Ventilation Analyses at the Waste Isolation Pilot Plant Post Radiological Event

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On the evening of February 14, 2014, radiological sensors underground at the Waste Isolation Pilot Plant (WIPP) facility detected a radiation release. This sensor triggered a reconfiguration of the ventilation system from a flow of 123 m3/s (260,000 cfm) to 28.3 m3/s (60,000 cfm) through two HEPA filtration trains. The ventilation system has been kept at a filtered flow of 28.3 m3/s (60,000 cfm) since the radiation event. Approximately two months after the event several of the high efficiency pre-filters in the filter trains were showing an increase in differential pressure, which is indicative of filter loading. This paper describes the analyses performed to engineer a "by-pass" inlet to the operating fan in order to maintain 28.3 m3/s (60,000 cfm) while taking one filter train off line. Once the train was off-line, the pre-filters could be changed out. Operating at the filtered flow rate also resulted in noticeable impacts from natural ventilation pressure, particularly in the winter months. This too is described in the paper along with the proposed modifications to the current ventilation configuration. Proposed modifications include the addition of fans and filter trains on surface in parallel with the existing system and the addition of an underground booster fan to increase flow to the "clean" side of the facility.

Keywords: Mine ventilation design, nuclear waste repositories.

1. Introduction

The Waste Isolation Pilot Plant (WIPP) facility is the only transuranic waste repository in the United States. The facility is located approximately 30 miles East of Carlsbad, New Mexico (Figure 1). The WIPP facility is a U.S. Department of Energy facility designed for the permanent disposal of transuranic radioactive waste. Transuranic waste typically consists of materials which have come in contact with radioactive substances. This can include gloves, tools, rags, and assorted machinery used in the production of nuclear fuel and weapons. The WIPP facility opened in 1999 and had completed emplacing waste in 6 of 8 panels. The repository horizon is 655 m (2,150 ft) below surface in the Salado geologic formation (salt).

In February 2014, two incidents occurred at WIPP. On February 5th, a salt haul truck caught fire. Workers were evacuated and the underground operations were shut down. Nine days later, on the evening of February 14th, a second, unrelated event occurred when a continuous air monitor (CAM) alarmed. The CAM measured airborne radioactivity close to the panel where active waste emplacement operations were occurring. The CAM alarmed in the evening and no personnel were underground at the time of the incident. Figure 2 is a drawing of the WIPP facility and shows the location of these two events. The CAM alarm triggered an automatic ventilation system switch from one primary unfiltered fan to filtration mode where all air exhausting the underground passes through high efficiency filter banks. The cause of the release is likely due to a container of waste self-heating in Panel 7, Room 7.

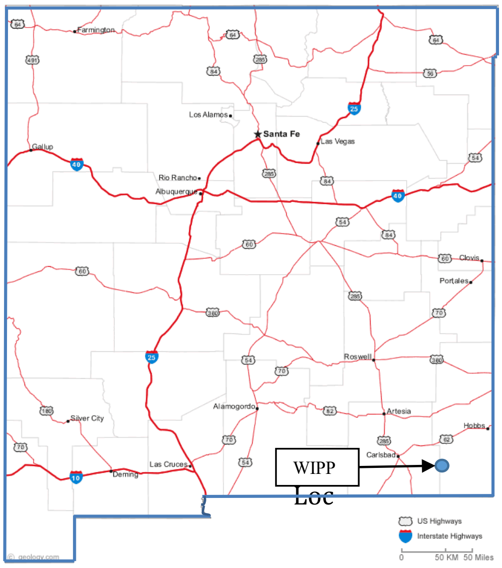

Fig. 1. Location of WIPP facility.

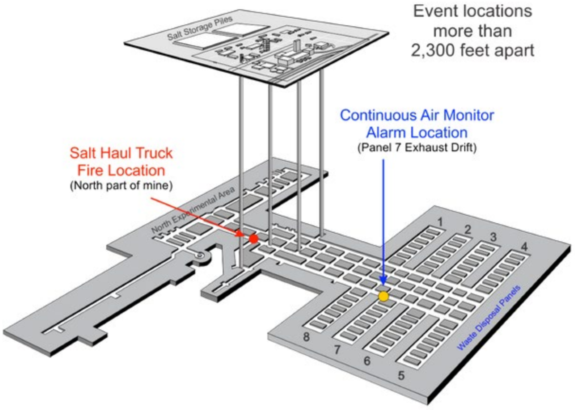

Fig. 2. WIPP facility and location of incidents.

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The efforts at WIPP since the radiation event have included investigations into what caused the radiation event and establishing work areas in the underground for ground control activities (e.g. rock bolting and scaling). From a ventilation perspective, the key work has been developing a methodology to replace air filters in the filtration building and concepts to increase total filtered exhaust capacity. In addition, understanding the impact of natural ventilation pressures (NVP) on the airflow distribution became more important while in filtration mode.

2. Ventilation and primary fan description

The underground ventilation system at WIPP is divided into four primary splits. These are the North area, the construction area, the disposal area and the waste shaft station area. Figure 3 shows these areas. The surface fans consist of three 445 kW (600 hp) “700” series centrifugal fans and three 175 kW (235 hp) “860” series centrifugal fans. Figure 4 shows the surface fan configuration along with the filtration building.

Prior to the radiologic event, in normal operation, the ventilation system discharged unfiltered air. One or two of the unfiltered 700 fans were typically operated. Two 700 fans will generate a volume of approximately 225 m^3/s (475,000 cfm). One 700 fan in operation will generate a flow of 125 m^3/s (265,000 cfm).

Since the radiologic event, the ventilation system has been maintained in filtration mode. In this mode, one of three filtration 860 fans operate to deliver 28.3 m^3/s (60,000 cfm) to the underground and through the filter trains inside of the filtration building. Two filter trains are in parallel, each with a capacity of 14.2 m^3/s (30,000 cfm). A filter train contains four filter banks in series; these are one moderate efficiency (60-65%) bank, one high efficiency (90-95%) bank, and two HEPA (High Efficiency Particulate Air of 99.97% efficiency) banks of filters.

3. Operating the facility in filtration mode

In filtration mode only 28.3 m^3/s (60,000 cfm) is exhausting the underground. Because the repository horizon is 2,150 ft below surface and the air expands as it courses up the Exhaust Shaft (ES), the actual airflow on the horizon is approximately 26.0 m^3/s (55,000 cfm). This mode isolates portions of the underground by closing all connections between the construction circuit and the disposal circuit. In addition, air from the north circuit is isolated by closing a strategic door in the north circuit return. The primary circuit in this configuration is air intaking the Waste Shaft (WS) and coursing across to the ES. However, intake air is also provided by leakage across bulkheads separating the construction and north end to the disposal and waste shaft station circuits. In filtration mode the primary ventilation function is to maintain underground flow from the clean area to the disposal circuit and ensure all exhaust air from the disposal circuit and waste shaft station passes through the surface filtration system. Because the WIPP facility is constructed in a salt horizon, the ground predictably creeps. This action results in squeeze on bulkheads. A typical bulkhead with regulator is shown on Figure 5. As seen, the bulkhead consists of steel center section with conveyor belt material as flashing around the edges. The bulkhead steel supports are designed to slide both vertically and horizontally to allow for some relief to the squeeze. The design works well, but inevitably leads to some leakage across each bulkhead. This air leakage accounts for a significant amount of the total flow in filtration mode. The leakage is from the north and construction circuits (clean side) to the disposal circuit.

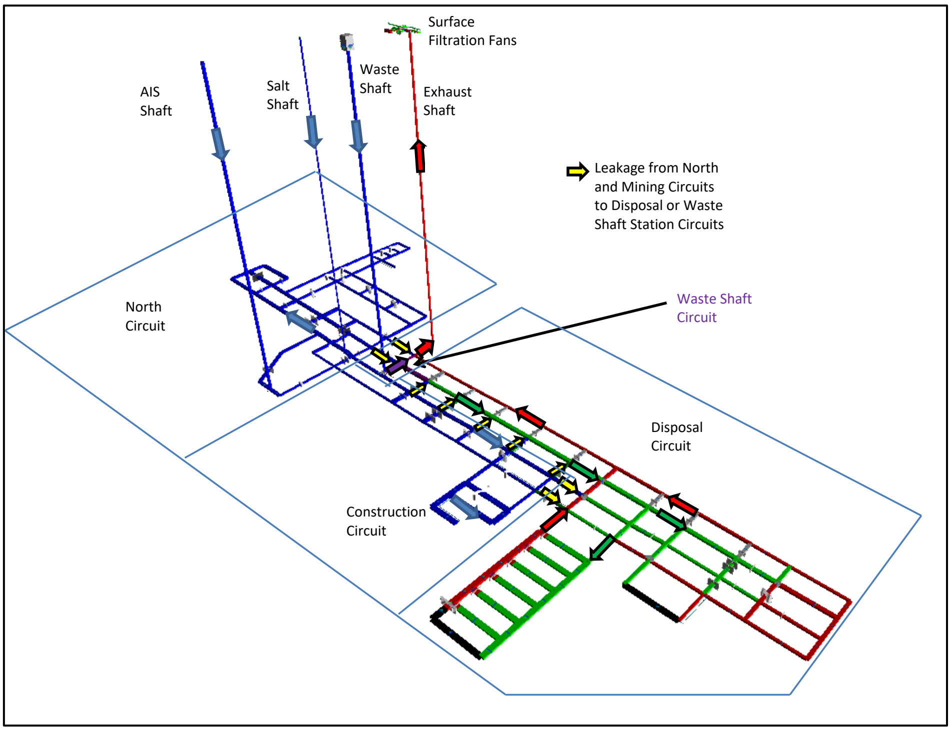

Fig. 3. Underground ventilation circuits at WIPP.

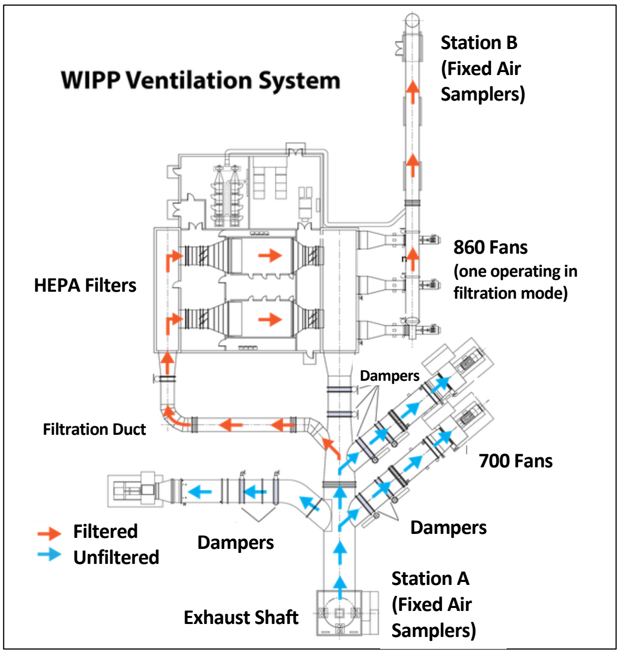

Fig. 4. WIPP surface fan configuration.

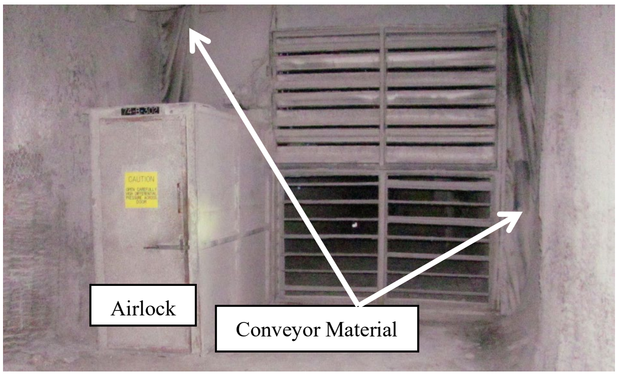

Fig. 5. Example of bulkhead with regulator at WIPP.

3.1 Ventilation configuration for filter change out

The 860 fans were originally designed at WIPP to provide 28.3 m^3/s (60,000 cfm) at very high operating pressures. The reason for this was in the mid-1980s these fans were going to be the only surface fans for the facility. All three fans would operate in parallel, by-passing the filter units and delivering about 85.0 m^3/s (180,000 cfm) with a fan total pressure of approximately 3.7 kPa (15 in. w.g.). Subsequently, the design changed to include the 700 fans and a third intake shaft (the Air Intake Shaft). The flow through each 860 fan can be adjusted using an inlet vane control (IVC). Because the fans were specified for high pressure, the IVC needs to be adjusted significantly to fix the airflow at 28.3 m^3/s (60,000 cfm). Figure 6 shows an 860 fan curve. To maintain the design flow the IVC is set to approximately 50% of full open.

After the radiation event, the differential pressures across the filters were continuously monitored. Engineers noted that the moderate and high efficiency filters in both filter trains were increasing in pressure while the HEPA filters maintained a steady pressure drop. Figure 7 shows the filter arrangement for each filter train. It was thought that the truck fire incident may have resulted in some build up on the moderate and high efficiency filters of soot and smoke, causing these filters to load with moisture exhausting from the underground.

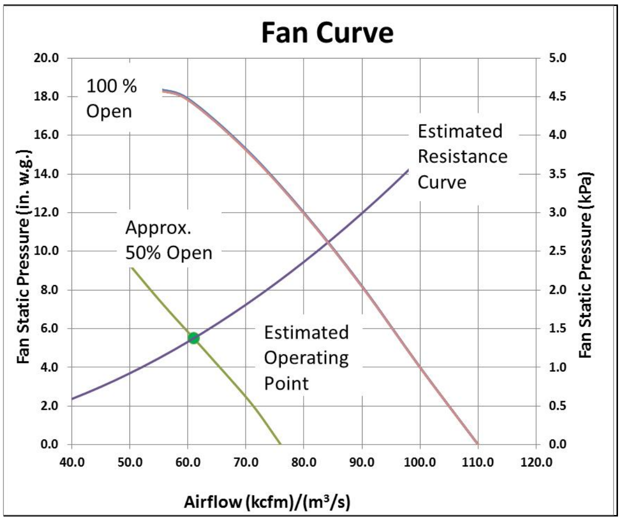

Fig. 6. 860 fan curve.

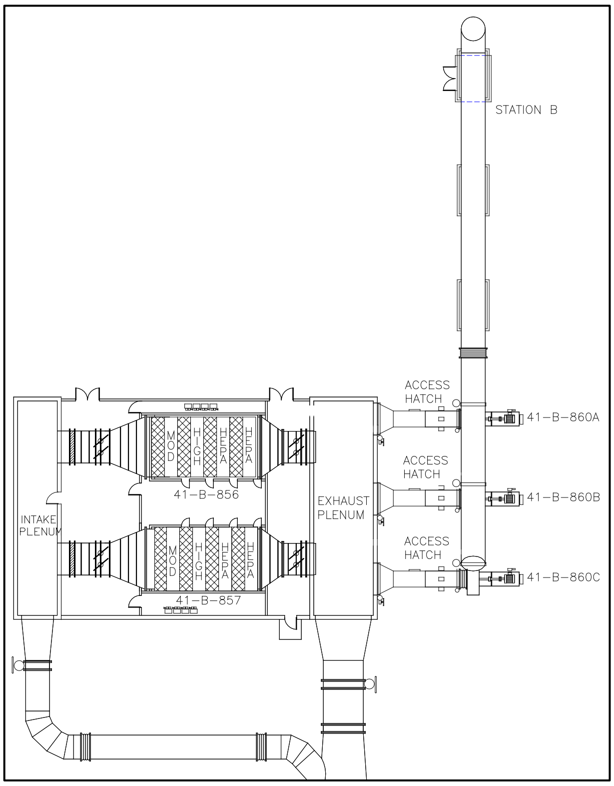

Fig. 7. Filter arrangement drawing.

Even though the differential pressure for these filters was well below the design limit values for filter failure, project management decided that it would be best to change out the moderate and high efficiency filters in each filter train. To do this one filter train needed to be taken off line while maintaining some flow to the underground. This would produce an underground airflow of only 14.2 m^3/s (30,000 cfm).

The site ventilation engineer became concerned that attempting to operate an 860 fan with an IVC setting capable of providing this low flow would result in excessive vibration of the 860 fan. Vibration on the 860 fans was noted to be relatively high and the project did not wish to exacerbate the potential problem. Therefore, another option was required to maintain the 860 fan at 28.3 m^3/s (60,000 cfm) but only allow 14.2 m^3/s (30,000 cfm) through the single operating filter train.

Engineers investigated the 860 fan system and noticed an access hatch on the inlet side to each fan (see Figures 7 and 8). Opening this hatch on one of the non-operating fans and opening an isolation damper to the filter train exhaust plenum, air could be short-circuited into the adjacent operating fan while maintaining a nominal 14.2 m3/s (30,000 cfm) through the operating filter train.

The calculation used to verify the opening size of the hatch was to calculate the area from the following orifice equation (in imperial units):

$$A_o = CQ(\rho/p)^{0.5} \qquad (1)$$

Where A_0 = Orifice Area (m^2 or ft^2)
C = Constant (1.2 [SI] or 48.8924 [IMP])
Q = Airflow (m^3/s or kcfm)
p = Differential Pressure (Pa or milli-in. w.g.)
ρ = Air Density (kg/m^3 or lb_m/ft^3)

Fig. 8. 860 fan access hatch with isolation damper.

This equation to compute the orifice area is in the ventilation simulation package VnetPC Pro+. Applying a fixed airflow to the hatch in the model resulted in an estimate of the required area to achieve the required flow through the hatch while maintaining flow through one filter train while the other filter train was being worked on. Modeling showed an area of 0.55 m^2 (6 ft^2) would be sufficient to achieve the design flows. Field testing using hot wire anemometers and a digital manometer resulted in setting the regulator area to 0.72 m^2 (7.75 ft^2). The model results were found to be a reasonable predictive tool in setting the regulator area. Field testing confirmed airflow through a single filter train at 14.2 m^3/s (30,000 cfm) while maintaining at least 28.3 m^3/s (60,000 cfm) through the operating 860 fan. Vibration was not an issue during the filter change out.

To switch from one filter train to the other for changing the moderate and high efficiency filters, the process involved opening the filter train that had been changed out in parallel with the filter train to be changed. The by-pass regulator was opened fully during this process. Once both filter trains were open, the filter to be changed was isolated from the circuit and the by-pass regulator adjusted to deliver the desired flow distribution to limit flow through the single filter train to 14.2 m3/s (30,000 cfm).

4. Impact of natural ventilation pressure

Natural ventilation pressure (NVP) at WIPP can be significant. NVP is caused by an imbalance in air density between two columns of air. The WIPP site is at an elevation of approximately 1,000 m (3,200 ft) above sea level. It is in a high desert and diurnal variations cause temperatures to swing from 30 ºC (86 ºF) to -1 ºC (30 ºF). In addition, seasonal changes can record temperatures as low as -10 ºC (14 ºF) to as high as 41 ºC (106 ºF). These wide temperature swings result in NVPs that can assist or oppose flow into the underground. Calculations of NVP have shown during cold winter conditions, pressures as high as 0.6 kPa (2.4 in. w.g.) can be applied assisting airflow into the facility. In summer, a negative pressure (opposing flow to the underground) of -0.35 kPa (-1.4 in. w.g.) have been measured.

In filtration mode the impact of NVP is more pronounced. Therefore, to maintain flow at 28.3 m^3/s (60,000 cfm), the 860 fan only needs about 1.5 kPa (6 in. w.g.) (see Figure 6). Of this delivered pressure the filter train pressure drop is approximately 1.0 kPa (4 in. w.g.) This means only 0.25 to 0.5 kPa (1.0 to 2.0 in. w.g.) is available to move air through the underground and through the surface ductwork. There can be times when the NVP is greater than the delivered fan pressure.

With high winter NVPs and three intake shafts, Air Intake Shaft (AIS), Salt Handling Shaft (SHS), and Waste Shaft (WS), if unchecked, air will downcast the larger diameter AIS and air will upcast the SHS and potentially upcast the WS (by pushing air through bulkheads and doors to the waste shaft station). When the radiologic event occurred in February, 2014 it was a relatively cold day. It was noted that after the shift to filtration that evening, air at that time was significantly downcasting the AIS and upcasting the SHS. The SHS was acting like a “relief valve” for the additional air entering the facility. This had no impact on maintaining air leakage from the “clean” side of the underground to the disposal circuit. In fact, the high NVP resulted in significant differential pressures across bulkheads separating the construction and north areas from the disposal circuit (forcing more air towards the disposal circuit). The excess air entering the AIS was simply upcasting the SHS.

To minimize the impact of NVP, site operators with engineering consent, have covered the top of the AIS with brattice. With the AIS covered, the primary intakes are the SHS and WS. This is the current configuration at the site and will likely continue until ventilation upgrades are complete.

5. Ventilation upgrades to support recovery

WIPP currently is working on recovering the underground from the radiologic event in order to resume normal activities. Recovering from this accident will require isolating the emplacement room where the accident occurred, decontaminating areas where there is contamination, conducting ground control operations, and installing an interim closure system for panel 6 (it was in the process of having a closure system installed at the time of the accident).

With the current 28.3 m^3/s (60,000 cfm) fan flow, it is challenging to do the recovery activities listed in a timely manner. Diverting the limited airflow to strategic areas in the underground will achieve this task, but parallel activities may not be possible because of the limited total airflow. Therefore, two ventilation modifications are to be installed at WIPP. The first, called Interim Ventilation System (IVS) installs additional filtration capacity to increase flow through the ES. The second is to install an underground booster fan to increase airflow to the construction and north air circuits. This is called the Supplemental Ventilation System (SVS). These systems are being brought on line until a permanent ventilation system upgrade is installed at WIPP.

5.1 Interim ventilation System

To support recovery efforts additional filtered air exhaust is required. This will be achieved by installing new surface filtration units. IVS will increase total surface filtration capacity by two more filter trains on the surface. Each new filter train will handle an additional 12.7 m^3/s (27,000 cfm). This will increase the total filtered air exhaust to 53.8 m^3/s (114,000 cfm). This total is comprised of 28.3 m^3/s (60,000 cfm) from the 860 fan plus 25.5 m^3/s (54,000 cfm) through the new filter units. The increase in flow will allow for recovery activities to be performed in the disposal circuit and will also allow for resumption of limited waste handling operations, once the clean-up and room and panel closure systems are installed.

Figure 9 depicts the proposed new surface filtration units. Each filter train will have a dedicated fan (called 960 fans). The intake side of the filter train will connect to one of the existing 700 fan ducts with the exhaust duct routed to the current exhaust duct to Station B. Station B is a monitoring point for air exhausting the underground and all air is designed to pass through this station (see Figure 7). The IVS is expected to be operational by mid to late 2015.

5.2 Supplemental ventilation system

After the IVS is installed and operational the airflow exhausting the WIPP underground will be limited to 53.8 m^3/s (114,000 cfm). This is insufficient flow to support mining activity in the construction area and experimental work in the north areas of the mine (see Figure 3). Therefore, engineers have developed a system where a booster fan is installed in the underground that will pull air down the AIS and push air to the north area and construction area. The air downcasting the AIS will upcast the SHS and pass through to the disposal circuit to supplement the air downcasting the WS.

The booster fan will be located in the S-90 drift at the base of the AIS. The design is for 61.3 m^3/s (130,000 cfm) passing through the booster fan. Of this between 33 and 38 m^3/s (70,000 and 80,000 cfm) will upcast the SHS. The AIS was selected as the downcast shaft because of its greater capacity than the SHS. Pulling 61.3 m^3/s (130,000 cfm) through the 3.1 m (10 ft) diameter SHS (with fixed buntons and guide arrangements) would require significant fan pressure, particularly when the cage is stationed at the shaft collar. Figure 10 shows the location of the booster fan and predicted airflow distribution through the underground. A control bulkhead will be installed to the north of the SHS so intake air from S-90 can course north and return to the SHS from the east.

The S-90 fan motor will be equipped with a variable frequency drive (VFD) to maintain the flow at 61.3 m^3/s (130,000 cfm). A flow sensor will be installed in the booster fan for the purpose of automating the VFD setting. However, in very cold surface conditions, the NVP may apply a significant pressure that would cause the S-90 fan to behave more as a regulator than a fan.

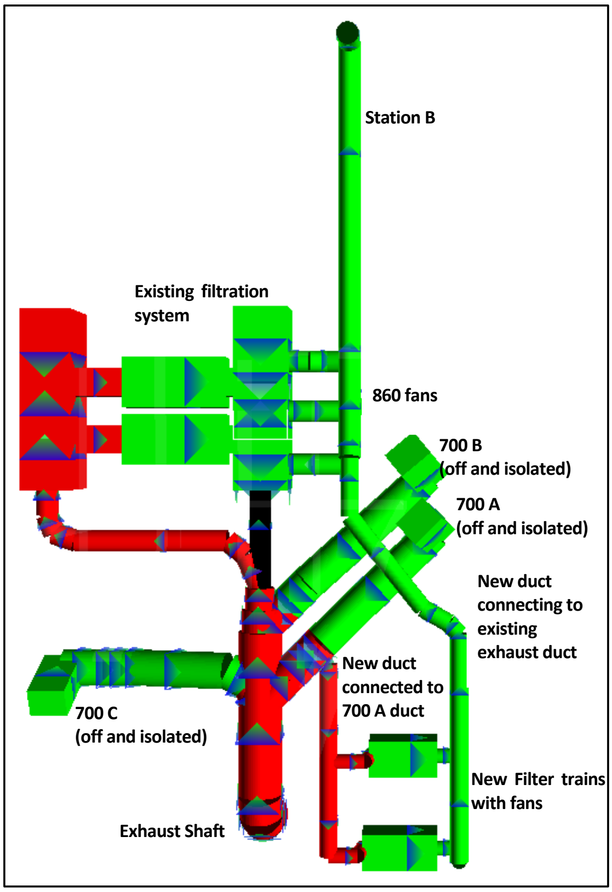

Fig. 9. Surface arrangement for IVS.

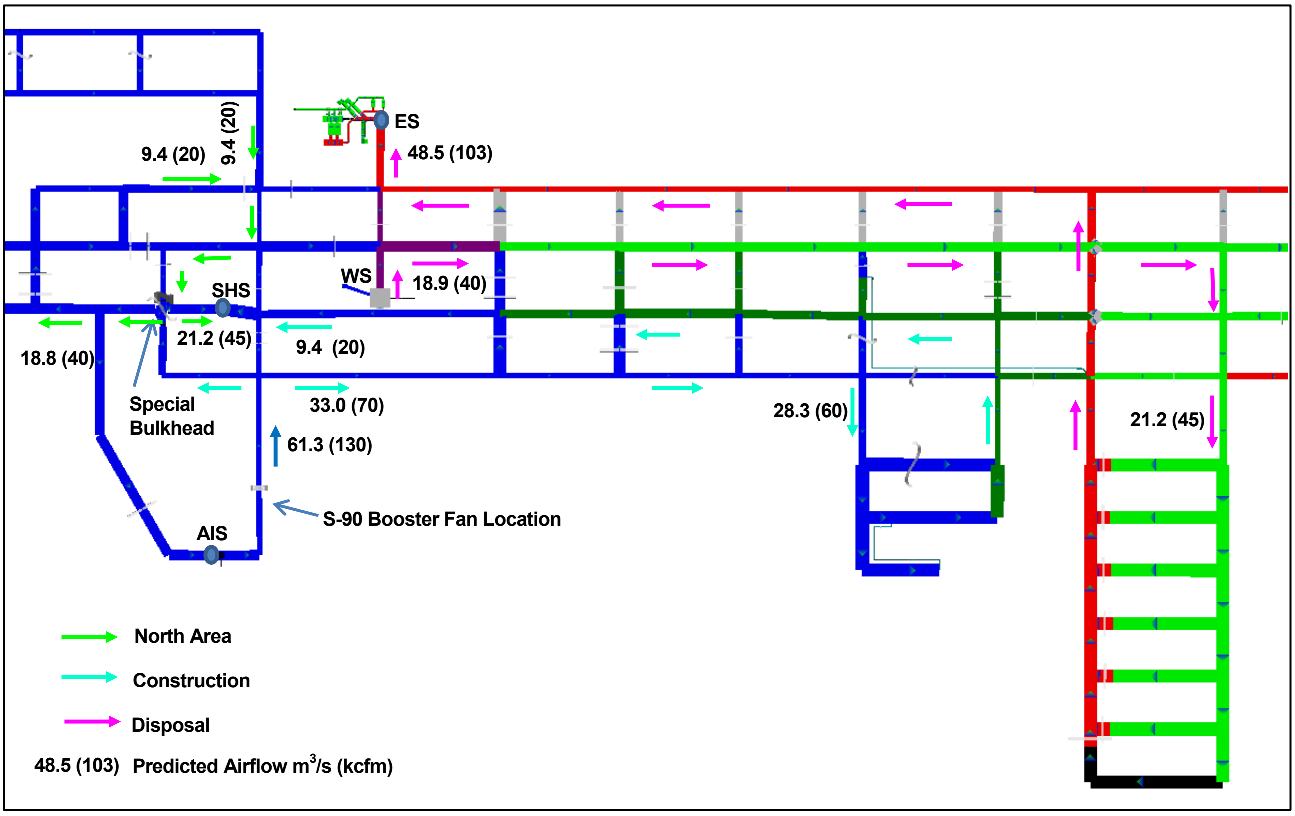

Fig. 10. Proposed IVS/SVS underground ventilation circuits at with predicted airflows at WIPP.

In order to maintain a constant flow through the fan, in addition to a VFD the outlet of the fan will have a louvered regulator that will be controlled by an electric actuator. In high winter NVP conditions the fan VFD will adjust to a low value then the regulator will begin to close to maintain the flow. This will allow the fan to operate in a stable range while controlling NVP impacts on the underground flow distribution. The S-90 fan was specified to handle the highest pressure predicted from the maximum summer conditions where the NVP can oppose flow to the underground. In this condition, the VFD will operate closer to full load with the regulator wide open.

5.3 Control logic for IVS and SVS system operation

After the IVS and SVS systems are installed at WIPP it will be necessary to understand how the two systems interact. The base analysis assumes all filtration fans are in operation along with the S-90 fan. Engineering modeled the ventilation system when one or more surface fans are off line. In this situation it is possible for the S-90 fan to push air into the disposal circuit and then drive air from the disposal return towards the WS. This is an undesirable consequence of operating an underground booster fan with a loss of surface fan operation. Therefore, control logic was developed that will automatically shut down the S-90 fan should flow reversal be monitored at the regulator separating the waste shaft station from the disposal return. This control will be hardwired from the differential pressure sensor on this regulator to the programmable logic controller for the S-90 fan.

Engineering also analyzed the impact of losing the S-90 fan while operating the IVS fans. The SVS brings air down the AIS and upcasts the SHS. Of the 48 m^3/s (103,000 cfm) entering the ES, only 19 m^3/s (40,000 cfm) is intake air from the WS. This results in 29 m^3/s (60,000 cfm) of intake air coming from the construction and north areas of the underground (leakage through bulkheads and controlled inlet through regulators). Concern was raised over the potential time delay, following the S-90 fan power loss, before the upcast column of air in the SHS reverses to provide airflow necessary to ventilate the disposal circuit.

To ensure flow is maintained through the AIS shaft to provide air to the disposal circuit, the S-90 fan upon loss of power will fail open (that is the damper will stay open allowing air to flow through the fan assembly). With this condition, modeling showed that there was a minimal impact on the overall ventilation system when the S-90 fan is turned off.

In addition to the underground control system monitoring differential pressure and the S-90 fan operational condition, all data from both the surface fans and underground will be transmitted to the Central Monitoring System (CMS) at WIPP. The CMS will also have the ability to stop any operating fan. Therefore, should an alarm be noted caused by a fan outage or other event, the CMS operator could manually turn off the underground fan.

With the SVS and IVS in place, the underground ventilation system at WIPP will be able to recover from the radiologic event and begin limited operation until a permanent upgrade to the WIPP ventilation system is installed

5.4 Permanent ventilation upgrades

At present the Department of Energy is evaluating numerous options to upgrade the permanent ventilation system at WIPP. These options may include a new shaft, increased surface filtration capacity and other capital improvements. The recommended permanent ventilation system upgrades have not been determined at the time of preparing this paper.

Acknowledgments

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