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**Toxic Vapor Cloud Impacts From
Accidental Releases of Anhydrous
Ammonia and Nitrogen Dioxide at
the ICPP NO_x Abatement Facility**

Michael L. Abbott

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**TOXIC VAPOR CLOUD IMPACTS FROM
ACCIDENTAL RELEASES OF ANHYDROUS
AMMONIA AND NITROGEN DIOXIDE AT
THE ICPP NO_x ABATEMENT FACILITY**

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Published April 1992

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ABSTRACT

This report evaluates potential atmospheric and human health impacts that may result from accidental releases of anhydrous ammonia and nitrogen dioxide at the Idaho Chemical Processing Plant (ICPP) NO_x Abatement Facility. Excess process gas releases are evaluated using a traditional Gaussian puff model. Dense two-phase aerosol releases from an 18,000 gallon liquified ammonia storage tank and a 6,000 gallon tanker truck accident are evaluated using the refined vapor dispersion model, SLAB. The SLAB results are also compared to those using the neutral-buoyancy puff model. A SLAB sensitivity analysis is presented which examines various combinations of ambient temperatures and wind speeds in order to determine worst-case downwind air concentrations. The results from the storage tank releases indicated that potentially serious ammonia concentrations (greater than 1000 ppm) could result at downwind distances ranging from 150 meters (relief valve malfunction) to approximately 3 kilometers (catastrophic tank failure). The tank failure scenario produced concentrations that could be rapidly fatal (greater than 5000 ppm) out to 1.3 kilometers. Under worst-case meteorological dispersion conditions, recognized exposure limits (IDLH, TLV-STEL) were exceeded for very large distances (greater than 15 kilometers).

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TOXIC VAPOR CLOUD IMPACTS FROM ACCIDENTAL RELEASES
OF ANHYDROUS AMMONIA AND NITROGEN DIOXIDE
AT THE ICPP NO_x ABATEMENT FACILITY

1.0 INTRODUCTION AND PURPOSE

This report evaluates potential human health impacts resulting from accidental atmospheric release of hazardous chemicals during operation of the proposed NO_x Abatement Facility (NAF) at the Idaho Chemical Processing Plant (ICPP). Six potential accidents involving releases of anhydrous ammonia (NH₃) and nitrogen dioxide (NO₂) are evaluated and downwind air concentrations are calculated using a Gaussian "Puff" model¹ and the refined vapor dispersion model, SLAB². Maximum ground-level concentrations are compared to the chemical's 15-min Short Term Exposure Limit (STEL) established by the American Conference of Governmental Industrial Hygienists (ACGIH)³ and human toxicity hazards are discussed.

2.0 METHODS

2.1 Identification of Accident Scenarios

Six accident scenarios that could occur during operation of the NAF were identified by ICPP project management^{4,5}:

1. NH₃ Valve Failure - excess process NH₃ gas from a 70 psig, 400-ft long, 1-in diameter underground pipeline is discharged to the 250-ft ICPP main stack.
2. NH₃ Slip - excess NH₃ gas is released to a cell and is then discharged out the 60-ft NAF stack. Potential release quantities are 10, 100, and 1000 ft³.

3. NO_x Process Line Break - a process line containing NO_x gas at a concentration of 33,000 ppm breaks in a cell. NO_x is discharged to the NAF 50-ft stack at rate of 2000 scfm for 5-min. In the stack, it mixes with 25,000 scfm of ventilation air.
4. NH₃ Storage Tank Relief Valve Malfunction - A pressure relief valve on one of the 18,000 gallon NH₃ tanks malfunctions and releases NH₃ to the atmosphere for 30 minutes prior to mitigation. The valve orifice is assumed to be 1-cm in diameter.
5. NH₃ Storage Tank Rupture - One of the 18,000 gallon tanks in the NH₃ storage area fails catastrophically. The entire contents of the tank are immediately released to the atmosphere.
6. NH₃ Tanker Truck Accident - A tanker truck loaded with 6000 gallons of NH₃ has a major accident enroute to ICPP. The entire contents of the tanker truck are immediately released to the atmosphere.

2.2 Air Dispersion Modeling

Downwind concentrations at ground-level were calculated for a 15-min averaging time for comparisons to the **TLV-STEL** (Threshold Limit Value-Short Term Exposure Limit) - a 15-minute time-weighted average exposure which should not be exceeded at any time during a work day³. For the larger NH₃ releases, concentrations are also compared to the **IDLH** (Immediately Dangerous to Life and Health) level. The IDLH is the maximum concentration from which, in the event of a respirator failure, one could escape within 30 minutes without experiencing any escape-impairing or irreversible health effects⁶. The 15-min average concentrations calculated in this analysis will be equal to or conservatively bound a 30-min average concentration, depending on the release duration and the downwind transport time. For NH₃, the STEL and IDLH values are 24 mg/m³ and 350 mg/m³, respectively (20°C). For NO₂, the values are 9.6 mg/m³ and 96 mg/m³.

2.2.1 Stack Gas Releases

2.2.1.1 Model Description. Accident scenarios 1 through 3 involve stack releases of pure or diluted vapors (no liquid droplet aerosol). Simple Gaussian plume or puff models¹ may be used to treat air dispersion of chemical vapors if the pure vapor density is similar to air (neutrally buoyant) or if a chemical is in a small enough concentration that it behaves as a "trace" gas (like air). The vapor density of NH_3 is 0.6 (air = 1); therefore, NH_3 gas is lighter than air and the pure vapor will quickly disperse into the atmosphere when released (assuming no aerosol formation). However, the stack gas releases evaluated in this assessment will be rapidly diluted with large quantities of ventilation air prior to release. Under these conditions, the NH_3 will likely exhibit neutral buoyancy, and a Gaussian "trace" gas model will provide a conservative estimate of ground-level concentrations. Although pure NO_2 gas is heavier than air (vapor density = 1.58), the NO_x /ventilation air *mixture* evaluated in this analysis was calculated to have a relative vapor density of 1.23. A gas mixture with a relative vapor density of less than 1.5 may be evaluated using a "trace" gas model⁷.

The NH_3 and NO_2 releases were estimated to occur over relatively short time intervals (less than the 15-min averaging time) and can therefore be modeled using the integrated form of the Gaussian "puff" equation¹:

$$\Psi(x,y,0) = \frac{Q}{\pi \sigma_y \sigma_z u} \text{EXP} \left[-\left(\frac{h^2}{2\sigma_z^2} \right) \right] \quad (1)$$

where

$\Psi(x,y)$ = integrated concentration of puff (mg-s/m³)

Q = total mass released (mg)

$\sigma_{y,z}$ = standard deviation of the puff in the y and z directions (m)

u = wind speed (m/s)

h = height of release (m)

The σ_y and σ_z values are taken from Kunkel⁸ for Pasquill-Gifford (P-G) stability category F (stable).

Worst-case (generic 95%) dispersion conditions at ICPP have generally been specified as stability class F and 2 m/s wind⁹. A more conservative 0.5 m/s wind speed has been specified for ground-level releases and downwind distances of less than 2 km to account for building drag effects. For these analyses, a 2 m/s wind speed is considered to be a reasonably conservative assumption.

For stack releases, equation (1) is not conservative for near-field receptors (within 0.5 to 2 km, depending on the stack height) because the plume will not reach the ground. For ICPP workers, fumigation conditions will generally result in much higher air concentrations. This meteorological phenomenon occurs when the nocturnal temperature inversion at the surface is being broken up by surface heating shortly after sunrise and usually lasts from 60 to 90 minutes.¹⁰ Fumigation limits vertical dispersion to the area between the ground and the base of the inversion layer. At the INEL, morning mixing heights associated with this inversion layer are estimated to occur at 100-m regardless of the season¹⁰. To simulate fumigation conditions for ICPP worker exposure, the following equation is used¹:

$$\chi_F(x,0) = \frac{Q}{(2\pi)^{0.5} u h_i \sigma_y} \quad (2)$$

where $\chi_F(x,0)$ = concentration at ground-level during fumigation (mg/m³)
 h_i = height of the inversion layer (m)

Although equation (2) is a steady-state plume equation, it may be used to calculate integrated puff concentration when "Q" is in total mass (mg).¹ A conservative procedure used at the INEL and specified by NRC for nuclear plant accidents¹¹ has been to set the height of the inversion layer (h_i) equal to the stack height.

The 15 minute average concentration (C_{avg}) was calculated by dividing the integrated puff concentrations in equations (1) and (2) by 900 seconds (t_{avg}):

$$C_{avg} (mg/m^3) = \frac{\psi (mg-s/m^3)}{t_{avg} (s)} \quad (3)$$

2.2.1.2 Model Parameters. For the stack releases (accident scenarios 1 through 3), a release mass (Q, in grams) was calculated using the following equations:

$$Q = nMW \text{ and } n = PV/RT \text{ (ideal gas equation)}$$

where

- n = amount of gas (moles)
- MW = gas molecular weight (g/mole)
- P = gas pressure (atm)
- V = gas volume (L)
- R = gas constant (0.0821 L atm mole⁻¹ °K⁻¹)
- T = gas temperature (°K)

The molecular weights of NH₃ and NO₂ are 17.03 g and 46.01 g, respectively. For the stack releases, the NH₃ and NO₂ vapors are assumed to equilibrate to an ambient stack temperature of 20°C. In this analysis, 100% of the NO_x is assumed to be NO₂.

NH₃ Valve Failure--The volume and mass of pure NH₃ in the pipe was calculated to be 62 L and 250 g, respectively. Using the ideal gas equation, and assuming the same temperature between the 1-in line and the stack, the 62 L of NH₃ in the 70 psig line will expand to 350 L once it is discharged to the stack:

$$V_s = P_i V_i / P_s$$

$$V_s = (5.6 \text{ atm})(61.8 \text{ L}) / 1 \text{ atm} = 350 \text{ L}$$

where

V_s = NH_3 volume in stack

P_i = NH_3 line pressure (70 psig+12.2 psia @ 5000 ft)(1 atm/14.7 psi) = 5.6 atm

V_i = NH_3 volume in line (62 L)

P_s = NH_3 pressure in stack (assumed = 1 atm)

For the initial screening calculations, this NH_3 volume was conservatively assumed to be released as a single "puff" at the top of the main stack (76.2-m high).

NH_3 Slip--For the initial screening calculations, only the bounding 1000 ft^3 release was evaluated. Assuming this volume is 100% NH_3 vapor at a cell pressure and temperature of 1 atm and 20°C, the total mass was calculated to be 2.0E+04 g NH_3 . For the initial screening calculations, the NH_3 was assumed to be released as a single "puff" at the top of the NAF stack 18.3 m high).

NO_x Process Line Break--Using the ideal gas equation, the 3.3% NO_x gas leak can be shown to be equal to a NO_x volume concentration of 6.3E+04 mg/m^3 at 20°C (the conversion reduces to: $\text{mg}/\text{m}^3 = \text{MW}/24.04 \times \text{volume fraction} \times 10^6$). The total NO_x /air mixture released to the NAF stack is 2000 $\text{ft}^3/\text{min} \times 5 \text{ min}$, or 1.0E+04 ft^3 (280 m^3).

The source term parameters for accidents 1 through 3 are summarized in Table 1.

Table 1. Accident scenario source term release parameters.

Accident	Gas Volume (L)	Gas Mass (g)	Gas Conc. (%)	Release Height (m)
NH ₃ valve failure	350 L	250	100	76.2
NH ₃ slip	2.8E+04 ^a	2.0E+04	100	18.3
NO _x line break	2.8E+05 ^b	1.8E+04	3.3	18.3

a. For initial screening calculations, only bounding release 1000 ft³) evaluated.

b. NO₂ and air mix at 20°C.

2.2.2 Aerosolized NH₃ Releases

2.2.2.1 Model Description. Accident scenarios 4 through 6 involve releases of a pressurized liquified gas (NH₃) with a boiling point (-33°C) that is less than ambient temperatures. Under these conditions, a 2-phase aerosol cloud composed of NH₃ gas and suspended liquid NH₃ droplets will form¹². The resulting cloud will remain very cold during downwind transport as the latent heat of vaporization is transferred from the surrounding air to the NH₃ droplets. This will result in initial dense gas behavior (gravity slumping) which cannot be simulated using a Gaussian "trace" gas model.

The SLAB² model is one of several refined air toxics dispersion models¹² currently available that provides a more detailed treatment of the physical, chemical, and thermodynamic processes that may influence dispersion of chemical vapor clouds. SLAB simulates dispersion of denser-than-air gases, the thermodynamics of two-phase vapor-droplet formation and evaporation, the heating of cold clouds (e.g. NH₃) at the ground surface, and includes lofting of the cloud if it becomes lighter-than-air. The model uses averaged forms of the conservation equations for mass, momentum, energy, and species to calculate spatially-averaged and time-averaged cloud properties for two different dispersion modes: steady-state plume and transient puff.

2.2.2.2 Model Parameters. The downwind dispersion of NH_3 calculated in SLAB is dependent upon chemical storage temperature and ambient air temperature, in addition to meteorological factors (stability class, wind speed). SLAB input parameters were therefore calculated for the lowest (-9°C , January) and the highest (20°C , July) average monthly temperatures at the INEL.¹⁰ Temperature-dependent release parameters include (Table 2):

- Tank storage pressure (P_{st})
- Initial liquid mass fraction (droplets) (CMEDO)
- Initial two-phase (vapor/droplet) cloud density (ρ_m)

Table 2. Temperature-dependent SLAB parameters calculated for 2-phase (vapor/droplet) releases of pressurized liquified NH_3 .

Month	Temp ($^\circ\text{C}$) ^a	P_{st} (atm)	CMEDO ^b	ρ_m (kg/m ³)
January	-9	2.9	0.924	11.22
July	20	8.2	0.833	5.18

a. INEL monthly average¹⁰

b. Mass fraction in the gas phase (F) = 1-CMEDO.

Tank storage pressures (P_{st}) were taken from the vapor pressure vs. temperature curve for NH_3 given in Matheson.¹³ The initial liquid mass fraction (CMEDO) and the mixture (vapor/droplet cloud) density (ρ_m , in kg/m³) are given by:²

$$CMEDO = 1 - c_p \frac{(T_s - T_b)}{L} \quad \text{and}$$

$$\rho_m = \frac{1}{(1 - CMEDO)/\rho_v + (CMEDO)/\rho_L}$$

where c_p = Liquid heat capacity at constant pressure (4294 J/(kg-°K))
 T_s = Temperature of source material (°K)
 T_b = Boiling point temperature of source material (239.72°K)
 L = Latent heat of vaporization (1370840 J/kg)
 ρ_v = Vapor density at the boiling point (0.87 kg/m³)
 ρ_L = Liquid density (682.9 kg/m³)

The values for the parameters listed above are taken from the SLAB User's Guide for anhydrous ammonia. The value for ρ_v (0.87 kg/m³) was calculated using:²

$$\rho_v = \frac{(MW)(P_a)}{(R_g)(T_b)}$$

where MW = Molecular weight of NH₃ (0.01703 kg)
 P_a = Ambient atmospheric pressure (101325 N/m²)
 R_g = Gas constant (8.31431 J/(mole-°K))
 T_b = Boiling point temperature of NH₃

Storage Tank Relief Valve Failure--This release was modeled as a "vertical jet" source type in SLAB. The NH₃ mass release rate from a 1-cm diameter (0.785 cm²) valve orifice was calculated using the equation for continuous relief valve discharges (two-phase flow) given in EPA-450/4-88-009:¹⁴

$$q_m = 0.76 A \sqrt{\rho_m P_{st}}$$

where q_m = total discharge rate for the liquid/vapor mixture (g/s)
 A = release area (cm²)
 ρ_m = mixture (vapor/droplet aerosol) density (g/cm³)
 P_{st} = tank storage pressure (dynes/cm²)

Using the values for ρ_m and P_{st} listed in Table 2, the January and July release rates were calculated to be **108 g/s** and **124 g/s**, respectively. Dividing by the aerosol densities (ρ_m), these mass release rates correspond to aerosol volume release rates of 9.6E-03 m³/s (20.4 ft³/min) during January and 2.4E-02 m³/s (50.7 ft³/min) during July.

NH₃ Storage Tank Rupture--This release was modeled as an "instantaneous" source type in SLAB. The total mass of one 18,000 gallon tank was calculated to be 44,230 kg using a conservative NH₃ liquid density of 40.43 lb/ft³ (20°F)^{xx}. The initial volume of the 2-phase cloud after expansion to 1 atm was calculated by dividing the release mass by the 2-phase mixture density (ρ_m , Table 2). For the January (-9°C) release, the initial volume was calculated to be 3940 m³. For the July (20°C) release, the initial volume was calculated to be 8540 m³. The release height was assumed to be 4-m, based on conceptual design drawings.

NH₃ Tanker Truck Accident--This release was also modeled as an "instantaneous" source type in SLAB. The total mass of the 6,000 gallon tanker truck was calculated to be 14,740 kg. The initial volume of the 2-phase cloud after expansion to 1 atm was calculated by dividing the release mass by the 2-phase mixture density (ρ_m , Table 2). For the January (-9°C) release, the initial volume was calculated to be 1310 m³. For the July (20°C) release, the initial volume was calculated to be 2850 m³. The release height was assumed to be 2-m.

2.2.2.3 SLAB Meteorological Input Parameters. SLAB runs were made using several combinations of ambient temperatures and wind speeds in order to determine worst-case (highest) potential downwind air concentrations (Appendix A). In contrast to traditional Gaussian models, *higher* wind speeds resulted in the higher site boundary concentrations.

Lower wind speeds allowed more time for the aerosol cloud to completely vaporize, resulting in lofting of the cloud at shorter downwind distances. Once the cloud begins to loft, ground-level air concentrations decrease rapidly (Appendix A). Likewise, higher ambient temperatures increased the rate of aerosol vaporization which also resulted in lofting of the cloud at shorter distances. Based on these observations, final SLAB runs were made using the following values for temperature and wind speed:

<u>Accident</u>	<u>Temperature (°C)</u>	<u>Wind Speed (m/s)</u>
Tank Rupture (Instant)	-9 (Jan)	1, 2, 4.2
Truck Accident (Instant)	-9 (Jan)	2, 4.2
Relief Valve (Vertical Jet)	-9 (Jan), 20 (July)	2, 4.2

The wind speeds chosen represent:

- 1 m/s: the lowest practical value that should be used in Gaussian models¹⁵
- 2 m/s: a generic worst-case value for site-boundary dispersion at the INEL⁹
- 4.2 m/s: the highest monthly average wind speed at the INEL (April)¹⁰

Other meteorological input parameters used in the SLAB runs are:

- Stability Class: F (stable)
- Surface roughness (ZO): 0.03 m (level desert)
- Relative humidity: 70% (February)

3.0 RESULTS

Ground level 15-min concentrations as a function of distance are shown in Figures 1 through 9. Inhalation health effects are taken from reference [16]. The results are summarized below.

NH₃ Valve Break. The maximum 15-min concentration at ground-level was calculated to be **0.15 mg/m³** at 100-m distance from the main stack. This is well below the TLV-STEL limit (24 mg/m³) and the lowest level at which minimal irritation effects has been observed (3.5 mg/m³ or 5 ppm).

Figure 1. 15-min average NH₃ concentrations at ground-level resulting from a valve break and release of 350 L of NH₃ gas to the ICPP main stack.

1000-ft³ NH₃ Slip. The maximum 15-min concentration at ground-level occurred under fumigation conditions and was calculated to be 51 mg/m³ (36 ppm) at 100-m distance from the NAF stack. At 250 m from the stack, the concentration fell below the STEL limit (24 mg/m³). Acute exposures in the concentration range from 9-50 ppm have been observed to cause nasal dryness, olfactory fatigue, and moderate irritation. Downwind concentrations resulting from NH₃ releases from 100 ft³ and 10 ft³ can be determined by dividing the results in Figure 2 by 10 and 100, respectively.

Figure 2. 15-min average NH₃ concentrations at ground-level resulting from an NH₃ slip and release of 1000 ft³ of NH₃ gas to the 18.3-m NAF stack.

NO_x Process Line Break. The maximum 15-min concentration at ground-level occurred under fumigation conditions and was calculated to be **36 mg/m³** (69 ppm) at 100-m distance from the NAF stack. At 450 m from the stack, the concentration fell below the STEL limit (9.6 mg/m³). The maximum concentration is below the level (100 ppm) that has been observed to cause serious health problems (pulmonary edema). Exposure to concentrations below 50 ppm may result in impaired pulmonary defense mechanisms.

Figure 3. 15-min average NO₂ concentrations at ground-level resulting from a NO_x process line break and release of NO₂ gas to the 18.3-m NAF stack.

Storage Tank Relief Valve Malfunction. The maximum 15-min ground-level concentration was $3,400 \text{ mg/m}^3$ and occurred at approximately 20-m from the tank (Figure 4). At 100-m, the concentration was $1,000 \text{ mg/m}^3$. The concentration decreased below the IDLH level at 300-m distance and below the STEL level at 1.5 to 2 km. Although concentrations from 1500 to 10,000 ppm (1060 to 7080 mg/m^3) may cause serious pulmonary health effects, the impacts from this release are not considered to be high risk due to the narrow width of the cloud (17-m effective half-width at 20-m). Individuals in the path of the plume would easily detect the pungent NH_3 odor and could readily escape. The maximum concentration at the site boundary (13.7 km) was 1 mg/m^3 (Figure 5).

Figure 4. Near-field NH₃ concentrations resulting from a tank relief valve malfunction.

Figure 5. Maximum 15-min NH₃ concentrations at the site boundary (13.7 km) resulting from a tank relief valve malfunction.

Storage Tank Rupture. The maximum 15-min ground-level concentration was approximately 100,000 mg/m³ and occurred at approximately 20-m from the tank (Figure 6). At 100-m, the concentration was 50,000 mg/m³. The maximum concentration at the site boundary (13.7 km) was 120 mg/m³ (Figure 7). The concentration decreased below the IDLH level at approximately 7 km and did not decrease below the STEL level for at least 18 km at wind speeds greater than 1 m/s. At a wind speed of 1 m/s, the aerosol cloud completely evaporated and lofted at approximately 10-km. Modeled concentrations beyond 14 km are very uncertain and likely overestimated due to the high probability that meteorological conditions will change before the cloud reaches those distances.

Gaussian "puff" model results for the same release mass and initial volume are also plotted in Figures 6 and 7. At close-in distances (less than 600-m), the puff model predictions are less than those calculated by SLAB. This is likely due to SLAB's ability to account for initial gravity slumping in the cold, dense NH₃ cloud. At longer distances (Figure 7), the puff model concentrations are greater than those calculated by SLAB.

These results indicate that potentially serious health impacts may occur within 3-km downwind of this release (concentrations range from 1000 to 100,000 mg/m³). Health effects from short-term exposures of 1500 to 10,000 ppm (1060 to 7080 mg/m³) include fatalities due to delayed pulmonary edema, bronchopneumonia, or asphyxiation due to spasms, inflammation, or edema of the larynx. Concentrations downwind that exceed 5000 ppm (3540 mg/m³) (approximately 1.3 km) may be rapidly fatal to those who are exposed to the cloud.¹³

Figure 6. Near-field NH₃ concentrations resulting from an 18,000 gallon storage tank rupture.

Figure 7. Maximum 15-min NH₃ concentrations at the site boundary (13.7 km) resulting from an 18,000 gallon storage tank rupture.

Tanker Truck Accident. The maximum 15-min ground-level concentration was approximately 25,000 mg/m³ immediately next to the release (Figure 8). At 100-m, the concentration was 15,000 mg/m³. The maximum concentration at the site boundary (13.7 km, assuming the accident occurs at ICPP) was 50 mg/m³ (Figure 9). The concentration decreased below the IDLH level at approximately 4 km and did not decrease below the STEL level until approximately 18 km. However, modeled concentrations beyond 14 km are very uncertain and likely overestimated due to the high probability that meteorological conditions will change before the cloud reaches those distances.

Gaussian "puff" model results for the same release mass and initial volume are also plotted in Figures 8 and 9. Again, the puff model predictions do not account for the sharp peak immediately next to the source and are higher than those predicted by SLAB at longer downwind distances.

These results indicate that potentially serious health impacts may occur within 1.5-km downwind of this release (concentrations range from 1000 to 25,000 mg/m³). Concentrations downwind that exceed 5000 ppm (3540 mg/m³) (approximately 500 m) may be rapidly fatal to those who are exposed to the cloud.

NH₃ - 14,740 kg Tanker Truck Accident Near-Field Concentrations

Figure 8. Near-field NH₃ concentrations resulting from a 6,000 gallon tanker truck accident.

Figure 9. Maximum 15-min NH₃ concentrations at the site boundary (13.7 km) resulting from a 6,000 gallon tanker truck accident.

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APPENDIX A
SLAB SENSITIVITY RUNS

NH₃ - 44,230 kg INSTANTANEOUS
Minimum Monthly Temperature (Jan, -9°C)

Figure A-1. SLAB maximum 15-min NH₃ concentrations at ground-level for various wind speeds and an ambient temperature of -9°C (lowest monthly average temperature at the INEL--January).

NH₃ - 44,230 kg INSTANTANEOUS
Annual Average Temperature (5.6°C)

Figure A-2. SLAB maximum 15-min NH₃ concentrations at ground-level for various wind speeds and an ambient temperature of 5.6°C (INEL annual average).

NH₃ - 44,230 kg INSTANTANEOUS
Maximum Monthly Temperature (July, 20C)

Figure A-3. SLAB maximum 15-min NH₃ concentrations at ground-level for various wind speeds and an ambient temperature of 20°C (highest monthly average temperature at the INEL--July).

Figure A-4. SLAB maximum 15-min NH₃ concentrations at ground-level for various monthly temperature averages at the INEL and at a wind speed of 1 m/s.

Figure A-5. SLAB maximum 15-min NH₃ concentrations at ground-level for various monthly temperature averages at the INEL and at a wind speed of 2 m/s.

Figure A-6. SLAB maximum 15-min NH₃ concentrations at ground-level for various monthly temperature averages at the INEL and at a wind speed of 3.4 m/s (annual average for INEL).

Figure A-7. SLAB maximum 15-min NH₃ concentrations at ground-level for various monthly temperature averages at the INEL and various wind speeds.

END

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