In-Place Leak Test of HEPA Filter Banks Using a Multiple Sampling Technique for the Underground Ventilation System at the Waste Isolation Pilot Plant

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ABSTRACT

The Underground Ventilation System (UVS) at the Waste Isolation Pilot Plant (WIPP) provides airflow through the underground facilities located approximately 2,150 feet (655 meters) below the surface. The exhaust air is filtered through two HEPA filter units operating in a parallel arrangement to achieve 60,000 cfm (28,317 L/s) of ventilation. While the HEPA filter units were installed in 1986, the service of the units was historically limited to periodic surveillance testing, including a monthly operational test. However, a radiological event at WIPP on February 14, 2014 automatically reconfigured the UVS into a filtration mode of operation, placing the two HEPA filter units into continuous service. The filter units have aerosol distribution and sample manifolds for performing in-place leak test of each HEPA filter bank. From recent operational experience, the original manifolds were revealed to be dated in comparison to current industry standards and limited information was available on the initial qualification of the manifolds, in particular those manifolds used to obtain a downstream sample during testing. This paper describes a recent effort to perform an in-place leak test, using a multiple sampling technique, which was more conservative and better aligned with the ASME N510 (Testing of Nuclear Air-Cleaning Systems) standard. The paper also describes proposed modifications that will improve the quality of future surveillance tests.

INTRODUCTION

The Department of Energy's (DOE) Waste Isolation Pilot Plant (WIPP) is the only repository in the United States for permanent disposal of transuranic waste. Transuranic waste is the byproduct of Cold War production of nuclear weapons and it typically consists of clothing, tools, debris, and other items contaminated with plutonium and other radioactive elements. The WIPP site is located in southeastern New Mexico, approximately 26 miles (42 km) from the City of Carlsbad, and the repository is 2,150 ft. (655 m) below the surface in a 2,000 ft. (610 m) thick salt bed, formed 250 million years ago. Transuranic waste is permanently disposed in repository rooms mined into the geological formation.

In the evening of February 14, 2014, a radiological event occurred in the disposal area of the facility. A continuous air monitor (CAM) alarmed when it measured airborne radioactivity near the active disposal room in the underground (see Fig. 1). No employees were in the underground areas at the time the CAM alarmed. The radiological event automatically reconfigured the Underground Ventilation System (UVS) into a filtration mode of operation. This mode of operation allows the airborne contamination released by a breached waste container in the underground to be routed to the HEPA filter units and minimizing the release of contamination to the environment.

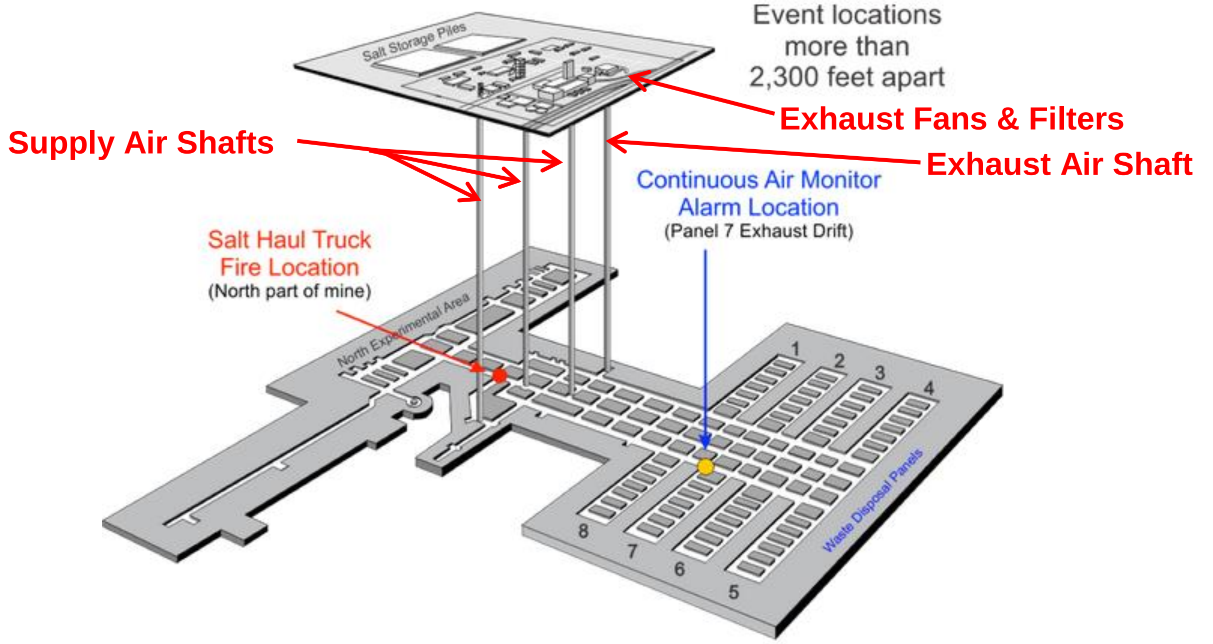

Fig. 1. February 2014 Location of Radiological Event in the WIPP Underground Facility

Underground Ventilation System

The Underground Ventilation System (UVS) provides a flow of fresh air to the array of underground pathway drifts and repository disposal rooms, and provides a suitable environment for personnel and equipment operating in the underground facility at WIPP. The air is supplied to the underground facility through three shafts and exhausted through a single shaft by exhaust fans located on the surface (Fig. 1). The exhaust air is filtered through two HEPA filter units operating in a parallel arrangement to achieve 60,000 cfm (28,317 L/s) of ventilation. Historically, the UVS was also designed to operate in an unfiltered mode of ventilation that bypassed the HEPA filters, achieving a capacity of 460,000 cfm (217,094 L/s) of airflow. However, the radiological event at WIPP on February 14, 2014 placed the two HEPA filter units into continuous service, reducing the volume of airflow through the underground and subsequently limiting the operation of mining and waste handling equipment (primarily diesel engine driven).

The filter units are walk-in units with an airflow capacity of 30,000 cfm (14,158 L/s) and each unit consists of four banks of filters in series. Each bank contains 21 filters, clamped into frames, and arranged seven filters wide and three filters high. The first and second banks are pre-filters with a Minimum Efficiency Reporting Value (MERV) of 11 and 14, respectively (see Table 1). The third and fourth banks use HEPA filters with an efficiency of 99.97% for 0.3μm particles as tested by the manufacturer and independently verified by a DOE approved Filter Testing Facility (FTF).

Table 1. General Information on Air Filter Efficiencies and Applications [3]

MERV Rating	Minimum Particle Size	Tested Efficiency	Typical Controlled Contaminant
1–4	> 10.0 μm	<20%	Pollen, dust mites, cockroach debris, sanding dust, textile fibers, carpet fibers
5–8	10.0–3.0 μm	<20% to 35%	Mold, spores, dust mite debris, cat and dog dander, hair spray, fabric protector
9–12	3.0–1.0 μm	40% to 75%	Legionella, humidifier dust, lead dust, milled flour, auto emission particulates
13–16	1.0–0.3 μm	89% to >95%	Bacteria, droplet nuclei (sneeze), cooking oil, most smoke and insecticide dust, most paint pigments
17–20	< 0.3 μm	≥99.97% to ≥99.999%	Virus, carbon dust, sea salt, smoke

An in-place leak test is performed on the HEPA filters after each HEPA filter replacement and at least once every year, using existing provisions for in-place leak testing on the units. The filter units are equipped with permanent manifolds used for sampling and injection of challenge aerosol during the in-place leak test. There is a manifold upstream of the first HEPA filter bank used for injection of challenge aerosol during testing. A second manifold is downstream of the first HEPA filter bank and upstream of the second HEPA filter bank. The second manifold has been used for both injection and sampling of challenge aerosol. A third manifold is downstream of the second HEPA filter bank and is used for sampling. Fig. 2 denotes the general arrangement of the filter banks and manifolds for each filter unit.

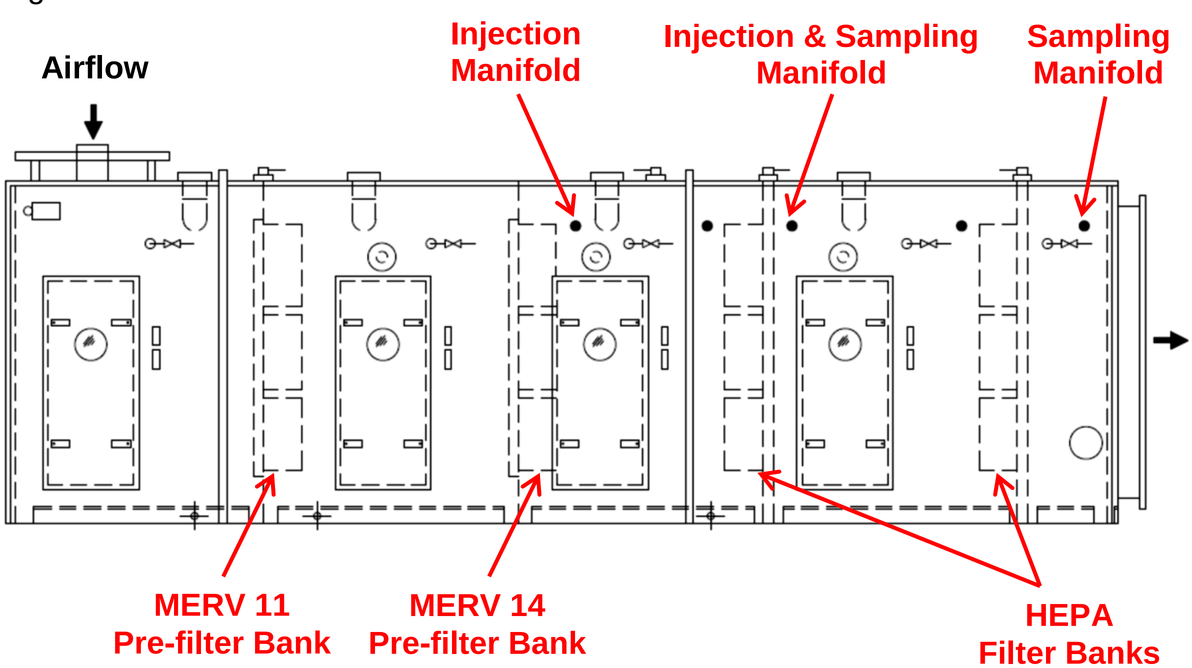

Fig. 2. Design of the UVS HEPA Filter Units

While the filter units have manifolds for injection of challenge aerosol upstream of the HEPA filter banks, the design of the manifolds is dated in comparison to current practices and designs. There is also no information on adequate qualification of the manifolds. Based on historical test data, the injection manifolds may provide adequate air-aerosol mixing uniformity across the HEPA filter banks, but this remains unverified through recent performance testing of the manifolds. Due to the design and location, the sampling manifolds are unlikely to provide a representative sample of the aerosol concentration downstream of the HEPA filter banks during an in-place leak test. This is evident for the manifold downstream of the first HEPA filter bank used for both injection and sampling.

Historically, the in-place leak tests on the filter units for the UVS have been performed using the existing manifolds with no alternate means or available methods. The requirement has been to perform the test in accordance with the ASME N510-1989 standard. With the recent experience at WIPP, proper in-place leak testing of the HEPA filters is of greater importance to safety and quality.

METHOD

As a conservative effort, the filter units were tested using an alternate test method. Using Section 11 (Multiple Sampling Technique) of ASME N510-1980 as technical guidance, an in-place leak test of the filter units was performed utilizing the multiple sampling technique to obtain a representative sample downstream of the HEPA filter banks. It should be noted that both the upstream HEPA filter bank and the downstream HEPA filter bank were tested as a single bank.

The sample location was positioned in the downstream ventilation duct for each filter unit, after a duct transition section that connects the filter housings to the outlet isolation dampers. The downstream samples were obtained by inserting a Pitot tube through four evenly spaced ports on top of the rectangular duct (Fig. 3). The sample location for each sample position was based on the spacing of an equal area traverse. Challenge aerosol was injected upstream of the first HEPA filter banks, using the existing injection manifolds.

The in-place leak test was performed by injecting a continuous stream of challenge air-aerosol mixture upstream of the HEPA filter banks. The challenge aerosol, Polyalphaolefin (PAO), was injected using a NUCON® SN-10 pneumatic aerosol generator. The upstream concentration was measured by obtaining a single point sample near the middle of the HEPA filter bank, using a probe inserted into the filter housing. The downstream concentration was measured in a sampling plane perpendicular to the duct, using a traverse pattern with 24 sample points. The maximum concentration reading at each traverse sample point was measured at the downstream location.

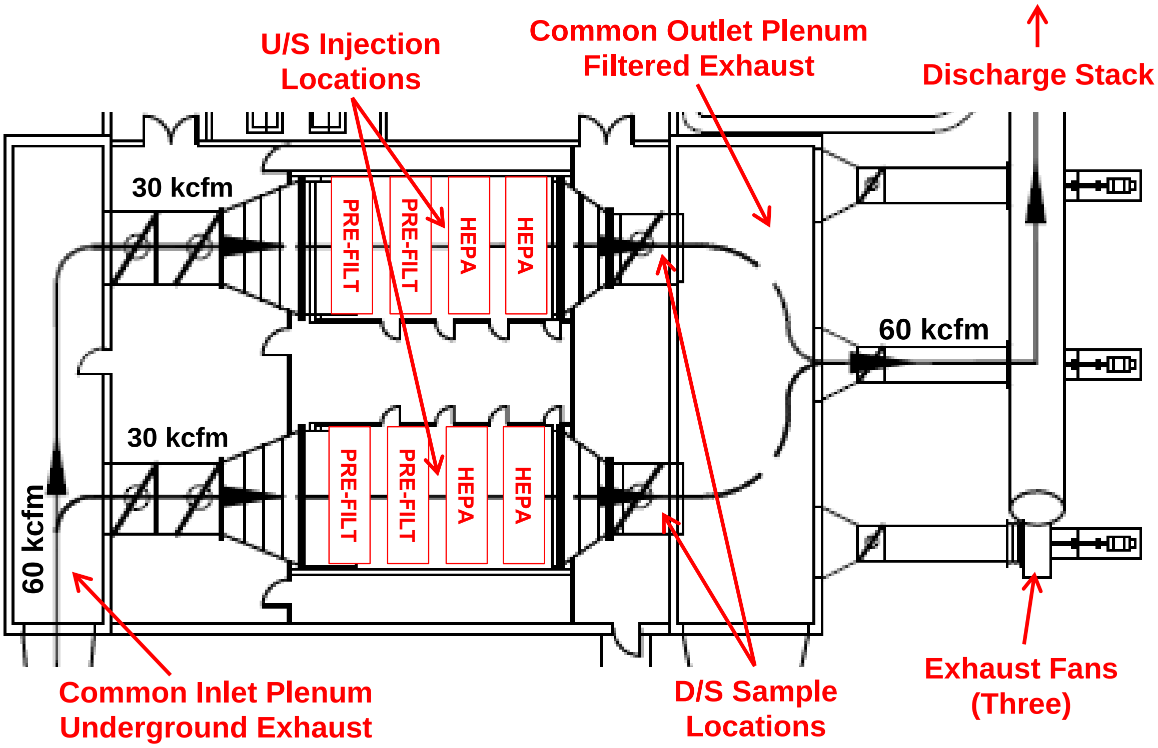

Fig. 3. Filter Unit Injection and Sample Locations for Alternate Test Method

Using the technique described in Section 11 of the ASME N510-1980 standard, the leak rate across the HEPA filter banks was determined using the following approach. The average concentration in the sample plane was calculated from:

$$\bar{X} = \frac{\sum_1^n X_i}{n} \qquad \text{(Eq. 1)}$$

where $\bar{X}$ is the average concentration, X_i are the individual, maximum concentration readings at each traverse point, and n is the number of readings obtained by the traverse pattern (i.e., 24 readings).

The standard error of the downstream sample was calculated from:

$$S_{\bar{X}} = \sqrt{\left(\frac{\sum_1^n (X_i - \bar{X})^2}{n(n-1)}\right)} \qquad \text{(Eq. 2)}$$

where $S_{\bar{X}}$ is the standard error of $\bar{X}$.

The standard error from (Eq. 2) is applied to the average concentration from (Eq. 1) to determine the percent penetration for a 95% confidence level from:

$$P_{95} = \bar{X} \pm tS_{\bar{X}} \quad \text{(Eq. 3)}$$

where t is determined from the t-distribution for n degrees of freedom. In this case t = 2.0. For conservatism, the percent penetration from (Eq. 3) is estimated for the maximum result possible.

Lastly, the leak rate across the filter banks is determined from:

$$L = 100\left(\frac{C_d}{C_u}\right) \quad \text{(Eq. 4)}$$

where L is the leak rate, C_d is the concentration downstream (same as P_{95}), and C_u is the concentration upstream.

RESULTS

With the system operating under nominal airflow conditions 30,000 cfm (14,158 L/s) through each filter unit, the in-place leak test indicated that the leak rate across the HEPA filter banks was much less than the allowable limit of 1%, as defined per WIPP Technical Safety Requirements for operability. As shown in Table 2, the first filter unit demonstrated downstream sample readings typically less than 0.01% when a concentration of 40% was injected upstream of the HEPA filters. The average downstream concentration was calculated to be 0.01% with a standard error of 0.0004%. Therefore, the downstream penetration was conservatively estimated to be at most 0.0108% and the leak rate was 0.03%.

Table 2. Downstream Concentration of Traverse Samples for First Filter Unit

Traverse Point	Port A Max. Reading	Port B Max. Reading	Port C Max. Reading	Port D Max. Reading
1	< 0.01	0.01	< 0.01	0.02
2	< 0.01	< 0.01	< 0.01	0.01
3	< 0.01	< 0.01	< 0.01	0.01
4	< 0.01	< 0.01	< 0.01	< 0.01
5	< 0.01	< 0.01	< 0.01	< 0.01
6	< 0.01	< 0.01	< 0.01	< 0.01

The second filter unit also demonstrated readings typically less than 0.01% when a concentration of 100% was injected upstream of the HEPA filters (Table 3). The average downstream concentration was calculated to be 0.01% with a standard error of 0.0004%. Therefore, the downstream penetration was also estimated to be at most 0.0108% and the leak rate was 0.01%.

Table 3. Downstream Concentration of Traverse Samples for Second Filter Unit

Traverse Point	Port A Max. Reading	Port B Max. Reading	Port C Max. Reading	Port D Max. Reading
1	0.01	< 0.01	< 0.01	< 0.01
2	< 0.01	< 0.01	< 0.01	< 0.01
3	< 0.01	< 0.01	0.02	< 0.01
4	< 0.01	0.01	0.01	0.01
5	0.01	< 0.01	< 0.01	0.01
6	< 0.01	< 0.01	< 0.01	< 0.01

DISCUSSION

The alternate test method was an effort at WIPP to improve the quality of the in-place leak tests for the HEPA filters used in the Underground Ventilation System. This was a conservative approach to address the indeterminate qualification of the manifolds, specifically those used for sampling. While other approaches could have been used, there were limitations due to the operational demand for maintaining maximum ventilation through the WIPP underground facilities. Options that required prolonged ventilation outages or reduced ventilation were not feasible. As such, the alternate test method was preferred due its minimal impact on ventilation.

The downstream sample location was also selected due to the overall arrangement and operation of components for the ventilation systems. The current design of the WIPP UVS did not allow for operating only one filter unit with the in-service exhaust fan. In this configuration, the challenge of obtaining a sample further downstream (i.e., after the exhaust fan) would be a dilution of the sample due to airflow from the other in-service filter unit. Flow through the in-service fan also could not be reduced much below 50,000 cfm (23,597 L/s). The fans rely on variable inlet vane controls that allow for minor flow adjustment before excessive vibration and instability is demonstrated by the fan. Lastly, the distance between the upstream and downstream sample locations, going from inside the filter building to the exhaust fans, was more than 200 ft. (61 m). The distance was determined to be impractical for running sample lines to one aerosol detector during testing. As a short-term option, the alternate test method, using the selected downstream location, was likely the best approach until permanent modifications are implemented for in-place leak testing on the WIPP Underground Ventilation System filter units.

Planned Modifications

The long-term improvement for the WIPP filter units will include replacement of the existing manifolds and qualification testing of the manifolds per ASME AG-1 (Code on Nuclear Air and Gas Treatment). The injection manifolds will be upgraded in design to ensure proper air-aerosol mixing uniformity of challenge aerosol upstream of the HEPA filter banks. The “dual purpose” injection and sample manifold, located downstream of the first HEPA filter bank as shown in Fig. 3, may be replaced by a manifold dedicated for injection only. As such, a sampling manifold may be added upstream of the second HEPA filter bank for in-place leak testing of the first HEPA filter bank. A sampling manifold will be installed in the same location used during the recent alternate test method. Due to the proximity of the existing sampling manifold to the second HEPA filter bank, approximately 1 ft. (0.3 m), the sample location from the alternate test will provide better mixing for the downstream sample manifold. Overall, these modifications will be an effort to improve the quality of the in-place leak tests and assure that the WIPP filter units will continue to perform their intended function.

Acknowledgments

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