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Key words:

accident analysis
ventilation
contamination
transport, environmental

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Abstract

The Waste Isolation Pilot Plant (WIPP) is a 655-meter deep mine near Carlsbad, New Mexico, used to dispose the nation's defense transuranic waste. Limited airborne radioactivity was released from a container of radioactive waste in WIPP on 14 February, 2014. As designed, a mine ventilation filtration system prevented the large scale release of contamination from the underground. However, isolation dampers leaked, which allowed the release of low levels of contaminants after the event until they were sealed. None of the exposed individuals received any recordable dose. While surface contamination was limited, contamination in the ventilation system and portions of the underground was substantial. High efficiency particulate air (HEPA) filters in the operating ventilation system ensure continued containment during recovery and resumption of disposal operations. However, ventilation flow is restricted since the incident, with all exhaust air directed through the filters. Decontamination and natural fixation by the hygroscopic nature of the salt host rock has reduced the likelihood of further contamination spread. Contamination control and ventilation system operability are crucial for resumption of operations. This article provides an operational assessment and evaluation of these two key areas.

Introduction

The mission of the Department of Energy's (DOE's) WIPP is to provide permanent, underground disposal of defense-related transuranic (TRU) and TRU-mixed wastes (wastes that also have hazardous chemical components). TRU is defined as having alpha activity greater

than 37000 Bq/gm for radioactive isotopes with atomic numbers higher than uranium and half-life greater than 20 years.

WIPP is a deep geologic repository mined out of a thick evaporite bed of Permian salt approximately 655 meters below the surface. TRU waste typically consists of debris, solids and soils resulting from the research and production of nuclear weapons and post-cold war environmental restoration. Both the above ground and sub-surface facilities are shown in Figure 1. There are four shafts from the surface to the waste repository level. There are four ventilation circuits in the mine; air comes in from the air intake, salt hoist, and waste handling shafts. There is, by design, a direct path from waste handling to the exhaust shaft. The north, mining, and disposal circuits are separate until they combine at the exhaust shaft. [Poppiti, 2016]

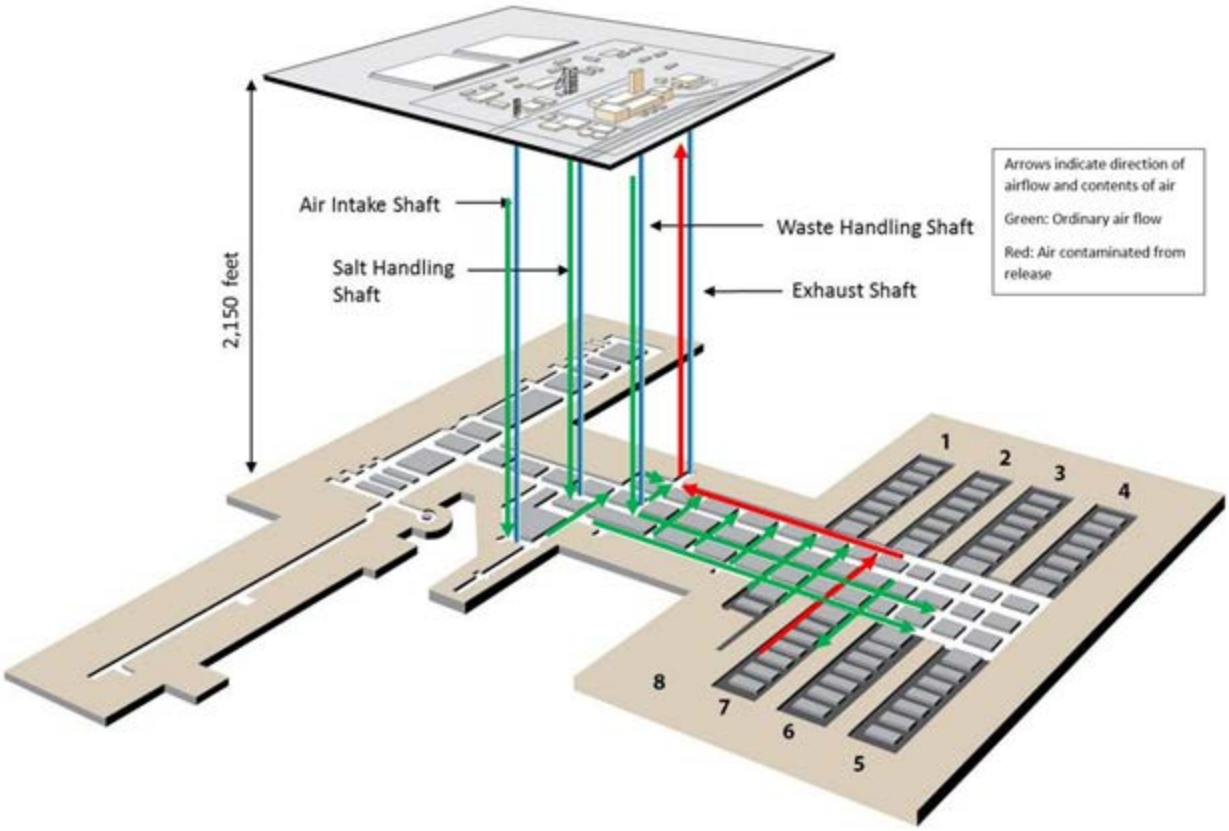

Figure 1

There are seven existing waste disposal areas in WIPP called panels. Construction of planned Panel 8 is not yet complete. Each complete panel is comprised of 7 rooms and each room is approximately 1390 square meters by 4.2 meters high. The southernmost point of the waste disposal area is about 1 kilometer away from the exhaust shaft.

On February 14, 2014, there was a release of radiological materials from a TRU waste container in the WIPP underground. A description of the accident, an exothermic reaction of an organic absorbent with nitrates in a 55-gallon drum, and analysis, has been previously reported [United States Department of Energy, 2015].

A continuous air monitor downstream of the waste detected the release and an automatic sequence of ventilation changes was initiated. The large surface fan pulling air from the underground turned off, and smaller fans on the exhaust side of the HEPA filters turned on, thereby directing all flow from the underground through the filters. The ventilation rate underground reduced from 12,300 to less than 1,700 m^3/min. Normally, the only contamination from a release in this controlled underground airflow would be along the exhaust drifts and shaft. However, 10 days before the release, in a completely unrelated event, a large haul truck caught fire in the northern part of the underground. The fire event resulted in several unplanned and undocumented changes in bulkheads and doors used underground to control the ventilation.

As a result, it is believed that several areas in the south part of the underground experienced very low to no flow conditions because of reduced flow and changes in the bulkheads and doors. With little or no flow for a period of time, the airborne aerosol was able to move throughout the south end of the facility, resulting in a more complex contaminant distribution than would otherwise be expected.

A radiological survey was conducted during the mine reentry process. Figure 2 shows surface alpha activity and provides the nomenclature for labeling the underground drifts (i.e. tunnels). The release took place in Panel 7, Room 7, along drift S-2180. As indicated in the survey map, Panel 7, drift S-2180, and portions of drifts E-300 and S-400 were highly contaminated, along with the exhaust shaft and the above ground ventilation system. A high contamination area has greater than 33 Bq/100 cm^2 removable contamination and a contaminated area has greater than .33 Bq/100 cm^2 removable.

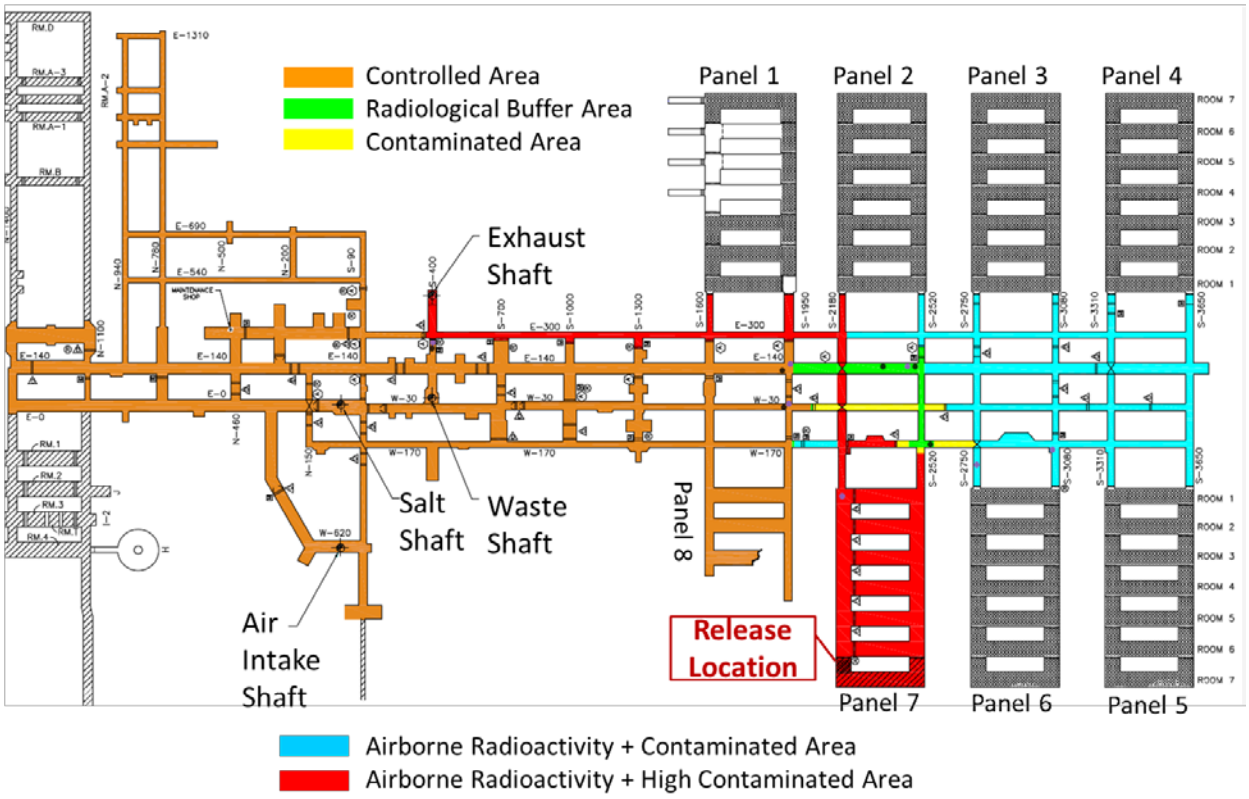

Figure 2

The inventory of the container that reacted was 1.036×10^{11} Bq, composed primarily of 8.14×10^{10} Bq of Am-241 and 1.713×10^{10} Bq of Pu-239. It is difficult to estimate the total amount of radioactive material released, but the accident investigation board estimated that 70 to 100% of the inventory was released into Room 7 [2]. Regardless of the amount released, most of that material remains in room 7. Less than 4×10^{9} Bq reached the surface (a majority of which was captured in the HEPA filters), and contamination in the mine comprises only about 1×10^{8} Bq.

The concentration of radioactive material in the exhaust air is continuously sampled. Air samples at locations before the HEPA filters were collected at various times after the release. These samples represent the average air concentration during the period between samples.

Samples collected after the release indicate a logarithmic decrease (over time) in airborne concentration, with a characteristic clearance time of about 8 hours, which is consistent with very slow ventilation through the contaminated volume underground. This is also consistent with the interpretation that the combustion aerosol consisted of very small particulate, and that gravitational settling was very small. The great majority of airborne radioactivity outside Room 7 stayed suspended during diffusion through the south end of the mine and eventually was trapped in the filtration system at the surface.

Because of the concern that other drums of nitrate oxidizer mixed with organic absorbent in Room 7 might undergo a similar reaction, and because Room 7 was highly contaminated during the accident (> 17,000 Bq/100 cm^2 near the source container), Room 7 was sealed to isolate the room and prevent any further release and possible exposure. No measureable events have occurred since that time.

Following the accident investigation, the main focus was to get WIPP back into operation as quickly as possible while ensuring worker and public safety. Increasing the rate of waste emplacement is essential for the Department to meet its obligations for movement of TRU material from waste generator sites. Contamination control, including control of airborne contamination, and ventilation system operability are two major areas that are crucial for WIPP operations.

Contamination control is a primary consideration because the only disposal space currently available is in Panel 7, and Panel 7 was contaminated during the accident. Construction had started on a new disposal area (Panel 8); however, resumption of construction is limited due to the requirement to continue to filter the exhaust. In any case, it

takes at least 1 year to construct a new panel and, even under the best conditions, Panel 8 wouldn't be ready for disposal for at least a year.

The goal of achieving operational status in the shortest time dictates using Rooms 1 ,2, 3 and 5 of Panel 7. Waste emplacement in Rooms 4, 6, and 7 are prohibited. Equipment, debris and other material from contaminated areas underground were placed in Room 6 for storage and are intended to be disposed in place. Decontamination of Rooms 1 ,2, 3 and 5 facilitates disposal operations and improves worker safety by mitigating the spread of contamination and lowering the likelihood of exposure. Several methods were evaluated to mitigate contamination.

Experimental

The Idaho National Laboratory (INL) evaluated several methods of decontaminating WIPP salt, using surrogate contaminants and americium (^{241}Am) [Demmer 2014]. The following describes water washing. An americium tracer solution (^{241}Am 300 Bq/ml) was applied to salt coupons and steel plates in a stippling fashion. Stippling consists of placing 47 small drops, in this case about 25 µl each, of the tracer on the surface of the target material. The tracer was applied to two steel plates and three salt coupons. The salt coupons used were ~100 cm^2 by 3 cm thick coupons. Steel coupons were also 100 cm^2. As the tracer was applied to the surface of the salt, it was observed that it did not “bead”, but wicked into the surface pores, cracks, and imperfections. The structure of the salt appears to have ~1 cm grains, which allows solution to absorb into the intergranular areas. This level of tracer yields measured alpha contamination of about 350 Bq/100 cm^2 for the steel plates and about 50 Bq/100 cm^2 for the salt coupons. After the salt coupons were allowed to dry, they were washed with 20 ml of deionized water to establish the efficacy of water washing. Radiometric counting was done by a Ludlum 2224 "scaler" handheld meter, using a 60 second count.

Air samples were collected on glass fiber filters. Mine air samples were collected using Hi-Q Mobile Cart, Giraffe/Goose Neck Air Samplers, MRV-Series and the Hi-Q Outdoor, Mobile, Continuous Duty Air Samplers, PSU-Series for Portable Air Samplers (PAS) or the Bladewerx SabreAlert2. Samples were collected at 56.6 liters per minute (lpm) for 24 hours. The Bladewerx SabreAlert2 flow is normally between 4 and 5 lpm for 6 to 8 hours. All air filters

were counted on a Tennelec Extra Low Background counting system (Proportional Counter) for 10 minutes.

Results and Discussion

Of the decontamination methods tested (dry brushing, vacuum cleaning, water washing, strippable coatings, and mechanical grinding), the most practical was water washing. Effectiveness is very high, and it is easy and rapid to deploy.

Results of the salt washing experiments are shown in Table 1. That is, the same amount of tracer applied to the salt (350 Bq) showed ~13% of the surface activity found on the steel plates. The tracer had likely penetrated into the salt matrix, and its detectable activity had become attenuated. The alpha activity data shows that removal efficacy averaged 96% and was consistently ≥ 95%. The water wash was collected and counted. An average of 31% of the total activity applied was recovered which implies that the majority of the contamination has become fixed in the salt. That is, of the 350 Bq applied, 109 Bq was recovered in the wash water, and 2 Bq was left on the surface, which means that 239 Bq remains undetectable in the salt matrix.

These results suggest that any surface contamination in salt could effectively be removed with a light water wash of the walls. Any surface contamination that isn't carried away with the wash water is absorbed into the salt matrix and becomes fixed. The wash water flows into the prevalent cracks and fissures in the host rock matrix where the floor and walls join.

Table 1 Results of Water Washing Tests

Sample	Applied Bq	Measured Bq after Application	Measured Bq after Decon	Percent removed	20 ml water Wash Bq (Average of 3 samples)
Salt - 1	350	48	2.4	95	
Salt - 2	350	44	1.8	96	109
Salt - 3	350	55	1.2	98	
Steel - 1	350	360			
Steel - 2	350	349			

In fact, observation and experience suggests that any contamination on a salt surface is likely to be incorporated into the salt over time because brine forms on the salt surface when the humidity in the air rises above the deliquescence point (73%). Miners describe this phenomenon by saying the rock becomes “greasy”. When the brine layer forms we do not know exactly how thick it becomes and expect that it varies with humidity and time. People can “feel” particles and films greater than about 10 µm, which suggests that the layer, when formed, is at least that depth. When the humidity drops below 73%, the water evaporates and the brine solidifies, trapping some (or most) of the material on the surface into the re-crystallized salt. As this cycle repeats, contamination is pushed deeper into the salt. Surface contamination measurements, swipes and 1-cm deep samples taken before and after fresh-water washing suggest that TRU contamination migrates at least 20 to 40 µm into the salt. The migration range of the alpha particles from Am and Pu are less than 40 µm in salt. Direct frisk

readings on water washed rock surfaces range from about a tenth to a half of the radiological content of physical samples taken at the same footprint and analyzed radiochemically. This is a direct indication of the alpha self-absorption due to the contaminant being embedded in the surface layers of the halite rock.

Initial fresh-water washing of Rooms 1 through 5 was completed by the end of September 2015 and included washing the walls (ribs) of the drifts with water. The roof of the drift (the back) was not washed.

Some of the airborne particulate clearly flowed through the exhaust shaft during the release itself because contamination reached the filters on the surface. However, it's likely the exhaust shaft is not contaminated. Water seeps into the exhaust shaft through cracks in the exhaust shaft liner located between 15-25 meters below the surface, with the principal seepage cracks located at 23-25 meters below ground surface. Fluid is located in the sandstones of the Lower Santa Rosa Formation and mudstones of the upper Dewey Lake Red Bed Formations at these depths. The fluid level around the exhaust shaft has remained between 14 and 15 meters below ground surface since monitoring began in 1996 when three wells were drilled near the shaft. Based on two pumping tests using these wells, and observations of quarterly exhaust shaft video inspections, it is estimated that 4 lpm, generating 5450 liters of fluid per day, leak into the exhaust shaft. Since the accident, essentially all this infiltrating fluid reports to the base of the exhaust shaft. This liquid is collected in interceptor wells near the base of the exhaust shaft in the underground. It is pumped out, and disposed at the surface. Basically, the exhaust shaft is continuously washed at about 4 lpm and any contamination is removed. Brine samples collected from the interceptor wells are radiologically analyzed. In the few months

after the event, very low concentrations of ^{241}Am were detected and the water was sent to an off-site treatment facility for disposal. Within a few months, all samples were below the detection limit and the brine intercepted is solar evaporated in a lined pond at the surface near the WIPP facility.

Fairly extensive sampling and analysis was conducted in the south part of the mine from S2180 to S3080 and E300 to W170. These areas were not washed. Ninety nine salt samples (100 cm^2) were taken from the floors in these areas to a depth of about 1 cm. All samples showed less than 0.2 Bq/gm of alpha. In addition, three hundred swipe samples were taken from equipment in those areas. The equipment was in place during the release event and was not moved or decontaminated prior to sampling. All but 12 samples showed less than 0.3 Bq/100 cm^2; the highest sample was 0.6 Bq/100 cm^2.

The data in Table 2 shows air sampling data taken at various locations in the southern part of mine in October 2015. The highest values are below 0.04 Bq/m3, which is below the concentration that would require posting as an airborne contamination area.

Table 2 - October 2015 air sample data for Panel 7 and south end of mine (Bq/m^3)[a]

E-140/S-2750	PANEL7/RM1/EXHAUST	PANEL6/EXHAUST/S3080	PANEL6/INTAKE/S2750	E140/S3080	Panel 7 / S-2520	W-30 / S-2750
α Decay	α Decay	α Decay	α Decay	α Decay	α Decay	α Decay
MDC	MDC	MDC	0.0027	0.0392	0.0008	0.0003
0.007	0.0013	MDC	MDC	MDC	0.0002	0.0006
0.012	MDC	0.0035	0.0023	MDC	0.0003	0.0005
0.007	0.0014	0.0016	MDC	0.004	0.0003	0.0005
	0.0025	0.0015	MDC	0.0113	0.0002	0.0015
	MDC	0.0007	MDC	0.0041	0.0002	0.0004
	0.0007	0.0044	MDC	MDC	0.0003	0.0009
	0.0025	0.0021	0	0.0403	0.0002	0.0009
	MDC	MDC	MDC	0.0074	0.0003	0.0003
	MDC	MDC	MDC	0.0127		
	0.0007	MDC	MDC			
	0.0015	MDC	0.0008			
	0.0055	MDC	0.0007			
	MDC	0.0015	MDC			
	0.0014	0.0094	0.0014			
	0.0015	MDC	0.0058			

[a]All samples exceeded minimum volume for required DAC sensitivity

In summary, Panel 7 has been washed with fresh water, and the contamination washed from the walls and floors is fixed in the salt matrix. Any contamination on the back (ceiling) of Panel 7 is likely also fixed due to cycling of humidity in the mine, either from the intake air or from water washing of the walls. The southern end of the mine shows little or no removable contamination and solid samples show that these areas of the mine were probably not contaminated during the event above 0.33 Bq/100cm^2. E-300 (the exhaust drift) wasn't washed, but it is expected that most of the contamination will become fixed due to cycling of the humidity. The exhaust shaft is likely not contaminated because there is a natural flow of 4-8 lpm of water down its walls, which effectively continually decontaminates the exhaust shaft.

Airborne contamination data taken over 18 months for the exhaust filters are shown in Figure 3. These data were collected at Station A at the surface upstream of the exhaust HEPA filters. These data show that the concentration of airborne alpha in the exhaust air is low, with a nominal concentration less than 0.002Bq/m^3 (0.02 DAC). The Derived Air Concentration (DAC) used is a weighted average of ^{241}Am and ^{239}Pu. DAC values are based on either a stochastic (committed effective dose) dose limit of 0.05 Sv or a deterministic (organ or tissue) dose limit of 0.5 Sv per year, whichever is more limiting. In the case of ^{239}Pu and ^{241}Am the DAC is based on the 0.5 Sv limit to bone surface (i.e., the non-stochastic limit).

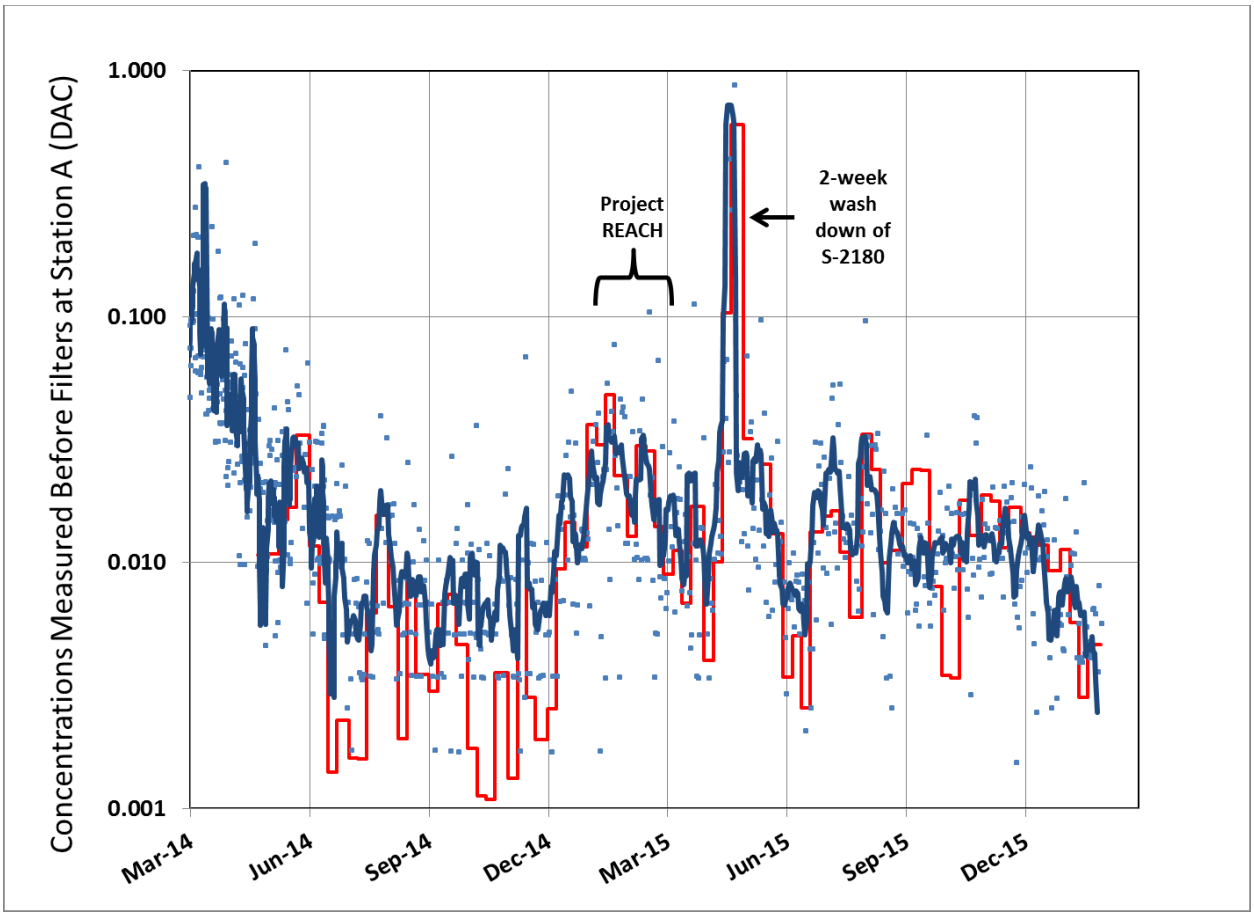

Figure 3

Two periods worth noting are annotated on Figure 3. The first is in January 2015 (labeled Project REACH in Figure 3). These approximately month long elevated levels were a result of a significant effort to photograph and physically inspect every container in Room 7 of Panel 7 to ensure no other waste containers were involved in the release event. A crew of workers wearing powered air-purifying respirators used a mechanical boom stretched over 30 meters out over the stacked containers in Room 7. While efforts were made to minimize disturbing surfaces of the waste stack, there were inevitable scrapes and brushes of the boom and camera equipment across contaminated surfaces. Any radioactive particulate that had loosely settled on the containers and emplacement materials would not have been trapped like

that deposited on the hygroscopic halite and could become airborne. The room has been sealed and further release from those areas isn't possible.

The second period of note is a two week spike that occurred in April 2015. This coincided with a dedicated effort to wash down the walls and floor of the exhaust drift from Panel 7 (S-2180). This drift represents the most contaminated area in the underground. A powered cart with a large water tank (2000 liters) and orchard sprayer was used to apply about 12 liters of fresh water per linear meter along the drift. The drift was first hand sprayed to wet the surface and then the water was sprayed behind the cart as it advanced into the contamination. This method attempted to minimize the amount of material mechanically disturbed during the water application.

This drift was the most highly contaminated area outside of Room 7, and accounts for the elevated airborne levels measured at Station A. That is, decontamination of the most contaminated area resulted in the highest concentration on the Station A filters. While airborne levels were significantly higher during this period, it is notable that they did not exceed an average of about 0.08Bq/m^3 (0.45 DACs). While this level is above the posting limit for airborne contamination (0.1 DAC) [10 CFR 835], the airborne levels quickly fell below 0.004 Bq/m^3after decontamination was complete.

The air sampling data, combined with an understanding of how surface contamination becomes fixed in a salt matrix (i.e., within the structure of the mine itself), leads to the conclusion that airborne contamination in the mine is below posting requirements and will remain so unless the surface structure of those areas are disturbed. An administrative control

to prevent any significant disturbance, or mitigation actions during heavy equipment operation, should allow complete down posting of the mine.

Although estimates vary, a ventilation rate on the order of 12,000 m^3/min is necessary to support full operations, which includes mining (e.g., completion of Panel 8), waste disposal, and maintenance activities. The existing ventilation system has been operating in filtered mode since the accident and all exhaust passes through HEPA filters prior to discharge, which currently limits the flow rate to 1,700 m^3/min. Increasing the ventilation rate is a critical component of returning WIPP to full operation.

Portions of the ventilation system were sealed shortly after the accident to ensure all exhaust would be filtered and no additional contamination would be released. The method used to seal the ventilation system and the concern for spreading contamination would make it difficult to return the existing system to normal (12,000 m^3/min unfiltered) service.

There are two ventilation upgrades (interim and supplemental) designed to increase the ventilation rate until a replacement ventilation system is installed and operational. The interim system is installed and operating. The two upgrades provide additional filters and fans that will be operated in parallel with the existing system and increase the overall amount of airflow from the 1,700 m^3/min to 5,000 m^3/min. All exhaust air will be passed through HEPA filters prior to discharge.

The replacement system will generate flow rates up to 15,000 m^3/min. This system is being designed to filter only the air traveling through areas that were contaminated (the

disposal circuit) during the accident. About 7,500 m^3/min will be filtered and the rest (primarily the construction circuit) will be exhausted without filtration.

Conclusions

Data and our analysis leads to the conclusion that there is no removable contamination (above 0.3 Bq/100 cm^2) in the mine - with the exception of Panel 7, Room 6, and the exhaust drift (S2180 through E300) - and any residual contamination is fixed. All of the measurements taken since the accident support these conclusions. The data from the Station A filters clearly show that the likelihood of airborne contamination above 0.1 Bq/m^3 is extremely low, especially if reasonable administrative controls are in place for the mechanical disturbance of the ground, walls (ribs) and ceiling (back).

WIPP is the only disposal site in the United States designated for defense related TRU waste and the long-term availability of WIPP is vital for the Department of Energy to meet its commitments to dispose of TRU waste.

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