Emergency Response and Process Hazards Analysis Charts

An ioMosaic Corporation
White Paper

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ioMosaic Corporation

Risk Management and Assessment Practices

Emergency Response and Process Hazards Analysis Charts

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December 6, 2018

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1 Introduction

Chemical processing facilities need reliable emergency response plans and systems (ERPS) in order to manage technological risks to plant personnel, the surrounding communities, and the environment. An optimal emergency response system is one that enables plant emergency response personnel to quickly identify release details (such as leak location, size, and conditions) and how far the release is going to be transported downwind. The impact of most release scenarios is typically realized within the the first ten minutes. For example, a neutrally buoyant toxic vapor chemical release that occurs at ambient wind speed conditions of 5 m/s will be transported 1.5 kilometers in 5 minutes. This does not leave much time for emergency response personnel to run computer models in real time to determine the extent and direction of the dispersion. Time is of the essence during a chemical release. Emergency response time can be minimized by pre-planning for credible leak scenarios.

Many plants have their own meteorological towers providing real time data. Some have invested in real time systems for predicting in real time where the potential impact zones are and/or will be and when the impact is likely to be realized and how severe it will be. This information is often visualized on site and surroundings maps. The results would then be communicated to plant and community emergency responders so that they could take appropriate action in the form of evacuation plans for local communities, industries, schools, traffic control plans, and alerting medical facilities for treating potential exposure.

This type of real-time emergency response is challenging and often unreliable. Many operating companies feel that emergency response planning guidelines prepared well in advance of potential emergencies provide a more reliable and quicker alternative.

2 Planning for Emergencies

Depending on the chemical type, source conditions, the leak can be all vapor, liquid, or multiphase. A single flow chart can be be developed that covers hundreds of potential leak scenarios for a given chemical or chemical mixture. Once the leak rate is determined then dispersion or consequence charts can also be developed for quick and reliable estimation of potential impact zones. A reasonable estimate of the flow rate is essential for performing any subsequent dispersion or consequence calculations so that the estimated impact zones are not overly conservative and do not cause unnecessary evacuations and notifications.

Regardless of whether a real-time system or pre-planned emergency response guidelines and charts are used, emergency response personnel first must assess the leak type, location size, and conditions. This is difficult to do during an emergency. Leak detection of the actual event is critical. Emergency response guidelines data is also very useful for PHA consequence assessment.

Well prepared emergency response plans should address:

- Site map preparation and plant zoning (zoning the plant will make retrieval of data much easier during an actual emergency

- Weather data selection

- Consequence criteria selection (toxicity, thermal radiation, noise, explosion overpressure, environmental impact limits)

- Leak scenario identification

- Leak scenario definition - type (source: pipe, vessel (hole), flange, relief device, size, conditions (Temp. pressure, composition), location, elevation, direction

- Dispersion criteria (wind direction, wind speed, stability class)

- Source (leak/release) modeling

- Dispersion modeling (gas jet, 2-phase jet, evaporative pool)

- Dispersion results and interpretation

- Emergency Response Planning guide preparation (Data management and retrieval)

- Procedure for using the Emergency Response Planning Guide

- Training for personnel in using the Emergency Response Planning Guide (whether it is electronic, paper or both)

- Reporting

Preplanned emergency response guidelines and charts are typically provided in paper and/or electronic forms. An ERPS can be setup in a computer system as a drop-down menu based system or it can simply be in a paper binder or binders that are clearly tabbed for easy information retrieval. Paper may be more reliable and probably necessary as a backup anyway.

This information should be located in the shift supervisors office, the plant command center or wherever the emergency response activities/coordination are monitored and controlled. Also, there needs to be a trained operator for the ERPS system and its data.

When a leak or a release is detected, the field operator or the observer in the field would contact the shift emergency response office and notify them of the leak and provide some details regarding the leak. For example, a leak has been detected in zone 1. The leak is on a 2-inch flange on a chlorine feed line. The ERPS operator would start entering the data via the drop down menus: Zone 1, chlorine feed line; 2-inch flange leak; select current weather conditions based on real time meteorological data (wind speed 8 mph, wind direction NE, stability D (based on time of day and weather conditions). This data would pull up a pre-prepared aerial map for the leak scenario as defined by the operator. The aerial map will show the concentration profiles/contours in 10 - 15 minute increments. The operator could look at the map and determine the concentration based on the leak start time and the current time. For example, if the elapsed time is 30 minutes, the second profile/contour (two 15-minute increments is now of the UFL at the point of interest (zone 2 control room, fence line, nearby highway, access road). Of course, 45 minutes of elapsed time would be the third profile/contour and 60 minutes would be the fourth profile and so on. The

documentation doesnt have to be computerized, it can simply reside in a binder(s) with tabs. A computer may be better and faster for data retrieval. However, the electronic system depends on correct inputs as well as a reliable source of power.

3   Site Meteorological Data

Most industrial sites collect their own meteorological data. This hourly data, often measured at 10 meters elevation, typically includes wind speed, wind direction, ambient temperature, ambient pressure, relative humidity, cloud cover, solar flux, and rain fall. This data is then used to establish atmospheric stability, wind rose, wind direction, and wind speed probabilities. Computer codes like SuperChems Expert include meteorological data processors to develop necessary data for consequence/dispersion modeling. For USA sites, two conditions are prevalent, neutral stability at 5 m/s wind speed (D/5) and stable atmosphere at 2 m/s wind speed (F/2). On average, neutral conditions occur between 70 and 80 % of the time and stable conditions occur between 20 and 30 % of the time. Neutral conditions are used as representative of daytime conditions while stable conditions are used as representative of night time conditions.

Where actual measurements are not available, data can be obtained from the nearest airport and processed to develop likely atmospheric conditions for the site in question. The data shown in Figure 1 represents almost 30 years of data from Houston Hobby airport processed by SuperChems Expert for E, F, and G stability classes combined.

4   Flow Map Charts

One of the most important aspects of consequence modeling is accurate representation of the "source term". The "source term" refers to how much material is released, in what phase, how fast, how long, and how much of it becomes immediately airborne or airborne over time. The quality of emergency response and process hazards analysis can be improved substantially by incorporating flow maps such as the one shown in Figure 2.

Flow maps are generated using detailed and validated methods for pure chemicals or mixtures and cover single and multiphase flow. SuperChems Expert dynamic flow models cover subcooled, supercritical, vapor, liquid, two-phase, retrograde, and reacting flows for pure components and mixtures. A variety of options can be selected from complex piping arrangements to nozzle flow methods with user specified thermodynamic paths. Flow map charts can be constructed to cover expected process conditions and can produce accurate estimates very quickly.

For example a vinyl acetate release at 251 C and 1000 psia (69 bara) from a 2 in^2 ($1.29 \times 10^{-3} \text{ m}^2$) flow area with sharp edges (Cd = 0.62), yields a mass flux of 300,000 $\text{lb/in}^2/\text{hr}$ (58,590 $\text{kg/m}^2/\text{s}$) and a mass flow rate of 372,000 lb/hr (46.8 kg/s). The flow will be all vapor according to the flow map and as a result will all be airborne.

Figure 1: Meteorological data summary from Houston Hobby airport processed by SuperChems Expert
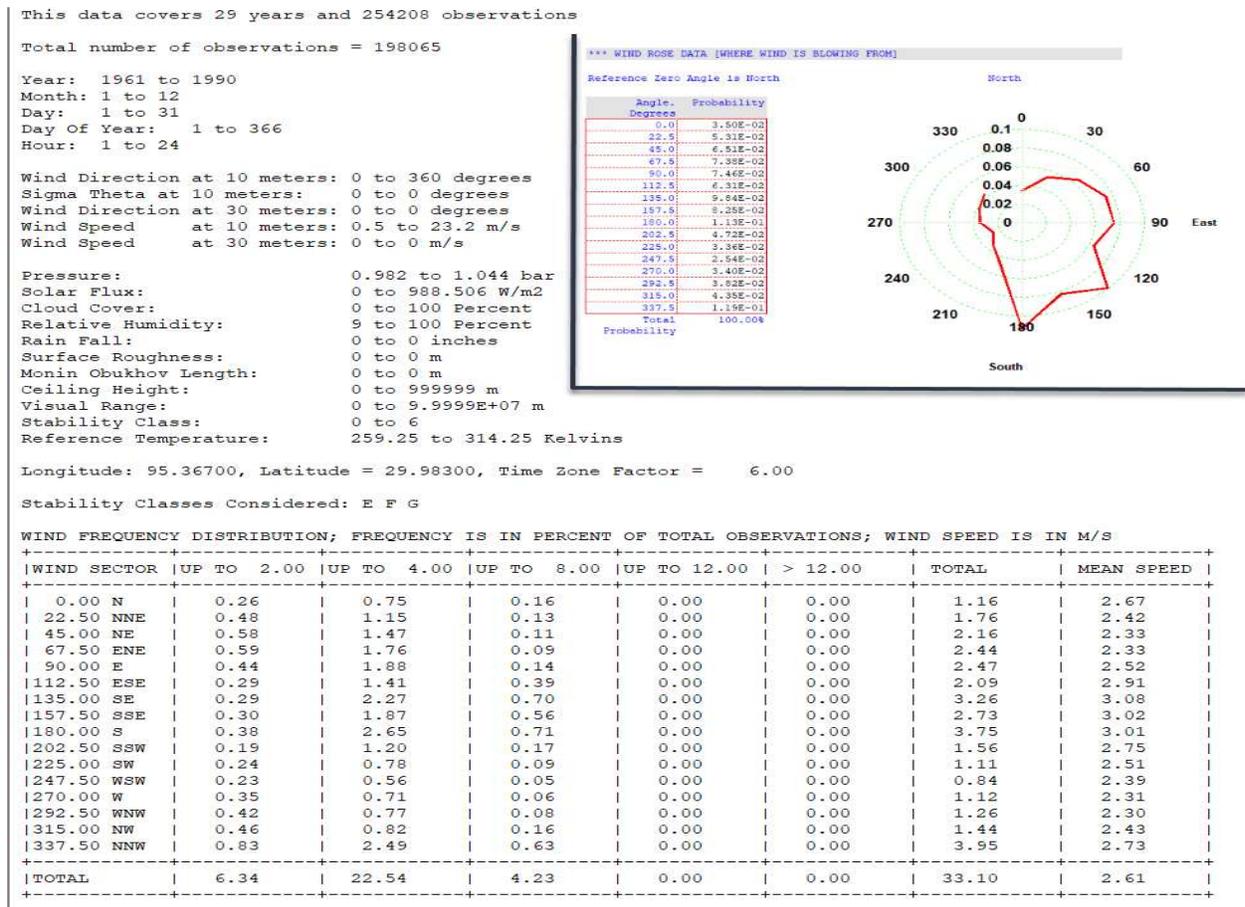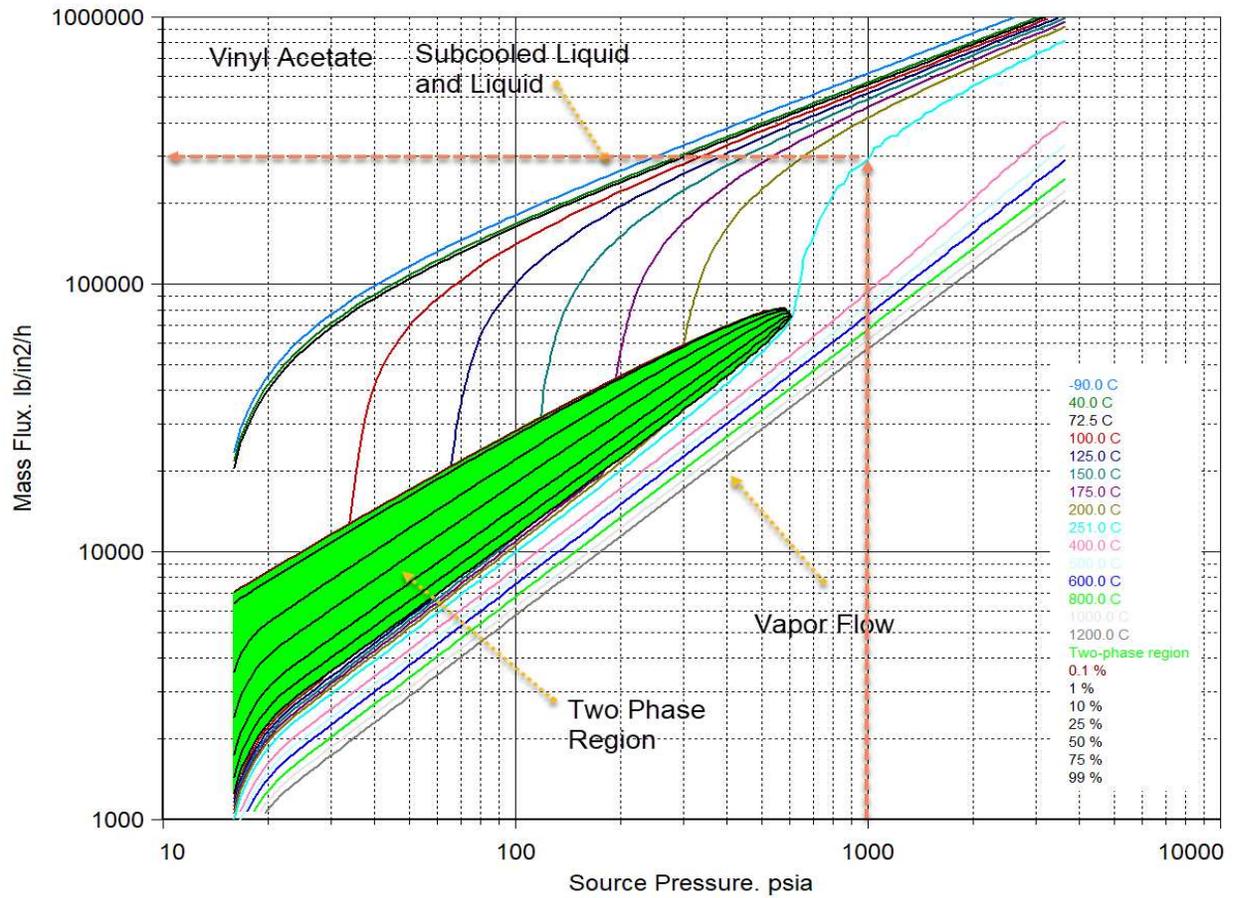


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This data covers 29 years and 254208 observations

Total number of observations = 198065

Year:   1961 to 1990
Month: 1 to 12
Day:   1 to 31
Day Of Year:   1 to 366
Hour:  1 to 24

Wind Direction at 10 meters: 0 to 360 degrees
Sigma Theta at 10 meters:    0 to 0 degrees
Wind Direction at 30 meters: 0 to 0 degrees
Wind Speed    at 10 meters: 0.5 to 23.2 m/s
Wind Speed    at 30 meters: 0 to 0 m/s

Pressure:                   0.982 to 1.044 bar
Solar Flux:                 0 to 988.506 W/m2
Cloud Cover:                0 to 100 Percent
Relative Humidity:          9 to 100 Percent
Rain Fall:                  0 to 0 inches
Surface Roughness:          0 to 0 m
Monin Obukhov Length:       0 to 0 m
Ceiling Height:             0 to 999999 m
Visual Range:               0 to 9.9999E+07 m
Stability Class:            0 to 6
Reference Temperature:      259.25 to 314.25 Kelvins

Longitude: 95.36700, Latitude = 29.98300, Time Zone Factor =    6.00

Stability Classes Considered: E F G
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WIND FREQUENCY DISTRIBUTION; FREQUENCY IS IN PERCENT OF TOTAL OBSERVATIONS; WIND SPEED IS IN M/S

WIND SECTOR	UP TO 2.00	UP TO 4.00	UP TO 8.00	UP TO 12.00	> 12.00	TOTAL	MEAN SPEED
0.00 N	0.26	0.75	0.16	0.00	0.00	1.16	2.67
22.50 NNE	0.48	1.15	0.13	0.00	0.00	1.76	2.42
45.00 NE	0.58	1.47	0.11	0.00	0.00	2.16	2.33
67.50 ENE	0.59	1.76	0.09	0.00	0.00	2.44	2.33
90.00 E	0.44	1.88	0.14	0.00	0.00	2.47	2.52
112.50 ESE	0.29	1.41	0.39	0.00	0.00	2.09	2.91
135.00 SE	0.29	2.27	0.70	0.00	0.00	3.26	3.08
157.50 SSE	0.30	1.87	0.56	0.00	0.00	2.73	3.02
180.00 S	0.38	2.65	0.71	0.00	0.00	3.75	3.01
202.50 SSW	0.19	1.20	0.17	0.00	0.00	1.56	2.75
225.00 SW	0.24	0.78	0.09	0.00	0.00	1.11	2.51
247.50 WSW	0.23	0.56	0.05	0.00	0.00	0.84	2.39
270.00 W	0.35	0.71	0.06	0.00	0.00	1.12	2.31
292.50 WNW	0.42	0.77	0.08	0.00	0.00	1.26	2.30
315.00 NW	0.46	0.82	0.16	0.00	0.00	1.44	2.43
337.50 NNW	0.83	2.49	0.63	0.00	0.00	3.95	2.73
TOTAL	6.34	22.54	4.23	0.00	0.00	33.10	2.61

Figure 2: Vinyl acetate flow map generated by SuperChems Expert

5   Toxicity Limits

Toxicity limits of concern can include limiting concentration, dosage, or even probability of receiving a dangerous dose (probit) values. Toxicity limits used for emergency response typically use the Emergency Response Planning Guidelines (ERPG) values developed by the American Industrial Hygiene Association (AIHA). The current list of ERPG values as of 2013 is provided on the AIHA web site (see Table 1). ERPG limits are one-hour exposure limits.

ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing any symptoms other than mild transient adverse health effects or without perceiving a clearly defined objectionable odor.

ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.

ERPG-3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects. ERPG-3 is similar to Emergency Exposure Guidance Levels (EEGLs) provided by the National Research Council's Committee on Toxicology.

Toxicity levels of concern used to develop emergency response charts may include ERPG-1, 2, and/or 3. For short release/exposure durations, ERPG concentrations can be used as dosage limits (ppm-min). ERPG-2 or ERPG-2 equivalent dosage values are normally used.

An EEGL is defined as a concentration of a gas, vapor, or aerosol that is judged to be acceptable and that will allow healthy military personnel to perform specific tasks during emergency conditions lasting from 1 to 24 hours. Exposure to concentrations at the EEGL may produce transient irritation or central nervous system effects but should not produce effects that are lasting or that would impair performance of a task.

In addition to EEGLs, the National Research Council has developed Short-Term Public Emergency Guidance Levels (SPEGLs), defined as acceptable concentrations for exposures of members of the general public. SPEGLs are generally, set at 10-50 % of the EEGL and are calculated to take account of the effects of exposure on sensitive, heterogeneous populations. The advantages of using EEGLs and SPEGLs rather than IDLH values are (1) a SPEGL considers effects on sensitive populations (2) EEGLs and SPEGLs are developed for several different exposure durations, and (3) the methods by which EEGLs and SPEGLs were developed are well documented in National Research Council publications.

6   Liquid Pools Evaporation Charts

For liquid releases that occur at or below the normal boiling point, a liquid pool will form first. The evaporation rate from the pool surface will be less than the liquid release, even for liquid pools that are unbounded. If the release is at the normal boiling point, the vaporization rate will approach the liquid feed rate for unbounded pools, especially for cryogenic liquid releases. The liquid spill

Figure 3: Pool vapor emission rate for a 10 minute liquid release of Vinyl Acetate. D stability. 4.5 m/s wind speed.
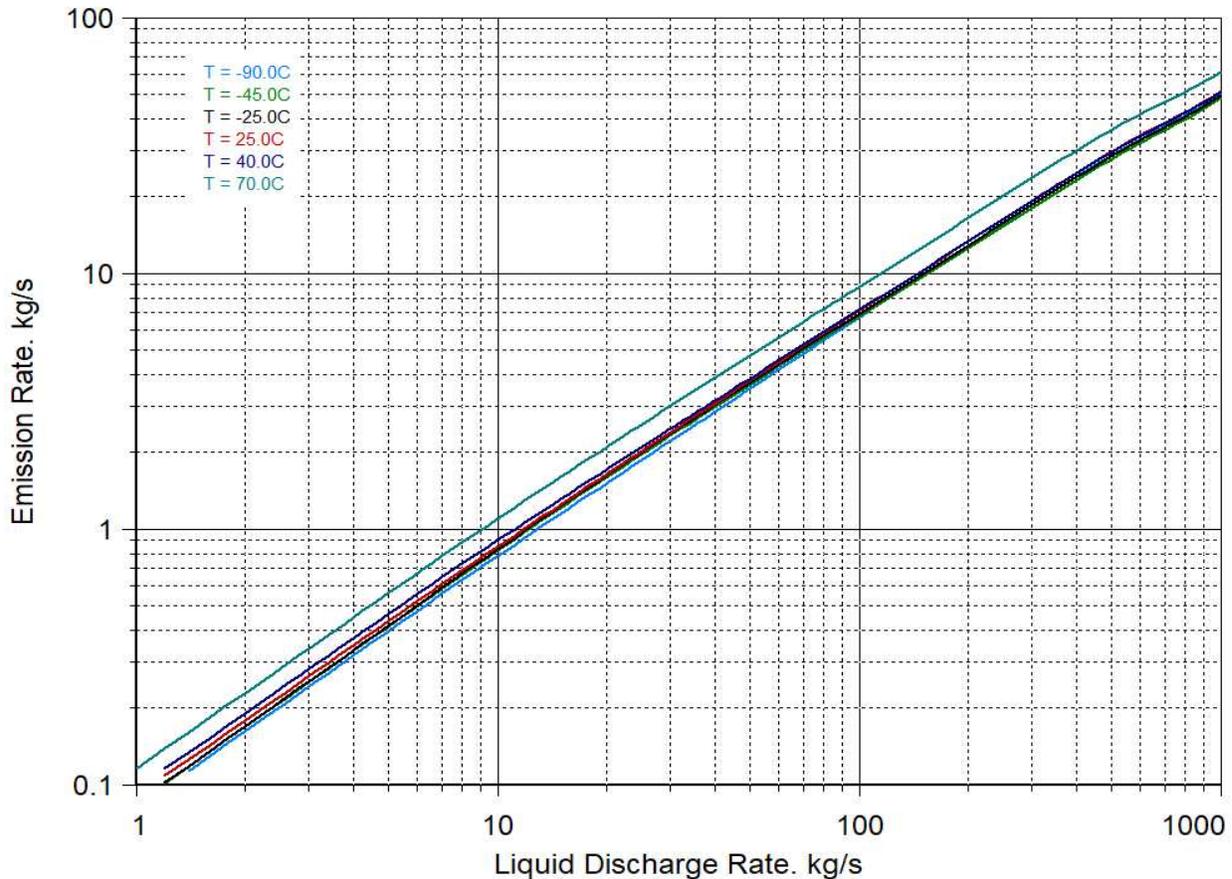
surface will cool down over time leading to less conduction heat gain by the liquid in the pool.

Depending on the spill surface type, liquid can also percolate into the soil and the airborne vapor rates are further reduced. The concentration of the vapor at the liquid pool surface is also less than 100 %, unless the liquid is boiling. For an unbounded liquid vinyl acetate spill at 40 C and 4.5 m/s wind speed on average soil, the surface concentration is estimated to be approximately 10 % which is within the flammable limits.

ERPHA charts will normally include a reduction factor, typically from 10 to 20 %, to account for pool formation and evaporation. The release rate is multiplied by this reduction factor and then used as an emission rate for the dispersion models.

ERPHA charts can also include a liquid pool evaporation chart which allows the user to quickly estimate the maximum or average vaporization rate for a liquid release at different liquid release temperature as well as the expected duration of the evaporation since the evaporation process is slower than the liquid release process. Figure 3 shows such a chart for vinyl acetate at different release temperatures. The average vapor emission rate is approximately 10 % of the liquid release rate, even for a cryogenic liquid release. Higher wind speeds lead to higher emission rates from

liquid pools. As a result, a single liquid pool evaporation chart can be provided at neutral conditions to enable the calculation of emission rate for a specific liquid discharge rate. For example, a 40 kg/s liquid spill at 40 C as shown in Figure erpha:fig2 will result in an average emission rate of 3 kg/s or 7.5 % of the liquid discharge rate.

7   Toxicity Dispersion Charts

Because toxicity limits are typically small, toxicity dispersion charts can be constructed to yield reasonable estimates despite some level of initial dilution that occurs at or near the source for high pressure releases. Transient Gaussian puff models are recommended to use for the development of toxicity dispersion charts. These models can handle the transient nature of flow (duration and rate), source dimensions, low wind conditions, and also can be used to generate dispersion charts for elevated released.

Dispersion distances are significantly influenced by the release duration, flow rate, the source elevation, the surface roughness of terrain, and atmospheric stability and wind speed. For ERPHA charts we normally assume that the entire flow rate becomes airborne for vapor flow and for two-phase flow. There are cases where two-phase flow can result in the formation of liquid droplets and rain-out of the liquid droplets. Liquid rain out forms a liquid pool and evaporates to form another vapor emission source for the dispersing cloud. Although dispersion charts can be further refined to account for liquid rain out and the subsequent evaporation from the liquid pools, this is not normally done for ERPHA charts due to the expected uncertainties surrounding the leak scenario. The charts are intended to yield reasonable and prudent estimates of the potential extent of toxicity impact.

Figure 4 illustrates the impact of source elevation on hazard distances at and ERPG-2 equivalent dose of 4500 ppm-min for vinyl acetate at F stability and a wind speed of 2.6 m/s. The receptor elevation is 1 meter and the surface roughness is also 1 m, which consistent with an industrial site setting.

We note from Figure 4 that elevated releases do not result in impact at ground level close to the source. The impact is realized away from the source. An airborne rate of 2 kg/s (15,873 lb/hr) of vinyl acetate will have no impact for elevated releases where the source elevation is more than 10 meters (32 ft). A ground level release results in downwind distance equal to 400 meters (1,310 ft) and a maximum crosswind distance of 25 meters (80 ft).

Additional ERPHA dispersion charts can be generated at specific release and receptor elevations and multiple toxicity limits as shown in Figure 5.

Ground level impact from elevated releases may only be realized further away from the source. This behavior is illustrated in Figure 6. The maximum centerline concentration profile is shown from an elevated release at 25 m for receptor heights of 1 m and 25 m. We note that the concentration level is zero up to a distance of 135 m from the release location at a receptor height of 1 m. Figure 7 shows the footprint of this elevated release at a concentration limit of 500 pm. The impact at 1 m receptor elevation is not realized up to a distance of 375 m.

Figure 4: Dispersion chart at ERPG-2 equivalent dose for a 10 minute release of Vinyl Acetate. F stability. 2.6 m/s wind speed.
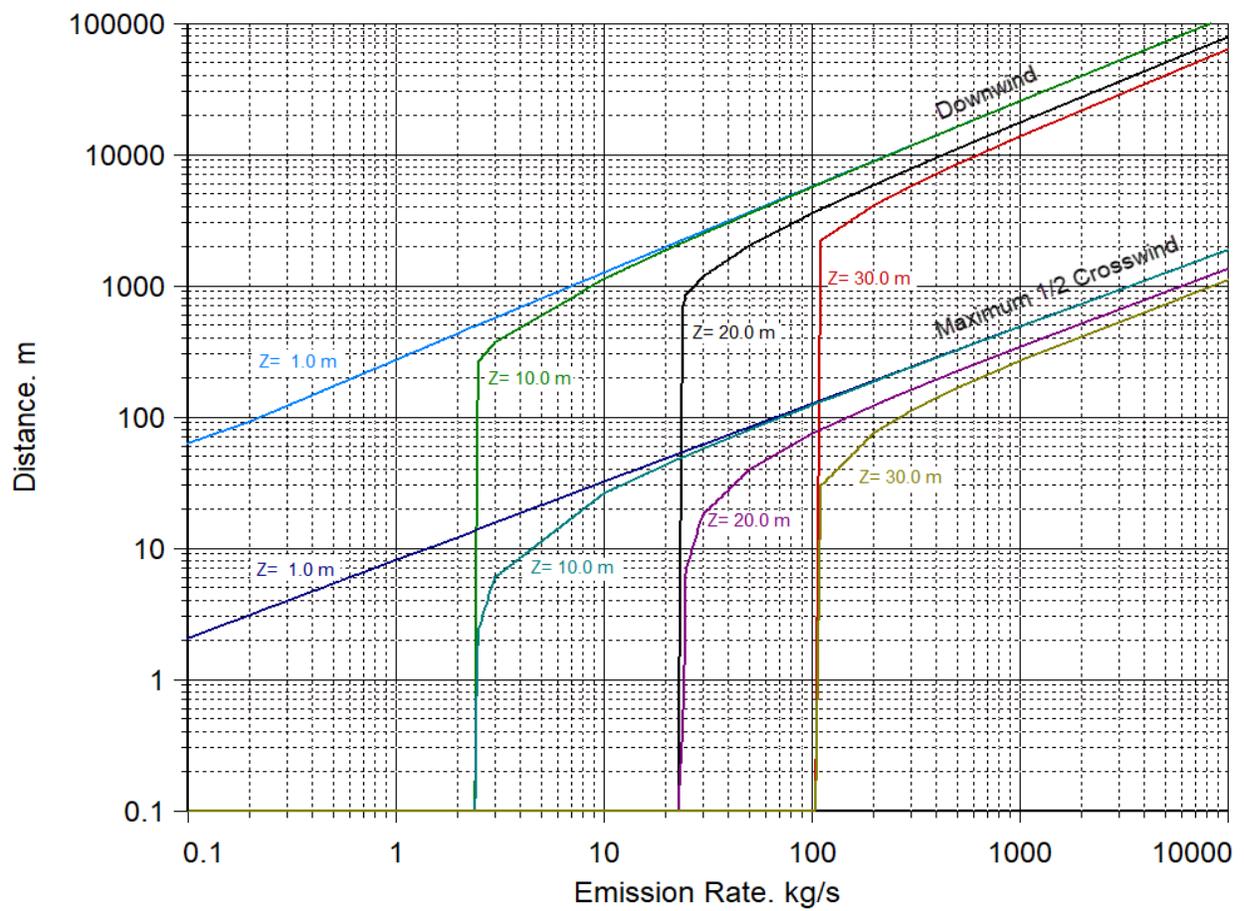
Figure 5: Dispersion chart at ERPG equivalent dose for a 10 minute release of Vinyl Acetate. F
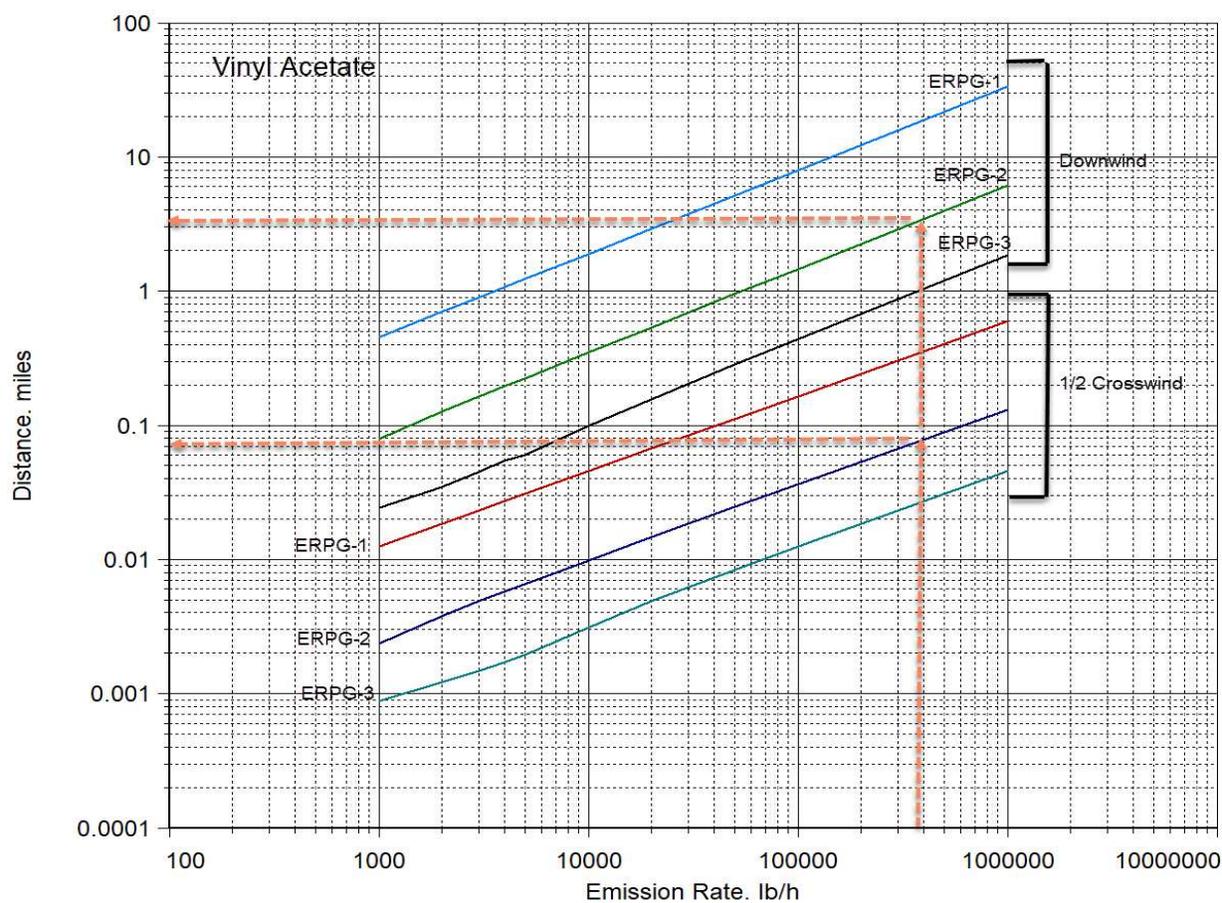stability. 2.0 m/s wind speed.

Figure 6: Typical Gaussian centerline concentration profile from an elevated release
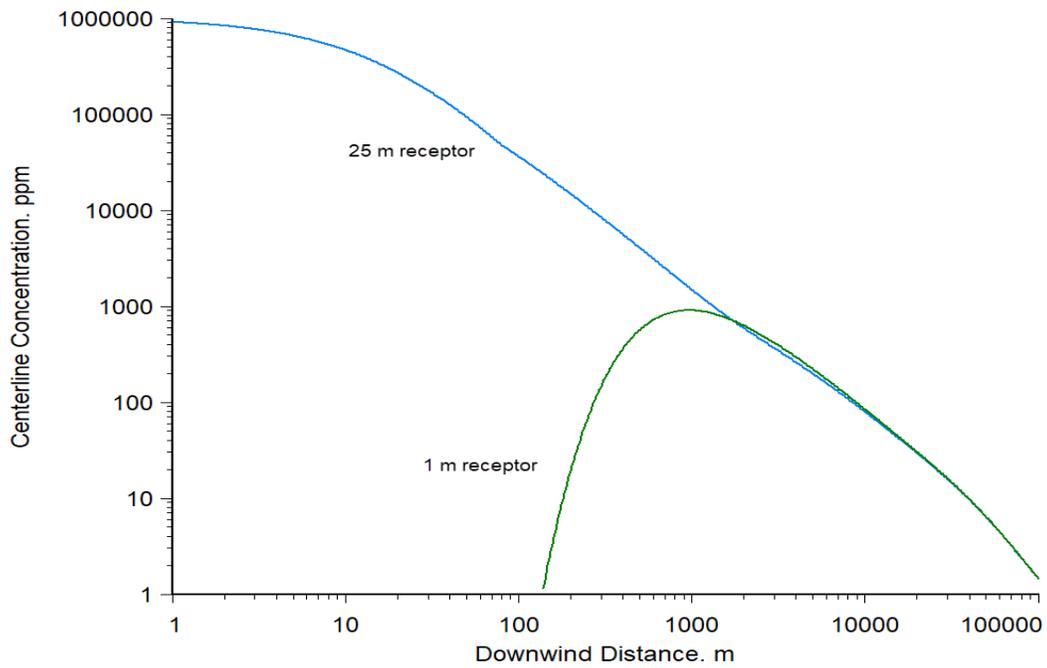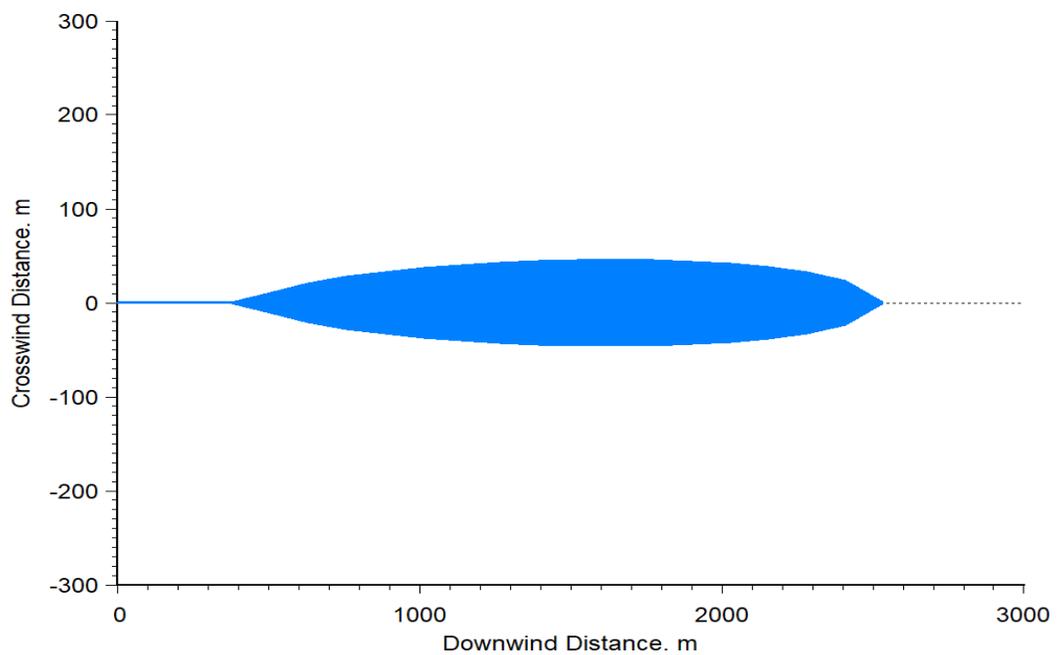

Figure 7: 500 ppm isopleth for elevated release

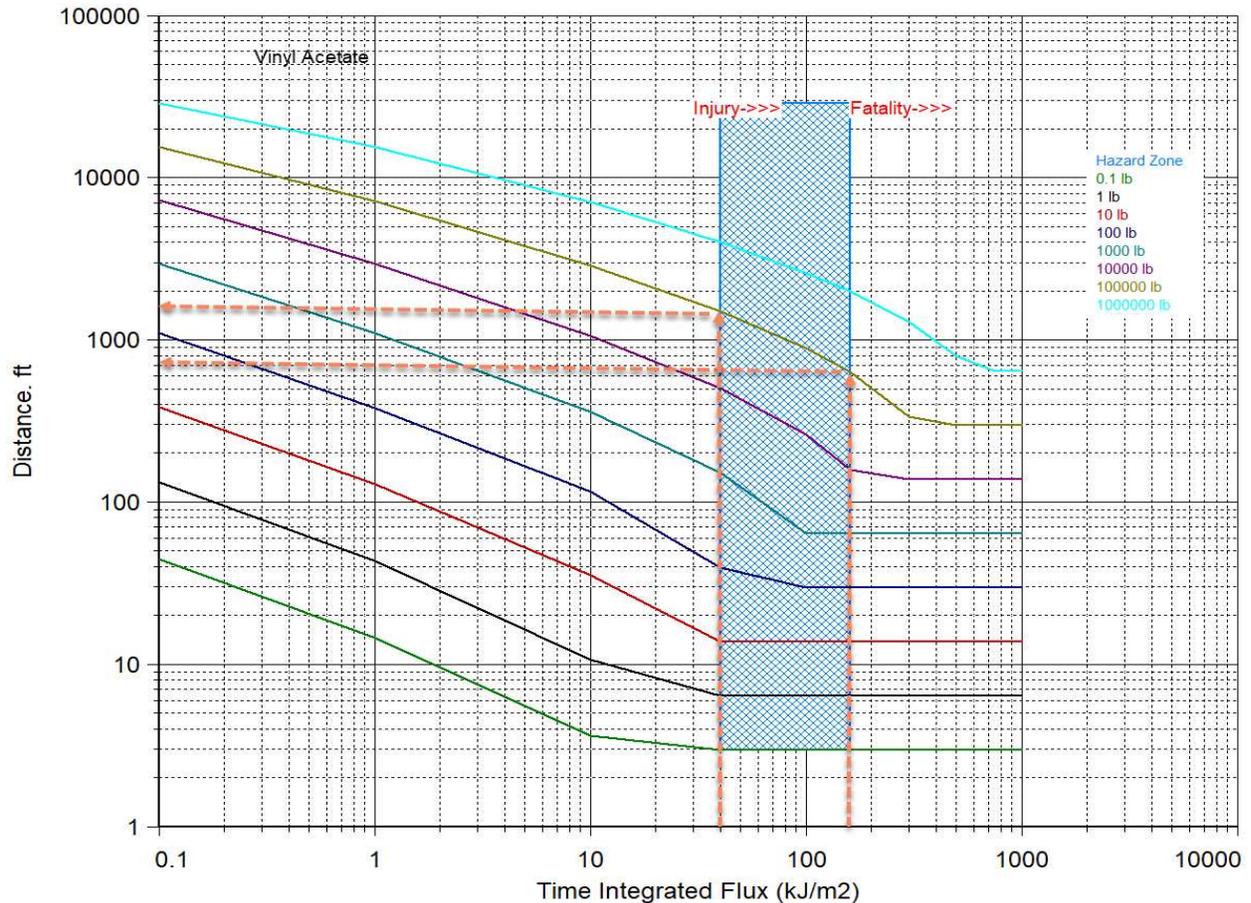Figure 8: Thermal radiation hazards (fireball) for vinyl acetate

8   Fire and Explosion Charts

Fire and explosion hazards depend on the release type/flammability and on whether ignition is immediate or delayed. For example, immediate ignition of a liquid release can result in a pool fire while a delayed ignition may result in a vapor cloud or flash fire and/or a deflagration, followed by a pool fire near the release point. Immediate ignition of a high pressure release can result in a flame jet while a delayed ignition can result in a fireball and/or an explosion followed by a flame jet near the source. We can construct ERPHA charts that can yield conservative estimates of potential hazard zones based on total mass released by considering unconfined vapor cloud explosion and fireball hazards only. Such charts are shown in Figures 8 and 9. Overpressure hazard zones are often established based on total mass released while thermal radiation hazards from fireballs are typically established based on 60 seconds of flow.

Figure 9: Overpressure hazards for vinyl acetate
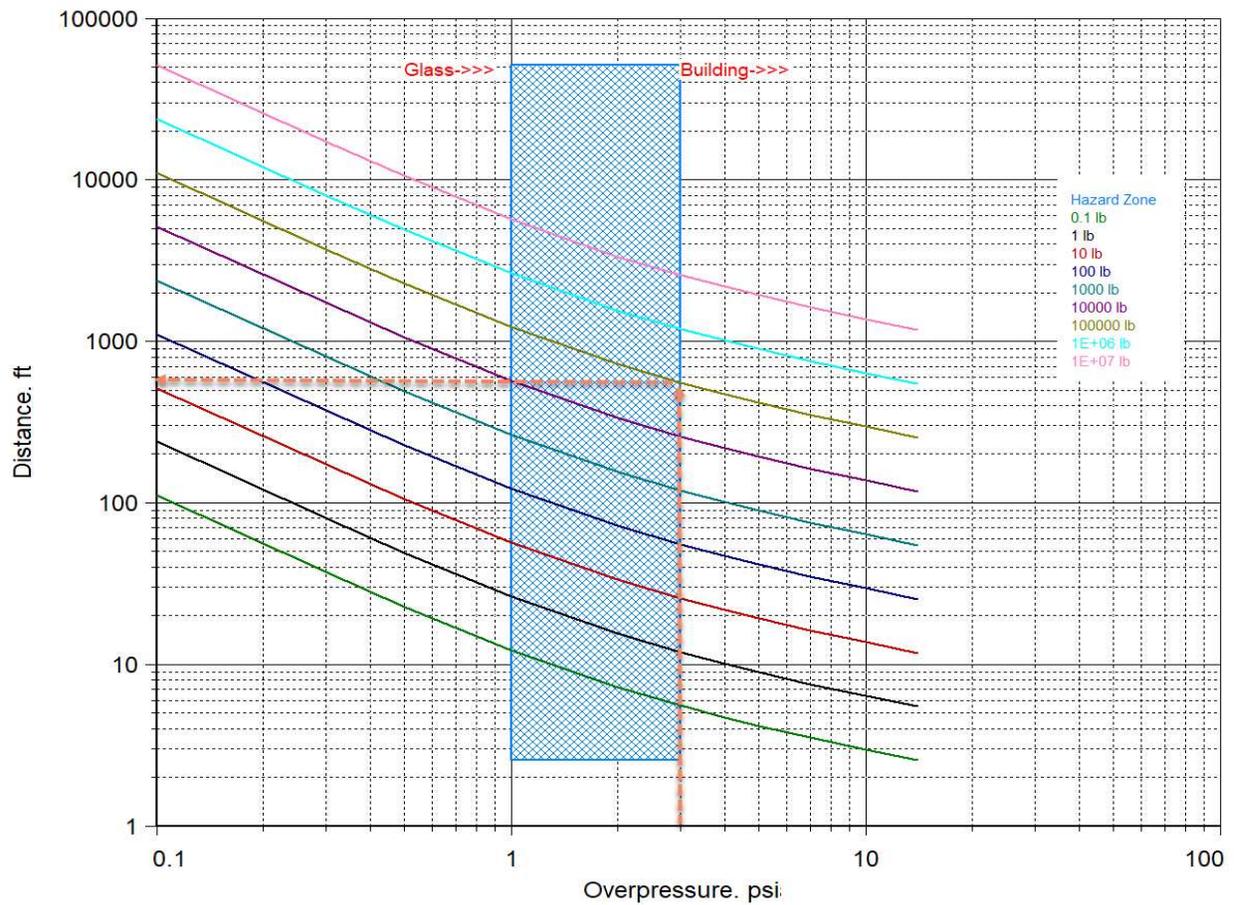
9   Process Hazards Analysis Charts and Data

Additional information that can be provided with ERPHA charts include toxicity, chemical stability, fire and explosion data, corrosion data, and chemical incompatibility data. One or more chemical interaction matrices can be provided to illustrate how a specific chemical interacts with other process chemicals and commonly available substance like water, iron, chlorides, hydrocarbons, etc. This data can help improve the quality and efficiency of a PHA study. Figure 10 illustrates a typical chemical interaction matrix automatically generated by SuperChems Expert.

10   Chemical Specific ERPHA Charts

ioMosaic will periodically publish ERPHA charts for specific chemicals and chemical mixtures. Please visit our web site at www.iomosaic.com to download chemical specific ERPHA charts.

11   Conclusions

ERPHA charts provide quick and reliable methods to include in emergency response plans and systems. These charts can be developed for pure components and for mixtures alike using detailed models. ERPHA flow maps can reduce a myriad of potential releases into simple charts that can be quickly and accurately used by emergency response personnel. ERPHA charts can also improve the quality of PHA and risk assessment studies.

Figure 10: A Simple Chemical Interaction Matrix and Hazards Data for Vinyl Acetate

A 2013 ERPG Values

Table 1: 2013 AIHA Published ERPG Values in ppm

Chemical	CAS	ERPG-1	ERPG-2	ERPG-3
Acetaldehyde	75-07-0	10	200	1000
Acetic Acid	64-19-7	5	35	250
Acetic Anhydride	108-24-7	0.5	15	100
Acrolein	107-02-8	0.05	0.15	1.5
Acrylic Acid	79-10-7	1	50	250
Acrylonitrile	107-13-1	10	35	75
Allyl Chloride	107-05-1	3	40	300
Ammonia	7664-41-7	25	150	750
Arsine	7784-42-1	NA	0.5	1.5
Benzene	71-43-2	50	150	1000
Benzene, ethylenated, by-products from (Dowtherm Q)	68987-42-8	ID	$150 \, \text{mg/m}^3$	ID
Benzoyl Chloride	98-88-4	0.3	5	20
Benzyl Chloride	100-44-7	1	10	50
Beryllium	7440-41-7	NA	$25 \, \mu\text{g/m}^3$	$100 \, \mu\text{g/m}^3$
Bis (Chloromethyl) Ether	542-88-1	ID	0.1	0.5
Boron Trifluoride	7637-07-2	$2 \, \text{mg/m}^3$	$30 \, \text{mg/m}^3$	$100 \, \text{mg/m}^3$
Bromine	7726-95-6	0.1	0.5	5
1,3-Butadiene	106-99-0	10	200	5000
n-Butyl Acetate	123-86-4	5	200	3000
n-Butyl Acrylate	141-32-2	0.05	25	250
n-Butyl Isocyanate	111-36-4	0.01	0.05	1
Carbon Disulfide	75-15-0	1	50	500
Carbon Monoxide	630-08-0	200	350	500
Carbon Tetrachloride	56-23-5	20	100	750
Chlorine	7782-50-5	1	3	20
Chlorine Dioxide	10049-04-4	NA	0.5	3
Chlorine Trifluoride	7790-91-2	0.1	1	10
Chloroacetyl Chloride	79-04-9	0.05	0.5	10
o-Chlorobenzylidene Malononitrile	2698-41-1	$0.005 \, \text{mg/m}^3$	$0.1 \, \text{mg/m}^3$	$25 \, \text{mg/m}^3$
Chloroform	67-66-3	NA	50	5000
Chloromethyl Methyl Ether	107-30-2	NA	1	10
Chloropicrin	76-06-2	0.075	0.15	1.5
Chlorosulfonic Acid	7790-94-5	$2 \, \text{mg/m}^3$	$10 \, \text{mg/m}^3$	$30 \, \text{mg/m}^3$
Chlorotrifluoroethylene	79-38-9	20	100	300
Cobalt Hydrocarbonyl (given as cobalt.)	16842-03-8	ID	$0.9 \, \text{mg/m}^3$	$3.0 \, \text{mg/m}^3$
Crotonaldehyde	4170-30-3	0.2	5	15
Cyanogen Chloride	506-77-4	NA	0.05	4
Diborane	19287-45-7	NA	1	3
1,2-Dichloroethane	107-06-2	50	200	300
2,4-Dichlorophenol	120-83-2	0.2	2	20
Dicyclopentadiene	77-73-6	0.01	5	75

Table 1: 2013 AIHA Published ERPG Values in ppm (continued)

Chemical	CAS	ERPG-1	ERPG-2	ERPG-3
Diethylbenzenes, mixed isomers (Dowtherm J)	25340-17-4	10	100	500
Diketene	674-82-8	1	5	50
Dimethylamine	124-40-3	0.6	100	350
Dimethyl Disulfide	624-92-0	0.01	50	250
Dimethylformamide	68-12-2	2	100	200
Dimethyl Sulfide	75-18-3	0.5	1000	5000
Dowtherm J	25340-17-4	10	100	500
Dowtherm Q	68987-42-8	ID	150 mg/m^3	ID
Epichlorohydrin	106-89-8	5	20	100
Ethanol	64-17-5	1800	3300	NA
Ethyl Acrylate	140-88-5	0.01	30	300
Ethyl Chloroformate	541-41-3	ID	5	10
2-Ethyl hexanol	104-76-7	0.1	100	200
Ethylene Oxide	75-21-8	NA	50	500
Ethylidene Norbornene	16219-75-3	0.2	100	500
Fluorine	7782-41-4	0.5	5	20
Fluorosulfonic acid	7789-21-1	2 mg/m^3	10 mg/m^3	30 mg/m^3
Formaldehyde	50-00-0	1	10	40
Furfural	98-01-1	2	10	100
Gasoline	86290-81-5	200	1000	4000
Gluteraldehyde	111-30-8	0.2	1	5
HCFC-123 (2,2-Dichloro-1,1,1-Trifluoroethane)	306-83-2	ID	1000	10,000
HCFC-124 (2-Chloro-1,1,1,2-Tetrafluoroethane)	2837-89-0	1,000	5,000	10,000
HCFC-142b (1-Chloro-1,1-Difluoroethane)	75-68-3	10,000	15,000	25,000
Hexachlorobutadiene	87-68-3	1	3	10
Hexafluoroacetone	684-16-2	NA	1	50
Hexafluoropropylene	116-15-4	10	50	500
1-Hexene	592-41-6	NA	500	5,000
HFC-152a (1,1-Difluoroethane)	75-37-6	10000	15000	25000
HFO-1234yf (2,3,3,3-Tetrafluoropropene)	754-12-1	NA	24000	NA
HFO-1234ze (1,3,3,3-Tetrafluoropropylene)	29118-24-9	NA	15000	69000
Hydrazine	302-01-2	0.5	5	30
Hydrogen Chloride	7647-01-0	3	20	150
Hydrogen Cyanide	74-90-8	NA	10	25
Hydrogen Fluoride	7664-39-3	2	20	50
Hydrogen Peroxide	7722-84-1	10	50	100
Hydrogen Selenide	7783-07-5	N/A	0.2	2
Hydrogen Sulfide	7783-06-4	0.1	30	100
Iodine	7553-56-2	0.1	0.5	5
Isobutyronitrile	78-82-0	10	50	200
2-Isocyanatoethyl Methacrylate	30674-80-7	ID	0.1	1
Isoprene	78-79-5	5	1000	4000
Isopropyl Chloroformate	108-23-6	ID	5	20
Lithium Hydride	7580-67-8	0.025 mg/m^3	0.1 mg/m^3	0.5 mg/m^3
Maleic Anhydride	108-31-6	0.2	2	20

Table 1: 2013 AIHA Published ERPG Values in ppm (continued)

Chemical	CAS	ERPG-1	ERPG-2	ERPG-3
MDI (Methylene Diphenyl Diisocyanate)	101-68-8	NA	$5\,\mathrm{mg/m^3}$	$55\,\mathrm{mg/m^3}$
Mercury Vapor	7439-97-6	N/A	0.25	0.5
Methanol	67-56-1	200	1000	5000
Methyl Bromide	74-83-9	NA	50	200
Methyl Chloride	74-87-3	150	1000	3000
Methyl Chloroformate	79-22-1	NA	2	5
Methyl Iodide	74-88-4	25	50	125
Methyl Isocyanate	624-83-9	0.025	0.25	1.5
Methyl Mercaptan	74-93-1	0.005	25	100
Methyl tert-Butyl Ether	1634-0404	50	1000	5000
Methylene Chloride	75-09-2	300	750	4000
Methylene Diphenyl Diisocyanate (MDI)	101-68-8	$0.2\,\mathrm{mg/m^3}$	$2\,\mathrm{mg/m^3}$	$25\,\mathrm{mg/m^3}$
Monomethylamine	74-89-5	10	100	500
Nitric Acid WFNA	7697-37-2	1	10	78
Nitrogen Dioxide	10102-44-0	1	15	30
Nitrogen Trifluoride	7783-54-2	NA	400	800
1-Octanol	111-87-5	5	20	150
1-Octene	111-66-0	40	800	2000
Oleum	8014-95-7	$2\,\mathrm{mg/m^3}$	$10\,\mathrm{mg/m^3}$	$120\,\mathrm{mg/m^3}$
Perchloroethylene	127-18-4	100	200	1000
Perfluoroisobutylene	382-21-8	NA	0.1	0.3
Phenol	108-95-2	10	50	200
Phosgene	75-44-5	NA	0.5	1.5
Phosphine	7803-51-2	NA	0.5	5
Phosphoric Acid	7664-38-2	$3\,\mathrm{mg/m^3}$	$30\,\mathrm{mg/m^3}$	$150\,\mathrm{mg/m^3}$
Phosphorus Pentoxide	1314-56-3	$1\,\mathrm{mg/m^3}$	$10\,\mathrm{mg/m^3}$	$50\,\mathrm{mg/m^3}$
Phosphorus Trichloride	7719-12-2	0.5	3	15
Propylene Glycol Methyl Ether Acetate	108-65-6 α-isomer	50	1000	5000
Propylene Glycol Methyl Ether Acetate	70657-70-4 β-isomer	50	1000	5000
Propylene Oxide	75-56-9	50	250	750
Silane, Dimethyldichloro	75-78-5	2	10	75
Silane, Methyltrichloro	75-79-6	0.5	3	15
Silane, Tetrachloro	10026-04-7	0.75	5	37
Silane, Tetraethoxy	78-10-4	25	100	300
Silane, Tetramethoxy	681-84-5	NA	10	20
Silane, Trichloro	10025-78-2	1	3	25
Silane, Triethoxy	998-30-1	0.5	4	10
Silane, Trimethoxy	2487-90-3	0.5	2	5
Silane, Trimethylchloro	75-77-4	3	20	150
Silane, Vinyl Trichloro	75-94-5	0.5	5	50
Sodium Hydroxide	1310-73-2	$0.5\,\mathrm{mg/m^3}$	$5\,\mathrm{mg/m^3}$	$50\,\mathrm{mg/m^3}$
Stibine	7803-52-3	ID	0.5	1.5
Styrene	100-42-5	50	250	1000
Sulfur Dioxide	7446-09-5	0.3	3	25
Sulfuric Acid (Oleum)	8014-95-7	$2\,\mathrm{mg/m^3}$	$10\,\mathrm{mg/m^3}$	$120\,\mathrm{mg/m^3}$

Table 1: 2013 AIHA Published ERPG Values in ppm (continued)

Chemical	CAS	ERPG-1	ERPG-2	ERPG-3
Sulfur Trioxide	7446-11-9	2 mg/m^3	10 mg/m^3	120 mg/m^3
Sulfuric Acid	7664-93-9	2 mg/m^3	10 mg/m^3	120 mg/m^3
Sulfuryl Chloride	7791-25-5	0.3	3	15
Tetrafluoroethylene	116-14-3	200	1000	10,000
Tetrahydrofuran	109-99-9	100	500	5000
Thionyl Chloride	7719-09-7	0.2	2	10
Titanium Tetrachloride	7550-45-0	5 mg/m^3	20 mg/m^3	100 mg/m^3
Toluene	108-88-3	50	300	1000
Toluene 2,4- (2,6-) Diisocyanate (TDI)	584-84-9 and 91-08-7	0.01	0.15	0.6
1,1,1-Trichloroethane	71-55-6	350	700	3500
Trichloroethylene	79-01-6	100	500	5000
Trimethylamine	75-50-3	0.1	100	500
Triuranium Octaoxide	1344-59-8	ID	10 mg/m^3	50 mg/m^3
Uranium Dioxide	1344-57-6	ID	10 mg/m^3	30 mg/m^3
Uranium Hexafluoride	7783-81-5	5 mg/m3	15 mg/m^3	30 mg/m^3
Uranium Trioxide	1344-58-7	ID	0.5 mg/m^3	3 mg/m^3
Vinyl Acetate	108-05-4	5	75	500
Vinyl Chloride	75-01-4	500	5000	20,000
Vinylidene Chloride	75-35-4	ID	500	1000

NA not appropriate

ID insufficient data

a This level is 25 % of LEL

b This level is 10 % of LEL

About the Author

Dr. Melhem is an internationally known pressure relief and flare systems, chemical reaction systems, process safety, and risk analysis expert. In this regard he has provided consulting, design services, expert testimony, incident investigation, and incident reconstruction for a large number of clients. Since 1988, he has conducted and participated in numerous studies focused on the risks associated with process industries fixed facilities, facility siting, business interruption, and transportation.

Prior to founding ioMosaic Corporation, Dr. Melhem was president of Pyxsys Corporation; a technology subsidiary of Arthur D. Little Inc. Prior to Pyxsys and during his twelve years tenure at Arthur D. Little, Dr. Melhem was a vice president of Arthur D. Little and managing director of its Global Safety and Risk Management Practice and Process Safety and Reaction Engineering Laboratories.

Dr. Melhem holds a Ph.D. and an M.S. in Chemical Engineering, as well as a B.S. in Chemical Engineering with a minor in Industrial Engineering, all from Northeastern University. In addition, he has completed executive training in the areas of Finance and Strategic Sales Management at the Harvard Business School. Dr. Melhem is a Fellow of the American Institute of Chemical Engineers (AIChE) and Vice Chair of the AIChE Design Institute for Emergency Relief Systems (DiERS).

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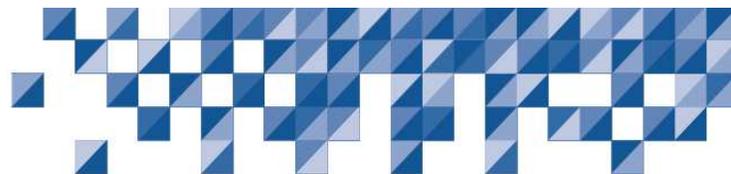E-mail. melhem@iomosaic.com

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