NATIONAL TRANSPORTATION SAFETY BOARD
Investigative Hearing
Norfolk Southern Railway general merchandise freight train 32N derailment with subsequent hazardous material release and fires, in East Palestine, Ohio, on February 3, 2023

GROUP	D
EXHIBIT	
58	

Agency / Organization

Norfolk Southern Railway

Title

CHARM model BLEVE catastrophic failure theoretical outcomes for East Palestine, Ohio.

VC Railcar Catastrophic Failure

Theoretical Outcomes

-- Not Actual -- Developed for Planning Purposes only --

Disclaimer

- Model was produced in the absence of specific site conditions or details regarding the nature of flame impingement or status of railcar's contents.
- This model could under-predict catastrophic outcomes resulting from conditions not reflected herein.
- The CHARM model was used within the realm of its capacities. Some variables may not be accounted for, thus the model's run details and function calculations have been included for transparency.
- Models can only provide a range of potential outcomes rendered less effective if input data is incorrect or mis-representative.

Scenario Characteristics

- CHARM Model used (https://www.charmmodel.com/)
- 105J300 VC Railcar
  - 27,600 gallons instantly released by pressure rupture of railcar
  - 48ft tank length, 9.9 ft tank diameter (Greenbrier Pressure Tank Car Specs)
- Explosion overpressure
  - Railcar pressure – 225 psi (safety valve rating of 105J300)
  - 27,600 gallons released
  - Detonation (flame speed Mach 1) occurring < 1s after vapor release
- BLEVE Radiation
  - Depicts thermal radiation as a result of fireball from full vapor detonation

Explosion Overpressure

Depicting pressure wave from vapor cloud explosion 1 second after total railcar release.

Complex Hazardous Air Release Model (CHARM®)

Technical Reference Manual

By Mark W. Eltgroth, Ph.D.

7.0 EXPLOSION OVERPRESSURES

CHARM calculates overpressures or shockwave pressures for two scenarios: a sphere bursting due to failure of the vessel and an unconfined vapor cloud explosion. Both of these phenomena are modeled using methods from Baker et al. (1983).

7.1 Sphere Burst Overpressure

Although the equations described here are strictly for the mechanical failure of a pressurized sphere, they are used for all cases of pressurized failure. A mechanical failure, such as in an instantaneous gas release, is always assumed to be from a spherical vessel.

Two important factors in a pressurized vessel failure shockwave calculation are the storage pressure and the amount of material stored. Pressure has the units of energy density and describes the amount of energy available for shockwave formation.

The equation for calculating the maximum overpressure of a sphere burst is provided by Liepman and Roshko (1967):

$$\frac{p_1}{p_0} = \frac{p_{s0}}{p_0}\left\{1 - \frac{(\gamma_1 - 1)\left(\frac{a_0}{a_1}\right)\left(\frac{p_{s0}}{p_0} - 1\right)}{\sqrt{2\gamma_0\left[2\gamma_0 + (\gamma_0 + 1)\left(\frac{p_{s0}}{p_0} - 1\right)\right]}}\right\}^{\left(\frac{-2\gamma_1}{\gamma_1 - 1}\right)} \quad \textbf{(7-1)}$$

where p_1 = pressure inside the sphere;
p_0 = atmospheric pressure;
p_{s0} = air shock pressure at the instant of burst;
γ_1 = C_p/C_v for gas in sphere;
γ_0 = C_p/C_v for air;
C_p = specific heat at constant pressure;
C_v = specific heat at constant volume;
a_0 = speed of sound in air; and
a_1 = speed of sound in sphere;

The parameter that must be solved for by iteration, is p_{s0}/p_0.

The value used in CHARM is the overpressure ($\overline{P}_S$), which is defined as follows:

$$\overline{P}_S = \frac{p_s}{p_0} - 1 \quad \textbf{(7-2)}$$

At the sphere surface, the overpressure equation is:

$$\overline{P}_{S0} = \frac{p_{s0}}{p_0} - 1 \quad \textbf{(7-3)}$$

The other parameter required for predicting the overpressure at distances downwind is an energy-scaled radius ($\overline{R}$). At the surface of the sphere, the energy-scaled radius ($\overline{R}_1$) given by Baker is:

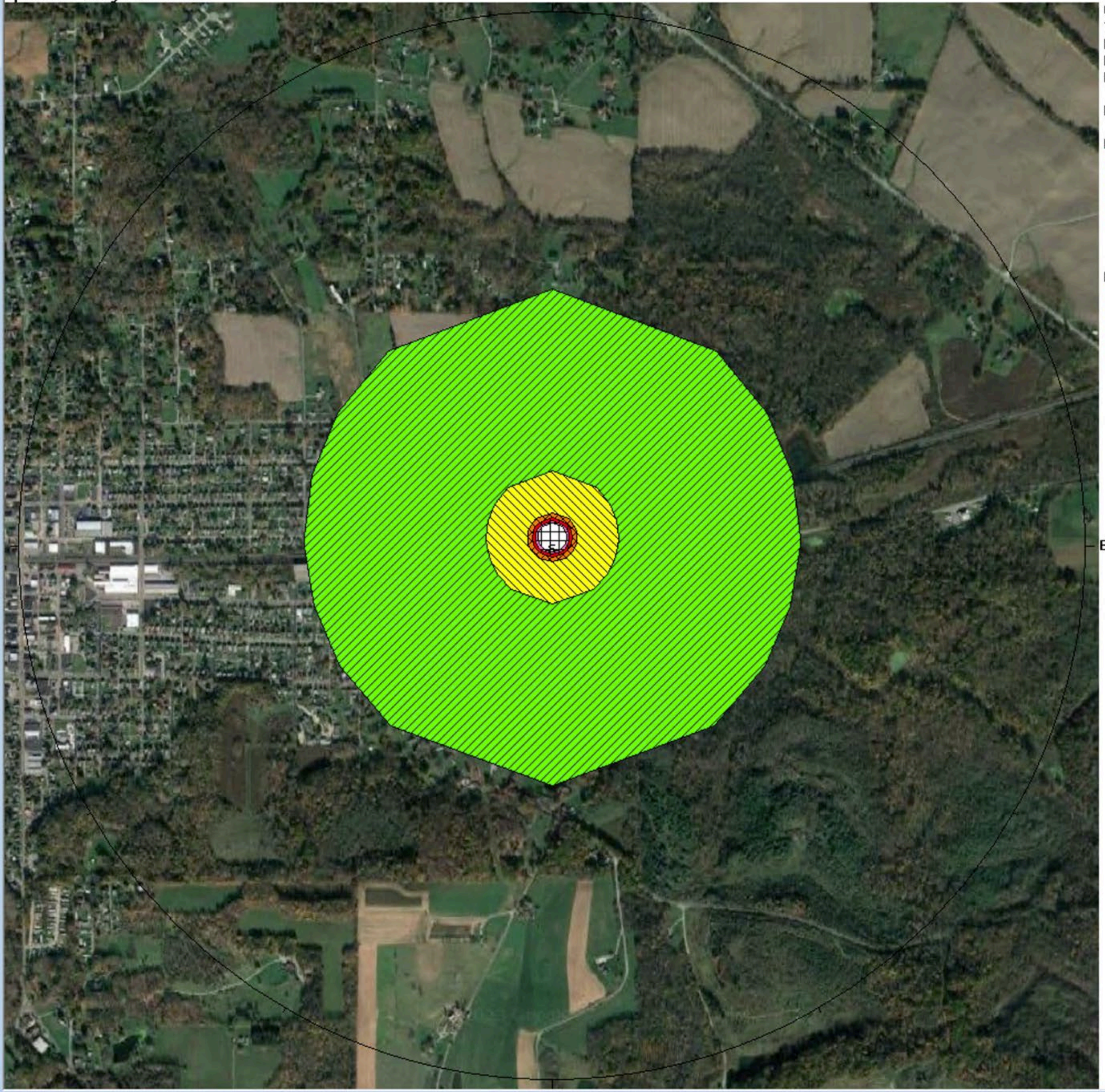
$$\overline{R}_1 = \left[\frac{3(\gamma_1 - 1)}{4\pi\left(\frac{p_1}{p_0} - 1\right)}\right]^{\frac{1}{3}} = \frac{r_1}{R_0} \quad \textbf{(7-4)}$$

where r_1 = radius of the sphere;
R_0 = energy radius
$= \left(\frac{E}{p_0}\right)^{\frac{1}{3}}$
E $= \left(\frac{p_1 - p_0}{\gamma_1 - 1}\right)V_1$; and
V_1 = volume of sphere.

Once the values of $\overline{P}_S$ and $\overline{R}$ are known at the sphere surface, a curve that agrees with these values can be selected from Figure 7-1. Once a curve is selected, if either value, $\overline{R}$ or $\overline{P}_S$, is known, the other can be calculated. The curves shown in Figure 7-1 have been digitized, and CHARM interpolates the actual curve to use once the conditions at the sphere surface are known. The dimensional pressure and radius can be found by multiplying the dimensionless overpressures and radii by p_0 and R_0, respectively.

Vapor Cloud Explosion 7

105J300 Vinyl Chloride Railcar
Species: Vinyl Chloride



Vapor Cloud Explosion
Time: 00=01
Height: 0 ft
Radius: 5000 ft
Plot Scale 1:30676

Flame Spd(M): 0.147

Hatch	Pres(psi)	Max Dist
green	0.58	2408 ft
yellow	2.18	703 ft
orange	5.8	316 ft
red	7.25	269 ft
pink	10.2	242 ft
white	14.5	218 ft

Hatch	Pres(bar)	Max Width
green	0.04	4650 ft
yellow	0.15	1240 ft
orange	0.4	465 ft
red	0.5	372 ft
pink	0.7	317 ft
white	1	270 ft

Overpressure Damage Estimates

The following are the peak pressures formed in excess of normal atmospheric pressure by blast and shock waves:

Overpressure (psi) Note:1 bar = 14.5 psi	Expected Damage
0.03	Occasional breaking of large windows already under stress.
0.04	Loud noise (143 dB); sonic boom glass failures.
0.10	Breakage of small windows under strain.
0.15	Typical pressure for glass failure.
0.30	Some damage to house ceilings; 10% window glass breakage.
0.40	Limited minor structural damage.
0.50-1.0	Windows usually shattered; some window frame damage.
0.7	Minor damage to house structures.
1.0	Partial Demolition of houses; made uninhabitable.
1.0-2.0	Corrugated metal panels fail and buckle. Housing wood panels blown in.
1.0-8.0	Range for slight to serious injuries due to skin lacerations from flying glass and other missiles.
1.3	Steel frame of clad building slightly distorted.
2.0	Partial collapse of walls and roofs of houses.
2.0-3.0	Non-reinforced concrete of cinder block walls shattered.
2.3	Lower limit of serious structural damage.
2.4-12.2	Range for 1-90% eardrum rupture among exposed populations.
2.5	50% destruction of home brickwork.
3.0	Steel frame building distorted and pulled away from foundation.
3.0-4.0	Frameless steel panel building ruined.
4.0	Cladding of light industrial buildings ruptured.
5.0	Wooded utility poles snapped.
5.0-7.0	Nearly complete destruction of houses.
7.0	Loaded train wagins overturned.
7.0-8.0	8-12 in. thick non-reinforced brick fail by shearing of flexure.
9.0	Loaded train box cars demolished.
10.0	Probable total building destruction.
15.5-29.0	Range for 1-99% fatalities among exposed populations due to direct blast effects.

Source: Lees, F.P, Loss Prevention in the Process Industries, Vo,. 1, Butterworths, London and Boston, 1980.

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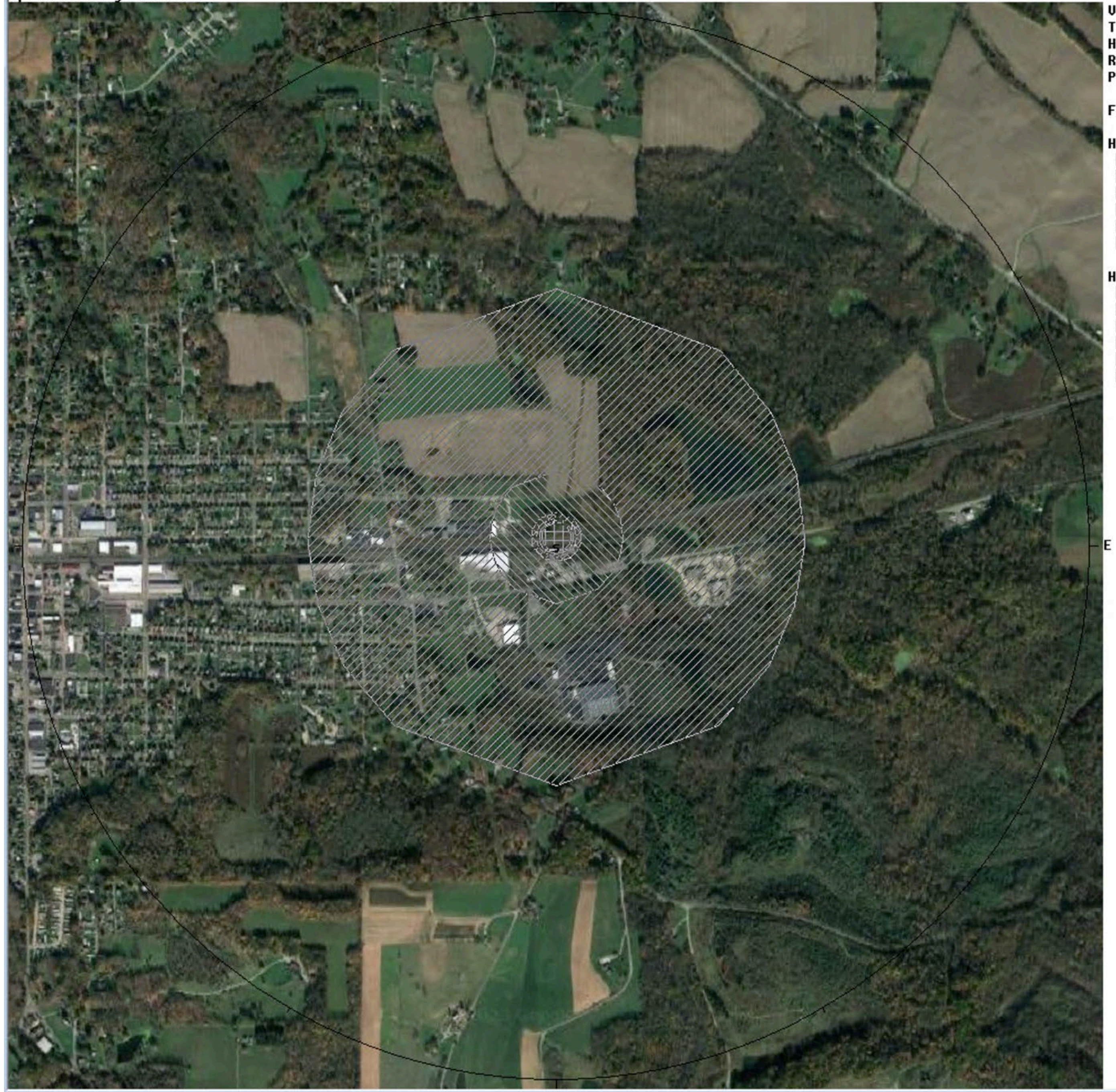

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Study - projectile range of fragments from VC BLEVE Events – analysis of > 100 vessel failures

“The range distribution for LPG, vinyl chloride monomer and ammonia are fairly similar, although no very long ranges have been observed in this sample from ammonia vessels. As a rough guideline it might be assumed that 80% of fragments will travel less than 200m, the remainder travelling anything up to about 1km.”

Holden, P. L., & Reeves, A. B. (1985). Fragment hazards from failures of pressurized liquefied gas vessels. In *IchemE symposium series* (Vol. 93, pp. 205-220).

IChemE SYMPOSIUM SERIES No. 93

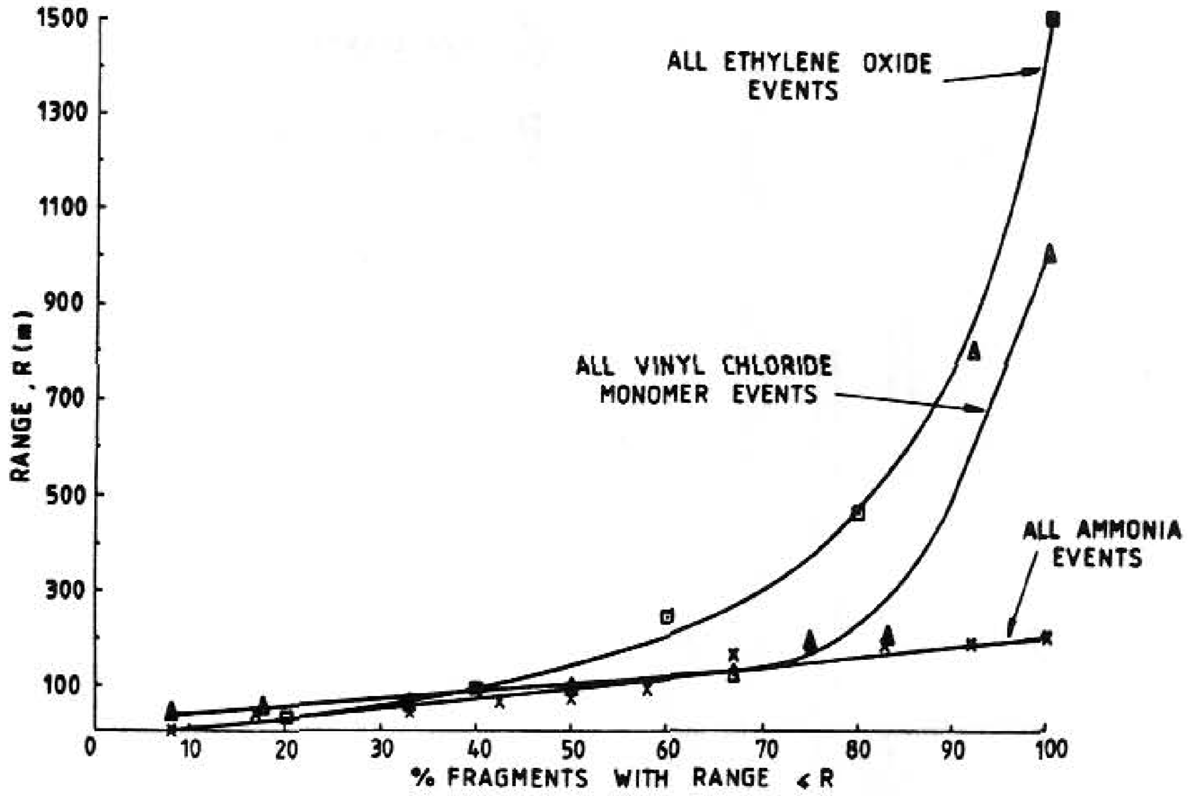

FIG. 3 RANGE Vs. % FRAGMENTS FOR VARIOUS CHEMICALS

BLEVE Radiation

Depicting thermal radiation resulting from BLEVE and subsequent fireball of vapor

5.0 FIREBALL/BLEVE ALGORITHM

The Fireball/BLEVE (Boiling Liquid Expanding Vapor Explosion) algorithm is one of the simplest in CHARM; only a few equations must be solved. The method comes from Moorhouse and Pritchard (1982) and Roberts (1982). Instead of being derived from fundamental principles, the BLEVE equations are parametric.

5.1 Calculation of the Efficiency of Explosion

An efficiency of explosion is either entered by the user or calculated by CHARM. If calculated, the explosion efficiency (ν) is a function of the vapor pressure of the material and is:

$$\nu = 0.27 P_S^{0.32} \quad \textbf{(5-1)}$$

where P_S = vapor pressure in Pascals of the chemical at the storage pressure.

The radius (R_f) of the ensuing fireball (in meters) is calculated as follows:

$$R_f = 2.665\, m_{kg}^{0.327} \quad \textbf{(5-2)}$$

where m_{kg} = mass of material in kilograms involved in the explosion.

The duration (Tf) of the fireball in seconds is given as:

$$T_f = 1.089\, m_{kg}^{0.327} \quad \textbf{(5-3)}$$

Finally, the amount of radiation (W) being emitted is given as:

$$W = \frac{H_c\, m_{kg}\, \nu 1000}{T_f} \quad \textbf{(5-4)}$$

where W = energy emission rate in watts; and
Hc = heat of combustion of the material in Joules per gram.

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5.2 Calculation of Fluxes

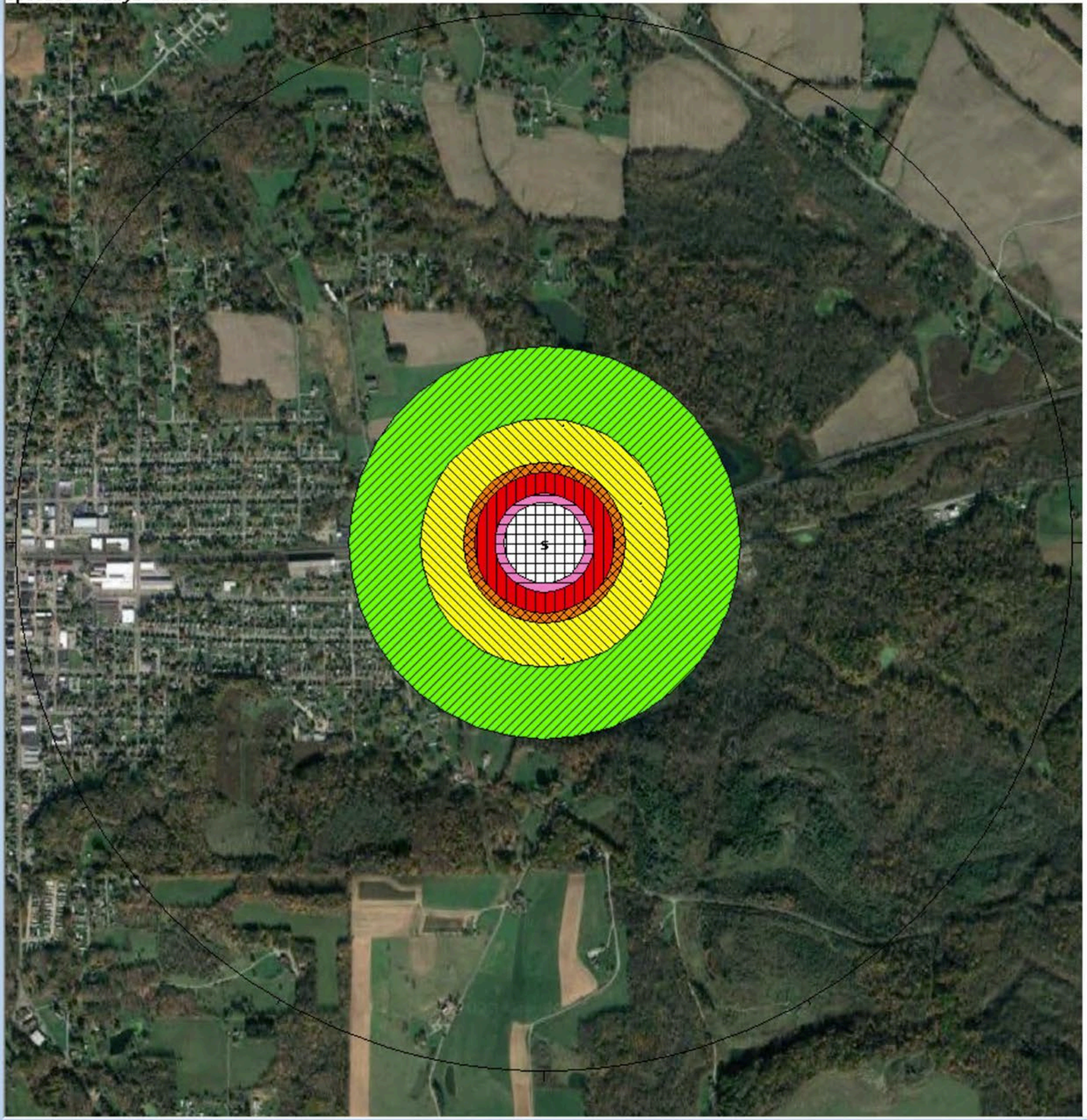
Once the energy emission rate (W) is calculated, the fluxes can be determined at any distance from the source. The fireball is assumed to be a point source. As such, the flux (F) at some distance (r) from the fireball can be calculated using the inverse square property of radiation:

$$F = \frac{W}{4\pi r^2} \quad \textbf{(5-5)}$$

Because the fireball is assumed to be a point source, either F or r can be specified and the other parameter calculated.

BLEVE Radiation 4

105J300 Vinyl Chloride Railcar
Species: Vinyl Chloride



BLEVE Radiation
Height: 0 ft
Radius: 5000 ft
Plot Scale 1:30676

Duration: 46.7 sec
Heat Rate: 6.42e+06 kW
Flame center: 0 ft
Flame radius: 375 ft
Burn Efficency: 0.16
RMP Dist: 1049 ft

Flux Units: kW/m²

Hatch	Flux	Radius
	1.6	1854 ft
	4	1172 ft
	9.5	761 ft
	12.5	663 ft
	25	469 ft
	37.5	383 ft

Hatch	Flux	P(fatal)
	1.6	0.00
	4	0.00
	9.5	0.01
	12.5	0.08
	25	0.82
	37.5	0.99

Eose: (kW/m²)^(4/3)-sec

Hatch	Flux	Dose
	1.6	87.39
	4	296.50
	9.5	939.53
	12.5	1354.65
	25	3413.50
	37.5	5861.22

Thermal Radiation Damage Estimates

The following are thermal radiation flux values and the expected damage estimates associated with each:

Radiation intensity (kW/m2)	Expected Damage
1.6	Will cause no discomfort for long exposure.
4.0	Sufficient to cause pain to personnel if unable to reach cover within 20 seconds; however, blistering of the skin (second degree burns) is likely; 0% lethality.
9.5	Pain threshold reached after 8 seconds; second degree burns after 20 seconds.
12.5	Minimum energy required for piloted ignition of wood; melting of plastic tubing.
25.0	Minimum energy required to ignite wood at indefinitely long exposures (nonpiloted).
37.5	Sufficient to cause damage to process equipment.

Source: *Guidelines for Chemical Process Quantitative Risk Analysis*, American Institute of Chemical Engineers Center for Chemical Process Safety, NY, NY, 1989.

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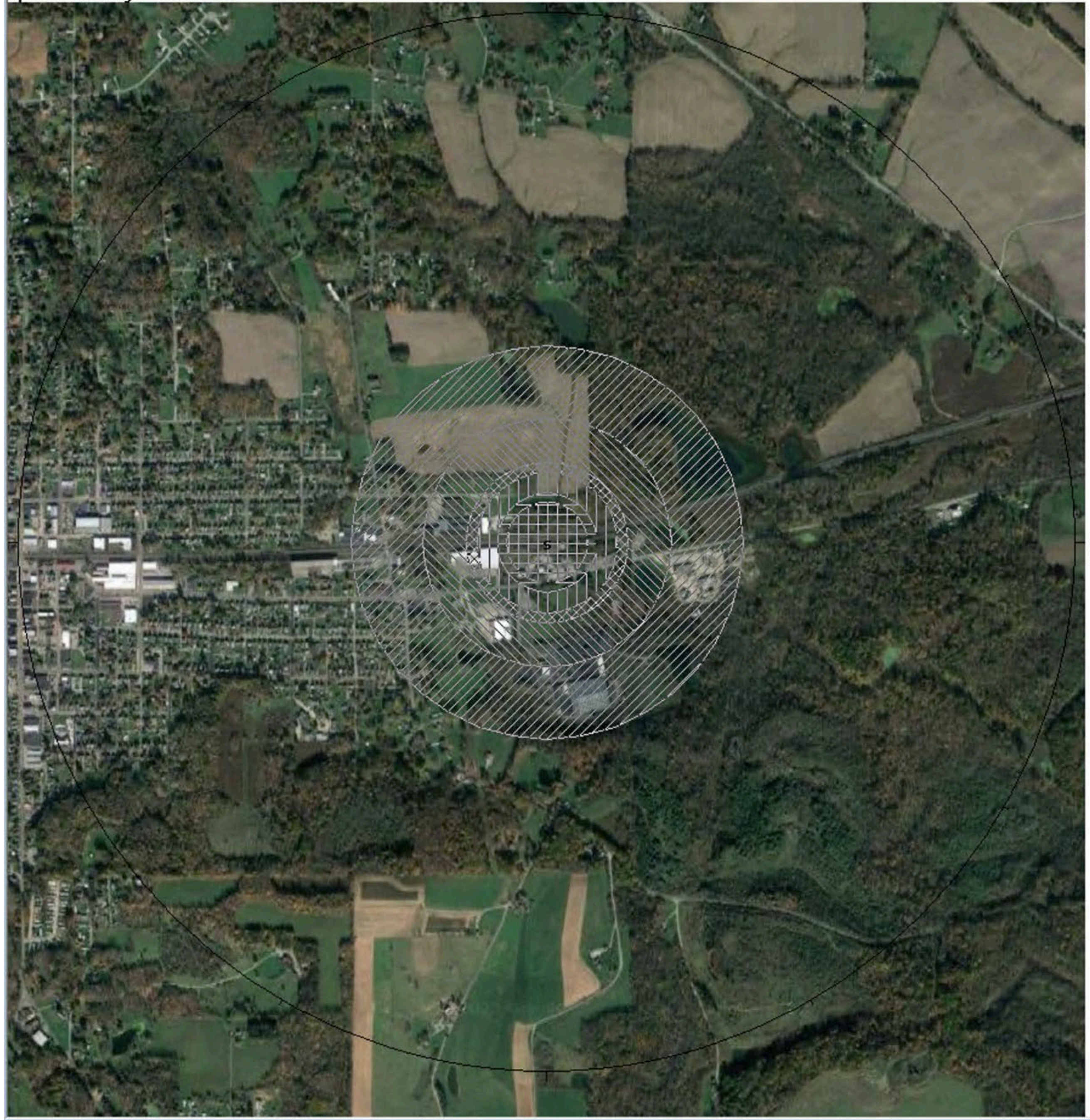

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