Modeling the Underground Ventilation System at the Waste Isolation Pilot Plant to Ensure Proper Ventilation Alignment

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On the evening of February 14, 2014, radiological sensors underground at the Department of Energy's (DOE) Waste Isolation Pilot Plant (WIPP) facility detected a radiation release. This sensor triggered a reconfiguration of the ventilation system from a flow of 123 m^3/s (260,000 cfm) to 28.3 m^3/s (60,000 cfm) through two high-efficiency particulate air (HEPA) filtration trains. The ventilation system has been kept at a filtered flow of 28.3 m^3/s (60,000 cfm) since the event. The DOE is currently investigating upgrades to the ventilation system that will include additional surface fans and filtration units, an additional booster fan in the underground, and a long range recovery ventilation plan. SRK Consulting with Nuclear Waste Partnership (NWP) engineers extensively modeled the underground ventilation system at WIPP to determine if a single differential pressure sensor at one strategic location could be used to validate the underground airflow distribution. A proper alignment for the underground ventilation system was airflow passing from the "clean" side to the disposal side with all disposal air exhausting through surface fans with filtration units. This paper describes this study and its conclusion that it was possible to use a single device to monitor for ventilation configuration acceptance.

Introduction

The Waste Isolation Pilot Plant (WIPP) facility is the only transuranic waste repository in the United States. The facility is located approximately 35 miles East of Carlsbad, New Mexico. 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 six of eight original panels. The repository horizon is 655 m (2,150 ft) below surface in the Salado geologic formation (salt).

On February 14th, 2014 a continuous air monitor (CAM) alarmed in Panel 7. 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. 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 was due to a container self-heating in Room 7 of Panel 7. Since the event, Room 7 has been isolated from the underground ventilation system by the installation of bulkheads at each end of the room.

The efforts at WIPP since the radiation event have included investigations into what caused the radiation event, establishing work areas in the underground for ground control activities (e.g. rock bolting and scaling), installing additional surface fan and filtration capacity to increase airflow to the underground and engineering studies on permanent ventilation system upgrades.

The permanent ventilation system upgrades will include new surface fans with filtration system for airflows up to 255 m^3/s (540,000 cfm). A new shaft is also being considered as part of the permanent ventilation system project.

The increased short-term surface fan and filter system is called the interim ventilation system (IVS) upgrade. A design basis risk assessment was performed on the current ventilation system and the IVS. The goal of this study was to determine if a single differential pressure (DP) sensor placed in a strategic location was an adequate measure to validate flow direction in the underground facility to ensure air from the clean areas of the underground facility moves to the disposal circuit and that the air is ultimately sent to the filter units on surface. The exhaust from Panel 7 is currently contaminated from the release event and it is critical that the ventilation system at WIPP passes air from clean to contaminated areas. This paper describes the results of a detailed study that showed it was possible to monitor a single DP sensor in the underground that would indicate flow moved from clean to contaminated areas in the facility during normal operating conditions and would alarm during upset conditions.

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 1 shows these areas. Airflow enters the mine through three shafts, the Air Intake Shaft (AIS), Salt Handling Shaft (SHS), and the Waste Shaft (WS) (see Figure 1). Bulkheads separate the North and Construction circuits from the Disposal circuit. Regulators strategically positioned in the facility maintain the differential pressure to be from the North and Construction circuits towards the Disposal circuit. A fourth circuit simply passes air from the Waste Handling Shaft to the Exhaust Shaft through the waste shaft station. A regulator, called bulkhead (BH) 308, at the return side of the waste shaft station, controls air in this circuit. 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 2 shows the surface fan configuration along with the filtration building. This figure also shows the IVS fan and filter system along with a typical filter assembly consisting of Mod, High and two HEPA filter units. Prior to the radiologic event, in normal operation, the ventilation system discharged unfiltered air. One or two of the 700 fans were typically operated. Two 700 fans generated a volume of approximately 225 m^3/s (475,000 cfm) while one 700 fan in operation generated 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 860 filtration fans operate to exhaust 28.3 m^3/s (60,000 cfm) from the underground and through the filter trains inside of the filtration building. With IVS in operation an additional 25.5 m^3/s (54,000 cfm) is available to the underground increasing the total flow through the surface fans to 53.8 m^3/s (114,000 cfm). Isolation dampers between the 700 fans and the surface duct remove these fans from the primary ventilation exhaust.

Figure 3 shows the design flow underground to support waste handling operations. The criteria for emplacing waste in the underground is for over 19.8 m^3/s (42,000 cfm) in a single open emplacement room in Panel 7, a flow of 9.4 m^3/s (20,000 cfm) through bulkhead number 308 (BH308), and a differential pressure on BH308 of at least -0.1 in. w.g. flowing in the correct direction from the WS to the Exhaust Shaft (ES) (a negative differential pressure indicates the flow is from the WS to the ES).

Outline of Study

The goal of the study was to determine if a single differential pressure (DP) sensor at BH308 was an adequate measure to validate flow direction in the underground facility. During the study, the results of the differential pressure at BH308, the Waste Hoist Tower, and BH313 and the direction of airflow in the WS were carefully monitored. In order to ensure a single DP sensor could be used for this purpose, the study analyzed a comprehensive list of design parameters and settings. These parameters included varying seasonal natural ventilation pressure (NVP) conditions, different combinations of operating fan(s), varying fan airflow, different regulator and ventilation infrastructure settings, and various upset configurations representing sudden ventilation control changes or failures.

NVP is a key variable that significantly affects the ventilation system at the WIPP facility. One of the main drivers of NVP, is variances in surface temperatures. At the WIPP facility, cold surface temperatures assist the fans in driving air through the system. In a ventilation model, these are typically represented by fixed pressure fans placed on the intake shafts configured to push air down each shaft. At WIPP, this is denoted as positive NVP. Hot surface temperatures on the other hand, impede flow through the intake shafts. In a ventilation model, these are typically represented by fixed pressure fans placed on the intake shafts configured to push air up each shaft. This is denoted as negative NVP. Modeled NVPs at the WIPP site were based on previous measurements collected over the past 20 years as well as recordings and observations made during recovery work since the February 2014 release event.

Table 1 shows the various NVPs used for this study. The table shows NVPs used for both very cold winter conditions and very hot summer conditions. To minimize the effect of NVP on the underground flow distribution, the AIS shaft was covered (the shaft collar has a steel grated cover that conveyor belt type material was placed on top). Covering the AIS minimizes flow through this shaft and forces the surface fans to draw air down the Salt Handling Shaft and Waste Shaft. This offers better control on the underground differential pressures and flow directions. This study included options where the AIS was both covered and uncovered.

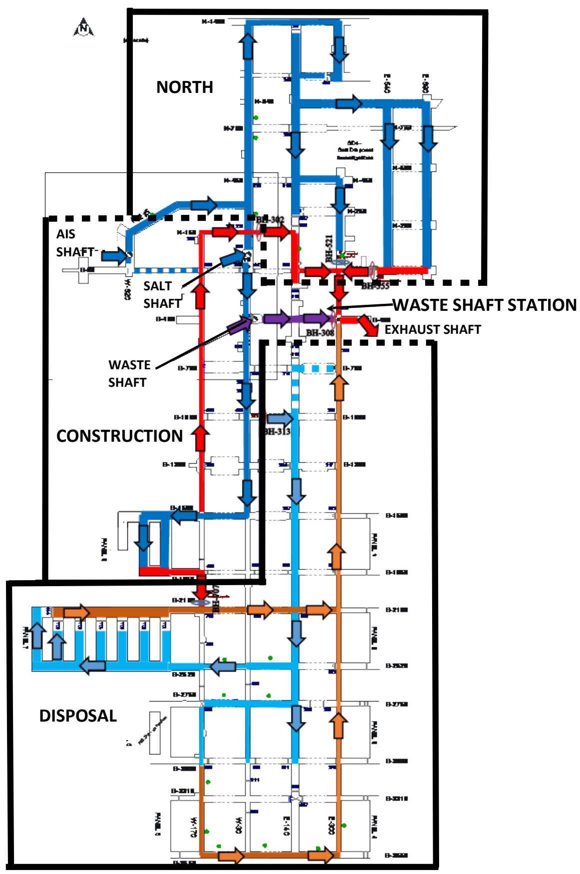

Figure 1: Underground ventilation circuits at WIPP.

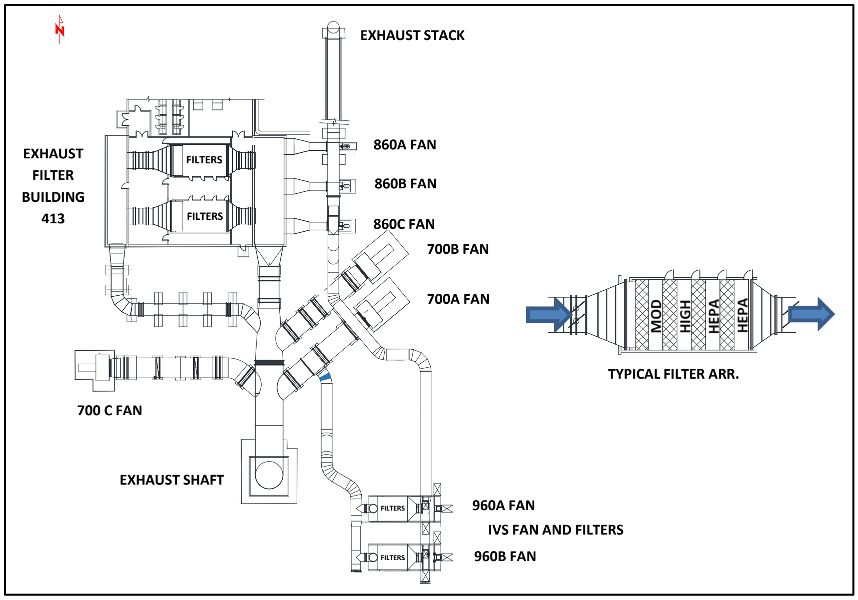

Figure 2: Surface fans and filters (one 860 fan operates with two new 960 fans for IVS)

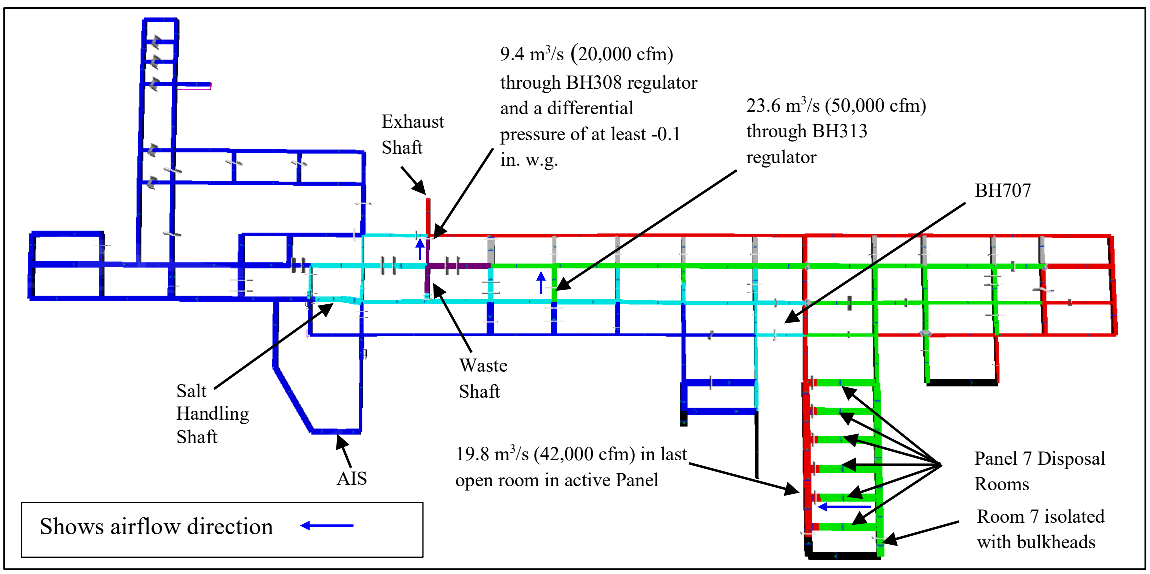

Figure 3: Plan view of key underground infrastructure settings for IVS operation

Table 1: Natural Ventilation Pressures used in study.

NVP Condition	AIS Collar	Shaft NVPs Pa (in. w.g.)		
		AIS	SHS	WS
Summer	Covered	-150 (-0.6)	-249 (-1.0)	-150 (-0.6)
Winter	Covered	0.0* (0.0)	+498 (+2.0)	+74 (+0.3)
Summer	Uncovered	-249 (-1.0)	-249 (-1.0)	+150 (+0.6)
Winter	Uncovered	+498 (+2.0)	0.0** (0.0)	+74 (+0.3)

*AIS is covered and will upcast in winter conditions

**SHS will upcast in winter conditions with AIS uncovered

Different combinations of fan configurations and fan airflows were also set up in order to test the range of possible operating conditions at the WIPP facility. Four different modeling scenarios were set up for different fan configurations. These four fan configurations include scenarios with one 960 series fan in operation, other scenarios with two 960 fans in operation, scenarios with one 860 fan and one 960 fan in operation, and scenarios with one 860 fan and two 960 fans in operation.

As well as different fan configurations, calculations also determined that variances in the flow of the surface exhaust fans could also exist. It was determined that the 860 fans could vary by as much as 0.7 m^3/s (1500 cfm) and the 960 fans could vary by as much as 0.2 m^3/s (500 cfm). It was for this reason that for a number of the models a bracketing study was performed to study the variances in surface airflow that could be possible. Models with minimum airflow involving two 960 fans at 12.5 m^3/s (26,500 cfm) and an 860 fan at 27.6 m^3/s (58,500 cfm) were developed. As well models with maximum airflow through the surface fans involving two 960 fans at 13.0 m^3/s (27,500 cfm) and one 860 fan at 29.0 m^3/s (61,500 cfm) were modeled.

Ventilation regulator and infrastructure settings that were varied include adjusting BH308 and BH313 regulators, covering and uncovering the AIS, opening and closing the BH401 and BH401A doors, and opening and closing the Auxiliary Air Intake Tunnel (AAIT). The AAIT is a regulated intake plenum that controls airflow through the Waste Shaft. Reasons for adjustments to these infrastructures are explained later in this paper. The last of the design parameters modeled for this study were five upset configurations representing sudden uncontrolled ventilation changes to the system. The five upset conditions modeled were: a failure of BH336 or BH707, or a failure or opening of both doors in BH303 and BH310, BH415 and BH416, or BH320 and BH319.

Figure 4 shows a diagram highlighting the locations of the upset conditions. For each set of doors and regulators, models were constructed to approximate a failure. A failure or opening of both doors was modeled as an airway without any restrictions. This was not considered likely as all airlock drive-through doors are interlocked and even if opened at the same time, operations personnel would be in position to close a door relatively quickly. Also, a failed bulkhead would leave some restriction in the airway. Nonetheless, this modeling approach was considered conservative. The study did not consider multiple simultaneous failures or other unusual unanticipated control configurations. For example, a failure of BH303 and BH310 would not necessarily be modeled with BH308 closed, unless BH308 was closed in the base case configuration.

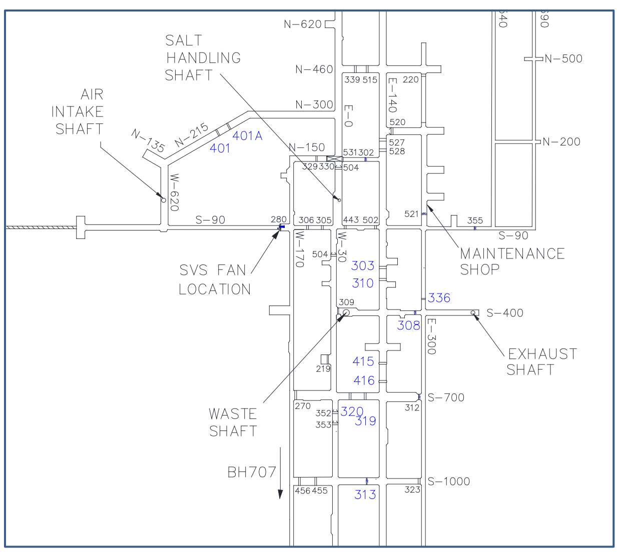

Figure 4: Underground location of key bulkheads, doors and regulators.

Results

At the start of the design process a series of basic modeling configurations were developed. Table 2 shows the basic design configurations used for the study. From these basic parameters all other modeling variations were developed. For the condition showing either one 960 fan or one 860 fan at half flow and the condition showing one 860 fan or two 960 fans, models were only developed using the 960 fans since they approximate nearly the same surface airflow. Also, since the two 960 fans together generate slightly less airflow than the 860 fan, this was considered a conservative approach.

Table 2: Basic configurations for various fan operating conditions

Operating Fan(s)	Nominal Flow (u/g) at Exhaust Shaft	AIS	SHS Collar	BH401/BH401A doors	SVS Fan Mandoor/Reg.	BH308 Regulator	BH313 Regulator	BH303/BH310	BH415/BH416	BH309 Fans	Panel 7	BH between W-30/E-140
1-960 or 1-860*	24 kcfm to 27 kcfm	Covered	Covered	Closed	Closed	Closed	Closed	Closed	Closed	off	Not important	Closed
1-860 or 2-960	54 to 49 kcfm	Covered	Open	Closed	Closed	Set at 10 kcfm	Closed	Closed	Closed	off	Six rooms closed one room regulator open	Closed
1-860 and 1-960	80 kcfm	Covered	Open	Closed	Closed	Set at 20 kcfm	Set at 25 kcfm	Closed	Closed	off	Six rooms closed one room regulator open	Closed except BH313
1-860 and 2-960	105 kcfm	Covered	Open	Closed	Closed	Set at 20 kcfm	Set at 50 kcfm	Closed	Closed	can be on	Six rooms closed one room door open	Closed except BH313
1-860 and 2-960	105 kcfm	Uncovered	Open	Open	Closed	Set at 20 kcfm	Set at 50 kcfm	Closed	Closed	can be on	Six rooms closed one room door open	Closed except BH313

* 1-860 during filter change out mode, fan to exhaust 30 kcfm from underground.

For each fan configuration shown in Table 2, a base model was created based on no NVP conditions. This was termed the neutral NVP model. Regulators were set in the underground facility to give the desired airflows for the neutral condition. For example, with all surface fans operating, Figure 3 shows BH308 at 9.4 m^3/s (20,000 cfm) and BH313 at 23.6 m^3/s (50,000 cfm). To achieve these flows, the model was set at the regulator minimum resistance value (based on previously measured data), then a "fixed quantity" branch was applied. The model then returns a resistance value to achieve the desired airflows. This resistance value was then used for BH308 and BH313 regardless of NVP conditions. Modeling this way means that the BH308 and BH313 regulators were not adjusted to give desired flows for high or low NVP conditions, but rather the flows through these regulators were allowed to change naturally as NVP conditions fluctuate. This approach was deemed realistic as in practice, the regulators will not be adjusted continuously.

From these base models, winter and summer NVPs were applied. This result was considered the base configuration for each fan operating scenario, giving three base models (neutral NVP, summer NVP, and winter NVP) per scenario. From these base models, five upset models were developed. These upset models varied only the upset configurations previously described in each base model. This design process was followed for each of the first three basic configurations shown in Table 2 (one 960 fan, two 960 fans, and one 860 fan with one 960 fan). Figure **5** highlights a design diagram of creating models.

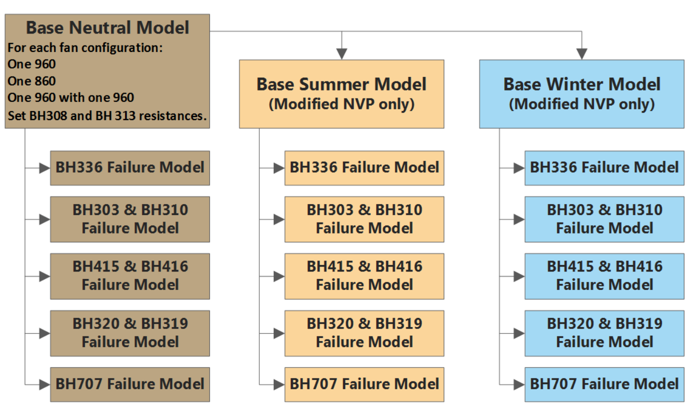

Figure 5: Design diagram for each of the first three base configurations

For the fourth basic configuration, which included the two 960 fans and one 860 fan operating, a slightly different design process was used. Models were set up for two different surface fan flows: minimum flow (both 960 fans at 12.5 m^3/s (26,500 cfm) and the 860 fan at 27.6 m^3/s (58,500 cfm)) and maximum flow (both 960 fans at 13.0 m^3/s (27,500 cfm) and the 860 fan at 29.0 m^3/s (61,500 cfm)). Two separate sets of models were created to form a bracketing study with regard to the amount of possible airflow through the fans. Some variation in airflow quantity can be expected for various reasons including atmospheric conditions and fan installation differences, and tolerances of airflow monitoring systems on the fans.

For each set of fan airflow scenarios, different NVP conditions were modeled for both very warm summer conditions and cold winter conditions. For each base model, flows are specified for the BH308 and BH313 regulators. To achieve these flows, the model was set at the regulator minimum resistance value; then a "fixed quantity" branch was applied and the model returns the appropriate resistance value (This is the same modeling process as described in the previous set of models). These resistances were also not modified with NVP fluctuations, but rather flows were allowed to change naturally.

As in the previous models, five similar upset models were also generated for each NVP condition. To create the five upset models, the same design process as with the previous base configurations was followed (removing the regulator/door resistance completely). With each set of models for minimum and maximum flow, two sets of upset models were created during winter NVP conditions. These include upset configurations for when the AAIT was open and closed. In either set of upset conditions, the BH308 and BH313 regulators were not adjusted from their setting during the neutral base case model. Figure 6 shows the creation process of the set of models for the fourth base configuration.

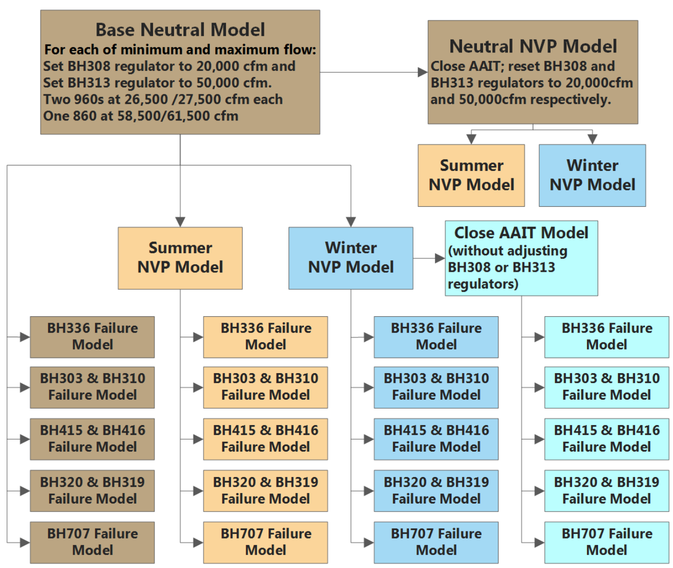

Figure 6: Design diagram for the fourth base configuration

One additional study was tested which involved modeling two 960 fans with one 860 fan operating while uncovering the AIS and opening the BH401 and BH401A doors. This scenario models the anticipated effects of this ventilation change for neutral, summer, and winter NVP conditions. For each of these NVP conditions, models were developed showing the AAIT regulator closed and opened. The main scenarios of concern for these models were during winter NVP conditions. During cold winter conditions with the AIS and the BH401 and BH401A doors open, the net NVP in the shafts drive air to upcast the SHS and the WS.

During winter NVP conditions, an upset configuration showing BH303 and BH310 was modeled with both AAIT closed and open. The reason for modeling this scenario was to show that there exist upset scenarios which result in the WS upcasting while the BH308 DP sensor was not assuredly in alarm. While the results of modeling show a base configuration during winter NVP where this was the case, the results were close to showing an upcasting WS but not quite with BH308 in alarm. However, an upset scenario with BH303 and BH310 open definitely shows BH308 not in alarm while the WS was upcasting. This condition results in fresh air from the North entering the shaft station and upcasting the WS while BH308 was maintained in the correct direction and may not be in alarm.

The results of this study generated a large amount of data. An example of the results is given on Table 3. A low differential pressure alarm at BH308 indicates a possible reversal of air through this location which indicates air moving from the disposal exhaust towards the Waste Shaft. For BH308 a value with an ^ indicate pressures that may, but cannot be assured to, result in an alarm for BH308. For BH313, values with an * indicate results with relatively small differential pressures (<0.05 in. w.g.) leaking from W-30 to E-140.

Table 3: Example result with two 960 fans in operation with accident scenarios.

	NVP	860 Fan	960 Fan 1 (27.5 kcfm)	960 Fan 2 (27.5 kcfm)	WS Flow Direction	WS Flow (kcfm)	WHT DP (in. w.g.)	BH308 DP (in. w.g.)	BH313 DP (in. w.g.)	Panel 7 Flow (kcfm)
Base Configuration	Neutral	off	on	on	Down	8.3	-0.38	-0.57	-0.72	18.1
	Winter	off	on	on	**Up**	5.3	**0.16**	-0.22	-1.01	20.3
	Summer	off	on	on	Down	10.7	-0.64	-0.61	-0.68	17.8
BH336 Open	Neutral	off	on	on	Down	9.0	-0.45	**-0.10^**	-0.33	11.8
	Winter	off	on	on	**Up**	6.9	**0.26**	**0.02**	-0.64	14.8
	Summer	off	on	on	Down	11.2	-0.71	-0.14	-0.30	11.3
BH303/BH310 Open	Neutral	off	on	on	Down	7.6	-0.33	-0.62	-0.70	18.0
	Winter	off	on	on	Up	8.8	**0.43**	-0.45	-0.89	19.7
	Summer	off	on	on	Down	10.4	-0.61	-0.64	-0.68	17.7
BH415/BH416 Open	Neutral	off	on	on	Down	10.9	-0.67	**-0.04**	-0.48	25.5
	Winter	off	on	on	**Up**	3.7	**0.08**	**-0.03**	-0.92	23.7
	Summer	off	on	on	Down	13.0	-0.95	**-0.04**	-0.43	25.7
BH320/BH319 Open	Neutral	off	on	on	Down	6.0	-0.20	**-0.06^**	**-0.001***	31.5
	Winter	off	on	on	**Up**	11.2	**0.70**	**0.07**	**-0.002***	37.6
	Summer	off	on	on	Down	9.5	-0.51	**-0.10^**	**-0.001***	30.5
BH707 Open	Neutral	off	on	on	Down	6.4	-0.23	**-0.07^**	**-0.010***	**-7.1**
	Winter	off	on	on	**Up**	11.1	**0.69**	**0.07**	**-0.020***	**-10.0**
	Summer	off	on	on	Down	9.5	-0.51	**-0.01**	**-0.011***	**-6.6**

[shaded box]: WS upcasts, but BH308 not in alarm [0.02 shaded box] BH308 is in an Alarm condition. ^ indicates alarm condition but close to set point.

* indicates BH313 at very low pressure but flow in correct direction.

Summary of Results

The primary conclusion determined in this study was that the negative DP at the 308 Bulkhead confirms that all air in the disposal circuit is exhausted to E-300 to S-400 and up the Exhaust Shaft regardless of the configuration of the exhaust fans or regulators and/or doors within the underground facility. This negative pressure does not necessarily prove air downcasts the Waste Shaft. However, in those scenarios where BH308 was not assuredly in alarm and the Waste Shaft was upcasting, leakage air from the North Circuit (clean, fresh air) entered the waste shaft station from the North and not a reversed flow through BH308. Fresh air leaking from the North may split in the Waste Shaft Station at S-400 and course through BH308 and up the Waste Shaft when high winter NVPs are present. In this situation, the study showed there can be airflow upcasting the Waste Shaft while maintaining an acceptable DP on BH308.

In no scenario analyzed did air from the disposal panel move from Disposal circuit return to intake without the BH308 differential sensor being in alarm. Moreover, no model results showed air moving from disposal to the construction circuit. Provided fans are operating, there was not a driving force to pass air from the Disposal into the Construction circuit. Certain models had very low differential pressures between Construction and Disposal circuits, but the flow direction was maintained from the Construction circuit into the Disposal circuit. Additionally, no air moved to the disposal intake from the disposal circuit return. This study validated using the BH308 DP sensor as a reliable indicator of acceptable flow distribution at WIPP.

References

[1] McPherson, M.J., Subsurface Ventilation Engineering, 2009 Published by Mine Ventilation Services, Inc., 823 pgs.

[2] U.S. Department of Energy, Waste Isolation Pilot Plant Recovery website: http://www.wipp.energy.gov /wipprecovery/accident_desc.html