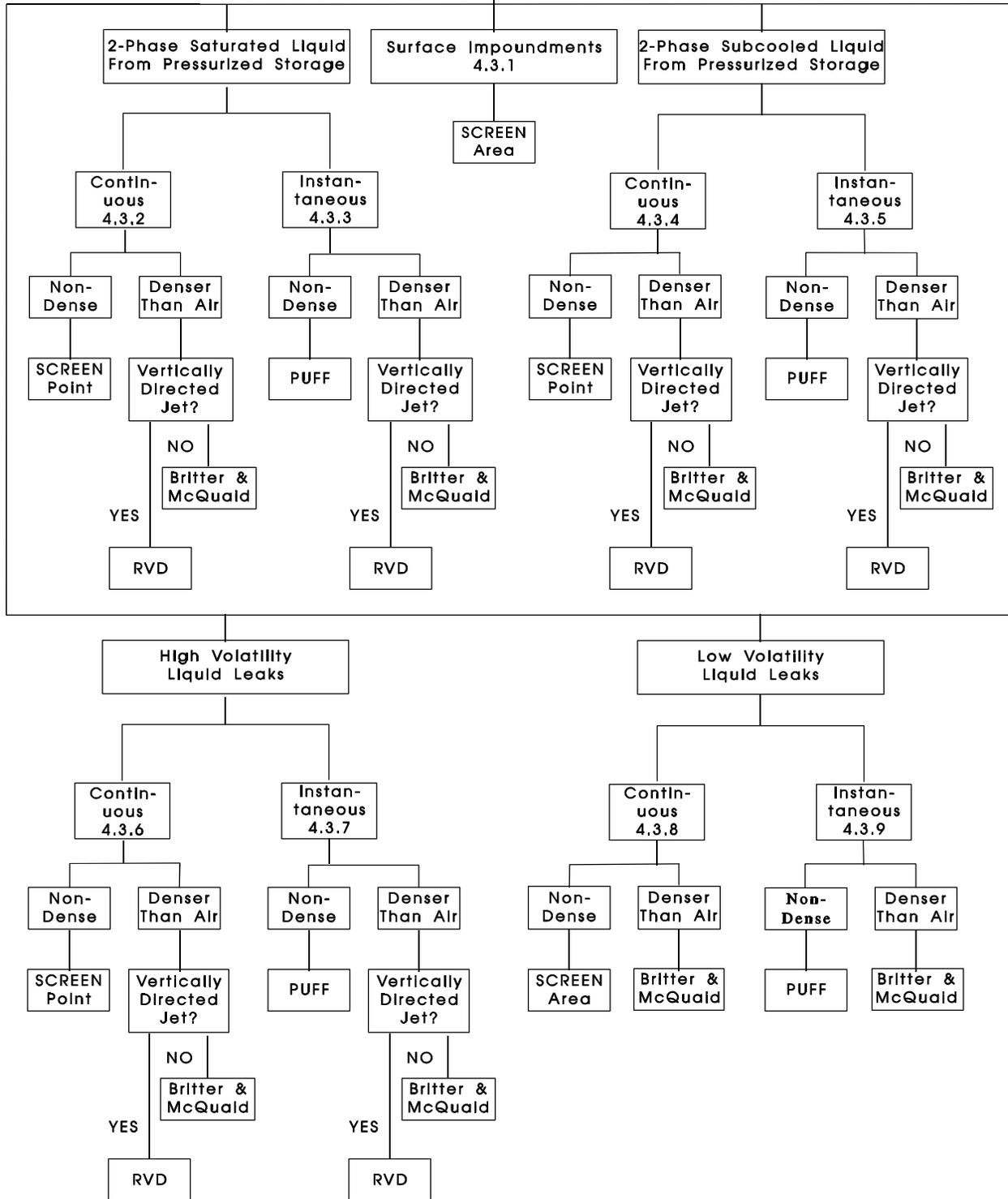


LIQUID RELEASE TYPE



2.4.2.1 Continuous Release

1. Perform buoyancy check as a first check.

A. Calculate the density of air using the following:

$$\rho_{air} = \frac{P_a M_a}{R T_a} \quad (2.4-1)$$

where $R = 8314$ (J/kg-mole \cdot K). The molecular weight of air is assumed equal to 28.9 (kg/kmol), and atmospheric pressure is 101325 (Pa).

B. If $D_2/D_{air} > 1$, then the buoyancy is negative; go to steps 2 or 3. Otherwise, buoyancy is neutral or positive and the SCREEN model for a point source should be used.

2. For a vertically directed jet release, the release Richardson number, Ri , is calculated using the following equation:

$$Ri = \left[g \left(\frac{D_2}{D_{air}} - 1 \right) \frac{Q_m}{u D_0 D_2} \frac{u_{10}^2}{(u_c/u_0)^2} \right] \quad (2.4-2)$$

where g is the acceleration of gravity (m/s^2), D_2 is the plume density (kg/m^3), D_{air} is the ambient density (kg/m^3), Q_m is the exhaust gas mass flow rate (kg/s), u is the wind velocity at the top of the stack (m/sec), D_0 is the stack diameter (m), u_{10} is the wind velocity at 10m above the ground, u_c/u_{10} is the ratio of friction velocity (m/s) to the wind speed at 10m (m/s). In version 2.0 of the RVD model, this ratio is assumed to equal 0.06 for all atmospheric stability classes. The value of u is calculated via the equation:

$$u = u_0 (h_s/10)^p \quad (2.4-3)$$

where h_s is the stack height (m) and p is the wind speed profile exponent, which varies as a function of atmospheric stability. By using $g = 9.81$ m/s^2 , $u = 1$ m/sec , $u_c/u_{10} = 0.06$, $u_{10} = 1$ m/s , the Richardson number is reduced to:

$$Ri = 2,725 \left(\frac{D_2}{D_{air}} \right) \frac{Q_m}{D_0 D_2} \quad (2.4-4)$$

U = 1 m/sec was chosen as a screening method for determining denser-than-air effects. However, denser-than-air effects do not always correspond to largest hazard extent.

3. For other denser-than-air releases, Britter-McQuaid recommend that denser-than-air effects be ignored if:

$$U_r \left/ \left(\frac{D_2 \& D_a}{D_a} \right) \frac{g Q_m}{D_2 D U_r^3} < 0.005 \quad (2.4-5)$$

where g is the acceleration of gravity (m/s²), E is the release rate in kg/s, D is the (low-momentum) horizontal dimension of the source(m), U_r is the wind speed at 10 m (m/s), D₂ is the discharge (depressurized) density of air (kg/m³). See Section 5.0 for additional explanation.

Thus, if the wind speed during the release is known, then it can be inserted in the equation and a determination can be made whether a dense gas model should be used. Selections are summarized in the table below:

**TABLE 2-2
MODEL SELECTION FOR CONTINUOUS RELEASE**

Continuous	Criteria		Models
1. Buoyancy Check	D ₂ /D _{air} ≤ 1 D ₂ /D _{air} > 1	Passive (Go to '2. or 3.')	SCREEN
2. Vertically Directed Jet	Yes - Ri > 30 Ri < 30 No - (Go to '3. Other')	Dense Nondense	RVD SCREEN
3. Other	Ri < (1/6) ³ Ri > (1/6) ³	Dense Passive	B-M SCREEN

2.4.2.2 Instantaneous Release

1. Perform buoyancy check as a first check.
 - A. Calculate the density of air using equation 2.4-1.

- B. If $D_2/D_{air} > 1$, then the buoyancy is negative; go to step 2 or 3. Otherwise, buoyancy is positive and the PUFF model will be used.
2. For a vertically directed jet release, calculate the release Richardson number as shown in equation 2.4-4.
 3. For other denser-than-air releases, Britter-McQuaid recommend that denser-than-air effects be ignored if:

$$\left[\left(\frac{D_2 \& D_{air}}{D_{air}} \right) \frac{g (E_t/D_2)^{1/3}}{U_r^2} \right]^{1/2} \# 0.2 \quad (2.4-7)$$

where g is the acceleration of gravity (m/s^2), D_2 is the discharge density (kg/m^3), D_{air} is the ambient density (kg/m^3), E_t is the total amount of material released (kg), and U_r is the wind speed at 10 m (m/s).

If denser-than-air effects are determined to be important, then the Britter-McQuaid model is used. Otherwise, the release is considered non-dense (passive) and the PUFF model applies. Selections are summarized in the table below:

**TABLE 2-3
MODEL SELECTION FOR INSTANTANEOUS RELEASE**

Continuous	Criteria		Models
1. Buoyancy Check	$D_2/D_{air} \leq 1$ $D_2/D_{air} > 1$	Passive (Go to '2. or 3.')	PUFF
2. Vertically Directed Jet	Yes - $Ri > 30$ $Ri < 30$ No - (Go to '3. Other')	Dense Nondense	RVD PUFF
3. Other	BM Criteria > 0.2 BM Criteria ≤ 0.2	Dense Passive	B-M PUFF

2.5 Considerations for Time-Varying and Time-Limited Releases

A release is considered time-varying if the release rate varies with time. Typically, this behavior might be expected because the reservoir pressure and temperature vary with time. As discussed in Chapter 4, reservoir pressure and temperature would be expected to vary with time if the release rate was very large in comparison with the reservoir volume. For these conditions, the release rate decreases with time so that the maximum release rate can be determined from initial reservoir

(stagnation) conditions. Therefore, a screening method which uses the initial reservoir conditions would be expected to overestimate the release rate; this overestimation could be quite large depending on the situation.

A release is considered (only) time-limited if the release rate is constant over the duration of the release, but the release duration is short in comparison with other important time scales (e.g., the averaging time used to assess the toxicity, or the cloud travel time to a downwind position of interest). Typically, this behavior might be expected if, for example, an automatic shutoff system is assumed to stop the release after a specified (generally short) time period. The release rate for time-limited releases can still be estimated using the screening methods outlined in Chapter 4; the total amount of material released Q could then be estimated by $Q_m T_d$ where Q_m is the release rate and T_d is the release duration. (i.e., $Q = Q_m T_d$)

Finally, a release may be both time-varying and time-limited. As in the time-varying case, a screening method which uses the initial reservoir conditions can be used to (over) estimate the release rate, and the total amount released Q could again be estimated by $Q_m T_d$ where Q_m is the release rate and T_d is the release duration. Of course, the (estimated) total amount released can not exceed the amount of material on hand before the release.

2.6 Denser-Than-Air Materials

In this workbook, the discussion of gas leaks are for materials stored as a gas which remains entirely in the gas phase throughout the depressurization process. Two-phase leaks can result for materials which are stored under pressure and will depressurize when released to the atmosphere. This depressurization will then result in the formation of two contaminant phases (saturated liquid and vapor). Two-phase leaks occur for gases which cool so that condensation occurs during the depressurization process, and for high volatility liquids (liquids whose normal boiling point is below the ambient temperature) which are stored typically above ambient pressure. For screening purposes, a release from the liquid space is considered to form an aerosol when the liquid is stored at a temperature above its boiling point (and ambient pressure); this assumption becomes more unrealistic as the storage pressure approaches ambient pressure (or equivalently as the storage temperature approaches its boiling point).

A high volatility liquid is considered to be a material whose boiling point is below the ambient temperature; a high volatility material will be released as a liquid if the storage pressure is near ambient pressure whereas release from high

pressure storage will result in aerosol formation; aerosol formation is assumed when the liquid is stored at a temperature above its (depressurized) boiling point. In contrast, a low volatility liquid is considered to be a material whose boiling point is above the ambient temperature; a low volatility material stored at moderate to low pressure (and where the boiling point is above the storage temperature) will typically be released as a liquid and form a pool or puddle on the ground. Releases of low volatility materials typically do not exhibit denser-than-air effects. Table 2-4 summarizes this information.

**TABLE 2-4
(DEPRESSURIZED) RELEASE PHASE FOR SCREENING PURPOSES***

Storage Phase	(Depressurized) Release Phase
Gas	Gas Aerosol possible (when $T_2 < T_b$)
High Volatility Liquid ($T_b < T_a$)	Liquid ($T_b \leq T_1$) Aerosol ($T_b < T_1$)
Low Volatility Liquid ($T_b \geq T_a$)	Liquid

* where T_a is ambient temperature, T_b is the (ambient pressure) contaminant boiling point temperature, T_1 is the (initial) storage temperature, and T_2 is the depressurized release temperature.

In this workbook, two-phase leaks are assumed to occur for saturated liquids which are liquids stored at a (elevated) pressure equal to their vapor pressure for the storage temperature. Subcooled liquids are liquids stored at a pressure above their vapor pressure for the storage temperature.

2.7 Dispersion Screening Estimates for Denser-Than-Air Contaminants

A lot of effort has been focused over the past few years on estimating (by physical and mathematical models) the dispersion of denser-than-air contaminants in the atmosphere (as part of the overall concern of hazard assessment). Because physical models (wind tunnels) are not used directly for the purposes of a screening procedure as is desired for this discussion, direct use of physical models are not discussed here. Mathematical models (i.e., models which can be reduced to mathematical expressions) can be divided among three categories:

1. Complex models are typically based on the solution of the conservation equations of mass, momentum, and (thermal) energy;

they make no *a priori* assumptions about the distribution (shape) of the important dependent variables (such as contaminant concentration). Complex models (theoretically) have the capability of (rigorously) taking into account the effect of many complicating factors (such as the influence of obstacles); these capabilities are largely untested at present. Complex models typically are costly in terms of preparation time, computation time, and user sophistication; as such they are obviously unsuited for use in a screening program.

2. Similarity models are also based on the solution of the same conservation equations as complex models; however in contrast to complex models, similarity models make assumptions about the distribution (shape) of important dependent variables. Typically, similarity models do not take into account the influence of obstacles. However, many similarity models have been extensively compared to the large number of recent field test programs aimed at studying denser-than-air contaminants; some similarity models (e.g., DEGADIS) have been found to reproduce the range of the field results quite well. Unfortunately, this success comes at the (modest) cost of preparation time and user sophistication which may not entirely fit the mold of a screening program, but in fact, this "state-of-the-art" implies that proven similarity models should be the next tool applied if a screening program identifies a release scenario as a potential problem.

3. Correlation models are based on a dimensional analysis of the important parameters which influence the important dependent variables (e.g., distance to a given concentration level and area covered by a plume or puff) and on information gathered from field test results, laboratory results, and other mathematical models. The stated objective of a correlation-based model is to fit the observed data (on which it is based) within a certain factor (typically two). Because of the nature of a simple correlation, this approach is well suited for use in a screening program. The RVD and the Britter-McQuaid models are derived from correlations based on different wind tunnel experiments.

The screening techniques presented here are designed to identify release scenarios which may violate safety or health criteria. The simplifying assumptions inherent in these screening methods are specifically aimed at decreasing the amount of information required from the user and decreasing the computation time and sophistication. More refined assessment techniques should be applied to a release scenario which is identified by these screening procedures as violating safety or health criteria. As with any hazard assessment, these screening techniques should be applied with due caution.

Refined release rate estimates may involve more detailed analysis of the specifics of the release as well as application

of more refined engineering methods (e.g., Lees (1980) and Perry et al. (1984)). Refined atmospheric dispersion models which account for denser-than-air contaminant behavior (such as DEGADIS; Spicer and Havens (1989)) can be applied. It should be noted that the screening assumptions inherent in the methods suggested by Britter and McQuaid (1989) and the RVD model (EPA, 1989) may become less justifiable for contaminants with more complicated thermodynamic behavior after release to the atmosphere -- particularly ammonia (NH_3), liquefied natural gas (LNG), and hydrogen fluoride (HF); more sophisticated atmospheric dispersion models may be used to account for such circumstances.