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# Development and Evaluation of a HEPA Filter for Increased Strength and Resistance to Elevated Temperature



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# DEVELOPMENT AND EVALUATION OF A HEPA FILTER FOR INCREASED STRENGTH AND RESISTANCE TO ELEVATED TEMPERATURE*

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## Abstract

We have completed a preliminary study of an improved HEPA filter for increased strength and resistance to elevated temperature to improve the reliability of the standard deep pleated HEPA filter under accident conditions. The improvements to the HEPA filter consist of a silicone rubber sealant and a new HEPA medium reinforced with a glass cloth. Three prototype filters were built and evaluated for temperature and pressure resistance and resistance to rough handling. The temperature resistance test consisted of exposing the HEPA filter to 1,000 scfm (1,700 $m^3$/hr) at 700°F (371°C) for five minutes. The pressure resistance test consisted of exposing the HEPA filter to a differential pressure of 10 in. w.g. (2.5 kPa) using a water saturated air flow at 95°F (35°C). For the rough handling test, we used a vibrating machine designated the Q110. DOP filter efficiency tests were performed before and after each of the environmental tests. In addition to following the standard practice of using a separate new filter for each environmental test, we also subjected the same filter to the elevated temperature test followed by the pressure resistance test. The efficiency test results show that the improved HEPA filter is significantly better than the standard HEPA filter. Further studies are recommended to evaluate the improved HEPA filter and to assess its performance under more severe accident conditions.

## I Introduction

Previous studies have shown that the standard glass fiber HEPA filter may be structurally damaged under accident conditions that may occur in nuclear facilities(1-10). These studies have shown that the HEPA filter may be damaged when it is exposed to high values of

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temperature, moisture, smoke loadings, air flows, and pressure drops. The moisture weakens the strength of the filter medium and also restricts the air flow which causes an increased pressure drop. The smoke loadings from fires also restricts the air flow. due to the deposits. If the blower in the ventilation system has sufficient power to overcome the increased filter air resistance, then it is possible to structurally damage the filter medium and even blow out the entire medium from the HEPA frame.

The earliest environmental tests on HEPA filters were developed by the U.S. Army and specified in MIL-F-51068[11]. This standard describes a heated air test in which HEPA filters are exposed to an air flow at 700°F (371°C) for five minutes. It also describes a pressure resistance test in which a filter is exposed to a sufficient flow of humid air to produce a pressure drop of 10 in. w.g. for one hour. Another test method in the standard is the rough handling test in which the HEPA filter is vibrated. These tests comprise a portion of the tests that are required for HEPA filters to be used in U.S. Department of Energy facilities. Although these tests were adequate to address many environmental challenges for U.S. Army applications, they were not sufficient to evaluate the variety and severity of accident conditions postulated in nuclear accidents.

To investigate the performance of HEPA filters under simulated accident conditions, special test facilities were built in the U.S. and Europe. Los Alamos National Laboratory built a test facility at the New Mexico State University to study the effects of pressure shocks and tornados on HEPA filters. [1] A fire test facility was built at Lawrence Livermore National Laboratory to study the effects of fire and smoke on the ventilation system and HEPA filters.[2] The KFK institute in Germany built separate test facilities for high humidity and for high air flow studies.[3,4,9,10] The Atomic Energy Authority in England built a high temperature filter facility to measure filter efficiency under hot dynamic conditions.[5,6] The French CEA also built a similar high temperature facility for studying HEPA filters.[7] Except for the high temperature facilities, the other test facilities cannot measure the filter efficiency under the test conditions. The practice is to expose the filter to the desired environmental condition and then measure the filter efficiency in a separate test.

Previous researchers have shown that the reliability of the HEPA filter can be significantly improved by replacing components of the filter with stronger and/or more temperature resistant materials. Pratt [6] described a HEPA filter using a glass cloth reinforced filter medium from Lydall Inc. along with an unspecified high temperature sealant to seal the medium into the filter case. The filter was able to survive an exposure to 932°F (500°C) air flow with no observable damage. No efficiency measurements were reported. Ruedinger et al [9,10] also described high strength HEPA filters made with the reinforced HEPA paper from Lydall Inc.. They also described pleat separators made with inclined corrugations, that also improved the filter strength. They did not report any efficiency measurements. Ruedinger et al[10] reported that the German nuclear power plants are now using the higher strength HEPA filters.

The present study represents a preliminary effort to develop a HEPA filter with improved reliability to withstand accident conditions in U.S. nuclear facilities. This work represents a continuation of the previous work by Ruedinger[9-10] and Pratt[6] in developing a more robust HEPA filter. Like these previous researchers, we also used the glass cloth reinforced HEPA media from Lydall Inc. to make our prototype HEPA filter. In addition we used RTV silicone rubber for the sealant to seal the HEPA media into the frame for greater temperature resistance.

We had several prototype filters built and evaluated them against standard HEPA filters at the Rocky Flats Plant Filter Test Laboratory. This laboratory has existing test facilities for conducting heated air tests, pressure resistance tests and rough handling tests as specified in MIL-F-0051068[11]. Although more severe tests would be a better representation of potential accident conditions, there are no U.S. facilities comparable to those in Europe for high temperature and moisture exposure. Nevertheless, we felt that the available test facilities at Rocky Flats would still provide a relative comparison of the performance between the prototype and standard HEPA filter.

## II Prototype HEPA Specification

The specifications for the prototype HEPA filter are given in Table 1. The elements of the specification affecting frame, gasket, separators, and test performance are not unique. The requirements conform to Military Specification MIL-F-51068.[11] The variation by which temperature resistance and strength were sought was centered on the filter medium and the sealant. The filter medium was a water-repellent treated medium of glass fibers, corresponding to the Military Specification MIL-F-51079[12], but supplemented with a single scrim of glass monofilament. The monofilament measured 6.5 um in diameter and had a mesh size of 42 by 31 filaments to the inch. The filter was positioned for test with the scrim on the downstream face.

The conventional media to frame sealant for HEPA filters that is currently marketed is a polyurethane material containing a fire retardant. A room-temperature vulcanizing silicone rubber was chosen instead for this design. Although RTV silicone rubber is a more expensive material, its selection to provide additional temperature resistance for a specialized application was a logical choice.

Table 1. Specification of Prototype Filter

| | |
|---|---|
| Dimensions | 24 x 24 x 11.5 inches, excluding gasket. |
| Frame | 304 or 409 Stainless Steel. Four frame members to be preformed with double flanges, joints coated with sealant identified below before closing and closed with four bolts, nuts, and cut lock washers. |
| Medium | Lydair 3255-LW1. |
| Separators alloy | 3003-H19, 1145-H19, or 5052-H39 Aluminum of 0.0015 inch minimum thickness. |
| Sealant | Room Temperature Vulcanizing Silicone Rubber, Dow Corning 116. |
| Gasket | Oil-Resistant Expanded Cellular Rubber, ASTM D1056 SCE-43 or -44, 3/4 inch of width and 1/4 inch of thickness. |
| Test Performance | Penetration not to exceed 0.03% when tested at air flows of 1,000 and 200 SCFM with a Q107 DOP Penetrometer. Resistance to air flow of 1,000 SCFM not to exceed 1.0 inch, water gauge. |

Filters were fabricated to the design specified. Each was visually examined and tested for dioctyl phthalate (DOP) penetration at the DOE Filter Test Facility, Rocky Flats Plant, Golden, Colorado, and each conformed to the specification imposed on the manufacturer. These figures were maintained as a base so that penetration of a filter after testing could be used to assess degradation of the unit.

## III Filter Evaluation

The test filters were subjected to one or two of three different tests: heated air test, pressure resistance test, and rough handling test.

### Heated Air Test

Apparatus for the heated air test is shown in the sketch of Figure 1. It consists of a duct containing a blower, a natural gas manifold, adjustable vanes, and a movable exhaust duct that serves as a chuck to hold the filter in the path of the heated air. The Rocky Flats heated air apparatus generates an air flow of 1,000 standard cubic feet of air per minute (SCFM) (1,700 $m^3$/hr) which is heated to 700°F (371°C). The rig incorporates a number of improvements in design from the original model at the Edgewood Area of Aberdeen Proving Ground, Maryland, and the Underwriters Laboratories apparatus located at Northbrook, Illinois. The test method is described in Underwriters Laboratories Standard UL 586.(3)

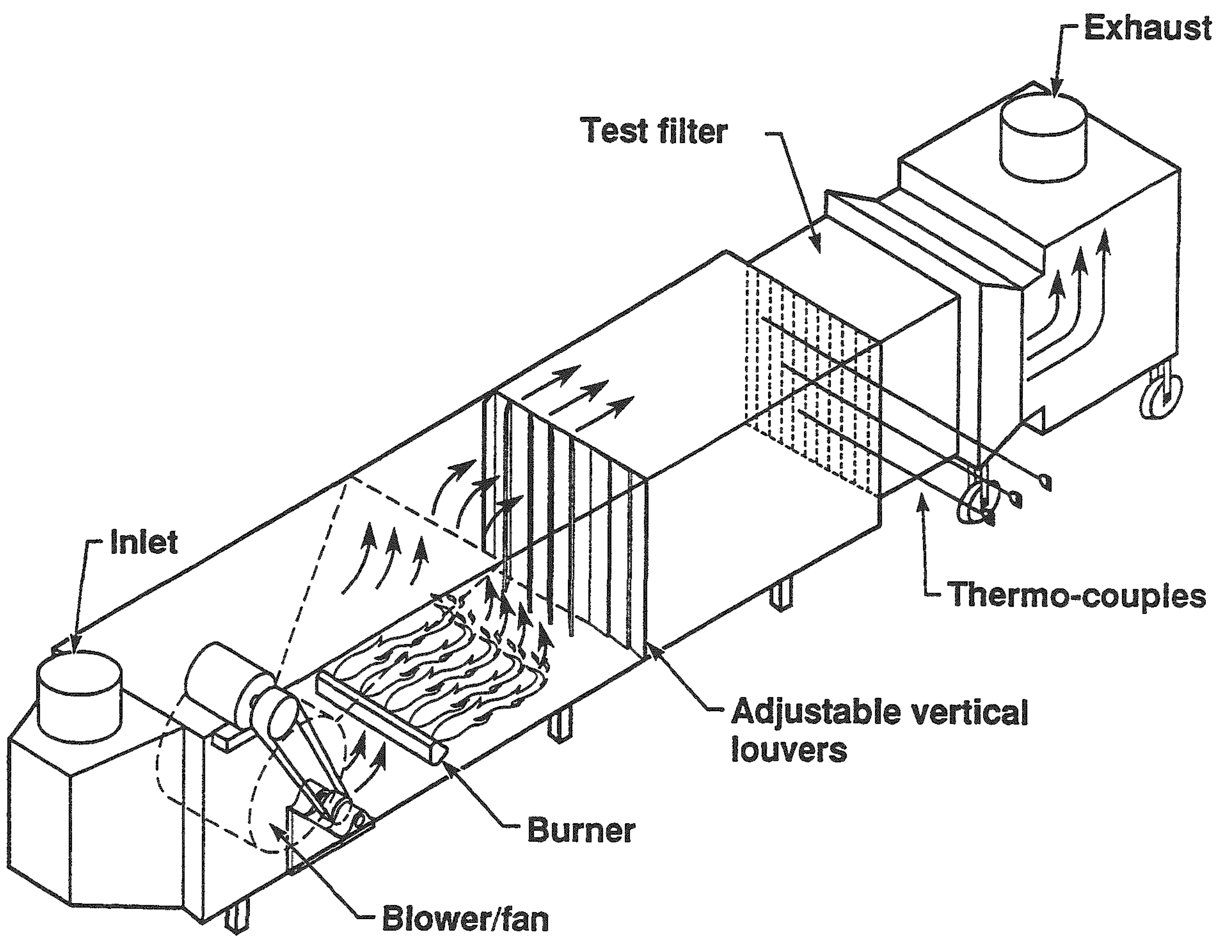


Figure 1 Heated Air Test Apparatus

One of the prototype filters was placed in the holding chuck of the heated air rig, shown in Figure 2. The blower was started and the air temperature was brought to 700 ±50°F (371 ±28°C), at which point the five-minute test began. Following this period of exposure, the gas flame was discontinued, and continued air flow cooled the apparatus to 80-100 degrees to permit removal of the filter.

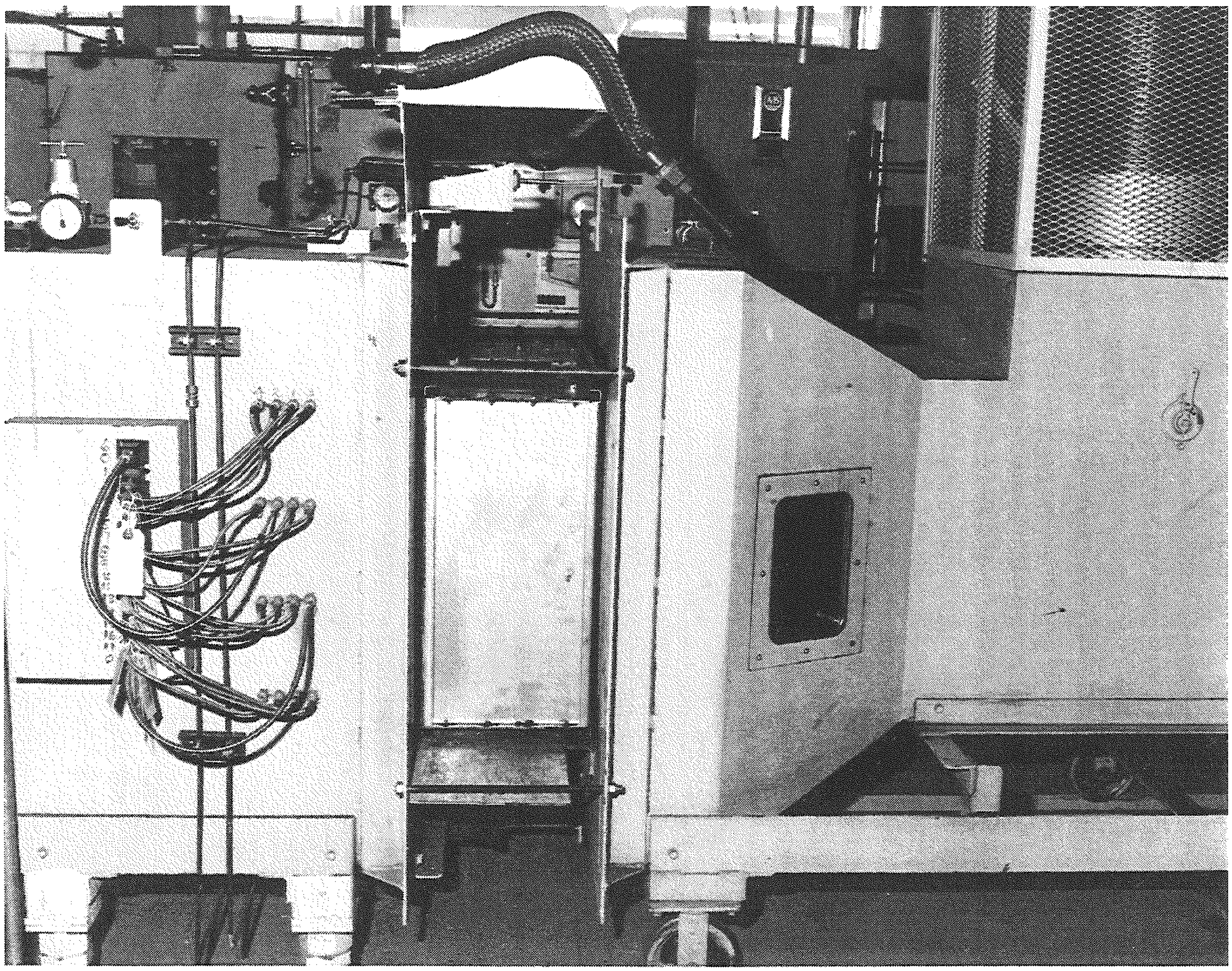

Figure 2 Filter Holding Chuck

Inspection of the prototype unit following the heated air test identified only one change. A few pleats of medium and separators deflected in the center of the pack and near the lower edge of the frame. This is shown in Figure 3. The change is attributed to expansion of the metal frame under the heat of the test and subsequent contraction after cooling. Pratt and Green(5) observed tears along the pleats when a high temperature sealant was used to join the filter pack to a metal frame. Ensinger et al(15) had observed similar kinking of the filter pleats, but no tears, when the conventional HEPA media was glued to a steel frame with silicone adhesive.

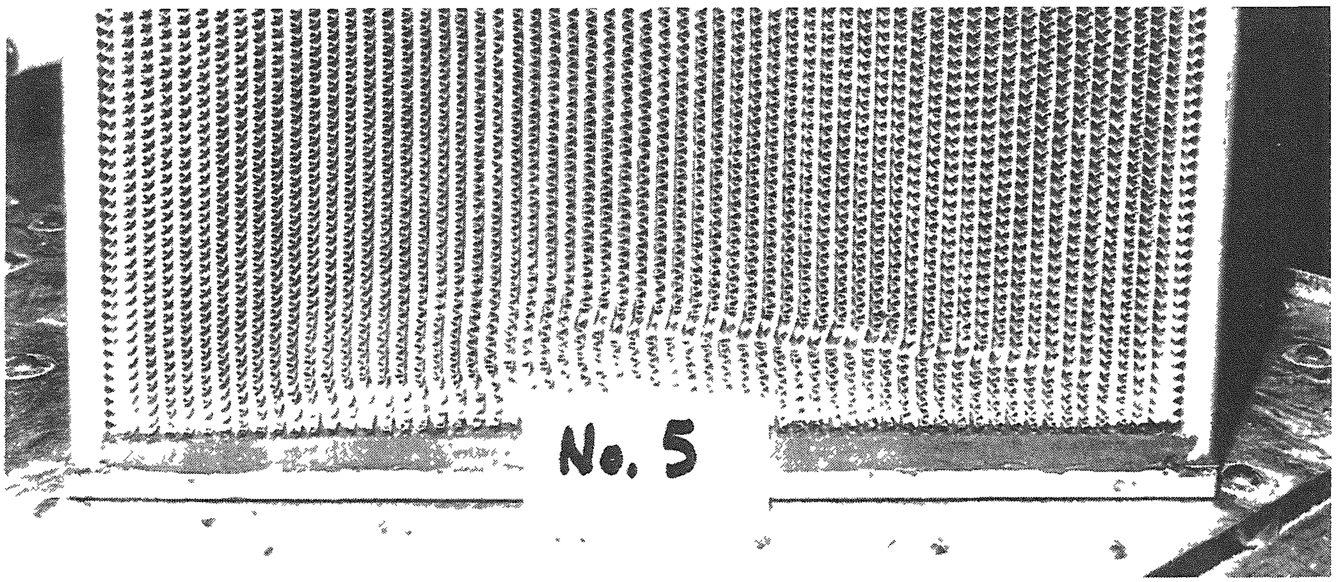


Figure 3 Deflected Medium and Separators

A standard HEPA filter fabricated with a wood frame and polyurethane as the sealant was designated as a control and subjected to the same test procedure. Following the testing, both units were measured for penetration with the Q107 DOP Penetrometer. Results of this stage of testing are given in Table 2.

Table 2 Results of Heated Air Test

| | Percent Penetration | |
|---|---|---|
| | Before | After |
| Filter Unit A | 0.010 | 0.070 |
| Control | 0.016 | 0.500 |

These two filters together with another of the prototype units were placed in an environmental chamber for 24 hours, Figure 4, where the relative humidity was controlled at 95%, ±5%, and the temperature was held at 95 ±5°F (35 ±3°C). Test filters are preconditioned in preparation for the pressure resistance test.

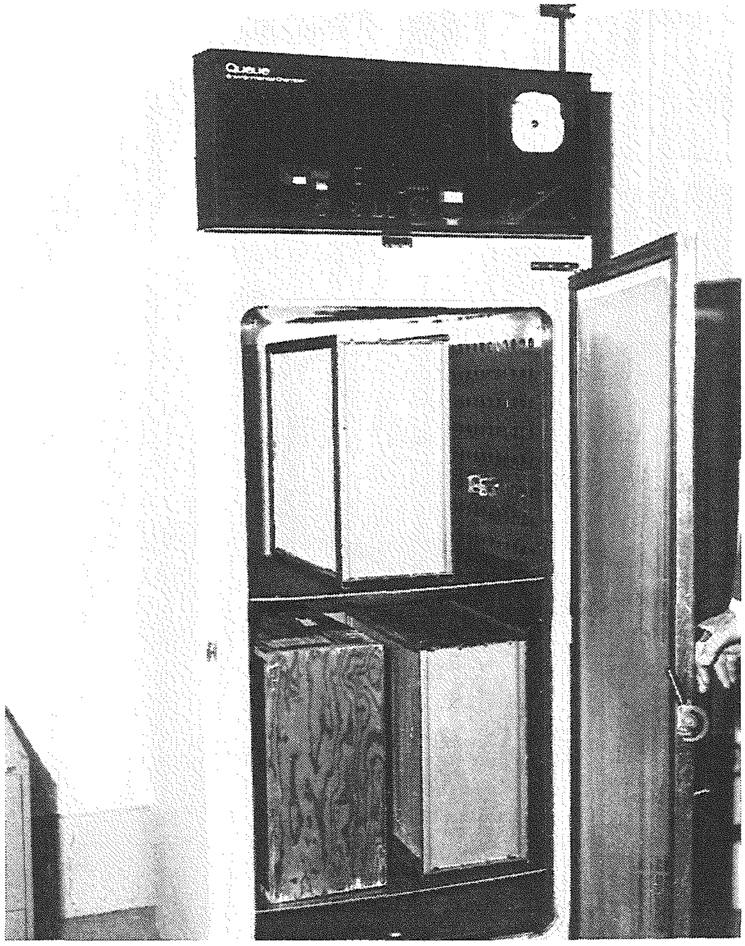

Figure 4 Environmental Chamber

Pressure Resistance Test

The pressure resistance test apparatus is an elongated elliptical chamber through which air and moisture are recirculated to a test filter. An overhead view of the Q160 pressure resistance apparatus at Rocky Flats Plant is shown in Figure 5. A filter that is positioned for testing as viewed through the access door opening is shown in Figure 6. Refer to the the simplified sketch shown in Figure 7 to better understand the test procedure. The blower is started together with the introduction of steam, condensing to water droplets, and the volume of air is increased to maintain a resistance of 10 inches water gauge (2.5 kPa) across the filter. Water droplets are generated at a rate of one pound ±1/4 pound (114 g) per 1,000 cubic feet (1,700 $m^3$) of air. At 10 inches (2.5 kPa) of pressure drop the air flow, combined with the moisture, measures between 7,000 to 8,000 cfm (11,900 - 13,600 $m^3$/hr) . This pressure is maintained on the filter for a minimum of one hour.

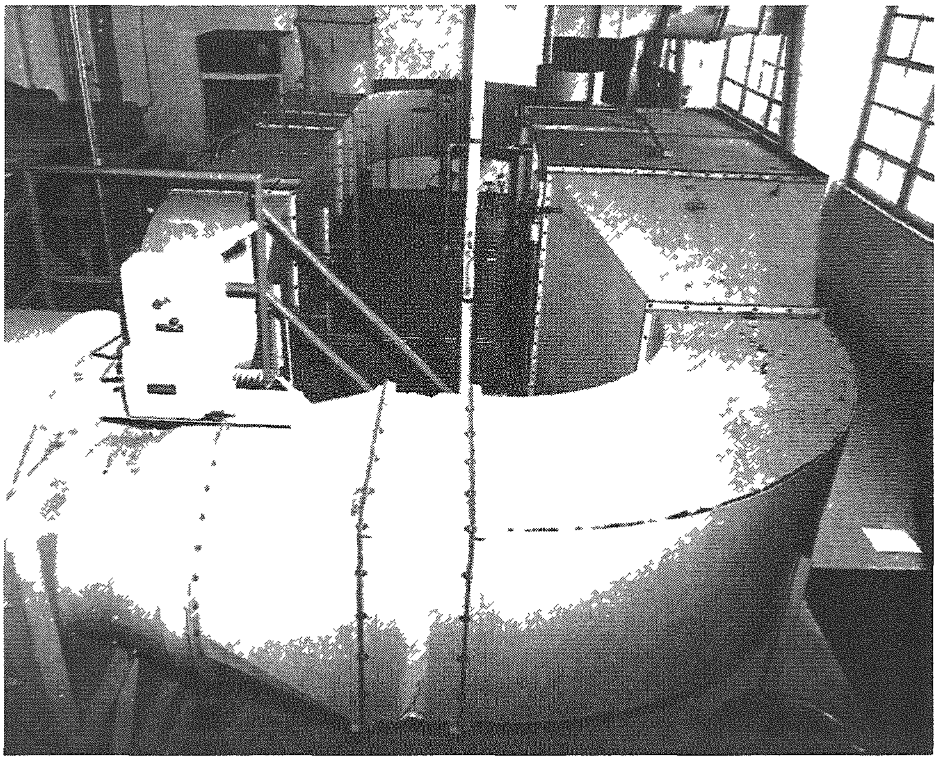

Figure 5 Pressure Resistance Apparatus

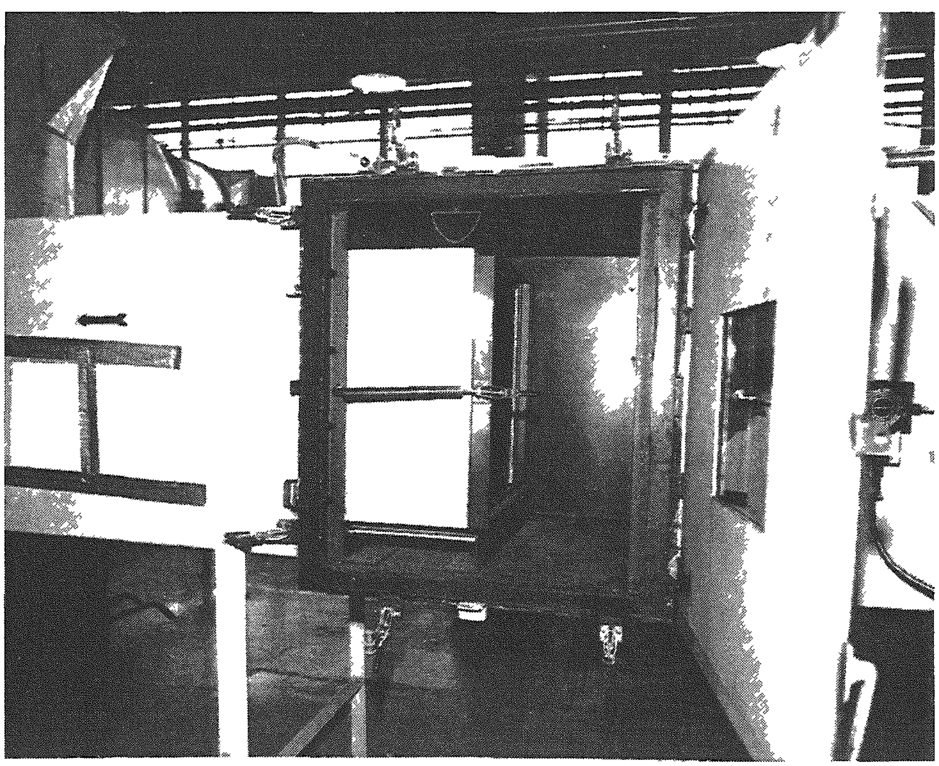

Figure 6 Test Filter with Access Door Open

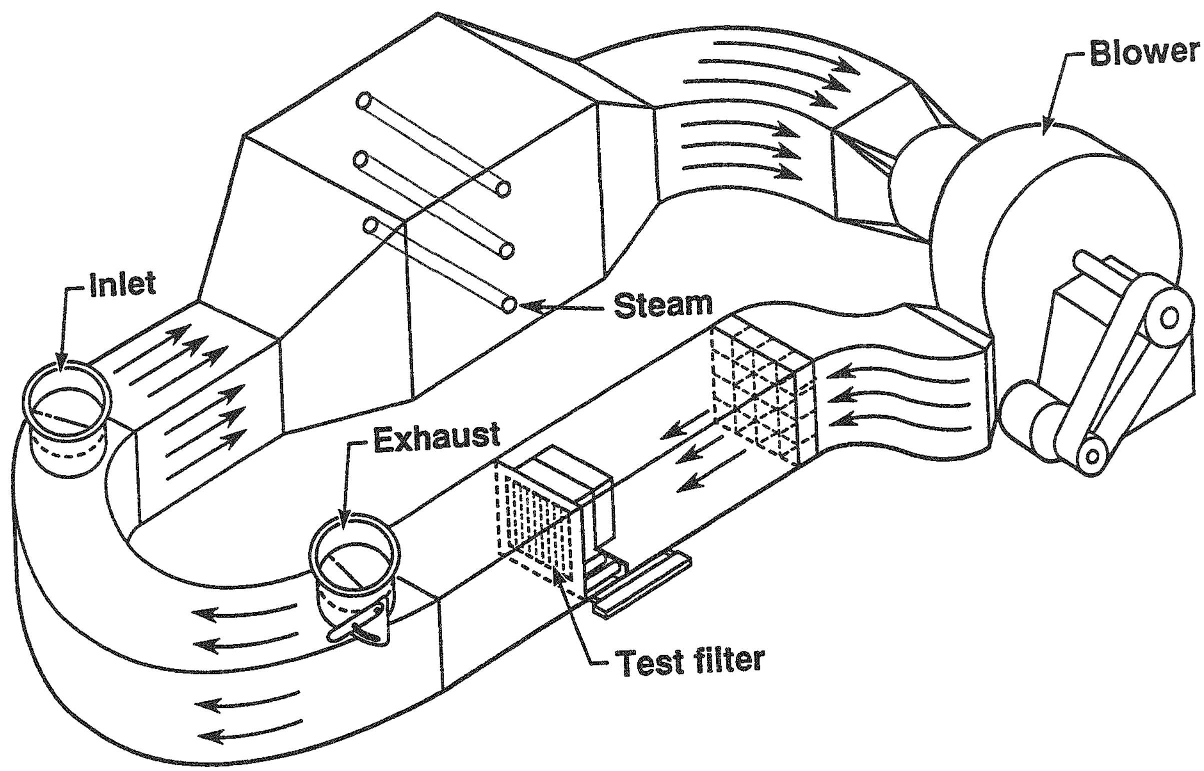


Figure 7 Diagram of the Pressure Resistance Apparatus

Although the practice at the Edgewood Area of Aberdeen Proving Ground is to measure penetration of the filter promptly after its test, the procedure at Rocky Flats is to terminate water droplets and continue the air briefly to remove detectable water and let the filter stand over night before measuring its penetration. The Rocky Flats modification assumes that any perforations of the filter from the pressure resistance test will be detected where otherwise they might be bridged and occluded by residual moisture.

The three filters which had been preconditioned for 24 hours were tested with the Q160 pressure resistance equipment. Results are shown in Table 3.

Table 3 Results of Heated Air and Pressure Resistance Tests

| | Percent Penetration | | |
|---|---|---|---|
| | Before Testing | After Heated Air | After Pressure Resistance |
| Filter Unit A | 0.010 | 0.070 | 0.070 |
| Control Filter | 0.016 | 0.500 | 1.000 |
| Filter Unit B | 0.005 | --- | 0.006 |

Filter Unit A changed from an initial penetration of 0.01% to 0.07% after the heated air test, which is better than expected, and showed no additional increase after exposure to a 10-inch (2.5 kPa) pressure drop of air and water for an hour. In contrast, the control filter increased from 0.016 to 0.5% after the heated air test and additionally to 1.0% after the pressure test. Figure 8 shows the severe charring of the urathane sealant on the upstream side of the filter. The charring was equally severe on the the downstream side. Two vertical linear cracks in one pleat are visible in the center of the downstream face, Figure 9. These cracks appeared after the combined exposure of heated air and pressure resistance. A second prototype filter, unit B, was subjected to a one hour pressure resistance test and showed only a slight increase in penetration from 0.005% to 0.006%. Comparing the penetration of filter unit B to unit A shows that the heated air test is more damaging to the HEPA filter than the pressure resistance test.

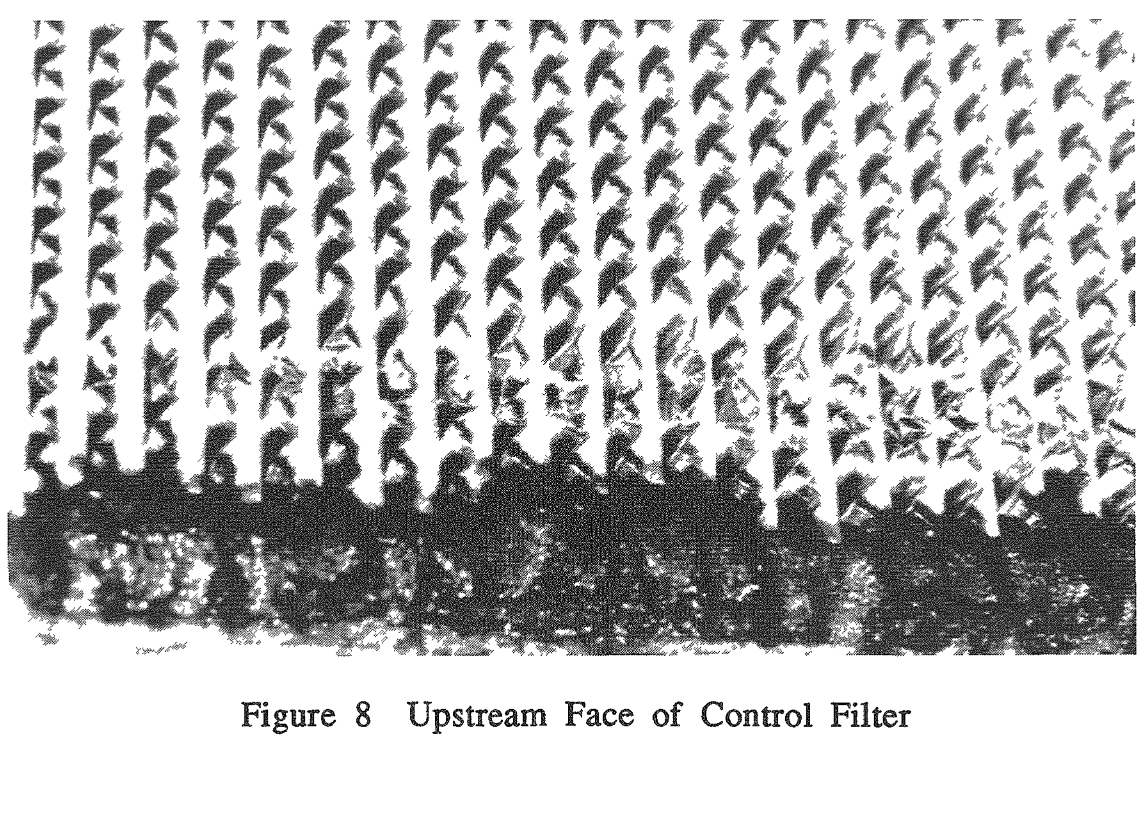

Figure 8 Upstream Face of Control Filter

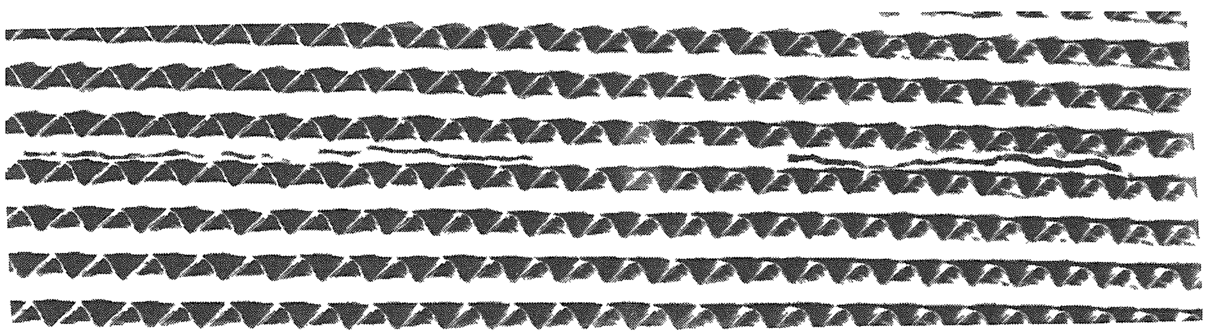

Figure 9 Cracked Pleats on Downstream Face

The maximum allowed penetration of a filter after exposure to heated air is 3.0% according to MIL-F-51068 although any excess beyond 1.0% after this test is a rare occurrence. The performance of the control filter therefore was within the allowable increase of penetration. The ruptured pleat following the pressure resistance test was not expected, however. All of the filters met the current test requirements.

Rough Handling Test

The rough handling test has been used for many years and the test procedure is described in the 1956 issue of MIL-STD-282.[4] The equipment in essence is a vibrating machine designated the Q110 and is designed to simulate transportation vibrations. It provides a platform, to which the filter is attached, and it mechanically moves the bed 200 cycles per minute at an amplitude of 3/4 inch. A view of one of the two cams that lifts and drops the platform is shown in Figure 10.

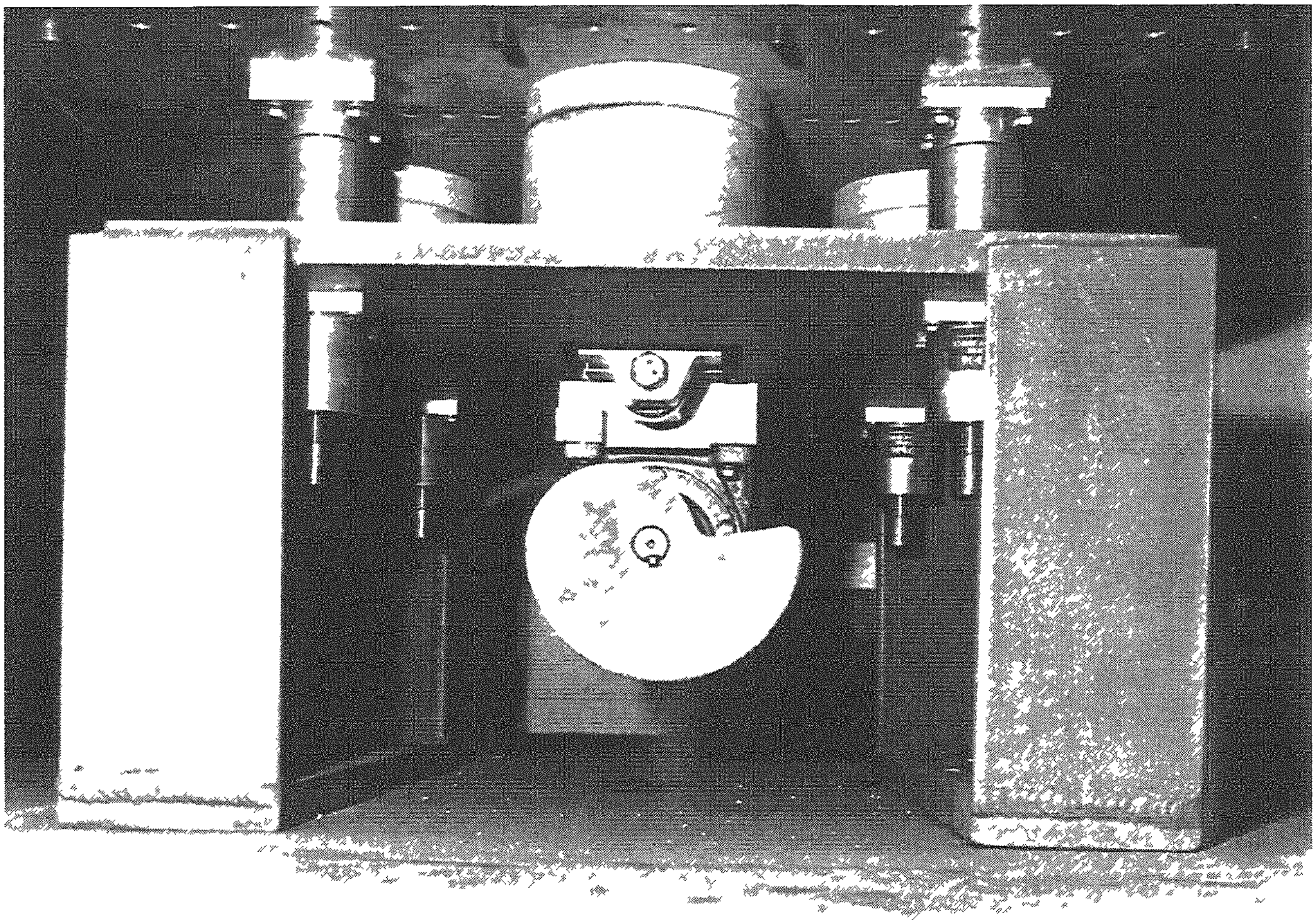

Figure 10 Cam for Lift/Drop Platform on Rough Handling Apparatus

The normal test procedure is to remove the filter from its shipping carton and strap it to the Q110 Vibrating Machine for test. Sixteen years of quality assurance testing at Rocky Flats dictated that transportation of the filter induced more mechanical damage than any other cause. Therefore the test procedure for rough handling was modified to test the filter within its shipping carton. Frequency of 200 cycles per minute and amplitude of 3/4 inch were unchanged. Damage is determined by any increase of DOP penetration above the penetration recorded upon initial test following receipt of the filter. The original procedure to test the uncartoned filter element removed from its shipping carton required two long threaded studs to which a bar was bolted across the filter. The modified test procedure employs four such studs positioned on four sides of the filter packaged in its shipping carton. A plate is bolted to the four studs to hold the filter enclosed in its shipping carton to the platform. The studs and plate are shown in Figure 11. Figure 12 depicts the enclosed filter ready for testing.

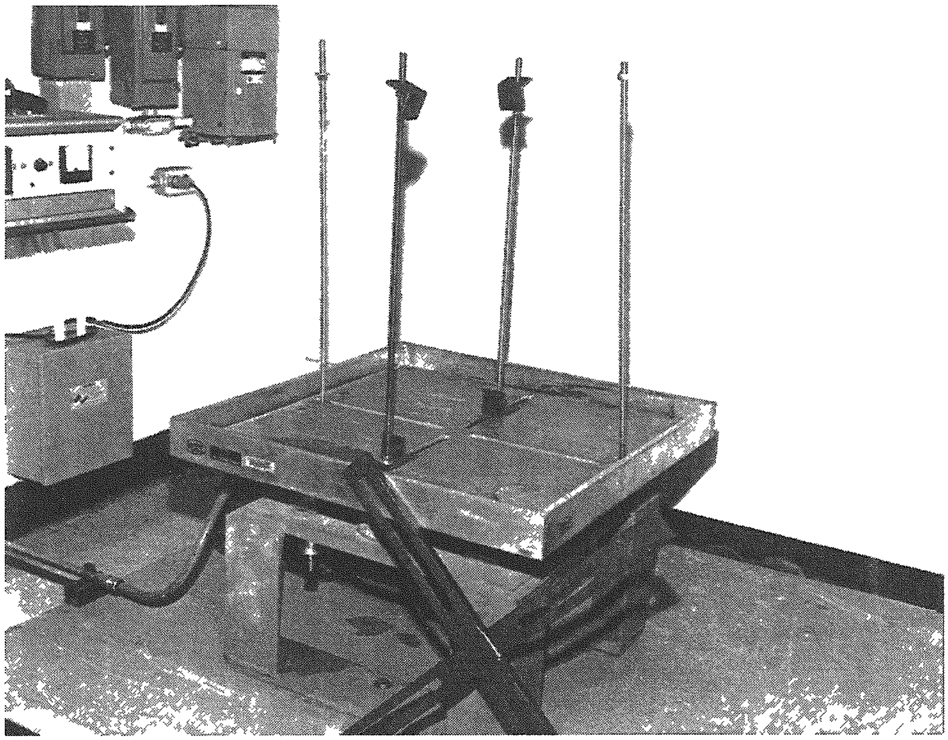

Figure 11 Rough Handling Test Apparatus

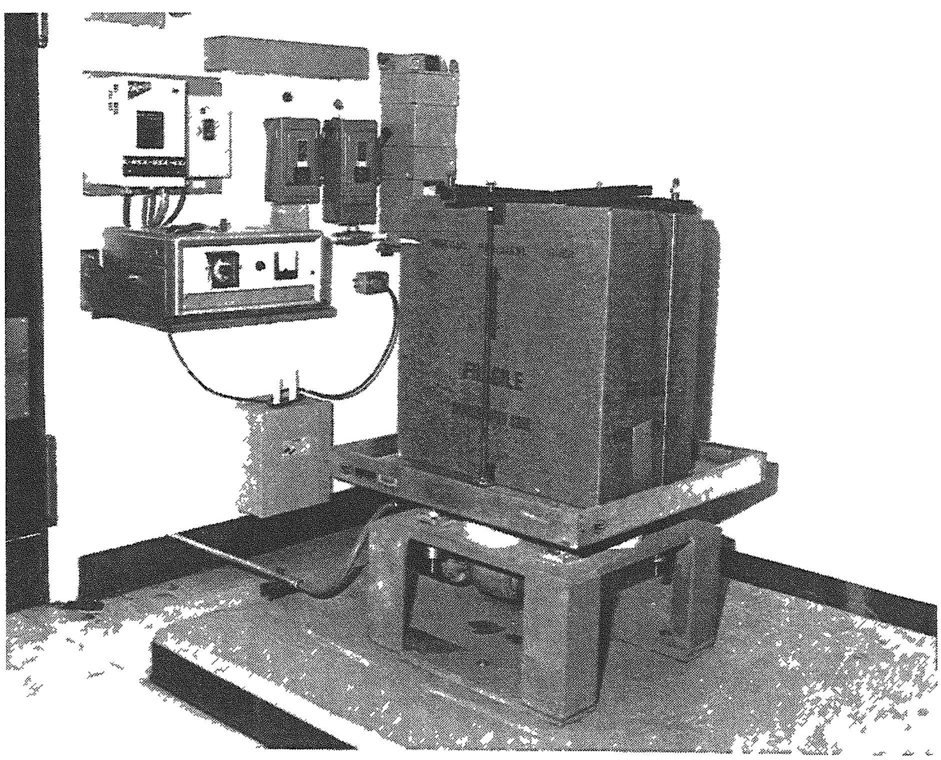

Figure 12 Enclosed Filter Ready for Testing

One of the prototype filters, enclosed in its carton, was bolted to the platform of the Q110 Vibrating Machine, and the test apparatus was operated for the 15 minutes stipulated for the test. Penetration of the filter before and after testing is given in Table 4.

Table 4 Results of Rough Handling Test

| | Percent Penetration | |
|---|---|---|
| | Before | After |
| Filter Unit C | 0.006 | 0.006 |

Penetration through Filter Unit C was unchanged after the rough handling test.

## IV. Conclusion

All of the tests described above are termed destructive tests. They are intended to evaluate the fire resistance, strength, and reliability of the design of a HEPA filter. Many HEPA filters, of both conventional and novel design, have withstood these tests at the Edgewood Area of Aberdeen Proving Ground. This is required for identification on the Qualified Products List (QPL) of the Department of Defense. In addition, many models of HEPA filters have successfully undergone the heated air test of UL 586 in order to bear the "UL" label. Although these tests were adequate to address many environmental challenges for Army applications, they are not sufficient to evaluate the variety and severity of accident conditions postulated in nuclear accidents. We have nevertheless used these tests because of their availability and the fact that they can provide a relative comparison between prototype and standard HEPA filters.

This study differs from most previous investigations of HEPA filters under accident conditions in that the same test filter was subjected to more than one environmental test. The previous practice was to subject a filter to only one destructive test. In our study, we evaluated the prototype and standard HEPA filters in a test sequence consisting of a heated air test followed by a pressure resistance test. Ruedinger et al[10] had previously reported that they used a test sequence consisting of elevated temperature in still air, pressure resistance in high air flow, and humid air resistance to qualify filters for use in nuclear reactors.

The results from our preliminary study show that the prototype filter can withstand exposures to heated air and higher pressure significantly better than the standard HEPA filter. The scrim backed medium and the silicone rubber seals are considered the most significant contributors to the improved performance of the prototype, and the design might be given serious consideration for use in applications subjected to a harsh environment and to design basis accidents in nuclear facilities. We recommend that further studies be conducted to assess the filter's performance under more severe accident conditions.

## V. Acknowledgment

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