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Radiological Source Term Estimates for the February 14, 2014 WIPP Release Event

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March 2015
SRNL-STI-2014-00579, Rev 0

SRNL.DOE.GOV

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Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2014-00579

Keywords: ***Transport modeling, source attribution, radiological waste***

Retention: *Permanent*

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Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

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AIB	Accident Investigation Board
ARF	Airborne Release Fraction
CAM	Continuous Air Monitor
CEMRC	Carlsbad Environmental Monitoring Research Center
DOE	Department of Energy
DR	Damage Ratio
EPA	Environmental Protection Agency
FAS	Fixed Air Sampler
LPF	Leak Path Factor
MAR	Material at Risk
RF	Respirable Fraction
SRNL	Savannah River National Laboratory
TAT	Technical Assistance Team
WIPP	Waste Isolation Pilot Plant

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1.0 Overview

The airborne fraction of the February 14, 2014 release of radioactivity from WIPP Panel 7, waste room 7 (P7R7) was characterized by modeling the transport, dilution, and deposition of the material through the WIPP underground ventilation exhaust system. Model simulations were run for a default 1 Curie (Ci) release from the R7 bulkhead door for various release durations and contaminant deposition rates along the exhaust path. For each simulation, source term and model derived values of instantaneous and integrated activity along the exhaust path were scaled to produce a total activity of 100 milliCi (mCi) in the effluent at the location of the Station A fixed air sampler (FAS), located above ground just upstream of the exhaust stack HEPA filters (see Fig. 1). A total release amount of 100 mCi at Station A is within a range of estimates reported for the Station A FAS. Scaled results from each of the modeling scenarios were then evaluated with respect to air sample data collected from the continuous air monitor (CAM) located at the end of the P7 exhaust drift, additional radiological samples taken from P7 drift surfaces following the event, and results from a 1998 experimental study of the transport and fate of particulate releases from a WIPP waste room (P1R7).

The Environmental Protection Agency's RISK (v 1.9.7) indoor air modeling system was selected for this analysis. RISK was configured to simulate flow through a series of rooms representing segments along the exhaust path from the waste room to Station A. The ventilation flow for each segment was based on real-time flow data recorded during the event, as provided by the WIPP Accident Investigation Board (AIB).

The Station A FAS provides the most reliable source of data available on the airborne release from P7R7, although disparate values from three sources were reported: (1) an isotopic analysis performed by the Savannah River National Laboratory (SRNL) for a FAS collection filter that was in operation during the course of the release (Diprete, et al, 2014); (2) measured FAS activity reported by WIPP (Hayes, 2014); and (3) estimated Station A FAS activity reported by the Carlsbad Environmental Monitoring Research Center (CEMRC) (Nelson, 2014). Based on these data, a representative value of 100 mCi was selected as the basis for scaling model results. According to the SRNL analyses, approximately 90% of the activity collected on the FAS filter was Am-241, with the remaining 10% consisting primarily of Pu-239 and Pu-241.

Isotopic analyses of ten filter samples retrieved from the P7 CAM indicate that a total activity of approximately 74 mCi was transported out of P7 over a period of about one hour after the start of the event. The instrument then failed, likely before the release had fully cleared the panel. Furthermore, log entries recorded while the P7 CAM was operational indicate that intake flows for each of the ten filters retrieved from the instrument were characterized by low or obstructed conditions. As a result, data from the CAM can only support lower bound estimates of the total release.

Assuming a constraint that the CAM sampled at least one-fourth of the entire release, and that modeled values of deposition within P7 agree with observed values to within 20%, possible airborne release amounts from R7 range from approximately 0.3 to 1.5 Curies. This suggests that between 5% and, at most, 20% of the radiological inventory from the estimated 9 Ci contained within the suspect waste drum, i.e., drum 68660 (Giaquinto, 2014), was released as suspended airborne material and exhausted from R7.

2.0 Effluent Air Monitoring Data

Effluent air monitoring data were available from CAM-151, located near the exit of the P7, and the Station A FAS which is located above ground just upstream from the exhaust stack HEPA filters. Monitor locations are indicated on Fig. 1.

2.1 P7 CAM

Sample collection filters retrieved from the P7 CAM were analyzed by SRNL (DiPrete, et al, 2014). A total of 17 filters were analyzed, 13 of which sampled activity attributable to the release. Many of these 13 filters were observed to have been blackened by smoke.

Total filter activity was reported for 10 isotopes. About 80 percent of the total activity consisted of Am-241, 10 percent Pu-239, and 10 percent Pu-241. Total activity of Am-241 present on each of the 13 filters is summarized in Table 1 (Col. 3). The one-sigma uncertainty in the analysis of Am-241 was 10%. Using these data, the total Am-241 activity in the P7 ventilation air at the location of CAM-151 sample inlet (Table 1, Col. 4) was estimated by multiplying filter activity by the ratio of the P7 ventilation flow to the CAM sample intake flow as expressed by Eq. (1).

Total effluent activity = $\Sigma_{i=3,13}$ (Ventilation flow$_i$ / CAM sample flow$_i$) x filter activity$_i$ (1)

where the subscript, i, refers to filter number. This calculation assumes drift air sampled by the CAM is representative of the entire drift volume, i.e., the activity is uniformly dispersed within the drift.

Filter no.	Sample duration (min)	Am-241 on filter (pCi)	Estimated Am-241 through drift (μCi)	Operating indicator
3	*	5.59E+03	2.0E+02	Low flow
4	1.26	3.27E+03	6.2E+01	Broken filter
5	4.22	4.82E+03	8.7E+00	Low flow
6	4.22	2.61E+06	4.7E+03	Obstructed flow
7	3.2	1.58E+05	2.8E+02	Obstructed flow
8	3.22	2.69E+06	4.8E+03	Obstructed flow
9	1.27	3.32E+06	6.0E+03	Broken filter
10	5.22	3.08E+06	5.5E+03	Low flow
11	4.22	3.14E+06	5.6E+03	Obstructed flow
12	4.22	1.57E+06	2.8E+03	Obstructed flow
13	1.80	3.93E+06	7.1E+03	Failure
Total			**3.7E+04**	

* Sample 3 filter placed in operation some time before the R7 event

Table 1. Radioactive Release Estimates based on CAM-151 Sample Collections

Based on the operations log for the P7 CAM provided by WIPP, the initial alarm for an off-normal event was triggered by activity collected on Filter 3, prompting a switch of the WIPP underground ventilation system to filtration flow. Ventilation flow data for the event was available from flow meter V10 located at the end of Panel 7 near the CAM (see Fig. 2). Flow rates through the drift were observed to be near the design value of 90,000 cubic feet per minute (cfm) until 2314 hours (local time) February 14, 2014 when the flow begins to drop rapidly to a filtration flow of approximately 4500 cfm at 2317 hours. To determine the total activity transported by P7 ventilation air, a flow of 90,000 cfm was assumed for the period represented by Filter 3 and 4500 cfm was assumed for filters 5-13. An average of the two flows (47,250 cfm) was assumed during the transition period represented by Filter 4. Sample flow for P7 CAM, as indicated in the diagnostics log, averaged around 2.5 cfm.

The resulting estimated total Am-241 activity in the P7 ventilation air, determined from Eq. 1 using the CAM filter data was 37 mCi. In addition, the total activity in the effluent estimated for Am-241 was divided by the length of the associated sample then divided again by the concurrent P7 exhaust flow to calculate instantaneous Am-241 activity concentrations. Activity concentrations ranged from a typical value of 10 $\mu Ci/m^3$ to a peak value of 40 $\mu Ci/m^3$.

The CAM operations log file also contained information providing additional context to the filter samples, such as the load and discharge times for each individual filter, sampling start and stop times, and conditions significant to data collection or causing initiation of filter change-out. These data show that the time interval between the completion of one sample to the start of collection for the next was consistently 1.75 minutes.

To determine the additional airborne activity exiting P7 during filter change-out, an average activity flux through the drift cross-section at the CAM sample inlet (total Am-241 activity in Col. 4 divided by the sample duration in Col. 2) before and after each filter change-out was multiplied by the change-out period of 1.75 minutes. The change-out duration was determined from the operations log file. A sum of the results over each of the ten exchange intervals gives a total unmonitored Am-241 activity in the P7 ventilation air of 22 mCi. Finally, the contribution of Pu-239 and Pu-241 was included by multiplying the total Am-241 activity of 59 mCi (37 mCi monitored, 22 mCi unmonitored) by a factor of 1.25 (i.e., 20% / 80% +1). This results in an **estimated total activity of 74 mCi** exhausted from P7 prior to CAM failure.

An inspection of sample results from the available filters suggest no discernable time-dependent pattern to the activity detected within the exhaust, i.e., no indication that the release was beginning to clear P7 at the time of CAM failure. Characterizing the distribution of activity from Room 7 release along the direction of ventilation transport is further complicated by variability in the WIPP ventilation flow after the system was placed in filtration mode. The ventilation data indicates flows oscillated about the prescribed design value of 5000 cfm for several minutes and at times approached values near 1000 cfm. Contamination found in Panel 7 upstream of Room 7 suggests that a flow reversal may have occurred, at least on a local scale. In summary, data from the P7 CAM can only define a lower bound on the total activity exhausted from P7.

2.2 Station A FAS

Three reported values of radioactivity in the ventilation air at Station A, as estimated from the Station A FAS, were considered for this study:

(1) An isotopic analysis was performed by SRNL for a FAS collection filter in operation during the course of the release (Diprete, et al, 2014). This analysis showed that approximately 90

percent of the activity was Am-241, with Pu-239 and Pu-241 each contributing about 5 percent to the total. The corresponding 1-sigma uncertainty in the analysis for these isotopes of interest was estimated to be less than 10%. The Am-241 activity on the FAS sample was subsequently multiplied by the ratio of the flow through the exhaust duct (60,000 cfm during filtration flow) to the sample flow (2 cfm) to determine that approximately 36 mCi of Am-241 was present in the effluent at Station A. Adjusting this number to account for the 10% of the release that was Pu-239 and Pu-241 results in a total of 40 mCi.

(2) An analysis of filter samples conducted by the WIPP contractor for the Station A FAS, as well as Station B FAS downstream of the stack HEPA filters, resulted in reported releases of 110 mCi (Nelson, 2014) and 1.88 mCi (Hayes, 2014), respectively.

(3) The CEMRC analyzed filter samples from the Station A FAS activity and reported a total activity of 260 mCi (Nelson, 2014).

Given these data, the P7R7 event was assumed, for the purpose of this analysis, to be represented by a total effluent activity of 100 mCi at Station A. This value is consistent with a HEPA filter efficiency resulting in a release of 1.88 mCi at Station B.

3.0 Experimental Data on Particulate Deposition

A series of experiments conducted within the WIPP underground in 1998 provide quantitative estimates of particulate removal (deposition) during transport of a release through the ventilation exhaust to the exhaust stack (Archer, et al, 1998). The experimental releases consisted of 2 gram samples of various metal compounds having densities and particle sizes analogous to the plutonium forms potentially present at WIPP, i.e., a salt form, an oxide form, and an elemental form. The samples were released over a period of a few minutes from a location just upstream of P1R7. Experiments were conducted for a range of possible ventilation conditions including normal mode (2 fans operational), alternative mode (1 fan operational), and filtration mode. Air samples were collected by a CAM or FAS located at the exit of the waste room (C_0), midway between rooms 3 and 4 in Panel 1 (C_{250}), the end of Panel 1(C_{1250}), and at Station A above ground (C_{4000}), where C represents the total material collected on the sample and the subscript denotes the distance from the source in feet. Additional filters were deployed to collect samples from the walls and floors within the waste room and along the exhaust path.

Results from these experiments showed that the amount of material retained within the WIPP underground (not including HEPA filtration) ranged from 94.6 to greater than 99.9 percent of the initial release, depending on the form of the material. The values summarized in Table 2 represent the ratio of the total material collected on CAM or FAS filters at three locations along the exhaust path to samples collected at the exit to P1R7. The fractional values in the table were interpolated from log-linear plots provided in the 1998 report which depict the average of results over all experiments for a given Pu form and particle size range. The variations about the average values listed in Table 2 bound the results from individual experiments.

Radiological samples collected within P7 a few weeks after the Room 7 fire provide some additional information for characterizing deposition. Gross alpha analysis indicated total activities of 40,000 disintegration per minute (dpm) at the R7 bulkhead, 30,000 dpm in the P7 exhaust drift at Room 6, and 20,000 dpm in front of Room 1. Processes affecting the deposited

Sample Analog	C_{250}/C_0	C_{1250}/C_0	C_{4000}/C_0
5-10 μ Salt Particles	0.33 ± 0.15	0.25 ± 0.20	0.03 ± 0.01
5-10 μ Pu-Oxide	0.30 ± 0.31	0.20 ± 0.16	0.10 ± 0.05
1-5 μ Pu Metal	0.25 ± 0.21	0.10 ± 0.08	0.01 ± 0.01
Average	0.3	0.2	0.05

Table 2. Ratios of total material collected on filter samples at select locations along the WIPP exhaust path from Room 7, Panel 1 to Station A during the 1998 release experiment.

material between the time of the P7R7 release and sample collection several weeks later, such as resuspension or chemical transformation, limit the applicability of these data. However, assuming that the effects of these processes were consistent at all locations within Panel 7, the ratios of deposition between the down drift locations are useful. The ratio of deposited material *D* between Room 1 and 6 was D_1/D_6 = 0.67 and between Room 1 and 7 was D_1/D_7 = 0.5.

4.0 Fate and Transport Model Description and Configuration

The Environmental Protection Agency's (EPA) RISK model (v 1.9.7) was selected for conducting simulations of the transport, dilution, deposition, and subsequent resuspension of radioactive releases from P7R7 through the WIPP underground exhaust ventilation system. This model is recommended by EPA for calculating the exposure of individuals to sources of indoor air pollution. Model performance has been tested against experimental data and found to provide reliable results (EPA, 2014). The model predicts a time dependent concentration in each of a sequence of rooms using the expression:

$$V_i \frac{dC_i}{dt} = C_{i,IN} Q_{i,IN} - C_i Q_{i,OUT} + S_i - D_i \qquad (2)$$

where,

i is the room number,
V_i is the volume of the room (m^3),
C_i is the predicted concentration in the room (Ci/m^3),
dt is the model timestep (hr),
$C_{i,IN}$ is the concentration entering the room (Ci/m^3),
$Q_{i,IN}$ and $Q_{i,OUT}$ represent the airflow entering or exiting the room (m^3/hr),
S_i represents any source material released in the room, including resuspension (Ci/hr) and
D_i is the amount material removed from the room, including deposition (Ci/hr).

Airborne contaminants within a room are assumed to be instantaneously well-mixed, i.e., no concentration gradient exists within a 'room'.

The model domain for this investigation consisted of 13 rooms representing segments of the WIPP exhaust path leading from the Room 7 bulkhead, to the exhaust stack at the Station A

FAS (see Figure 3). Specific 'rooms' were created for areas of interest where air monitoring or deposition data are available, including segments within Panel 7 beginning at the Room 7 bulkhead extending down the drift to Room 5, Rooms 3-4, Rooms 1-2, and the end of the Panel 7 exhaust drift including the P7 CAM sample inlet.

Airflows for each of these rooms were based on analysis of ventilation flow measurements from within the WIPP facility obtained from the AIB. Flows entering each room from adjacent rooms not explicitly part of the domain were specified and the total flow was set to match the measured flow prior to the release (normal mode ventilation) and the subsequent reduction in airflow (filtration mode ventilation). Based on the room dimensions and measured airflows, it was estimated that it would take approximately 5 minutes for the initial release from Room 7 to reach CAM-151 at the exit of Panel 7. The reduction in flow which occurred after the CAM alarm was received was simulated in the model by the application of a scaling factor.

The model requires that the airflow scaling factor be applied equally across the entire domain and at the same time. Because ventilation system flow compiled by the AIB was seen to scale differently at different points within the underground, two airflow reduction factors, 5% and 15%, were used in modeling. The value of 5% was based on the change in flow within Panel 7 which was reduced following the CAM-151 alarm from 90 kcfm at the V10 measurement station to 4.5 kcfm. The value of 15% was determined by averaging the flow reduction at all measurement stations between Panel 7 and the exhaust stack.

The source was modeled as a short term release from an area of 1 m^2 which represents the approximate size of the opening in the Room 7 bulkhead. The release duration was constrained by the requirement that it needed to be longer than a period of two model timesteps to be adequately resolved in the model. Release durations from 1 minute to 1 hour were simulated and the release rate was assumed to be constant over the duration of the release. For each scenario, a unit release rate (1 Ci/hr) was initially used to calculate instantaneous and total activity throughout the model domain. The source strength was then scaled to result in an integrated activity of 100 mCi at the Station A FAS.

Deposition and resuspension are modeled by RISK as

$$D = v_d C_a A\, dt \qquad (3)$$

and

$$R = F_c M_s A\, dt \qquad (4)$$

where

D and *R* is the amount of deposited (Ci/m^2) or resuspended material (Ci/m^2), respectively,
v_d is a user-specified deposition velocity (m/hr),
C_a is the airborne concentration (Ci/m^3) within the room,
A is the depositional surface area within the room (m^2; including the floor, walls and ceiling),
dt is the model timestep (hr),
F_c is the fractional rate of resuspension (fraction of deposited material resuspended per hour), and
M_s is the amount of deposited material (Ci/m^2).

Deposition of the contaminant was controlled primarily through the selection of deposition velocity which is dependent on the size and type of particles released, chemical form of the contaminant (i.e., salt, oxide, etc.) and the characteristics of the drift surface. Since this information is not readily available or easily accommodated in the model, calculations were performed for a range of deposition velocities from 0.001 to 0.25 cm/s. Resuspension was simulated using a resuspension factor of 0.01. Estimated values of instantaneous and integrated concentration due to resuspension were found to be negligible relative to comparable values resulting from the initial release.

5.0 Modeling Results and Source Term Estimates

Model simulations were generated for combinations of release times of 1, 3, 6, 10, 15, and 60 minutes, flow reductions of 5% and 15%, and deposition velocities of 0.001, 0.01, 0.05, 0.1, and 0.25 cm/s. Tables 3 (flow reduction to 15% of normal ventilation) and 4 (flow reduction to 5% of normal ventilation), summarize scaled values of source term at the R7 exit, as well as peak instantaneous and total integrated activity in the ventilation exhaust at the location of the P7 CAM, for the indicated values of deposition velocity. The scaling was based on a total activity of 100 mCi in the exhaust air at Station A. The tables also show the model estimated duration of elevated activity at the location of the P7 CAM. Similarly, model results summarized in Table 5 (flow reduction to 15% of normal ventilation) and 6 (flow reduction to 5% of normal ventilation) give model predicted values of the fractional decrease in total deposition or total activity for the indicated locations along the exhaust path. Note that results for higher deposition velocities (0.1 cm/s and larger) are not shown due to unfavorable comparison to the evaluation criteria summarized below.

Since the data available for characterizing the release (i.e, the P7 CAM, post event sampling, and the 1998 release experiment) are incomplete or potentially unrepresentative, some bounding criteria were imposed as a practical means for identifying a reasonable range of likely results. The selected criteria are summarized, as follows, in their order of application:

(1) Total activity at the location of the P7 CAM was less than four times the observed activity, i.e., the P7 CAM data represents at least one-fourth of the total airborne release exhausted from P7.
(2) The airborne release at the P7 exit lasted at least one hour but no more than 4 hours.
(3) Deposition ratios (D_1/D_6 and D_1/D_7) were within 20% of observed values.
(4) Activity ratios (C_{250}/C_o, C_{1250}/C_o, C_{4000}/C_o) were within the range of values summarized in Table 2.

Modeling scenarios with results closest to these criteria are included in Tables 3-6. Shaded cells in the tables show values that meet the criteria, In general, these scenarios were characterized by relatively light deposition, i.e., deposition velocities 0.01 cm/s or less.

V_d (cm/s)	Est. Release (Ci)	Integrated Activity (mCi)		Release Duration at CAM-151 (hr)	Peak Conc. at CAM-151 ($\mu Ci/m^3$)
		CAM-151	Stn A FAS		
Flow reduction to 15%, 3 minute release					
0.001	**0.3**	210	100	1.6	8
0.01	**0.4**	250	100	1.5	10
0.05	1.0	560	100	1.2	19
Flow reduction to 15%; 6 minute release					
0.001	**0.4**	210	100	2.0	7
0.01	**0.5**	250	100	1.7	8
0.05	1.4	590	100	1.4	16
Flow reduction to 15%; 10 minute release					
0.001	**0.5**	210	100	2.0	6
0.01	**0.6**	250	100	1.8	7
0.05	1.7	606	100	1.5	13
Flow reduction to 15%; 15 minute release					
0.001	**0.5**	200	100	2.2	5
0.01	**0.7**	250	100	2	6
0.05	2.0	550	100	1.7	11

Table 3. Estimated release amounts from the P7R7 exit required to produce a total integrated activity of 100 mCi at the Station A FAS sample inlet for various values of release duration and deposition velocity, and a WIPP ventilation flow reduction to 15% of normal flow. Highlighted entries are results that meet model evaluation criteria.

V_d (cm/s)	Est. Release (Ci)	Integrated Activity (mCi)		Release Duration at CAM-151 (hr)	Peak Conc. at CAM-151 (μCi/m³)
		CAM-151	Stn A FAS		
Flow reduction to 5%; 1 minute release					
0.001	**0.4**	140	100	3.3	6
0.01	**0.7**	220	100	2.8	10
0.05	3.6	1000	100	2.4	48
Flow reduction to 5%; 3 minute release					
0.001	**0.3**	185	100	3.5	5
0.01	**0.5**	300	100	3.1	8
0.05	3.0	1630	100	2.6	45
Flow reduction to 5%; 6 minute release					
0.001	**0.4**	230	100	3.9	4
0.01	**0.8**	370	100	3.4	6
0.05	5.2	2100	100	2.9	38
Flow reduction to 5%; 10 minute release					
0.001	**0.6**	270	100	4.1	5
0.01	**1.1**	450	100	3.7	5
0.05	8.1	2520	100	3.1	36

Table 4. Estimated release amounts from the P7R7 exit required to produce a total integrated activity of 100 mCi at the Station A FAS sample inlet for various values of release duration and deposition velocity, and a WIPP ventilation flow reduction to 5% of normal flow. Highlighted entries are results that meet model evaluation criteria.

V_d (cm/s)	Est. Release (Ci)	Fractional Difference in Activity Deposited		Fractional Reduction in Predicted Integrated Airborne Activity		
		D_1/D_6	D_1/D_7	C_{250}/C_0	C_{1250}/C_0	C_{4000}/C_0
Observed Data		**0.67**	**0.5**	**0.25-0.33**	**0.1 – 0.25**	**0.1 – 0.01**
Flow reduction to 15%; 3 minute release						
0.001	0.3	0.77	0.79	0.80	0.56	0.48
0.01	0.4	0.76	0.78	0.78	0.52	0.39
0.05	1.0	0.74	0.72	0.68	0.39	0.17
Flow reduction to 15%; 6 minute release						
0.001	0.4	0.83	0.44	0.81	0.56	0.48
0.01	0.5	0.81	0.43	0.77	0.53	0.39
0.05	1.4	0.73	0.38	0.66	0.38	0.17
Flow reduction to 15%; 10 minute release						
0.001	0.5	0.73	0.26	0.81	0.56	0.49
0.01	0.6	0.70	0.25	0.77	0.52	0.39
0.05	1.7	0.61	0.21	0.65	0.37	0.17
Flow reduction to 15%; 15 minute release						
0.001	0.5	0.64	0.22	0.81	0.56	0.49
0.01	0.7	0.61	0.21	0.77	0.51	0.39
0.05	2.0	0.51	0.17	0.64	0.36	0.17

Table 5. Fractional differences in values of deposition or integrated airborne activity within the drift for various locations down the P7 exhaust drift and at the Station A FAS sample inlet corresponding to the model simulations summarized in Table 3. Highlighted entries are results that meet model evaluation criteria.

V_d (cm/s)	Est. Release (Ci)	Fractional Difference in Activity Deposited		Fractional Reduction in Measured Airborne Activity		
		D_1/D_6	D_1/D_7	C_{250}/C_0	C_{1250}/C_0	C_{4000}/C_0
Observed Data		**0.67**	**0.5**	**0.25 – 0.33**	**0.1 – 0.25**	**0.1 – 0.01**
Flow reduction to 5%; 1 minute release						
0.001	0.4	0.59	0.32	1.3	0.79	0.71
0.01	0.7	0.59	0.33	1.2	0.70	0.46
Flow reduction to 5%; 3 minute release						
0.001	0.3	0.68	0.9	1.2	0.66	0.54
0.01	0.5	0.67	0.89	1.1	0.58	0.34
Flow reduction to 5%; 6 minute release						
0.001	0.4	0.63	0.45	1.1	0.55	0.44
0.01	0.8	0.61	0.43	1.0	0.48	0.27
Flow reduction to 5%;10 minute release						
0.001	0.6	0.53	0.2	0.95	0.46	0.36
0.01	1.1	0.51	0.19	0.87	0.40	0.22

Table 6. Fractional differences in values of deposition or integrated airborne activity within the drift for various locations down the P7 exhaust drift and at the Station A FAS sample inlet corresponding to the model simulations summarized in Table 4. Highlighted entries are results that meet model evaluation criteria.

Results

Results summarized in Tables 3-6 suggest the following characteristics of a Room 7 release:

- Activity detected by the P7 CAM prior to failure (i.e., 74 mCi) requires a release from Room 7 of at least 0.2 Ci.
- Source terms exceeding 1.5 Ci are possible only if CAM-151 sampled less than one-fourth of the total release exhausted through Panel 7 and actual deposition rates in the Panel 7 exhaust drift were much higher than those suggested by subsequent sample data, (i.e., much lower values for D_1/D_6 and D_1/D_7.)
- In general, scaled release amounts between 0.3 Ci and 0.7 Ci for scenarios with deposition values of 0.001 to 0.01 and release durations of 3-6 minutes appear to provide the best overall agreement with the evaluation criteria.
- Data from the 1998 WIPP study of deposition for Pu compounds released into the underground ventilation exhaust system do not appear to provide a good representation of the P7R7 release, which was primarily Am-241.

Evaluation of Waste Drum Release Fractions

The final step in the analysis was to determine the likelihood that the estimated source term emerging from R7 was due to a single waste drum (i.e. the suspect drum 68660). Published release fractions used in design safety analysis for transuranic facilities subject to external events (DOE, 2007) were applied to estimate radiological inventories that could produce source terms (ST) from R7 in the range of 0.3 to 1.5 Ci. The basic algorithm used to derive the airborne source term from a waste container is given as:

$$ST = MAR \times DR \times ARF \times RF \times LPF \quad (5)$$

where,

MAR is the total activity inventory available to be acted upon by a given physical stress;
DR is the fraction of the MAR impacted by the event;
ARF is the fraction of activity impacted by the event that becomes airborne;
RF is the fraction of the total ARF that can be inhaled by humans; and,
LPF is the fraction of the RF that migrates through ventilation, etc. to be released to the atmosphere.

The quantity to be determined is MAR, so Eq. (5) becomes:

$$MAR = ST / DR \times ARF \times RF \times LPF \quad (6)$$

The recommended values for DR, ARF, and RF provided in DOE (2007) are taken from DOE Handbook, DOE-HDBK-3010-94 (DOE, 1994). For waste containers directly affected by a fire or combustion event, the recommended value for DR is 1 with values for ARF x RF ranging from 5E-4 to 1E-2. For this analysis, the LPF was assumed to be 1, i.e. there is no loss of contaminant inside Room 7 due to deposition or other factors. Anecdotal reports indicate limited radiological activity within the waste room beyond the immediate vicinity of the suspect drum suggesting most of the released aerosols may have been entrained in the ventilation flow through the room and transported into the Panel 7 drift; i.e., depositional loss within R7 was small. Improved estimates for an LPF value may be possible provided more sample data from inside the waste room becomes available.

Release fractions contained in DOE (1994) and DOE (2007) are based on available data for experiments conducted over a range of accident types and levels of accident stress. The recommended values were chosen to give 'reasonable bounding values' since they are often derived from a limited number of representative experiments that present highly variable results. Individual accidents could involve levels of stress beyond that which characterized the experimental data, and DOE (1994) acknowledges that extrapolation of values over a limited range may be valid. Possible increases to the ARF x RF values by a factor from 2 to 5 are recognized as reasonable. Given that waste drum 68660 has been shown by the DOE Technical Assistance Team (TAT) to have experienced an event characterized by significant overpressure with an attendant fire likely affecting much of the drum's contents, release fractions greater than published values are considered possible.

Estimates of MAR based on Eq. (5) for source terms ranging from 0.3 to 1.5 Ci are summarized in Table 7. Values of ARF x RF equal to the most conservative of the values from DOE (2007), i.e., equal to 0.01 or less, would likely require multiple waste containers within Room 7. The estimated total activity contained in drum 68660 was estimated to be 9 Ci (Giaquinto, 2014). For a release limited to 68660, airborne release fractions as high as 5 to 10, and possibly as high as 20 times the most conservative published value would be required. In other words, between 5 and at most 20 percent of the total radioactivity in the drum would have been ejected from the drum in the form of suspended, respirable aerosols (aerosol diameter less than 10 microns).

Source Term (Ci)	**Affected Inventory (MAR), in Ci**			
	ARF x RF = 0.01	ARF x RF = 0.05	ARF x RF = 0.1	ARF x RF = 0.2
0.3	30	6	3	1.5
0.7	70	14	7	3.5
1.5	150	30	15	7.5

Table 7. Estimated values of material at risk (MAR) for various values of source term and release fractions.

6.0 Conclusions

The airborne fraction of the February 14, 2014 release of radioactivity from P7R7 was characterized by modeling the transport, dilution, and deposition of the material through the WIPP underground ventilation exhaust system and comparing model results to available data. Model simulations using the EPA's RISK indoor air quality model were generated for combinations of release times from R7 of 1, 3, 6, 10, 15, and 60 minutes, WIPP post-event ventilation flow reductions of 5% and 15% of normal flows, and radioactivity deposition velocities of 0.001, 0.01, 0.05, 0.1, and 0.25 cm/s. Scaled results from each of the modeling scenarios were subsequently evaluated with respect to air sample data collected from the continuous air monitor (CAM) located at the end of the P7 exhaust drift, additional radiological samples taken from P7 drift surfaces following the event, and results from a 1998 experimental study of the transport and fate of particulate releases from a WIPP waste room (P1R7).

Overall, the best agreement between model results and data-based evaluation criteria was obtained for an airborne release from R7 of between 0.3 Ci and 0.7 Ci, relatively low deposition velocities of 0.001 to 0.01 cm/s, and release durations of 3-6 minutes. Using published guidance on release fractions for waste containers applicable to design safety analysis for transuranic facilities subject to external events (DOE, 2007), a release of between 5 to at most 20 percent of the total radioactive inventory in the waste drum (68660) suspected to have produced the event would have been ejected from the drum in the form of suspended, respirable aerosols (aerosol diameter less than 10 microns).

Due to several significant uncertainties, the results are expressed as a relatively broad range of estimates. Monitoring data available from the P7 CAM was substantially incomplete and this limitation required imposing practical extrapolations on the magnitude and duration of monitoring results to establish some reasonable upper bound on the possible R7 source term. Furthermore, a thorough characterization of the physical properties of the airborne material released from R7, e.g., a particle size distribution, chemical form of the Am-241, etc., were not available. Previous experimental data on particulate deposition within WIPP was based on Pu releases; however, Am-241 likely interacts differently with the salt surfaces present along the transport path than the Pu forms studied. Representative sampling of the drift walls for contamination after the event also was limited. Finally, modeling of the release assumed well behaved flows during and after the ventilation system was placed in filtration mode. However, data from flow monitor V10 show some oscillation in the flows over the period of a few minutes before the flows became steady at the filtration rate. Contamination found in the Panel 7 drift upstream of ventilation flow suggests that a flow reversal may have occurred. A temporary flow reversal within Panel 7 could be the result of the heat generated locally by the fire in Room 7 or more generally from the underground ventilation system adjusting to the sudden switch to filtration flows.

7.0 References

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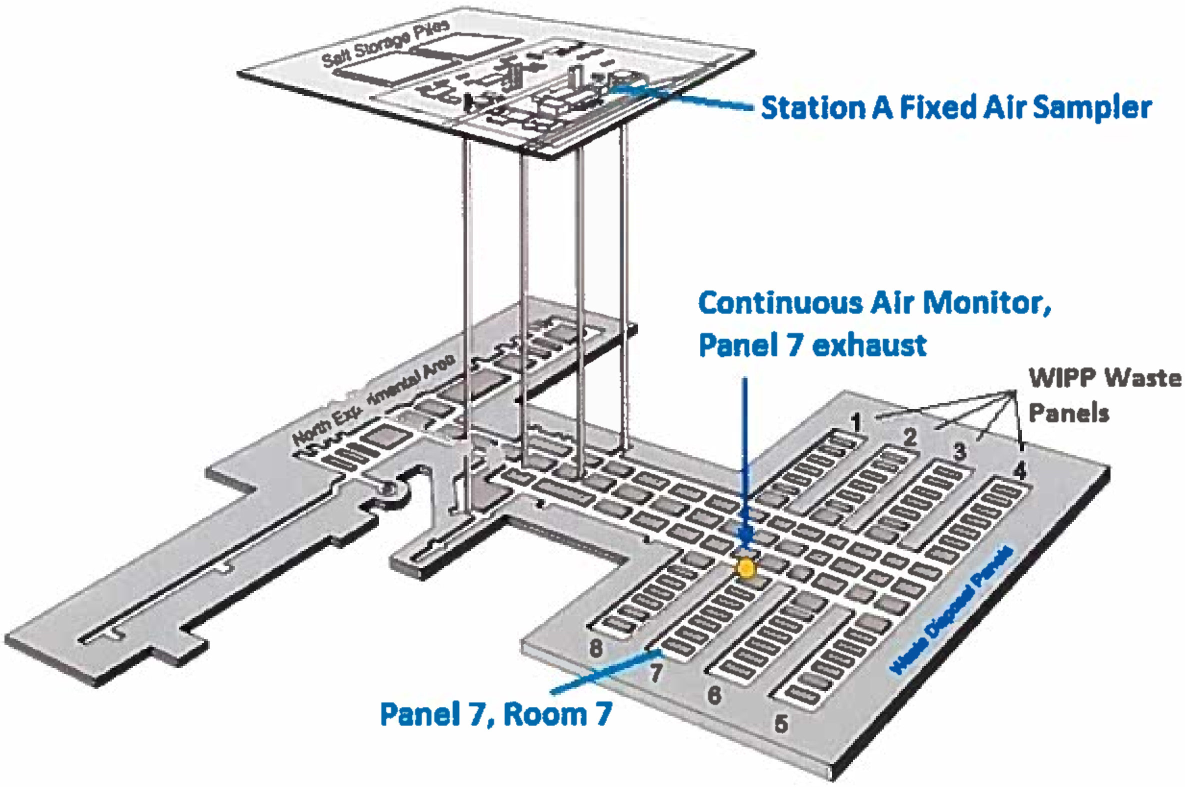

Figure 1. Map of the WIPP Facility, with the locations of P7R7 and pertinent air samplers noted.

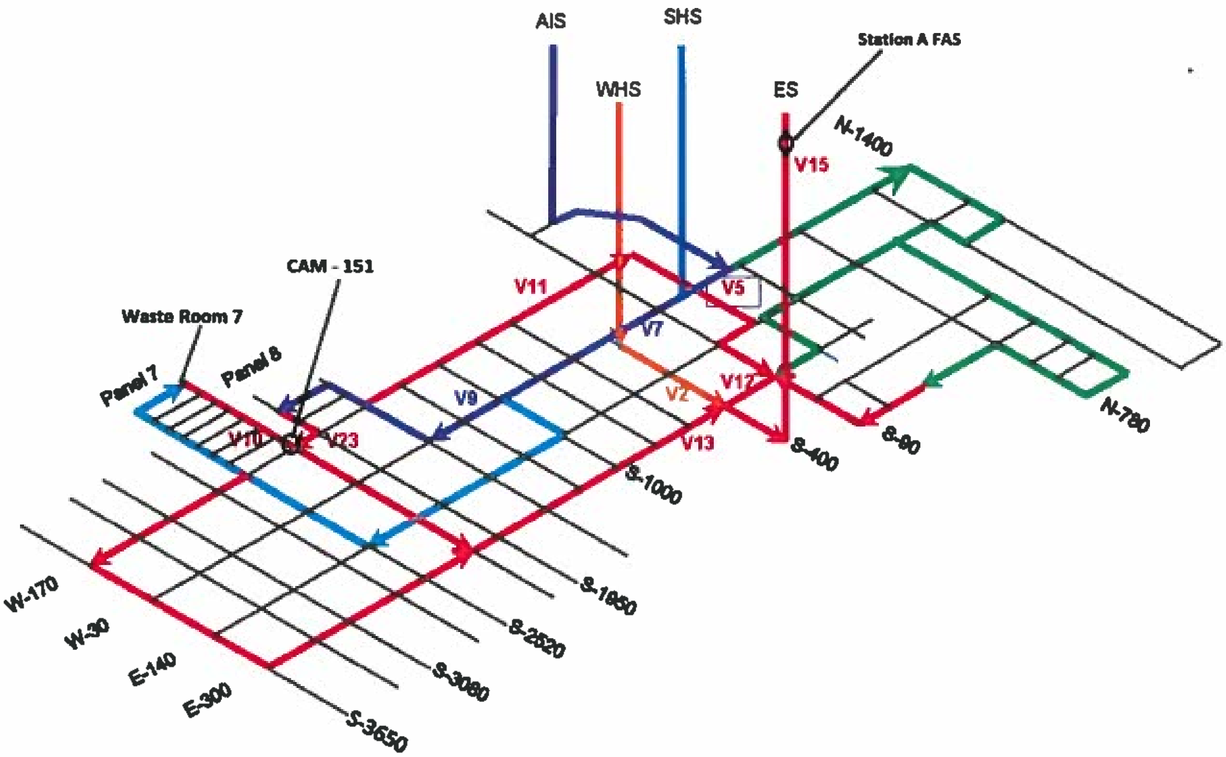

Figure 2. Layout of the WIPP underground depicting the exhaust flow path to the release stack (ES). Locations of Room 7 in Panel 7, CAM-151 and the Station A FAS are noted.

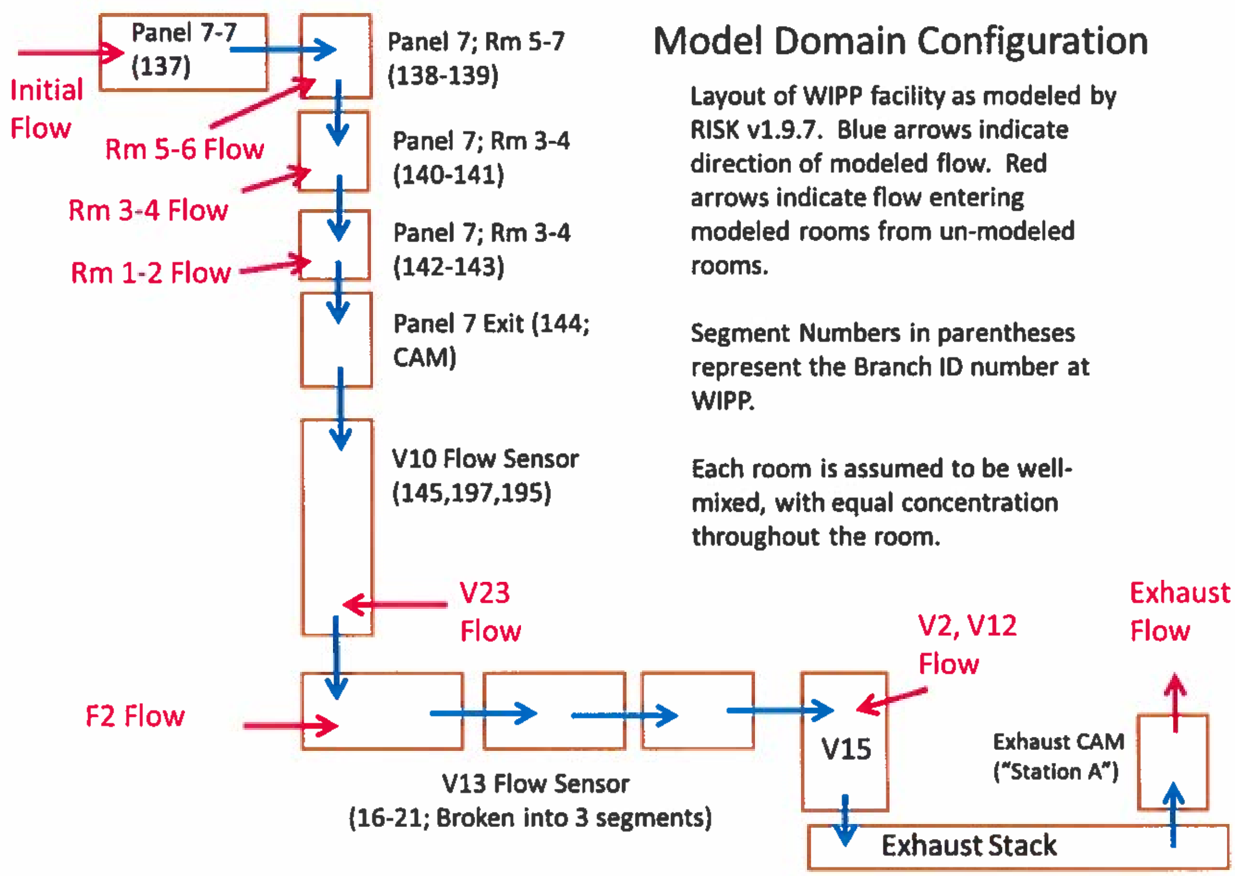

Figure 3: Description of RISK model domain. Each box represents a modeled room and arrows represent the direction of flow. Flow from un-modeled rooms was based on measurements in the WIPP facility or estimates provided for modeling purposes.