SAFETY OF HEPA FILTER UNITS IN HANFORD B-PLANT EXHAUST VENTILATION SYSTEM

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1. SUMMARY AND CONCLUSIONS

This report reviews the safety of High Efficiency Particulate Air (HEPA) filter units used in the Exhaust Ventilation System of the 221-B Canyon (B-Plant) at the Department of Energy (DOE) Hanford site near Richland, Washington. Four HEPA filter units, known as the A- through D-Filters, have been used at the B-Plant since 1966 to prevent the release of radionuclides from the processing of cesium and strontium materials.[1] Since this time, the HEPA filter units have accumulated between 10^8 and 10^9 rads of exposure. Exposures continue to accumulate at a rate of approximately 10 million rads per year.

The A- through C-Filter units have been retired from service. The current operating unit, the D-Filter, is near the exposure level where the A- and B-Filters were when they were retired from service. In addition, the D-Filter is down to the last two stages of filtration, and pressure drops across the last two stages are either behaving anomalously or indicating that the next to the last HEPA filter bank (Filter #2) may be experiencing breakthrough.

A fifth installed, but unused, filtration unit (E-Filter) could be placed in service after appropriate check-out and testing. The check-out and testing should require no more than a few weeks of time. In the past, there have been various recommendations to place E-Filter in service, but these recommendations were never acted upon.[2,3,4] However, current plans are not to place E-Filter in service and retire the D-Filter until an independent filtration system required for B-Plant decommissioning is installed and operational. This is currently projected to be years away. The D-Filter will only be retired if allowable differential pressure or release rates are exceeded. There is another filtration unit (F-Filter) that could be used as a standby unit.[4]

It is well known that radiation exposure, aging, repeated wettings, and certain adverse environmental conditions will degrade HEPA filter materials.[5,6,7,8,9,10,11] However, there is a lack of definitive experimental data and adequate operational experience to provide both technical justification for the continued use of HEPA filters with a radiation exposure of approximately 10^8 rads coupled with other degradation mechanisms (i.e., D-Filter). Additionally, sole reliance on normal filter testing methods is not acceptable, because these test results are not indicative of the true mechanical strength of the filter materials after such a high radiation exposure.

The primary conclusions of this safety review of the HEPA filter units in the B-Plant exhaust ventilation system are these:

a. The D-Filter is near the accumulated radiation exposure at which other B-Plant HEPA filters were retired (about 10^8 rads) and appears to be showing signs of failure (i.e., breakthrough). Retiring the D-Filter and placing the E-Filter in operation, after appropriate testing, would significantly reduce the potential and severity of radiological releases during normal operations and accidents. In addition, the F-Filter could be made ready for service and placed in standby.

b. In the B-Plant interim safety basis (ISB) accident analysis,[12] Westinghouse Hanford Corporation (WHC) calculated a hypothetical dose of approximately 200 rem Effective Dose Equivalents (EDE) on site and approximately 100 mrem EDE off site from a postulated failure of the filter units. This safety analysis assumes structurally sound HEPA filters--not HEPA filters weakened by very large radiation exposures, aging, and repeated wettings. Therefore, the potential exposures may be significantly greater than those indicated in the B-Plant ISB.

c. The outlet water seals do not provide reliable isolation of the retired HEPA filter units.[13] The water seals will be used to keep the retired A- through C-Filters isolated until the decommissioning phase, when the final disposal of the filters will be addressed. However, the water seals are subject to evaporation, potential leaks, and inadvertent steam jetting. The Board's staff believes that leaving the outlet water seals in their present configuration for several more years does not appear to be prudent. It appears that additional effort is warranted to identify an alternative that would provide enhanced reliability and not adversely impact future remediation of the filters.

d. The current deactivation plans for B-Plant include the bypass and isolation of the HEPA filter units. The remediation of these filters, which contain large amounts of radionuclides (approximately 750,000 Curies of cesium-137 and strontium-90), will be deferred to the decommissioning phase. There are no firm plans or estimates of when the remediation of the filters will take place. Considering the large source term, a history of intrusions (i.e., flooding of filter cells), and the potential for a large release to the environment, it would be prudent to expedite the remediation of these filter units.

e. There is no DOE standard or consensus industry standard that provides definitive criteria for HEPA filters subject to high radiation exposure, aging, and adverse environmental conditions. The lack of such a standard subjects all DOE defense nuclear facilities to a greater uncertainty regarding the ability of aging HEPA filters to prevent the inadvertent release of nuclear materials to the environment. It also leads to the operation of HEPA filters in a realm beyond available experimental data.

2. BACKGROUND

a. Exhaust Ventilation System Description

The exhaust ventilation system in the B-Plant contains HEPA filters and an emergency backup sand filter to filter the exhaust air from operations in the canyon before it is released to the environment through a stack. The system has five HEPA exhaust filter units (A- through E-Filter) and a partially complete F-Filter (Figure 1). Figure 1 also depicts the number of stages of HEPA and prefiltration available, and a detail depicts D-Filter operating with three stages bypassed. The A-, B-, and C-Filters have been retired from service behind outlet water seals (Figure 2), which prevents air flow through the units. The D-Filter has been operating since 1979. The E-Filter has never been used. The D- and E-Filter each have a capacity of 75,000 standard cubic feet per minute (scfm) of air. A- through D-Filter contain significant radionuclide loadings (Appendix B). The exhaust airflow is controlled by ventilation fans and dampers, instrumentation, and the canyon ventilation control system. As shown in Figure 1, exhaust fans draw exhaust air from the canyon building through the exhaust ventilation duct, through D-Filter, and then they discharge the exhaust air through the stack. Appendix A provides a detailed description of the design and operating history of the B-Plant exhaust ventilation system.

b. Deactivation and Decommissioning Plans

In December 1995, the B-Plant began a planned three-year deactivation program under the direction of DOE's Office of Nuclear Material and Facilities Stabilization. During the deactivation program, a new exhaust ventilation filter system (Project W-0059) will be constructed to bypass all existing filters. The new filtration system is scheduled for completion by September 1998, but may be delayed by budgetary or other considerations. The current plan is to continue to use the D-Filter until the new filter system becomes operational. At that time the current filters will be isolated by some yet to be determined means. When the deactivation program is complete, the B-Plant will be transferred to DOE's Office of Environmental Restoration for decommissioning. Although the existing filters will be included in the decommissioning plan, the schedule and final disposition of the filters have not been determined.

Ventilation System Schematic

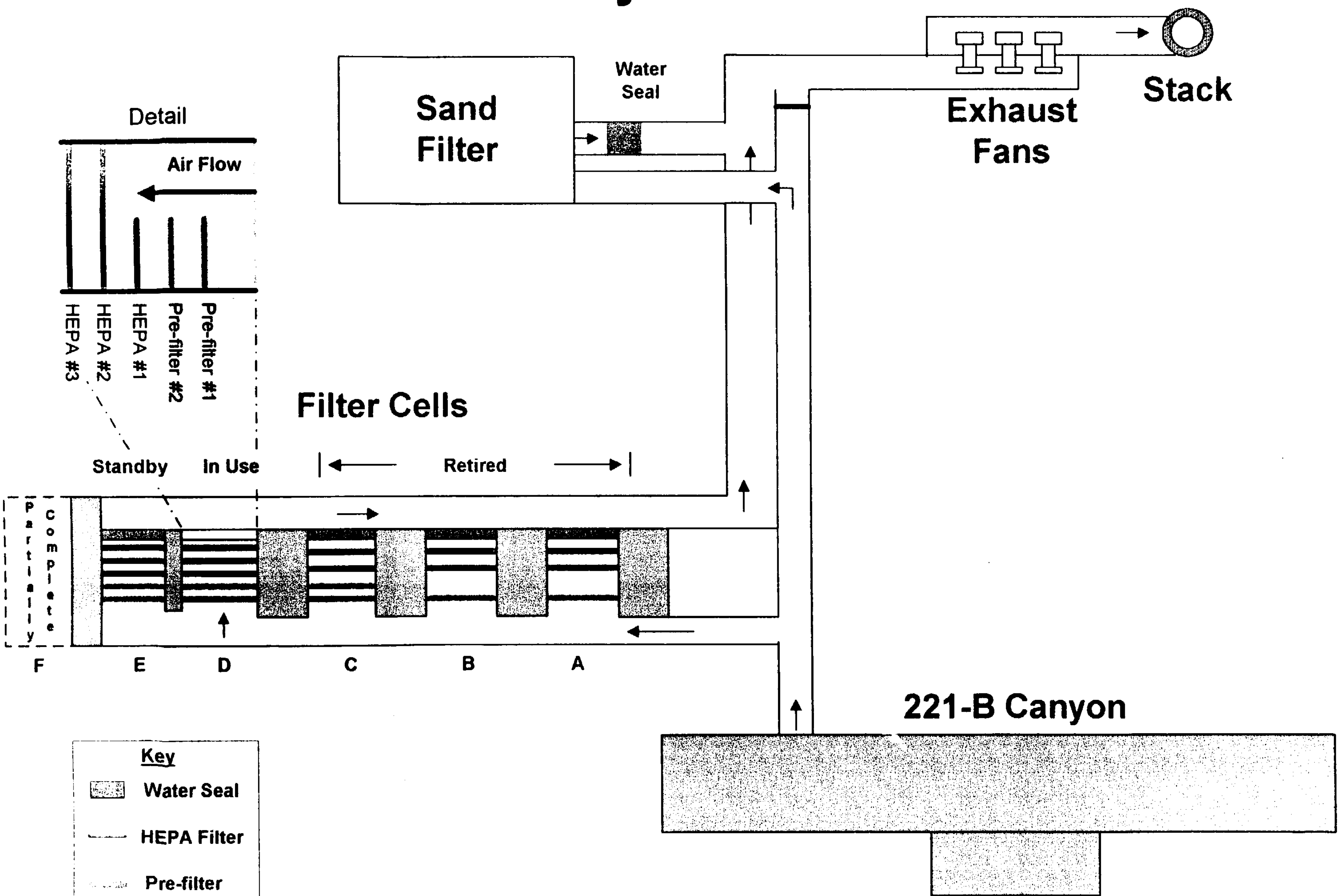

Figure 1

Outlet Water Seal Design

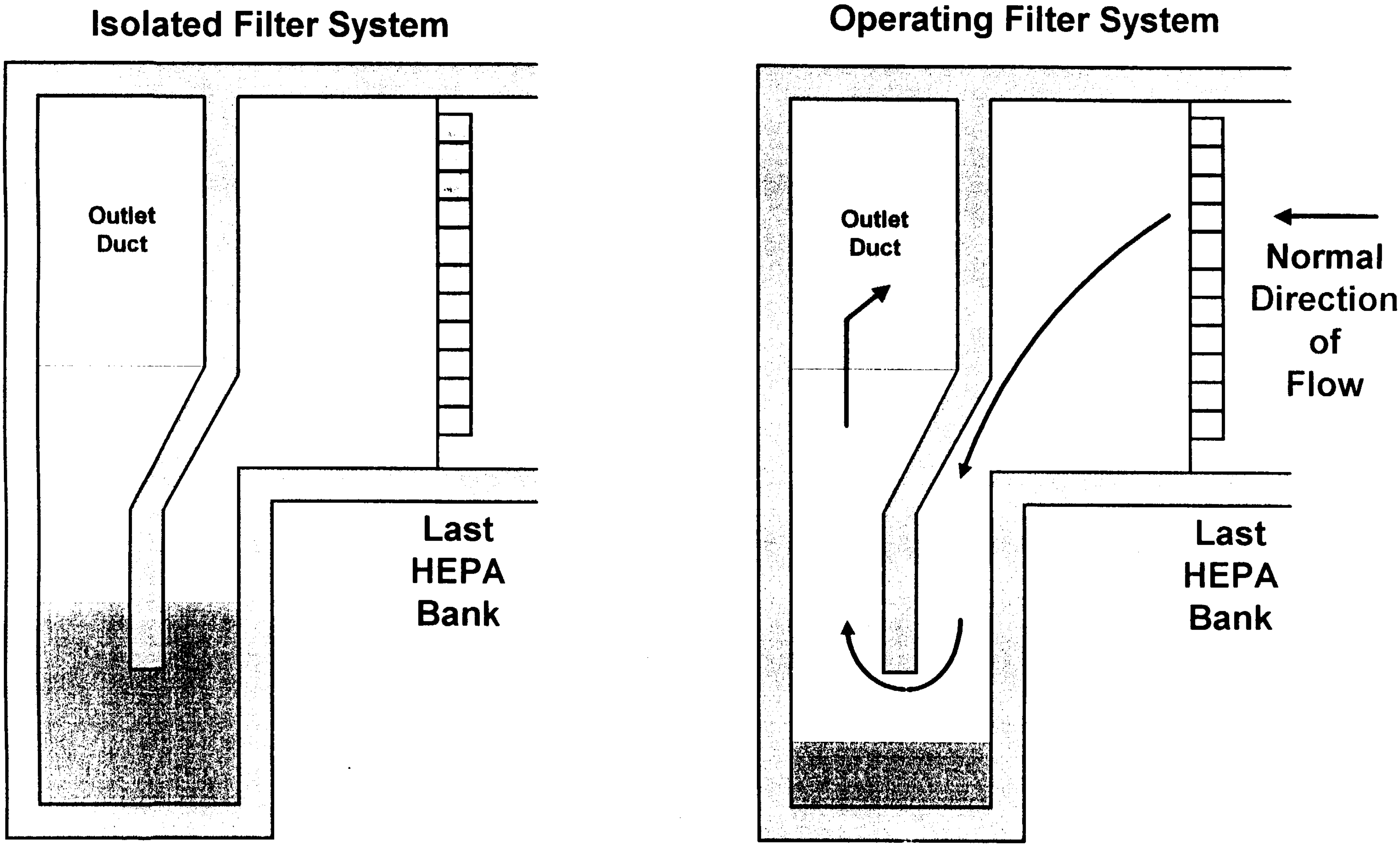

Figure 2

3. TECHNICAL DISCUSSION

a. HEPA Filter Performance

(1) D-Filter Operating Configuration

The D-Filter unit is now operating with only the last two HEPA filter banks (i.e., Filters #2 and #3). The two pre-filter banks and the first HEPA filter bank have been bypassed due to excessive differential pressure. The D-Filter is estimated to have a radionuclide inventory that is about an order of magnitude higher than the A-, B-, or C-Filter (Appendix B). Also, the current estimated accumulated exposure (Appendix C) of D-Filter is approximately that of A- and B-Filter when they were retired in 1993. Exposure continues to accumulate on A-, B-, and D-Filters at a rate of approximately 10 million rads per year. It should be noted that the WHC inventory and exposure accumulations estimates for A-, B-, and D-Filters are inconsistent but within measurement and calculational accuracy. Further, the C-Filter inventory and exposure estimates are inconsistent and are not explainable.

(2) Filter Testing

Filters are tested in place by use of an aerosol simulant. In the past, dioctylphthalate (DOP) has been used as the simulant. A noncarcinogenic aerosol simulant, poly alpha-olefin (PAO), is used today. The aerosol simulant is vaporized and introduced into the upstream side of a filter. The upstream and downstream aerosol simulant concentrations are measured with a light scattering photometer. Typically a concentration change of five to six orders of magnitude can be detected with the photometer. One bank of HEPA filters can produce four orders of magnitude concentration change. Therefore, two banks in series can produce concentration changes beyond the capability of the typical photometer. Conversely, obtaining any measurable concentration of aerosol simulant across two banks of HEPA filters may indicate that one of the banks is not properly operating (i.e., filter breakthrough).

The American Society of Mechanical Engineers (ASME) Standard N510, *Testing of Nuclear Air Treatment Systems*,[14] is a nationally recognized standard used for testing of installed HEPA filtration units. It is applicable to systems designed in accordance with ASME Standard N509, *Nuclear Power Plant Air Cleaning Units and Components*,[15] and is selectively applied to older systems. For B-Plant, the following requirements of ASME N510 are not met: air flow distribution, air aerosol uniformity, and concentration measurement across each stage. Therefore, the test results need to be viewed with some degree of uncertainty. The D-Filter was last tested on April 28, 1995, and showed a 0.004% (4×10^{-5}) penetration across both filter banks,[16] which meets the current WHC acceptance criteria.[17] However, with a normal filter efficiency of 99.95%, a penetration of 2.5×10^{-7} would be expected. A penetration of 4×10^{-5} is within the measurement capability of the photometer and indicates that the two HEPA banks are operating at a somewhat degraded efficiency.

(3) Filter Differential Pressure Limits

The maximum design differential pressure for a new HEPA filter is about 10 inches of water column for 1,000 scfm of air flow. The manufacturer's recommended differential pressure limit, for establishing allowable filter loadings, is 4 inches of water column. In order to take into account the potential loss of mechanical strength due to high radiation exposure, WHC has established an operational differential pressure limit of 1 inch of water column across the D-Filter bank. WHC believes that this limit is sufficiently conservative. While this limit is in a conservative direction, it is arbitrary and lacks an experimental basis. Moreover, operational experience and experimental data indicate that filter testing with an aerosol simulant and differential pressure measurements are not indicative of the true mechanical strength of the filter materials or the integrity of the filter.[6,7,10]

(4) D-Filter Differential Pressure Measurements

The expected differential pressure across a new HEPA filter is about 1 inch of water column for each 1,000 scfm air flow. Each D-Filter bank consists of 80 HEPA filters in parallel, with a flow rate of approximately 30,000 scfm. This implies that the differential pressure across a "new" HEPA filter would be approximately 0.375 inch of water column.

The current differential pressure drop across the last HEPA filter bank (Filter #3) is approximately 0.42 inch of water column, whereas the differential pressure across the other operating HEPA filter bank (Filter #2) is approximately 0.35 inch of water column. The detail on Figure 1 depicts the various filter banks. Based on the data, there is either a problem with the instrumentation or the first HEPA filter bank (Filter #2) is operating at less than acceptable performance. Based on operating experience, one would expect the downstream HEPA filter bank (Filter #3) to have a lower differential pressure than the upstream HEPA filter bank (Filter #2) because of the increased loading on the upstream HEPA filters. Additionally, the differential pressure across Filter #2 is less than that expected for a new HEPA filter, while the differential pressure across Filter #3 is greater than that expected for a new HEPA filter. This could mean that Filter #3 is slightly loaded and that Filter #2 has experienced localized breakthrough.

WHC speculates that the flow path around the bypassed filters (pre-filters and HEPA Filter #1) creates a flow pattern such that there is a nonuniform flow (i.e., nonuniform air velocities upstream of HEPA Filter #2) that could influence the static pressures measured by the instrumentation. However, it appears more likely that the lower differential pressure across Filter #2 is due to localized breakthrough of the filter that would result in a lower flow resistance and a lower differential pressure. The breakthrough is most likely localized based on the Filter #2 differential pressure measurements and the results of the filter testing. However, additional information (e.g., sampling between the filters) would be necessary to determine whether breakthrough has actually occurred.

b. HEPA Filter Degradation Mechanisms

(1) Radiation Degradation

(a) Organic Materials: Typical HEPA filters contain several organic components that are susceptible to radiation induced damage. These include the following:

- gasket (usually neoprene)
- casing (3/4" plywood - the cellulose structure of the wood plies and the cellulose-glue structure of the intermediate plies)
- glue that holds the filter pack to the casing
- binder that holds the filter glass paper mat together
- water repellent applied to the filter paper
- separator materials

Several references discuss radiation damage to HEPA filters.[5,6,7,8,9,10,11] Based on the literature, at exposures of 10^8 rads or greater, the HEPA filter paper is expected to lose its water repellency and tensile strength, and the neoprene gasket is expected to become hard and brittle. These materials will continue to degrade with radiation exposure. At about 10^9 rads, the wood casing will begin to degrade.

(b) Decision to Retire A-, B-, and C-Filters: A 1992 Occurrence Report[18] concerning the Unreviewed Safety Question (USQ) for accumulated radiation exposure on B-Plant HEPA filters states that ". . . filters in banks A, B, and C [have] reached the order of 100 million (10^8) rads . . ." putting them at risk of failure through disintegration of the paper, wood, or adhesive components. Closure of the USQ[19] and supporting documentation[20] address the A-, B-, and C-Filters and state that they have been retired. D-Filter, which at the time had about one half the exposure (approximately 65 million rads) and which now has more than 100 million (10^8) rads, was not addressed. Further, the USQ does not address the fact that the D-Filter is estimated to have a much larger estimated inventory than either A-, B-, or C-Filters.

The Occurrence Report[18] identified the lack of guidelines which provide limits for radiation exposure to HEPA filters as a potential root cause of the USQ. However, the closure of the USQ did not include a commitment to develop HEPA filter exposure guidelines nor have any been developed.

(c) Filter Exposure Limits: Although it has been known for years that significant amounts of radiation exposure can damage HEPA filters, there are no DOE or consensus industry standards that provide limits on radiation exposure for HEPA filters.[5,6,7,8,9,10,11] An implied limit is provided in the sample specifications in Energy Research and Development Administration (ERDA) 76-21, *The Nuclear Air Cleaning Handbook*, which suggests 6.4 x 10^7 rads for testing of the filter paper for both strength and water repellency.[11] Others have suggested a value of 0.5 x 10^8 rads for a 50% reduction in tensile strength.[9] Filter performance and integrity data, such as tensile strength, do not appear to be available for radiation exposure levels greater than about 10^8 rads.

As previously discussed, the extent to which HEPA filter materials may be weakened or degraded by high radiation exposure cannot be determined by the normal filter testing methods. Filtration properties, such as aerosol simulant efficiency and resistance to air flow, can give erroneous indications of satisfactory performance when, in fact, the tensile strength of the HEPA filter paper has been seriously degraded.[9] Therefore, the ability of a HEPA filter--exposed to very high radiation levels--to continue to perform adequately cannot be predicted based solely on normal filter testing or differential pressure measurements.

(2) Other Filter Degradation Mechanisms

There are several degradation mechanisms, other than radiation, that can adversely affect filter performance and weaken the filters. These include aging, wetting, exposure to acids, and operational history.[10] Again, there are no established limits or guidelines for HEPA filter use as a function of these parameters.

c. HEPA Filter Failure Consequences

The B-Plant Authorization Basis documents include postulated accidents associated with the failure of the HEPA filters.[12,20,21] One scenario involves the gradual evaporation of the water seals and the release of a small fraction of the material held up on the filter. For this scenario, WHC calculates no significant off-site consequences, and on-site consequences are approximately 0.50 rem EDE.[20]

An unmitigated seismic event is analyzed where it is postulated that the stack falls onto D-Filter, which causes it to collapse. Concurrently, there is high temperature degradation of A-, B-, and C-Filters, and the sand filter also collapses. This postulated scenario leads to a WHC calculated dose of approximately 200 rem EDE on-site, and 100 mrem EDE off-site.[12]

In both scenarios, the consequences calculated by WHC are based on the release of respirable material from a dropped, but structurally sound, HEPA filter. This assumption may not be valid for HEPA filters that have been significantly weakened by radiation exposure of greater than 10^8 rads coupled with other degradation mechanisms. It is postulated that these weakened filters could release more respirable material, causing higher consequences.

d. Water Seal Reliability

Although water seals may be appropriate for remotely operating inaccessible filter units, they do not provide a reliable long-term isolation function for retired or deactivated filter units. The water seals were not designed to meet single failure criteria and could be subject to inadvertent rapid draining (e.g., steam jetting) or gradual draining (e.g., evaporation, leaks). The water seals are also subject to overfilling that can flood the filter cells and wet the HEPA filters, which would further degrade the integrity of the filters. The flooding can also provide another mechanism for transport of radionuclides from the HEPA filters to the environment. As noted in Appendix A, retired filter units have been inadvertently flooded on two occasions.[22,23,24]

In the past, WHC had considered various alternative schemes for isolating HEPA filters, including grouting and use of a nonvolatile liquid or foam material. All of these alternatives were rejected, and there are no near-term plans to replace the water seals. Leaving the outlet water seals of the retired filter units in their present configuration for several more years does not appear to be prudent. It appears that additional effort is warranted to identify an alternative that would provide enhanced reliability and not adversely impact future remediation of the filters. For example, the suitability of using a fine sand should be analyzed. The sand could be pneumatically and remotely substituted for the water, would be temporary, and would not be susceptible to inadvertent jetting.

APPENDIX A

B-PLANT FILTERS DESIGN AND OPERATING HISTORY

1. Filter Cell Structures

The HEPA filter units, shown in Figure 1, are contained in separate cell structures constructed of reinforced concrete and steel. The cell structure design, shown in Figure 2, includes an outlet water seal to isolate each filter cell individually from the exhaust air stream. B- and C-Filter also have an inlet water seal. The inlet seals were to provide isolation of these filters when future filters were installed, but the isolation is now provided with a concrete plug. There is an automatic filling system which maintains the water level in the outlet water seals. The water seal levels can also be monitored and adjusted manually. The water seals of all the HEPA filter cells are now filled except for the outlet seal of the operating D-Filter. A drainage sump is also located in each filter cell to collect any overflow from the water seals.

2. Filter Design and Operating History

   a. A- and B-Filters: The A- and B-Filter cells consist of a 60% pre-filter and two stages of HEPA filters. The A-Filter, which operated for 100 months between December 1966 and December 1974, was removed from service when radionuclide concentration in the exhaust air stream increased significantly, indicating filter failure. The B-Filter, which operated for 100 months between November 1968 and December 1974, was shut down due to a hole in the filter, suspected wetting of the filter, and a suspected degradation of the glue and gasket material from sustained radiation exposure. Potentially high radiation levels which preclude filter replacement were not adequately considered in the design. The filters were retired in 1993.

   In 1992, an unobserved raw water feed line caused an over-flow of the water seal and subsequent flooding of the A-Filter cell. The lower one-third of the filter was submerged in water for about one and one-half weeks until the water was pumped out.[22] From a video taken in 1994, the metal screens on the front (upstream) face of the filters appear to be intact, but the integrity of the filter material or the seals cannot be determined.[24] On February 5, 1996, a second flooding event occurred when an underground water fill line for the outlet seals of the A- and B-Filter cells ruptured.[23] This caused an overflow of the A- and B-Filter outlet seals and wet the bottom 2 to 3 inches of the filters.

   b. C-Filter: The C-Filter cell, placed in service in February 1972, consists of a 90% pre-filter and two stages of HEPA filters. The pre-filter, which was designed to be replaceable, has a roughing screen divided into three sections. Each pre-filter section contained a glass fiber bag filter preceded by a glass fiber pad. However, the pre-filter was never replaced because of a large accumulation of radioactive particulate and the resultant high radiation exposure. Due to excessive pressure drop, the pre-filter failed in February 1975.

However, the C-Filter was operated for an additional 33 months without the pre-filter. The C-Filter was retired from service in October 1978.

c. D-, E-, and F-Filters: The D- and E-Filter are each equipped with two banks of 85% efficiency pre-filters and three banks of HEPA filters. The two pre-filter banks and the first HEPA filter bank incorporate design features which allow the upper one-quarter of the filter to be lowered. The remaining three-quarters of the filter banks remain fixed. This feature permits bypassing one or more filter banks should excess pressure drop occur due to filter loading. The final two HEPA filter banks are permanently mounted.

A stainless steel mesh fire screen is installed approximately four feet upstream of the first pre-filter bank. Each pre-filter and HEPA filter unit is also equipped with a stainless steel mesh fire screen downstream of each unit. Each individual pre-filter of both pre-filter banks is a bag type filter equipped with sheet metal separators coated with intumescent paint to retard propagation of any potential filter fire to other filters of the same bank. The intumescent paint absorbs heat through the mechanism of forming air bubbles, providing an insulating barrier on the surfaces of the metal separators, and thus insulating one filter from the other.

The D-Filter, which was placed in operation in 1979, is currently on-line. The E-Filter is similar to the D-Filter, but has never been placed in service. In the past there have been recommendations to place the E-Filter in service.[2,3,4] In 1985, the operating contractor, Rockwell International, recommended[2] ". . . that immediate action be taken to ready the E-Filter for service." Again in 1993, WHC[3] states "B-Plant intends to place the fifth canyon exhaust filter (E-Filter) on line . . . because the D-Filter has already exceeded its expected useful life." These recommendations were not implemented.

There is an additional filter, F-Filter, that has been constructed.[4] It is similar to D- and E-Filters, but presently does not have any HEPA filters or pre-filters installed. The F-Filter is isolated from the E-Filter by remotely removable blocks. The F-Filter would need to be outfitted with filters and field tested to be ready for standby service.

d. Filter Instrumentation: Instrumentation is installed to measure filter air temperatures and the pressure drop across individual filter banks. Access and sample ports are also provided to: (1) test the filters in accordance with the intent of selected portions of ASME N510; (2) obtain representative air samples after each filter bank; and (3) insert radiation instrumentation to assess radionuclide accumulation on the filters.[14]

e. Sand Filter: The emergency backup sand filter, constructed in 1948 to serve the plant when it was operated as a plutonium separation plant, is on emergency standby. Exhaust air flow would diverted to the sand filter in the event of a fire in the process cells. The sand filter has a low filtration efficiency (about 99%) compared to the efficiency of an installed HEPA filter unit (greater that 99.9%). The sand filter can be activated in several minutes by manipulating the HEPA filter and sand filter water seals.

APPENDIX B

B-PLANT FILTERS RADIONUCLIDE LOADING ESTIMATES

The amount of radioactivity on the B-Plant filters has been estimated on several occasions since the early 1970s. The most recent estimate in 1993 takes into account information obtained from the flooding of the A-Filter cell in 1992. These estimates are given in Table B-1. These values represent the maximum inventory thought to be on the filters. The D-Filter was not updated in 1993 because the information obtained from the flooding incident was not considered applicable.

Table B-1. B-Plant HEPA Filter Inventory Estimates[20,25]

Filter	Estimated Inventory - (Curies)	
	Cesium-137	Strontium-90
A	18,000	12,000
B	43,000	29,000
C	25,000	16,000
D	550,000	50,000
E	0	0
Totals	636,000	107,000

APPENDIX C

B-PLANT FILTERS RADIATION EXPOSURE ESTIMATES

Estimates of the accumulated exposure on each of the B-Plant filter cells are reproduced in Table C-1.[20,25] Significant uncertainties are possible in the actual values of the radiation exposure estimates. This is primarily due to uncertainties in determining the quantity of the inventory (Curies) actually on the filters. Actual exposures differing by an order of magnitude would not be surprising.

Table C-1 shows that the D-Filter is currently approaching a level of exposure considered adequate to require retirement of the A- and B-Filters in 1993. Also, the rate of accumulation for A-, B-, and D-Filters is of the order of one to ten million rads per year. From Tables B-1 and C-1, it appears that the estimated accumulated exposure for D-Filter is too low. Finally, the exposure accumulations and inventory estimates for C-Filter (Table B-1) are inconsistent and unexplainable.

Table C-1. B-Plant HEPA Filter Estimated Accumulated Exposure[20,25]

Filter	Estimated Accumulated Exposure (Millions of rads)	
	Through 1992	Through 1997
A	150	170
B	140	170
C	1,200	1,500
D	65	109*
E	0	0

* Only through 1996

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