

## **Development of Test Stand and Test Plan for Qualification of Sintered Fiber Metal Media Filters**

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### **ABSTRACT**

High efficiency particulate air (HEPA) filtration technology is commonly used in Department of Energy (DOE) facilities that require control of radioactive particulate matter (PM) emissions due to treatment or management of radioactive materials. Although HEPA technology typically makes use of glass fiber media, metal and ceramic media filters are also capable of filtering efficiencies beyond the required 99.97%. Sintered metal fiber filters are good candidates for use in DOE facilities due to their resistance to corrosive environments and resilience at high temperature and elevated levels of relative humidity. Their strength can protect them from high pressure or pressure spikes and allow for back pulse cleaning, which can extend lifetime use. The use of these filters also has the potential to reduce the cost of filtration in these DOE facilities due to lifetime cost savings. However sintered metal media filters are not currently in use in DOE facilities because ASME AG-1 section FI pertaining to qualification of metal media filters has not been approved due to a lack of protocols and performance criteria for qualifying section FI filters. The Institute for Clean Energy Technology (ICET) has developed a test stand design and test plan capable of assisting in the qualification ASME AG-1 section FI filters. The data provided from ICETs test stand and test plan should be sufficient to establish the missing protocols and performance criteria needed for approval of section FI.

### **INTRODUCTION**

High efficiency particulate air (HEPA) filters are commonly employed to control particulate matter (PM) emissions from processes that involve management or treatment of radioactive materials. Facilities within the US Department of Energy (DOE) complex are particularly likely to make use of HEPA filters in the processing of exhaust gases prior to release to the environment. In May of 1999, the Defense Nuclear Facilities Safety Board (DNFSB) released Technical Report 23 entitled *HEPA Filters Used in the Department of Energy's Hazardous Facilities*. [1] This report expressed concerns for the potential vulnerability of HEPA filters in vital safety systems. Later that same year DOE initiated a response to the DNFSB's Recommendation 2000-2 by implementing measures with regard to 100 percent quality assurance testing of HEPA filters and a review of vital safety systems in general [2]. DOE's actions in this matter were also timely with regard to concerns voiced by citizen groups over the performance of HEPA filters and how functional status is monitored. Of particular concern are the threats to filter performance posed by water and smoke. While these two threats are both associated with fire scenarios, leaking reheaters also pose a wetting threat to filters.

The most moisture resistant and high strength medium that can be used in manufacturing of HEPA filters is sintered metal powder or fiber media. Section FI of the American Society of

Mechanical Engineers' (ASME) Code on Nuclear Air and Gas Treatment (AG-1) is being developed to specify requirements for these filters in nuclear containment applications. This section will be applicable to the full range of filtering efficiencies, including HEPA. The major barrier to completing the code section is development of a test stand for collecting data necessary to specify performance requirements for use and for filter qualification. A research grade test stand is needed to collect performance data, establish qualification protocols, and specify qualification testing requirements.

Work on development of Section FI of the ASME AG-1 standard has been ongoing for over a decade.[3,4] A multitude of issues has plagued finalizing this standard. Virtually all of them have dealt with the dramatic differences between metal media and fibrous glass media. HEPA filters used in nuclear containment applications have virtually always utilized fibrous glass media. This limits the conditions in which they can be operated: (1) Excessive moisture must be avoided; (2) back pulsing cannot regenerate conventional FC filters; (3) the tensile strength of fibrous glass media restricts maximum operating differential pressures; (4) fibrous glass media can be degraded by chemical constituents like high pH aerosols or HF; and (5) potting materials for fibrous glass filters have relatively low tolerance for elevated temperatures. and

HEPA filtration technology typically makes use of glass fiber media, yet metal and ceramic filters are also capable of filtering efficiency beyond the required 99.97%. The Nuclear Air Cleaning Handbook (NACH) dictates that the ASME AG-1 must be used when dealing with nuclear applications for HEPA filters.[5,6] Glass fiber filters are known to have a weakness to elevated levels of upstream pressure, temperature and relative humidity.[7] Advantages of metal media filters are their resistance to corrosive environments, resilience to high temperature and levels of relative humidity, and their strength, which can protect them from high pressure or pressure spikes.[8,9]

The sintered metal fiber media makes an especially good candidate for use in the elevated conditions due to its typically lower pressure drop compared to that of sintered metal powder media.[10] Metal media filters have been shown to exhibit efficiencies as high as 0.9999999 for specific test conditions.[11] Also, these filters can be back pulsed with compressed air to dislodge surface particulate matter, extending the life of the filter. Metal media filters are more expensive than their glass fiber counterparts, yet due to the high pressure back pulse and burst strength, the metal filters have applicability in conditions fibrous glass media do not, and may also offer lifetime cost savings.[12]

The goal of this project is the development of a test stand for the establishment of the qualification criteria posed upon the Section FI metal media filters. The primary objective for this test stand is to provide filter qualification data, with possible future use for examining loading characteristics and assesses the capabilities of a wide range of metal media elements.

## **FILTER QUALIFICATION**

Qualification for section FI filters covers several different categories. The filters must be tested for: resistance to rated air flow, test aerosol penetration at rated air flow and at 20% rated air flow, resistance to pressure, test housing/tube sheet leaks, resistance to spot flame, loading and cleaning, and resistance to rough handling. ICET will perform qualification tests for resistance to air flow, test aerosol penetration, and resistance to heated air.

*Resistance to Rated Air Flow* – This test assures that the differential pressure of a clean filter is within specified normal values of the unit's rated airflow. The proposed AG-1 section FI-5110 for

metal media filters states that pressure drop across the medium for metal media filters shall not exceed 80% of the prescribed value for the assembled metal media filter set by the Owner with ambient temperature airflow through the medium, when tested as specified in FI-I-4221 at minimum velocity corresponding to rated flow of the unit to be assembled. The air flow shall be computed from the ratio of filter area being tested to the total effective area of the finished filter, times the rated flow of the finished filter. The rated air flow requirements for various sizes of metal media filters can be found in section FI-4131-1.

*Test Aerosol Penetration* – The section FI Metal Media Filters FI-5122 states that DOP or DOS of 0.3  $\mu\text{m}$  not to exceed 0.03% for HEPA filters by compared aerosol concentration upstream and downstream.

*Resistance to Heated Air* – The filter elements will be tested for resistance to heated air. The section FI Metal Media Filters FI-5150 states that elements will be exposed to the rated flow rate at 400  $^{\circ}\text{C}$  (750  $^{\circ}\text{F}$ ) to test for failure due to high temperature. During the elevated temperature testing only dP and dT will be recorded due to the effects of the high temperature. Test aerosol penetration and resistance to rated airflow will both be performed again after the resistance to heated air to determine any effects of the elevated temperature on the elements.

## **PROJECT STATUS**

The ASME Committee on Nuclear Air and Gas Treatment (CONAGT) Section FI Project Team has worked diligently to provide performance criteria for a test stand to qualify metal media filters. This has been in conjunction with parallel efforts to clearly specify requirements for filter performance. ICET has been a member of the Section FI Project Team and has incorporated conclusions of the Project Team into the design of a test stand. This design has been reviewed and refined at the past two CONAGT meetings and is currently under fabrication at ICET. The Project Team meeting in February identified additional equipment needs including a larger air compressor, heat exchanger, demister/mist eliminator, and aerosol sampling system.

The FI Project team has determined that a test stand needs to have the capability of testing to 69 kPa (10 psig) of differential pressure with volumetric airflows up to 7.1  $\text{m}^3/\text{min}$  (250 cfm). This will require a large compressor and ancillary equipment to reduce air temperatures and remove both moisture and aerosols. Super-ambient upstream air pressures represent a technical difficulty for a variety of reasons. Compressed air must be cooled and cleaned before being injected into the test stand. Upstream test stand components (flanges, vessels, etc.) must be capable of withstanding operating pressures, challenge aerosols must be produced/injected under increased pressure, and a reduced pressure slipstream must be provided to upstream measurement devices without altering relative concentrations of particle sizes of the challenge aerosol. All aspects of the test stand design have been reviewed by FI Project Team members.

The test stand design is provided in Figure 1.

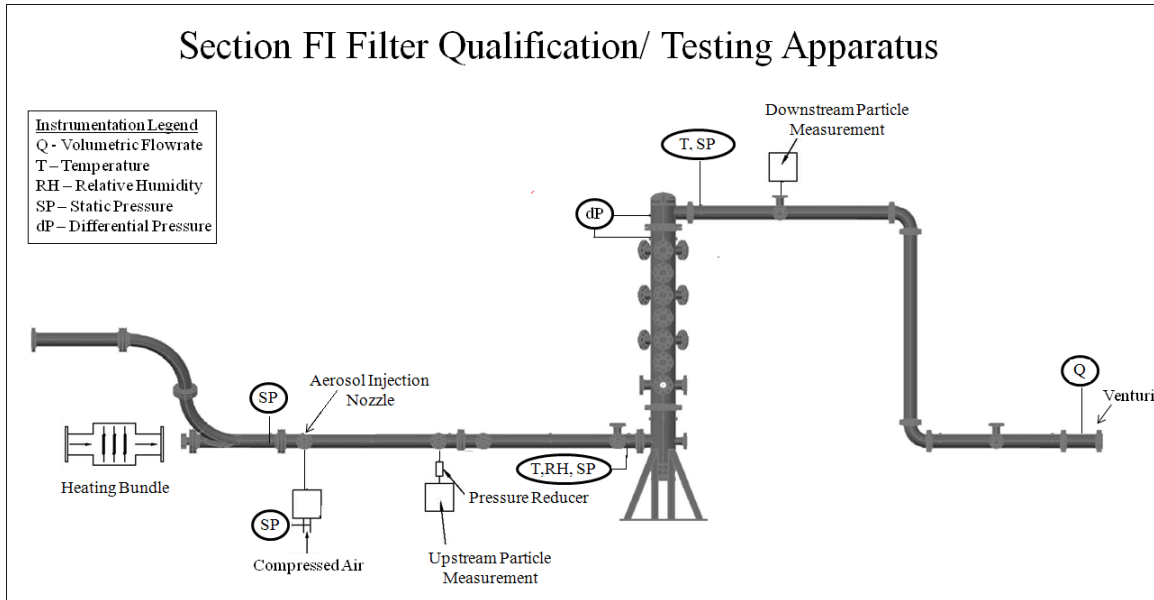


Figure 1. Design drawing of the MSU FI filter test stand

## TEST STAND

### Application

The data provided by this test stand can play a significant role in the development and approval of ASME AG-1 section FI. The test stand designed by ICET will be used to qualify clean sintered metal media filters using positive pressure air flow. The test stand is designed to test filter elements for resistance to rated air flow FI-5110, test aerosol penetration FI-5120, and resistance to heated air FI-5150. The test stand can test up to three filter elements at one time and will provide significant data on the performance of sintered metal media filters.

Differential pressure transmitters across the filter elements will provide the pressure drop and resistance of the clean filter elements at rated flow rates. This will provide data for the resistance to airflow portion of the testing. The anticipated initial pressure drop across the filter is in the range of 0 to 30 kPa so for the best accuracy differential pressure gages of 0 to 17.4 kPa., 0 to 35 kPa and 0 to 103 kPa. are used.

The Dioctyl Phthalate (DOP) aerosol generator existing at ICET will provide aerosol for the efficiency test of the filters. The particle measurement devices shown in the Particle Measurement Instrumentation section of this paper will measure the concentration of particles in the upstream and downstream sections to determine the efficiency of the filter elements.

The high temperature resistance testing will require using the two existing air heaters at ICET of 150 kW and 72 kW heating capacity. These will heat the airstream to above 400 degrees Celsius. While heating, the differential pressure across the filter elements will be monitored to determine any effects of the high temperature to the filters. The efficiency of the filter elements will also be tested after the high temperature resistance testing. This is done to check for effects of the high temperature on the efficiency of the filter elements. This test will provide the data required to determine the potential risks associated with exposing these filter elements to high temperatures.

In the future this test stand will be modified to be capable of using blow back or back pulse cleaning on filter elements. The ability to use blow back cleaning can greatly increase the role that this test stand can play in getting approval of section FI. Capabilities to use blow back cleaning will make it possible to do life time testing of these filter elements. This can provide valuable information as to the long term benefits of using sintered metal media filters.

## Capabilities

The capabilities of the ICET test stand design include:

- Upstream compressed air
- Upstream aerosol generation
- Upstream air heating
- Upstream sample pressure reduction
- Upstream sample dilution
- Up and down stream particle concentration
- Ability to continuously display and record volumetric flow rate, temperature, relative humidity, static pressure, and differential temperature and pressure across the filter.

## Test Stand Components

*Air Supply* - A blower with a variable speed drive will be used in place of a compressor for flow rates from 1.6 to 5.7 m<sup>3</sup>/min (55 to 200 CFM). Because of the limited range of the blower, flow rates below 1.6 m<sup>3</sup>/min (55 CFM) will be accomplished using an air compressor with a flow controller. Because heat will be generated during compression of the air, a water chiller will be used to cool the compressed air to 30 degrees C.

*Pressure Reduction Device* - A pressure reduction device is required to reduce the pressure of the upstream airflow for aerosol sampling. The higher pressure in the upstream section of the test stand exceeds the capabilities of the aerosol sampling equipment. The pressure reduction device is used to reduce the pressure of the sample from the pressurized line down to ambient pressure for sampling of the aerosol. The pressure reduction device will be designed according to the dimensions from "Design and Performance Evaluation of a Pressure-Reducing Device for Aerosol Sampling from High-Purity Gases". [13] The pressure reduction device combines an orifice plate with an expansion chamber to reduce the pressure of the sample airstream. Once constructed characterization of the pressure reduction device will be required to determine any particle loss associated with the device.

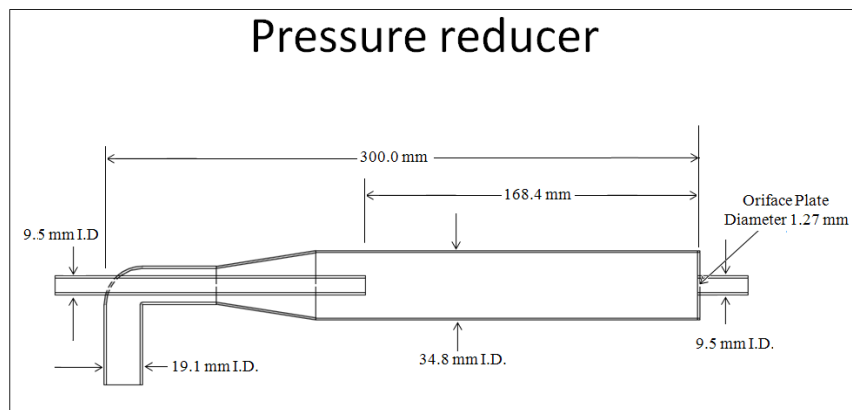


Figure 2. Pressure Reducer Design

*Aerosol Generation* - Upstream aerosol generation for efficiency test will be generated using the existing polydisperse DOP generator at ICET.

*Piping* - The upstream and downstream piping will be 15.2 cm (6 inch) stainless steel piping. The upstream and downstream piping will contain several ports for sampling. Couplings on the piping will allow for readings of pressure, temperature, and relative humidity.

*Air Heating* - The airstream inside the test stand is required to be heated to 400 degrees Celsius for the resistance to heated air testing. The air stream for the high temperature testing will be heated using the two existing air heaters at ICET that have a heating capacity of 150 kW and 72 kW

*Insulation* - Because the temperature inside the test stand will reach 400 degrees Celsius, fiberglass insulation will be used on all exposed piping for safety and reduction of heat loss from the test stand.

*Temperature Measurement* - The temperature inside the test stand will be measured at several locations including immediately before and after the filter elements to ensure they reach the required temperature. Omega Mini Temperature Transmitters with PT100 TRD Probes will be used to monitor the temperature in the test stand.

*Differential Pressure Measurement* - Differential pressure transducers will be used across the filter elements to monitor the pressure drop across the elements. Omega differential pressure transducers with various ranges will be used to monitor the differential pressure across the filter elements.

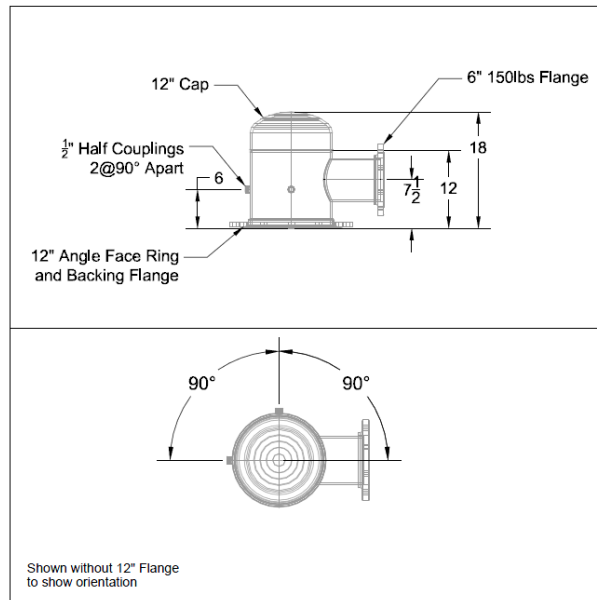
*Static Pressure Measurement* - The static pressure in the test stand will be monitored in several locations to ensure that the pressure in the test stand does not exceed 15 psig. ProSense pressure transmitters will be used to monitor the static pressure at various locations inside the test stand.

*Relative Humidity Measurement* - The relative humidity of the airstream in the test stand will be monitored to ensure consistent humidity levels during testing. Vaisala dew point and temperature transmitter will be used to monitor the relative humidity inside the test stand.

*Flow Measurement* - The flow rate inside the test stand must be monitored to assure that the filter elements are being tested at the rated flow for the elements. A Primary Flow Signal 6" venturi will be used downstream to monitor the flow rate.

*Housing* - The housing for the test stand will hold the filter elements being tested. The housing is made of schedule 40 stainless steel piping with a diameter of 30.5 cm (12 inch) and a total height of 4.6 m (15 feet). Because of the size of the test stand it will be taken apart into three sections. First the top section will be removed, and then the middle section with the filter elements will be lifted by a chain hoist and set on the ground. Next the tube sheet with the filter elements inside will be lifted out of the middle section for disassembly. The top section of the housing is 0.61 m (2 feet) long with an outlet port to the downstream section of the test stand and a dome cap welded on the top. Couplings on the top of the housing will allow for differential pressure and temperature across the filter elements to be measured.

The separate sections are connected together using 1034 kPa (150 lb) class flanges. The design for the top of the housing is shown in Figure 3.



The middle section of the housing is 2.44 m (8 feet) long so that filter elements up to 2.44 m (8 feet) long may be tested. The middle section has several ports available down the length of the section for sampling and visual examination of filter elements. In the future these ports will make it possible to examine the filter elements as they undergo blow back cleaning. Couplings on the housing will allow for differential pressure and temperature across the filters to be measured.

The design for the middle section of the housing is shown in Figure 4.

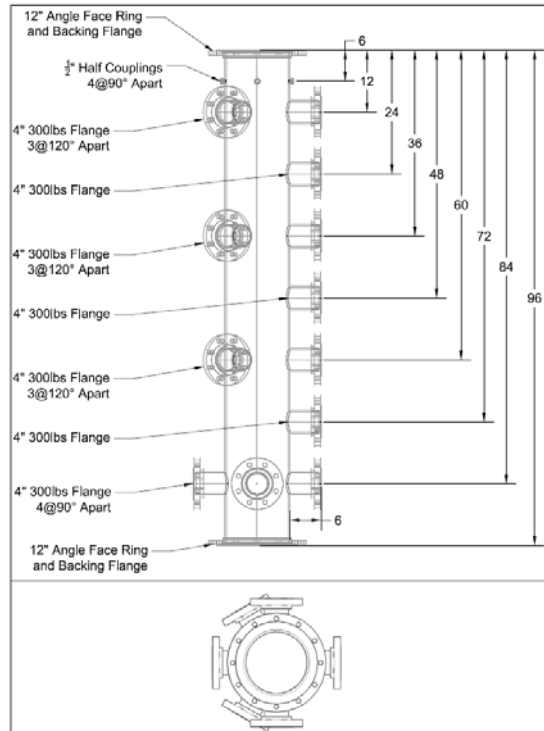


Figure 4. Housing Middle Section

The bottom of the housing will consist of a 0.9 m (3 ft) section with an inlet port connected to the upstream piping for the air flow to enter through, a sampling port to allow for sampling inside the housing, and a dome cap with a drainage port welded on the bottom that will allow the test stand to be cleaned out. Couplings on the bottom section allow for temperature and pressure readings.

The design for the bottom of the test stand is shown in Figure 5.

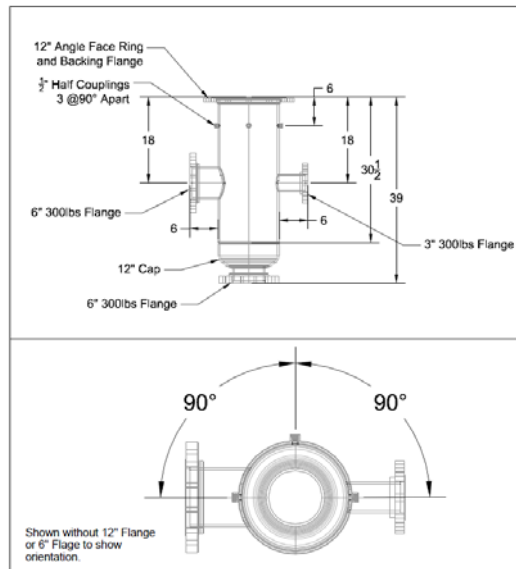


Figure 5. Housing Bottom Section



*Tube sheet* - A tube sheet designed by ICET capable of holding up to three filter elements will be secured inside the housing attached between the upper and middle sections of the housing. The design of the tube sheet allows for the elements to be attached individually onto the tube sheet to ensure proper sealing of the filter elements. Figure 6 shows the design of tube sheet.

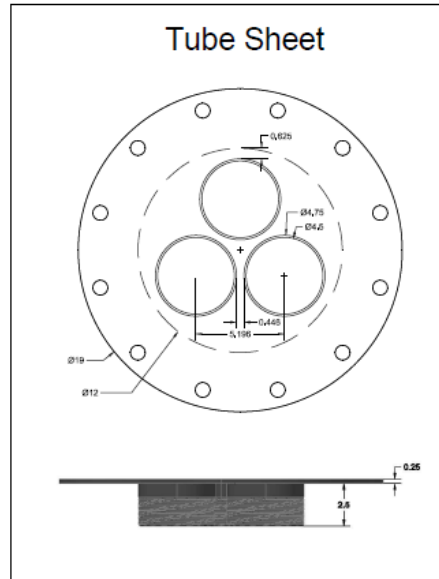


Figure 6. Tube Sheet

*Frame* - Because of the size of the test stand, a structure is needed to support the weight of the housing for assembly and disassembly. The housing will be located within the frame of the structure. This structure will also use a chain hoist connected to a beam across the top to lift and move the housing. This structure provides platforms for personnel to stand on beside the upper and middle sections of the assembled housing during testing. These platforms allow for access to ports on the sides of the test stand. The design of the structure is shown in Figure 7.

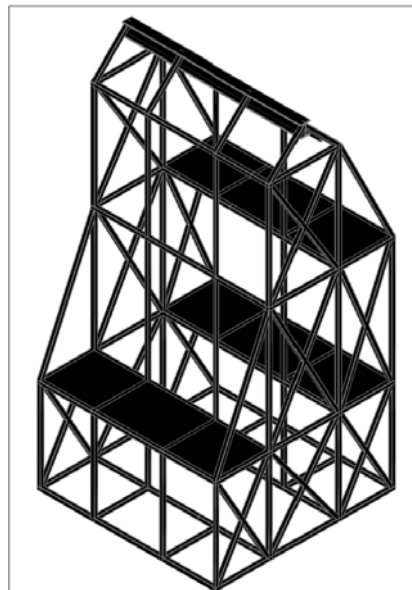


Figure 7. Test Stand Platform

## Current Test Stand

The top of the housing is shown in Figure 8.



Figure 8. Top Section of the Housing

The middle section of the housing is shown in Figure 9.



Figure 9. Middle Section of Housing

The bottom section of the housing is shown in Figure 10.



Figure 10. Bottom Section of the Housing

The upstream piping connected to the bottom of the housing is shown in figure 11.



Figure 11. Upstream Piping

The instrumentation for the housing will be installed onto the housing upon completion of construction.

## Calculations

*Pipe and Flange Selection* - The piping for the test stand is required to handle a maximum of 15 psig and 750 degrees F. ANSI/ASME B 31.1 for stainless steel piping shows schedule 40 stainless steel pipe to be sufficient to withstand 400 deg C at 103 kPa (15 PSI). According to ANSI B16.5 flange pressure class of 2068 kPa (300 lb) will be sufficient for the prescribed conditions in the test stand.

*Flow Rate* - The flow rate inside the test stand will be monitored using a venturi downstream of the housing. Because of the expansion of the air through the filters due to the change of pressure, change in flow rate from the upstream to the downstream sections will be accounted for in the calculation of the upstream flow rate by using conservation of mass. The following equations were used to determine the upstream flow rate [14].

$$\text{mass}_{\text{in}} = \text{mass}_{\text{out}} \quad (\text{Eq. 1})$$

$$\text{Volumetric}_{\text{flow}} = \text{Velocity} \times \text{Area} \quad (\text{Eq. 2})$$

$$\text{Mass}_{\text{flow}} = \text{Volumetric}_{\text{flow}} \times \text{Density} \quad (\text{Eq. 3})$$

The area is the cross sectional area of the piping. The density is the density of the air at the specified temperature and pressure and the velocity is found using the downstream venturi.

*High Temperature* – Resistance to high temperature testing will require that the filter media be heated to 400 Deg C (750 F). Air will be heated to using existing air heaters at ICET. Using an energy balance the required inlet temperature can be determined. The following equations were used to determine the temperature requirements of the inlet air [14].

$$E_{\text{in}} = E_{\text{out}} \quad (\text{Eq. 4})$$

$$q = \text{mass}_{\text{flowrate}} \times C_p \times (T_{\text{Entrance}} - T_{\text{Exit}}) \quad (\text{Eq. 5})$$

$$q = \frac{T_{\text{inside}} - T_{\text{ambient}}}{R_{\text{Total}}} \times \text{Area} \quad (\text{Eq. 6})$$

$$R_{\text{Total}} = R_{\text{inconv}} + R_{\text{condpipe}} + R_{\text{condinsulation}} + R_{\text{outconv}} \quad (\text{Eq. 7})$$

*Weight* – The large size of the test housing requires that the weight of the housing be found to ensure that the supports for the test stand will be able to withstand the load without failing. The weight of the housing was calculated to be 771 kg (1700 lb). The legs of the test stand were designed to withstand the weight of the housing as well as provide lateral stability. The following equations were used to determine the weight of the test stand.

$$\text{Weight} = \text{Density}_{\text{steel}} \times \text{Volume}_{\text{steel}} \quad (\text{Eq. 8})$$

## Aerosol Sampling Locations

The test stand will be comprised of three distinct sections: Upstream of housing, filter element housing, and downstream of housing.

*Upstream of Housing* – For the 15.24 cm (6 inch) pipe used in fabrication of the test stand, the aerosol sampling location upstream of the filter housing must be a minimum of 8 pipe diameters or 1.22 m (4 feet) downstream of any flow disturbance such as a bend in the pipe, a venturi, or point of aerosol injection. Likewise, this aerosol sampling location must be a minimum of 10 pipe diameters or 1.52 m (5 feet) upstream of any flow disturbance such as the filter housing.[15] Therefore the upper section of the test stand where sampling will occur must be at minimum of 2.75 m (9 feet) long. Additional length has been added to the upstream section to allow for multiple sampling ports. The test stand upstream of the housing will consist of approximately 3 m (10 feet) of 15.24 cm (6 inch) stainless steel piping, access ports, an air compressor, electric air heating bundle, volumetric flow control valve, DOP Generator, flow control sensor, particle measurement instrumentation, and air property measurement instrumentation.

*Downstream of housing* – As with the upstream sampling section of the test stand, the aerosol sampling location downstream of the housing must be a minimum 8 pipe diameters downstream of disturbances and 10 pipe diameters upstream of disturbances.[15] Therefore the aerosol sampling location downstream of the housing must be at least 1.22 m (4 feet) downstream of the filter housing and 1.52 m (5 feet) upstream of any flow disturbance such as a downstream venturi or pipe bend. The downstream measurement section of the test stand must then be at least 2.75 m (9 feet) long. Additional length has been added to the upstream section to allow for multiple sampling ports.

## **PARTICLE MEASUREMENT INSTRUMENTATION**

Aerosol measurement instrumentation that has been used in filter testing at ICET will be available for use with this test stand. Table 1 contains a listing of these instruments along with their particle size measurement ranges and maximum and minimum concentration ranges.

Table I. ICET Aerosol Measurement Instrumentation

<b>Instrument</b>	<b>#/cc (min)</b>	<b>#/cc (max)</b>	<b>Particle Size Distribution (µm)</b>
Scanning Mobility Particle Sizer (SMPS) <ul style="list-style-type: none"> <li>• TSI Model 3080 Electrostatic Classifier</li> <li>• 95 cm Custom Differential Mobility Analyzer (DMA)</li> <li>• TSI Model 3775 Condensation Particle Counter (CPC)</li> </ul>	2	1x10 <sup>8</sup>	0.008 - 1
Scanning Mobility Particle Sizer (SMPS) <ul style="list-style-type: none"> <li>• TSI Model 3080 Electrostatic Classifier</li> <li>• TSI Model 3081 Differential Mobility Analyzer (DMA)</li> <li>• TSI Model 3772 Condensation Particle Counter (CPC)</li> </ul>	2	1x10 <sup>8</sup>	0.008 – 0.6
TSI Model 3321 APS (with TSI Model 3302A Diluter)	1	1x10 <sup>3</sup> (1x10 <sup>5</sup> )	0.3 – 20
TSI Model 3340 LAS	<0.02	1.8x10 <sup>3</sup>	0.90 – 7.5

A compressor (or blower) will be used to initiate a flow of 50-200 CFM and no more than 15 psig upstream in the test stand. Because of the high pressure of the system upstream pressure reduction will be required for the particle measurement instrumentation. The upstream particle measurements will be accomplished using an APS and SMPS. Upstream pressure reduction for the APS and SMPS will be accomplished using a pressure reduction device. A diluter will be used with the APS to dilute the sample down by 100X so the particle concentration will be within the range for the APS. The SMPS will not require dilution. The downstream particle measurements will be accomplished using the LAS unless the particle concentration exceeds  $1.8 \times 10^3$  #/cc, at which point a CPC such as a TSI Model 3772 with a maximum concentration of  $1 \times 10^4$  will be used. No dilution or pressure reduction should be required downstream due to ambient pressure and low particle counts.

## **POTENTIAL BENEFITS**

Metal media filters can be produced to withstand a wide range of differential pressures, chemical exposures, and conditions that would rapidly destroy fibrous glass filters. Section FI of the AG-1 standard offers the potential to have durable, regenerable nuclear grade HEPA filter systems designed and implemented in applications unsuitable for existing filters. There are two major obstacles to finalizing Section FI for balloting and approval: (1) the infrastructure to qualify this very different type of filter and (2) testing protocols and data for specifying performance/qualification segments of Section FI.

The DOE Nuclear Air Cleaning Handbook requires that all equipment used in nuclear containment ventilation systems be compliant with the ASME AG-1 standard. This project will establish essential infrastructure necessary for finalizing Section FI. The test stand and accompanying instrumentation will have the capacity to generate data sufficient to establish approved methodology/protocols for qualification of metal media filters. There will also be the ability to use this test stand to design a functional and cost-effective qualification test stand.

It is imperative that all aspects of this work be conducted in accordance with the ANSI/ASQ Z1.13-1999 standard to ensure usability of work products.[16] ICET will implement its quality assurance program in manner consistent with the ANSI standard.

## **ACKNOWLEDGEMENTS**

We acknowledge the support of this work under DOE Cooperative Agreement DE-FC01-06EW07040.

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