required change components are readily available in one convenient package. Consult Camfil Bulletin 3410.

Construction Materials

Alternate materials of construction are available. As an example, the units are available in various grades of stainless steel sheet metal. Please consult the factory if your application requires non-listed components of construction.

Dampers

Dampers allow isolation of components during filter change or decontamination processes. Camfil manufacturers low-leakage and bubble-tight designs. Consult Camfil Bulletin 3440.

Decontamination Ports

Camfil can provide decontamination ports for the injection of materials designed to force neutralization of contaminants. This photo shows plug sitting on top of the port assembly. Plug type is ring-seal positive.

DOP/Freon Test Ports

To facilitate in-place filter evaluation Camfil can supply integral tests ports for the sampling of the challenge aerosol. Commonly referred to as DOP/Freon test ports, they are also applicable to today's modern technology of alternate test challenges.

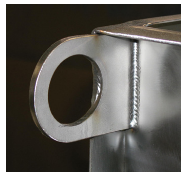
Drilled Flanges

Camfil can provide pre-drilled duct connection flanges. Holes are typically 7/16" in diameter with spacing not to exceed 4" (per DOE-HDBK-1169-2003 "Nuclear Air Cleaning Handbook"). For a bolt hole drawing of your housing model, please consult the factory .

Filter Change-out Tray

A filter change-out tray provides support for the filters during the service process. Connecting conveniently to the door latches it can support filters and bagging components up to 300-lbs. Filter change-out trays are highly recommended for housing applications where ladders may be required for service or housings are in a difficult-to-reach location, or where heavy carbon adsorbers may be applied. Consult Camfil Bulletin 3410.

Lifting Lugs



Camfil can provide lifting lugs for unit transport and support during installation. The lugs are of 1/4" thick 304L stainless steel and have a pre-drilled 1-1/2" hole. Common lifting lug locations include the top or side of the housing.

Plenums & Transitions

Camfil can manufacture all components required for complete system integrity. Matching plenums of the same construction as the housing are available to mate with existing equipment or ductwork. Transitions are also available to mate to equipment offsets.

Prefilter Housings

Camfil can provide housings with integral prefilter sections for application of 2", 4", or 6" deep prefilters. Various prefilter configurations are available. Camfil can provide most of the filtration components that may be required. Consult Camfil Bulletin 3403 for prefilter section information.

Pressure Gages

Camfil can provide factory-mounted differential pressure gages to evaluate resistance across individual filters or any combination of internal components. Gage connections include copper tubing and brass fittings. Stainless steel tubing and fittings are also available.

Pressure Taps (static)

Static pressure taps are available to facilitate the connection of gages or other ancillary equipment. For on-site application of gages, taps include a removable brass plug.

Security & Cinching Straps

Replacement straps are available. Consult Camfil Bulletin 3410.

Swivel Door Latches

Camfil housings are available with swivel door latches to allow the latches to swing away from the filter change opening. Door latch components are captive as a precaution against dropping or losing them. Swivel door latches are highly recommended for housing applications where ladders may be required for service, or housings that are in a difficult-to-reach location.

Test Sections (in-place)

Test sections allow evaluation of filters without the on-site inline space penalties associated with the proper mixing of aerosol challenges. Standard test sections allow evaluation of an entire bank of filters. Scan test sections allow evaluation of individual filters to ensure that an individual filter does not have any leaks. All testing is accomplished without exposing the service personnel to contaminants contained by the housing. Consult Camfil Bulletin 3407-0902 for standard test sections and scan test sections.

Weather Covers

Although Camfil housings are weatherproof, an optional weather cover of the same construction materials as the housing, may be included to prevent water accumulation on the top of the housing. Standard weather covers are attached and sealed against weather intrusion. If pre-drilled flanges are required the weather cover is bolted to the housing to allow access to mounting flanges.

Additional Options

(require factory consultation)

Casters

Camfil CamContain Housings may be mobilized with casters to allow use of the units in alternate locations.

Certified Weld Inspection (CWI)

Visual weld inspection can be performed by a certified weld inspector qualified to Section 6.1 of the American Welding Society Standards For Qualification and Certification of Welding Inspections, QC1-96. The inspections will be performed under the guidelines of AWS D9.1M/D9.1:2000.

Flanges

Quarter-inch thick stainless steel plate flanges are available. The flanges can be furnished with 7/16" diameter holes no more than 4" on center as recommended in DOE-HDBK-1169-2003 "Nuclear Air Cleaning Handbook", or to mate-up with standard pipe flange bolt hole patterns. Standard raised-face, slip-on, stainless steel flanges per ASA B16.5 are also available.

Deformation Testing

Non-destructive deformation testing is available. This test confirms systems will not deform at higher pressures.

Dye Penetrate Testing

Dye penetrate testing is available to evaluate for weld defects.

Electric Heaters

Electric heaters with pre-wired connection boxes are available.

High/Low Pressure Options

Camfil can assemble components to meet the pressure requirements of most applications.

High-Temperature Construction

Camfil housings are available with construction components that can accommodate process air to 450° F (232° C).

Humidifiers
Humidifiers are available to meet specific application needs.

Insulation
Housings may be insulated. All insulation incorporates double-wall housing construction.

Low Leak Testing
Low-leak testing to lower than standard leak rates is available.

Metal Door Pocket
A metal door pocket to store Operations & Maintenance Manual (O & M) during system operation is available.

Moisture Removal Drains & Valves
Moisture removal drains and valves are available. These are typically applied in installations that have concerns with regard to condensation, or if moisture separators are used in the system.

Moisture Separators
Moisture separators applied as prefiltration are available. Camfil ECO Moisture Separators have an efficiency of 98% on 5-micron size droplets. Other variations of moisture separators are available (consult factory).

Mounting Bases
Custom mounting bases are available. These are applied for seismic security or to match a roof curb.

Mounted Fans/Controls
Camfil will assemble complete trains of containment that can include particulate filtration, gaseous filtration and ancillary components such as fans and controls.

Seismic Qualification
CamContain GB Housings can be qualified in accordance with the criteria of the Uniform Building Code (1994 & 1997). Multiple module systems consisting of filter housings, test sections, dampers, etc. can be qualified per application to meet most levels of severe seismic requirements. Additional information to provide assurance of seismic qualification requires factory consultation.

The Complete System
Camfil manufactures all of the components that may be required in a containment train of housings. From the filter, to the bag, to the dampers that isolate the system, quality is assured through unparalleled component compatibility. Performance and protection from one source, Camfil, a worldwide leader in air filtration technology and production.

Quality Assurance

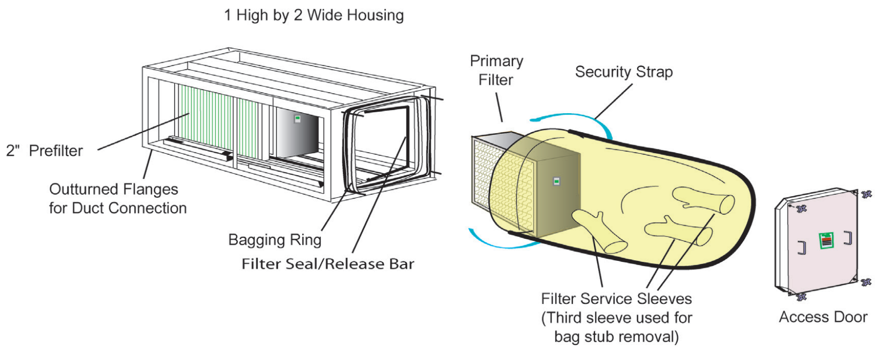
Any Industry that has processes of concern that may include possibly hazardous exhaust components (gases and/or particulates) has a vested interest in the well-being, and health and safety of employees or others that may have proximity to the process. Additionally, cognizant authorities including the United States Government, State bodies and engineering societies have defined minimum standards of care with respect to many hazardous containment applications. At the bare minimum, equipment assembled for these processes must be manufactured to exacting quality control procedures.

Camfil has in place, various quality control initiatives that ensure that our products meet or exceed these standards. These programs are inclusive of raw materials acquisition, procedures of transport and storage, preparation and assembly of these materials to a final product form, and the testing and qualification to ensure the finished product meets or exceeds the letter of the Standards.
Camfil product manufacturing facilities have been audited by various entities and found to be acceptable. These procedures are part of a living doctrine that is updated based upon improved technologies and the increased needs of the applications. Camfil containment products are manufactured under a Camfil Quality Assurance program, including the basic requirements of ASME-NQA-1 when specified.

Camfil Absolute filters and ASHRAE grade filters that may be used in containment applications are manufactured in ISO 9001:2000 facilities. Camfil Nuclear Grade Absolute filters complying with the requirements of Section FC of ASME AG-1 are manufactured under an ASME NQA-1 Quality Assurance Program.

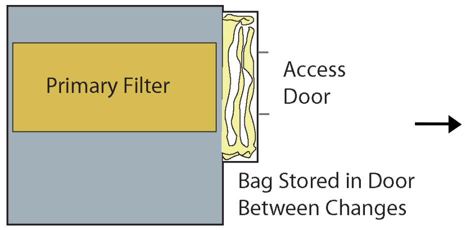
Additional quality assurance procedures are in place to meet the needs of specific end users. These procedures are available for review and modification by end users, our authorized representatives, and Camfil.

Bag-In/Bag-Out Concept



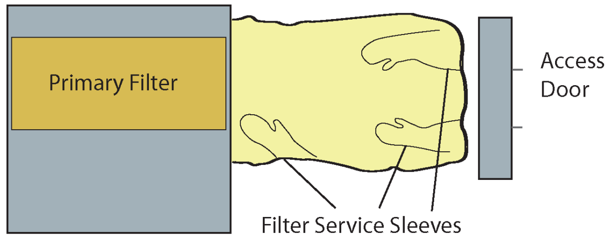
CamContain Housings are designed with safety in mind. Each housing is shipped with an instruction book detailing how to change the filters. The basics of filter change include installing the new filters in the change-out bag, securing the bag over the ribbed openings on the housing door opening, and performing the filter change entirely within the bag.

STEP 1



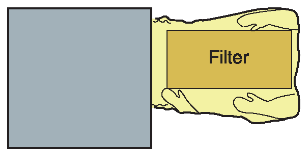
During operation the filter (s) are in place and the bag is stored in the door

STEP 2



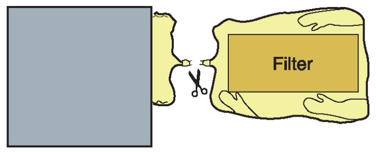
After removing the access door, extend the bag, and use the bag gloves to carefully move the contaminated filter into the bag.

STEP 3



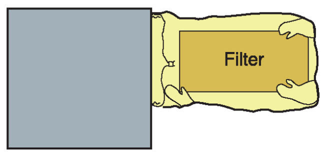
Remove the contaminated filter from the housing, supporting the filter on a table, or optional change-out tray.

STEP 4



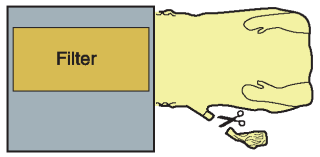
Seal the bag with banding ties between the filter and the door opening. Cut the bag with shears to contain the used filter.

STEP 5



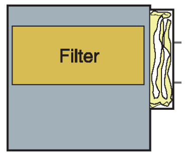
Place a new filter in a new bag and secure the new bag opening to the housing door opening. Move the old bag stub into the new bag cavity and install the filter.

STEP 6



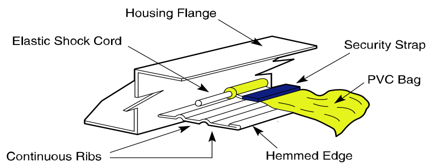
Move the old bag stub into the third service glove sleeve and seal the sleeve with banding ties between the bag body and the glove sleeve.

STEP 7



Carefully fold the bag and place in the door cavity. Replace door.

Bagging Flange Detail



The illustration above portrays how the bag is placed over the ribs and held in place there by an elastic shock cord and security strap.

Model Designator

CamContain™ GB Housing

CF-3X3-012 P-1GB-SS

Number of Filters High
(height of housing)
½ = One (1) filter high (half size)
1 = One (1) filter high
2 = Two (2) filters high
3 = Three (3) filters high
4 = Four (4) filters high
5 = Five (5) filters high
6 = Six (6) filters high

Number of Filters Wide
½ = One (1) filter wide (half size)
1 = One (1) filter wide
2 = Two (2) filters wide
3 = Three (3) filters wide
4 = Four (4) filters wide
5 = Five (5) filters wide
6 = Six (6) filters wide

Prefilter Size
(depth of prefilter)
(height and width to match nominal dimensions)
0 = No prefilter

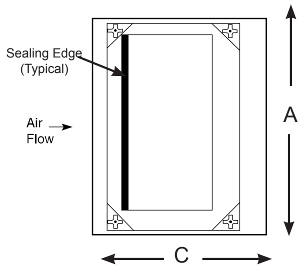
Primary Filter Size
(depth of primary filter)
12 = 11½" Actual filter depth
16 = 16" Actual filter depth
18 = 18" Actual filter depth
CF- 1X1-012P-1FB-SS will require a filter with actual dimensions of 24" X 24" X 11½"

Housing Sheet Metal Type
SS = T-304L Stainless steel (standard)
AS = Aluminized steel
316L = T-316L Stainless steel

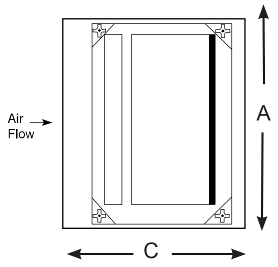
Housing Type/Series
GB = Gasket seal bag-in/bag-out
GN = Gasket seal non-bag-in/bag-out (Camfil Bulletin 3405)
FB = Gel seal bag-in/bag-out (Camfil Bulletin 3401)
FN = Gel seal non-bag-in/bag-out (Camfil Bulletin 3404)

Access Door Arrangement
1* = One (1) access door on one side of housing
2 = Two (2) access doors, one access door on each side of housing
* Housing can only accommodate 2" deep prefilter and primary filter

Filter Type
P = Particulate
C = Carbon adsorber (HEGA)



Typical door arrangement 1 with a single primary filter. Designed to accommodate primary filter (s) through one door opening. Actual primary filter depth may be 11½", 16" or 18".



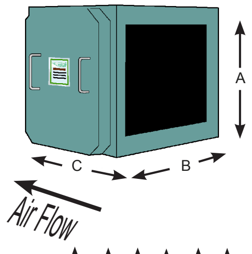
Typical door arrangement 1 with prefilter and primary filter. Designed to accommodate prefilter (s) and primary filter (s) through one door opening. Prefilter depth limited to 2". Primary filter depth may be 11½", 16" or 18".

Housing Dimension A = Height B = Width C = Depth

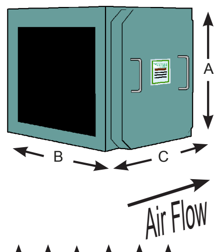
Above arrangements show upstream, downstream and upstream primary filter seals respectively. Arrangement 1 is also available with downstream primary filter seal when in-place scan testing is required.

CamContain™ GB Housing

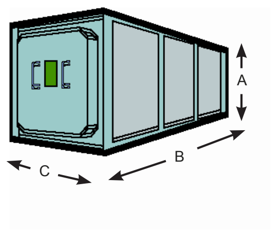
Left Hand Access

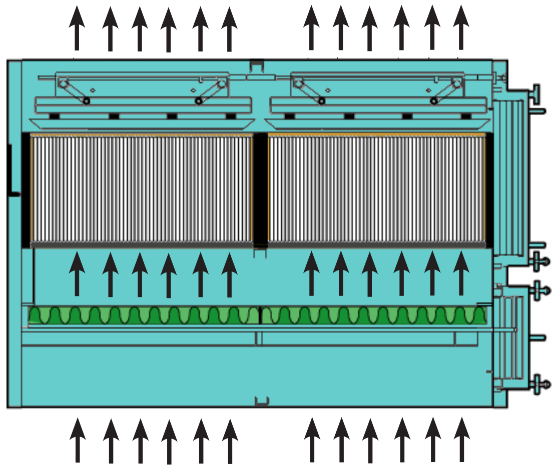


Right Hand Access



1 high by 3 wide





Camfil housings feature smooth surface construction. Pocket areas, that would allow contaminant build-up are minimized. All pressure retaining joints on the interior of the housing are continuously welded.

Housing Size/Configuration Chart - 012-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	N/A	12	1	18	15	26	135
1/2 x 1	N/A	12	1	18	27	26	175
1 x 1	N/A	12	1	30	27	26	210
1 x 2	N/A	12	1	30	51	26	320
1 x 3	N/A	12	1	30	75	26	425
2 x 1	N/A	12	1	60	27	26	375
2 x 2	N/A	12	1	60	51	26	570
2 x 3	N/A	12	1	60	75	26	745
3 x 1	N/A	12	1	90	27	26	540
3 x 2	N/A	12	1	90	51	26	815
3 x 3	N/A	12	1	90	75	26	1070
4 x 1	N/A	12	1	120	27	26	700
4 x 2	N/A	12	1	120	51	26	1060
4 x 3	N/A	12	1	120	75	26	1390

Housing Size/Configuration Chart - 016-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	N/A	16	1	18	15	30	145
1/2 x 1	N/A	16	1	18	27	30	195
1 x 1	N/A	16	1	30	27	30	230
1 x 2	N/A	16	1	30	51	30	345
1 x 3	N/A	16	1	30	75	30	460
2 x 1	N/A	16	1	60	27	30	410
2 x 2	N/A	16	1	60	51	30	615
2 x 3	N/A	16	1	60	75	30	805
3 x 1	N/A	16	1	90	27	30	590
3 x 2	N/A	16	1	90	51	30	880
3 x 3	N/A	16	1	90	75	30	1150
4 x 1	N/A	16	1	120	27	30	765
4 x 2	N/A	16	1	120	51	30	1145
4 x 3	N/A	16	1	120	75	30	1497

Housing Size/Configuration Chart - 018-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	N/A	18	1	18	15	33	155
1/2 x 1	N/A	18	1	18	27	33	205
1 x 1	N/A	18	1	30	27	33	245
1 x 2	N/A	18	1	30	51	33	370
1 x 3	N/A	18	1	30	75	33	485
2 x 1	N/A	18	1	60	27	33	435
2 x 2	N/A	18	1	60	51	33	645
2 x 3	N/A	18	1	60	75	33	850
3 x 1	N/A	18	1	90	27	33	625
3 x 2	N/A	18	1	90	51	33	930
3 x 3	N/A	18	1	90	75	33	1210
4 x 1	N/A	18	1	120	27	33	815
4 x 2	N/A	18	1	120	51	33	1210
4 x 3	N/A	18	1	120	75	33	1575

Housing Size/Configuration Chart - 212-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	2	12	1	18	15	26	135
1/2 x 1	2	12	1	18	27	26	175
1 x 1	2	12	1	30	27	26	210
1 x 2	2	12	1	30	51	26	320
1 x 3	2	12	1	30	75	26	425
2 x 1	2	12	1	60	27	26	375
2 x 2	2	12	1	60	51	26	570
2 x 3	2	12	1	60	75	26	745
3 x 1	2	12	1	90	27	26	540
3 x 2	2	12	1	90	51	26	815
3 x 3	2	12	1	90	75	26	1070
4 x 1	2	12	1	120	27	26	700
4 x 2	2	12	1	120	51	26	1060
4 x 3	2	12	1	120	75	26	1390

Housing Size/Configuration Chart - 218-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	2	18	1	18	15	33	155
1/2 x 1	2	18	1	18	27	33	205
1 x 1	2	18	1	30	27	33	245
1 x 2	2	18	1	30	51	33	370
1 x 3	2	18	1	30	75	33	485
2 x 1	2	18	1	60	27	33	435
2 x 2	2	18	1	60	51	33	645
2 x 3	2	18	1	60	75	33	850
3 x 1	2	18	1	90	27	33	625
3 x 2	2	18	1	90	51	33	930
3 x 3	2	18	1	90	75	33	1210
4 x 1	2	18	1	120	27	33	815
4 x 2	2	18	1	120	51	33	1210
4 x 3	2	18	1	120	75	33	1575

Housing Size/Configuration Chart - 216-1GB

Housing Size (H x W)	Prefilter Depth (inches)	Primary Filter Depth (inches)	Door Arrange-ment	Dimen-sion A (inches)	Dimen-sion B (inches)	Dimen-sion C (inches)	Shipping Weight (lbs)
1/2 x 1/2	2	16	1	18	15	30	145
1/2 x 1	2	16	1	18	27	30	195
1 x 1	2	16	1	30	27	30	230
1 x 2	2	16	1	30	51	30	345
1 x 3	2	16	1	30	75	30	460
2 x 1	2	16	1	60	27	30	410
2 x 2	2	16	1	60	51	30	615
2 x 3	2	16	1	60	75	30	805
3 x 1	2	16	1	90	27	30	590
3 x 2	2	16	1	90	51	30	880
3 x 3	2	16	1	90	75	30	1150
4 x 1	2	16	1	120	27	30	765
4 x 2	2	16	1	120	51	30	1145
4 x 3	2	16	1	120	75	30	1497

Standard Specification for Camfil GB Containment Housing

1.0 – General

1.1 - Housing shall be Camfil CamContain GB-series side-access bag-in/bag-out, gasket seal housing. The housing shall be adequately reinforced to withstand a negative or positive pressure of 15" water gage. Housing design and filter arrangement shall allow air to enter and exit housing without changing direction. The housing shall accommodate standard size filters that do not require any special attachments or devices to function properly in the housing.

1.2 – Sizes shall be noted on enclosed drawings or other supporting materials.

2.0 – Construction

2.1 – Housing shall be constructed of 14 gauge and 11 gauge T-304L stainless steel metal. All pressure retaining joints and seams shall be continuously welded with no porosities. Joints and seams requiring intermittent welds, such as reinforcement members, shall be intermittently welded. Housing shall be free of burrs and sharp edges. All weld joints and seams that are a portion of any gasket setting surface, (duct connection flanges and filter sealing surfaces), shall be ground smooth and flush with adjacent base metals. All welded joints and seams shall be wire brushed to remove heat discoloration. The housing shall be reinforced to withstand a positive or negative pressure of 15" w.g. The upstream and downstream ductwork connections shall have 1 1/2" outward-turned flanges.

2.2 - The housing shall have a bagging ring around each filter access port that is sealed by a gasketed filter access door. The filter access door gasket shall be silicone and shall be replaceable, if necessary. The bagging ring shall have two (2) continuous formed raised ridges to secure the PVC change-out bag. The bagging ring shall be hemmed on the outer edge to prevent the change-out bag from tearing.

2.3 – Ancillary hardware including filter clamping mechanism, door handles, door studs and labels shall be 300 series stainless steel. The threaded pivot blocks in the filter clamping mechanisms shall be of brass construction. Filter access door knobs shall be cast aluminum and designed to prevent galling of threads.

2.4 – A filter clamping mechanism shall be operated by means of a standard wrench from outside the housing. The clamping mechanism shall include two pressure channel assemblies with eight springs per filter and exert a minimum filter sealing force of 1,400 pounds per full size filter, 1050 pounds per half size filter, and 700 pounds per quarter size filter. The force shall be applied as an even, uniform load along at least 80% of the top and bottom of each filter outer frame. The filter clamping mechanism adjustment penetration through the housing wall shall be sealed airtight.

2.5 - One (1) Camfil manufactured PVC change-out bag shall be furnished with each filter access port. Change-out bags shall be 8-mil. thick with a yellow translucent, non-sticking, matte finish. It shall include a 1/4" diameter elastic shock cord hemmed into the opening of the bag so when stretched around the housing bagging ring flange, a secure fit is created. The bag shall include three (3) integral glove ports to assist in filter change-out. One (1) nylon security strap shall be included per filter access port to prevent the bag from sliding off the bagging flange during the change-out process. Design of components shall be such that all change-out operations shall be within the bag so there is a barrier between the worker and the filter at all times.

3.0 – Performance

3.1 - All welding procedures, welders, and welder operators shall be qualified in accordance with *ASME Boiler and Pressure Vessel Code, Section IX*. All production welds shall be visually inspected by qualified personnel, per Camfil standard procedure number *CFW-10001, Visual Inspection of Welds*, which incorporates the workmanship acceptance criteria described in *Section 5 & 6 of AWS D9.1-1990, Specification for Welding of Sheet Metal.*

3.2 - The filter housing shall be manufactured under a Camfil Quality Assurance Program (see Note 1 below). The filter housing shall be factory tested for filter fit, flatness of filter sealing surface and operation of filter clamping mechanism. The filter sealing surface and the complete assembly pressure boundary shall be leak tested by the pressure decay method as defined *in ASME N510-1995 Reaffirmed., Testing of Nuclear Air Cleaning Systems*, paragraphs 6 and 7. The filter sealing surface shall be tested at +10" water gage and have a maximum leak rate of 0.0005 cfm per cubic foot of housing volume. The overall system pressure boundary shall be leak tested at +15" water gage and have a maximum leak rate of 0.0005 cfm per cubic foot of housing volume.

3.3 - Change-out bags shall be capable of continuous operating to temperature extremes of 0° F to 150° F.

3.4 – Multi-wide housing shall be equipped with a filter removal rod to pull the filters to the change-out position. The removal rod shall operate from the inside of the filter change-out bag.

Note 1 (to specifying engineer): Camfil manufacturers all of its containment products using more than one Quality Assurance Program. Our *product-wide* Quality Assurance Program is a stringent process that ensures the equipment is produced in conformance with our understanding of the intended application. However, this *product-wide* program does not address all the items specified in ASME-NQA-1. If this product must be manufactured under an ASME NQA-1 Quality Assurance Program, please add the following to this statement "including the basic requirements of ASME NQA-1." Please contact the factory if specific clarifications are required.

Optional specification items on next page.

CamContain™ GB Housing

Optional Specification Items

The format of these additional specification items includes a section numbering system consistent with today's requirements. Items beginning with the numeral 1 relate to general items, numeral 2 for construction components, and 3 for performance criterion. Dependent upon the option there may be an addition to one or more specification sections. Replace the # with a proper sequencing number based upon options selected.

Banding Kit
2.# - A banding kit that includes a case/lap apron, a heavy duty tie-banding gun, PVC bag cutting shears, a 7" cinching hook-and-loop fastener strap and ten 100-lb tensile strength banding ties shall be provided. Banding kit shall be manufactured by same manufacturer that manufactures the housing.

Decontamination Ports
2.# - Housing shall be provided with decontamination ports for injection of materials to neutralize contaminants. (Specify details. Contact factory for assistance).

DOP/Freon Test Port
2.# - Challenge aerosol sampling ports shall be provided upstream and downstream of each primary filter access door. The port shall be 3/8" FIPS and include a hex head brass plug for periods when it is not in use.

Drilled Duct Connection Flanges
2.# - Housing shall include pre-drilled flanges to facilitate attachment to ductwork. Holes shall be 7/16-inch diameter with spacing between holes not to exceed 4" as recommended in DOE-HDBK-1169-2003 "Nuclear Air Cleaning Handbook".

Filter Change-out Tray
2.# - A filter change-out tray of stainless steel welded construction shall be provided. The tray shall be designed for attachment to door studs during filter change. The tray shall be capable of supporting 300 pounds. (Specify quantity required).

Lifting Lugs
2.# - Lifting lugs, constructed of 1/4-inch thick Type 304 stainless steel shall be provided on the (side, top) of the housing. The lugs shall be capable of supporting the housing without housing deflection during transport and installation.

Prefilter Housings
See Camfil Bulletin 3403.
Factory-Mounted Pressure Gages

2.# - Housing shall include factory mounted pressure gages to measure any combination of pressure drop across prefiltration, final filtration, or combination thereof (specify requirements). Gage increments shall be as noted on enclosed drawings or other supporting materials. Gage tubing shall be copper construction with brass compression fittings.

Pressure Taps (static)
2.# - Static pressure taps with 1/4-inch FIPS threads that allow field installation of static measurement gages or other measurement devices shall be included upstream and downstream of filter stages. Taps shall allow measurement across (prefilter only, prefilter and primary filter system, primary filter only, or overall systems including multiple prefilter and primary filter combinations). (Specify requirements).

Security Strap
2.# - ( ) additional security straps shall be included.

Cinching Strap
2.# - ( ) additional cinching straps shall be included.

Swivel Door Latches
2.# - Housings shall be equipped with swivel door latches that shall completely swing-away from the filter change opening. All latching components shall remain captive during change.

Test Sections
2.# - Consult Camfil Bulletin 3407.

Weather Cap
2.# - Housing shall be provided with a weather cap that shall promote moisture run-off and prevent moisture accumulation on the top of the containment housing. The weather cap shall be constructed of the same materials as the housing and shall be (intermittently welded and sealed against weather intrusion, bolted to the housing to allow access to housing mounting flanges).

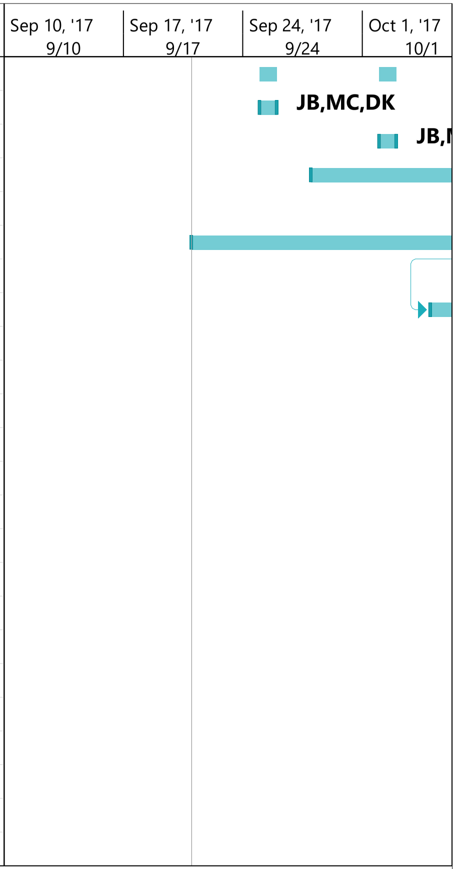
Items in parenthesis ( ) require selection.

ISO 9001:2008
Certified Quality System

Appendix B: Project Planning

Attached is both the fall and spring semester project plans for Team 6.

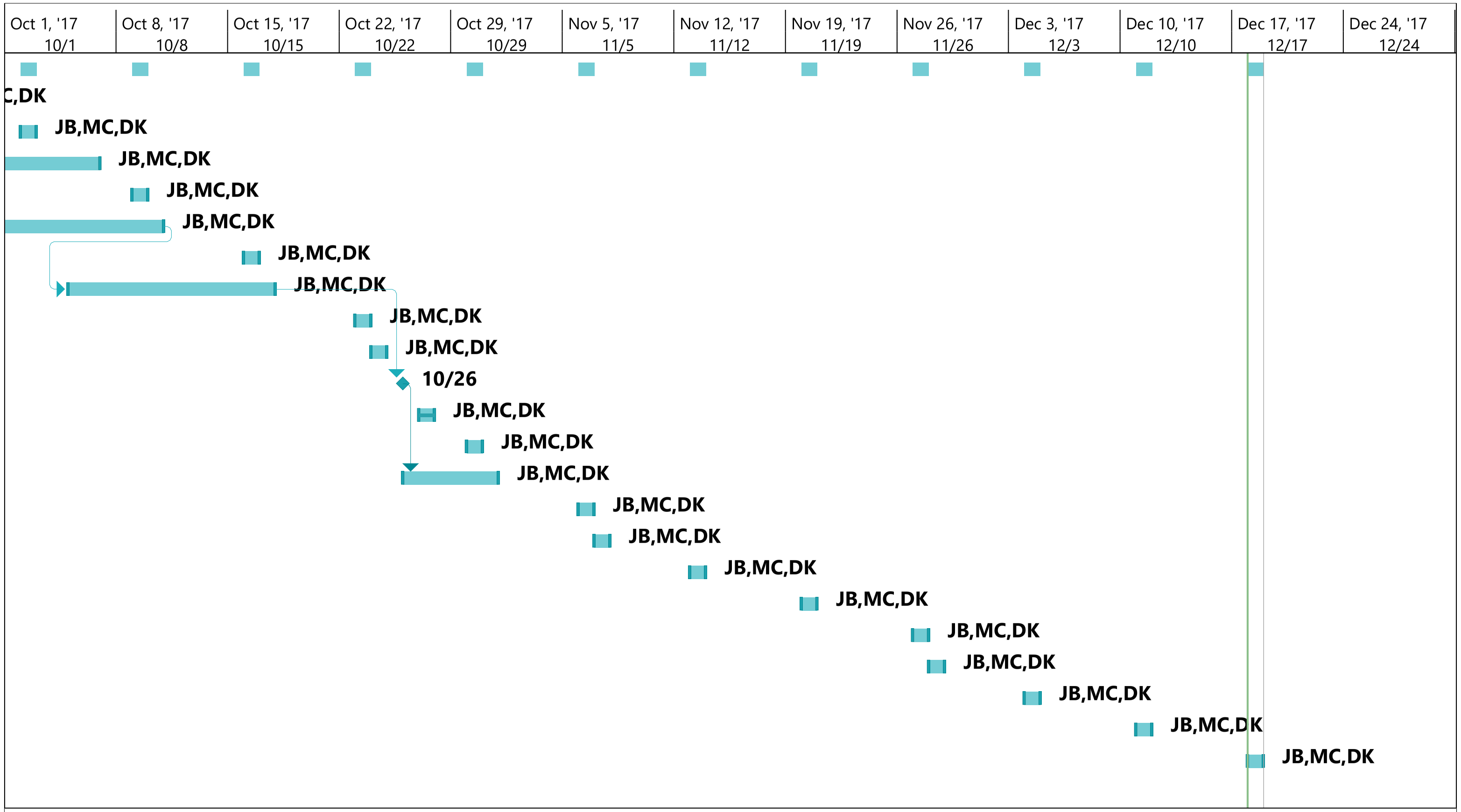
ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Weekly Meeting**	**63 days**	**Thu 9/21/17**	**Mon 12/18/1**	
2			Weekly Meeting 1	1 day	Mon 9/25/17	Mon 9/25/17	
3			Weekly Meeting 2	1 day	Mon 10/2/17	Mon 10/2/17	
22			Problem Definition	7 days	Thu 9/28/17	Fri 10/6/17	
4			Weekly Meeting 3	1 day	Mon 10/9/17	Mon 10/9/17	
15			Patent Search	14 days	Thu 9/21/17	Tue 10/10/17	
5			Weekly Meeting 4	1 day	Mon 10/16/17	Mon 10/16/17	
16			Design Concepts	9 days	Thu 10/5/17	Tue 10/17/17	15
6			Weekly Meeting 5	1 day	Mon 10/23/17	Mon 10/23/17	
24			Tele-conference with	1 day	Tue 10/24/17	Tue 10/24/17	
17			First Presentation	0 days	Thu 10/26/17	Thu 10/26/17	16
21	✓		Tour of RINSC reactor	1 day	Fri 10/27/17	Fri 10/27/17	
7			Weekly Meeting 6	1 day	Mon 10/30/17	Mon 10/30/17	
18			Updated Design Specs	4 days	Thu 10/26/17	Tue 10/31/17	17
8			Weekly Meeting 7	1 day	Mon 11/6/17	Mon 11/6/17	
23			Design conference with	1 day	Tue 11/7/17	Tue 11/7/17	
9			Weekly Meeting 8	1 day	Mon 11/13/17	Mon 11/13/17	
10			Weekly Meeting 9	1 day	Mon 11/20/17	Mon 11/20/17	
11			Weekly Meeting 10	1 day	Mon 11/27/17	Mon 11/27/17	
19			Proof of Concept	1 day	Tue 11/28/17	Tue 11/28/17	
12			Weekly Meeting 11	1 day	Mon 12/4/17	Mon 12/4/17	
13			Weekly Meeting 12	1 day	Mon 12/11/17	Mon 12/11/17	
14			Weekly Meeting 13	1 day	Mon 12/18/17	Mon 12/18/17	
20			Bi-Weekly Meetings				



Project: Team06_Capstone_Proj
Date: Mon 12/18/17

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 1



Project: Team06_Capstone_Proj
Date: Mon 12/18/17

Task	▬	Inactive Summary	▭	External Tasks	▬
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Milestone	◆	Duration-only	▬	Deadline	⬇
Summary	┏━┓	Manual Summary Rollup	━	Progress	━
Project Summary	┏━┓	Manual Summary	┏━┓	Manual Progress	━
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Inactive Milestone	◇	Finish-only	]		

Page 2

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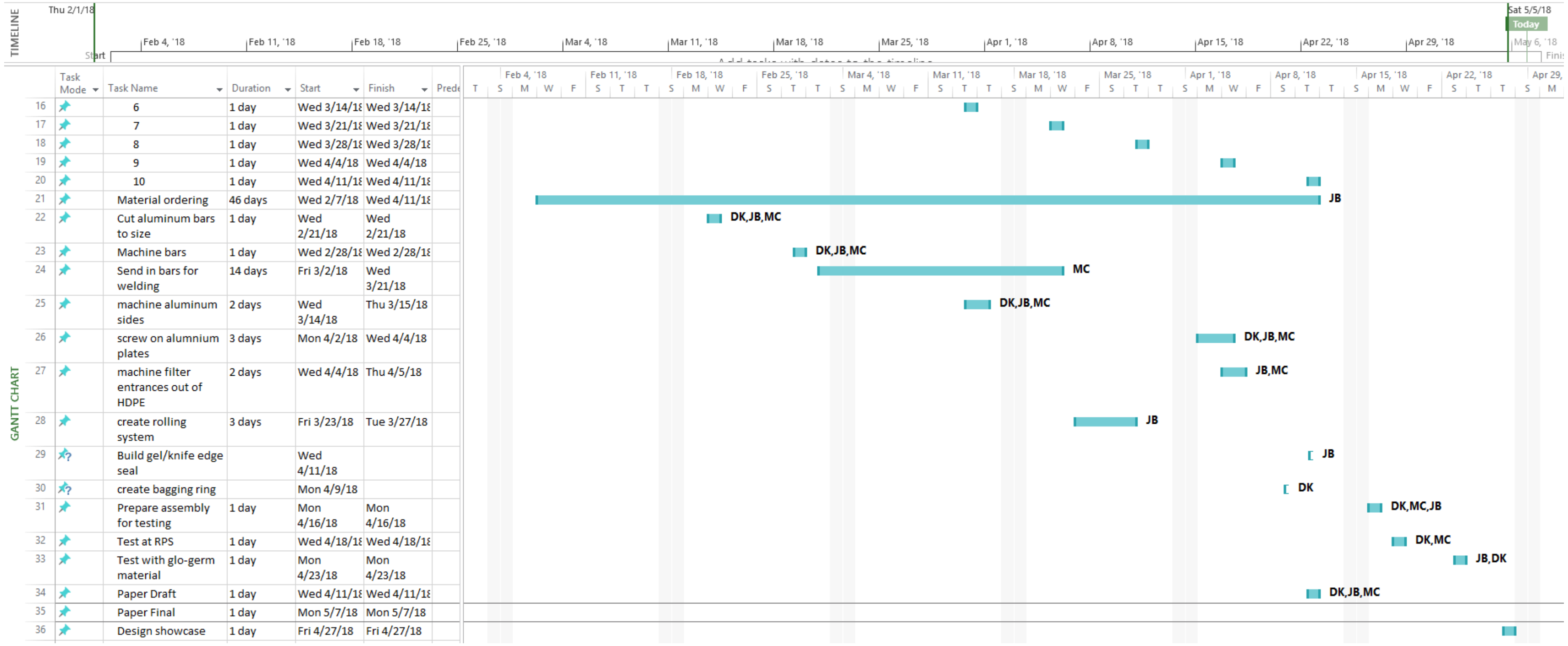

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17		7	1 day	Wed 3/21/18	Wed 3/21/18	
18		8	1 day	Wed 3/28/18	Wed 3/28/18	
19		9	1 day	Wed 4/4/18	Wed 4/4/18	
20		10	1 day	Wed 4/11/18	Wed 4/11/18	
21		Material ordering	46 days	Wed 2/7/18	Wed 4/11/18	
22		Cut aluminum bars to size	1 day	Wed 2/21/18	Wed 2/21/18	
23		Machine bars	1 day	Wed 2/28/18	Wed 2/28/18	
24		Send in bars for welding	14 days	Fri 3/2/18	Wed 3/21/18	
25		machine aluminum sides	2 days	Wed 3/14/18	Thu 3/15/18	
26		screw on alumnium plates	3 days	Mon 4/2/18	Wed 4/4/18	
27		machine filter entrances out of HDPE	2 days	Wed 4/4/18	Thu 4/5/18	
28		create rolling system	3 days	Fri 3/23/18	Tue 3/27/18	
29	?	Build gel/knife edge seal		Wed 4/11/18		
30	?	create bagging ring		Mon 4/9/18		
31		Prepare assembly for testing	1 day	Mon 4/16/18	Mon 4/16/18	
32		Test at RPS	1 day	Wed 4/18/18	Wed 4/18/18	
33		Test with glo-germ material	1 day	Mon 4/23/18	Mon 4/23/18	
34		Paper Draft	1 day	Wed 4/11/18	Wed 4/11/18	
35		Paper Final	1 day	Mon 5/7/18	Mon 5/7/18	
36		Design showcase	1 day	Fri 4/27/18	Fri 4/27/18	

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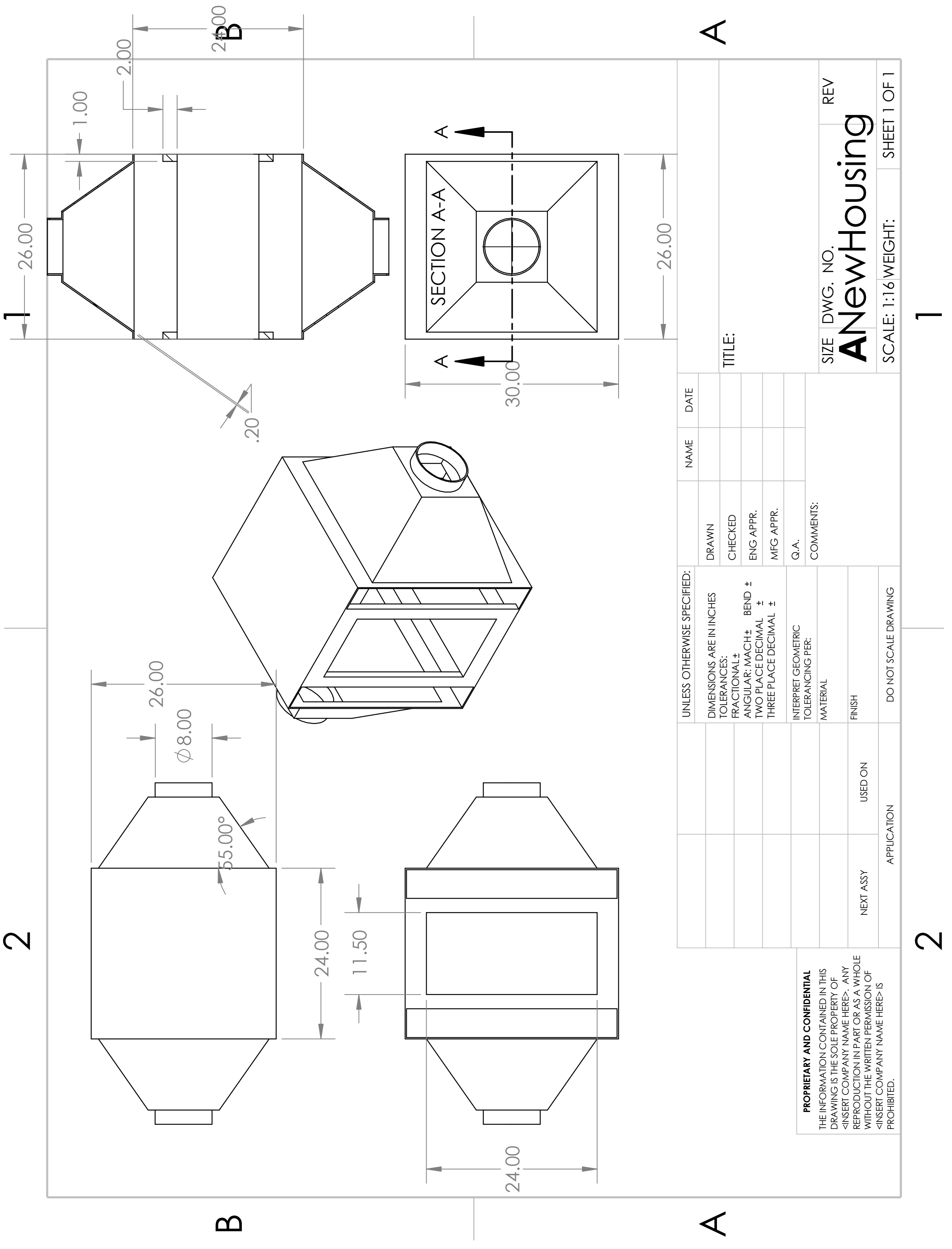
Appendix C: Detailed Drawings of Design

The following are the detailed drawings of each individual part within the product assembly, and one exploded render of the final design assembly. Manufacturing tolerances are to be assumed as +/- 0.01" unless otherwise specified, as the team is still in contact with *RPS* for the proper manufacturing practices of HEPA housings.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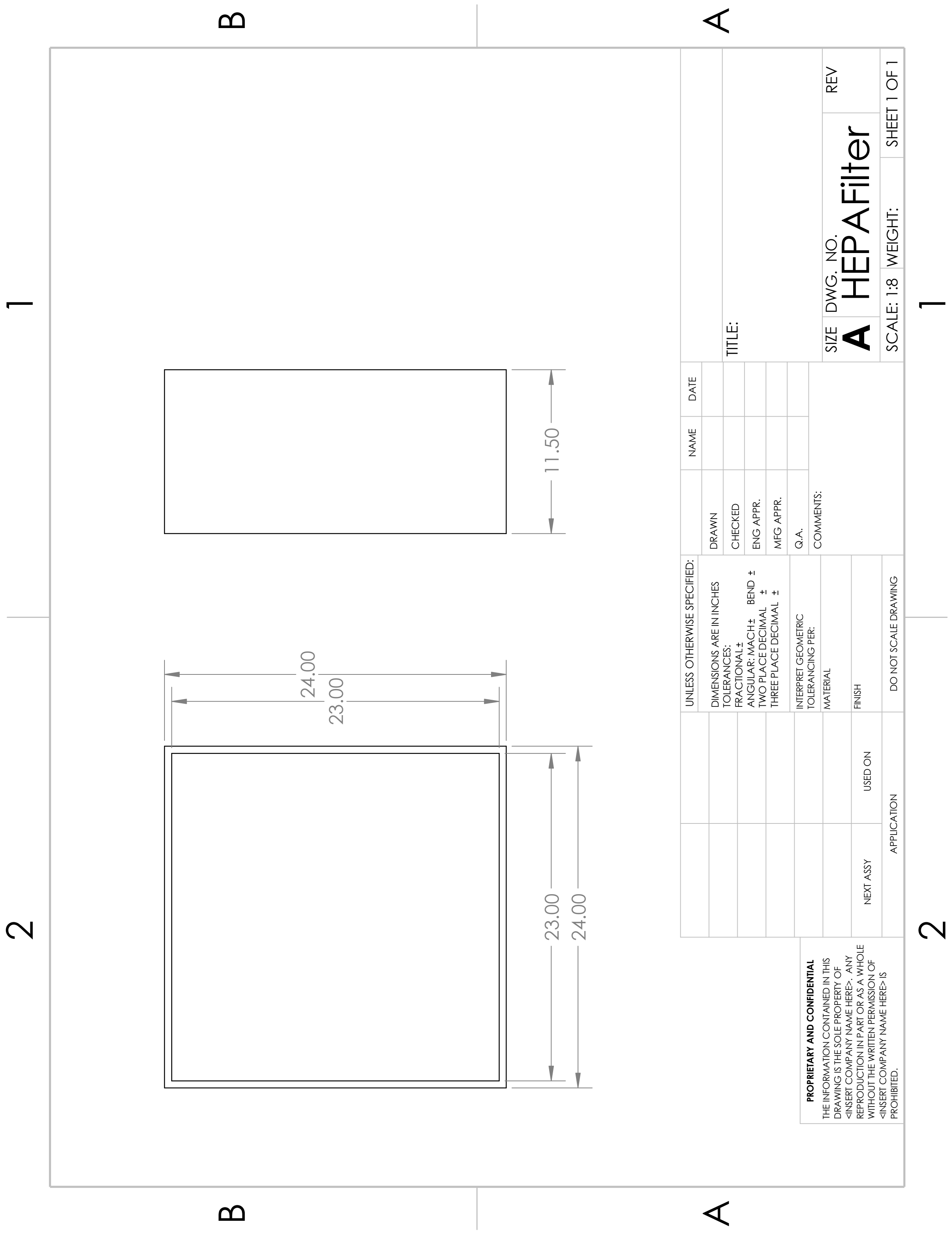
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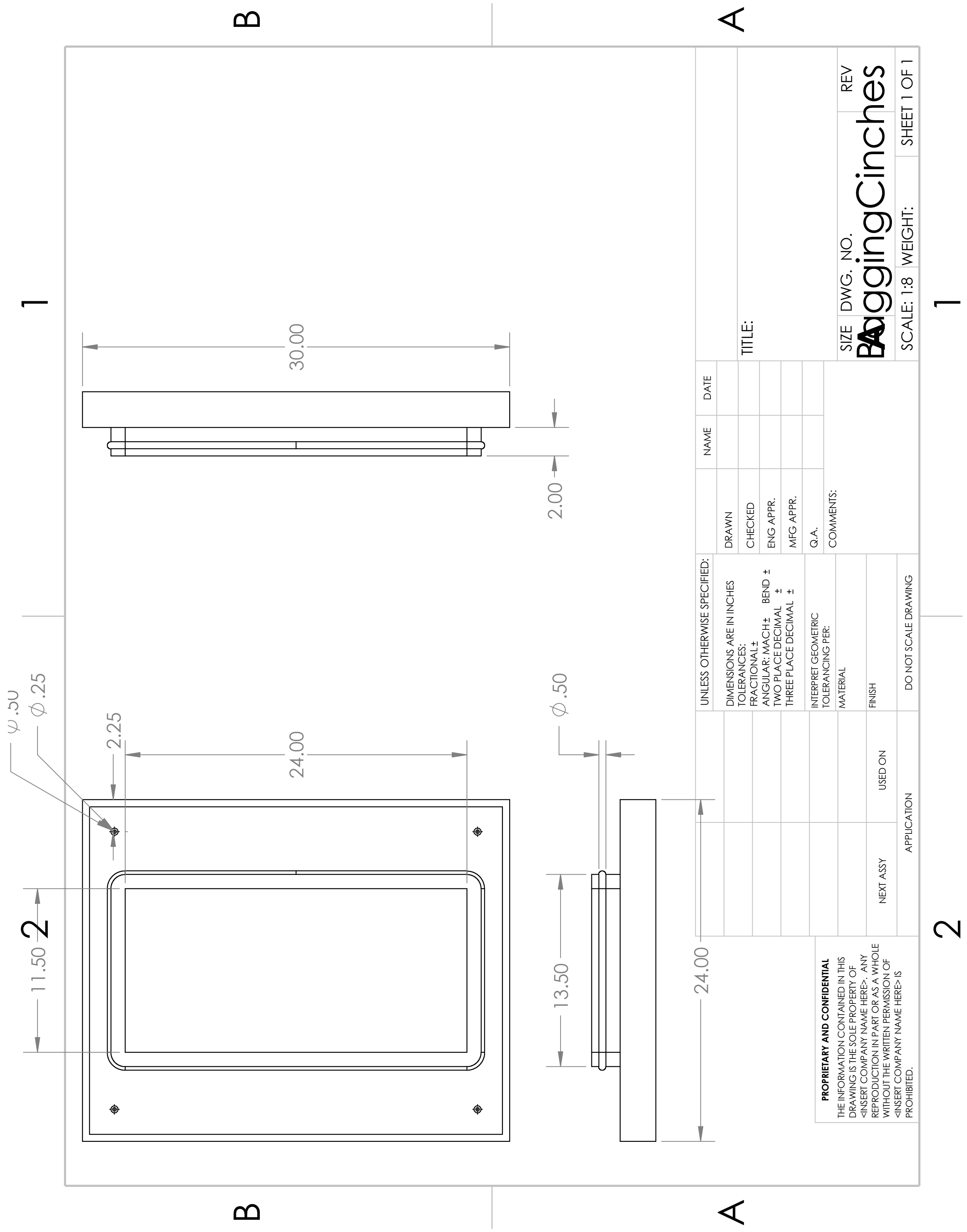
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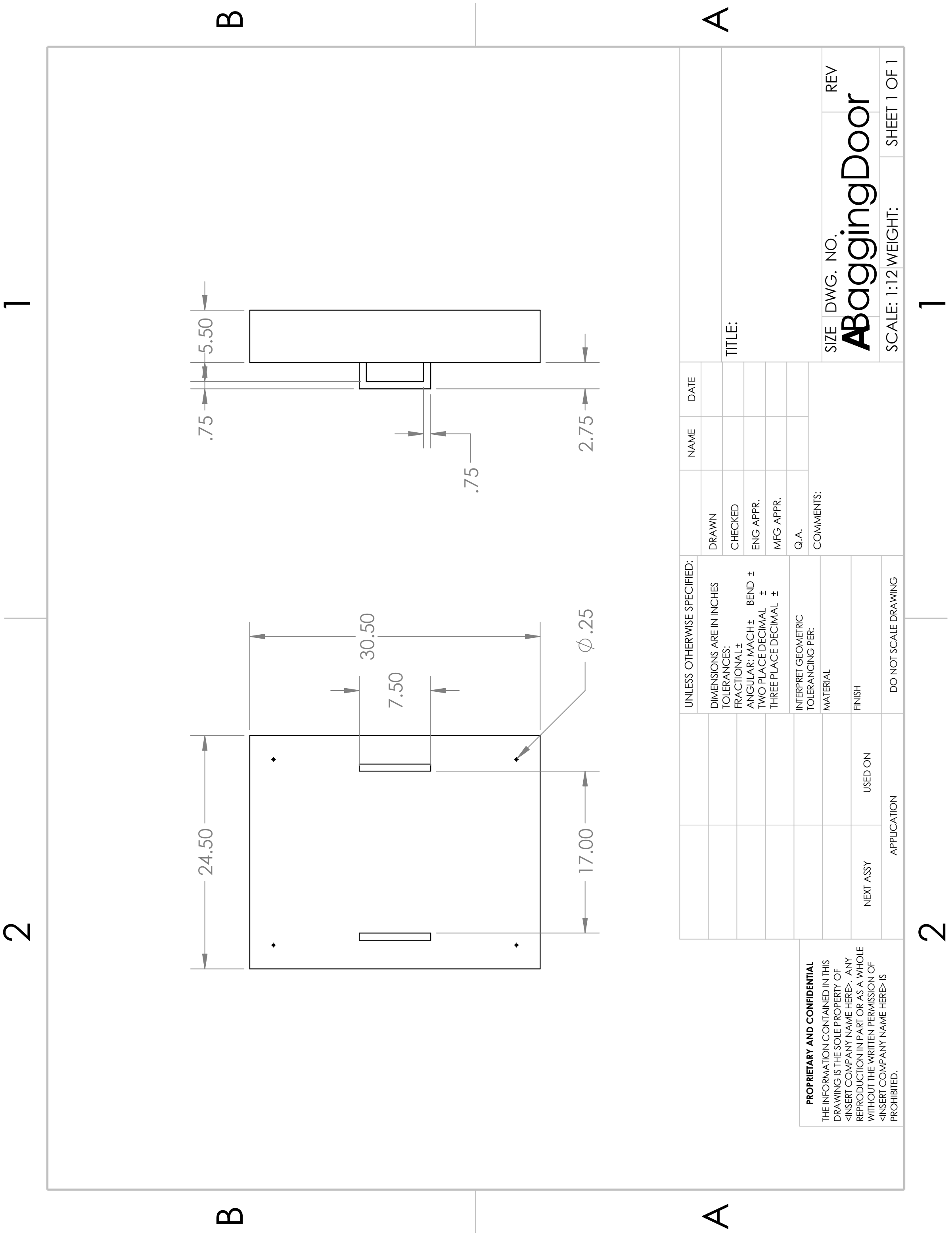
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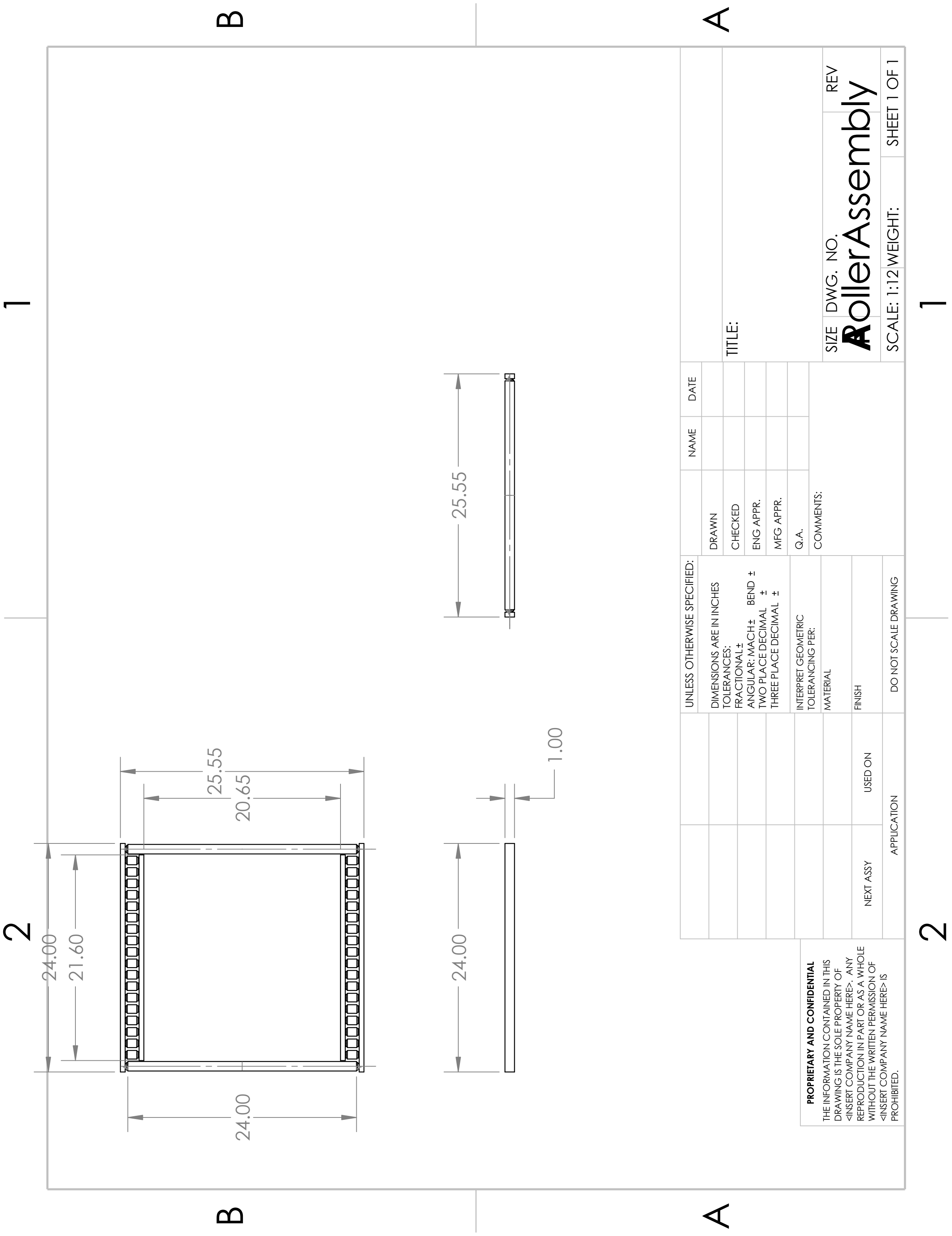
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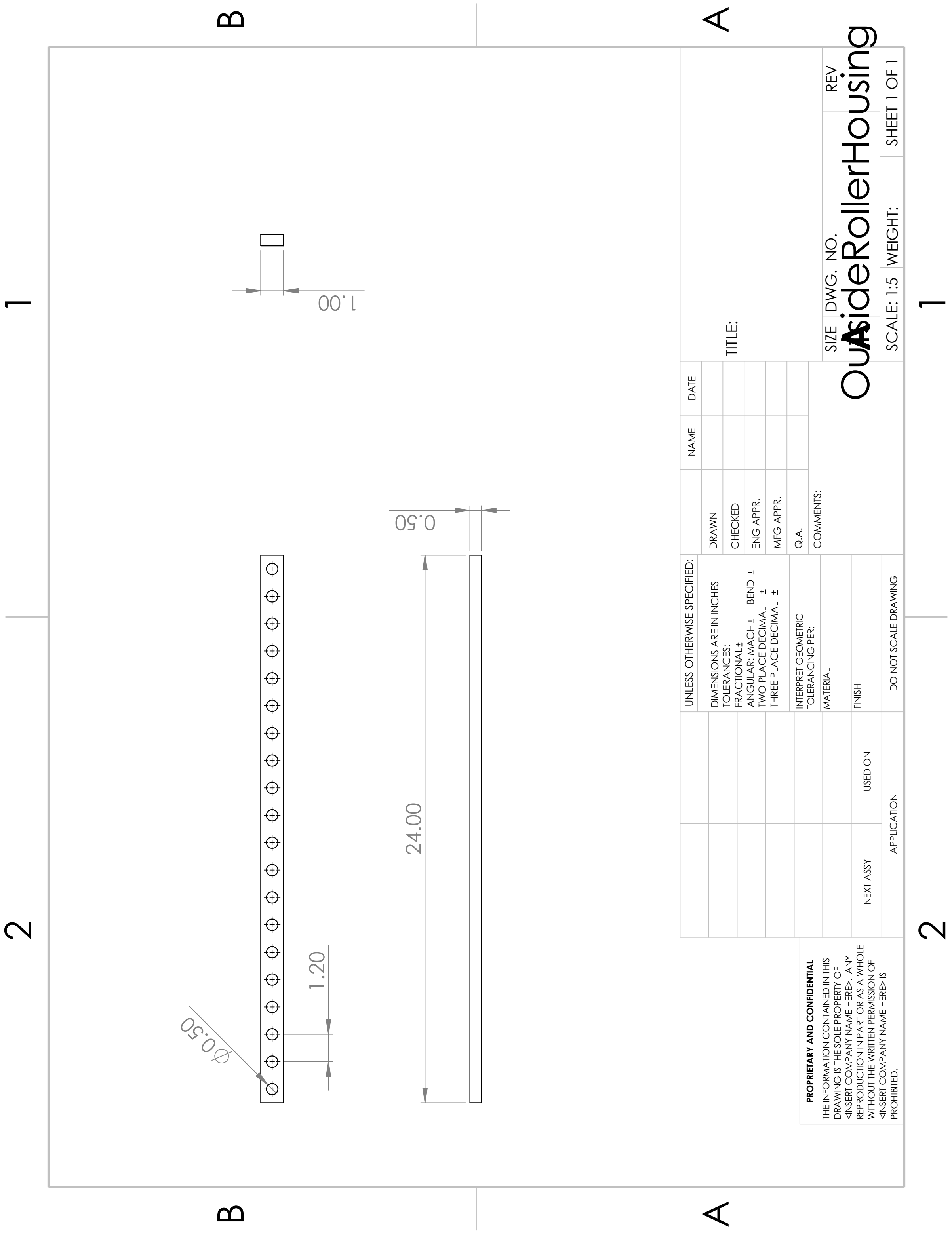
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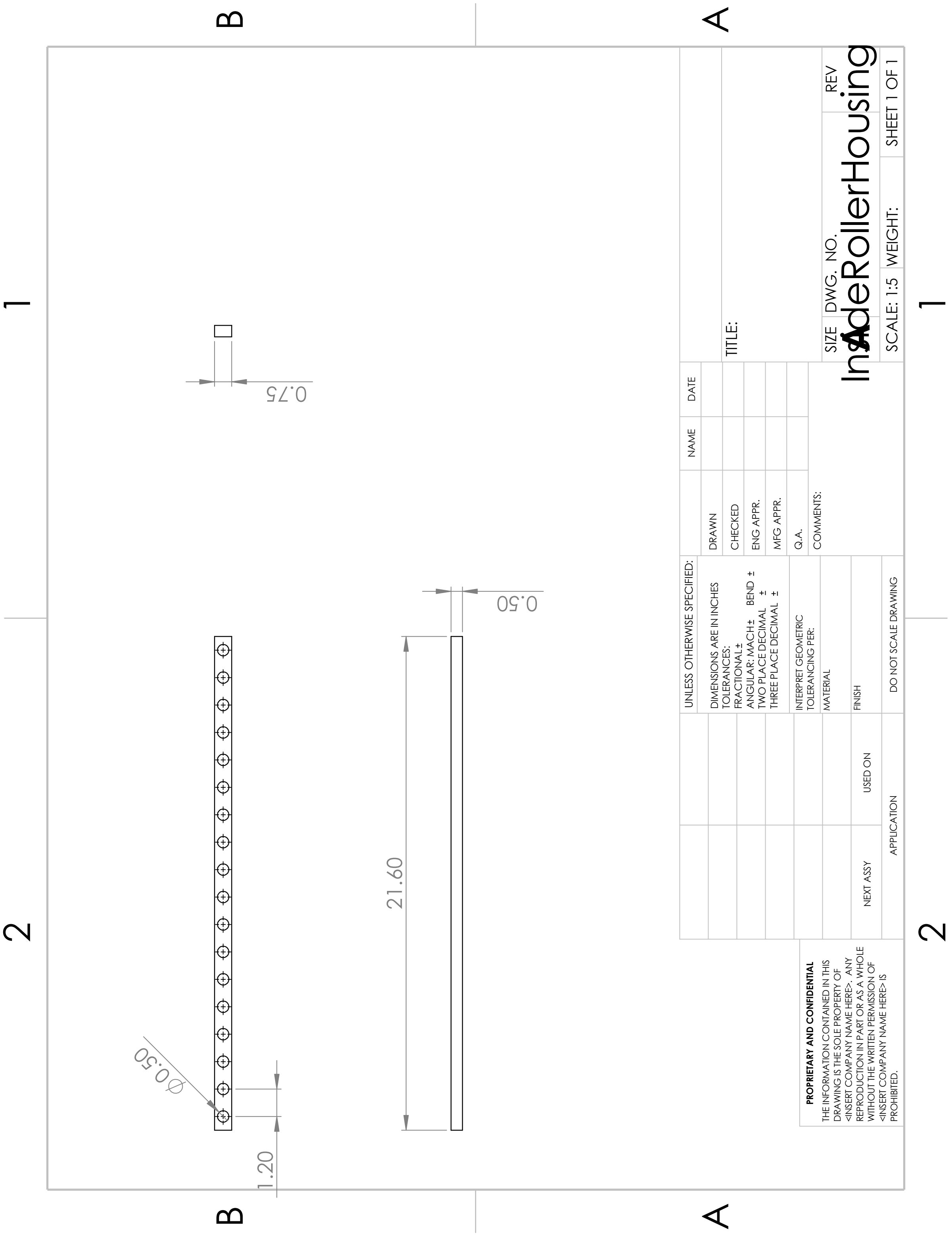
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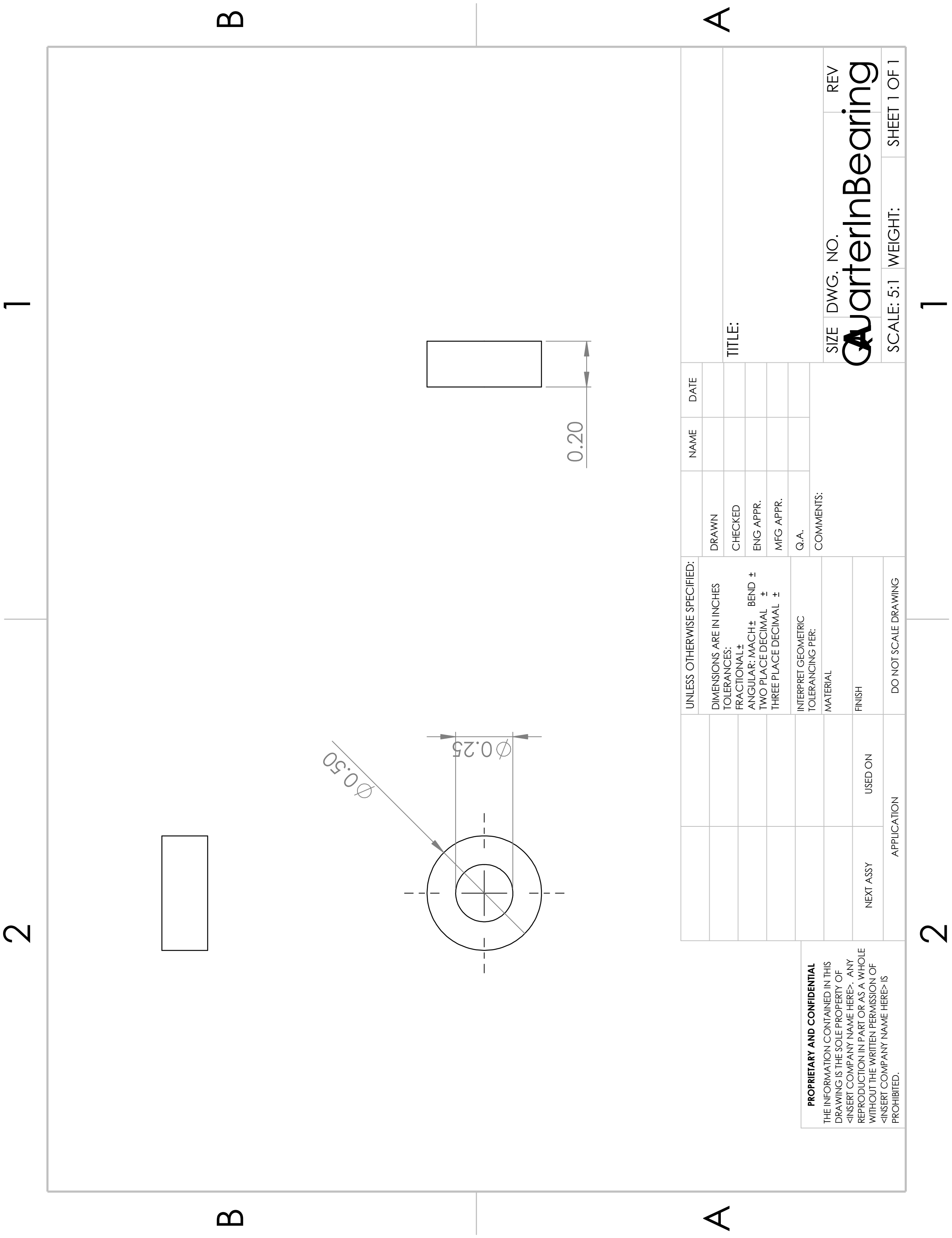
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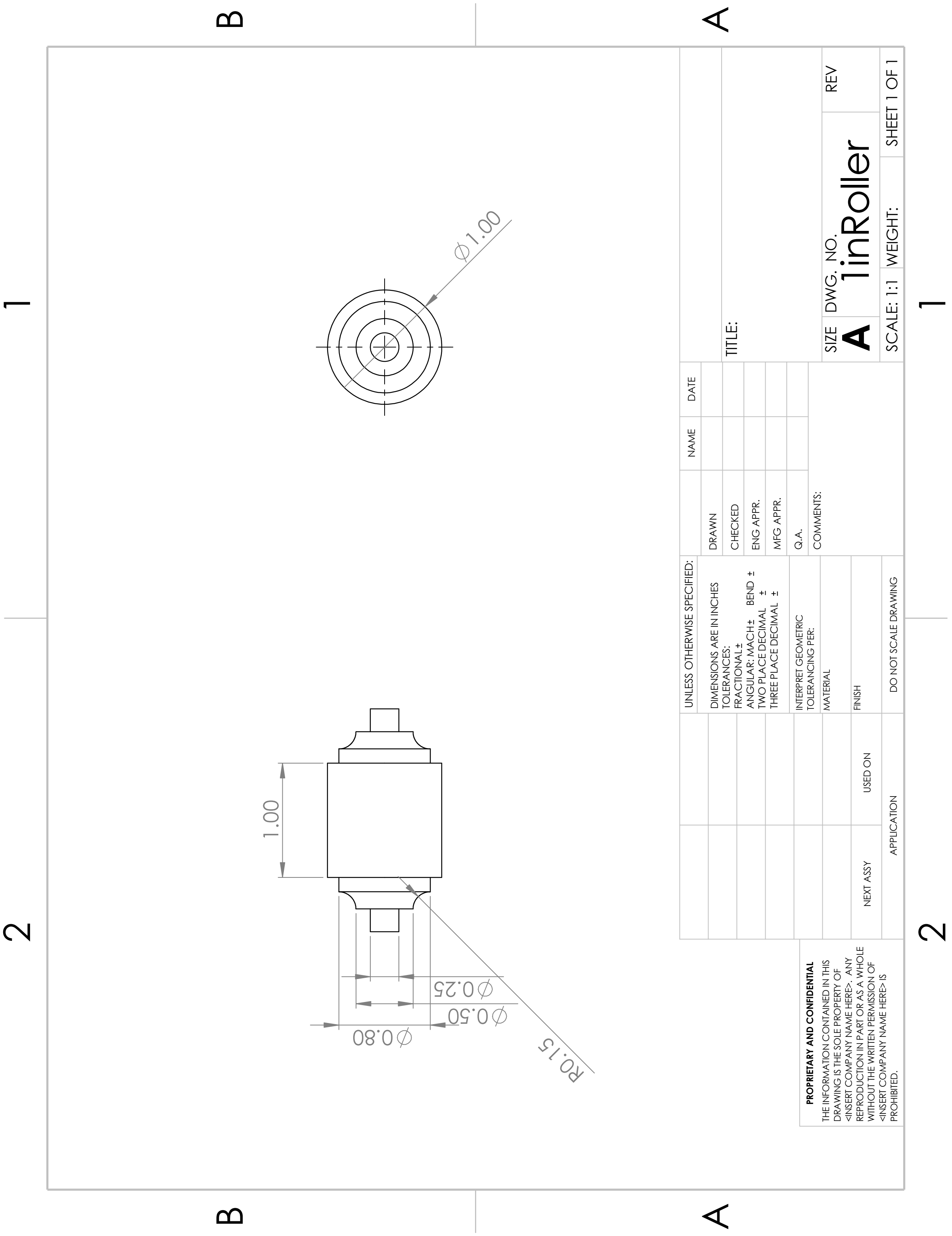

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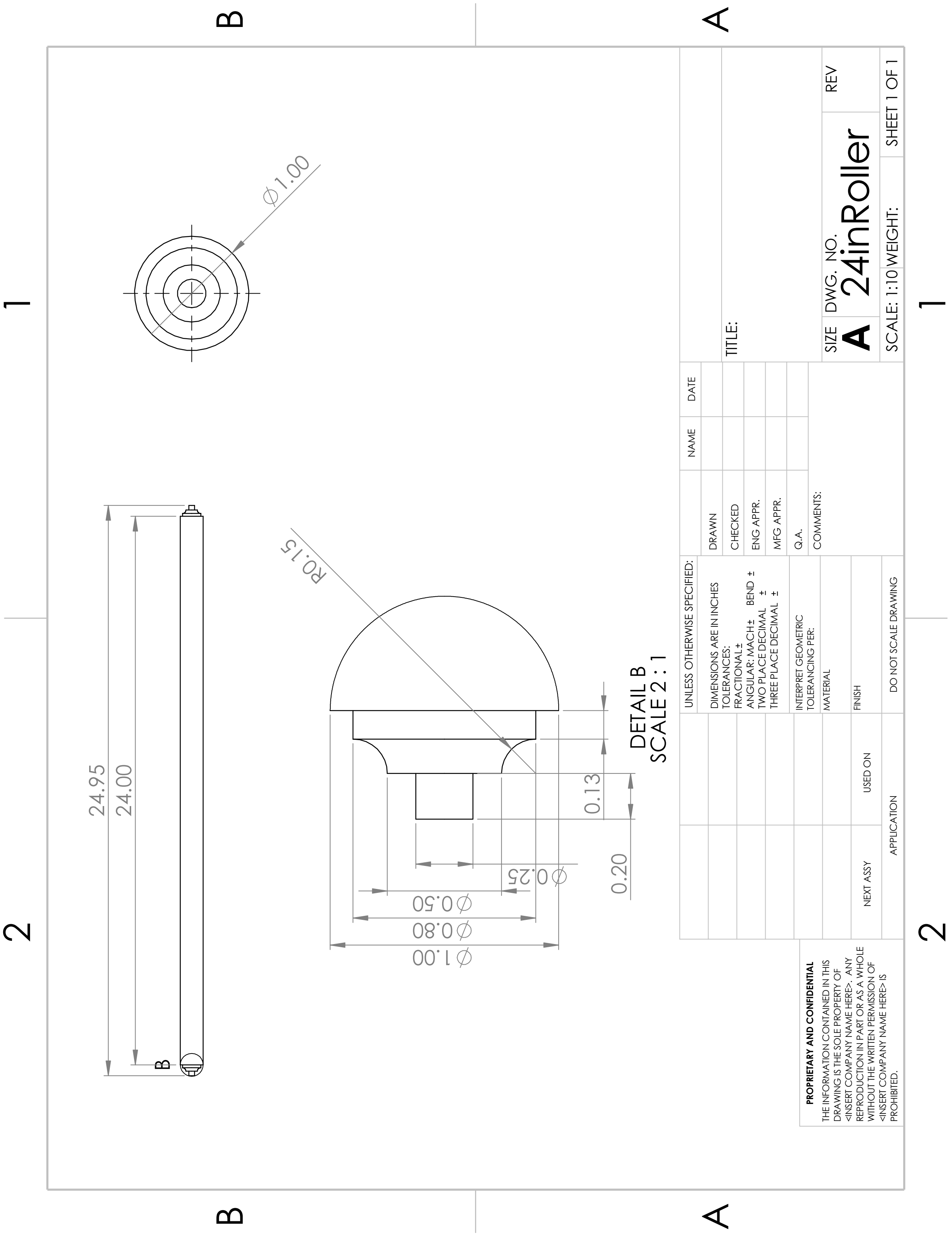
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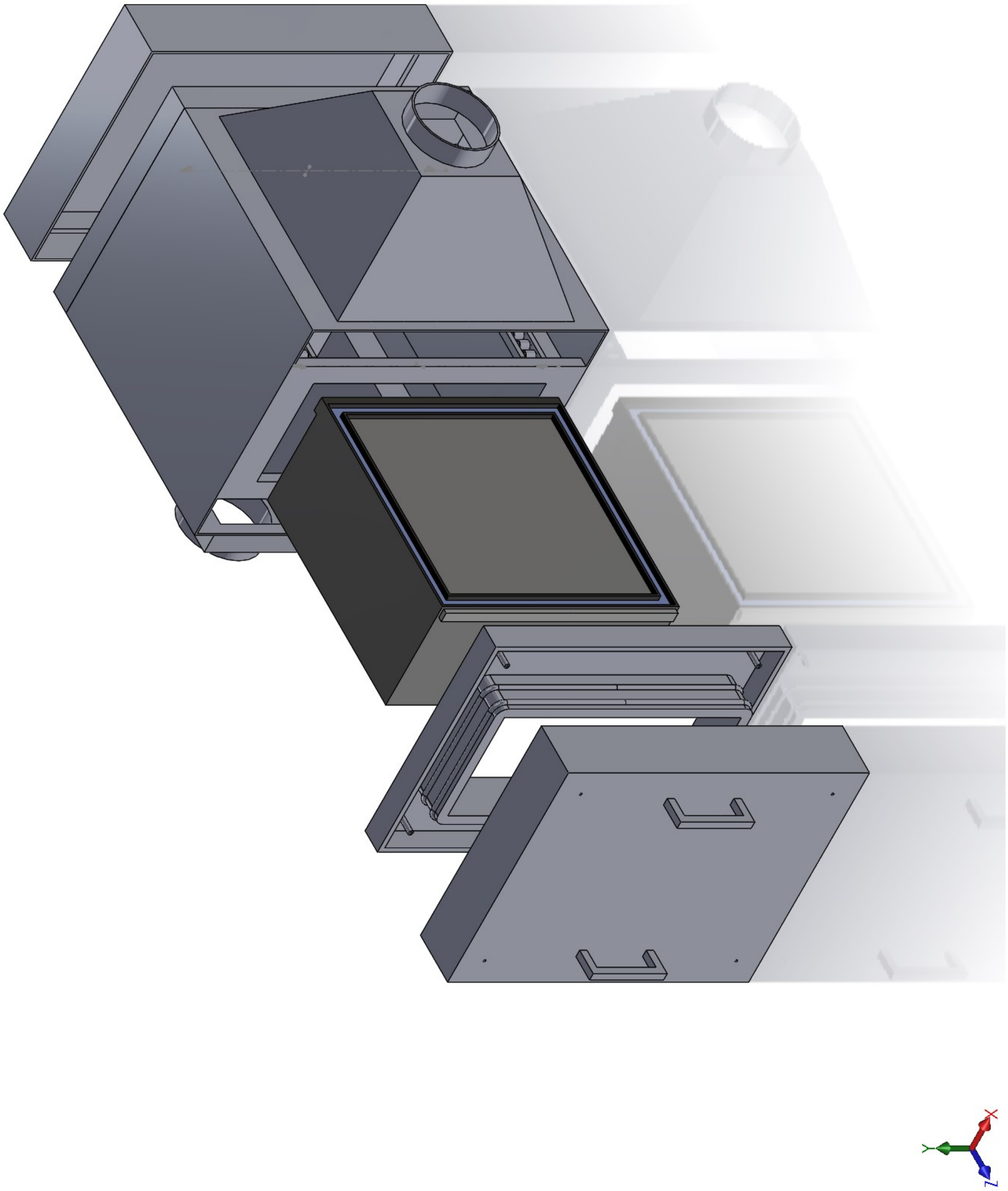
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Appendix D: Material Properties

Below are the physical properties data-sheets of the selected Neoprene compound, silicon gel compound, and stainless steel alloy described in the report.

RUBATEX®
INTERNATIONAL, LLC

PRESS MOLDED BUNS

PHYSICAL PROPERTIES

Type	**R-431-N**
Polymer	**Neoprene (CR)**
Color	**Black**
ASTM D-1056-67 Classification	**SCE-43**
ASTM D-1056-00 Classification **Suffix Requirements**	**2C3** **B2, C1, F1, M**
ASTM D-6576-00 Type II	**Grade A or B Medium**
UL 50 / 508 (JMST2 File #MH9949)	
25% Compression Resistance1) [psi]	**9 - 13**
50% Compression Set2) [%]	**25**
Density3) [lb/ft^3]	**18 - 28**
Water Absorption4) [lb/ft^2]	**0.1 max.**
Tensile5) [psi]	**115 min.**
Elongation6) [%]	**175 min.**
Flammability7) – FMVSS302	**Pass**
– UL 94	**HBF – 1/16” min.**
Standard Sheet Size [in] ±3%	**42” x 45”**
Expected Yield [in] From full bun-thickness -based on 2 level cuts	**1.75”**

1) 25% Compression Resistance	ASTM D-1056
2) 50% Compression Set	ASTM D-1056
3) Density	ASTM D-1056
4) Water Absorption	ASTM D-1667
5) Tensile	ASTM D-412
6) Elongation	ASTM D-412

7) Flammability - This item and any corresponding data refer to typical performance in the specific test indicated and should not be construed to imply this material’s behavior in other fire conditions. UL 94-test valid for specific rating and thickness only. See UL 94 listing for details. (File # E55475).

Other gauges and widths may be available. Please refer to Customer Service

Note: SAEJ 18 is equivalent to ASTM D-1056
Mil 6130 has been replaced by ASTM D-6576-00

Issued 10/01/04

Appendix E: Department of Energy Nuclear Air Cleaning Handbook

The DOE Nuclear Air Cleaning Handbook contained vital information for team 8 on the specifics of $HEPA$ filtration, and especially testing procedures. The team used Chapter 8 in the creation of the test procedures.

8.4 Filter Test Facility Acceptance Testing of HEPA Filters

HEPA filters are critical to the safety of workers and the public in the event of an accident at a nuclear facility. The greatest care is taken to ensure these filters perform both as designed and as assumed in the facility safety analysis. The U.S. Atomic Energy Commission (AEC) identified the need for QA testing of HEPA filters between 1957 and 1958. During this period, the AEC randomly selected filters from stock, and a significant number were found defective. In 1959, the AEC initiated QA testing at the Hanford and Edgewood Arsenal sites. Operations at the Oak Ridge FTF (ORFTF) and Rocky Flats FTF (RFFTF) followed in January 1963 and 1974, respectively. Historically, these FTFs have provided over 40 years of progressive QA testing and delivery of critical quality components. The ORFTF is the last of the three DOE HEPA FTFs remaining. DOE continues to perform 100 percent QA receipt inspection and efficiency-pressure drop testing on certain HEPA ventilation filters produced for use in DOE nuclear facilities. This is done to ensure that filtration efficiency reliably meets DOE specification requirements and that the last barriers of protection against the release of particulate radioactivity to the environment at DOE nuclear facilities are performing as they should. Historically, the rejection rate continues to fluctuate, as shown in **Table 8.1** below, with a high of 18.7 percent in 1996 decreasing to 1.6 percent in 1999, then increasing to 9.8 percent and 8.1 percent in 2000 and 2001, respectively. These significant reported rejection rates indicate that vendor testing alone is not sufficient to reliably produce a HEPA filter of at least 99.97 percent efficiency.[11]

Table 8.1 – Oak Ridge Filter Test Facility Testing Activities (Fiscal Year 1996 to 2003)

Fiscal Year	*Number Received*	*Number Accepted*	*Number Rejected*	*Resistance*	*Penetration*	*Manufact-uring Defects*	*Does Not Meet PO and/or Spec*	*Shipping Damage*	*Percent Rejection Rate*
1996	2,643	2,150	493	371	70	35	17	0	18.7
1997	2,916	2,814	102	59	20	7	16	0	3.5
1998	2,305	2,237	68	1	28	3	34	2	3.0
1999	2,362	2,325	37	0	31	6	0	0	1.6
2000	3,597	3,241	356	0	44	36	270	6	9.9
2001	2,722	2,505	217	1	39	46	123	8	8.0
2002	2,110	2,008	102	0	20	42	32	8	4.8
2003	2,772	2,621	151	0	26	93	27	5	5.4
Total	21,427	19,901	1,526	432	278	268	519	29	7.1

The operating policy of DOE's filter testing program, contained in DOE-STD-3022-98, *DOE HEPA Filter Test Program*,[12] calls for testing all HEPA filters intended for environmental protection at a DOE-operated FTF (ORFTF). Delivery of certain HEPA filters to the FTF for QA review is mandatory for all DOE facilities. This service is also available to the public on a fee basis. The FTF test results are added to the information on the filter case. The test procedures at the FTF call for "penetration and resistance tests," "visual inspection for damage and visible defects," and other "visually verifiable requirements." Except for filters rated at less than 125 cfm, penetration tests are to be conducted at 100 percent and 20 percent of rated airflow capacity, and the maximum penetration of 0.3-μm particles at both airflow rates is 0.03 percent, in accordance with DOE-STD-3025-99.[7] Penetration tests may be conducted using a monodisperse aerosol and a total light-scattering photometer or a polydisperse aerosol with a single particle counting and sizing instrument. A QA program for the DOE FTF is contained in DOE-STD-3026-99, *Filter Test Facility Quality Program Plan*.[13] Specifications for HEPA filters to be used by DOE contractors are contained in DOE-STD-3020-97, *Specifications for HEPA Filters Used by DOE Contractors*.[4]

Visual Inspection

Immediately prior to installing new HEPA filters in a system they should be thoroughly inspected visually by a trained inspector for any damage to the filter frame, filter pack, and gaskets or fluid seal.

Visual inspection is an integral and vital part of every acceptance or surveillance test. A careful visual examination should be made of each internal and external component prior to installation to verify that the items have been received in satisfactory and serviceable condition. After installation, the system should be checked as part of the acceptance test procedure to make sure that all required items have been properly installed. A suggested checklist is provided in Section 5 of ASME N510,[14] which may be used to verify that system design and construction are in accordance with ASME N509.[15] ASME AG-1 also provides guidance for visual inspection in Section 5.0 and Appendix 1 of Section AA.[3] Preparation of the proper visual checklist is the most important part of the test procedure. The checklist should cover all major potential problems without further testing, including the relevant items identified in Section 5.0 of ASME N510,[14] and also should incorporate the field observation checklist items listed in Appendix C of ASME N509[15] where applicable. Certain items listed in the recommended checklist in ASME N510[14] are only observable prior to installing the components. Experienced field test personnel should be, and have been, able to find bank leak paths of a few tenths of a percent by visual examination, as well as many other potential problems not identified by the actual leak test procedures. Appendix B of this Handbook provides guidance and a sample checklist for HEPA filters used at DOE facilities that must meet DOE-STD-3020.[4]

8.5 In-Place Component Tests and Criteria

System tests fall in two broad categories: (1) prestartup acceptance tests to verify that components have been installed properly and without damage and that the system can operate as intended, and (2) surveillance tests made periodically after the system has been placed in operation to demonstrate its ability to continue performing its intended air cleaning function. Surveillance tests are leak tests of the HEPA filter and adsorber installations. To provide guidance for the preparation of test procedures, details of acceptance and surveillance tests are given in ASME N510,[14] and ASME AG-1.[3] In all cases, tests should be preceded by careful visual inspection, as previously discussed in Section 8.4.

8.5.1 Component Acceptance Testing

Acceptance tests also fall into two broad categories: (1) those that relate to the permanent elements of the system, ducts, housing, mounting frames, and location of test ports, and (2) those that verify the installation and condition of the primary air cleaning components (HEPA filters and adsorbers). Acceptance tests of HEPA filter and adsorber installations are identical to the surveillance tests of those elements and are covered in Section 8.6. Tests in the first category include leak tests of ducts, housings, and primary-component mounting frames; airflow capacity and distribution tests; gas residence time tests for systems containing adsorbers; duct-heater tests for systems containing heaters; and air-test aerosol mixing-uniformity tests. The acceptance test program for a particular system may contain any or all of these tests, depending on the nature of the system and its importance (i.e., the potential consequence of a failure of, leakage from, or release from the system).

NRC Regulatory Guides recommend the full battery of acceptance tests for engineered safety feature (ESF) systems, and the requirements for testing safety-related nuclear air treatment system components are covered by NRC Regulatory Guide 1.52.[16] In addition, requirements for testing of non-safety-related nuclear air treatment system components are covered by NRC Regulatory Guide 1.140.[17] Neither the ASME N510[14] standard nor the two regulatory guides are consistent in their requirements, and a coordinated version and further clarification are long overdue. The new 2001 revisions of both regulatory guides incorporate references to AG-1[3] in an attempt at consistency. While not perfect, they are a big improvement over the previous versions. Lesser systems may not warrant such stringent testing. On the other hand, these tests, which are conducted only once when a new or rebuilt system is accepted, provide an assurance of system reliability that cannot be obtained in any other way. The ASME CONAGT (responsible for ASME N510[14]) recommends that these tests be considered for any high-reliability system.

The original standard for nuclear air cleaning component testing was developed by the American National Standards Committee's N45.8.3 ad hoc group which was incorporated into the first version of *Testing of*

Nuclear Air Cleaning Systems, (ANSI N510-1975)[14] was later revised to ANSI/ASME N510-1980,[14] then ASME N510-1989.[14] This standard was updated by the ASME CONAGT Group, and a final version for acceptance testing was issued as ASME AG-1,[3] Section TA, "Field Testing of Air Treatment Systems." (Note: Section TA of AG-1 addresses the acceptance field testing of the system and its components. The standard for routine field surveillances is still under development. The seventh draft revision of the standard is entitled, ASME N511-2003, *Standard for In-Service Testing of Nuclear Air Treatment, Heating, Ventilating, and Air Conditioning Systems*. The basic precepts of ASME N510[14] and ASME AG-1,[3] Section TA, are listed below).

- All components (prefilters, mist eliminators, HEPA filters, adsorbers, etc.) are qualified and tested as individual components. Their original efficiency is established, and "as-installed" tests do not require further "efficiency testing." Only the in-place test is conducted to ensure the integrity of components is maintained and that no bypass exists.
- The housing is of the desired strength and integrity, which can be measured by isolating the unit envelope housing and leak testing under the specified pressure differential conditions.
- The framework integrity (framework holding critical components such as HEPA filters and adsorbers) can be measured by using blank off plates and pressure differential leak tests.
- When critical components are installed, the in-place leak test measures only the quality of the installation of the components.

The standard writers assumed that the components are well designed and that pyramiding of the four above-listed precepts will realistically measure the adequacy of the installed operating air cleaning unit.

For clarity, it must be reiterated that the definition of the "Air Cleaning Unit" is an assembly of components that together comprise a single subdivision of a complete air cleaning system, including all the components necessary to achieve the air cleaning function of that subdivision. A unit includes a single housing, with the internal components (filters, adsorbers, heaters, instruments, etc.) installed in or on that housing.

Acceptance tests are outlined in Table 1 of ASME N510[14] and in ASME AG-1,[3] Section TA. Before assembly, personnel should assure that all components meet the specified criteria. Typical QA acceptance only assures that paperwork is available. This paperwork should be checked both for original supply and for replacement parts. Before installing components, personnel should perform the following tests:

- Visual Inspection,
- Duct Leak Test,
- Housing Leak Test, and
- Mounting Frame Leak Test.

During and immediately after installation of components, personnel should perform the following tests:

- Visual Inspection,
- Airflow Capacity and Distribution Test,
- Air/Aerosol Mixing Uniformity Test,
- In-Place Leak Test HEPA Stage,
- Remove Adsorbent and Perform Laboratory Testing (to establish baseline carbon efficiency),
- In-Place Leak Test Adsorber Stage, and
- Duct Damper Bypass Leak Test (if required).

The tests listed in ASME N510,[14] Table 1, include:

- Visual Inspection – Section 5 (to ensure that components are properly installed and are not damaged);
- Duct and Housing Leak and Structural Capability Test – Section 6 (to ensure the installed housing has leakage and structural integrity);
- Mounting Frame Pressure Leak Test – Section 7 (to ensure that no bypasses exist at welds, etc.);
- Airflow Capacity and Distribution Tests – Section 8 (to ensure that desired flows can be achieved with clean and dirty filters, and also that velocities through components are in the narrow range where the components were qualified individually;
- Air Aerosol Mixing Uniformity Test – Section 9 (to ensure the test aerosol injection and sampling ports are located properly to perform testing of the HEPA filter bank or adsorbent stage);
- HEPA Filter Bank In-Place Test – Section 10 (to establish that the HEPA filters are properly installed and were not damaged before or during installation);
- Adsorber Bank In-Place Test – Section 11 (to establish that the adsorbers were properly installed and that there is no major settling and/or channeling of the adsorbent);
- Duct Damper Bypass Test – Section 12 (to qualitatively assess leakage through bypass dampers in the system);
- System Bypass Test – Section 13 (to ensure that all filter banks and potential bypass leakage paths are assessed in the leakage test). All negatively pressurized portions to the flow discharge can be important and are frequently overlooked, e.g., fan shaft seals, damper control linkage, sample ports. The importance of the amount of bypass leakage is increased as the credit for removal of the contaminant increases in the system;[18]
- Air Heater Performance Test – Section 14 (to ensure that the heaters used for humidity control are capable of achieving the desired RH); and
- Laboratory Testing of Adsorbent – Section 15 (to quantify the efficiency of the carbon media for its ability to adsorb radioiodines).

Two critical items have to be understood in the use of ASME N510.[14] First, the standard is considered a test method for air cleaning systems designed according to ASME N509.[15] However, ASME N510[14] was initially issued in 1975, and ASME N509[15] in 1976, years when a large number of U.S. power reactors were already designed, and even many later, facilities were designed with only with limited adherence to common sense engineering practices or the requirements of ASME N509.[15] The second critical item is the potential for misinterpreting the Scope section of ASME N510,[14] which states that it is a “basis for the development of the test programs and detailed acceptance and surveillance test procedures,” and "that it be rigorously applied only to systems designed and built to ASME N509.”[15]

In spite of this rather clear scope definition, many facilities established their test methodology by either generally claiming that, “testing shall be in accordance with ASME N510,”[14] even when their systems were not designed for it (or according to NRC Regulatory Guide 1.52[16] or 1.140,[17] which refer to ASME N509[15] and N510[14] requirements). Some never developed a specific test program for each unit and system to modify the basic N510[14] procedures to ensure achievement and maintenance of the desired result (complete system integrity). The treatment of issues related to air cleaning unit and system testing here is based on ASME N510.[14]

If all of the referenced tests are performed sequentially every time and the airflows are well balanced from a specified intake point to a specified discharge point, then the test series may be considered a system test. However, if only parts of it are performed, it is not a system test—only an installed component section test (i.e., a HEPA filter bank or adsorber stage bank test).

8.5.2 Duct and Housing Leak Test

The level of duct and housing leaktightness (and therefore the acceptance criterion for the test) is based on the type of construction and the potential hazard (consequence) of a leak. Recommended maximum permissible leak rates for various duct and housing constructions are given in AG-1, Section TA.[3] The designer may specify tighter requirements based on the confinement requirements of the system.

Duct leak tests may be conducted by testing the entire ductwork system at one time or by testing one section at a time and blanking off the ends of the section under test. The second method is more practical for larger systems. When segmented, the permissible leak rate for the individual sections is based on the proportionate volume of that section. The apparatus and procedure for leak testing levels 1 and 2 ducts are described in the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) *HVAC – Duct Design*.[19] Using the described procedures outlined in ASME N510,[14] duct leak tests can also be developed with some modifications. The ASME N510 standard offers two test methods for housing leak test: the Pressure Decay Method (the most convenient for larger duct and housing systems) and the Constant Pressure Method (the most effective for smaller volumes).

Test methods for level 3, 4, and 5 ducts and for housings are described in Section 6 of ASME N510.[14] If the specified leak tightness cannot be met, leaks are located, repaired, and retested by one of the methods described in Section 6 of ASME N510.[14]

When performing the unit housing leak test, it is important to follow the normal procedures (door closing, etc.) and thereby avoid creating a once-in-a-lifetime condition that does not resemble normal operating procedures and conditions. The test is supposed to demonstrate that the unit housing will maintain the specified leaktightness during its operating life. Based on experience, this is an unrealistic expectation. There is always some deterioration of door gaskets, or occurrence of sprung doors, damaged threads on closures, and leaks due to maintenance work on the unit. To ensure the leak integrity of the housing is maintained, personnel should perform periodic retesting (every 10 years). However, the risk of spreading contamination does not warrant this test on ventilation systems that are in continual use in contaminated or potentially contaminated applications. Surrogate methods such as acoustical monitoring or tracer gas monitoring may be appropriate when entry into the housing is precluded.

8.5.3 Mounting Frame Pressure Leak Test

This test is performed to ensure the installed HEPA filter/adsorber mounting frame is installed with no leak paths through the structure. This is considered an optional test because the same evaluation is done after the filters are installed, and an in-place leak test is performed on the bank. However, this test may be useful for determining gross leakage prior to filter installation. Any repairs required must be done before installation of any HEPA filter/adsorber. This test is also the first check for any other leak paths through conduits, drains, etc., which communicate between the upstream and downstream side of a single bank of HEPA filters or adsorber banks. Realistic test performance requires the unit housing leak test to be performed and the specified leak criterion to be met. The acceptance value set in the specifications should always be realistic.

These tests are conducted to verify there are no leaks through the HEPA filter and adsorber mounting frames or through the seal between the mounting frames and the housing. The tests also verify there is no bypassing of the mounting frames through electrical conduits, drains, compressed air connections, and common anterooms of the housing, or other inadvertent leak paths. Familiar sources of leaks are weld cracks and incomplete welds. A properly designed mounting frame should have no penetrations (via conduits, piping, or ducts), and lighting, drain, and other ancillary systems should be designed so that no bypassing of the HEPA filters and adsorbers can occur. Nevertheless, unauthorized modifications are often made in the field. The purpose of this test is to disclose such occurrences, as well as any leaks caused by poor workmanship or shipping damage. The test is recommended for any installation, whether duct and housing leak tests are performed or not, but it is particularly necessary when subsequent in-place tests of the HEPA filter and adsorber stages will be performed using a shrouded method.

This test is conducted by first blanking off all openings for filters and adsorbers and closing or blanking off all openings in the housing, then conducting a soap-bubble or spray test aerosol leak test around all welds and other potential leak paths (as described in Section 7 of ASME N510).[14] After all leaks have been repaired, individual chambers of the housing should be checked by a pressure leak rate test to verify there are no bypasses that were not disclosed by the leak detection check. It is unnecessary to perform these tests from the upstream side of the mounting frame, and it is quite acceptable to test two mounting frames simultaneously by blanking off the openings of both and pressurizing the space between. Because the mounting frame pressure leak test is a chamber-by-chamber test of the housing, it can replace the need for a housing leak test.

8.5.4 Airflow Capacity And Distribution Test

This test is used: (1) to verify that the specified volume flow rate of the air can be achieved with the installed fan under actual field conditions at maximum and minimum filter pressure drop, and (2) to verify that the airflow distribution across each HEPA filter or adsorber stage is within the specified uniformity at the designed volumetric flow rates. ASME N509[15] and N510[14] require an airflow capacity of ±10 percent maximum deviation from design flow. This value is not well correlated to the assumption of NRC Regulatory Guide 1.52[16] and the radioiodine test methods specified in ASTM D3803.[20] The variation of ±10 percent in velocity through the adsorbent bed results in a very high variation of the methyl iodide-131 removal efficiency. Recent parametric testing for radioiodine removal efficiency showed that even the ±4 percent flow variation permitted in ASTM D3803[20] is too high to obtain good reproducibility. To ensure proper correlation of the results used to justify the potential performance of the adsorber stage, the volumetric flow through the adsorber stage should result in not less than a 0.25-sec residence time (for a 2-in.-thick bed). Therefore, a design flow of +0, -20 percent is much more realistic than the design of ±10 percent permitted by ASME N509[15] and N510.[14] Similarly, ASTM D3803[20] should require a velocity corresponding to 0.25-sec residence time and +4, -0 percent to achieve adequate reproducibility and to err on the conservative side. The procedure for airflow capacity testing recommends making pitot tube traverses of the ducts. However, the following values must also be considered.

Duct Size	*Number of Readings*	*Precision of Measurements*
<150 mm	1	±20 percent
400 < 150 mm	4	±12 percent
950 < 400 mm	8	±10 percent
>950 mm	12	±5 percent

mm = millimeter

ASME N510[14] is unclear about how the precision of the measurement should be used to achieve the ±10 percent specified flow capacity. Due to the convoluted design of the air cleaning system inlet and outlet ducts, it is often impossible to find an adequate duct location that is, as required by the American Conference of Governmental Industrial Hygienists (ACGIH) *Industrial Ventilation – A Manual of Recommended Practices*,[21] 10 duct diameters downstream and 5 duct diameters upstream of points where turbulence is induced in the airflow (e.g., elbows and junctions), which further subtracts from the precision of the velocity measurements. The location where the acceptance airflow capacity test was performed should be tagged (indicating the date, method used, etc.) to ensure that future tests are made at the identical location. For example, LLNL places test fittings at the locations used. The test fittings are about an inch in diameter to permit turning equipment 90 degrees after insertion and are capped. This makes them both durable and easier to find. ASME N510,[14] Table 1, requires this measurement to be an acceptance and surveillance test. However, experience shows that changes in airflow capacity occur in intervals as short as 18 months due to damper adjustments, pressure conditions at inlet points, duct disassembly and reassembly either upstream or downstream of the unit, etc. Therefore, this measurement should be a routine surveillance test item each time a unit or system surveillance test is made.

The actual text of ASME N510,[14] Section 8, indicates via a note that only the air distribution test is an acceptance test (presuming the airflow capacity is both an acceptance and a surveillance test, as it should be). The unit should be operated for 15 minutes prior to the test to achieve steady-state conditions. The airflow distribution test leaving the HEPA filter banks is required by ASME N510.[14] In many existing units, there is inadequate space to perform the test downstream of the banks. Any test performed on the entry side of these banks must be more conservative for the HEPA filter banks because of the flow-straightening characteristics of HEPA filters. Therefore, if such a test meets the criteria, it should be acceptable. [Note: The currently permissible separate airflow distribution uniformity of ±20 percent on top of a ±10 percent airflow capacity and a potential test error of ±10 percent results in permissible residence times in the adsorber section might be less than that presumed for the iodine-131 DF used to establish the authorization basis of the facility.]

8.5.5 Air-Aerosol Mixing Uniformity Test

The purpose of this test is to verify that the aerosol or challenge gas is introduced in order to provide uniform mixing in the airstream approaching the HEPA filter bank or adsorber stage to be tested. No safety credit should be claimed for HEPA filters or adsorbers that are not tested regularly to verify they continue to meet performance requirements. Although individual filter units and adsorber cells are tested by the manufacturer, in-place testing after installation is essential because of the damage and deterioration that can take place during shipping, handling, installation, and service. Therefore, an important phase of acceptance testing is verification that HEPA filter and adsorber installations can be tested satisfactorily. The design of many older systems permitted an acceptance test of the HEPA filters, but made testing after the system began operation nearly impossible. Some systems were designed to be so cramped that quantitative testing of the kind specified in ASME N510[14] was impossible due to poor airflow distribution or ducts that had unreachable portions of cross-sectional area. Such designs are not acceptable in high-reliability applications.

The test method described here includes tests to establish the adequacy of the test aerosol injection and upstream sampling port locations, but does not generate data reflecting the adequacy of the downstream sampling port location. Undoubtedly, the test should be a prerequisite for performance of any in-place test of a HEPA filter bank and adsorber bank stage. The verified locations of injection and upstream sample ports should be documented, and the locations should be tagged to indicate the date, method used, etc., as well as the tests to be conducted. All other ports found to be unsatisfactory should be tagged to prevent later accidental use of incorrect injection or sampling ports.

The aerosol/vapor injection point for the first HEPA bank and the adsorber stage should always be ahead of any unit or system bypass line, and the downstream sampling point for the second stage HEPA filter bank and for challenge aerosol/vapor should always be downstream of the return of the bypass line into the main duct.

Good testability requires provision of permanent test aerosol injection and sample ports or other planned and pre-established means for injecting the test aerosol and for taking reliable, well-mixed samples. Details of the air-aerosol mixing test are described in Section 9 of ANSI N510.[14] It is essential that the air and test agents mixture challenge to the filters (adsorbers) is thoroughly mixed so that the concentrations entering all points of the filters, including the upstream and downstream sample points, are essentially uniform. Adequate mixing upstream usually can be obtained by introducing the test aerosol at least ten duct diameters upstream of the filters or adsorbers, or by introducing it upstream of the baffles or turning vanes in the duct. When neither of these methods is practical, a Stairmand disk located four to six duct diameters upstream will provide satisfactory mixing. A Stairmand disk is a plate with the same geometric shape as the duct section that blocks the central half of the duct area. Air flowing past the disk creates vortices on the leeward side that compel turbulent and thorough mixing. The disk is placed into the duct for testing. At other times it is either removed, swung out of the way, or turned on a pivot so the long axis is parallel to the direction of flow. When duct arrangement makes it necessary to introduce the test aerosol directly into the filter housing, a design such as that discussed under multistage housings (Section 8.7) may be required. Extraction of the downstream sample at a point several duct diameters downstream of the fan will usually provide a well-mixed sample. Fan-shaft leakage should be considered in sampling downstream of the fan. Since leakage at the shaft will be in-leakage, sufficient air to dilute the downstream sample can be drawn in if the shaft annulus is large (yielding a low downstream concentration reading), or dust may be drawn into the fan to provide a high downstream reading (which may be particularly prevalent during construction). Application of a shaft seal, or at least a temporary seal, is recommended during testing. If this is not practical, a photometer leak reading should be taken with and without the aerosol generator "on" to establish shaft seal leakage.

The second aspect of testability—access—requires space for personnel and equipment; space to manipulate equipment without damaging filters or creating hazards for personnel; passages for getting personnel and equipment where they are needed; means of providing power (electrical, compressed air) to the equipment; access to both faces of the filters and adsorbers; adequate lighting; viewports; and other features that facilitate safe testing. Space also will be needed later during filter replacement for: (1) temporary storage of removed filters/adsorbers and their replacements, (2) crew movements required to effect the change (such as bagging in/out), (3) placement of tools, and (4) personnel, including both the filter technicians and any associated safety staff or radiation monitoring technicians. Consideration should be given to making the area easy to decontaminate if necessary by making the floor and area as free of cracks, crevices, and hard to clean/reach places as practical.

8.5.6 Duct Damper Bypass Test

Section 12 of ASME N510[14] requires testing of potential bypass leakage paths, through closed dampers or valves, to ensure that radioactive gases or particulates do not escape treatment through the HEPA and/or adsorber banks. This test allows testing of the potential leak path during the test aerosol or Halide test on the HEPA/adsorber banks, assuming the injection sample ports are located such that the potential bypass is included in the test envelope. Otherwise, the bypass (damper) may be tested using conventional pressure-testing techniques.

8.5.7 System Bypass Test

Section 13 of ASME N510[14] requires challenging of all potential bypass leakage paths and all portions of the nuclear air treatment system (including the housing stages) during the test sequence, which could potentially defeat the purpose of high efficiency nuclear air treatment components. All potential bypass leakage paths around the HEPA/adsorber banks must be included as a single overall leak test of the sum of the individual tests on the separate banks. In dealing with a series of HEPA or adsorber banks, each bank must be tested individually to ensure that contaminated air does not bypass the filter banks or escape treatment. Small system bypass leakage may be very significant for systems that have multiple HEPA banks with greater than 99.8 percent assigned efficiency per bank[18] (per the authorization basis).

8.5.8 Duct Heater Performance Test

Section 14 of ASME N510[14] requires the humidity control system for the carbon adsorber bank (which prevents water buildup on the carbon) to be tested to ensure satisfactory performance. For example, the voltage always has to be checked to make ammeter readings meaningful. The temperature should be checked sufficiently upstream and downstream of the heater to ensure an adequate rise in air temperature. The readings obtained also should be evaluated by a cognizant individual to ensure the desired RH can be achieved with the potential minimum and maximum environmental temperatures in the inlet stream.

8.6 Surveillance Testing

There are three types of surveillance tests: (1) in-place leak tests of HEPA filter banks using an accepted test aerosol, (2) in-place leak tests of adsorber stages using a slightly adsorbable gas such as the fluorocarbon Refrigerant-11, and (3) laboratory tests of samples of adsorbent withdrawn from the system to establish its remaining adsorption capacity. These tests are also employed as part of the acceptance procedure for new installations, with the exception that laboratory tests are made on samples of adsorbent taken from batch material as furnished.

Surveillance tests of HEPA filter and adsorber systems should be made at regular intervals after installation to detect deterioration and leaks that may develop under service conditions. Regular in-place testing of standby systems is necessary because deterioration can take place even when the systems are not being operated. Aside from component damage, frequently discovered causes of failure to meet in-place test requirements include loose clamping bolts; inadequate clamping devices such as C-clamps; foreign material trapped between gaskets and mounting frames, rough or warped mounting frame surfaces; cracked welds; unwelded joints in mounting frames; incorrectly installed components (e.g., HEPA filters installed with horizontal pleats); inadequate seals between mounting frames and housings; poorly designed mounting frames; and bypasses through or around conduits, ducts, or pipes that penetrate or bypass the mounting frames.

In-place tests should be made by introducing a test aerosol upstream of the bank to be tested. [Note: The upstream aerosol introduction should never be swapped to the downstream side. This actually occurred at one DOE facility where upstream introduction was a physical impossibility.] The concentrations of test aerosol upstream and downstream (upstream concentration is considered 100 percent) should then be determined, and penetration should be calculated from the ratio of concentrations. The reliability of this test is determined by: (1) the ability to properly introduce the test aerosol and obtain representative samples, and (2) the availability of physical access to the banks being tested. The first can be verified by an air-aerosol mixing test. This test should be made once, at the time of acceptance testing, and its satisfactory completion is required before both acceptance and future surveillance in-place testing of HEPA filters and adsorbers.

8.6.1 In-Place System Leak Test, HEPA Filter Banks

Section 8 and 9 of ASME N510[14] are prerequisites for the HEPA filter in-place system leak test. In cases where there are multiple series or parallel HEPA banks and associated bypass leakage paths, the guidance outlined in Section 13 of ASME N510,[14] "System Bypass Test," should be followed. The proper procedure to be used with dual HEPA filter banks is to introduce a test aerosol at the predetermined qualified location (the test port) upstream of the first bank, and then determine a downstream reading of the first filter bank between the first and second filter bank. If this determination is satisfactory, then while injecting at a point (or through a manifold) upstream of the second HEPA filter bank (between the banks), readings should be taken downstream of the second HEPA filter bank, preferably downstream of the fan.

There are three major types of in-place system testing methods. The first test method uses a light-scattering photometer with a polydispersed aerosol. The second method uses a shroud and/or scanning test technique, and the third uses a laser spectrometer in lieu of the forward light-scattering photometer. Due to differences in the designs of HEPA filter plenums throughout the DOE complex, as well as corresponding differences in testing techniques, the Defense Nuclear Facilities Safety Board recognized a need to standardize methods for in-place system testing at DOE sites. To address this need, a conference was held at the DOE Savannah River Site (SRS) to exchange information about the sharing of in place system testing technology among DOE contractors.[22] The conference concluded that all DOE sites basically used the same type of penetrometer, with the exception of LANL, which uses the laser spectrometer. In-place system tests of HEPA filter installations are made with a polydispersed test aerosol consisting of droplets with a light-scattering number mean diameter (NMD) of 0.7 µm and a size range of approximately 0.1 to 3.0 µm.[14] This range should be compared to the test aerosol used for efficiency testing by manufacturers and DOE's Filter Test Facility (ORFTF) which is a monodispersed aerosol with a light-scattering NMD of 0.3 ± 0.03 µm. The in-place system test is made by challenging the upstream side of the filter or filter bank with test aerosol smoke, then measuring and comparing (using a light-scattering photometer) the test aerosol concentration in samples of downstream (filtered) and upstream (unfiltered) air (**Figure 8.5**). If the system exceeds the specified maximum permissible penetration value, the downstream faces of the filters and mounting frame can be scanned with the photometer probe to locate localized high concentrations of test aerosol, indicating leaks. Figure 8.5 illustrates the basic equipment and a schematic of a standard test arrangement. [Note: Figure 8.5 is not intended to depict an actual system.] The instrument shown is a forward-light-scattering photometer with a threshold sensitivity of at least 10^{-3} µg/L for 0.2- to 1.0-µm particles, and a sampling rate of at least 1.0 cfm is recommended.[4] The instrument should be capable of measuring concentrations

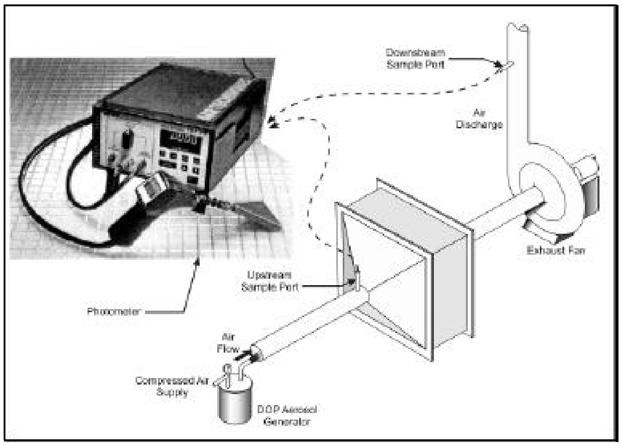

Figure 8.5 – Equipment Arrangement, In-place Testing of HEPA Filters

10^5 times the lower detection limit. An upstream concentration of 20 to 100 µg/L is desirable. Compact self-contained instrument packages are commercially available (**Figure 8.6**). Polydispersed aerosol may be generated thermally or by compressed air. Compressed-air generators are widely used for testing small systems. They are commercially available or can be "homemade" in sizes from 1 to 24 nozzles, as shown in **Figure 8.7**. Care must be taken in selecting the aerosol test agent, as some replacements for DOP have made a flame-throwing device out of the generator (see Chapter 10.6.2.1). A rule of thumb for determining generator capacity is not to exceed one Laskin nozzle per 500 cfm of installed filter capacity. Compressed-air generators are suitable for systems up to about 3,000 cfm; above this size they become cumbersome. Although gas-thermal generators are generally used for testing systems of 6,500 cfm installed capacity and larger, they have too much output for small systems (Figure 8.7). The engineer must not confuse this type of generator with the mono-dispersed test equipment used by filter manufacturers or the DOE ORFTF for determining the particulate efficiency of HEPA filters. The gas-thermal generator produces a polydispersed aerosol of about the same NMD and size range as the compressed-air generator. It is also small and can generally produce enough aerosol at a concentration of 40 to 50 µg of test aerosol/L to test banks up to 30,000 cfm installed capacity. Nitrogen must be used with some thermal systems to avoid a potential fire hazard.

Figure 8.6 – Commercially Available Packaged Forward-light Scattering Photometer for HEPA Filter In-place Testing

A detailed description of the procedure for conducting an in-place test of HEPA filters is given in Section 10 of ASME N510[14] and in ASME AG-1, Appendix TA.[3] A prerequisite of the test is a demonstrated ability to achieve good mixing of the test aerosol and air at the upstream and downstream sample points (Section 9, ASME N510).[14] For systems in which good mixing cannot be achieved, multipoint sampling and averaging may be used, in accordance with Section 11 of ANSI N510.[20]

An acceptance criteria of 0.05 percent maximum leakage for the in-place system test is recommended for systems that are designed in accordance with this handbook.

For the shroud/scan in-place test method (**Figure 8.8**), ASME N510 (1980),[14] the photometer, generator, and test aerosol are the same as those used in the standard test method described above.

A manifold is installed in the upstream and downstream shroud. The upstream shroud must be placed over a filter, and the generator turned on. It is important to verify that the aerosol mist is filling the shroud using an upstream sample/challenge manifold located in the shroud. When the 100 percent upstream concentration is obtained, the meter is set to 0 and the downstream reading is taken. If the downstream shroud method is used, the sample tube must be connected to the downstream shroud manifold, and the downstream shroud must be placed against the frame of the filter to be tested for a minimum of 15 ± 5 seconds as determined by the photometer operator. If the downstream scan method of testing is used, each filter and gasket must be probed. The photometer is then read, and the highest leak rate reading is recorded "as found." The final leak rate readings are recorded.

To calculate leak rates, the leak rate readings from the data are added together and the sum is recorded. This total is then divided by the number of filters in the filter stage, and the result is recorded, as expressed below.

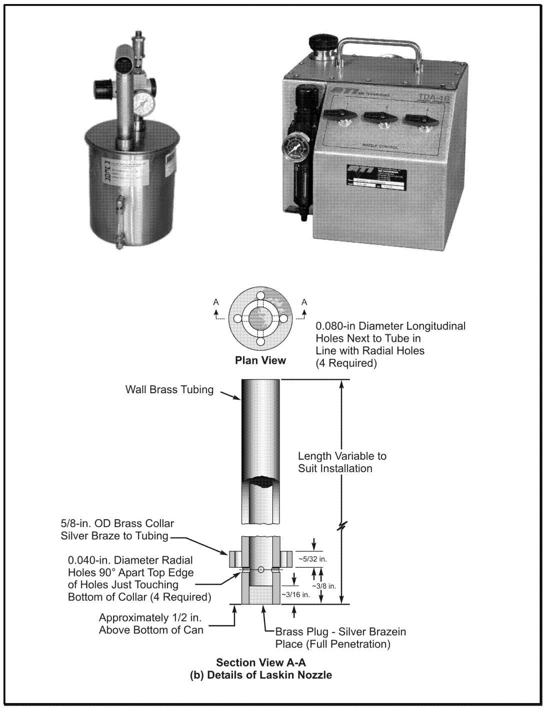

Figure 8.7 – Compressed Air-Operated Aerosol Generator

$$\frac{Sum(\text{As Found or Final})}{\text{Total Number of Filters}} = Overall(\text{As Found or Final})\ \text{Leak Rate}$$

Overall efficiency is determined by subtracting the overall leak rates ("as found" and "final") are subtracted from 100 percent and recording the result, as expressed below.

100 percent – Overall ("As Found" or "Final") Leak Rates = Overall (As Found or Final) Efficiency

A third test method, the single-particle particle-size spectrometer, was implemented at LANL using the guidelines of NE F 3-41T.[24] This modified procedure uses a laser particle size spectrometer with the capability of counting single particles downstream of two filter stages where DF of the first stage and overall system effectiveness are established. DF measurements as high as 10 were obtained,[25] indicating a high level of sensitivity that can be used on single-stage filters. The advantage of the single-particle particle-size spectrometer method is that it provides information on system performance relative to the most penetrating particle size of the filer system being tested. The downside is that the instrument is prone to malfunction, being a laboratory-type instrument, and is heavy, cumbersome, and expensive.

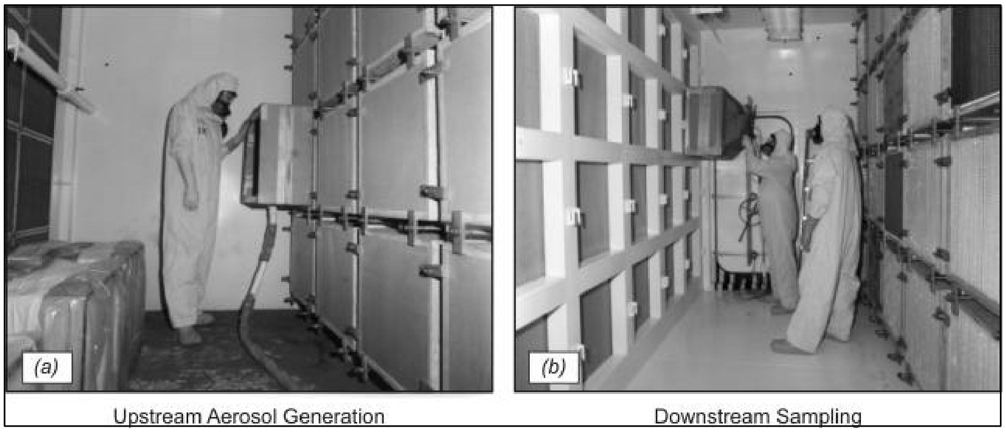

Figure 8.8 – Shroud Test

8.6.2 In-place Testing for Adsorbers

The in-place leak test of the adsorber bank (stage) measures bypass (mechanical) leakage around or through the installed adsorber bank. This test may be performed: (1) as an acceptance test to verify system design function following initial field installation; (2) after an abnormal incident, replacement, repair, or modification that may affect design function; or (3) as a periodical in-service (surveillance) test to monitor system condition and operational readiness.

Bypass leakage around the adsorber bank (stage) may result from mounting frame weld degradation, damaged or poorly compressed gaskets, common drains between housing compartments, common electrical conduits between housing compartments, and inadequately dampered bypass ducts. Bypass leakage through the adsorbent media may be due to poor adsorbent filling technique and subsequent settling from system vibration and air or gas pulsation.

Since the in-place leak test only provides a measure of bypass leakage, this test is often performed in conjunction with the laboratory test of the adsorbent media. Assuring that the adsorber bank meets bypass leakage acceptance criteria and the adsorbent media itself performs adequately provides the necessary information required to determine whether the adsorber bank is performing as designed.

There are two methods commonly used for in-place leak testing of the adsorber bank stage. One uses a fluorocarbon refrigerant gas or an alternative tracer gas. The other uses a radioactive tracer gas (iodine or methyl iodide). The first method, developed by Savannah River Laboratory,[25] is the most frequently used, particularly in commercial applications. The second method involves the use of radioactive isotopes and personnel licensed to handle them. This test should not be confused with a laboratory test of adsorbent media. Radioiodine tracer methods were developed primarily for DOE installations.[26, 27] Both in-place tests are leak tests designed to measure bypass leakage, and they must be supplemented with laboratory tests of samples taken from the adsorbers at the time of the in-place test to determine system leak tightness and the radioiodine removal efficiency of the adsorbent media. For commercial nuclear power plants, typical bypass leakage acceptance criteria for the adsorber bank (stage) range from 1.0 percent to 0.05 percent, depending on specific plant license bases. The current NRC Regulatory Guide 1.52 [16] requires that in-place leak testing for adsorbers be performed: (1) initially; (2) at least once each 24 months; (3) following the removal of an adsorber sample for laboratory testing if the integrity of the adsorber section is affected; (4) after each partial or complete replacement of a carbon adsorber in an adsorber section; (5) following detection or evidence of penetration or intrusion of water or other material into any portion of an ESF atmosphere cleanup system that may have an adverse effect on the functional capability of the adsorber; and (6) following painting, fire, or chemical release in any ventilation zone communicating with the system that may have an adverse effect on the functional capability of the system. The Regulatory Guide further specifies that the in-place leak test should be performed in accordance with Section 11 of ASME N510-1989[14] and the in-place leak test should confirm a combined penetration and bypass leakage quantity around or through the adsorber of 0.05 percent or less of the test gas at system rated flow of ± 10 percent.

8.6.2.1 Nonradioactive Tracer Gas Test

The first test, commonly referred to as the Freon™ test, is made by challenging the upstream side of the adsorber with a slightly adsorbable and readily desorbed fluorocarbon gas [usually Refrigerant-11, trichloro mono fluoromethane], then determining the concentrations immediately upstream of the adsorber bank and at a point downstream of the adsorber bank where satisfactory mixing with air occurs. Bypass leakage is calculated from the ratio of downstream-to-upstream reading, as follows.

Percentage Bypass = Reading Downstream/Leakage Reading Upstream

Since it is the *ratio* of concentrations that matter, the units may be expressed in terms of peak height or some other measure directly related to tracer concentration, although the measure may not necessarily reflect the actual volumetric or mass tracer concentration.

Refrigerant-112 was originally used, but is no longer produced. Refrigerant-112 was more strongly adsorbed by the adsorbent bed than Refrigerant-11 and allowed testing of banks under conditions of high RH or elevated adsorbent moisture content. With the introduction of ASME AG-1,[3] alternative, substitute tracer gases are allowed (permitting tracer gases with stronger adsorption potentials than Refrigerant-11), providing the selection is made in accordance with the AG-1,[3] Appendix TA-C, selection criteria. Noncommercial installations have successfully used alternative tracer gases.[28] When the carbon beds nondestructive test was developed, testing equipment consisted of a pump to draw upstream and downstream air samples from the adsorber system, two identical gas chromatographs with electron-capture detectors for measuring refrigerant gas concentrations, a timer, and several rotameters for determining sample dilution factors. The chromatographs had a linear range of about 1 to 100 parts per billion (ppb) (by volume) for detection of the refrigerant gas. Since the upstream concentration exceeded the linear range of the instrument, the sample was diluted with a known volume of air to bring it within the detection range of the chromotograph. Calibrated rotameters were used to determine the dilution factors. Currently, two types of equipment are used to perform this test. Traditional, noncontinuous chromatographs have been developed specifically for in-place leak testing, eliminating the need for rotameter dilution and providing microprocessor-based leak rate calculation. Modern chromatograph-based equipment used for the adsorbent in-place leak tests is shown in **Figure 8.9**. Continuously monitoring detectors are also used as shown in **Figure 8.10**. **Figure 8.11** shows a schematic of the test setup. Prefilters and HEPA filters in housings have no effect on the nonradioactive

Figure 8.9 – Modern Chromatograph-Based Equipment

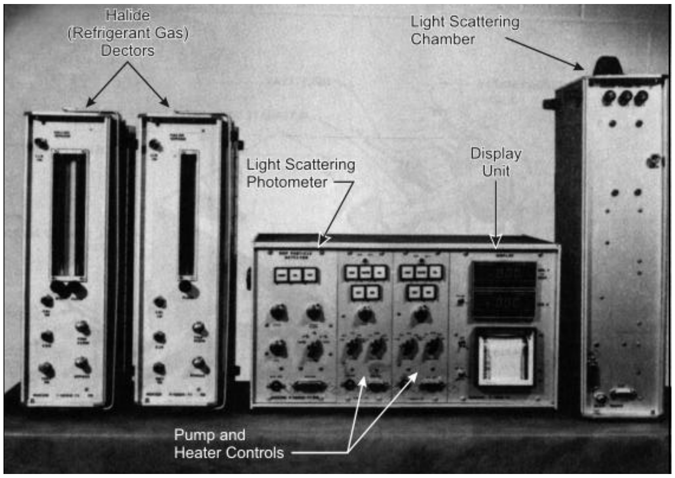

Figure 8.10 – Continuous Monitoring Charcoal Testing Equipment

tracer gas test. The test should be performed by experienced, trained personnel, and should be conducted in accordance with prescribed procedures (ASME N510,[14] Section 11). Use of the mixer shown in Figure 8.11 is not necessary if samples can be taken from an area that assures good mixing, e.g., downstream of the fan or downstream of duct bends or transitions that introduce turbulence into the airstream. Where good mixing cannot be achieved, temporary or permanently installed sampling manifolds constructed in accordance with ASME N509,[15] Appendix D, may sometimes be used.

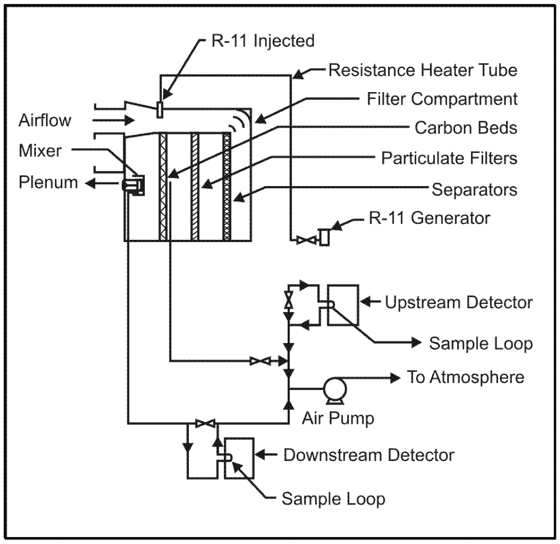

Figure 8.11 – Schematic of Charcoal Testing Setup

8.6.2.2 Radioactive Iodine Tests

These tests are currently used for routine adsorber-bank testing at Oak Ridge National Laboratory (ORNL) and the Hanford (Richland, Washington) facilities of DOE. Two tests are used, one with radioactively traced elemental iodine, and the second with radioactively traced methyl iodide. Equipment requirements for controlling the injection and sampling flows during elemental iodine testing include an iodine injection tube (**Figure 8.12**), two sampling units (**Figure 8.13**), a sample extraction pump, and two calibrated flowmeters. The sampling units are filled with charcoal of known efficiency for elemental iodine. The test gas is iodide-127 containing the iodide-131 tracer. A combination of injected radioactivity (in microcuries), sampling rate, and counting technique (usually dictated by the kind of counting equipment available) must be developed to give the required test precision. At ORNL, a combination of sampling and injection rates is selected which, with available counting equipment, will produce an upstream sampler radioactivity count between 8 x 10^5 and 5 x 10^6 counts per minute. These are not rigid limits, but are instead convenient target values with considerable latitude. Satisfactory tests have been made with sampling rates as low as 0.03 percent of the system flow rate, but sampling rates of about 1.0 cfm per 1,000 cfm (0.1 percent) of rated adsorber capacity are recommended.

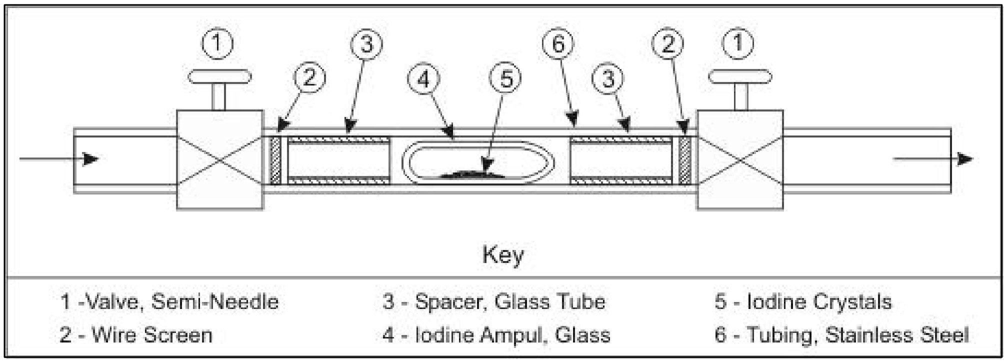

Figure 8.12 – Injector Tube for Radioactive Tracer Test

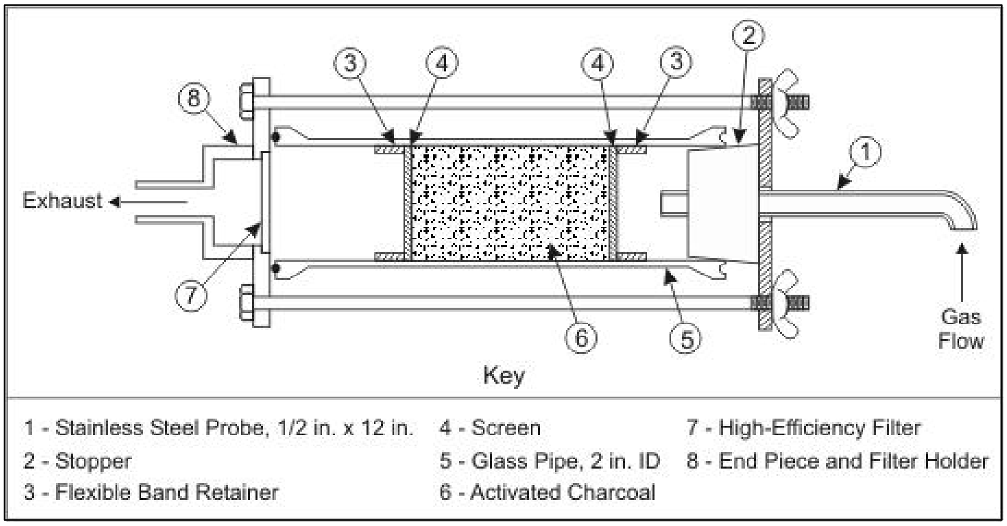

Figure 8.13 – Sampling Elements for Radioactive Tracer Test

The amount of iodine required and the size of the injector tube are not critical. The amount of iodide-127 is invariably 100 mg in the ORNL tests, although this amount may be doubled if excessive plateout in the upstream duct or housing occurs. The amount of iodide-131 tracer must be adjusted to give the radioactivity count noted above. The radioactive iodine source is prepared by mixing the required quantities of iodide-127 and iodide-131 as sodium iodine, precipitating the iodine fraction of palladium iodide by treatment with acidified palladium chloride, then decomposing the palladium-iodide under vacuum. The liberated iodide-127 and iodide-131 is collected in a liquid-nitrogen-cooled U-tube and transferred to a glass ampule that is installed in the injector (Figure 8.13). Preparation of the iodine and loading of the injector must be carried out in a laboratory equipped for handling radioactive materials. To inject iodine during the test, the injector tube is crushed, breaking the ampule and releasing the iodine vapor. Heat may be applied to the injector tube prior to its being crushed and also during the test to assist in vaporizing the iodine source. Compressed air is passed through the tube at a carefully controlled rate for 2 hours.

Figure 8.14 shows a typical in-place radioiodine-tracer test setup. After system flow and background radioactivity levels are established, iodine is injected far enough upstream to ensure adequate mixing with the main airstream, and samples are withdrawn simultaneously through the upstream and downstream sampling units. Injection of iodine is continued for approximately 2 hours, but system airflow and downstream sampling are continued for another 2 hours to catch any iodine that may desorb from the beds, in addition to that which penetrates immediately. Exhaust air from the sampling units is usually dumped back into the upstream side of the main system. The iodine content of the carbon in the samplers is determined by direct gamma spectroscopy, and the bypass leakage is determined from the following equation.

$$E = \left(1 - \frac{C_d}{C_u - B} \right) \tag{8.1}$$

Where

E = efficient, percent

Cd = iodine content of downstream unit, dis/min

Cu = iodine content of upstream unit, dis/min

B = background due to impurity iodine is charcoal, dis/min

The methyl iodide test for determining the efficiency of adsorbers for organic radioiodine compounds is similar to the test for elemental iodine and uses the same equipment, except for the injector. The injector used for the methyl iodide test is a U-tube and a vapor expansion chamber. Sampling and analytical procedures are the same as those for the elemental iodine test. The test vapor is methyl iodide-127 containing methyl iodide-131 tracer. Because the methyl iodine test determines a different property of the adsorbent and depends on a different sorption mechanism, it cannot be used in place of the elemental iodine test. Therefore, both tests are required for a complete evaluation of impregnated charcoal adsorbers. Both of these tests suffer from the limitations of using radioactive tracers in the field and from the number of variables that must be controlled to achieve reliable results.

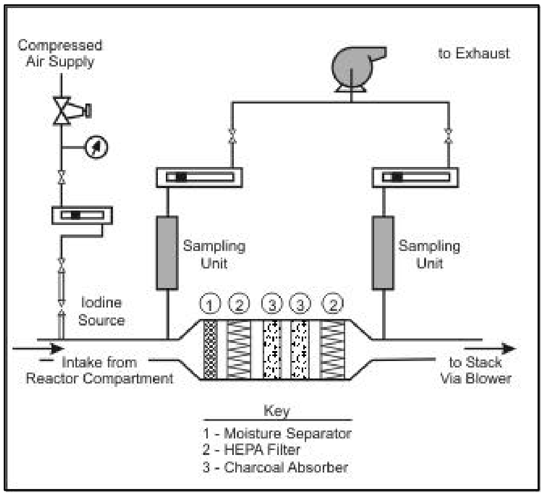

Figure 8.14 – Test Setup for Radioiodine Tracer Tests

8.6.3 Test Sequence and Frequency

The recommended test sequences and frequencies in both ASME N510[14] and NRC Regulatory Guides 1.52[16] and 1.140[17] are inadequate to ensure that an air cleaning system is maintained in an acceptable operational condition. ASME AG-1,[3] Section TA, provides updated guidance on testing sequence and frequency.

Surveillance Tests are outlined in Table 1 of ASME N510,[14] and are repeated in **Table 8.2**.

Additionally, due to the potential for unauthorized flow adjustment and duct damage, all air cleaning system airflows should be rebalanced at least every 5 years. Regularly scheduled testing and air balancing properly verifies the safe, effective operation of air cleaning systems and ensures that design parameters are being met and systems are operating within specified acceptance criteria. ASHRAE STD 111, *Practices for Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilating, Air Conditioning and Refrigeration Systems*[29] should be followed.

Table 8.2 – Surveillance Tests

Test	*Recommended Frequency* [a]
Visual Inspection	Before each test series [b]
Duct Leak Test	Acceptance [c]
Structural Capability Test	Acceptance [c]
Housing Leak Test	Acceptance and at least once every 10 years [c]
Mounting Frame Pressure	Optional Leak Test [d]
Airflow Capacity/Distribution	Acceptance [c] Surveillance [e]
Air-aerosol Mixing Uniformity	Acceptance [c] Test
In-place System Leak Test - HEPA	Acceptance after each HEPA filter replacement and at least once each operating cycle (every 12 months for DOE sites as a basis or more/less frequency, as determined by a technical evaluation) [c, f]
In-place System Leak Test - Adsorbers	Acceptance after each adsorber replacement and at least once each operating cycle [c, f]
Duct Damper Bypass Test	Acceptance and at least once each operating cycle [c, f]
System Bypass Test	Acceptance and at least once each operating cycle (See HEPA above) [c, f]
Air Heater Performance Test	Acceptance and at least once each operating cycle [c]
Laboratory Test of Adsorbent	Acceptance before each adsorber replacement, and at least once each operating cycle [c, g, h]

Notes:

[a] Field test of motors, valve and damper actuators, and fire protective systems are not covered in ASME N510.[14]

[b] The frequency of verifying loop seals and traps must be evaluated by the owner to assure integrity at all times.

[c] Acceptance tests must be made after completion of initial construction and after any major system modification or repair.

[d] The mounting frame leak test is a recommended, but optional, test that identifies the mounting frame leakage that would be included as a part of total bank leakage during HEPA filter bank and adsorber bank in-place leak tests. In many cases, a thorough visual inspection of the mounting frame ensures the mounting frame leakage component of total bank leakage will be minimal (significant leak paths can be visually located). It is left up to the owner to determine whether a mounting frame leak test is warranted based on the visual examination.

[e] Airflow capacity checks for surveillance purposes must be performed prior to any in-place leak test.

[f] Periodic in-place leak tests of systems located within reactor confinements and used only for recirculation are not recommended by the NRC.

[g] Adsorbents must be tested before installation or replacement to establish efficiency. Samples for laboratory testing should be taken before routine in-place testing of the installed system to verify the condition of the adsorbent.

[h] Adsorbent must be sampled and laboratory tests must be conducted to confirm performance at intervals not exceeding 720 hours of system operation for any system immediately following inadvertent exposure to solvent, paints, or other organic fumes or vapors that could degrade the performance of the adsorbent. The 720-hour requirement may be modified based on laboratory test history.

8.7 In-Place Testing for Multistage Systems

HEPA filters are sometimes used in series to increase system reliability or to reduce the effluent air concentrations released from transuranic materials-handling operations. Two questions of importance arise when HEPA filters are employed in series: (1) how can they be tested in place, and (2) what will be the ultimate DF?

With a lower size detection limit at 0.1 µm and excellent analytical characteristics, laser spectrometer counting and sizing instruments have been proposed as a feasible and satisfactory method for testing two or more HEPA filters in series when it is not possible to test each individually. Some uncertainties, however, remain. To have an adequate number of particles downstream for a statistically reliable penetration measurement, high upstream particle concentrations are required; this, in turn, calls for an accurate aerosol dilution device to reduce the particle concentration entering the laser spectrometer to a point where coincidence counting becomes insignificant. This often calls for a reducing concentration by 2 to 4 orders of magnitude, a difficult procedure. In addition, overall tests fail to indicate the status of individual filters in the series. This is important because there are no agreed-upon criteria for permissible penetration through two or more filters in series.

Systems that contain two or more HEPA filter stages and/or two or more adsorber stages in series in the same housing give special problems because of the difficulty of obtaining a representative single-point sample downstream of the first bank and the difficulty of introducing the second-stage test aerosol at a point where good mixing can be achieved. Some series banks are too close, so neither of these objectives can be achieved in the normal manner. Because of the high collection efficiency of the first-stage elements, sufficient test aerosol cannot be introduced upstream of the first stage to permit effective testing of the second stage. It has been shown that accepted test aerosols have no adverse effect on activated carbon or other adsorbents when used for testing nuclear air cleaning systems, and the refrigerant gases used to date have no adverse effect on HEPA filters.

8.7.1 First-stage Downstream Sample

The first-stage downstream sample can be obtained by using a multiple sampling technique. For testing multistage HEPA filter banks, scanning the downstream face of the stage to be tested is an approved technique, in accordance with the procedure outlined in Section 4 of Institute of Environmental Sciences and Technology (IEST) RP-34.1.[30] The recommended scanning pattern for each filter in the bank is shown in **Figure 8.15**. Prior to starting scanning, the upstream side of the stage is challenged with test aerosol and the photometer is adjusted to read 100 percent. A high concentration will always exist directly downstream of a leak. During the downstream scan, the relative magnitude of each leak is determined by turning the scale shift knob of the instrument until a reading about halfway between half and full scale is obtained. The reading is recorded, and the leak flow for that point is calculated from the following equation.

Figure 8.15 – Recommended Scanning Pattern

$$\frac{Leak - probe\ meter\ reading\ (percent)}{Upstream\ concentration\ (percent)} \times probe\ flow\ rate = leak\ flow \qquad (8.2)$$

where probe flow is the airflow capacity of the instrument.

The percent penetration of the total bank is calculated from this equation.

$$penetration = \frac{\sum n\ leak\ flows}{total\ flow} \qquad (8.3)$$

Defective filters must be replaced and installation deficiencies must be corrected before the final test is conducted. This method is considered more sensitive than the usual method of HEPA filter testing, and is recommended for multistage systems with plutonium or transuranic element source terms.[31]

8.7.2 In-Place Testing for Multistage Adsorber Systems

Systems containing two or more adsorber stages in series in the same housing pose the same problems as multistage HEPA filters. The same techniques can be used for gas injection and testing as used in the aerosol HEPA filter systems described above. Additionally, since any tracer gas injected upstream of the adsorber bank is only temporarily adsorbed, additional difficulty with desorption interference may be encountered when attempting to test subsequent adsorber stages. Normally, it is advantageous to start with the downstream bank when testing series adsorber banks to minimize desorption interferences. It may be possible to perform individual bank leak testing of series adsorber banks by using temporary or permanently installed sampling manifolds or by providing a temporary jumper duct to bypass airflow around the second stage to either the system fan or to a temporary auxiliary fan.

8.7.3 Test Aerosol/Gas Injection, throughout Second-Stage Upstream Sample

When the test aerosol/gas is introduced through an auxiliary duct, the upstream sample can be taken any place in the auxiliary duct (upstream of the bank to be tested), assuming the auxiliary duct is long enough to ensure good mixing and prefilters are not installed. When using an auxiliary blower, a downstream sample can be taken downstream of the blower. Another method of ensuring proper mixing of the test aerosol/gas with air is to shroud adjacent filters (adsorbers) and introduce the agent to each filter element (adsorber cell) individually by using a multiple discharge distributor, as shown in **Figure 8.16**. The upstream sample is taken downstream of the perforated distribution plate. The downstream sample is taken with a multipoint sampling probe (**Figure 8.17**). The penetrations of the individual filters (adsorbers) are averaged to find the gross bank penetration. This method requires that a mounting frame pressure leak test be made, usually at the time of acceptance testing,[32] and that the air-containing test gas be passed through a unit (filter or adsorber cell) or group of units one at a time. This method has the advantage of substantially reducing the total quantity of test aerosol/gas introduced to the system if scanning is required to locate leaks; however, it requires more time than the usual method of taking single-point upstream and downstream samples. The vapor test gases have no adverse effect on HEPA filters, and it is possible to inject the gas upstream of the HEPA filters when testing adsorbers. [Note: Shroud testing is rarely performed in the commercial nuclear plant environment.]

Figure 8.16 – Adsorber Tray Mounting Frame. "X" Cross Units Are for Test Gas Injection

Modern air cleaning systems should be designed to eliminate back-to-back series adsorber elements within a single housing. Gasketless deep-bed adsorbers or series adsorbers contained in separate, testable housings may be used when the design requires bed depths in excess of the standard two inches.

8.7.4 Adsorbent Sampling and Laboratory Testing

8.7.4.1 Sampling

The effectiveness of the adsorbent may be impaired due to aging, weathering, and/or poisoning by chemical contaminants. The charcoal ages as a result of oxidation of the adsorptive sites at the adsorbent surface.[33] Aging may occur in the drum (static) or in the operating air cleaning system (dynamic). Weathering typically occurs during system operation when the adsorbent is exposed to normal atmospheric, low-level contaminants in the airstream, e.g., oxides of nitrogen and sulfur and outgases from plant materials and equipment. Poisoning generally refers to an acute exposure of the adsorbent to chemical compounds that temporarily or permanently impair its ability to remove radioiodine and radioiodides. Periodic sampling of the adsorbent provides a means of providing a representative sample of adsorbent for radioiodine testing. The radioiodine laboratory test, together with the in-place adsorber leak test, provides a means of assessing overall adsorber system health.

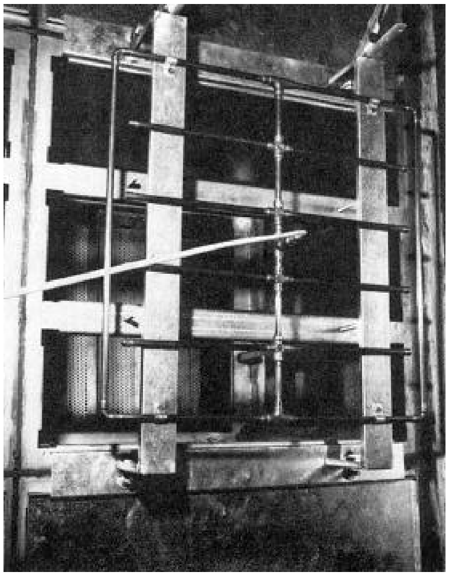

Figure 8.17 – Multiple Point Sample Probe

Figure 8.18 –Multicell System

Flow-through cartridges must be provided and installed in an area of the bank where air will flow through them, and not in obvious low-flow areas such as the outside edge of the mounting frame. If sample cartridges are not provided, other means of sampling are necessary. In a multicell system such as that shown in **Figure 8.18**, samples can be obtained by removing and emptying a cell, taking a sample of the loose adsorbent, refilling the cell (using a qualified filling procedure), and reinstalling it in the bank. For some adsorber systems, it may be possible to take a "grain thief" sample.[34] In small adsorber installations, when considering the cost of the tests and labor involved in obtaining the sample, it may be beneficial to simply replace the adsorbers or adsorbent. Some users have found it more economical to replace the adsorbent at the stipulated sampling frequency rather than making surveillance sample tests.

NRC Regulatory Guide 1.52,[16] Revision 3, currently requires that sampling and analysis be performed: (1) after each 720 hours of system operation, or at least once every 24 months, whichever comes first; (2) following painting, fire, or chemical release in any ventilation zone in communication with the system that may have adversely affect the functional capability of the carbon media; and (3) following detection of, or evidence of, penetration or intrusion of water or other material into any portion of an ESF atmosphere cleanup system that may have adversely affect the functional capability of the carbon media.[3]

When using a "grain thief" for sampling Type II (cartridge) or Type III (deep bed) adsorbers, multiple samples should be taken from all sections of the adsorber bank. For deep bed adsorbers, it is important to sample from below the tops of screens so that carbon from the overfill is not commingled with the service carbon. In filters with a bed thickness greater than two inches (50.8 mm), samples should be taken from the center of the bed. Samples taken from the inlet side of a carbon bank will show more radioiodine penetration than samples taken from the exit side. Therefore, samples should be taken symmetrically from the exit screen side, the entrance screen side, and the middle of the bed. After using a grain thief to sample a Type II adsorber, the tray should be "topped off" with new carbon (assuming the tray is to be reused), and then marked as "Not Representative for Future Sampling."

When sampling Type II adsorber trays, the entire tray should be emptied and the contents mixed to yield a homogeneous composite sample. A smaller, grab sample may be taken from the tray contents for laboratory testing. If the bank is not being replaced, a new tray must be installed in the bank and marked as "Not Representative for Future Sampling."

Sample canisters may be used to take a representative carbon sample from the adsorber bank. Sample cartridges must be provided in sufficient numbers to permit taking samples at specified intervals for the life of the adsorbent. Sample cartridges must be designed so that bed depth, airflow, and pressure drop across the cartridges are the same as for the adsorber stage. For this reason, the zero-flow hang-on cartridges shown in **Figure 8.19** are not acceptable. Properly designed sampling canisters should have a minimum diameter of 2 inches (50.8 mm) and should have the same bed depth as the main bank. Sampling canisters should be mounted vertically so that any bed settling within the canisters will not create a mechanical bypass of the carbon media.

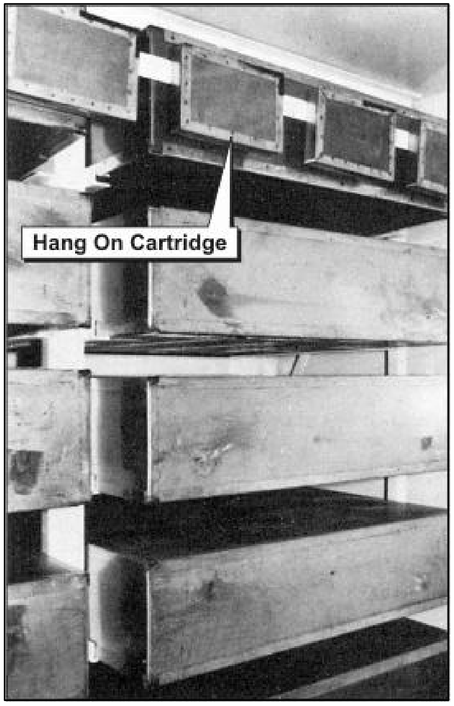

Figure 8.19 – Zero Flow Hang on Cartridges

All samples taken from an adsorber bank must be representative of the main bank. Any method used for sampling (grain thief, sample canister, dumping) must yield representative composite samples. One method of confirming that a sampling procedure is acceptable is to compare the radioiodine testing results from the sampling procedure with the radioiodine testing results from a representative sample of the main bank taken after the carbon is removed from the system. After a bank has been emptied, all of the carbon is accessible for sampling, allowing a true representative to be taken. If the test results obtained from a homogenized sample taken when the entire bed has been emptied are consistent with the results from in-situ sampling, then the sampling procedure is acceptable.

Carbon samples taken from the adsorber bank should be thoroughly mixed and packed into vapor-tight containers such as a plastic bottle. At least 125 ml of carbon for each two inches of bed thickness are required for the laboratory test. All samples that are to be sent to a testing laboratory must be marked with the following minimum information:

- Utility/Company,
- System Identity,
- Sample Date,
- Purchase Order Number,
- Test Standard (ASTM D3803-1989),[20]
- Test Temperature,
- Test Humidity,
- Face Velocity,
- Adsorbate (methyl iodide),
- Pressure,
- Bed Thickness, and
- Contact Person/Telephone Number.

Test results for samples sent to a laboratory for radioiodine penetration analyses must be available within 30 days of their sampling date.

8.7.4.2 Laboratory Testing

Most radioiodine laboratory testing on activated carbon samples taken from safety-related filtration systems installed in U.S. commercial nuclear power plants are conducted in accordance with ASTM D3803-1989.[20] This requirement was made mandatory by NRC Generic Letter 99-02,[31] issued in 1999. Other test standards that can be used for non-safety-related systems include ASTM D3803-1979[20] and 1986,[20] as well as RDT-M16-1T 1973.[34]

Table 8.3 Standard ASTM D3803-1989 [21] Testing Conditions

Temperature	54 degrees Fahrenheit
Humidity	95 percent
Face Velocity	12.2 m/min (40 fpm)
Pressure	29.91 in. Hg.
Methyl Iodide	1.75 mg/m3 Concentration
Equilibration Time	120 minutes
Pre-equilibrations	16 hours
Loading Time	60 minutes
Post Sweep	60 minutes
Bed Thickness	50 millimeters

Radioiodine penetration analysis is conducted in the laboratory using the ASTM D3803-1989[20] standard test method. Testing is conducted in sophisticated environmental chambers that are capable of precisely controlling the temperature and humidity. The activated carbon sample is loaded into stainless steel testing canisters, one canister for each two inches of adsorber bank bed depth. Along with two more canisters containing new carbon, the canisters with the activated carbon sample are assembled into a canister stack for testing. The canister stack is placed into the environmental chamber and plumbed into the testing system. The system environment is adjusted to the required temperature and humidity, normally 86 degrees Fahrenheit and 95 percent RH. All test parameters are monitored by a computer monitoring system for the duration of the test. After an initial thermal equilibration period, humid airflow is started through the carbon beds for the duration of the pre-equilibration and equilibration periods. The loading period begins with the introduction of methyl iodide into the airstream. The methyl iodide is fed into the system for a period of 60 minutes, called the loading period. After completion of the loading period, the injection of methyl iodide is stopped, and the humid air continues for an additional 60 minutes. This is called the “post sweep.” The carbon canisters are then disassembled and carbon from them is loaded into plastic counting canisters for analysis. Each carbon sample is counted in a gamma spectrometer to determine the amount of radioactivity contained in each carbon canister. Knowing the amount of radioiodine present in each carbon canister allows calculation of the radioiodine penetration in percent penetration.

Detailed descriptions of the penetration measurement may be found in ASTM D3803-1989.[20] Radioiodine laboratory testing on activated carbon samples taken from safety-related filtration systems installed in U.S. commercial nuclear power plants are conducted in accordance with ASTM D3803-1989.[20] Previous versions of ASTM D3803 (1979 and 1986) and RDT M16-1T-1973[34] are still specified for non-safety-related adsorber systems. However, for future licensees, currently applicable documents include NRC Regulatory Guide 1.52,[16] Revision 3, (safety-related) and 1.140,[17] Revision 3, (non-safety-related). Both of these Regulatory Guides now reference ASTM D-3803-89.[20]

Acceptance criteria for radioiodine penetration are described in the facility technical specifications for safety-related systems. For other systems, pertinent information related to system design performance may be found in vendor design documentation or the facility Final Safety Analysis Report.

8.7.4.3 Frequency of Testing

The following test schedule (**Table 8.4**) is suggested for both continuous and intermittent online adsorber systems designed in accordance with this Handbook.

Table 8.4 – Test Schedule for Adsorbers

Application	*Frequency*
All systems.	Before system startup, following any major system repair or modification, and following each filter (adsorber) replacement.
Radiochemical plants, fuel reprocessing plants, and laboratory fume hoods.	Semiannually or quarterly where high moisture loadings or high temperatures are involved. In some systems, frequent (even monthly) testing is often specified where the environment is particularly severe. The frequency may be reduced if experience indicates a lesser frequency is satisfactory.
Reactor post-accident cleanup systems and post-accident cleanup systems of fuel reprocessing plants.	Annually or 720 hrs of system operation, whichever comes first (as specified in NRC Regulatory Guide 1.52).[16]
Zone III or tertiary confinement [a] areas of facilities that handle radioactive materials.	Annually.
Zone II or secondary confinement [a] areas of plants and laboratories that handle radioactive materials.	Annually.
Zone I or primary confinement[a] areas (glovebox lines, hot cell exhaust, etc.) of laboratories and plants that directly handle moderate to large quantities of radioactive materials.	Semiannually unless experience indicates that annual testing is sufficient. If filters (adsorbers) are replaced at short (less than 6-month) intervals to limit exposure of personnel to radiation during a filter (adsorber) change, or to permit contact maintenance of the system by limiting the amount of radiation that can be collected in the filters (adsorbers), systems should be in-place [i.e., leak-tested following each filter (adsorber) change]. Laboratory testing of adsorbents may not be necessary if the adsorbent is replaced frequently.
Systems that are continually on standby, but are operated occasionally during plant maintenance to ventilate the system.	At least biannually.

[a] Zones and confinements are found in Chapter 2, Section 2.2.9.1.

8.8 Testing of Deep Bed Sand Filters

Deep bed sand filters are not true HEPA filters, although their efficiency approaches that of a true HEPA filter when tested for aerosol penetration using the test method described in Chapter 8 of this Handbook; a physical description is found in Chapter 9. This method, which is the same method used to leak test HEPA filter systems, uses a poly-dispersed aerosol with a light scattering mean diameter of 0.7 micron. Many experts believe this method of testing sand filters tends to over rate the filtration calculated efficiency, so it may be prudent to use another method of testing to confirm test data. One method of doing this is to measure the quantity of radioactive particulate in the airstream before and after it passes through the sand filter and compare them to the aerosol test result.

Aerosol should be injected into the system as far upstream of the sand filter as possible for good mixing. An Air-Aerosol Mixing Uniformity Test, as described in ASME N 510,[14] should be performed to determine the best injection point and sample points. A perforated dip tube designed and installed per ANSI N 13.1[32] should be used upstream and downstream of the sand filter to further ensure a representative sample of the aerosol concentration is used. The upstream and downstream concentration of background aerosols (dust test) that may interfere with the test results should be performed prior to the introduction of aerosol into the system. The background test is performed by setting the aerosol photometer's internal calibration feature to reference the instrument to a concentration equivalent of 100 micrograms of aerosol per liter of air. The background concentration is then measured upstream and downstream (upstream first) and recorded. The background levels should be stable and allow for detection of aerosol penetration smaller than the maximum allowable penetration. The aerosol should be injected into the sand filter for a period of 15 to 30 minutes, depending on the size and cfm of the sand filter, prior to the test sampling to allow time for distribution of the challenge aerosol throughout the sand filter.

8.9 Areas for Continuous Improvement

8.9.1 Qualified Products List

The QPL for qualification of HEPA filters, which was once maintained by the military, needs to be re-established and maintained. With the military's elimination of the QPL for HEPA filters, ASME Code AG-1[3] specifies that qualification may be performed by independent laboratories. The problem is that, with the exception of Edgewood Arsenal, no laboratories have the equipment or inclination to qualify filters. Review and updating of the qualification test protocol is required. Changes may be needed in the heated air, moisture overpressure, environment cycle, or rough handling tests. Additional tests may be needed.

8.9.2 Suggested Improvements and Testing Standardization

Improved field-testing methods and equipment require the adoption of testing standards to ensure consistent testing and results. Although commercial nuclear applications apply the ASME N510[14] and ASME AG-1[3] standards, DOE contractors require clarification of the applicable parts of these referenced standards. An in-place testing conference held at the DOE SRS recognized that standardization of DOE contractors' in-place testing procedures for DOE applications was in order. The group also identified the following areas for improvement:[23]

- Referencing ASME N510[14] for testing of DOE filter systems results in auditing confusion and problems in demonstrating compliance with the referenced requirements.
- Filter specification (ASME/DOE) clarification is needed.
- Improvements are needed in the areas of standards, procedures, training requirements, and certification for filter test technicians.
- A DOE guidance document or standard for testing unique filter systems at DOE sites should be developed.
- Guidance on filter service life should be developed.
- The challenge test aerosol used by DOE contractors should be standardized.
- Mandatory/optional requirements for the in-place test procedure should be standardized.
- More stringent receiving inspection/QA requirements need to be developed and more training of personnel in this area is needed.
- QPL requirements for cylindrical filters should be developed.
- A decision is needed concerning whether FTF QA testing will continue, and which facility will perform the qualification tests.
- A decision is also needed to establish the testing protocol for HEPA filter vacuums and portable ventilation units.

8.10 Review of In-Place Filter Testing at Selected DOE Sites

In 1992 and 1993, LANL performed a 2-year review[35] of the HEPA filtration systems at seven different DOE sites:

- Paducah Gaseous Diffusion Plant;
- Portsmouth Gaseous Diffusion Plant;
- LANL, Area 200 of FP4, Technical Area 55;
- Plutonium Fuel Fabrication Facility and Plutonium Experiment Facility at SRS;
- High Flux Beam reactor and Medical Research Reactor at Brookhaven National Laboratory;
- Buildings 38 and 50 at Mound Plant (Mound); and
- ORNL, High Flux Isotope Reactor, Radiochemical Engineering Development Center and Isotope Enrichment Facility.

Although significant differences among the sites were found, there were also several issues common to all seven. The observations were divided into four areas:

Policy Development. (Includes filter shelf life, filter service life, role of HEPA acceptance and in-place filter testing and system oversight.) The goal should be to provide a technical basis for setting maximum storage and service times after which filters must be discarded or replaced.

Testing Multi-stage Systems. (Includes overall system and individual stage testing.) Requirements in this area include clarification for the use of acceptance-testing filters, the need to test intermediate stages of multiple stage systems, appropriate requirements for testing filters used with gloveboxes, and the types and degree of administrative oversight and record-keeping necessary when HEPA filers are part of exhaust and air emission control systems.

Guidance on In-place Filter Testing and System Supervision. Includes testing practices, test equipment maintenance and calibration, special concerns of older systems, measurement uncertainty, pass/fail decisions, frequency of routine testing, analysis and reporting of testing results, and technical support and training of testing personnel.

Uncertainty in In-place Filter Testing Results. The issue of how such results are affected by measurement methods, system characteristics, and system abnormalities needs to be studied.

Two principal conclusions emerged from these reviews. First, there was an immediate need to develop information on how filter mechanical integrity decreases with time, and to use this information to establish limits on filter service life. Second, there was a general need to ensure the validity of in-place filter testing results and to improve testing practices. A mathematical framework for describing the effects of abnormal system features on testing results was proposed as an aid in understanding the uncertainty in in-place filter testing results.[37]

8.11 Testing Portable HEPA Filtration Systems

8.11.1 General Testing and Periodic Maintenance Considerations

Problems with operating portable HEPA filtration systems (PHFS), i.e., systems that can move and are often not visually observable or detectable by onboard instrumentation. Therefore, filter replacement and testing are important to the continued safe operation of the unit. In-place testing is designed not only to validate the HEPA filter, but also to verify the integrity of associated seals, gasketing, ducting, and housings regarding leakage.

All HEPA filters used in the system should be tested by the DOE FTF before initial use. In addition, the device should be leak-tested after installation at the site and prior to operation. Most importantly, a thorough leak test should be conducted anytime the unit is jarred, bumped, or moved. Leak tests are conducted by first injecting an aerosol challenge into the inlet of the PHFS and measuring the aerosol challenge concentration at the inlet to establish a 100 percent baseline. Then the detector samples particle free air to establish a 0.000 percent baseline. With these two baselines, created samples of the PHFS outlet can be sampled to measure any aerosol leakage.

Any entry into a PHFS must be consistent with local radiological controls, which is normally controlled by a radiological work permit. Radiation and contamination surveys should be performed periodically for PHFS in use, and the labels on these units should be updated. The frequency of radiation surveys should depend on the specific use of the unit.

PHFS tend to be overlooked when it comes to maintenance and testing. Many standards and procedures address maintenance and testing of permanent Heating, Ventilating, and Air Conditioning (HVAC) HEPA filtration systems. However, no national standards and procedures are available for PHFS. Worse, because of their size and portability, personnel assume they are functioning correctly. Ironically, these units are capable of discharging contamination over the specific areas of the work site they are supposed to be protecting if filter bypass leakage is occurring.

These units by their very nature are prone to leakage. This is mainly because they are small and portable, and thus are transported from workplace to workplace in the back of trucks and are subjected to substantial rough handling by workers. This action creates leaks in units that were previously tested, giving personnel a false sense of security. For this reason, these units should be tested anytime they are transported to another workplace. When testing PHFS, test personnel should apply the same rigorous procedures outlined in ASME N510[14] and ASME AG-1[3] for the permanent HVAC HEPA filtration systems. After all, PHFS perform the same functions and have essentially the same components as the permanent HVAC systems.

8.11.2 Reasons For Testing PHFS

- Poor PHFS design.
- Poor workmanship and inadequate quality control by the PHFS manufacturer.
- Leaks in the filter media itself.
- Leaks due to failure of the adhesive bond between the filter media and its frame.
- Leaks between the filter frame and cabinet sealing frame seals.
- Leaks between the cabinet main frame and the cabinet housing.
- Leaks in the cabinet or housing due to damage in transit or handling.
- Leaks from misalignment or misassembled components of the PHFS.
- Leaks resulting from incorrect or inadequate maintenance.
- Leaks resulting from improper installation and operation of the PHFS at the work site.

[Note: Many of the above items may not be applicable to units constructed and certified to ASME AG-1[3] criteria.]

8.11.3 Portable Filtration Systems Testing Applications

There are two basic designs for these systems: those that “pull” air through the HEPA filter and those that “push” air through it. Therefore, some units locate the HEPA filter upstream of the motor/blower assembly, and others place the HEPA filter downstream of the motor/blower. The advantages and disadvantages of each design concept are summarized in **Table 8.6**.

Table 8.6 – Downstream/Upstream HEPA Filter Locations in PHFS

(+) Advantages	***(-) Disadvantages***
Type A DOWNSTREAM HEPA	Type B UPSTREAM HEPA
(+) Easier access to HEPA filter for scanning or leak testing	(-) Difficult access to HEPA filter for scanning or leak testing
(+) May not require mixing chamber to assure uniform mixing of test aerosol	(-) Requires mixing chamber to assure uniform mixing of test aerosol
(-) Motor/blower may become contaminated	(+) Motor/blower should stay uncontaminated unless filter leaks
(-) Cabinet interior may become contaminated	(+) Cabinet should stay uncontaminated unless filter leaks

Design, materials, specifications, and quality of construction vary widely among PHFS. These variables have a tremendous impact on overall performance and effectiveness. In particular, the cabinet material must remain rigid and undistorted during shipping, handling, and the rigors of daily operation to prevent the contaminated air from bypassing the HEPA filter. The type and gauge of metal fabrication methods, braces, holes, cracks, fasteners, welds, gaskets, and seals must be designed, specified, and assembled with potential leakage, durability in service, and maintenance in mind. [Note: Many of the above items may not be applicable to units constructed and certified to ASME AG-1[3] criteria.]

8.11.4 Testing Problems and Special Considerations

Some of the designers and manufacturers of PHFS have not put much thought or effort into creating units with integrity leak tests in mind. Not only do they unintentionally "design in" leaks, but they also often overlook the inclusion of features that allow access to areas that are critical for leakage testing. Access to the downstream face of the HEPA filter for the purpose of scanning is virtually impossible in most units where the blower is downstream of the HEPA filter. A mixing chamber with baffles is necessary at the inlet of this type of unit to provide adequate challenge aerosol mixing. Downstream measurements of the exhaust airstream can be subject to error due to channeling—the opposite of mixing. The aerosol from a specific leak may simply remain concentrated in a segment of the exhaust airstream. Therefore, sampling must be done at various points across the face of the exhaust air outlet, in effect a "scanning" of the opening. A single-point sample is usually not representative of what is in the exhaust airstream because the leak becomes diluted with the particle free air. The same considerations are included in making air velocity measurements across the exhaust opening or duct in accordance with ANSI/ASTM 41-2 (1987).[36] A single-point reading is not representative as discussed in ACGIH *Industrial Ventilation – A Manual of Recommended Practice*.[21]

8.12 Testing HEPA Filter Vacuum Cleaners

HEPA filtered vacuum cleaners (HEPA-Vacs) are most commonly used to control particulate before it becomes airborne. They are also used to control airborne particles and liquids in and around work areas and to provide localized control of loose debris when work operations could potentially spread contamination. When used in the nuclear industry, HEPA-Vacs are commonly referred to as nuclear or radiological vacuum cleaners.

8.12.1 Description of Radiological Vacuum Cleaners

Radiological vacuum cleaners are generally well-constructed, well-sealed devices with a HEPA filter on the exhaust. They are normally mounted on a cart with a comfortable handle and lockable, steerable wheels for portability and control during use. The power module consists of a blower powered by an electric motor and controlled by an onboard switch. The filter module consists of a positively mounted and sealed HEPA filter protected by a prefilter. All units should have a positive plenum (tank)-to-vacuum head seal. Vacuums that have latches but provide a loose tank-to-head seal that depends on the vacuum force to provide a positive seal (as in many commercially available shop vacuums) should not be used.

Some vacuum cleaners are equipped with controllers that allow the worker to regulate the flow. This works well in providing negative ventilation in small glove bags. Using HEPA filtered vacuum cleaners can significantly improve how contamination is controlled.

An inline HEPA filter can be installed in the suction hose to collect radioactive material before it reaches the vacuum cleaner. Fittings can be made to connect the vacuum cleaner hose to the HEPA filter. As debris is sucked into the hose, it is deposited on the inline HEPA filter instead of the HEPA filter inside the vacuum cleaner. Temporary shielding should be installed around the inline filter before operation, as the filter becomes highly radioactive.

If a large amount of debris will be collected, installation of a waste drum in the suction hose should be considered to ensure the debris collects in a waste drum and not the vacuum cleaner. Commercial systems are available, or one can be made by welding two pipes into a spare drum lid. As each drum is filled, the lid can be installed on a new drum and a regular lid can be installed on the full drum. Personnel doses are reduced because the debris is collected directly into the waste drum instead of the vacuum cleaner.

Vacuum cleaners should be constructed of a material that is easily decontaminated without damage to components. Units that use silicone-based material to prevent leakage should not be used. All hose connections should provide positive seals and should be constructed of a material that will not be damaged by repeated use or rough handling.

HEPA filters should have a positive seal and pass in-place leak testing. The filter holddown clamps should provide the required force (20 pounds per square inch) to seal the filter and prevent dislodging during rough handling and repeated use. They should be constructed of a material that will not warp or bend with repeated use.

The HEPA filter replacement method should be both simple and achievable in minimum time to reduce exposure and the chance of radioactive contamination. The vacuum cleaners should be designed to ensure HEPA filter integrity under all conditions of use and to prevent unauthorized or accidental access to the inner surfaces of the vacuum. Units should be constructed with no sharp edges or burrs that could injure personnel or damage protective clothing.

HEPA filters used in HEPA-Vacs should meet the efficiency and construction requirements for HEPA filters listed in DOE -STD- 3025[7] and ASME AG-1.[3] The maximum flow rate of the device should not exceed the flow rate at which the HEPA filter was efficiency-tested. The HEPA filters should be certified at the DOE FTF.

8.12.2 Operation

HEPA-Vacs are used to cleanup radioactive debris. Improper use of HEPA-Vacs may result in generation of airborne radioactivity, loose surface contamination, or high dose rates. HEPA-Vacs used for radioactive material should be marked, “For Radioactive Service Only.” A nuclear safety review must be performed and documented prior to use of a HEPA-Vac for fissile material.

HEPA-Vacs must be appropriate for the type and amount of radioactive material involved. The health physicist is responsible for determining the levels of filtration required on the exhaust. Programmatic organizations are responsible for the following items:

- Maintaining control of HEPA-Vacs.
- Ensuring that HEPA-Vacs are tested semi-annually. (HEPA-Vacs must be retested if the integrity of the filter media or the sealing surface of the HEPA filter is compromised, if the HEPA filter is exposed to water or high levels of water vapor, or if the HEPA-Vac is transported to another area or site.)