Evaluation of 4-hr Test of Unfiltered Ventilation at the Waste Isolation Pilot Plant

WIPP Nuclear Waste Partnership

An AMENTUM-led partnership with BWXT and ORANO

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EXECUTIVE SUMMARY

This document provides the best estimate of maximum potential radionuclide release during restart and temporary operation of the 700C ventilation fan at the Waste Isolation Pilot Plant (WIPP). This document outlines the evaluation of unfiltered ventilation at WIPP to support disposal of the nation's currently identified, defense-related, transuranic (TRU) waste, or TRU mixed waste.

The original WIPP ventilation design provided a capacity of approximately 460,000 actual cubic feet per minute of unfiltered exhaust air through a combination of two (of three) surface fans including the 700A, 700B, and 700C fans, each operating at 240,000 standard cubic feet per minute. The existing Underground Ventilation System (UVS) is composed of the Underground Ventilation Filtration System (UVFS), the Interim Ventilation System (IVS), and the unfiltered Supplemental Ventilation System (SVS), for a maximum total flowrate of approximately 179,000 cubic feet per minute (cfm) (114,000 cfm filtered and 65,000 cfm unfiltered).

Since February 2014, when a radiological event occurred in the underground, the underground has been operating in filtration mode at a significantly reduced air flowrate (described above). None of the 700 fans has been in operation since the event in 2014. As diesel-powered equipment is used in the underground, sufficient airflow is needed to ensure a safe breathing environment for workers. To address air quality issues in the mine caused by low air flows, a plan was developed to reconfigure the UVS to allow it to operate in filtered or unfiltered mode. Due to its better relative material condition and the direction of its exhaust (in comparison with fans 700A and 700B), fan 700C was selected to be evaluated for return to operation to increase airflow in support of non-waste handling underground operations in an unfiltered configuration.

As portions of the underground and exhaust ductwork are contaminated with radioactive material from the 2014 event, operation of the UVS in an unfiltered condition has the potential to release low levels of radionuclides to the atmosphere. During start-up and testing of 700C, the exhaust will be redirected from the aboveground filter bank to an unfiltered exit from the system at the 700C fan effluent exhaust housing and monitoring and sampling for radioactive material in the exhaust will be conducted.

Air and salt samples collected inside the horizontal ventilation duct adjacent to 700C were analyzed statistically in a combination of conservative and best estimate methodologies to calculate the quantity of radioactivity that is available to be, and assumed will be, expelled to the atmosphere during the testing phase. Analysis of the radiological measurements performed in this area resulted in an estimated maximum of 0.000006 (6E-06) curies of removable activity that could potentially be available as readily transferable contamination and released into the atmosphere upon restarting 700C.

This potential release is estimated to deliver a resultant dose to the Maximally Exposed Offsite Individual (MEOSI) of 0.005 millirem (mrem); which represents 0.005 percent of the allowable annual limit set by the Environmental Protection Agency (EPA) of 10 mrem. This potential exposure is significantly lower than the site-specific natural radiological baseline (measured before WIPP facility disposal operations began) of 67.0 mrem per year (0.18 mrem/day). The daily dose rate from natural background is 6 times greater than the estimated maximum release from the 700C fan during the 4 hour test.

Restarting the 700C ventilation fan would not result in an estimated release above DOE regulatory limits as evaluated per 10 CFR 835, *Occupational Radiation Protection Program*, DOE Order 458.1, *Radiation Protection of the Public and the Environment,* and EPA limits in 40 CFR 61, *National Emission Standards for Hazardous Air Pollutants*.

ABBREVIATIONS AND ACRONYMS

Acronym	Term
AIS	Air Intake Shaft
ALARA	As Low As Reasonably Achievable
CAM	Continuous Air Monitor
CFM	Cubic Feet per Minute
CI	Curie
CMR	Central Monitoring Room
CMS	Central Monitoring System
DAC	Derived Air Concentration
DOE	U.S. Department of Energy
DPM	Disintegrations per Minute
EFB	Exhaust Filter Building
EPA	Environmental Protection Agency
ES	Exhaust Shaft
FPM	Feet Per Minute
GBq	GigaBecquerel
HEPA	High-Efficiency Particulate Air
IVS	Interim Ventilation System
KCFM	Thousand Cubic Feet per Minute
LWA	Land Withdrawal Area
MBq	MegaBecquerel
mCi	Millicuries
MEOSI	Maximally Exposed Offsite Individual
mrem	Millirem
mSv	millisievert
NARAC	National Atmospheric Release Center
PPE	Personnel Protective Equipment
RWP	Radiological Work Permit
SAC	Specific Administrative Controls
SBS	Safety Basis Supplement
SHS	Salt Handling Shaft
SV	Sievert

Acronym	Term
SVS	Supplemental Ventilation System
TBD	Technical Basis Document
TED	Total Effective Dose
TRU	Transuranic
UVFS	Underground Ventilation Filtration System
UVS	Underground Ventilation System
WHS	Waste Handling Shaft
WIPP	Waste Isolation Pilot Plant

UNIT CONVERSIONS

For consistency throughout this document, traditional (non-SI) units for radioactivity and radiation dose are used. Quantities in SI units can be calculated using the following conversion factors:

Physical Quantity	Traditional Unit	SI Unit
Activity	1 Curie (Ci)	37 GigaBecquerel (GBq)
	1 millicurie (mCi)	37 MegaBecquerel (MBq)
Radiation Dose	1 rem	0.01 Sievert (Sv)
	1 mrem	0.01 milliSievert (mSv)
Area	1 square foot	929 square centimeters
	1 square foot	0.0929 square meters

1 INTRODUCTION AND BACKGROUND

1.1 WIPP Facility Description and Overview

The WIPP facility is a geologic repository for the permanent disposal of defense-generated TRU mixed waste from various United States defense facilities that play key roles in a strategic mission of the U.S. Department of Energy (DOE). The WIPP Project is a critical component in supporting the national security objectives and in meeting DOE's statutory commitments related to the removal of TRU waste from DOE sites across the United States and the disposal of the TRU waste. TRU waste temporarily stored at sites around the country is shipped to the WIPP facility and disposed in rooms mined out of a salt formation 2,150 feet below the surface. The DOE began TRU waste disposal operations at the WIPP facility in 1999.

The WIPP facility is located in Eddy County in southeastern New Mexico; 26 miles east of Carlsbad. The land area set aside for the WIPP facility is 10,240 acres and is called the WIPP Land Withdrawal Area (LWA). The WIPP facility is located in an area of low population density. The area surrounding the WIPP LWA is used primarily for grazing and development of potash, oil, and gas resources.

The principal operations at the WIPP facility involve the receipt and disposal of TRU waste. Transuranic waste containers are transported to the WIPP facility in shipping containers certified by the United States Nuclear Regulatory Commission and the Department of Transportation. The WIPP facility is designed to receive and dispose of TRU mixed waste generated by US nuclear defense activities.

The WIPP facility is divided into surface structures, shafts, and underground structures. The surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground.

The primary surface waste handling operations at the WIPP facility are performed in the Waste Handling Building, which is divided into the contact-handled and remote-handled TRU waste processing areas and the Shaft Access Area. There are currently four shafts that extend from the surface to the WIPP underground – the Waste Handling Shaft (WHS), the Salt Handling Shaft (SHS), the Exhaust Shaft (ES), and the Air Intake Shaft (AIS) (see Figure 1).

The WIPP underground facilities include the waste disposal area, construction area, the experimental area (north of the shafts), and the shaft pillar area (consisting of the waste shaft station, and maintenance facilities).

A disposal panel currently consists of seven disposal rooms with an intake and an exhaust drift. A "drift" is a horizontal passage cut through the salt. Each room in a panel is nominally 33 feet wide by 13 feet high by 300 feet long. A disposal room is separated from the adjacent room(s) by pillars of salt approximately 100 feet wide by 300 feet long. The panel intake drift is approximately 20 feet wide by 13 feet high, while the exhaust drift is approximately 14 feet wide by 12 feet high. Within the Panel, the intake and exhaust drifts are approximately 33 feet wide by 13 feet high. Once panels are filled with TRU mixed waste, panel closures are planned to be installed.

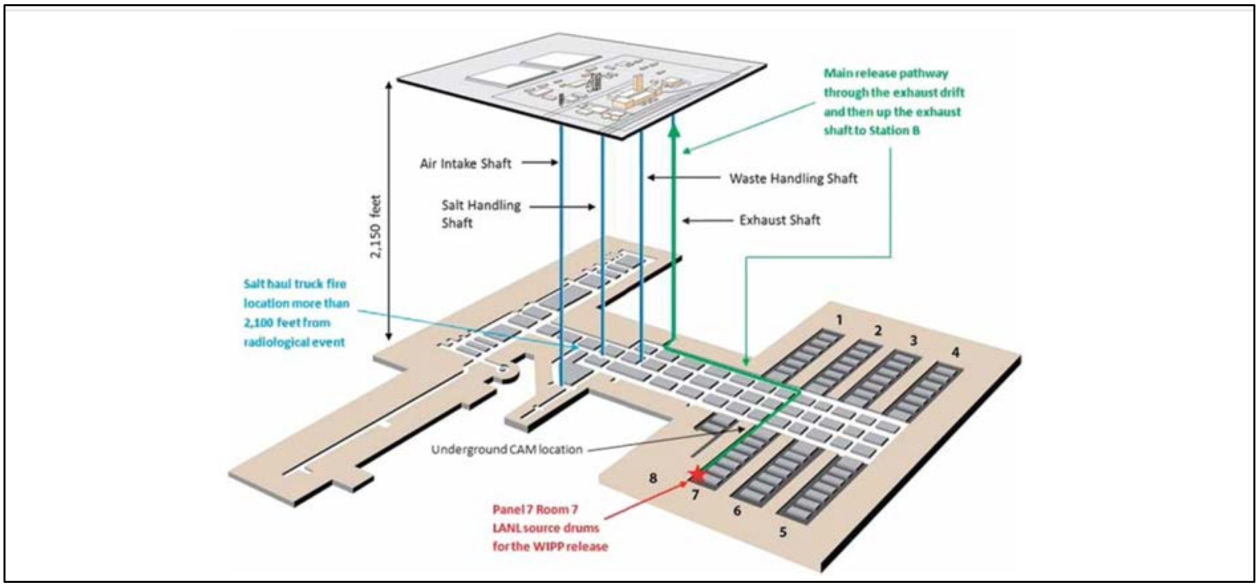

Figure 1 - WIPP Facility Configuration

1.2 February 14, 2014, Radiological Release Event at WIPP

The WIPP site experienced a radioactive particulate release in February 2014. During the event, Continuous Air Monitor (CAM)-151 detected an airborne radiological release in the underground. As shown in Figure 1, CAM-151 was located immediately downstream and outside of Panel 7 where waste was being emplaced. The waste emplacement operations had been suspended nine days earlier because of a vehicle fire in the underground on February 5. As soon as the CAM alarmed on the night of February 14, the WIPP's ventilation system automatically switched to the filtration mode, reduced the air flow, and directed the exhaust air stream through the filter banks when it reached the surface. This automated actuation of filtration mode was intended to protect aboveground workers at the site and the public in the surrounding areas by minimizing radiation releases to the environment in the event of an accident involving waste underground. As the ventilation system remains in filtration mode since 2014, the automatic actuation function is not needed and has been disabled.

The ventilation system appeared, at the time, to be functioning as designed, so there was no reason to suspect any substantial release to the environment.

It was later determined that a small portion of the contaminated air bypassed the High-Efficiency Particulate Air (HEPA) filters via leakage through two imperfectly sealing ventilation system dampers and was discharged directly to the environment from an exhaust duct ("X" in the center of Figure 2). The actual release to the atmosphere, based on on-site and near off-site monitors was very small, localized, and below limits established to protect the public and the environment. According to the estimates that have been independently reviewed, the amount of radioactivity released from the WIPP site was less than 1.5 mCi. The highest activity concentration detected on the surface was 3.1E-15 μCi/ml for ^{241}Am and 2.8E-16 μCi/ml for $^{239+240}$ Pu. The dampers have since been sealed off with high-density expanding foam insulation, closing this release path.

The calculated dose for 2014 (which includes the event) was 0.149 mrem at the WIPP fence line (See Appendix F). Note that the location of the MEOSI in 2014 was Smith Ranch WNW at 5.5 miles (8850 m), beyond the WIPP fence line. The calculated annual dose in 2014 was 0.00586 mrem.

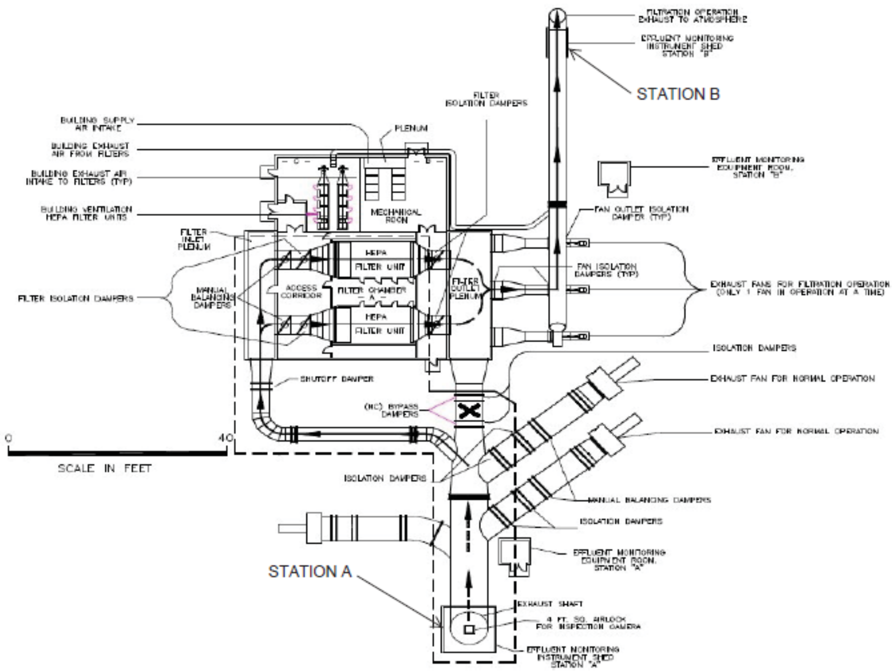

Figure 2 - 2014 UVS System Layout

2 EFFLUENT MONITORING AND FILTRATION SYSTEMS

Construction and ground control work in the underground use diesel-powered equipment. Airflow limitations restrict the amount of work activities but also create issues with air quality in the underground.

To address the air quality issues in the mine, evaluation to resume unfiltered ventilation by returning 700C fan to operations was conducted to analyze the UVS operating in filtered or unfiltered mode. Operating 700C will increase airflow to support underground operations in an unfiltered configuration; estimated flows are shown in Appendix A, Predicted Airflows with the 700C Fan Operating.

2.1 Underground Ventilation System Description

The UVS consists of fans, filters, and control elements above ground, and air direction structures and equipment in the underground, 2150 feet below the surface. While UVS includes air handling equipment, it is structured quite differently from a building ventilation system in that there is no active supply system, only exhaust. For the contaminated portion of the underground, UVS provides suction at the surface through the ES placing the underground at negative pressure relative to the above ground environment. Air supply to the mine is by pressure differential through the WHS, SHS, and AIS. See Appendix C for additional information on selected components of the UVS.

At lower flow conditions, air exchange in the mine is complicated by air temperature swings on the surface which could result in upcasting (upward flow in two of the intake shafts). Higher temperatures on the surface make surface air less dense and less resistant to upcasting.

Prior to the February 14, 2014 radiological release at WIPP, the UVS exhausted up to 460,000 cfm of unfiltered air through a combination of two (of three) surface fans including the 700A, 700B, and 700C (240,000 cfm) fans.

Since the 2014 event, the UVS has been operated only in filtration mode with all air from the contaminated portion of the underground passing through HEPA filtration before being released to the environment. At first, this used one of the 860 fans at 60 thousand cubic feet per minute (kcfm). Later, this was supplemented by the installation and use of the IVS.

The IVS consists of two parallel trains of fans (designated 960A & B) and an associated filter bank for each. The 960 fans draw air from one of the 700 fan inlet ducts, then deliver filtered air directly to the exhaust stack where it merges with the flow from a single 860 fan (if being operated). Each 960 fan/filter train can move 27 kcfm, for a total airflow of 54 kcfm (960A & B) only or 114 kcfm (both 960 fans and one 860 fan).

Also added to the UVS since 2014 is the SVS. The SVS consists of a fan located near the base of the AIS and is used for moving air in the uncontaminated sections of the underground. When the SVS fan is operating, the AIS supplies the intake air for the North and Construction Circuits. The North Circuit and a portion of the Construction Circuit are exhausted unfiltered to the atmosphere through the SHS. The majority of the Construction Circuit exhaust supplies the Disposal Circuit and is filtered prior to releasing to atmosphere. All potentially contaminated air is filtered prior to releasing to atmosphere.

Panels 1 through 6 have been withdrawn from the ventilation system through the use of Explosion Isolation Walls or Interim Panel Closure Systems. The area south of S2750 has been withdrawn from the ventilation system by use of closure bulkheads. Unventilated areas of the underground have barriers and are posted with appropriate signage in accordance with 30 CFR 57.8528.

The intent is to run the UVS, IVS, and SVS fans to distribute airflow volume underground. There may be times SVS may not be in use and the ventilation circuits underground will vary.

Air flow through the 860 fan/filter path is as follows: Air exits the underground via the exhaust shaft and is ducted to the reinforced concrete Inlet Plenum, passing isolation dampers for the three 700 fans. Air from the Inlet Plenum enters two parallel banks of filters (856 and 857). Each filter bank consists of four filter stages of increasing efficiency. In each train, the air must pass through the mod filters, followed by high efficiency filters, then two stages of HEPA filters in series. Air exits the filter banks into a common outlet plenum that is constructed of reinforced concrete. The three 860 fans (one at a time) can each take suction from the outlet plenum and exhaust to the horizontal exhaust stack (see Figure 3).

Figure 3 - Exhaust Stack and Station B

Air direction structures in the underground include bulkheads, air regulators, and overcasts. Their function is to channel and constrict air flow in the underground so that all desired areas receive a continuous flow of fresh air. The underground structures are designed to manage air pressure so that airflow is from clean to contaminated. For radiological considerations, airflow is from contaminated areas through the exhaust drift to the exhaust shaft, and then out of the mine.

At the top of the exhaust shaft is the effluent monitoring instrument shed shown at the bottom of Figure 4. The Station A and B samplers (Figure 4) have a flow rate of 2 cfm, so that any assay of the Fixed Air Sampler filters in a time interval can be scaled up by the exhaust flowrate in order to predict the air activity moving through the duct during the same time period from which the air sample was taken.

2.1.1 HEPA Source Term Estimation

The source term captured by the HEPA bank shown in Figure 4 passing Station A was obtained by summing all the total alpha activity measured at Station A and multiplying this by a single average ratio of flow rates of the effluent to the sampler. This resulted in a total activity value of approximately 120 mCi as TRU holdup deposited in the HEPA filtration system. This is approximately equal to the measurement of the activity that reached Station A.

2.1.2 Underground Source Term Estimation

Potential deposition of radionuclide contamination along the exhaust drift and shaft from a hypothetical release was investigated at the WIPP prior to operations (1998) by releasing multiple aerosols in the underground under controlled conditions and measuring their transport to the surface. Transmission factors to the surface varied by particle size with the highest transmission factor of 0.05 of the total release.

The container known to have been breached is estimated to contain around 7.1 Ci of radioactive material (see Section 3.1). Considering the 1998 test, the bulk of material released from its container remains in the underground and will be discussed in Section 3.1.

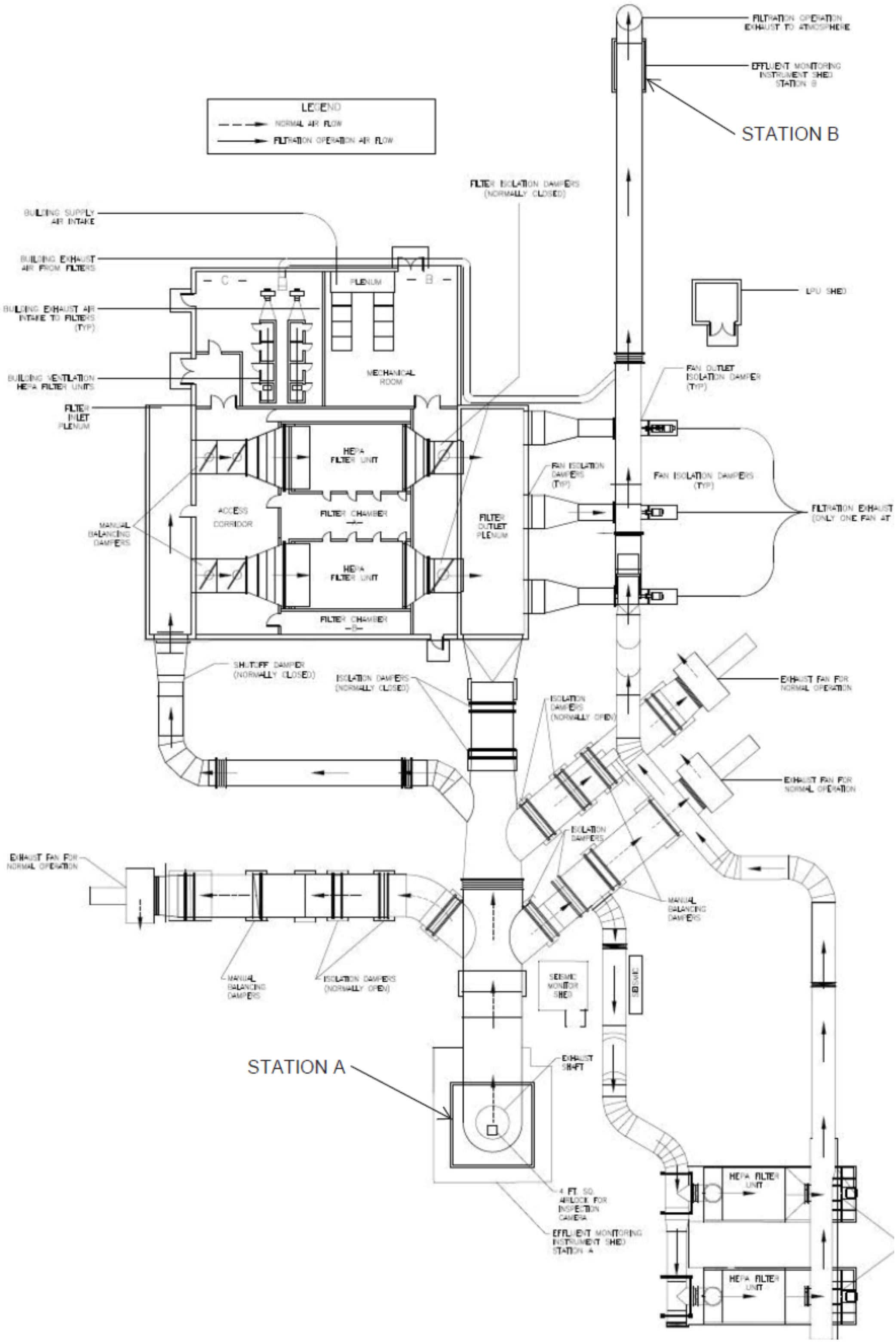

Figure 4 - Underground Ventilation System with IVS

Figure 5 below provides an aerial view of buildings and equipment previously discussed including Station A and associated above ground duct work, the 700, 800, and 900 series fans as well as the HEPA filter building and Station B.

Figure 5 - Aerial View of Underground Ventilation System

Figure 6 depicts the locations of areas and equipment described within this document.

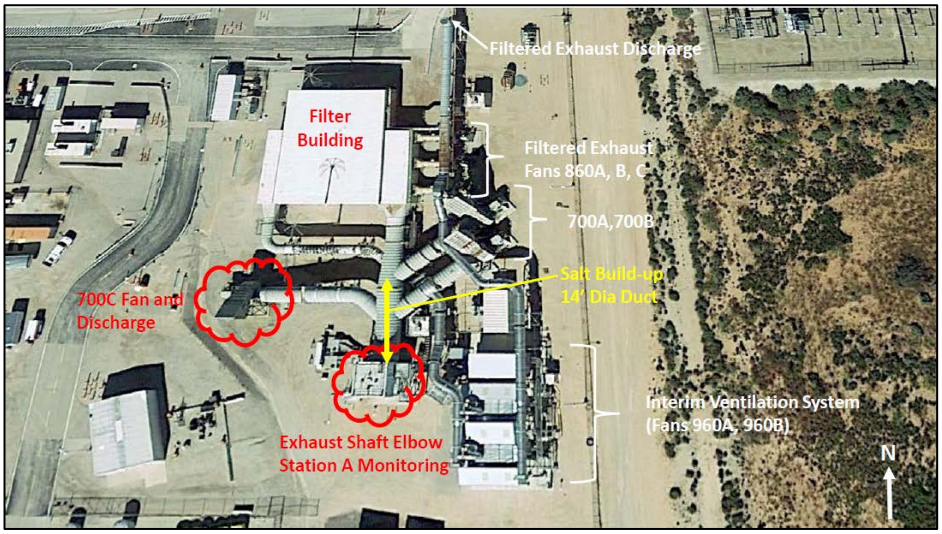

Figure 6 - Labeled Above Ground Image of the Ventilation System

Underground monitoring procedures require a CAM to be operable prior to operation of the 700C fan. This CAM is located at the exit of Panel 7 and monitors airflow through the active panel prior to being exhausted to the surface. This CAM provides alarm capabilities and indications to the Central Monitoring Room (CMR) which can initiate a shift to filtration, if necessary. The high flow rate CAM efficiency is 22% for Alpha measurements. Upon commencement of the 700C fan test plan, the level 2 alarm will be set to 19 derived air concentration (DAC)-hours, which is well below the typical operating alarm level of 40 DAC-hours, this alarm adjustment provides an additional layer of conservatism associated with the 700C fan testing evolution.

Figure 7 provides a ground level image of Station A. Station A is located over the underground ventilation exhaust elbow at the surface and samples using probes that extend 21 feet below the elbow in the ES. A depiction of the subsurface probes and their locations in the airshaft are included (see Figure 8). Also shown is the relative location of salt deposits.

Figure 7 - Location of Station A

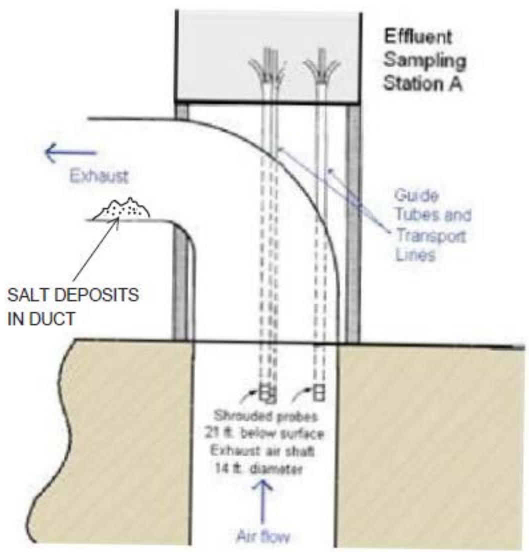

Figure 8 - Effluent Sample Station A

3 POTENTIAL RADIOLOGICAL RELEASE FROM 700C RESTART (HAZARDS ANALYSIS)

3.1 Current (Initial) Radiological Conditions

Prior to 2014, there were no measurable radiation releases in effluents from WIPP that could not be attributed to natural background (ubiquitous) radiation. Figure 9 is taken from the WIPP Environmental Report and shows the calculated doses to the maximally exposed individual at the WIPP fence line. Data for Figure 9 values are listed in Appendix F. The fence line dose provides a better basis for comparing historical data as the fence location has not changed, while the MEOSI location changes based upon occupancy and meteorological conditions. Since 2014, all effluent and sampling results have been isotopically consistent with the 2014 event results though in ever-decreasing quantities.

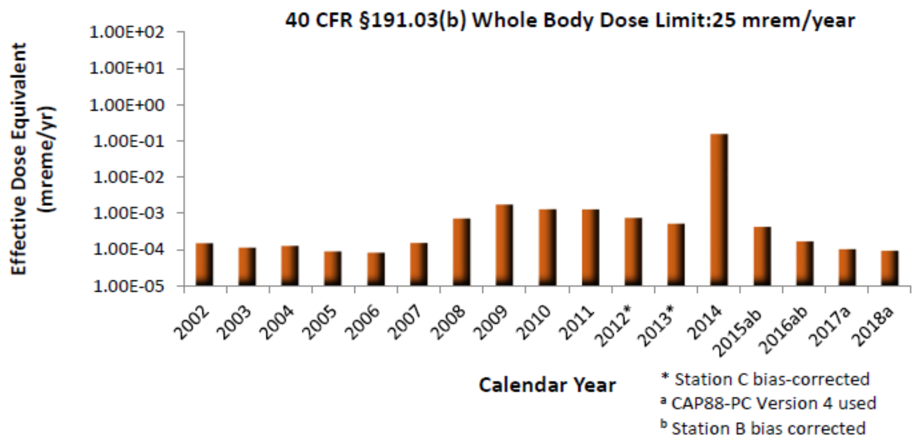

Figure 9 – Calculated Effluent Dose at WIPP Fence Line

The 2014 release at WIPP resulted in 120 mCi of Am-241 reaching the Station A sampler at the surface. Over 90% of released material was Am-241. Drum 68660 was identified as the source of the released material.

According to the Savannah River National Laboratory Technical Assessment Team Report, the inventory for salts of Drum 68660 was 0.91 g (3.1 Ci[1]) of Am-241. The nominal Am-241 content in that drum from processed liquid was 1.18 g (4.0 Ci). This yields a total Am-241 content of Drum 68660 of 2.09 g (7.1 Ci). The most recent annual (2018) Am-241 totals calculated 2.094E-07 Ci was released to the environment as measured at Station B and has been on a downward trend since the 2014 radiological release event.

3.1.1 Locations of Remainder of Drum 68660 Contents

As calculated above, the best estimate for the initial contents of drum 68660 is 7.1 Ci of Am-241. Approximately 8% of the activity measured at Station A were other nuclides, but for simplicity the nuclides are considered negligible. Following an exothermic reaction, sufficient pressure was generated in drum 68660 to burst open the drum lid and expel drum contents into

[1] Specific activity of Am-241=3.4 Ci/g

the normal ventilation airflow through Room 7 of Panel 7. The gases from the event were sufficiently hot to breach polypropylene bags filled with Magnesium Oxide (MgO) above the waste containers. The Am-241 entrained in the airflow had to pass through the piles of MgO on its way to the relatively small ventilation opening in the panel bulkhead at the end of the Panel 7 exhaust drift. From that point to Station A at the surface, the ventilation flow had to traverse roughly a mile of drifts and shafts, including two overcasts, with the opportunity to condense on the relatively cold surfaces along the way. Structures along that pathway include conduits and hundreds of ground control bolts holding up the upper surface of the drift.

It is likely that significant quantities of Am-241 are intermingled with the piles of MgO adjacent to drum 68660 and inside of Room 7 of Panel 7. Am-241 still located in the vicinity of the drum event will not be affected by the operation of 700C as Rooms 3-7 of Panel 7 have been isolated from the ventilation flow. Further, it is also likely that a smaller activity exists between the two overcasts on the exhaust route. The remainder of the Am-241 has plated out on downstream surfaces including becoming embedded in the salt walls of the passages.

Shortly after the event, Room 7 was sealed and further surveys near the event drum were discontinued for personal safety reasons. No comprehensive survey to determine the location of all Am-241 was performed.

3.1.2 Above Ground Sampling Procedures, Locations, and Results

On October 26, 2019, Radiological Control Technicians entered the horizontal ventilation duct adjacent to the 700C fan and performed surveys using portable radiation detection instruments. They also collected samples (wipes) that allow estimation of the amount of radioactive material that is readily dispersible (removable). Air and salt samples collected by the technicians were analyzed at the WIPP Laboratory.

Most swipe samples were collected from the sides of the ducts with the expectation that those locations would be more representative of the contamination that occurred from the February 2014 incident. In addition, since the sides of the ducts have typically thinner salt buildup than the bottom of the ducts, it was expected that contamination found might be more representative of the contamination deposited during the 2014 event.

A total of 96 swipe samples were collected from 48 locations, including some directly on the salt buildup in the lower areas of the ducts (see Figure 10). For each sampling location, the swipe with the greater activity was selected for the data set that was statistically analyzed, to conservatively estimate the maximum possible removable contamination. It is considered that salt of lesser contamination concentration might be on the surface layers covering those layers more representative of the salt contaminated as a result of the radiological incident in February 2014. All these things taken together are the essence of the “smart” sampling technique utilized-since the sampling was limited due to a number of constraints, including worker safety.

A view of conditions inside the horizontal ventilation duct (at the approximate location of sample 48 on Figure 10 looking south) is shown in Figure 11.

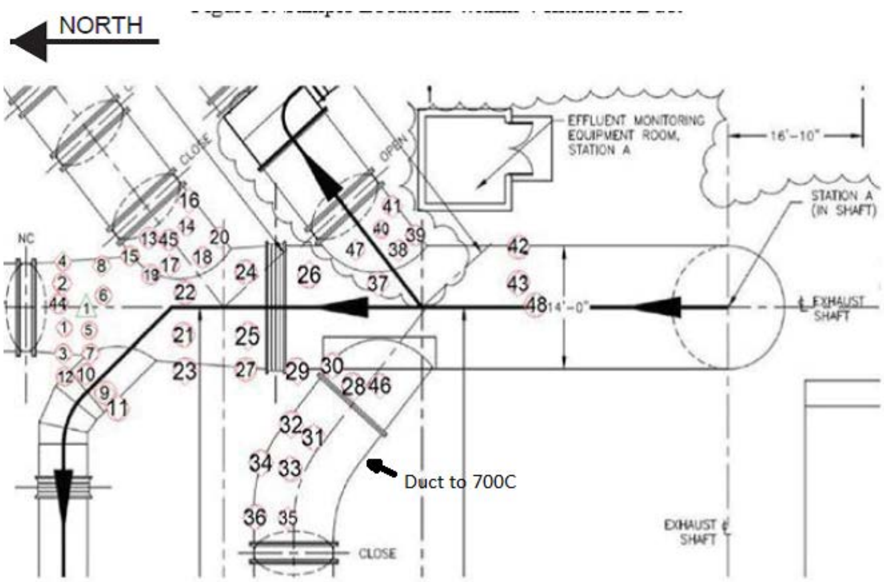

Figure 10 - Sample Locations within Ventilation Duct

Figure 9 - Main Duct Looking South Towards Elbow

During collection of the samples, salt fell off the swipes; this source of error is difficult to account for. Alpha particles are also completely occluded by very thin layers of salt. Due to the high number of samples and limitations on laboratory analysis capacity, the higher activity swipes were chosen to estimate the self-absorption correction to be applied to the samples in general. These samples were chosen to provide a reasonable estimate of total activity values to utilize for self-absorption calculations.

The swipes were counted for gross alpha activity using a Tennelec gas flow proportional counter and subsequently gamma counted for ^{241}Am by WIPP Laboratory. Most of the activity within the contamination in the mine is from ^{241}Am as documented in the DOE Accident Investigation Report. Using the assumed nuclide distribution (of which ^{241}Am is more than 92 percent by activity), the measured ^{241}Am activity values could be compared to the anticipated gross alpha values. Using the correction factor of approximately 1.0364 times (to account for the differing isotopic content as determined in TE 20-002) the ^{241}Am value provides an estimate of the true gross alpha value for each sample analyzed in this way. Using the "true" gross alpha values calculated for this set of samples and comparing those values to the gross alpha values reported by the Tennelec counter, an approximate, typical alpha self-absorption correction factor was calculated. This correction factor was applied to all the swipe samples to account for alpha self-absorption.

In addition, to further account for uncertainty, the top of the single-sided 99.5 percent confidence level for the mean (p = 0.005) was calculated, and that value was used as the contamination level in the calculations. The corrected results used for calculations are located in Appendix B, Final Corrected Results for Ductwork Radiological Samples.

The contamination level, as used in this document, for the top of the single-sided 99.5 percent confidence level for the estimate of the average of collected samples on the pathway to the 700C fan (via use of the T-distribution) is approximately 280.1 disintegrations per minute (dpm)/100 cm^2.

The surface area of the above-ground contaminated ducting is calculated in Appendix D. The calculated surface area is 3096.4 ft^2.

3.1.3 Below Ground Sampling Procedures, Locations, and Results

A comprehensive characterization of the potential source term in the underground was not performed due to the uncertainty with the underground source term, the media in which it is contained (salt), and the inaccessibility of isolated portions of the underground. As described in Section 3.1.1, the bulk of the original Drum 68660 content is believed to be isolated in Room 7 of Panel 7 with no ventilation flow. The remaining material at risk related to operation of the 700C fan has been either been fixed within the salt, deposited in or between overcasts, or potentially sealed off in other closed rooms throughout Panel 7. However, Station A analysis confirms that very low levels of radioactive material continue to be slowly released, they also indicated a downward trend since 2014. Although no waste handling will be permitted during the 700C fan testing evolution, a high flow rate CAM as pictured in Figure 12, will be located at the exit of Panel 7 during testing of the 700C fan to detect any potential increase in airborne radioactivity exiting the panel during the testing.

Three sampling heads as depicted in Figure 8 sample the air coming out of the exhaust providing a representative sample for analysis. These samples provide indication of any radioactive material potentially exiting the below-ground system.

Figure 10 - Canberra iCAM Alpha/Beta Air Monitor

3.2 Potential Mechanisms of Release during Restart

The removable activity results, as ascertained from swipe samples inside the applicable portion (see discussion below) of the above-ground ventilation system indicate a potential for loose radioactive material to be expelled to the atmosphere during the testing phase of the 700C fan. A large accumulation of salt (several tons) has built up which is typical due to air currents within the ventilation duct work (See Figures 8 and 11). In the past, similar accumulations of salt were broken up with water lances and washed back down the exhaust shaft. The radioactive material entrained within the duct work has precluded the removal of this salt accumulation as the lancing technique would resuspend all radioactive material encapsulated in the salt and the dislodged salt falling back down the shaft could severely restrict airflow at the base of the shaft. There would also be an increased concern regarding worker safety associated with the requirements to wear personal protective equipment (PPE) and respiratory protection within the duct work.

3.2.1 Resuspension

The area considered to be applicable to this evaluation is the area approximately between the center of exhaust shaft to furthest edge of 700C and 700A ducts, along with the 700A and 700C branches to their respective dampers. This area includes large amounts of salt deposits which were shown to have low levels of removable contamination on the surface. The single-sided top of the 99.5 percent confidence level for the estimate of the average contamination, corrected for self-shielding, was used as the contamination level for the leading surface of the dampers for the 700A and 700C fans (as discussed in Section 3.1.2). The damper surfaces are metal with an assumed thin layer of contaminated salt, rather than inches- or feet-thick layers of salt found in other areas of the duct, in which contamination is encapsulated. The leading surface area of the dampers for the 700A and 700C fans are about 5 feet in radius each, making a total effective surface area of about 157.1 square feet. The top of the single sided 99.5 percent confidence level is estimated to be about 280 dpm/100 cm^2 for the evaluation of the radiological impact of the operation of the 700C fan. This value was assumed to be evenly distributed throughout the area of consideration based on removable activity identified during the survey of the above ground duct work.

3.3 Calculation of Best Estimate of Maximum Dose

3.3.1 Calculation

Calculations were performed related to all aspects of the 700C fan testing evolution and associated surveys performed. Details associated with the calculations related to operation of the 700C fan can be found in TE 20-002, *Radiological Assessment of the Startup and Testing of the 700C Fan* and in Appendices B, D, and E.

Using conservative assumptions, these calculations, along with plume models using National Atmospheric Release Center (NARAC) methods, estimate a low-level release including resuspension of approximately 5.92E-06 Ci potentially released during the 4-hour period of operation for the 700C fan testing evolution. Calculations in Appendix E conservatively put the airborne concentration in the 700C duct at 0.726 DAC, lowering to 0.019 DAC at 100 feet from the exit screen of the fan at ground level.

The MEOSI, an office occupant at the Safety Significant Confinement Ventilation System, is at a distance of 1099 feet (335 meters) east-southeast of the 700C fan emission point. The calculated dose to the MEOSI is 0.00489 mrem using EPA code CAP88.

3.3.2 Comparison of Calculation Results with Applicable Standards and Thresholds for Protection of Human Health and the Environment

10 CFR 835, *Occupational Radiation Protection Program*

- Except for planned special exposures conducted consistent with §835.204 and emergency exposures authorized in accordance with §835.1302, the occupational dose received by general employees shall be controlled such that the following limits are not exceeded in a year:
  - A total effective dose (TED) of 5 rem (0.05 Sv).
  - The TED limit for members of the public exposed to radiation and/or radioactive material during access to a controlled area is 100 mrem (0.001 Sv) in a year.

- The calculated dose from the 4 hour test to the MEOSI is 0.005 mrem, well below the 100 mrem limit.

DOE Order 458.1, *Radiation Protection of the Public and the Environment*

- DOE radiological activities, including remedial actions and activities using Technologically Enhanced Naturally Occurring Radioactive Material, must be conducted so that exposure of members of the public to ionizing radiation will:
- Not cause a TED exceeding 100 mrem (1 mSv) in a year, an equivalent dose to the lens of the eye exceeding 1500 mrem (15 mSv) in a year, or an equivalent dose to the skin or extremities exceeding 5000 mrem (50 mSv) in a year, from all sources of ionizing radiation and exposure pathways that could contribute significantly to the total dose.
- The calculated dose from the 4 hour test to the MEOSI is 0.005 mrem, well below the 100 mrem annual limit.

40 CFR 61, *National Emission Standards for Hazardous Air Pollutants*

- Radionuclide emission measurements in conformance with the requirements of paragraph (b) of this section shall be made at all release points which have a potential to discharge radionuclides into the air in quantities which could cause an effective dose equivalent in excess of 1% of the standard. All radionuclides which could contribute greater than 10% of the potential effective dose equivalent for a release point shall be measured. With prior EPA approval, DOE may determine these emissions through alternative procedures. For other release points which have a potential to release radionuclides into the air, periodic confirmatory measurements shall be made to verify the low emissions.
- The calculated dose from the 4 hour test to the MEOSI is 0.005 mrem, well below the 10 mrem annual limit.
- Additional measurements will be made as described in Section 4 of this report.

DOE/WIPP 07-3372, REV. 6a SBS-2019-01, REV. 0a, *Waste Isolation Pilot Plant Documented Safety Analysis – Safety Basis Supplement (SBS)*

- This SBS addresses operation of unfiltered 700 exhaust fans for testing to evaluate long-term usage to provide increased underground airflow while performing construction and ground control work in the construction areas of the underground. Operation of an unfiltered 700 exhaust fan is necessary to maintain underground air quality during significant operation of diesel-powered equipment. This SBS will be revised or superseded to address the long-term use of unfiltered 700 exhaust fans for performing construction and ground control work in the construction areas of the underground.

The principles of as low as reasonably achievable (ALARA), maintaining personnel exposures as low as reasonably achievable, have been included in the planning of the 700C fan test and required for the 700C fan sampling plan. The sampling plan requires individuals involved to wear PPE and respiratory protection. ALARA practices were also taken into consideration for personnel not involved in testing by limiting access to the facility and requiring those on site to remain in doors until the conclusion of the test. The Radiological Work Permit (RWP) utilized for the test (RWP 20-007) also includes an extensive ALARA review. As involved workers will be wearing respiratory protection, the best estimate for dose to workers is not detectable.

3.4 Controls to Mitigate the Hazard

The following controls are to be in place to mitigate hazards during the 4-hour test.

3.4.1 Systems, Structures, and Components

CAMs located in the underground at the Panel 7 exhaust drift will provide indication of any elevation of airborne radiological activity from Panel 7, and initiate notification of the CMR to alert operators to shut down the unfiltered ventilation airflow and notify personnel to safely egress the underground. Additionally, continuous air monitoring is observed by an underground qualified worker. Upon detection of elevated airborne activity, this worker will communicate actuation of the alarm to the CMR. Receipt of the alarm by electronic signal or verbal communication alerts CMR operators to initiate actions to shutdown unfiltered ventilation and notify underground workers to evacuate. The Central Monitoring System (CMS) displays CAM operating parameters as well as CAM alarms. These precautions allow for CMR operators to initiate a manual shift to filtration.

CAMs will be placed in the four cardinal directions on the surface surrounding the 700C fan to ensure any increase in airborne radioactivity on the surface is detected during testing of the 700C fan. The purpose of these CAMs is to provide an indication of what is being released from the 700C fan exhaust. These CAMs will have alarms set to 8 DAC-hour. Any CAM alarm during testing of the 700C fan requires immediate shut down per Technical Basis Document (TBD) 20-003, *Sampling Plan.*

The CMS will display multiple indicators to operators including fan operations conditions and the condition of the dampers as well as vibrations of motor bearing and shaft bearings. These indications provide operators with the ability to secure the 700C fan if any parameter is found to be outside of the acceptable operating range.

3.4.2 Administrative Controls

The WIPP Documented Safety Analysis – SBS contains additional Specific Administrative Controls (SAC) that unfiltered ventilation, when the 700 fan is in use, requires:

- Vehicles/equipment having liquid-combustible capacity are prohibited from entering Panel 7. Any vehicles/equipment remaining in Panel 7 during unfiltered ventilation testing are secured and are greater than or equal to the minimum standoff distance from the Waste Face (SAC 5.5.9).
- The CMR Operator shuts down unfiltered ventilation testing upon notification of Panel 7 elevated airborne activity (SAC 5.5.10).

- Underground is in Disposal Mode with all Waste, external of closed Disposal Panels, located in Panel 7 (SAC 5.5.11).
- No Waste Handling, mining, or ground control, except as permitted (SAC 5.5.12), is in progress.
- Continuous air monitoring with alarm of elevated airborne activity is established in the Panel 7 exhaust drift with alarm/notification of the CMR (SAC 5.5.13).
- Facility Operations Personnel Minimum Staffing (SAC 5.5.14).

Operation of a 700 fan drawing air from the underground exhaust shaft provides unfiltered air release to the atmosphere. During unfiltered ventilation of the underground, the 860 and 960 fans are not operated.

Operation of a 700 fan for testing purposes is allowed once conditions in the underground are established to minimize the likelihood for certain accidental radiological events. However, restricting access to Waste containers does not remove all potential event scenarios. Therefore, Shutdown of Unfiltered Ventilation is necessary upon detection of a release in the underground. Continuous air monitoring at the Panel 7 exhaust and communications with the CMR provide the means to detect a release from Waste containers located within the panel. The CAM is only required at the exhaust drift as the fan operation would be drawing air out of Panel 7 through the exhaust drift; not the intake drift.

Notification to the CMR of a release permits manual shutdown of unfiltered ventilation, which stops the motive force necessary to exhaust the release above ground. The CMR notification also permits notification of underground workers to safely egress.

Meteorological conditions are required to be within a defined range prior to beginning of the 700C fan testing evolution. These controls include wind direction, between 330-degrees and 10-degrees (roughly NNW-N), wind speed below 6.3 meters per second (14 mph), stability class between A-C and no precipitation are required for testing.

PPE will be required for individuals involved in testing of the 700C fan. This PPE will consist of a single set of PPE and respirator which will provide adequate protection to those involved until conditions can be verified in order to downgrade this requirement.

4 MONITORING AND SAMPLING PROCEDURES DURING RESTART TESTING

4.1 Monitoring and Sampling Objectives during Restart Testing

During restart of the 700C fan for testing, multiple means of testing will be conducted to ensure the actual amount of radioactive material released is less than the calculated values for potential dose to the MEOSI. These test results will validate protection of the worker, public and environment.

In order to ensure adequate on-going worker protection, results from the initial 4-hr test of the 700C fan will be evaluated prior to allowing additional operation of the 700C fan.

Station A will continue to be monitored to further detect any potential increase in radioactive material released from the underground. 700C fan output will monitored at a frequency to be determined by actual results ascertained from the 700C fan testing evolution.

4.2 Sampler Locations and Types during Restart Testing

The sampling plan provides for monitoring for both airborne radioactivity and radioactive material which might be deposited on the ground through fall out. Airborne radioactivity sampling will consist of CAMs and Portable Air Monitors. For ground deposition, swipes will be taken for measurement of removable activity and portable contamination monitoring equipment will be used for total activity. Round aluminum ground deposition pans will be placed prior to the fan startup at the sample locations to allow for more accurate removable/total contamination surveys. The sample locations were identified by overlaying the three plume models representing a 330 degree to 10 degree wind direction range from the point of release assuming a wind speed of 3.71 m/s and Pasquill C stability class. Four CAMs will be placed in the cardinal directions for worker protection purposes only.

For example, Figure 13 depicts a filter head with reinforced membrane filter media, attached to vacuum tubing from a calibrated sample pump, to be held in the air stream near the center at a point near the top, and another point near the bottom of the fan shroud screen. The filter will be pointing into the airstream near the outlet, and the aspiration effects will be sufficient to require a correction factor for larger particles. The positioning of an upper and a lower sampler is intended to account for potential gravitational effects, although the fan exhaust is expected to be well-mixed. This design has not been finalized but provides an indication of potential methods to sample air exiting the system.

Figure 11 - Air Sampling on Face of 700C Fan

Low volume air samplers will be used to provide monitoring data related to the potential low level release of radioactive effluents during the testing evolution. The location of the low volume air samplers to be used in the test (shown in the following Figure 14) can be seen with expected release paths overlaid.

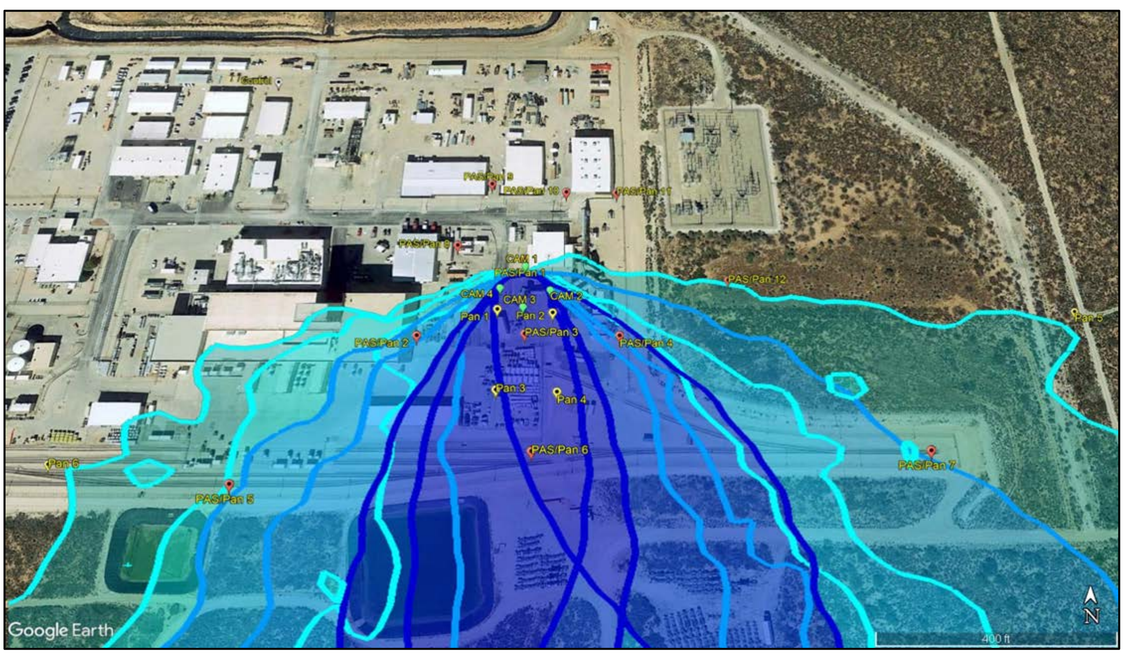

Figure 12 - Location of Low Volume Air Samplers and NARAC Plume Models

4.3 Worker Protection during Restart

As a precautionary measure, individuals involved with testing of the 700C fan will be required to wear one set of PPE as well as respiratory protection as outlined in the TBD for sampling during the evolution, up to and until conclusion of the four-hour test period. Onsite personnel not directly involved with the fan testing will be required to remain indoors. While elevated airborne activity levels requiring PPE and respiratory protection are not expected, it is deemed prudent for the first-time use of 700C with contamination present. Expected flows in the underground are shown in Appendix A.

Access to the facility will be controlled during testing, allowing only essential personnel on site as well as requiring those not directly involved with testing to remain indoors.

4.4 Dose Evaluation

No measurable dose is expected for workers or MEOSI during the 700C restart. This is also retrospective based on monitoring results. Monitoring results will be evaluated to ensure no protection factors have been exceeded and no for-cause bioassay needs to be conducted.

4.5 Administrative Procedures

Testing will be conducted utilizing formal Test Plans, Work Control Documents (procedures), Job Hazard Analyses, and RWPs. Work documents are developed utilizing multi-discipline inputs and approvals. Adherence to Disciplined Operations tenets will ensure that if unexpected results occur at any point, work will be paused and evaluated for continuation.

5 CONCLUSIONS

Renewed operation of the 700C fan will provide continued support for the WIPP mission. This support will come in many forms including improved worker safety and improved mission efficiency. The increased underground ventilation will ensure continued air quality for the workforce through the reduction of diesel exhaust emissions while simultaneously increasing the allowable operation of diesel-powered equipment. This additional equipment and operations will allow WIPP to carry out the facility mission more efficiently in a similar fashion as to that of the pre-2014 rad event. This ventilation increase will also allow the facility to achieve throughput rates closer to those intended in the facility design. Operation of an unfiltered 700 exhaust fan is strongly desired to maintain underground air quality during significant operation of diesel-powered equipment.

Adherence to limiting controls outlined in Section 3 during operation of unfiltered 700 exhaust fans for testing, including suspension of waste handling evolutions, will allow confirmation of assumptions and calculations for limiting values for effluents.

The initial four-hour controlled testing period is required to ensure continued operation of the 700C fan is safe for the workers, public and environment. There is potential for a release of radioactive material upon restart for the 4 hour test, estimated to contribute less than 0.005% of the allowable 10 mrem/year EPA regulatory limit.

6 REFERENCES

DOCUMENT NUMBER AND TITLE
10 CFR 835, Occupational Radiation Protection Program
30 CFR 57.8528, Unventilated Areas
40 CFR 61, National Emission Standards for Hazardous Air Pollutants
DOE Handbook, 2014
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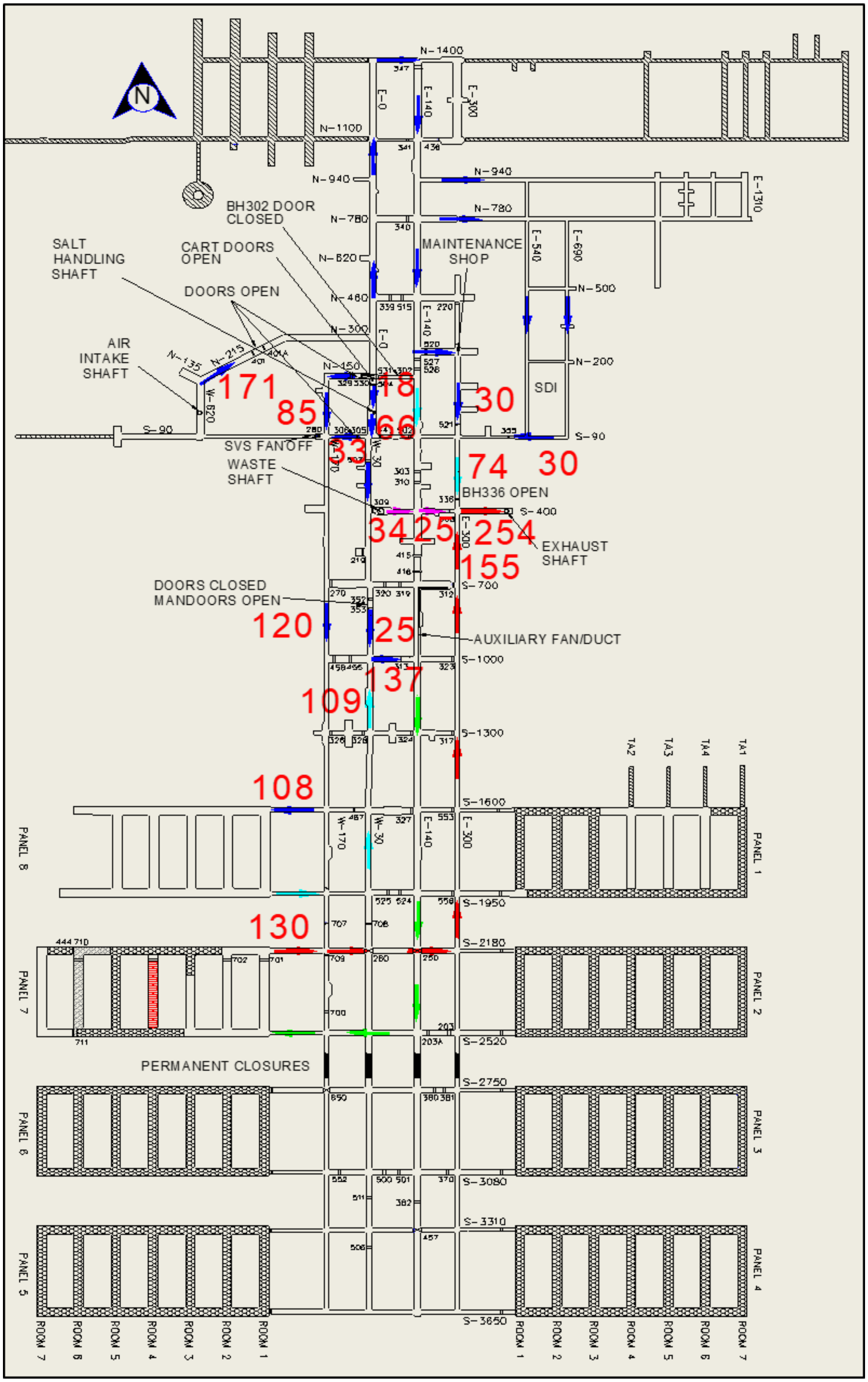
Archer, J., Sanchez, R., Strait, A., Underground Flow Measurement and Particle Release Test, Revision 0, December 1998
Hayes, R.B., 2016. Consequence assessment of the WIPP radiological release from February 2014. Health Physics, 110(4), pp.342-360
Thakur, P., 2016. Source term estimation and the isotopic ratio of radioactive material released from the WIPP repository in New Mexico, USA. Journal of environmental radioactivity, 151, pp.193-203
Willison, J., Radiological Conditions for Exhaust Filters, WIPP Calculation, Revision 1, March 2014
Savannah River National Laboratory, Waste Isolation Pilot Plant Technical Assessment Team Report, SRNL-RP-2014,01198, Revision 0, March 2015
00CD-0001, WIPP Mine Ventilation Plan
SBS-2019-01, Documented Safety Analysis – Safety Basis Supplement
TBD 20-003, Sampling Plan
TE 20-002, Radiological Assessment of the Startup and Testing of the 700C Fan
DOE/WIPP-19-3591, Rev. 0, Waste Isolation Pilot Plant Annual Site Environmental Report for 2018
U.S. Department of Energy Office of Environmental Management Accident Investigation Report, Phase 2, Radiological Release Event at the Waste Isolation Pilot Plant, February 14, 2014, April 2015

APPENDIX A, PREDICTED AIRFLOWS WITH THE 700C FAN OPERATING



Note: Numbers in red are airflows in kcfm

APPENDIX B, FINAL CORRECTED RESULTS OF DUCTWORK RADIOLOGICAL SAMPLES (FIGURE 9)

Sample Number	Tennelec Alpha dpm/sample	Corrected Tennelec Results Alpha dpm/sample	Sample Number	Tennelec Alpha dpm/sample	Corrected Tennelec Results Alpha dpm/sample
1	122.2	204.33	25	5.14	8.594
2	56.53	94.52	26	-0.57	-0.9531
3	464.82	777.2	27	42.26	70.66
4	307.79	514.6	28	5.14	8.594
5	133.62	223.4	29	19.42	32.47
6	47.97	80.21	30	42.26	70.66
7	1681.13	2811	31	176.45	295.0
8	122.2	204.33	32	136.48	228.2
9	1355.64	2267	33	13.7	22.91
10	30.84	51.57	34	82.23	137.5
11	507.65	848.8	35	36.55	61.11
12	227.84	381.0	36	119.35	199.6
13	79.37	132.7	37	2.28	3.812
14	27.98	46.78	38	5.14	8.594
15	45.11	75.43	39	65.1	108.9
16	207.86	347.6	40	2.28	3.812
17	50.82	84.97	41	33.69	56.33
18	13.7	22.91	42	2.28	3.812
19	102.22	170.9	43	2.28	3.812
20	127.91	213.9	44	7.99	13.36
21	19.42	32.47	45	16.56	27.69
22	13.7	22.91	46	10.85	18.14
23	187.87	314.1	47	7.99	13.36
24	53.68	89.76	48	2.28	3.812

To make better sense of the results, the Sign test non-parametric analysis and Gaussian parametric analysis (using the T-distribution) were performed with $p = 0.005$, to find the single-sided top of the 99.5 percent confidence level for the median and mean, respectively. Since the data has an unknown distribution, both types of analyses were performed. Sometimes, the values *roughly* predicted by the Sign test are higher than the values predicted by use of the T-distribution. It should be observed that the median was not a good predictor of the mean for this data set. The higher of the values from each analysis was chosen. For the 700C fan, sample points 24 through 48 were selected as being representative for the airflow pathway from the exhaust shaft to the 700C fan (See Figure 9).

The Derived Concentration Guideline Level (DCGLw) value within the Sign Test[2] was not derived. Rather, it was chosen until the number of positive results (for the Sign test) are two greater (as a conservative action) than the critical value for the confidence level chosen. In this way, if the single-sided top of the 99.5 percent confidence level estimate for the value for the median is greater than the top of the confidence level (assuming a Gaussian distribution), then that value will be chosen rather than the value calculated assuming a Gaussian distribution.

However, the top of the confidence level was much greater assuming a Gaussian distribution, so it was chosen. **For the 700C fan, sample points 24 through 48 were selected as being representative.**

Table B1 - Summary of Swipe Data Results Pertaining to 700C and Analysis (dpm/100 cm^2)

Maximum	Minimum	Median	Average	Top of Single-sided 99.5% Confidence Level for Average
295	0	23	60	280.1

The contamination level, as used in this document, for the top of the single-sided 99.5 percent confidence level for the estimate of the average (via use of the T-distribution) is approximately 280.1 dpm/100 cm^2.

[2] See the MULTI-AGENCY RADIATION SURVEY AND SITE INVESTIGATION MANUAL, that is, NUREG-1575, Rev. 1, EPA 402-R-97-016, Rev. 1, DOE/EH-0624, Rev. 1.

APPENDIX C, COMPONENT DESCRIPTIONS, WIPP VENTILATION SYSTEMS

This section contains more detailed descriptions of selected components.

FANS (860A, B, C)

The 860 fans are centrifugal type, rated at 70,000 cfm. Each is powered by a 460 Volt, 3 phase, and 60 Hertz motor nominally rated at 235 horsepower (see Figure C-1). The motors sit atop sheet metal pedestals that are bolted onto concrete pads. The 860 fan motors are original equipment from site construction and were the only mine ventilation fans prior to the construction of the AIS and the 700 (large) fans. The 860 fans have been replaced within the past ten years.

Figure C-1 - 860B and 860A Fan Motors

IVS FAN/FILTER UNITS (960A, B)

The parallel 960 fan/filter units are centrifugal type, rated at 27,000 cfm. Each has an associated multi-stage HEPA filtration bank. The units take suction from the 700A ducting and exhaust filtered air to the exhaust stack upstream of the exhaust of the 860 fans. The two fan/filter units can be operated independently or simultaneously.

BULKHEADS

Bulkheads are ventilation barriers in the underground that block and direct airflow (see Figure C-2). Bulkheads are of steel construction with rubber flashing adjacent to the salt face. Bulkheads needed for escape have man doors. Selected bulkheads will also have larger vehicle doors. The steel construction is necessary to meet 30 CFR 57 requirements. The rubber flashing will accommodate some ground movement while still directing airflow as designed.

Figure C-2 - Bulkhead with Vehicle and Man Doors

REGULATORS

Air regulators are adjustable louvers that restrict the flow of air in the underground and allow the control of flow quantities and direction. Louvers can be set for manual or remote operation (see Figure C-3). Regulators are electrically operated and fail as is. At present, only Regulators 308 (between the waste shaft and the exhaust shaft) and 313 (at the split between disposal air and mining air) are set to remote operation. All other regulators are in manual mode. When regulators are in remote operation they can be adjusted via the CMR.

Figure C-3 - 313 Regulator

OVERCASTS

Overcasts are air bridges that allow one airway to pass over another airway without mixing (see Figure C-4). Important overcasts are along the S-2180 exhaust drift from Panel 7 to E-300. Overcasts have high roof cuts at drift intersections with metal panels separating higher pressure clean air from lower pressure exhaust air.

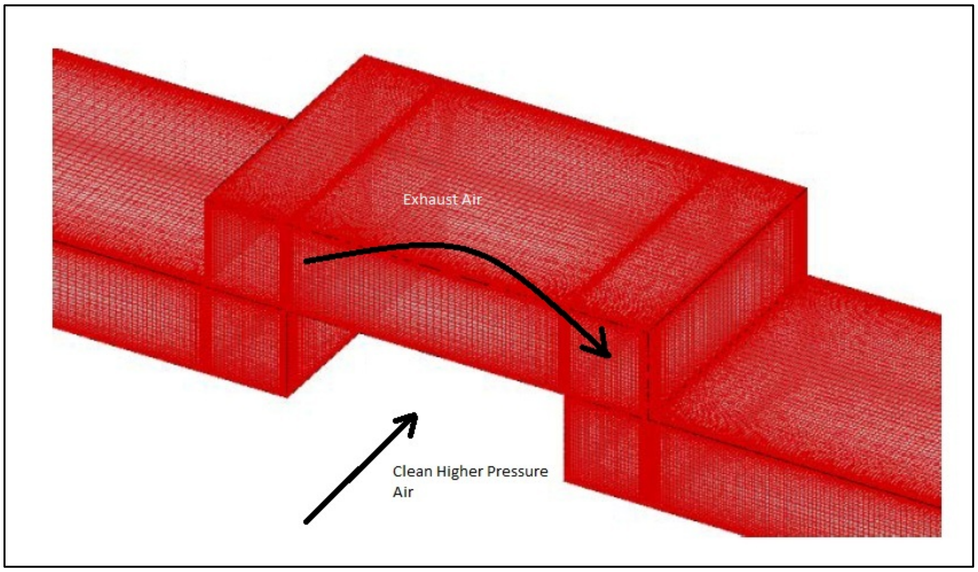


Figure C-4 - Schematic of Overcast

700 FAN ISOLATION DAMPERS

Each of the 700 fans has two butterfly-type isolation dampers in series. These dampers are currently closed. Pressure across the fans is inward due to the operating 860/960 fans.

SURFACE DUCTING

Exhaust air from the underground is pulled through a 12-foot diameter elbow which is bolted to the Exhaust Shaft Collar. The Exhaust Duct remains at a 12-foot diameter past the junction of the connections for fans 700A and 700C. The duct then reduces to 10 feet in diameter up to the Maintenance Dampers. In the 10-foot diameter section, the 700B and the duct to the filter building branch off. The Bypass Dampers are currently closed and have been sealed with foam to prevent leakage. A 6-foot diameter duct branches off the Exhaust Duct and transports air to the Inlet Plenum of the Exhaust Filter Building (EFB).

The Exhaust Duct is 0.25-inch steel through the 14-foot and 10-foot diameter section. It is 10 gauge steel for the remaining 6-foot diameter branch to the EFB. A portion of the 6-foot diameter ducting has been strengthened with fiberglass wrap.

EXHAUST STACK

The Exhaust stack is 120 feet in length and runs from the exhaust of the three 860 fans horizontally with a 90 degree elbow at the end. The elbow directs flow upward. The stack is constructed of 10 gauge steel. Station B has three sampling probes that take ANSI-qualified representative air samples from the duct prior to release to the environment.

APPENDIX D, CALCULATION OF DUCT SURFACE AREA

Surface Area of each Damper

$$A = \pi r^2$$

$$\text{Area}_{\text{sq ft}} = 3.14159\ (5^2) \approx 78.54 \text{ sq ft}$$

Where:

- A is the area in square feet.
- π is a constant approximately equal to 3.14159.
- r is the radius in feet = 5.

Therefore, the surface area of the two dampers combined is 2 X 78.54 sq ft = 157.1 sq ft.

Surface Area in cm^2 of applicable ducts

$$Surface\ Area\ of\ an\ Open\ Cylinder = 2\pi rh$$

Where:

- r is the radius of the cylinder (or duct) in feet.
- π is a constant approximately equal to 3.14159.
- h is the height in feet (or length in feet).

The dimensions of the ducts being considered are the following:

Table D1 - Length, Radius, and Surface Area of Ducts

Duct Description	Length (ft)	Radius (ft)	Surface Area (ft^2)
Center of Shaft to Furthest Edge of 700A and 700C Branches	50.65	7	2 * π * 7 * 50.65 = 2,227.7
700A Branch (Center Line) to First Damper	4.4	5	2 * π * 5 * 4.4 = 138.2
700C Branch (Center Line) to First Damper	23.25	5	2 * π * 5 * 23.25 = 730.4
		Sum of Areas for Ducts:	**3096.4 ft^2**

APPENDIX E, CALCULATION OF TOTAL REMOVABLE CONTAMINATION AND PUFF RELEASES

The total removable activity on the applicable surfaces is the activity that is considered to be subject to the “puff” release. As a conservative measure, an activity equal to the total removable activity is assumed to be released within the first 15 minutes. (Also, the activity concentration just beneath the previous removable activity is assumed to be of the same activity level and subject to resuspension evaluated via resuspension calculations.) Puff releases have the same consequences for different time periods because they are singular events that happen when the fan first starts.

Equation E1 - Removable Activity on Applicable Surfaces

$$Removable\ Activity_{dpm} = \frac{\left(Activity\ Concentration_{dpm}/_{100\ cm^2}\right)\left\{(A)(12\ *2.54)^2\ cm^2/_{ft^2}\right\}}{100\ cm^2\ units\ for\ activity\ concentration}$$

Where:

- Activity Concentration is the activity concentration of concern, such as 280.1 dpm/100 cm^2.(value from Table B1)
- A is the area in ft^2 with surface activity on it subject to resuspension, such as 157.1 ft^2 for the two dampers or 3096.3 ft^2 for the ducts.
- The 100 cm^2 units for activity concentration in the surface area is needed because the contamination is defined in units of 100 cm^2.

Equation E2 - Conversion from dpm to Curies

$$Curies = dpm/(2.22E + 12\ \text{dpm/Curie})$$

For example, the removable activity on the two dampers (combined area) is the following, from Equation E1:

$$Removable\ Activity_{dpm} = \frac{\left(280.1_{dpm}/_{100\ cm^2}\right)\left\{(157.1\ sq\ ft)(12\ *2.54)^2\ cm^2/_{ft^2}\right\}}{100\ cm^2\ units\ for\ activity\ concentration} = 4.09E + 05\ dpm$$

and

$$Curies = 4.09E + 05\ dpm/2.22E + 12 = 1.84\text{E-07 Ci}$$

The puff release from the dampers does not vary, no matter the different situations considered in this document because the damper surfaces are never covered with a fixative, so that the removable contamination that would be released in a puff is the same, regardless of the scenario.

For the ducts with 0% percent reduction (no fixative applied):

$$Removable\ Activity_{dpm} = \frac{\left(280.1 \, {}^{dpm}\!/_{100\ cm^2}\right)\left\{(3096.3\ sq\ ft)(12\ \ * 2.54)^2\ cm^2\!/_{ft^2}\right\}}{100\ cm^2\ units\ for\ activity\ concentration} = 8.06E + 06\ dpm$$

and

$Curies = 8.06E + 06\ dpm/2.22E + 12$ = 3.63E-06 Ci

Table E1 - Puff Releases in Curies for Ducts and Dampers

	Dampers (157.1 ft^2)	Ducts (3096.4 ft^2)
No Reduction (Fixative not applied)	1.84E-07	3.63E-06

Resuspension Calculations

The total DAC concentration within the plume being expelled is simply the sum of the contributions from resuspended activity and the activity coming from the exhaust shaft as measured by Station A. However, the resuspended activity is considered in four components, that is:

1. The chronic resuspension from the contaminated salt and surfaces encountered in the duct (other than the dampers),
2. The chronic resuspension from the contaminated salt on surfaces of the dampers,
3. The “puff release” from the contaminated salt and surfaces in the duct (other than the dampers), and
4. The “puff release” from surfaces of the dampers.

This section will detail the calculations regarding items 1 and 2 in the list above. Equations E3 or E4 and variants are used extensively in the calculations in this document. The resuspension calculations use information that is known, rather than assuming that which is unknown. From the sampling and surveys that were performed within the duct, certain information is known about the surface contamination. Calculations based upon volumetric source term of the estimated 60 tons of salt cannot be meaningful when there is so much uncertainty regarding the level of the source term, and the source term (which includes volumetric contamination) cannot be reliably estimated via surface contamination samples. Calculations based upon an equilibrium airborne concentration existing above or at a specified distance from a contaminated surface (using NUREG 1400 protocol) do not consider the worst case, but rather a very conservative one (and a responsible way of handling these circumstances) that is appropriate for this situation in which there is uncertainty regarding the total source term within the salt and also regarding its dispersibility—but something is known about the surface contamination concentration.

This refers to the fact that the quantity of activity in the salt is not fully known because it has not all been sampled, nor have meaningful volumetric surveys been performed. However, the activity in the salt must be less than the calculated source term (around 0.120 Curies transuranic activity) known to have come from the underground and up the exhaust shaft. [Hayes 2016]. The samples collected are primarily related to the surface contamination existing presently. The volumetric contamination underneath the surface contamination is largely unknown. There is estimated to be around 60 tons of salt in the above ground ducts.

Equation E3

$$DAC_R = \frac{\left(C_{dpm/100\ cm^2}\right)R_{m^{-1}}}{(H_{cm})(DAC_{Value})\left(2.22\ X\ 10^8{}_{dpm/\mu Ci}\right)}$$

Where:

- DAC_R = the equilibrium DAC concentration above a large surface due to resuspension.(dimensionless)
- $C_{dpm/100\ cm^2}$ = the average contamination level on the surface being considered in terms of dpm/100 cm^2.
- $R_{m^{-1}}$ = the resuspension factor (per meter) chosen as per TBD 2017-002 "Technical Basis for Determining Air Sampling Requirements in Support of WP 12-RE0352." In NUREG 1400, the assumption (from a mathematical point of view) is that this resuspension factor is applicable to the airborne *equilibrium* concentration for the volume above the surface 1 meter in height.
- H_{cm} = the height in centimeters of the volume being considered. Using this method of calculation, the entire equilibrium activity is assumed to be confined to a volume of this height. This results in an increased calculated value (for heights less than 100 centimeters) than would be calculated from NUREG 1400 methodology. For heights greater than 100 centimeters, the calculated value would be less than that calculated from NUREG 1400 methodology.
- DAC_{Value} = the DAC value (for 1 DAC concentration) given in terms of µCi/ml by 10 CFR 835 for the nuclide being considered.
- $2.22\ X\ 10^8{}_{dpm/\mu Ci}$ is a combined conversion factor.

Since the contamination level on the surface is assumed to be in terms of dpm/100 cm^2, then to assess the total contamination on the surface being considered, the area of the surface in cm^2 must be divided by 100 to find the number of 100 cm^2 sections that make up the surface. The total number of 100 cm^2 sections may be multiplied times the average contamination level (in terms of dpm/100 cm^2) to find the total activity (or dpm) that exists on the surface. Also, the conversion factor includes the conversion from dpm to µCi, which is, 2.22 X 10^6 dpm/µCi. Finally, (2.22 X 10^6 dpm/µCi) (100) = 2.22 X 10^8 dpm/µCi, as a combined conversion constant.

Regarding Equation E3, note the following:

Equation E4

$$Airborne\ Concentration_{\mu Ci/(ml\ or\ cm^3)} = \frac{(C_{dpm/100\ cm^2})\left(A_{cm^2}/100\right)(R_{m^{-1}})}{(A_{cm^2})(H_{cm})(2.22\ X\ 10^6{}_{dpm/\mu Ci})} = \frac{(C_{dpm/100\ cm^2})(R_{m^{-1}})}{(H_{cm})(100)(2.22\ X\ 10^6{}_{dpm/\mu Ci})}$$

A_{cm^2} (the total contaminated surface area) is divided by 100 to calculate the number of 100 cm^2 surface elements within A_{cm^2}. When this is multiplied times $C_{dpm/100\ cm^2}$ (the average contamination level on the contaminated surface), the result is the total dpm on the contaminated surface. Upon multiplication of this result times $R_{m^{-1}}$ (which is the equilibrium resuspension fraction), the result is the total equilibrium dpm in the volume of air under consideration above the contaminated surface. When this result is divided by $2.22\ X\ 10^6{}_{dpm/\mu Ci}$, the result is the total equilibrium µCi (due to resuspension) in the volume of air under consideration above the contaminated surface. $(A_{cm^2})(H_{cm})$ is simply the volume of air under consideration above the contaminated surface, where H_{cm} is the height of the volume above the surface, measured in centimeters. For these calculations, this distance from the surface was assumed to be 100 cm to conform to NUREG 1400 protocol.

When the airborne concentration [$Airborne\ Concentration_{\mu Ci/(ml\ or\ cm^3)}$] is divided by the DAC value (DAC_{Value}) for the radionuclide under consideration, the result is the equilibrium DAC concentration above a large surface due to resuspension, which has been designated as DAC_R in Equation E3.

Calculation of the resuspension activity from the dampers is as follows:

The resuspension factor is considered to be 1E-06 for the dampers. (The damper surfaces are metal with an assumed thin layer of contaminated salt rather than inches or feet thick layers of salt found in other areas of the duct, in which contamination is encapsulated. Because of this, currently a resuspension factor of 1E-06 is applied to the possible contamination on the 700A and 700C dampers.) To conform to NUREG 1400 protocol, H_{cm} = 100 cm. The DAC value is 5E-12 µCi/ml for Pu-239, Pu-240, and Am-241.

Then from Equation E4:

$$Airborne\ Concentration_{\mu Ci/(ml\ or\ cm^3)} = \frac{(C_{dpm/100\ cm^2})(R_{m^{-1}})}{(H_{cm})(100)(2.22\ X\ 10^6{}_{dpm/\mu Ci})} = \frac{(280.1343)(1E-06)}{(100)(100)(2.22\ X\ 10^6{}_{dpm/\mu Ci})} = 1.262\text{E-14 µCi/ml}$$

As illustrated previously:

Total ml/year expelled = 240,000 ft^3/min X 60 min/hr X 24 hrs/day X 365.24 days/year X $(12X2.54)^3$ ml/ft^3 = 3.574E+15 ml/year.

Then calculate the number of Curies within that volume expeled in a year.

Curies/year = 3.57435E+15 ml/year X the Airborne Concentration 1.2619E-14 µCi/ml X 1E-06 Ci/µCi = 4.51E-05 Ci/year. (When resuspension from the duct is greater than that from the dampers, the addition of this source term is a conservative measure.)

Calculation of the resuspension activity from the ducts is as follows:

The resuspension factor is considered to be 1E-04 for the ducts.

From Equation E4:

$$Airborne\ Concentration_{\mu Ci/(ml\ or\ cm^3)} = \frac{(280.1343)(1E-04)}{(100)(100)(2.22\ X\ 10^6{}_{dpm/\mu Ci})} = 1.26E\text{-}12\ \mu Ci/ml$$

As illustrated previously:

Total ml/year expelled = 240,000 ft^3/min X 60 min/hr X 24 hrs/day X 365.24 days/year X $(12X2.54)^3$ ml/ft^3 = 3.57435E+15 ml/year.

Then calculate the number of Curies within that volume expeled in a year.

Curies/year = 3.57435E+15 ml/year X the Airborne Concentration 1.26E-12 μCi/ml X 1E-06 Ci/μCi = 4.51E-03 Ci/year. Results are displayed in Table E2.

Table E2 - Resuspension (Contribution in Curies per Year)

Item	Curies/yr
Dampers	4.51E-05
Duct	4.51E-03
Totals	**4.56E-03**

Because resuspension of activity is considered a continuous process, the resuspended values may be calculated for any other time period by just dividing the time period in days by 365.24 days and then multiplying the result times the yearly value.

For example, for a four hour time period and zero percent reduction, it would be {(4/24) days/(365.24 days)} X 4.56E-03 = 2.08E-06 Curies.

Total Activity Expelled by the 700C Fan

At this point the total activity expelled may be determined by simply adding up the various source terms already calculated as shown in Table E3.

Table E3 - Curies per Time Period

Time Period	Station A	Resuspension	Damper Puff	Duct Puff	Totals
Year	5.30E-05	4.56E-03	1.84E-07	3.63E-06	5E-03
4 Hours	2.42E-08	2.08E-06	1.84E-07	3.63E-06	6E-06

Airborne Radioactivity Concentration and DAC Fraction inside the Duct

Equations E5 and E6 may be used to calculate the airborne radioactivity concentration and the DAC fraction inside the duct just before the air exits the duct. Both are of interest, but DAC Fraction is directly related to easily calculating Committed Effective Dose to anyone breathing air in which there is a specific known DAC fraction. In the case of Pu-239, Pu-240, and Am-241 (and a number of other nuclides), the DAC value is designed (per 10 CFR 835) to prevent anyone from exceeding the deterministic (or non-stochastic) dose limit of 50 rem before they reach a *calculated* stochastic dose of 5 rem. For internal dosimetry, the two types of doses would be distinguished and the actual stochastic and deterministic doses calculated.

Equation E5

$$Airborne\ Concentration = \frac{Total\ Activity\ within\ the\ Volume\ of\ Air}{Volume\ of\ Air}$$

Where:

- Total Activity within the Volume of Air is in terms of μCi.
- Volume of Air is in terms of milliliters

Equation E6

$$DAC\ Fraction = \frac{Airborne\ Concentration}{DAC\ Value} = \frac{Total\ Activity\ within\ Volume\ of\ Air}{(DAC\ Value)(Volume\ of\ Air)}$$

Where:

- Airborne Concentration is in terms of μCi/ml.
- DAC Value is that value appropriate for the nuclides of concern, such as 5E-12 μCi/ml for Pu-239, Pu-240, and Am-241.

From Table E3, the Curie totals may be found. The conversion from Curies to microcuries is:

Microcuries (μCi) = Curies X 1E+06 μCi/Curie

From this relationship the column entitled “Totals (μCi)” may be completed in Table E4.

The DAC fraction then is calculated as follows for the entries in Table E3. The first entry requires the volume for a year, and the last entry requires the volume for a four-hour time frame.

As illustrated previously:

Total ml/year expelled = 240,000 ft^3/min X 60 min/hr X 24 hrs/day X 365.24 days/year X $(12X2.54)^3$ ml/ft^3 = 3.57435E+15 ml/year.

Microcuries (μCi) = Curies X 1E+06 μCi/Curie = 4.61E-03 Ci X 1E+06 = 4.61E+03 μCi

$$DAC\ Fraction = \frac{4.61E+03\ \mu Ci}{(5E-12\ \mu Ci/ml\ )(3.57435E+15\ ml)} = 0.258\ DAC$$

And also, total ml/4 hours expelled = 240,000 ft^3/min X 60 min/hr X 4 hrs X $(12 \text{ X } 2.54)^3$ ml/ft^3 = 1.631E+12 ml

Microcuries (μCi) = Curies X 1E+06 μCi/Curie = 5.92E-06 Ci X 1E+06 = 5.92 μCi

$$DAC\ Fraction = \frac{5.92\ \mu Ci}{(5E-12\ \mu Ci/ml)(1.63105E+12\ ml)} = 0.726$$

Table E4 - Activity and DAC in Duct Time Period

Time Period	Totals (Ci)	Totals (μCi)	DAC Fraction in Duct
Year	4.61E-03	4.61E+03	0.258
4 Hours	5.92E-06	5.92	0.726

Total DAC Concentration within the General Vicinity of the 700C Fan

To roughly determine the DAC fraction in the general vicinity of the exit port of the 700C fan, a mathematical construct around the exit point of the 700C fan (an imaginary solid cylinder large enough to be representative of the area within 100 feet of the exit port) is conservatively used in this analysis. The effective throughput (cfm) of air from wind going through the area could be compared to the volume of air being expelled by the 700C fan to see what the dilution factor would be if equilibrium was assumed. To assume equilibrium is considered conservative because the fan delivers air upwardly at approximately 45 degrees with the horizontal, and upper wind currents would be expected to carry away *most of the particulate contamination* and disperse it before very much of it could reach the ground within a 100 foot radius or anywhere else on site.

Using the most prevalent wind speeds from 2018 data at 32.8 feet above ground level, the wind speeds varied from about 3.71 to 6.30 meters per second.[3] The more conservative number was used for this calculation, that is, 3.71 meters per second, because by use of this factor, the calculated effective throughput (cfm) of air from wind going through the area and the corresponding dilution factor would be reduced. The speed 3.71 meters per second is equivalent to 730.31 feet per minute.

$$Feet/min = (3.71\ meters/sec)(60\ sec/min)\left(\frac{100}{12 * 2.54}\right)feet/meter = \ 730.31\ feet/min$$

[3] See DOE/WIPP-19-3591 Waste Isolation Pilot Plant Annual Site Environmental Report for 2018 (Revision 0), Section 5.3.2, page 125.

However, to calculate the effective volume throughput (cfm) of air from wind going through the area, an effective height of the cylinder must be estimated. To accomplish this, an analysis of how the air is blown upwardly was done, and from this when outside wind speed and the speed of the air exiting the 700C fan are compared, an effective “top” of the cylinder may be estimated. Slot push calculations show that even at 40 feet from the exhaust point, the centerline peak push jet velocity is between approximately 800 feet per minute (fpm) and 1600 fpm, depending upon where (at a 45 degree upward angle) within the vertical centerline point in the plume, the peak velocity is calculated. Notice that 800 fpm is greater than the assumed wind speed of 730 feet per minute. The air from the 700C fan would be expected to penetrate at least this far, especially since much of the air at 40 feet would have a calculated centerline peak push jet velocity of 1600 fpm. However, higher wind speeds would also be expected to dilute the output of the 700C even more. Therefore, this method of determining the effective height is considered conservative. Many of these calculations (around 120) were performed to get a sense of the airflow from the 700C exit point.

Equation E7 - Slot Push Calculations[4]

$$V_x = \frac{1.2V_0}{\sqrt{\frac{aX}{B_0} + 0.41}}$$

Where:

- V_0 = the push average exit air velocity
- V_x = the peak push jet velocity at a distance X from the exit point
- a = a coefficient characteristic of device expelling the air (generally about 0.13 for slots and pipes)
- X = distance from the point of exit
- B_0 = one of the following:
  - ½ the total slot width (for free plane jet) if it is freely suspended well away from surfaces (and this constant was used for these calculations since the 700C exit point fits this criterion),
  - Equal to the slot width if next to a plane surface
  - For pipes with holes, B_0 is the width of a slot with equivalent area

It was observed that because of the design of the fan, more air goes out of the top of the 700C exit point than the lower portion of the exit. Therefore, it was assumed that 2/3 of the air goes out of the upper portion and 1/3 goes out of the lower portion. Centerline peak push jet velocities were performed for many distances using several categories.

[4] From section 3.8, starting page 3-19 ACGIH Industrial Ventilation Manual, 23rd Edition, 1998.

A calculation was performed to find the average air speed at the 700C exit point as follows:

Equation E8

$$Average\ Air\ Speed = \frac{Flow\ Volume_{CFM}}{Exit\ Area_{ft^2}} = \frac{Flow\ Volume_{CFM}}{Exit\ Length_{ft} * Exit\ Width_{ft}}$$

$$= \frac{240{,}000_{ft^3}/_{min}}{15.93_{ft} * 11.5_{ft}} = 1310_{ft}/_{min}$$

Three Considerations for Evaluating the Airflow

1. The peak push jet velocity from the top half of the 700C exit.

   Since most of the air comes out of the top half of the exit and the assumed direction is approximately 45 degrees with the horizontal, it is expected that more air comes out of the top part of the top half of the exit point. Therefore, the peak push jet velocity calculated will likely be underestimated and may be better representative of an “effective” peak push jet velocity.

2. The peak push jet velocity from the 700C exit as a whole, as though the same amount of air comes out of the top half as the bottom half.

   This was done to get a better sense of the average peak push jet velocity, and to be able to make a better decision regarding the possible height of the mathematical cylinder.

3. The peak push jet velocity from the bottom half of the 700C exit.

   Since most of the air comes out of the top half of the exit and the assumed direction is approximately 45 degrees with the horizontal, it is expected that more air comes out of the top part of the bottom half of the exit point. Therefore, the peak push jet velocity calculated will likely be underestimated and may be better representative of an “effective” peak push jet velocity.

These three scenarios are calculated differently. Although around 120 cases were calculated, <u>three of them were chosen</u> as being particularly pertinent, and they were the ones for X = 40 feet, and calculated with slightly different parameters. The smallest of the peak push jet velocities determine the extremely conservative method of determining how far out the plume would penetrate the external air stream (wind). At 40 feet out it was still faster than the assumed external air speed. Therefore, the set of peak push jet velocities at 40 feet from the exit point apply. The calculation is illustrated, as follows:

Parameters and Calculations for the Top Half of the 700C Exit Point

The 700C exit point is about 15.93 feet long and 11.5 feet wide. When the top half is considered, the width (11.5 feet) becomes the length, and the width becomes ½ the length, or about 7.965 feet. The peak push jet velocity calculation from the top half of the 700C exit has the following parameters (see Equation E8):

$$V_0 = Average\ Air\ Speed = \frac{Flow\ Volume_{CFM}}{Exit\ Length_{ft} * Exit\ Width_{ft}} = \frac{\frac{2}{3} * 240{,}000_{CFM}}{11.5_{ft} * 7.965_{ft}} = 1746.8\ FPM$$

Where:

- V_x = the peak push jet velocity at a distance X from the exit point (feet per minute)
- a = 0.13
- X = distance in feet from the point of exit = 40 feet
- B_0 = ½ times 7.965 feet = 3.9825 feet

$$V_x = \frac{1.2V_0}{\sqrt{\frac{aX}{B_0} + 0.41}} = \frac{1.2 * 1746.8}{\sqrt{\frac{0.13 * 40}{3.9825} + 0.41}} = 1600.3\ FPM$$

Parameters and Calculations for the Entire 700C Exit Point

The 700C exit point is about 15.93 feet long and 11.5 feet wide. The calculated peak push jet velocity calculation has the following parameters:

- V_0 = the push average exit air velocity = 1310 feet/minute, as previously calculated
- V_x = the peak push jet velocity at a distance X from the exit point (feet per minute)
- a = 0.13
- X = distance in feet from the point of exit = 40 feet
- B_0 = ½ times 11.5 feet = 5.75 feet

$$V_x = \frac{1.2V_0}{\sqrt{\frac{aX}{B_0} + 0.41}} = \frac{1.2 * 1310}{\sqrt{\frac{0.13 * 40}{3.9825} + 0.41}} = 1371\ FPM$$

Parameters and Calculations for the Bottom Half of the 700C Exit Point

The 700C exit point is about 15.93 feet long and 11.5 feet wide. When the bottom half is considered, the width (11.5 feet) becomes the length, and the width becomes ½ the length, or about 7.965 feet. The peak push jet velocity calculation from the bottom half of the 700C exit has the following parameters:

$$V_0 = Average\ Air\ Speed = \frac{Flow\ Volume_{CFM}}{Exit\ Length_{ft} * Exit\ Width_{ft}} = \frac{\frac{1}{3} * 240{,}000_{CFM}}{11.5_{ft} * 7.965_{ft}} = 873.4\ FPM$$

- V_x = the peak push jet velocity at a distance X from the exit point (feet per minute)
- a = 0.13
- X = distance in feet from the point of exit = 40 feet
- B_0 = ½ times 7.965 feet = 3.9825 feet

$$V_x = \frac{1.2V_0}{\sqrt{\frac{aX}{B_0} + 0.41}} = \frac{1.2 * 873.39}{\sqrt{\frac{0.13 * 40}{3.9825} + 0.41}} = 800.1\ FPM$$

Table E5 - Peak Push Jet Velocities (feet/min) at 40 feet from 700C Exit, and Assumed Wind Speed (feet/min)

Top Half of 700C Exit	Whole 700C Exit	Bottom Half of 700C Exit	Assumed Wind Speed
1600	1371	800.1	730.3

As can be seen from Table E5, the peak push jet velocity calculated from the bottom half of the 700C exit was the least of the peak push velocities calculated for a distance of 40 feet (about 800 fpm), which is greater than wind velocity selected as being appropriate. Therefore, 40 feet upwardly from the 700C exit point (at 45 degrees with the horizontal) was used as a conservative factor. Using the trigonometric relationship y = r cos(ϴ) for right triangles, where y = the vertical increase distance, r = 40 feet from the 700C exit point at a 45 degree angle with the horizontal, and ϴ = 45 degrees, y may be calculated as y = 40 feet * cos(ϴ) = 40 feet * 0.7071068 = 28.28 feet vertical increase in distance.

Since the air from the 700C exit is assumed to leave the exit at around a 45 degree angle, 40 feet at that angle would represent a change in height of about 28.28 feet upwardly.

In Table E6 it can be seen that the center of the exit port is about 31.81 feet above grade. Therefore, the top of the cylindrical mathematical construct is about 31.81 feet + 28.28 ft = 60.09 feet, as a conservative estimate for the effective top of the cylinder.

Table E6 - Physical Dimensions of 700C Exhaust Duct

Top of Screen elevation (ft)	3449.98
Bottom of Screen elevation (ft)	3434.05
Exhaust duct length (ft)	15.93
Width from Permit (ft)	11.5
Exhaust Area (ft^2)	183.195
Top of Fan Foundation elevation (ft)	3410.21
Top of Screen above Grade (ft)	39.77
Bottom of Screen above grade (ft)	23.83
Center of exit (ft)	31.81
Equivalent Diameter (ft)	15.27

Note: elevations are in feet above mean sea level.

The dilution factor is not directly related to the volume of the cylinder, but rather the vertical cross-sectional area through which the outside wind blows. The cfm from the wind is compared to the cfm from the 700C fan to calculate the dilution factor. Through a cross-sectional area (200 feet wide X 60.09 feet high) of 12018 square feet (that is, 200 feet X 60.9 feet X 730.31 feet/min for wind), the wind provides about 8,776,866 cfm. For equilibrium mixing, the DAC concentration of the plume is reduced by 240,000/(240,000 + 8,776,866) ≈ 0.02662.

The assumption of equilibrium mixing is a conservative assumption since most of the plume from the 700C would typically be carried off by the outside wind currents above.

This is the **dilution factor.** It may be multiplied times the DAC fraction in the duct to find the conservative contribution to the airborne radioactivity that comes directly from the output of the 700C fan within about 100 feet of the fan (especially near the ground surface), but not close to being within the plume. However, to better estimate the DAC fraction at ground level, deposition to and resuspension from the ground surface should be considered.

Re-dispersible Ground Deposition

Since the output of the fan is strongly upward at an estimated 45 degree angle, it is expected that in most cases that much of the radioactive plume will be broadly dispersed considerably above ground level. To make a rough estimation of the degree of re-dispersible ground deposition, the conservative assumption is made that the mix of radioactive particles within the solid cylinder defined above is homogenous and that the rate of particle deposition and particle resuspension are in equilibrium, as is the assumption in typical resuspension calculations. Again, using the most prevalent wind speeds from 2018 data at 32.8 feet above ground level (varying from about 3.71 to 6.30 meters per second), it is expected that a resuspension factor of 1E-04 is appropriate, especially since the method assumes homogeneity for the calculation of the DAC fraction directly contributed to by the 700C fan. (Note that the particle size distribution is both unknown and is probably not constant. A best estimate of 1E-04 was used for the resuspension factor.) To calculate the expected ground deposition, the expected DAC concentration within the solid cylinder (100 feet radius and 60.09 feet high) around the 700C exit point is calculated first, as discussed previously. The output of the fan can be viewed as a process where the airborne concentration is being produced at a constant rate and “feeding” the process of deposition where the process of deposition and resuspension are in equilibrium at ground level. (This refers only to that activity that is removable and re-dispersible by the wind.)

It is assumed in this special case that the activity resuspended is carried away by the wind and not immediately deposited again. However, a situation of equilibrium exists because the 700C fan provides a constant small airborne activity above the ground very much like the situation of an equilibrium existing in which the activity resuspended is also deposited again to the same or nearby surface.

If equilibrium between re-dispersible ground deposition and resuspension is assumed, then the re-dispersible ground deposition would give rise to an activity concentration (due to resuspension) equal to the airborne activity that it was being exposed to because of the operation of the fan. Therefore, after equilibrium has been established, an individual near ground level would be exposed to approximately twice the airborne concentration predicted from the output of the fan alone. Utilization of the reduction factor (0.02662) alone provides the DAC fraction within 100 feet directly contributed to by the 700C fan. However, at ground level this calculation will predict about half of the airborne radioactivity concentration to which an individual at ground level would be exposed, and the doubling effect produced by ground deposition would double the predicted airborne concentration.

Table E7 - DAC Fraction in Duct and within 100 Feet of 700C

Percent Reduction	Time Period	DAC Fraction in Duct	DAC Fraction Directly Contributed by 700C within 100 Feet	DAC Fraction at Ground Level within 100 Feet of 700C Fan
0% Reduction	Year	0.258	0.0069	0.014
0% Reduction	4 Hours	0.726	0.019	0.04

Calculation of Equilibrium Re-dispersible Activity Deposition

The equilibrium activity (in the context of this document) is that activity that is deposited on the soil surface (and other surfaces such as building surfaces) and is removable and subject to re-dispersion from the surface, typically by the wind. Equation E9 may be used, which is Equation E8 solved for the average dispersible contamination level on the surface (such as the soil, pavement, or building surfaces). (The particle sizes for this calculation are both unknown and are probably not constant. A best estimate of 1E-04 was used for the resuspension factor.)

Equation E9

$$C_{dpm/100\ cm^2} = \frac{(DAC_R)(H_{cm})(DAC_{Value})\left(2.22\ X\ 10^8{}_{dpm/\mu Ci}\right)}{R_{m^{-1}}}$$

Where:

- DAC_R = the equilibrium DAC concentration above a large surface due to resuspension.
- $C_{dpm/100\ cm^2}$ = the average dispersible contamination level on the surface being considered in terms of dpm/100 cm^2.
- $R_{m^{-1}}$ = the resuspension factor (per meter) chosen as per TBD 2017-002 “Technical Basis for Determining Air Sampling Requirements in Support of WP 12-RE0352.” In NUREG 1400, the assumption (from a mathematical point of view) is that this resuspension factor is applicable to the airborne *equilibrium* concentration for the volume above the surface 1 meter in height.
- H_{cm} = the height in centimeters of the volume being considered. Using this method of calculation, the entire equilibrium activity is assumed to be confined to a volume of this height. This results in an increased calculated value (for heights less than 100 centimeters) than would be calculated from NUREG 1400 methodology. For heights greater than 100 centimeters, the calculated value would be less than that calculated from NUREG 1400 methodology.
- DAC_{Value} = the DAC value (for 1 DAC concentration) given in terms of µCi/ml by 10 CFR 835 for the nuclide being considered.
- $2.22\ X\ 10^8{}_{dpm/\mu Ci}$ is a combined conversion factor.

Since the contamination level on the surface is assumed to be in terms of dpm/100 cm^2, then to assess the total contamination on the surface being considered, the area of the surface in cm^2 must be divided by 100 to find the number of 100 cm^2 sections that make up the surface. The total number of 100 cm^2 sections may be multiplied times the average contamination level (in terms of dpm/100 cm^2) to find the total activity (or dpm) that exists on the surface. Also, the conversion factor includes the conversion from dpm to µCi, which is, 2.22 X 10^6 dpm/µCi. Finally, (2.22 X 10^6 dpm/µCi) X 100) = 2.22 X 10^8 dpm/µCi, as a combined conversion constant.

The DAC fraction (the average over a year) within 100 feet of 700C and directly contributed by the output of 700C is utilized in the calculation.

Table E8 may be completed for $C_{dpm/100\ cm^2}$, that is, the Ground Deposition Subject to Resuspension, as follows:

$$C_{dpm/100\ cm^2} = \frac{(0.0069)(100)(5E-12)\left(2.22\ X\ 10^8{}_{dpm/\mu Ci}\right)}{1E-04} = 7.6$$

Table E8 - DAC Fraction in Duct, DAC Fraction within 100 Feet of 700C, and Dispersible Ground Deposition

Percent Reduction	Time Period	DAC Fraction in Duct	DAC Fraction Directly Contributed by 700C within 100 ft	DAC Fraction at Ground Level within 100 ft of 700C Fan	Ground Deposition Subject to Resuspension (dpm/100 cm^2)
0% Reduction	Year	0.258	0.0069	0.014	7.6

APPENDIX F, ENVIRONMENTAL REPORT DATA (FENCE LINE DOSE)

Table 4.28 – Comparison of Dose to the Whole Body to EPA Standard of 25 mrem/year per 40 CFR §191.03(b)

Year	Annual Dose (mrem/yr)	Percentage of EPA Standard
2002	1.51E-04	0.00060%
2003	1.15E-04	0.00046%
2004	1.27E-04	0.00051%
2005	8.86E-05	0.00035%
2006	8.16E-05	0.00033%
2007	1.52E-04	0.00061%
2008	7.14E-04	0.00286%
2009	1.71E-03	0.00684%
2010	1.31E-03	0.00524%
2011	1.29E-03	0.00516%
2012 *	7.55E-04	0.00302%
2013 *	5.25E-04	0.00210%
2014[a]	1.49E-01	0.59600%
2015[a,b]	4.23E-04	0.00169%
2016[a]	1.71E-04	0.00068%
2017[a]	1.04E-04	0.00042%
2018[a]	9.31E-05	0.00037%
40 CFR §191.03(b) Whole Body Limit	**25**	

*Station C bias-corrected.

[a] CAPP88-PC Version 4 used.

[b] Station B bias-corrected.