Mitigate the Hazards of Emergency Atmospheric Venting by Steam Injection

by

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SUMMARY

During major plant upsets, it is often necessary to safely relieve the process fluids contained in process equipment. The relieved vapors may be flammable and/or toxic, and the vapor clouds may be within the explosive range. There are several ways to control the hazards associated with the release of process fluids from process equipment. If process fluids are hazardous and environmentally persistent and if releases are common, then the cost of containment and treatment systems are usually justified. If process fluids are potentially hazardous, but not environmentally persistent, and if releases are rare, then atmospheric dispersion is not only less expensive, but also a wiser use of resources. However, if atmospheric dispersion is the disposal method of choice for vented vapors, then a brief quantitative consequence analysis should be conducted to assure safe venting.

Safe atmospheric dispersion can be achieved using very tall vents, but a much more practical approach is to inject steam into the vented vapors. This paper outlines a method to determine if atmospheric venting is safe. Where it is not, a method is described for the design of steam injection systems to achieve safe atmospheric dispersion of vapors vented from a pressure relief system. The consequence analysis method, the design method for steam injection, and the advantages of steam injection are then demonstrated with a practical example.

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INTRODUCTION

The chemical process industries and the petroleum production and refining industries use processes that release or transfer very large amounts of energy. Examples of processes, which release energy, are exothermic chemical reactions and high pressure let down systems. Examples of processes involving the transfer of large amounts of energy include those examples just given, along with numerous processes in which a lot of heat transfer occurs. Process upsets, such as external fire exposure to process equipment, can also result in high rates of uncontrolled transfer of thermal energy into process equipment. When a large amount of heat is transferred into a liquid, the liquid vaporizes, creating a volume of vapor that may be dozens of times greater than the original liquid volume. Process equipment seldom has holding capacity for these large volumes of vapor. Therefore, the equipment must either contain the vapor by compression to high pressures or the vapor must be vented to prevent excessive pressures from building up within the process equipment (Center for Chemical Process Safety, 1998; Edwards, et al., 1995). A typical process plant of the 20th century relies upon dozens to hundreds of pressure relief systems to prevent excessive overpressures. Without pressure relief systems to relieve pressurized gases and liquids, excessive overpressures could cause equipment to rupture when process upsets occur.

Gases and liquids relieved from pressure relief systems are usually first separated in a gas/liquid separator (Center for Chemical Process Safety, 1998; Edwards, et al., 1995). This is because liquids relieved from a process have a comparatively high density and small volume, and as such the liquid portion of the release can be easily contained or quenched. This is an important advantage, because the liquid portion of a typical two-phase release from a pressure relief system could be more than half of the mass released.

Conversely, the large volume of vented gases almost always requires that they be either treated or directly released to the atmosphere. The vented gases may be hazardous by virtue of toxicity and/or by virtue of flammability (Bravo, et al., 1997; Center for Chemical Process Safety, 1989, 1998; Ho, et al., 1998; Little and LeVine, 1988; Prugh and Johnson, 1988; Samdani, 1996). Direct atmospheric venting of flammable gases poses a number of potential hazards, including thermal radiation from an ignited release, engulfment in a fire ball, and vapor cloud explosion (Bodurtha, 1980; Center for Chemical Process Safety, 1989; Edwards, et al., 1995; Nolan, 1996). Delayed ignition of a vapor cloud allows wind to transport the cloud hundreds of feet from the source before a flash fire or a vapor cloud explosion might occur (Lees, 1996).

When process fluids must be released frequently, and when they are hazardous, then it is usually advisable to install containment and treatment systems to control the hazards (Center for Chemical Process Safety, 1998; Edwards, et al., 1995; Little and LeVine, 1988; Prugh and Johnson, 1988). This is particularly true when the process fluids contain environmentally persistent compounds.

However, in many cases there are processes that have never, or only rarely experienced a pressure relief event, and the process fluids are not environmentally persistent. In such a case, atmospheric venting of vapors relieved during emergency pressure relief can offer a safe and much less expensive approach. Use of the biodegradative capacity of the environment to dispose of rare pressure relief discharges of biodegradable compounds may be a prudent use of natural resources that has less environmental impact than the commitment of human and other natural resources to the creation of a large, costly, and seldom-used treatment system. This approach is somewhat analogous to the choice of natural attenuation (where it is the best choice) for remediation of contaminated soil and groundwater (Swett and Rapaport, 1998).

Whenever atmospheric venting of hazardous materials is contemplated, a simplified quantitative consequence analysis should be performed. This analysis should evaluate the potential effects, where applicable, of vapor cloud explosion, thermal radiation from continuous burning of the vented vapors, engulfment by a fire ball, and toxic gas exposure (Center for Chemical Process Safety, 1989; Edwards, et al., 1995; Prugh and Johnson, 1988). The components of the fluids to be relieved to the environment should also be evaluated for non-persistence in the environment. Unfortunately, the quantitative consequence analysis is often not done.

Methods for conducting a simplified quantitative consequence analysis are outlined here and illustrated with a practical example. Because the concentrations of heavy and hazardous organics may be high in relieved fluids, safe venting may require very high vent stacks…perhaps as high as several hundred feet above grade. This is because the heavy gases have densities that are higher than ambient air, so they tend to sink towards earth.

By use of steam injection, the relieved gas stream can be made more buoyant and less concentrated, and the gases may be vented at a higher velocity. All of these changes favor better dispersion. Despite these advantages, we have been unable to find any literature references to the use of steam injection to improve venting from pressure relief and pressure let down systems.

One potential drawback of steam injection is that the steam consumption and the instantaneous steam demand may result in additional relief valves lifting. Another potential disadvantage to steam injection is the possibility of partial condensation at high ratios of steam-to-vented hazardous gas, particularly during humid weather. With proper system design, these potential problems can be overcome.

Methods are presented for the design of steam injection systems to mitigate the hazards of pressure relief systems. The design methods are illustrated with a practical example.

METHODS TO CONDUCT A SIMPLIFIED QUANTITATIVE CONSEQUENCE ANALYSIS OF RELIEF VENTING

Fluids exiting a relief valve are subjected to mechanical shear. The greater the pressure differential between the process fluid and the atmosphere, the greater the shearing forces. If the fluid is a gas, the shearing action would translate into additional turbulence. If the fluid is a liquid, the shearing action may be sufficient to atomize all or part of the fluid, producing a mist, an aerosol.

When a large amount of volatile flammable material is rapidly dispersed to the atmosphere, a vapor cloud forms and disperses (Center for Chemical Process Safety, 1989). A lighter-than-air cloud will dissipate with little or no ground level impact. If, however, the vapor cloud is heavier than air, the cloud will fall to the ground before it can dissipate.

Vapor clouds contacting an ignition source, or possibly even static electricity if the conditions are favorable, can produce a deflagration. The deflagrations generally result in flash fires. A flash fire can also migrate back to the release point and ignite the vapor at the discharge of the relief valve tail pipe if the relieving conditions continue unmitigated.

Two important mechanisms for flame acceleration are thermal expansion and turbulence. Process structures contribute to partial confinement and turbulence, thus if many pieces of process equipment and many structures are present, it is likely that a flash fire will make the transition to a UVCE [Unconfined Vapor Cloud Explosion] (Center for Chemical Process Safety, 1989).

If the vapor cloud is toxic, plant personnel and civilian populations in the surrounding areas may be subjected to harmful concentrations of the material. Various exposure limits have been published for hazardous materials, including the Time Weighted Averages (TWA's) for exposures up to 10 hours in a workday during a 40-hour work week, the Short-Term Exposure Limit (STEL) for a 15 minute TWA exposure, and the Threshold Limit Values (TLV's) for 8 hour TWA concentrations. For exposures of brief duration, the STEL and the Immediately Dangerous to Life and Health (IDLH) concentrations for a 30 minute exposure have often been used. The Emergency Response Planning Committee of the American Industrial Hygiene Association has developed the Emergency Response Planning Guidelines (ERPG) levels 1, 2, and 3 for 100 hazardous chemicals (NIOSH Pocket Guide to Chemical Hazards, 1990; AIHA Emergency Response Planning Committee, 1999).

Aerosols containing large diameter particles or aerosols released in atmospheric conditions favorable for condensation may produce "rainout." Aerosol rainout can produce a liquid pool adjacent to the release point or some distance downwind, depending on the meteorological conditions. The liquid pool can absorb heat from the environment and vaporize, contributing to the initial vapor cloud or can continue producing a lower concentration cloud after the relief valve release has been mitigated. If the material is flammable, the liquid pool can be ignited and form a pool fire, subjecting personnel and equipment to thermal radiation.

The 1999 edition of the American Industrial Hygiene Association's (AIHA) Emergency Response Planning Guidelines lists ERPG-1, ERPG-2, and ERPG-3 concentrations for 100 hazardous materials. The current definitions of the ERPG levels are :

> ERPG-3: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.
>
> ERPG-2: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious adverse health effects or symptoms that could impair an individual's ability to take protective action.
>
> ERPG-1: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

When the EPA finalized its risk management program (RMP) rule, ERPG-2 values were identified as the toxic endpoints for offsite consequence analysis. The RMP rule also stipulates use of a 1.5 m/s wind speed and F atmospheric stability for the "worst case" scenario. The PHAST program can be setup to use 6 different wind speed/stability class combinations for each model run. The program also contains ERPG, IDLH and STEL concentrations for the toxic materials supplied with the program. The user can manually enter physical and chemical properties for additional materials as required.

To demonstrate the use of steam in mitigating potential ground level ERPG-2 impacts from relief valve discharges to the atmosphere, an example of a hazardous material release will be presented in the following sections. The results are shown for releases with and without steam injection, and using the PHAST input module as well as using input data from Aspen Plus (a process simulation package).

STEPS IN THE DESIGN OF A SAFE ATMOSPHERIC DISPERSION SYSTEM

The major steps in the design of a safe atmospheric dispersion system are outlined in Table 1.

Table 1 - Major steps in the design of a safe atmospheric dispersion system

- Evaluate the potential hazards of the current or proposed (for a new facility) atmospheric venting system
- If the existing system presents unacceptable atmospheric venting hazards, determine the feasibility of achieving safe venting by modifications to the existing vent system
- If reasonable changes in vent elevation and vent outlet size alone are insufficient, evaluate steam injection as a means to safe atmospheric venting

Subsequent sections of this paper describe these three major steps.

EVALUATE THE PROCESS HAZARDS OF THE CURRENT OR PROPOSED ATMOSPHERIC VENTING SYSTEM

Table 2 outlines the major steps in the evaluation of the consequences of atmospheric venting from a new pressure relief system (Center for Chemical Process Safety, 1989; Edwards, et al., 1995). There are many existing relief systems which vent hazardous fluids for which not all these steps have been followed. The adequacy of these systems can be evaluated by a similar procedure.

Likewise, the safety of atmospheric venting by existing or proposed pressure let down systems can be evaluated by an analogous method.

Table 2 - Steps in the analysis of the consequences of atmospheric venting from a new pressure relief system (Edwards, et al., 1995).

- Define credible relief scenarios for a pressure relief system.
- Size the relief valve orifice or the rupture disk diameter adequately to relieve the controlling relief scenario.
- Design inlet piping to relief device and outlet piping from relief device to atmosphere, including a vapor-liquid separation device if the relief system may be required to discharge liquids or two-phase, vapor-liquid mixtures.
- Assure that the proposed new system will vent at the minimum safe elevation for personnel protection from direct effects of the relief system discharge. (Typical criteria are that the vent outlet is at least ten feet above the nearest walk way or platform where personnel might be found.) Also be certain that noise insulation is provided where necessary.
- Conduct computer simulations of atmospheric dispersion for the major credible relief or blow down scenarios with the existing atmospheric venting system. Evaluate the following potential process hazards: (1) thermal radiation from a steady burning of the vented gases (2) hazards from a fireball caused by ignition of a vapor cloud (3) explosion overpressure from deflagration of a vapor cloud formed by atmospheric release (4) atmospheric dispersion of toxic gas.

IF THE EXISTING SYSTEM PRESENTS ATMOSPHERIC VENTING HAZARDS, DETERMINE THE FEASIBILITY OF ACHIEVING SAFE VENTING BY MODIFICATIONS TO THE EXISTING VENT SYSTEM

Table 3 summarizes the steps in evaluation of the feasibility of achieving safe atmospheric venting of relief discharges by modifications to a new or existing vent system. The steps in Table 3 should be followed when an existing or proposed new system has been found to create unacceptable hazards during pressure relief venting.

The best approach is to prevent relief venting. This may be feasible for many relief scenarios. For example, where pressure relief venting from a distillation column is caused by loss of condensing, instrumentation and controls can be provided to shut off steam to the reboiler of the column. Depending on the process dynamics of the controlled system, pressure relief venting will be either prevented completely or limited to a release of very brief duration. However, many relief scenarios exist which cannot be eliminated by instrumentation and control systems; examples include runaway reactions, external fire exposure, and some cases of failure of internal pressure boundaries. In those cases, refer to Table 3 as the next step in the development of a safe atmospheric venting system.

Because higher vent tip velocities give much higher plume rises for vented gases, the most rapid way to find the best venting conditions is to first determine the smallest vent tip diameter that will give acceptable pressure losses in the relief discharge piping, following the guidelines in Table 3. This assumes that the initial stack tip elevation is already high enough to avoid any adverse effects on personnel near the relief system when it discharges.

If using a small vent tip diameter with a conventional relief valve does not give adequate dispersion, then choose a balanced bellows relief valve (or consider buying a bellows conversion kit for an existing conventional relief valve). This will permit a further increase in the relief tip discharge velocity by use of a smaller vent tip, which in turn is allowed by the higher relief outlet piping pressure loss. If this maximum relief venting tip velocity still has not provided adequate atmospheric dispersion, then consider increases in stack tip elevation.

If a narrowed relief tip diameter and an elevated stack do not adequately mitigate relief venting, then steam injection should be considered. Methods to design for steam injection are outlined in the next section of this paper.

Table 3 - Steps towards achieving the safest atmospheric venting from a new or existing pressure relief system

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- Examine the root causes of the worst credible relief venting case to see if pressure relief venting can be prevented by controlling the source of energy that is powering the pressure relief event. Propose instrumentation and controls to prevent relief venting whenever that approach is practical. For cases that cannot be effectively prevented or mitigated by instrumentation and controls, proceed with the following steps.

- Using the appropriate consequence modeling software, predict the consequences of atmospheric venting if the vent stack outlet diameter is decreased. (Note that decreasing the tip diameter of the vent stack is usually much more effective in improving dispersion than increasing stack elevation.)

- The allowable pressure drop in the pressure relief outlet piping determines the minimum allowable tip diameter of the vent stack.

- For a pressure relief valve discharge, the allowable outlet pressure drop is ten percent of the set pressure (expressed as gage pressure) for conventional relief valves. For balanced bellows pressure relief valves, the allowable outlet pressure drop is typically about forty percent of the set pressure. (Determine the exact allowable for a given relief valve model by consultation with the relief valve manufacturer and reference to the manufacturer’s catalog.)

- For relief discharge through a burst rupture disk, the smallest allowable relief outlet diameter is determined by confirming that the relief piping, including the burst rupture disk, will permit the required maximum credible relieving flow through the relief system without exceeding the maximum allowable overpressure in the protected equipment.

- To optimize atmospheric venting at a given stack elevation, consider using outlet relief piping that is one line size larger than necessary up to the outlet tip of the relief system. This maximizes the allowable pressure loss across the outlet, therefore minimizing the outlet tip diameter and maximizing the outlet velocity and plume rise.

- The relief outlet piping tip should be gradually tapered from the upstream pipe diameter down to the outlet tip diameter to promote smooth flow and to maximize plume rise.

- If decreasing vent tip diameter does not result in adequate dispersion, then repeat dispersion calculations for higher stack tip elevations.

- If practical changes in vent elevation and vent outlet size alone are insufficient, evaluate steam injection as a means to safe atmospheric venting

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If a narrowed relief tip and an elevated stack adequately mitigate the worst credible relief case, then consequence analysis calculations should also be conducted for lower venting rates associated with other credible relief cases. This is because the lower relief tip velocities may give less effective dispersion for lower venting rates.

IF CHANGES IN VENT ELEVATION AND VENT OUTLET SIZE ALONE ARE INSUFFICIENT, EVALUATE STEAM INJECTION AS A MEANS TO ACHIEVE SAFE ATMOSPHERIC VENTING

If changes in vent outlet piping tip size and in vent tip elevation alone do not mitigate pressure relief discharges adequately, then steam injection should be considered (Table 4). Steam injection provides the following benefits:

- Dilutes vented organics
- Almost always decreases molecular weight and density of vented stream
- Often increases temperature of vented stream, thereby decreasing density further
- May decrease risk of condensation of vented vapors
- Increases tip velocity in outlet of relief piping, thereby increasing plume rise

Although no credit is taken for this effect, a properly designed steam injection system, using high velocity steam injection directed upward near the outlet of the relief piping may help to act like an ejector to give an even higher vent velocity, better plume rise and atmospheric dispersion.

Figure 1 is a schematic outline of a typical steam injection system. Steam is supplied to the relief outlet piping through a control valve. The control valve is opened by the flow controller, FC, whenever a high pressure is sensed either in the relief outlet piping by pressure switch (or pressure transmitter), PS1, or in the protected vessel by pressure switch (or pressure transmitter), PS2. The vent tip of the relief outlet piping is pointed vertically upward and is tapered to give the maximum exit velocity. The steam is injected vertically along the centerline of the relief outlet piping.

The use of redundant pressure sensors, in conjunction with a control strategy that turns on steam when either sensor detects a high pressure, increases the reliability of the steam injection system. More importantly, using independent pressure sensors at two different process locations improves functionality. Pressure sensor PS1 in the relief outlet piping insures that steam will be injected into the relief system discharge whenever the relief device is venting to the atmosphere. In that way, steam will be injected when venting is occurring during abnormal conditions. For example, if the spring in the relief valve breaks during pressure relief, or if the blowdown setting on the relief valve is incorrect, the relief valve may not reclose at the intended pressure. PS1 insures that steam injection will continue as long as relief venting is occurring, despite a column pressure below the setting where PS2 would indicate to FC to stop steam injection.

Pressure sensor PS2, which senses column pressure, will start steam injection just before the relief valve opens. This alerts personnel in the vicinity that pressure relief is about to begin, so that they can leave the area. It also begins to establish an upward flow of air in the vicinity of the vent tip before relief venting of hazardous vapors begins. This updraft should improve dispersion of the hazardous vapors during the initial period of relief venting.

Table 4 - Steps in the Design of a Steam Injection System to Mitigate Hazardous Pressure Relief Discharges

- If changes in vent elevation and vent outlet size alone are insufficient, evaluate steam injection as a means to safe atmospheric venting
- Calculate the minimum steam injection rate that will decrease the density of the vented mixture of injected steam plus the relieved hazardous gas to a value less than the density of ambient air. Call this steam rate Sr.
- Compute the temperature, pressure, and composition of the vented mixture of injected steam plus relieved gas for several steam rates varying from no steam to 1.5 Sr. Correct use of a process simulator makes these calculations simple and accurate.
- Conduct a quantitative consequence analysis for each of the vented mixtures from the previous step. Begin at the lowest steam rate. Stop when a steam rate is found that effectively mitigates the release.
- Recalculate the total pressure losses in the relief outlet piping. Note that total gas flow rate upstream of the steam piping entry point = (relief rate of hazardous gas), while total gas flow rate downstream of the steam piping entry point = [(relief rate of hazardous gas) + (steam injection rate)].
- If total pressure losses in relief outlet piping are unacceptably high, modify tip diameter (and also outlet piping diameter if necessary) to achieve acceptably low pressure losses. Increase steam injection rate if necessary to achieve acceptable risk reduction if required by larger tip diameter of relief outlet piping.

EXAMPLE OF A PRACTICAL APPLICATION OF STEAM INJECTION TO ACHIEVE SAFE ATMOSPHERIC DISPERSION

Description of example system

The use of steam injection to achieve safe and effective mitigation of an atmospheric release will be illustrated here with an example. The example chosen is a distillation column of moderate size that is used to purify Component A. Table 5 summarizes the characteristics of the pressure relief venting system and Component A. Table 6 lists the various credible pressure relief events which could lead to atmospheric releases. Because the mixture within the column only contains small amounts of impurities, the mixture vented from the pressure relief events is modeled as pure Component A.

Table 5 - Characteristics of Component A and of the Purification Column:

Molecular weight of Component A = A specific number between 70 and 90

Lower flammable limit = A specific number between 2 and 3 volume %

Upper flammable limit = A specific number between 10 and 14 volume %

ERPG 1 = 5 ppm; ERPG 2 = 75 ppm. ERPG 3 = 500 ppm (by volume)
(Based on 60 minute exposure time)

Set pressure of purification column relief valve = 20 psig

Vent tip elevation = 135 feet, pointed vertically

Vent tip diameter = 12 inches

Maximum allowable pressure drop in relief discharge piping = 8 psig
(40 percent of set pressure for balanced bellow relief valve)

Table 6 - Credible Overpressure Scenarios for Purification Column

Scenario	Relieving Flow Rate (pounds per hour)	Components of Relieved Fluid	Relief pressure in column A1 (psig)
Loss of condensing	160,000	Component A	22
External fire exposure	12,000	Component A	24
Reboiler tube rupture	13,200	Component A plus steam	22
Steam cleaning by water boil-up: loss of condensing	8,500	Steam	22

Consequence modeling approach used in example

Consequence modeling was initially done using Version 5.11 of a widely used commercial program called PHAST (Process Hazards Analysis Software Tool), marketed by DNV Technica. Most of the recent modeling work has been done with a more recent version, 5.22. The conclusions are significantly different; therefore, a few of the earlier results are presented to illustrate the differences. These differences will be discussed in a later section of this paper. The PHAST program provides quantitative estimates of a variety of potential adverse consequences of the release of a flammable and toxic compound.

Table 7 summarizes some of the relief scenarios modeled in this study. Results are also summarized in the table for the case of F-type atmospheric stability and a wind speed of 1.5 m/sec. These conditions are the same as those required to be modeled for purposes of preparing risk management plans under the US EPA's Risk Management Program.

The F stability atmosphere is considered moderately stable conditions, with minimum turbulence and with the air stratified near the ground. F stability is commonly found during calm nighttime conditions with little or no cloud cover. This type of atmospheric stability rarely occurs near small islands or near offshore installations. The F stability conditions modeled here are relatively unfavorable for atmospheric dispersion and are treated in this example as a worst credible atmospheric condition for purposes of designing the mitigation system.

Other choices (for example, D type atmospheric stability and a wind speed of 1.0 m/sec) are possible and would give somewhat different results. The D stability atmosphere is considered neutral, with no thermal or vertical mixing currents produced by solar heating during windy daytime conditions. This stability can also be typical of nighttime conditions with overcast or low level cloudiness.

Wind speed also has a strong effect on dispersion. For an example, see Table 7 for D type stability and wind speeds of 1, 5, 10, and 20 meters per second.

Table 7 - Summary of Relief Scenarios Modeled in This Study, Along with Key Results Using PHAST 5.11

(Results presented for D & F type atmospheric stability and various wind speeds)

Table 7.1

CASE DESCRIPTION Loss of Condensing With No Steam Injection

PHAST version 5.11 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
OA	**Toxic**											
	Conc of Interest	10	NA	42,610.0	NA	23,720.0	NA	14,390.0	NA	8,415.0	NA	143,500.0
	(1 ppm)	60	NA	36,270.0	NA	18,640.0	NA	11,280.0	NA	6,526.0	NA	119,600.0
	ERPG-1 (5 ppm)	60	NA	17,650.0	NA	6,325.0	NA	3,576.0	NA	2,358.0	NA	47,860.0
	ERPG-2 (75 ppm)	60	NA	3,113.0	NA	966.0	NA	758.3	NA	617.7	NA	5,520.0
	ERPG-3 (500 ppm)	60	NA	584.5	NA	298.7	NA	282.6	NA	295.8	NA	766.7
	Combustible											
	BLEVE / Fireball	--	NA	NI	NA	NI	NA	NI	NA	NI	NA	NI
	Jet Flame											
	4.0 kW/sq m	--	NA	NR	NA	NR	NA	125.20	NA	159.10	NA	NR
	12.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	37.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	Flash Fire	--	NA	31.65	NA	62.54	NA	90.97	NA	139.20	NA	47.80
	Late Ignition Explosion											
	0.3 psig	--	NA	NR	NA	197.10	NA	252.90	NA	313.10	NA	185.10
	2.0 psig	--	NA	NR	NA	97.39	NA	132.90	NA	184.20	NA	83.35
	3.0 psig	--	NA	NR	NA	89.50	NA	123.40	NA	174.10	NA	75.31

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted explosive impacts resulting from the release of 160,000 pph Component A.

Table 7.2

CASE DESCRIPTION Loss of Condensing With 16,000 pph Steam Injection

PHAST version 5.11 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
OAS	**Toxic**											
	Conc of Interest	10	NA	41,850.0	NA	23,130.0	NA	14,000.0	NA	8,084.0	NA	91,260.0
	(1 ppm)	60	NA	35,570.0	NA	18,120.0	NA	10,930.0	NA	6,236.0	NA	68,290.0
	ERPG-1 (5 ppm)	60	NA	17,120.0	NA	6,005.0	NA	3,360.0	NA	2,152.0	NA	20,210
	ERPG-2 (75 ppm)	60	NA	2,710.0	NA	904.4	NA	625.2	NA	447.5	NA	3,086.0
	ERPG-3 (500 ppm)	60	NA	531.9	NA	263.6	NA	207.9	NA	164.6	NA	771.2
	Combustible											
	BLEVE / Fireball	--	NA	NI	NA	NI	NA	NI	NA	NI	NA	NI
	Jet Flame											
	4.0 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	141.00	NA	NR
	12.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	37.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	Flash Fire	--	NA	38.58	NA	41.78	NA	41.87	NA	44.20	NA	59.98
	Late Ignition Explosion											
	0.3 psig	--	NA	NR	NA	113.20	NA	125.10	NA	130.40	NA	192.90
	2.0 psig	--	NA	NR	NA	60.28	NA	63.43	NA	66.53	NA	94.41
	3.0 psig	--	NA	NR	NA	56.09	NA	58.55	NA	61.48	NA	86.62

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted explosive impacts resulting from the release of 160,000 pph Component A + 16,000 pph Steam with the User Input module using Aspen Plus data.

Table 8 - Summary of Relief Scenarios Modeled in This Study, Along with Key Results Using PHAST 5.22

(Results presented for D & F type atmospheric stability and various wind speeds)

Table 8.1

CASE DESCRIPTION Loss of Condensing With No Steam Injection

PHAST version 5.22 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
1A & 3A	**Toxic**											
	Conc of Interest	10	96,820.0	97,660.0	54,060.0	54,630.0	32,300.0	32,530.0	19,300.0	19,400.0	>164,000.0	>164,000.0
	(1 ppm)	60	81,110.0	81,900.0	42,030.0	42,430.0	25,180.0	25,380.0	14,990.0	15,080.0	>164,000.0	>164,000.0
	ERPG-1 (5 ppm)	60	36,410.0	37,030.0	14,070.0	14,260.0	8,191.0	8,299.0	4,655.0	4,706.0	115,400.0	119,800.0
	ERPG-2 (75 ppm)	60	4,490.0	4,857.0	1,908.0	1,910.0	1,250.0	1,266.0	1,044.0	1,045.0	12,020.0	12,990.0
	ERPG-3 (500 ppm)	60	1,080.0	1,179.0	587.7	565.8	391.1	405.5	435.3	450.2	1,230.0	1,635.00
	Combustible											
	BLEVE / Fireball	--	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Jet Flame											
	4.0 kW/sq m	--	NR	NR	NR	NR	116.7	125.2	143.6	159.1	NR	NR
	12.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	37.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Flash Fire	--	22.76	28.40	44.11	55.04	64.63	81.70	102.00	130.30	34.27	41.04
	Late Ignition Explosion											
	0.3 psig	--	NH	NH	NH	NH	NH	NH	NH	190.70	NH	NH
	2.0 psig	--	NH	NH	NH	NH	NH	NH	NH	146.00	NH	NH
	3.0 psig	--	NH	NH	NH	NH	NH	NH	NH	142.40	NH	NH

NI = None Indicated

NR = Not Reached

NH = No Hazard

The model predicted explosive impacts resulting from the release of 160,000 pph Component A with the
User Input module using Aspen Plus data for a wind speed of 20.0 m/s; F Stability Class.

Table 8.2

CASE DESCRIPTION Loss of Condensing With 16,000 pph Steam Injection

PHAST version 5.22 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
1AS & 3AS	**Toxic**											
	Conc of Interest	10	94,530.0	94,670.0	53,760.0	53,560.0	32,000.0	32,140.0	18,800.0	18,850.0	>164,000.0	>164,000.0
	(1 ppm)	60	78,960.0	79,100.0	41,770.0	41,590.0	24,900.0	25,020.0	14,530.0	14,580.0	>164,000.0	>164,000.0
	ERPG-1 (5 ppm)	60	34,760.0	34,880.0	13,840.0	13,720.0	7,982.0	8,043.0	4,353.0	4,370.0	109,500.0	110,800.0
	ERPG-2 (75 ppm)	60	3,523.0	3,559.0	1,839.0	1,739.0	1,203.0	1,214.0	851.5	855.9	10,930.0	11,180.0
	ERPG-3 (500 ppm)	60	755.3	794.3	593.7	509.8	355.9	362.6	262.4	266.1	1,025.0	1,109.0
	Combustible											
	BLEVE / Fireball	--	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Jet Flame											
	4.0 kW/sq m	--	NR	NR	NR	NR	NR	NR	135.8	141.0	NR	NR
	12.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	37.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Flash Fire	--	13.48	15.08	28.55	31.45	38.95	43.51	44.57	47.08	21.47	23.59
	Late Ignition Explosion											
	0.3 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	2.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	3.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted no explosive impacts resulting from the release of 160,000 pph Component A + 16,000 pph Steam.

Table 8.3

CASE DESCRIPTION Loss of Condensing With 24,000 pph Steam Injection

PHAST version 5.22 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
1AS & 3AS	**Toxic**											
	Conc of Interest	10	NA	93,330.0	NA	53,200.0	NA	31,860.0	NA	18,720.0	NA	109,300.0
	(1 ppm)	60	NA	77,830.0	NA	41,290.0	NA	24,790.0	NA	14,460.0	NA	88,680.0
	ERPG-1 (5 ppm)	60	NA	33,870.0	NA	13,590.0	NA	7,927.0	NA	4,329.0	NA	48,610.0
	ERPG-2 (75 ppm)	60	NA	3,270.0	NA	1,794.0	NA	1,238.0	NA	845.7	NA	7,480.0
	ERPG-3 (500 ppm)	60	NA	813.2	NA	574.6	NA	391.3	NA	258.5	NA	2,151.0
	Combustible											
	BLEVE / Fireball	--	NA	NI	NA	NI	NA	NI	NA	NI	NA	NI
	Jet Flame											
	4.0 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	129.0	NA	NR
	12.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	37.5 kW/sq m	--	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR
	Flash Fire	--	NA	11.98	NA	25.17	NA	34.82	NA	42.29	NA	19.28
	Late Ignition Explosion											
	0.3 psig	--	NA	NH	NA	NH	NA	NH	NA	NH	NA	NH
	2.0 psig	--	NA	NH	NA	NH	NA	NH	NA	NH	NA	NH
	3.0 psig	--	NA	NH	NA	NH	NA	NH	NA	NH	NA	NH

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted no explosive impacts resulting from the release of 160,000 pph Component A + 24,000 pph Steam.
Loss of Condensing case can be eliminated by installation of an interlock to shutoff steam to the calandria on detection of high column base pressures.

Table 8.4

CASE DESCRIPTION Fire Case With No Steam Injection

PHAST version 5.22 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)		Distance (in Feet)	
			Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input	Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
2A & 4A	**Toxic**											
	Conc of Interest	10	28,660.0	29,590.0	9,730.0	10,430.0	5,678.0	6,048.0	3,215.0	3,444.0	93,010.0	100,500.0
	(1 ppm)	60	22,560.0	23,410.0	7,670.0	8,315.0	4,372.0	4,726.0	2,591.0	2,797.0	71,030.0	77,180.0
	ERPG-1 (5 ppm)	60	7,739.0	8,356.0	2,475.0	2,936.0	1,488.0	1,644.0	1,092.0	1,278.0	22,060.0	24,880.0
	ERPG-2 (75 ppm)	60	1,065.0	1,253.0	426.9	587.6	349.1	483.7	333.0	462.6	2,706.0	3,562.0
	ERPG-3 (500 ppm)	60	307.1	407.5	152.7	281.7	163.0	286.2	195.6	335.9	391.8	508.1
	Combustible											
	BLEVE / Fireball	--	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Jet Flame											
	4.0 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	12.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	37.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Flash Fire	--	12.61	41.70	27.30	113.70	42.31	140.20	88.38	143.80	18.23	72.99
	Late Ignition Explosion											
	0.3 psig	--	NH	NH	NH	206.9	NH	218.6	NH	201.2	NH	149.4
	2.0 psig	--	NH	NH	NH	137.9	NH	160.5	NH	158.6	NH	92.77
	3.0 psig	--	NH	NH	NH	132.4	NH	155.9	NH	155.3	NH	88.29

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted explosive impacts resulting from the release of 12,000 pph Component A with the User Input module using Aspen Plus data.

Table 8.5

CASE DESCRIPTION — Fire Case With 16,000 pph Steam Injection

PHAST version 5.22 — 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet) Model Input	Aspen Input	Distance (in Feet) Model Input	Aspen Input	Distance (in Feet) Model Input	Aspen Input	Distance (in Feet) Model Input	Aspen Input	Distance (in Feet) Model Input	Aspen Input
			1.0 m/s; D		5.0 m/s; D		10.0 m/s; D		20.0 m/s; D		1.5 m/s; F	
2AS & 4AS	**Toxic**											
	Conc of Interest	10	25,570.0	27,210.0	9,207.0	9,466.0	5,404.0	5,737.0	3,133.0	3,599.0	76,940.0	76,950.0
	(1 ppm)	60	19,740.0	21,300.0	7,188.0	7,429.0	4,105.0	4,413.0	2,529.0	2,971.0	57,910.0	57,930.0
	ERPG-1 (5 ppm)	60	5,728.0	7,032.0	2,118.0	2,308.0	1,436.0	1,664.0	1,081.0	1,467.0	16,030.0	16,110.0
	ERPG-2 (75 ppm)	60	910.4	712.3	375.5	513.4	324.0	519.5	298.7	672.8	982.8	1,100.0
	ERPG-3 (500 ppm)	60	218.0	238.9	131.8	276.4	161.5	335.7	187.0	507.0	245.1	185.7
	Combustible											
	BLEVE / Fireball	--	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Jet Flame											
	4.0 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	12.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	37.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Flash Fire	--	1.55	3.50	3.75	7.02	4.80	9.67	6.59	16.14	2.66	5.26
	Late Ignition Explosion											
	0.3 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	2.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	3.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted no explosive impacts resulting from the release of 12,000 pph Component A + 16,000 pph Steam.
Interlocking reboiler steam on high column base pressure eliminates all relief cases except external fire.
External fire exposure is mitigated effectively by lower steam injection rate of 16,000 pph. Therefore, use a combined strategy of interlocking steam and lower steam injection rate.

Table 8.6

CASE DESCRIPTION Loss of Condensing With 16,000 pph Steam Injection
PHAST version 5.22 10 Minute Release

Case Comparisons	Output Parameter	Avg Time (Min)	Distance (in Feet) 1.0 m/s; D		Distance (in Feet) 5.0 m/s; D		Distance (in Feet) 10.0 m/s; D		Distance (in Feet) 20.0 m/s; D		Distance (in Feet) 1.5 m/s; F	
			3AS	C3AS	3AS	C3AS	3AS	C3AS	3AS	C3AS	3AS	C3AS
3AS &	**Toxic**											
C3AS	Conc of Interest	10	94,670.0	97,720.0	53,560.0	55,890.0	32,140.0	33,450.0	18,850.0	19,750.0	>164,000.0	>164,000.0
	(1 ppm)	60	79,100.0	81,690.0	41,590.0	43,380.0	25,020	26,040.0	14,580.0	15,290.0	>164,000.0	>164,000.0
	ERPG-1 (5 ppm)	60	34,880.0	36,160.0	13,720.0	14,310.0	8,043.0	8,395.0	4,370.0	4,591.0	110,800.0	118,300.0
	ERPG-2 (75 ppm)	60	3,559.0	3,921.0	1,739.0	1,833.0	1,124.0	1,243.0	855.9	913.3	11,180.0	11,980.0
	ERPG-3 (500 ppm)	60	794.3	873.2	509.8	527.0	362.6	374.2	266.1	293.4	1,109.0	1,005.0
	Combustible											
	BLEVE / Fireball	--	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Jet Flame											
	4.0 kW/sq m	--	NR	NR	NR	NR	NR	NR	141.00	128.1	NR	NR
	12.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	37.5 kW/sq m	--	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Flash Fire	--	15.08	15.72	31.45	32.52	43.51	45.06	47.08	66.87	23.59	24.48
	Late Ignition Explosion											
	0.3 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	2.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	3.0 psig	--	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

NI = None Indicated
NR = Not Reached
NH = No Hazard

The model predicted no explosive impacts resulting from the release of 160,000 pph Component A + 16,000 pph Steam.
Both Cases Modeled as Aspen Input (Case 3AS used 50 degF as ambient and surface temperature where C3AS was corrected to 80 degF).

Example results - mitigation of toxic effects of Component A

Table 7 and 8, along with Figures 2 though 16, summarize modeling results for the example system. Note that Table 8 proposes a combined strategy for mitigation of the various pressure relief events. The worst credible relief scenario is loss of condensing. It leads to a release rate of 160,000 pph of Component A. This scenario dictates the size of the pressure relief system. Use of a smaller vent tip, in combination with an elevated stack, is impractical. The required stack height would be approximately 200 feet above grade, more than 85 feet above the top of the distillation column. Injection of a large flow rate of steam (24,000 pph) is required to achieve mitigation of this scenario by steam injection alone. However, the steam injection system costs less than one fourth of the cost of an elevated stack. The elevated stack was also deemed impractical because the required guy wires would limit access to columns and other equipment in the manufacturing unit, especially during shutdowns. The elevated stack would also be an eyesore and a navigation hazard for aircraft.

Interlocking shut the steam supply to the reboiler for the Purification Column whenever high base column pressure is detected will stop the pressure relief event either before it begins or very soon into the event.

This base column pressure interlock on reboiler steam will also mitigate two other relief scenarios: (1) tube rupture in the reboiler and (2) loss of condensing during water boilup for column cleaning. However, interlocking reboiler steam will not prevent pressure relief during external fire exposure to the Purification Column. Nonetheless, in the fire scenario, a comparatively low steam injection rate of 16,000 pph is more than adequate to decrease grade level concentrations of Component A from above the hazardous 500 ppm ERPG 3 level to well below the acceptable 75 ppm ERPG-2 level. This is because the relief rate for the fire scenario is only 12,000 pph of Component A. Although the plume rise due to velocity is much less than in the loss of condensing scenario, the high proportion of steam in the vented vapors greatly decreases the mean molecular weight and the density of the plume.

Use of a combined strategy of both an interlock on base column pressure to reboiler steam, and an interlock on relief outlet piping pressure to steam injection has another advantage. When an intermediate steam flow is injected automatically in response to an elevated pressure in the relief outlet piping, it will mitigate those momentary relief discharges that might occur with scenarios other than the fire case. This is important because the response time of the control system to a pressure surge caused by loss of condensing or a tube rupture may not be quick enough to prevent a very brief relief discharge of at most several minutes duration. If desired, dynamic process modeling could be used to quantitatively evaluate the combined response of the column relief and mitigation systems.

The choice of a base pressure interlock on reboiler steam has another advantage. It leads to an intermediate steam injection rate of 16,000 pph. The effect of the added load on the plant steam generation system will be less severe than the higher rate (24,000 pph) that would have been required to mitigate the flow of Component A in the loss of condensing case.

Example results - Mitigation of flammability hazards by steam injection

Table 8 is also an extensive tabulation of the key results from the PHAST consequence analyses of the various example cases modeled. Flammability hazards were comparatively limited. BLEVE's are not expected, and late ignition explosions are expected for the 160,000 pph venting rate associated with loss of condensing; but these cases will be eliminated by the high base column pressure interlock on reboiler steam.

A result that at first seems surprising is that late ignition explosions, with damaging overpressures of 3 psig, could occur more than 150 feet from the vent tip in the case of unmitigated fire exposure relief. Fortunately, steam injection eliminates explosion hazards for the fire exposure case.

Thermal radiation at 4.0 kW/sq m from an ignited vent was a minor hazard for the 160,000 pph venting rate, but that case is mitigated by the high base column pressure interlock. Without the interlock, injection of 16,000 pph of steam eliminates all cases except for a wind speed of 20 m/sec and D type stability. Thermal radiation from a jet flame (ignited vent) was not a concern for the fire relief case, even without steam injection.

Flash fires represented significant hazards within 130 to 140 feet of the vent tip for both the loss of condensing case and the fire exposure case (Table 8). Steam injection reduced the diameter of the flash fire by roughly a factor of two.

COMPARISON OF DIFFERENT MODELING APPROACHES

Comparison of PHAST 5.11 with PHAST 5.22

Table 7 and 8 and Figures 2 through 16 permit a comparison of the predictions of two recent versions of PHAST, PHAST 5.11 and PHAST 5.22. The predictions of the two versions of PHAST are significantly different. For example, compare Figure 2 with Figures 4, 5 and 6 for the loss of condensing case and a venting rate of 160,000 pph of Component A. Comparison of Figure 3 with Figures 7, 8 and 9 is even more dramatic. These are the predictions for a venting rate of 160,000 pph of Component A and a steam injection rate of 16,000 pph. Version 5.11 predicts that the steam injection rate successfully mitigates the concentration of Component A to below the ERPG-2 concentration. In contrast, Version 5.22 predicts that higher steam rates are needed.

Figures 10 and 11 represent the predictions for ground level concentrations when 24,000 pph of steam are injected into the relief valve discharge. Figures 12, 13, and 14 indicate the plume profile for the fire case with no steam injection, while Figures 15 and 16 predict the plume profile when 16,000 pph of steam is injected.

A recent paper by Woodward (1998), then of DNV Technica, the company marketing PHAST, described an extensive new database of field tests of atmospheric dispersion during F type stability. Presumably, these new data were incorporated into the PHAST 5.22 model for F type stability. Those who used PHAST 5.11 or an earlier version for the purposes of consequence analysis for the

U.S. EPA risk management program may wish to recheck their results with the newer and presumably more valid version of PHAST.

Comparison of PHAST model of a mixture with an ASPEN PLUS model

Even the latest version of PHAST cannot directly model the steam injection process. PHAST is not set up to model mixing of two different streams, each from a different composition, temperature, and pressure. Consequently, a process simulator, such as ASPEN PLUS, was used to generate the composition, temperature, pressure, and thermophysical properties of the vented mixtures exiting the relief vent stack. Table 8 compares results obtained by the two different methods. Differences are significant. The PHAST modeling predictions, based on the ASPEN PLUS input, are the most reliable results of the two data sets.

CONCLUSIONS

Atmospheric venting can be a safe and economical way of disposing vapors relieved from processes during emergency conditions, provided those fluids do not accumulate in the environment as hazardous substances, and provided that releases to the environment are rare. If atmospheric venting is selected as the disposal method of choice, then a quantitative consequence analysis should be conducted to assure safety in atmospheric venting.

If atmospheric venting could occur frequently, or if vented fluids would persist in the environment and cause harmful effects, then treatment and containment systems should be considered to prevent release.

If an existing or proposed vent system presents unacceptable hazards, first consider decreasing the outlet nozzle size and raising the stack height to improve safety. Often, these measures will not suffice, but steam injection into the outlet section of relief piping will almost often make relief venting to the atmosphere safe. This paper outlines methods to determine the consequences of venting hazardous vapors to the atmosphere, together with methods for the optimal design of pressure relief venting systems.

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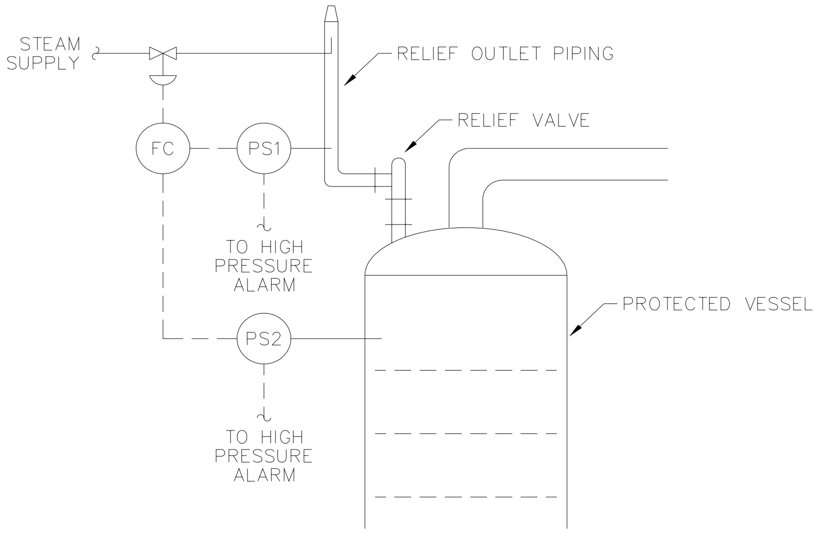
Figure 1
Typical Pressure Relief System
Augmented by Steam Injection



Legend:

PS1 = Pressure transmitter or pressure switch that senses pressure in pressure relief outlet piping.

PS2 = Pressure transmitter or pressure switch that senses pressure in protected vessel.

FC = Flow controller that turns on steam whenever either PS1 or PS2 detects high pressure.

Figure 2

Loss of Condensing
Venting Rate at 160,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

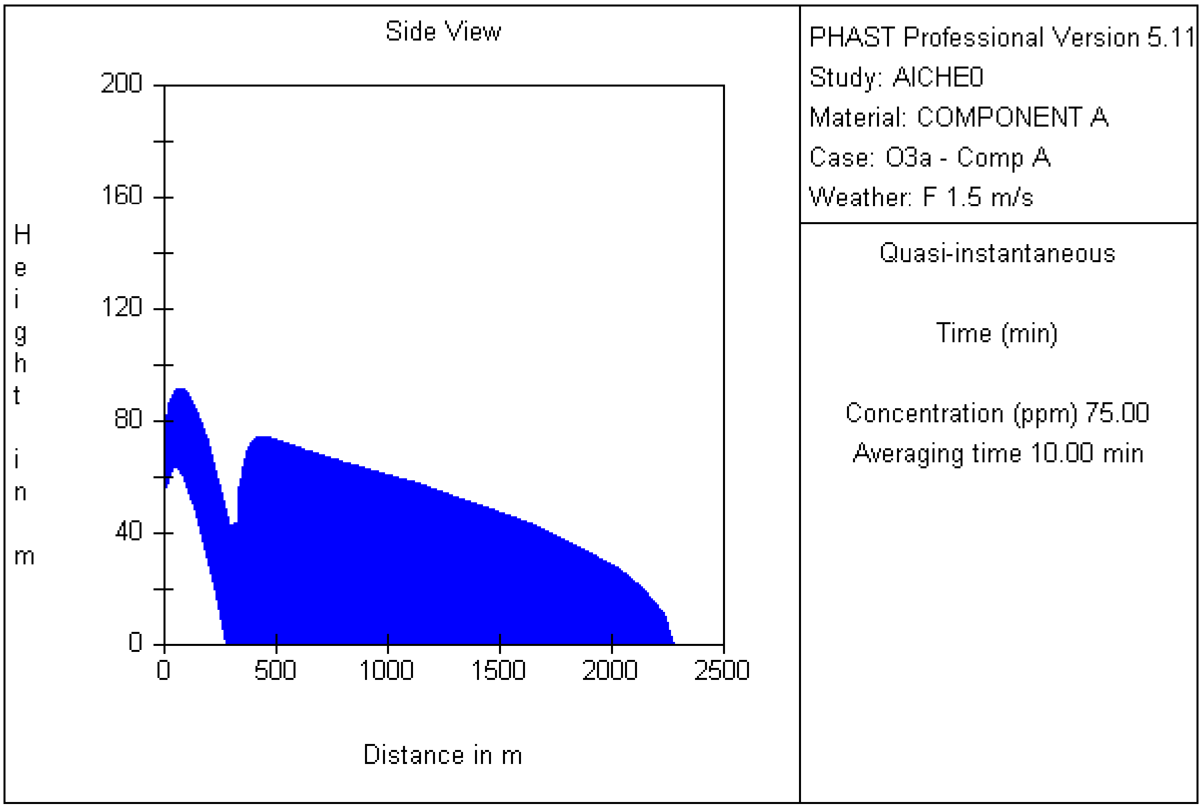


Figure 3
Loss of Condensing
Venting Rate at 160,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet

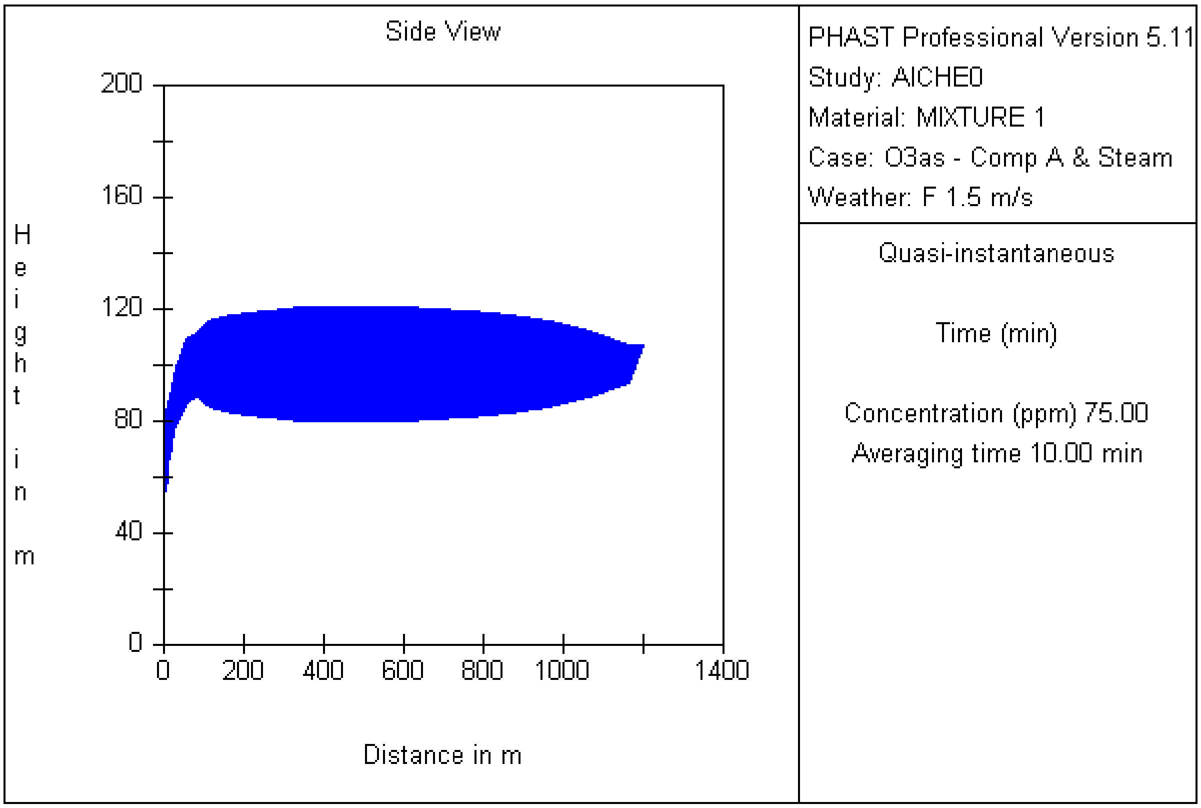


Figure 4
Loss of Condensing
Venting Rate at 160,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

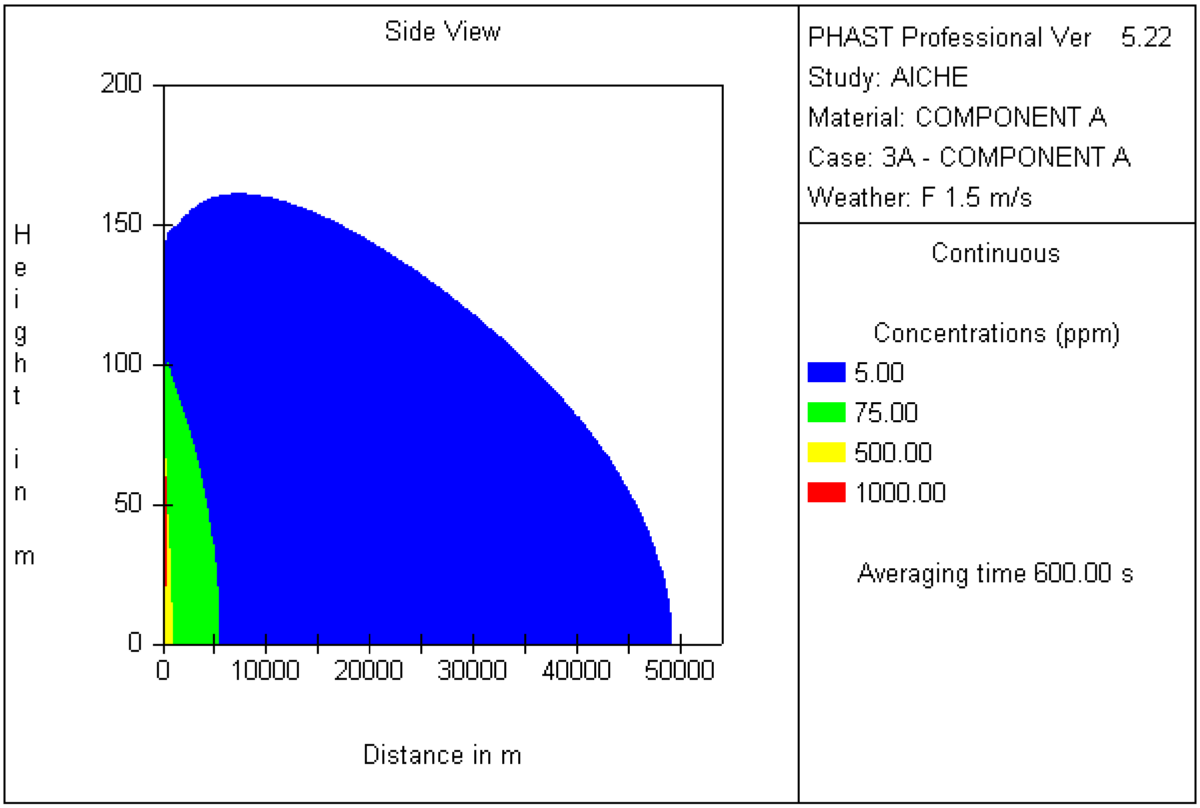


Figure 5
Loss of Condensing
Venting Rate at 160,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

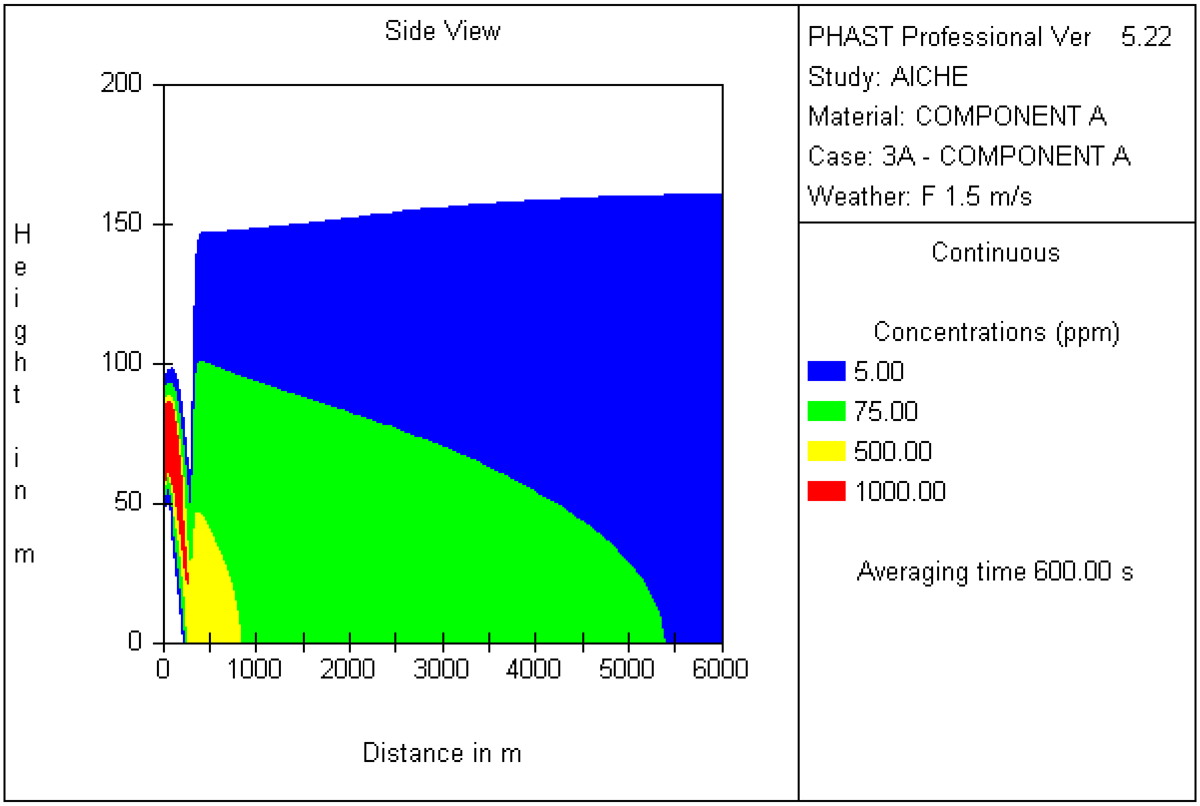


Figure 6
Loss of Condensing
Venting Rate at 160,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

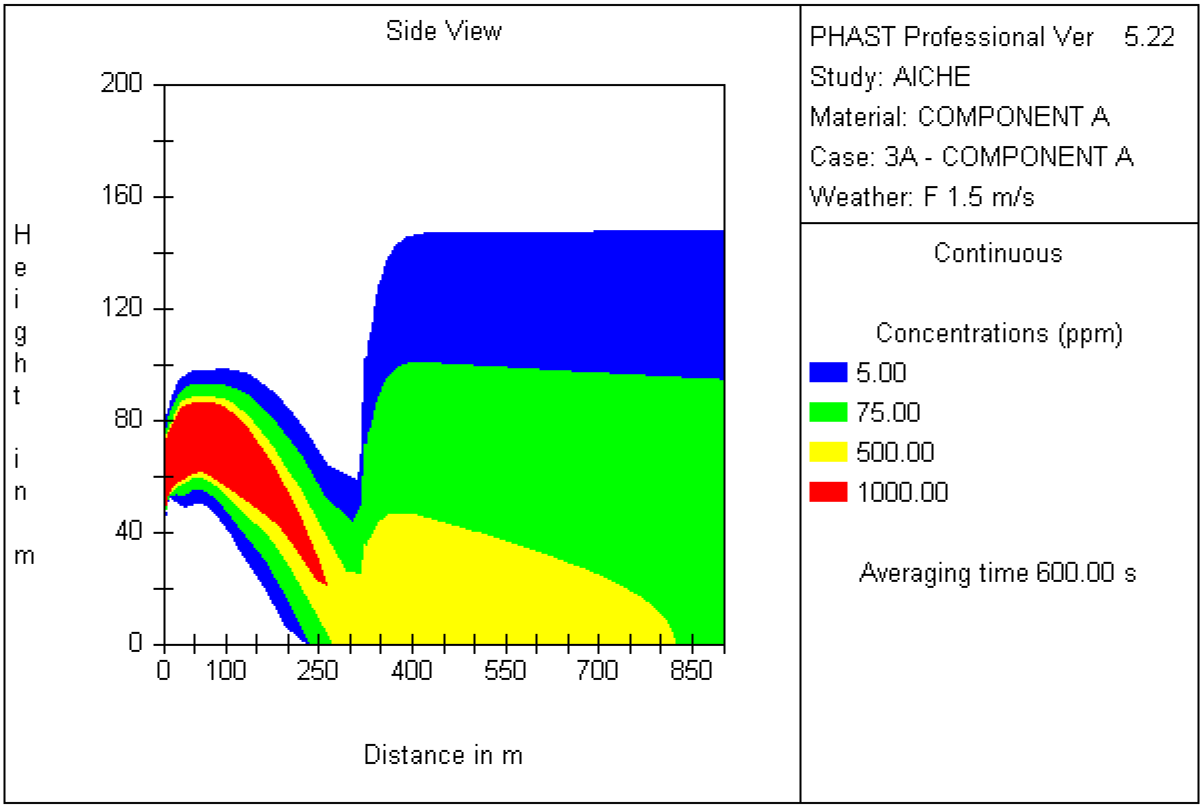


Figure 7
Loss of Condensing
Venting Rate at 160,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet

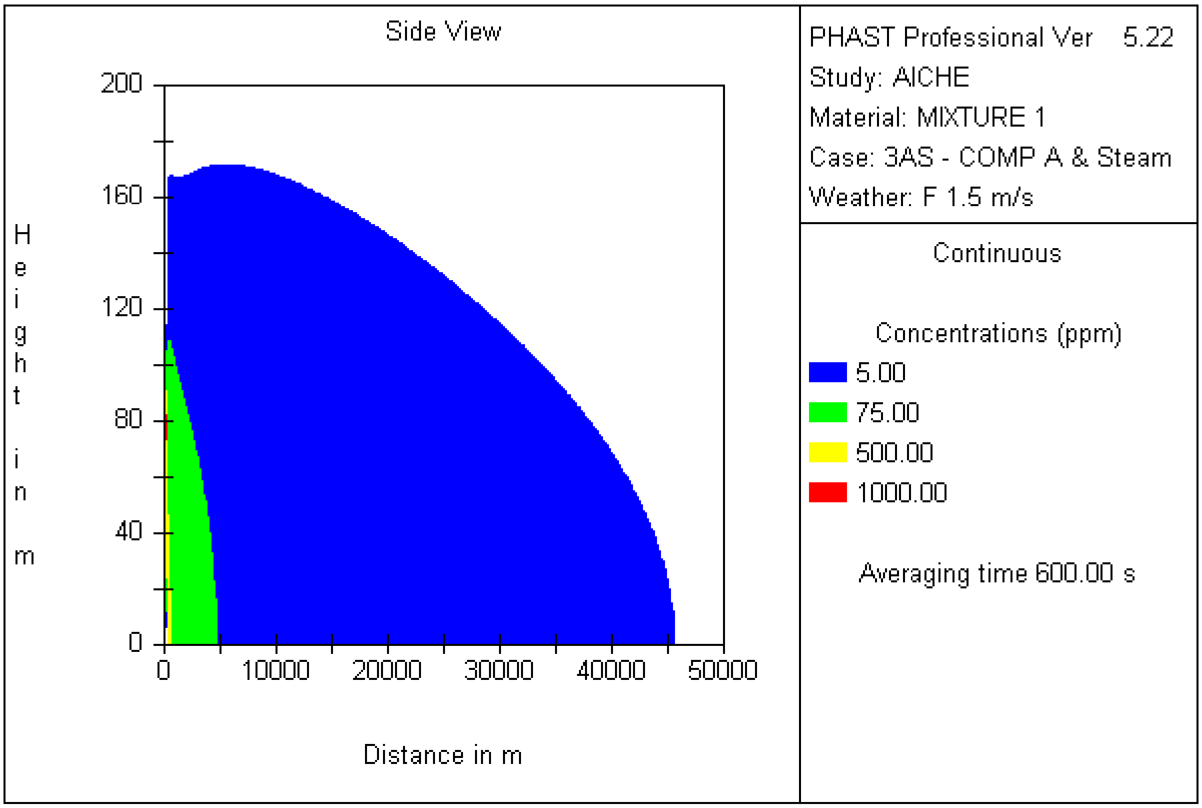


Figure 8
Loss of Condensing
Venting Rate at 160,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet

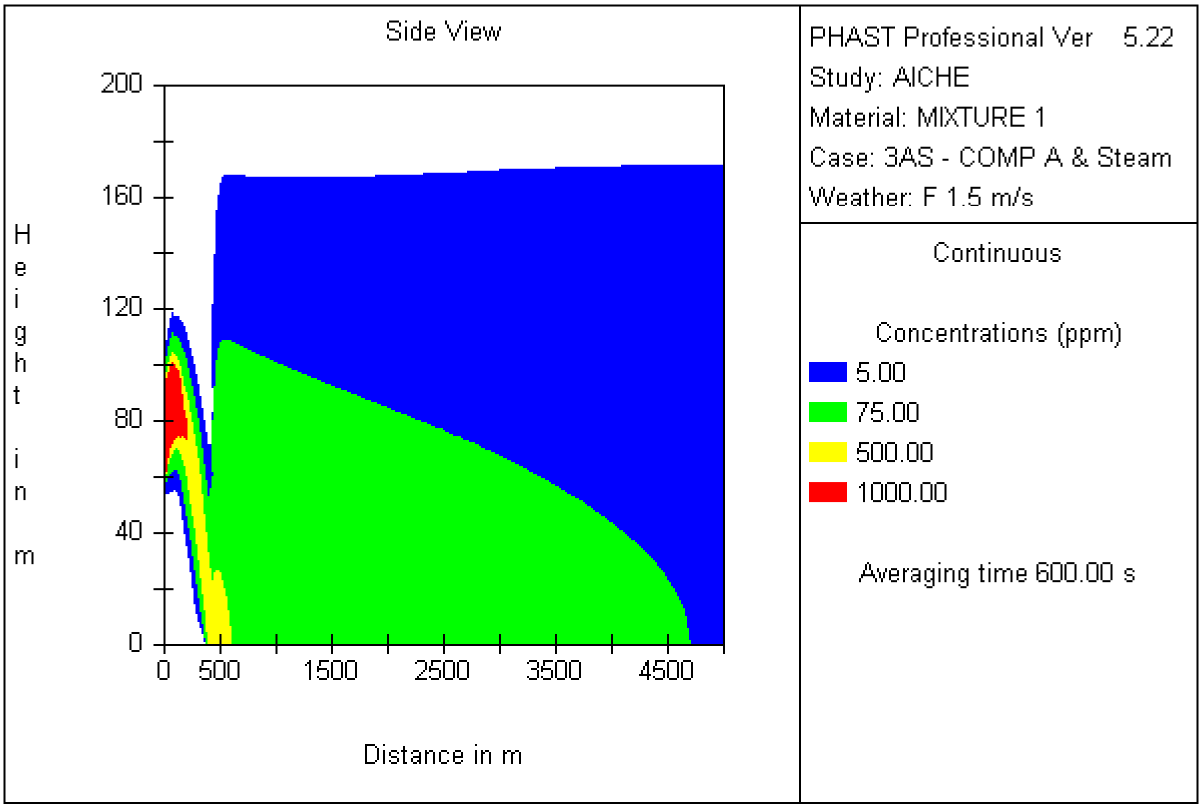


Figure 9
Loss of Condensing
Venting Rate at 160,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet

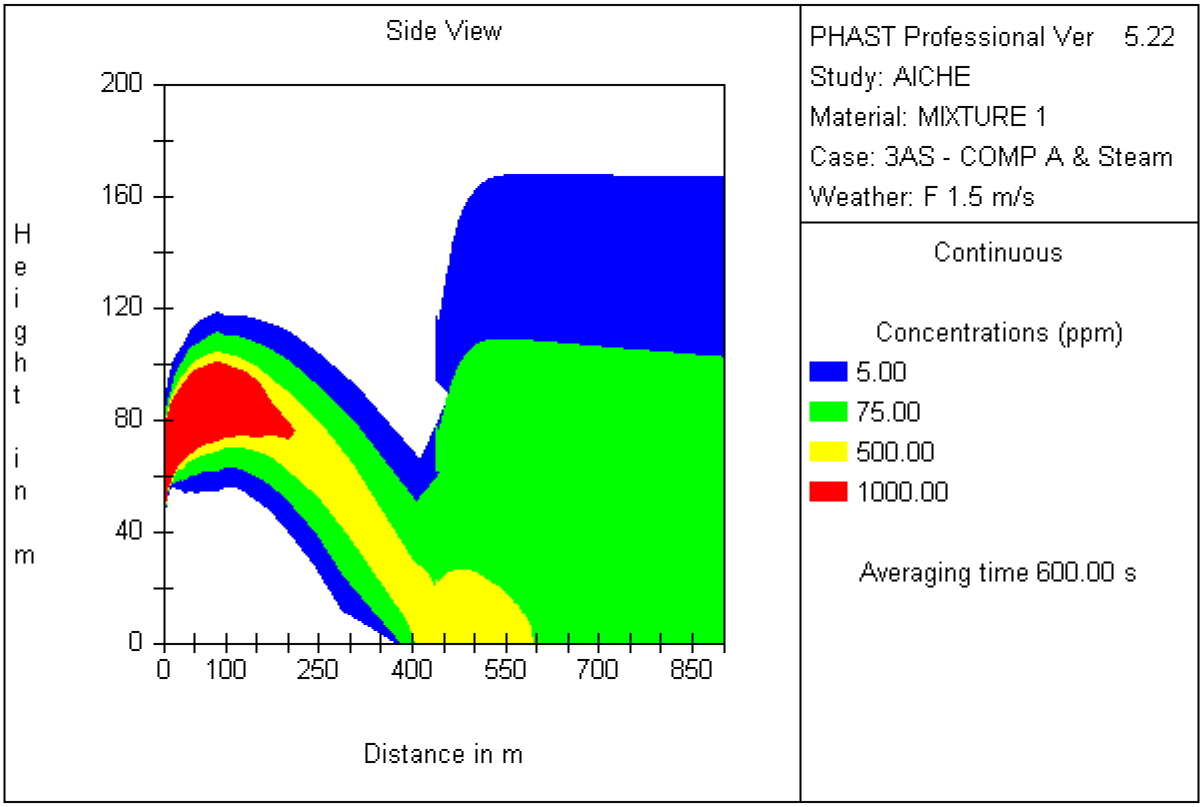


Figure 10
Loss of Condensing
Venting Rate at 160,000 pph With 24,000 pph Steam Injection
Release Point Elevation at 135 Feet

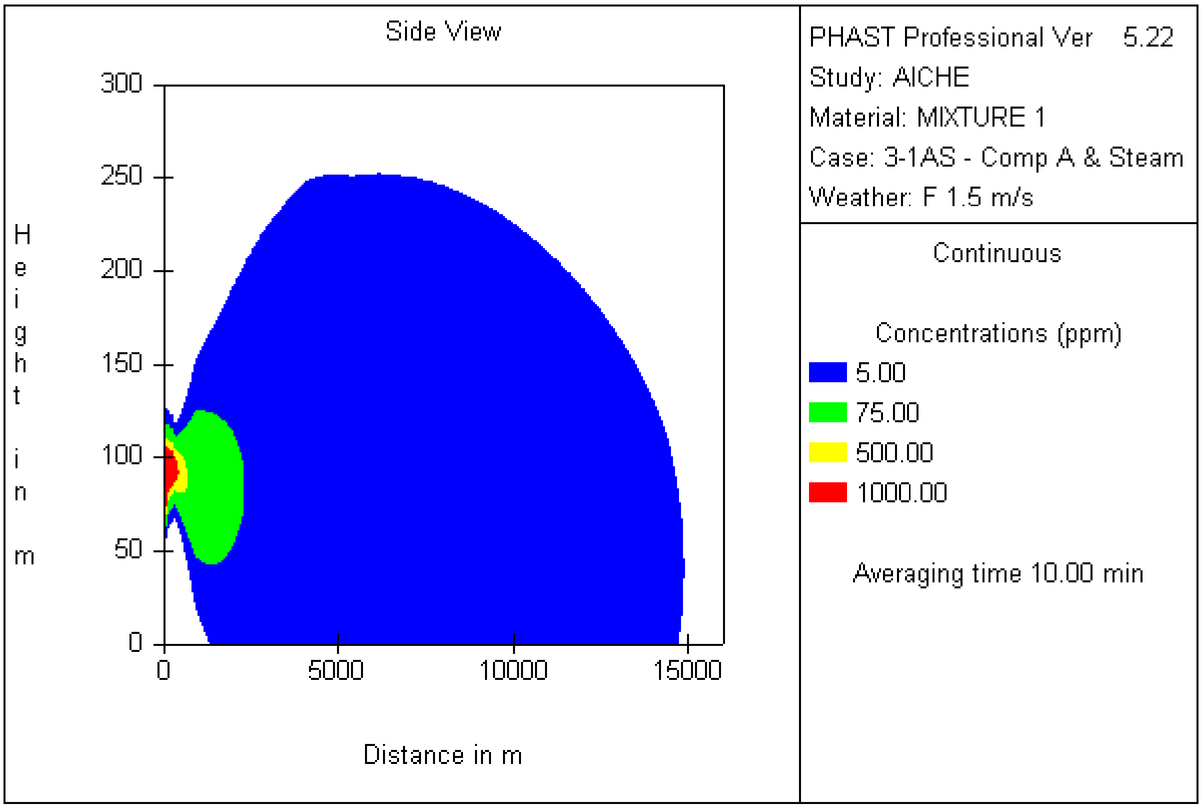


Figure 11
Loss of Condensing
Venting Rate at 160,000 pph With 24,000 pph Steam Injection
Release Point Elevation at 135 Feet

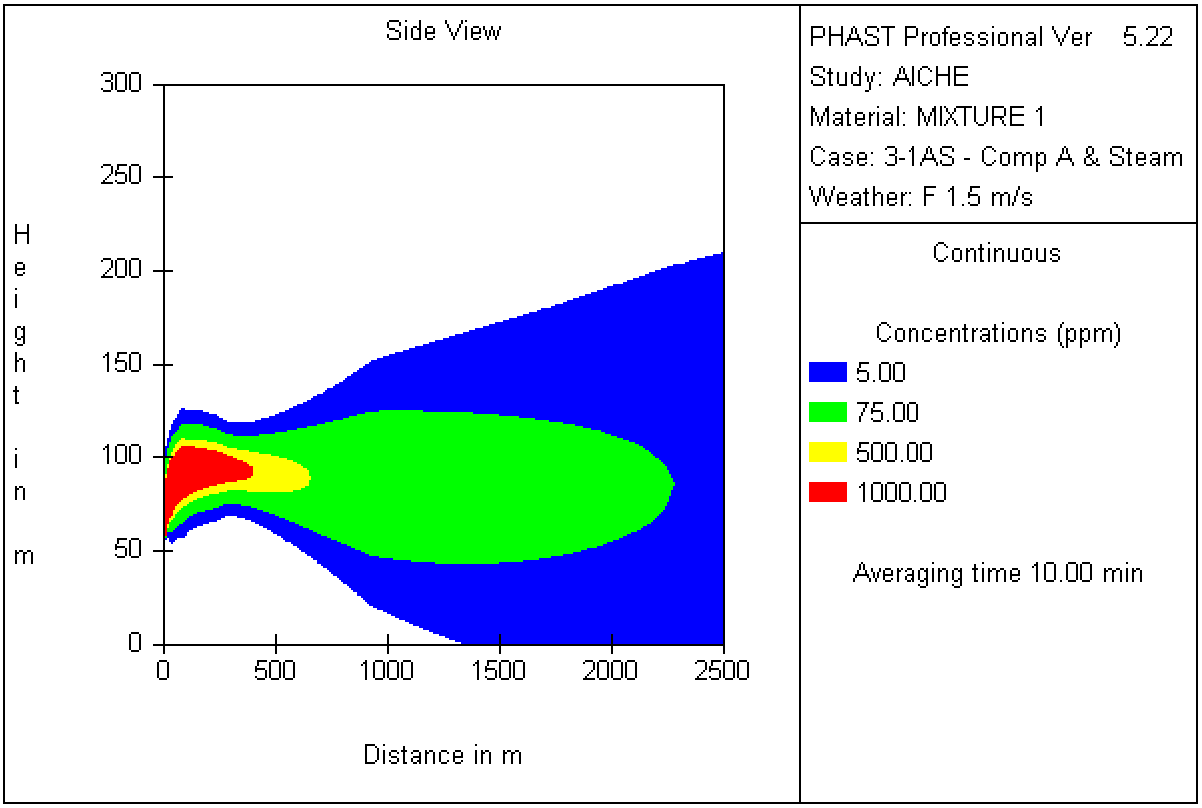


Figure 12
Fire Case
Venting Rate at 12,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

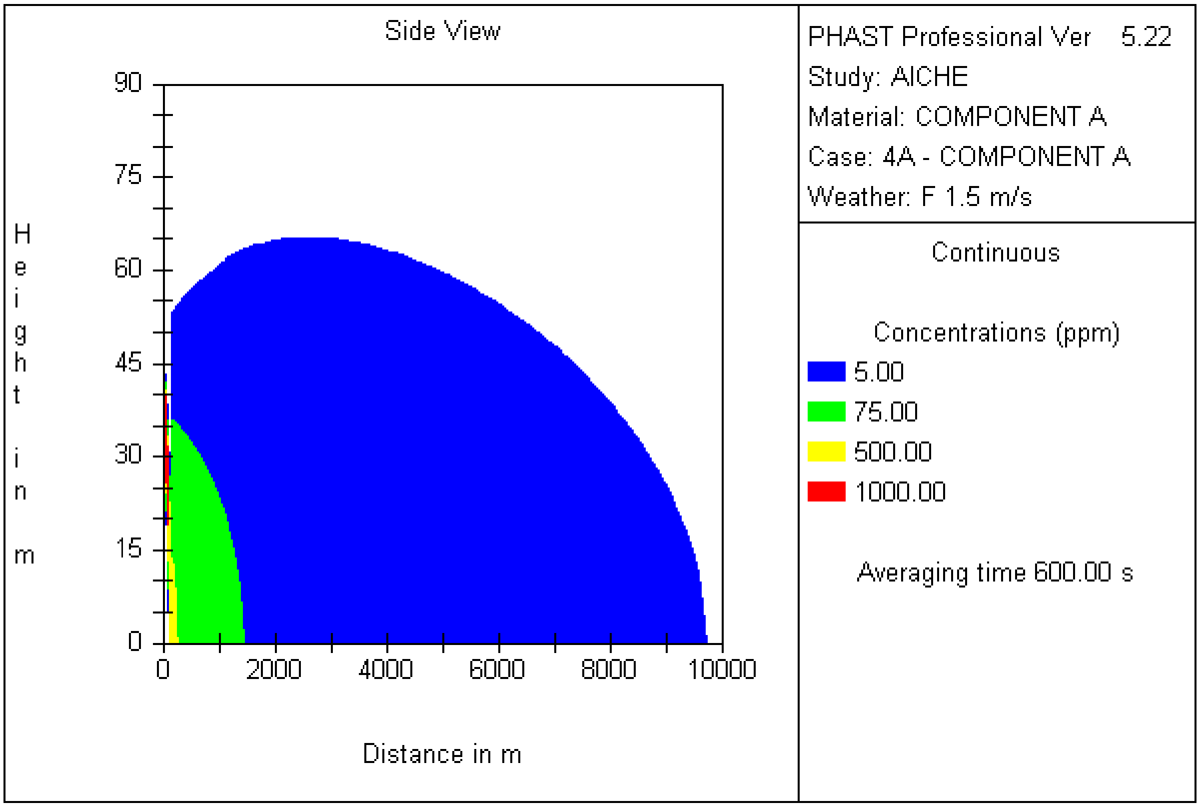


Figure 13
Fire Case
Venting Rate at 12,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

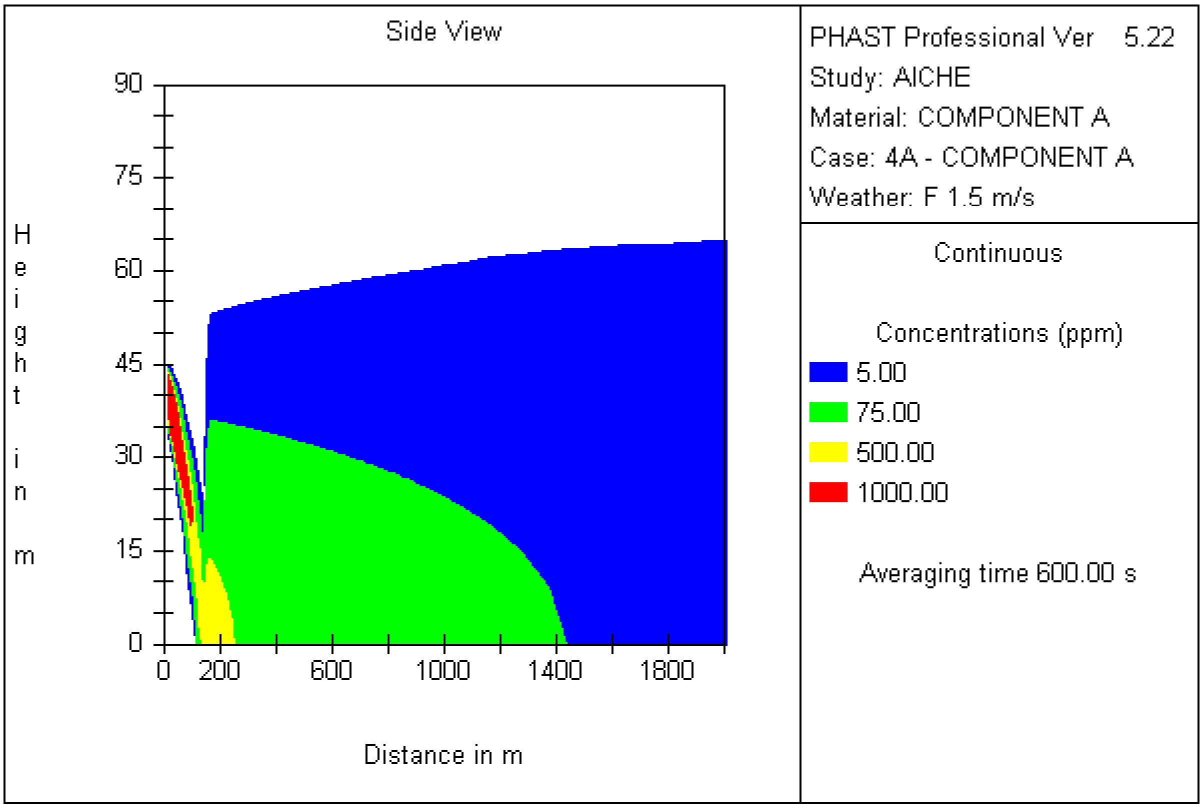


Figure 14
Fire Case
Venting Rate at 12,000 pph With No Steam Injection
Release Point Elevation at 135 Feet

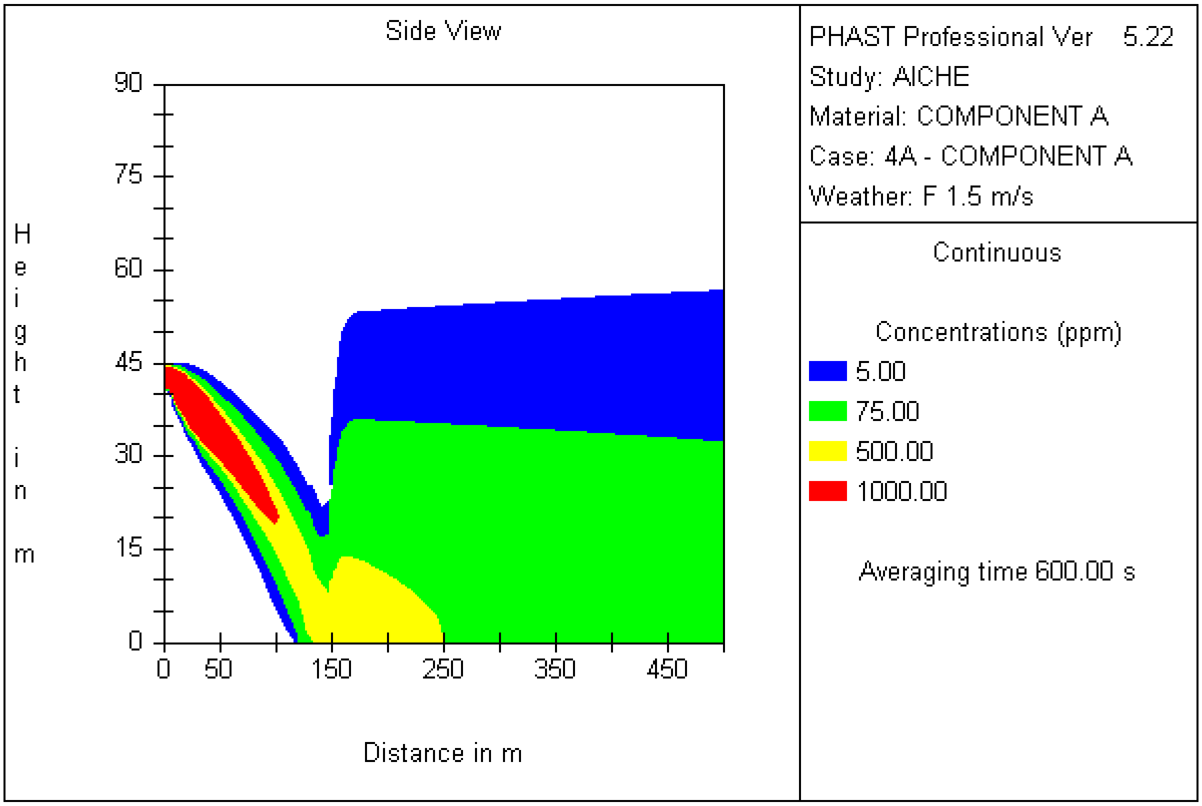


Figure 15
Fire Case
Venting Rate at 12,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet

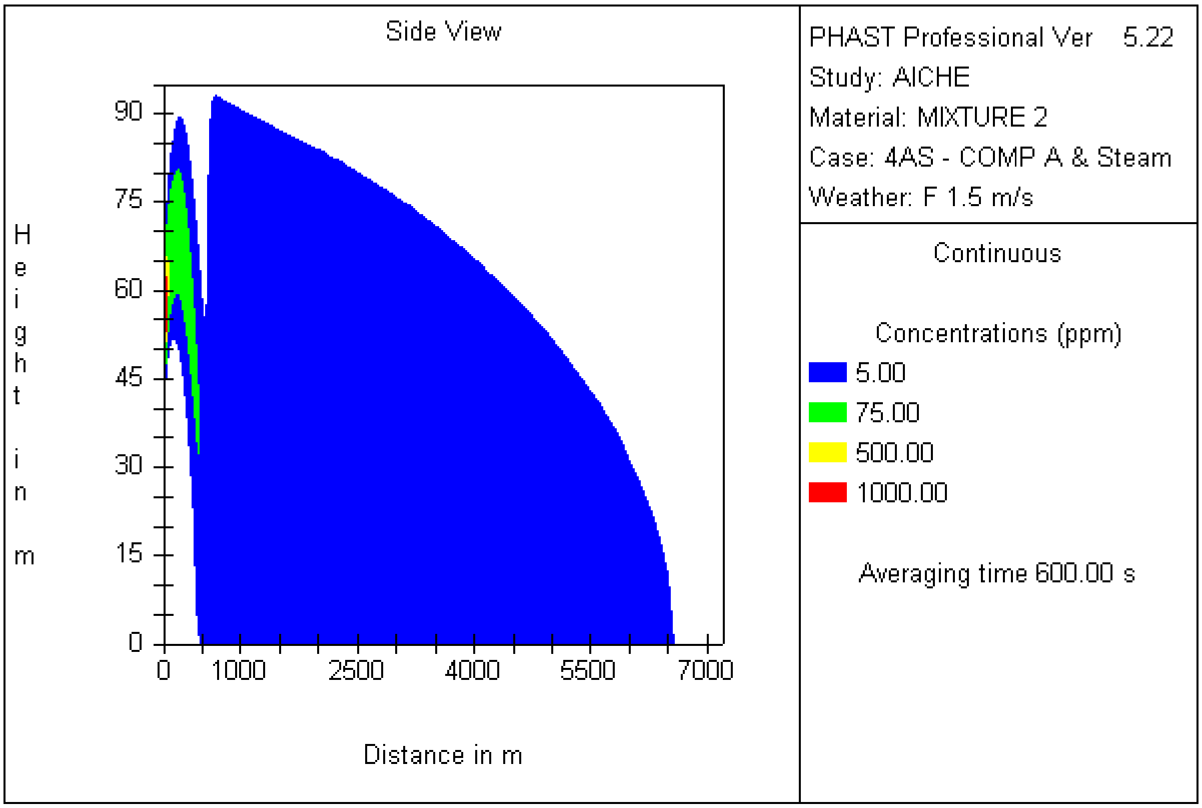


Figure 16
Fire Case
Venting Rate at 12,000 pph With 16,000 pph Steam Injection
Release Point Elevation at 135 Feet