NON-ROUTINE FLARING MANAGEMENT:

MODELLING GUIDANCE

Alberta Government

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Preface

The Alberta Environment and Sustainable Resource Development (ESRD) *Non-Routine Flaring Management: Modelling Guidance* replaces the document entitled *Emergency/Process Upset Flaring Management: Modelling Guidance*, and is intended for flare operations that either require an *Environmental Protection and Enhancement Act* approval, that operate under a Code of Practice for emissions to the atmosphere, or where required by other regulatory agencies such as the Energy Resources Conservation Board.

ESRD has developed this Guidance to ensure consistency in the use of air dispersion models for regulatory applications in Alberta. The practices recommended within this Guidance are a means to ensure that these objectives are met.

The Guidance outlines ESRD's air dispersion modelling requirements and methods for non-routine flares. Although some specific information on air dispersion models is given, the user should refer to user guides and reference materials for the model of interest for further information on air dispersion modelling. The Guidance will be reviewed regularly to ensure that the best available tools are being used to predict air quality.

Additional information relevant to source and dispersion models can be located at these web pages:

(to be determined)	Air Quality Modelling Guideline (AQMG). Revised April 2013.
(to be determined)	ESRD Meteorological data for dispersion models
(to be determined)	ERCB Directive 060: Upstream Petroleum Industry Flaring, Incinerating and Venting
(to be determined)	*ERCBflare* model
(to be determined)	*ABflare* model
(to be determined)	CAPP Framework Sour Non-Routine Flaring

Thank-you Dr. Brian Zelt, Ph.D., P.Eng. of ZeltPSI for your assistance.

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1 Introduction

The primary use of Alberta Environment and Sustainable Resource Development (ESRD) *Non-Routine Flaring Management: Modelling Guidance* (Guidance) is to provide air dispersion modelling guidance for any facility that has a non-routine flare that requires an *Environmental Protection and Enhancement Act* (EPEA) approval, Code of Practice, or where required by the Energy Resources Conservation Board (ERCB). ERCB Directive 060 requires air dispersion modelling for sour and acid gas combustion using flares. Definitions consistent with Directive 060 are provided in Appendix A.

Non-routine flaring can occur due to planned or unplanned events. The duration and flow rates will vary depending on the nature of the flaring event. Designing sour or acid gas flare stacks to meet the *Alberta Ambient Air Quality Objectives* (AAAQO) for sulphur dioxide (SO_2) during all dispersion conditions can be difficult due to the high emission rates and complex terrain.

1.1 Purpose of the Guidance Document

This Guidance outlines a methodology for air dispersion modelling that should be used to determine appropriate non-routine flaring management practices. The methodology has been developed to (i) ensure that consistency is maintained in the modelling for each facility, and (ii) all facilities are evaluated on the same predictive basis. There are differing scientific views on many methods of air dispersion modelling, and not all facilities are the same design. However, it is essential that the overall methodology for assessment is consistent to allow for simple comparison between different facilities.

Most air dispersion models have a minimum averaging time of 1-hour based upon commonly available meteorology data and air quality objectives. Non-routine flaring events can be shorter than 1-hour and are infrequent and intermittent. This Guidance provides a consistent methodology for modelling air quality impacts and relates them to ambient air quality objectives.

1.2 Statutory Authority

This Guidance is issued by Alberta Environment and Sustainable Resource Development (ESRD), under Part 1, 14 (4), the *Environmental Protection and Enhancement Act, 1992* (EPEA). This document replaces all previous versions of the Alberta Emergency/Process Upset Flaring Management: Modelling Guidance (AENV 2003).

For further details on air dispersion modelling, please refer to the *Air Quality Modelling Guideline* (AQMG, ESRD 2013). This Guidance should be read in conjunction with the *Alberta Ambient Air Quality Objectives* (AAAQO, ESRD 2011) and the *Air Monitoring Directive* (ESRD 2006) as amended.

Non-routine flare modelling guidance provided in this document is specific to modelling non-routine flaring (non-continuous flaring sources) using specific models and specific modelling techniques. This Guidance may not be appropriate for general air dispersion modelling, in regards to model selection, model settings, emission sources or scenarios.

2 Source Modelling

2.1 Non-Routine Flaring

Routine flaring occurs on a regular basis due to the normal operations of a facility. Routine flaring can occur on a continuous or semi-continuous basis with individual flaring event durations ranging from 1-hour to 1-year (8760 hours) and having a cumulative flaring duration of more than 1-month per year (720 hours.) Routine flaring should be modelled using a continuous source as per *Directive 060* (ERCB 2013) and the AQMG.

Non-routine flaring is distinguished from routine flaring by the magnitude, frequency and duration of flaring events. Non-routine flaring is generally characterized by infrequent occurrence, high-emission rates and short event durations (ranging from sub-hourly to several days). As such, non-routine flaring modelling presents several air dispersion modelling challenges that are addressed in this document.

Non-routine flaring events are intermittent, infrequent and are the result of operating conditions that are outside normal steady state plant process and equipment operations. There are two types of non-routine flaring: planned and unplanned.

Planned flaring: Flare events where the operator has control over when flaring will occur, how long it will occur and the flow rates. Planned flaring results from the intentional de-pressurization of processing equipment or piping systems. Examples of planned flaring include: pipeline blowdowns; equipment depressurization; loss of normal control during start-ups; facility turnarounds and well tests. Planned flaring events can occur: during specific times of day and make use of favourable meteorological periods; or season of the year. Air quality management plans for planned flaring may be developed based on the air dispersion modelling predictions.

Unplanned flaring: Is emergency or upset operational activities closely associated with facility health and safety. Flare events where the operator has no control of when flaring will occur. There are two types of unplanned flaring: upset flaring and emergency flaring. *Upset flaring* occurs when the operations are outside the normal operating conditions and flaring is required to aid in bringing the unit operations back under control. Examples of upset flaring include: off-spec product; hydrates; loss of electrical power; process upset; and operation error. *Emergency flaring* occurs when safety controls within the facility are enacted to depressurize equipment to avoid possible injury or property loss resulting from explosion, fire or catastrophic equipment failure. Examples of upset flaring include: pressure safety valve overpressure; and emergency shut down. Emergency flaring is a design scenario with the objective to depressurize the facility as quickly and safely as possible.

The limits on the annual cumulative amount of flaring for non-routine flaring are summarized in Table 1.

Table 1: Non-Routine Flaring Annual Cumulative Hour Limits

Non-Routine Flaring Type	Maximum Cumulative Hours Per Calendar Year Flare Emits
Planned	720
Unplanned	88

2.1.1 Flare Source Parameter Prerequisites

The flare design and performance should meet the requirements of *Directive 060* (ERCB 2013). A non-routine flaring assessment should consider all of the operations that may lead to planned and unplanned non-routine flaring. For a particular event, the following basic information will be required to determine the appropriate non-routine flaring source conditions (see Appendix B):

- Stack height (m),
- Stack top inside diameter (mm) or equivalent based upon total exit area,
- List of facility non-routine flaring event types,
- For each non-routine flaring event type, raw gas and fuel gas compositions (mole fractions) and flow rates ($10^3 m^3/d$) during duration of release,
- A description of how the flaring rate changes with time during the event, including the duration,
- For transient emissions, initial and final vessel pressure (kPa), temperature (K) and control valve orifice diameter (mm).

2.2 Flaring Rate Categories

Non-routine flares are categorized and modelled according to how the flaring rate varies with time. The four non-routine flare source categories are described in Table 2 and illustrated in Figure 1.

A long-term steady flare may have a constant or variable (random) flare rate in time. A short-term steady flare is similar to a long-term steady flare, except that it has a shorter and finite duration. Both the long-term steady and short-term steady flare rates (being either constant or variable rate) are simplified for modelling purposes to be constant in time rates representative of the range of the actual rate.

Blowdowns have a decreasing flow rate because mass is only leaving the vessel or pipeline as the upstream valves are closed. The exponential transient rate is a special case of a blowdown because it can be described mathematically as a function of time that can be represented by multiple short term steady rates with a duration set to conserve mass. Similarly, the user-defined transient rate is a more complex version of the blowdown.

Table 2: Non-Routine Flare Rate Categories

Rate Category	Source Modelling Refinement Level	Non-Routine Flare Source Description
Long-Term Steady	1	A steady (continuously emitting) non-routine flaring rate that: • lasts more than 1 hour to several days, • uses 3 constant rates to represent the maximum, average and low emission rates.
Short-Term Steady	2	A steady (constant in time) non-routine flaring rate that: • lasts several minutes but less than 24 hours, • uses 3 constant rates to represent the maximum, average and low emission rates.
Exponential Transient (blowdown)	3	A transient (time-varying) non-routine flaring rate that: • lasts several minutes but less than 24 hours, • is represented by an exponentially decreasing emission rate sequence of puffs of specified duration, • is typical of a single stage blowdown (vessel or pipeline).
User-Defined Transient (blowdown)	4	A transient (time-varying) non-routine flaring rate that: • lasts several minutes but less than 24 hours, • is represented by random sequence of emission rates and durations determined by the user, • is typical of a multi-stage blowdown (vessels and pipelines).

The modelling refinement level qualitatively describes the complexity of the source model associated with source category. In general, the long-term steady source category is the least complex and the user-defined transient source category is the most complex. Once a non-routine flare source is defined and categorized, the source model can be created using an equal or lower modelling refinement level. For example, a short-term steady flare could be modelled as a short-term steady flare (refinement level 2) or could it could be modelled with less sophistication (less complexity) using a long-term steady source model (refinement level 1). Source modelling approaches are described in more detail in Section 3 (see also Table 5).

Note that as shown in Figure 1, at least three representative flow rates are used to evaluate the potential range of the expected flaring.

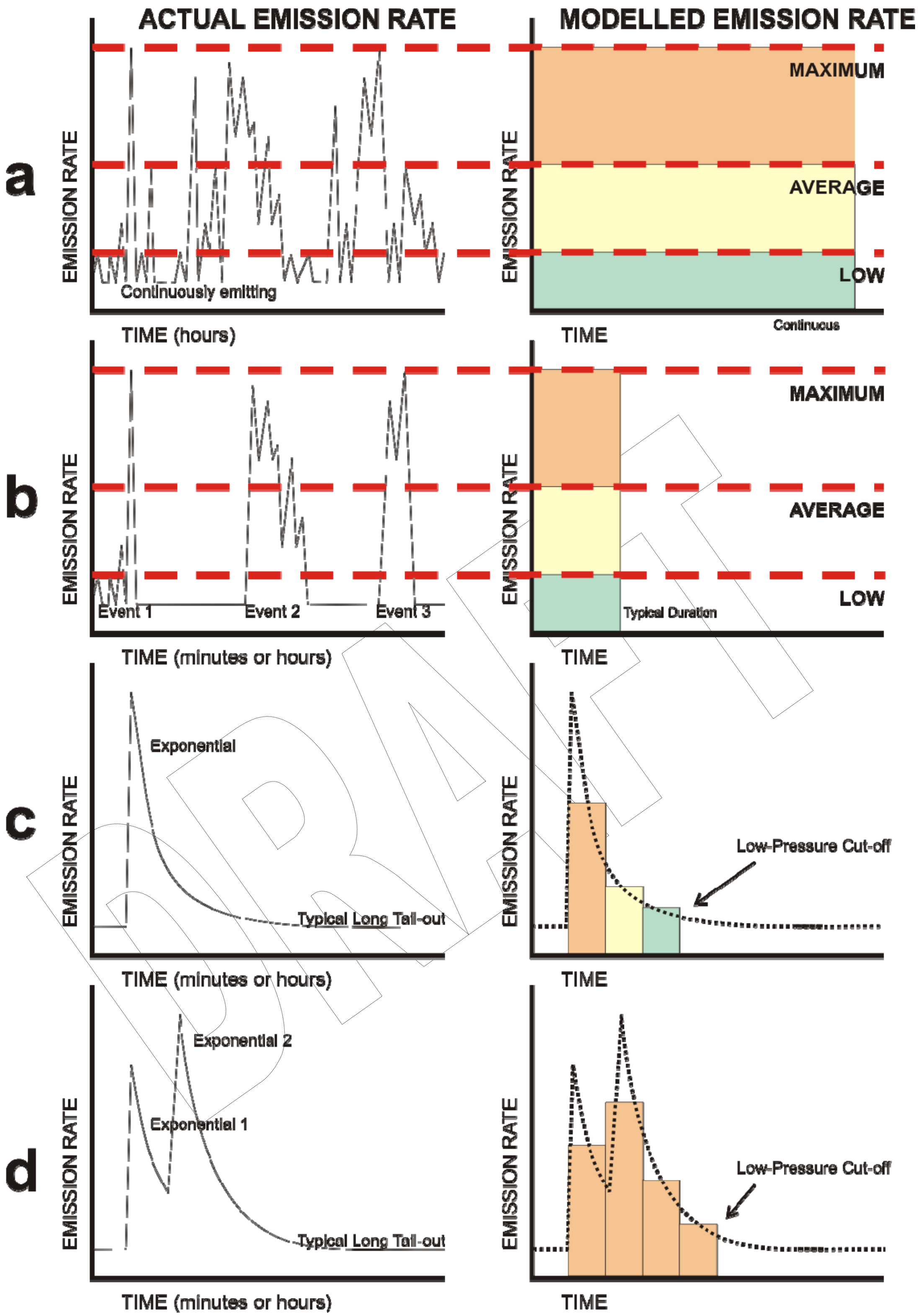

Figure 1: **Flare Rate Categories Showing Variations with Time for: 1a) Long-Term Steady, 2b) Short-Term Steady, 3c) Exponential Transient, and, 4d) User-Defined Transient**

The different rate categories could also be considered levels of refined air dispersion modelling, thus, conservative assumptions can be made to use a flare source category type as a screening method. If the predicted air quality is acceptable, then more refined methods would be unnecessary. However, because of the complexities in the non-routine flare modelling, each modelling technique may produce a different (higher or lower) result. The modeller must be aware of all aspects of the flare event (from source emission rate, plume rise to dispersion) to ensure that the chosen modelling scenario is actually conservative in comparison to a more refined modelling technique. The modelling report should outline the assumptions made by the modeller in this regard.

2.2.1 Long-Term Steady Rate

A non-routine flare source could be characterized as a long-term steady flaring (Figure 1-1a) source taking into account the following factors:

1. The emission rate for the flare may be constant or vary randomly during the flaring period. Three representative emission rates should be modelled:
    a. the maximum flaring rate,
    b. an average flaring rate (arithmetic average), and
    c. a representative low rate (such as the geometric mean or 1/8th maximum flaring rate used for well test approvals).
2. Both the total gas flared rate and the sulphur component of the flared gas should be considered. The maximum sulphur rate may not occur at the maximum flared gas rate, therefore the events should be considered independently. The lower rates (average and low) should be considered because the lower rates will have a lower plume rise.

The maximum flaring rate will be the licensed flaring rate (i.e., the flaring rate that cannot be exceeded) and H_2S composition for new applications. For existing operations the maximum flaring rate can be based on the maximum expected conditions (i.e., the rate and composition based on operating trends that will not be exceeded). The licenced or maximum expected sour or acid gas composition should be used.

The average rate is appropriate for the mid-rate flare assessment because it is representative of the total mass released to the environment. The geometric mean is appropriate for the low-rate flare assessment because it is representative of the average rate for skewed (logarithmic) distribution flare rates. The lowest allowable rate can be set as a management approach.

Long-term steady flare source parameters and emission rates can be calculated using the *ERCBflare* spreadsheet source model for screening assessments or the *ABflare* source model for refined assessments.

2.2.2 Short-Term Steady Rate

A non-routine flare that has a per event duration less than 24 h and has a variable emission rate (Figure 1-2b) can be modelled as a short term steady emission. Events longer than 24 h are modelled as long-term steady rates. Short-term steady emission sources can be estimated by:

1. Emission rates for short-term steady non-routine flares can be estimated as above for long-term steady rates, taking into account the shorter duration of each event.

2. Short-term steady flares are different than long-term steady flares in that they have a finite duration and can be conceived to be a puff (or cloud) dispersing downwind of the source. The finite duration puff will disperse in the vertical, cross-wind and along wind directions, whereas a long-term flare effectively disperses only in the vertical and cross-wind direction. Therefore, a flare modelled as a short-term steady flare will have lower predicted concentrations compared to long-term flare predicted concentrations, if the puff duration is less than 1 h.
3. A non-routine flare that is modelled as a short-term steady source must be modelled with three representative flow rates to evaluate the potential range of the expected flaring (maximum, average and low emission rates).

Short-term steady flare source parameters and emission rates can be calculated using the *ERCBflare* spreadsheet source model for screening assessments or the *ABflare* source model for refined assessments.

2.2.3 Exponential Transient Rate

A non-routine flare that has duration less than 24-h and has a transient emission rate resulting from the depressurization of a single vessel, facility or pipeline can be modelled as a transient blowdown (Figure 1-3c). An exponential transient emission source can be estimated by:

1. A transient blowdown is similar to the short-term rate (Section 2.2.2) except the emission rate and flare source description is represented as a mathematical function in time. The transient blowdown is characterized using an exponential curve which is a close approximation to a single stage (single vessel) blowdown. The exponential blowdown can be described based upon a few initial source conditions using multiple puffs with successively lower mass.
2. Transient flares are different than short-term steady flares in that there are multiple sequential puffs each with a finite duration dispersing downwind of the source.
3. A non-routine flare that is modelled as an exponential transient source must be modelled with a minimum of three emission rate scenarios, representing high, medium and low emission rates.

Exponential transient flare source parameters and emission rates can be calculated using the *ERCBflare* spreadsheet source model for screening assessments or the *ABflare* source model for refined assessments.

2.2.4 User Defined Transient Rate

A non-routine flare that has a duration less than 24-h and has a transient emission rate resulting from the depressurization of multiple vessels of variable gas composition can be modelled as a user defined transient blowdown (Figure 1-4d). In this case the modelling proceeds almost identically with the transient (Section 2.2.3) except the blowdown calculations and gas composition are determined by the modeller using multiple runs of the *ABflare* source model for refined assessments.

2.3 Flare Pseudo-Parameters

Before air dispersion modelling can begin, the non-routine flaring rates and durations must be simplified into a source model. This process is called source characterization.

A flare is illustrated in Figure 2 and is characterized by the following features:

1. An external combustion process (combustion of gases open to direct influence of wind speed, wind direction, ambient pressure and ambient temperatures).
2. Emissions occur at an elevated height above the ground.
3. The emissions are related to the input gas composition and can be described mathematically as a function of meteorological conditions (as it pertains to combustion or conversion efficiency).
4. The emission source (height and location relative to flare tip, diameter, velocity and temperature) can be described mathematically as a function of meteorological conditions, momentum and buoyancy flux of the flare, and stack height. This mathematical characterisation is referred to as *pseudo*-parameters (e.g., source height, diameter, velocity and temperature).

Most air dispersion models have been developed based upon buoyant and momentum plume rise from conventional stacks which are, in turn, based upon the physical stack dimensions (height and diameter) and stack top exit velocity and temperature. These parameters can be calculated for a flare source from the momentum flux at the flare tip and buoyancy flux from energy released to the plume through combustion. The calculated *pseudo*-parameters are not actual physical dimensions of the flame but are entered into the air dispersion models as if they were a conventional stack. When used in this way an air dispersion model will interpret the source inputs so that the plume rise is correct.

The flare *pseudo*-parameters are also a function of the ambient meteorology (wind speed at the flare stack tip height and direction) as represented in Figure 3. When the wind speed is low compared to the exit velocity of the flared gases (Flare a), the effective location of the emission source for the flare is almost the same as the flare location, but with a greater effective stack height. When the wind speed is high compared the exit velocity of the flare gases (Flare b), the effective location of the flare source can be offset several metres to tens of metres from the location of the stack. Stack top downwash can further reduce the effective height of the source.

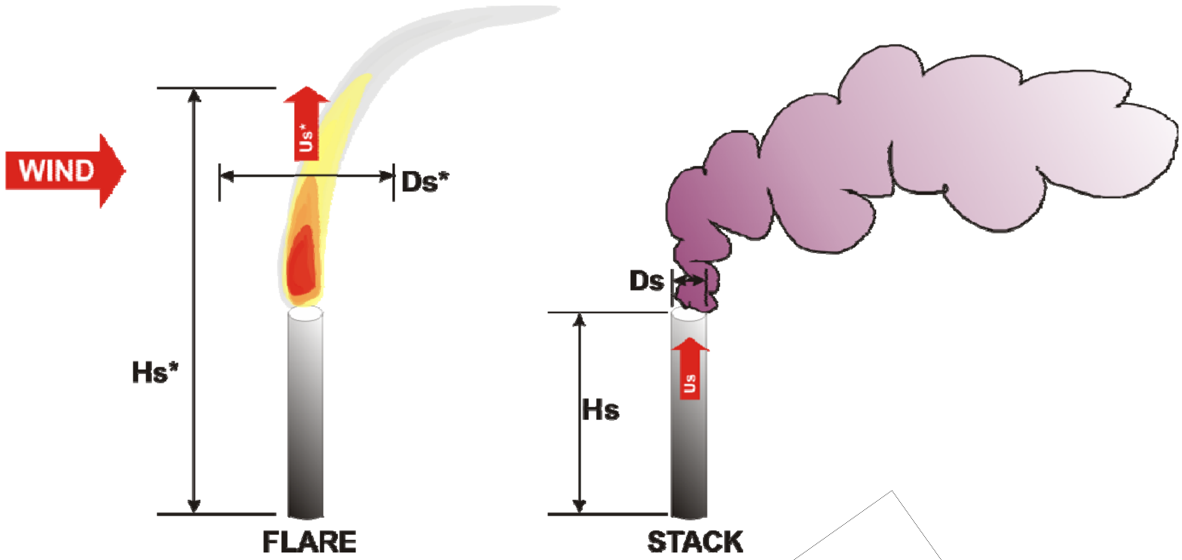

Figure 2: Flare Source Compared to a Conventional Stack Source

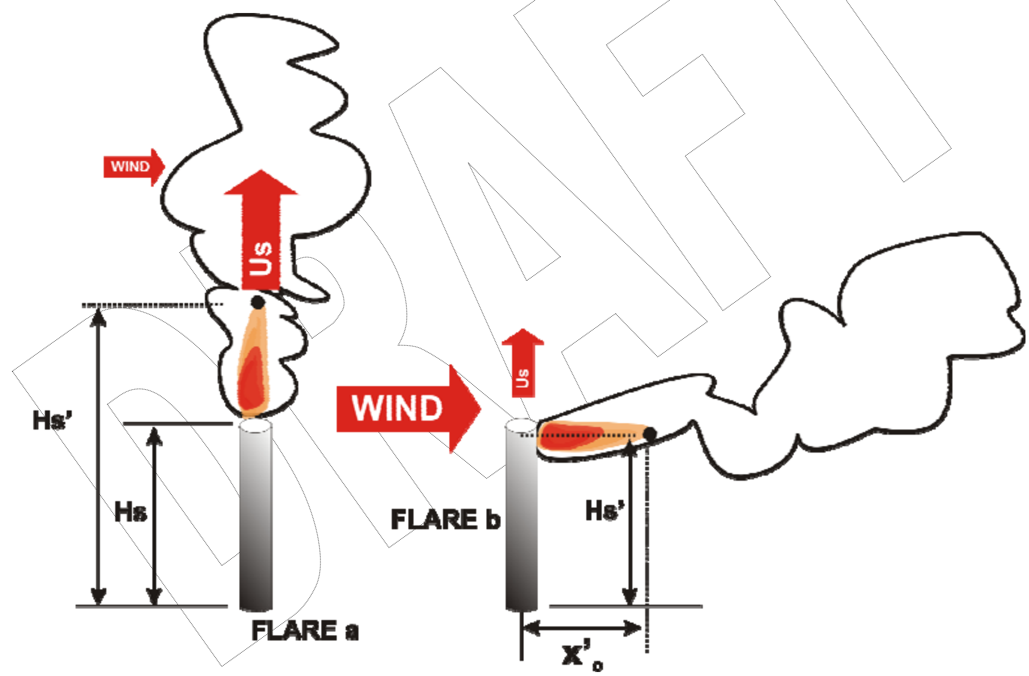

Figure 3: Flare Source Sensitivity to Meteorology for Low Wind Speed (Flare a) and High Wind Speed (Flare b) compared to Exit Velocity of Flared Gases

3 Dispersion Modelling

3.1 Models

The air dispersion modelling for non-routine flaring can range in complexity from screening to refined. Screening modelling can be performed using *AERSCREEN* (USEPA 2012). Refined air dispersion models such as *AERMOD* (USEPA 2011) or *CALPUFF* (Scire 2000) are used for refined modelling but could also be used for non-routine flare modelling screening level assessments, depending on the source model and options selected.

There are two types of Lagrangian dispersion models in common use: plume models (*e.g.*, *AERSCREEN* and *AERMOD*) and puff models (*e.g.*, *CALPUFF*). Plume models assume steady-state meteorology from the source following the wind-direction at all downwind locations. Thus, they include vertical and cross-wind dispersion of the plume. Steady-state models have developed to include some effects of complex terrain. Steady-state plume models are suitable for a wide range of modelling applications where the emission source is steady-state. Careful interpretation of the modelling results should be considered when applying a steady-state plume model to non-steady-state non-routine flaring modelling. The results in such modelling may be overly conservative. Puff models are non-steady-state allowing for temporal changes in meteorology and source emissions. A non-steady-state model can be used with steady-state emissions inputs.

AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

CALPUFF is a non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. *CALPUFF* can be applied for long-range transport and for complex terrain.

ERCBflare and *ABflare* are tools for both screening and refined assessments of non-routine flaring.

3.2 *ERCBflare*

ERCBflare is screening level air dispersion modelling tool that determines the source parameters for continuous, long-term steady, short-term steady and exponential transient rate flare modelling. It takes into account the hour by hour source characterization that results due to changing meteorological conditions to determine representative *pseudo*-parameters for the flare. *ERCBflare* uses *AERSCREEN* but also provides a bridge to refined modelling by providing an input file for *AERMOD*.

3.2.1 *AERMOD* Switch Settings

The AQMG must be followed for *AERMOD* configuration with the exception of the stack-tip downwash run control variable (NOSTD) which should be used to turn off stack tip downwash because the source input parameters (as determined by *ERCBflare* or *ABflare*) account for low wind speed stack tip downwash.

3.3 *ABflare*

Non-routine flares with continuous, steady, exponential transients or user defined transient rates can be modelled using the *ABflare* modelling tool to determine the source parameters. The *pseudo*-parameter calculations used in *ABflare* are the same as *ERCBflare*. The *ABflare* tool creates a *CALPUFF* input file. *ABflare* takes into account the time varying meteorology conditions to determine the source *pseudo*-parameters. The model determines the effective (*pseudo*-parameters) for source height, diameter, temperature, combustion efficiency and effective source location as a function of the input meteorology at the source location.

The *ABflare* model can output a *CALPUFF* arbitrary source file similar to the steady non-routine source file (Section 2.2.2) and the results of the modelling can be post-processed in the same manner.

Different than both the continuous and steady non-routine flare source conditions, the transient flare accounts for the peak rate all the way down to the final low rate. *ABflare* uses a constant gas composition for the transient flare; therefore, if the actual blowdown has a transient gas composition, the modeller should carefully consider the assumed gas composition. In particular, a conservative assumption would use the lowest heating value normalized with the highest sulphur emission rates. If this assumption was too conservative, then the user defined transient flare may be required.

3.3.1 *CALPUFF* Switch Settings

Air dispersion modelling for puff-mode non-routine flares is performed using the *CALPUFF* modelling system to account for the short-term transient nature of the flare events, complex terrain commonly found in Alberta, and the ability to model puffs. This complexity of modelling cannot be performed in the *AERMOD* model since the plume model assumes instantaneous dispersion from source to infinite distance. The *CALPUFF* switch settings are listed in Table 3:

Table 3: Required *CALPUFF* Switch Settings for Non-Routine Flare Modelling

Parameter	Setting	Description
MPDF	1	Computes dispersion parameters associated with the PDF formulation for the convective boundary layer (1=on)
MSHEAR	1	Power law wind speed profile (1=on)
MTRANS	1	Transitional plume rise from source to final rise height (1=on)
MDISP	2	Dispersion parameter to use the micro-meteorological parameterization (2= micro-meteorological)
MTIP	0	Stack tip downwash effects are not to be included in the *CALPUFF* source adjustments, since they are already accounted for with the *ERCBflare* or *ABflare* source model (0=off)

3.4 Meteorology

For non-routine flaring, the AQMG should be followed for refined air quality modelling assessments. In highest to lowest order of preference for meteorological data:

1) 1-year of on-site meteorology, or
2) 5-years of ESRD provided standard meteorological data for regulatory applications.

For screening assessments using *AERSCREEN*, pre-defined sets of meteorological parameters that change with season are used.

3.4.1 Terrain and Domain

The domain size for the non-routine flaring should be selected similar to the AQMG, that is, the modelling domain should be selected large enough to demonstrate closed contours for the concentration threshold of interest. The meteorological domain should be selected larger than the modelling domain to account for edge effects and recirculation flows. A typical modelling domain extends 10 km from the source and a typical meteorological domain extends 15 km from the source.

The grid resolution should be selected so that *CALMET* can adjust wind field flow patterns to the terrain. For slowly varying terrain, a larger grid resolution (e.g., 1000 m) can be used, whereas, in complex terrain a smaller grid resolution (e.g., 200 m) may be required.

3.4.2 AERMET

The *ERCBflare* modelling tool requires the meteorological conditions at the flare stack height at the flare location. The predictions are sensitive to the land use classification (which also defines the surface roughness) therefore a default value is provided based on the location of the flare.

3.4.3 CALMET

Non-routine flare modelling using *ABflare* is a refined modelling approach. Accordingly, the most advanced accepted science should be used within the *CALMET* modelling system. *CALMET* modelling options will depend upon site specific meteorological data available. The recommended practice for *CALPUFF* modelling is:

1. ESRD regulatory meso-scale meteorological data for initialization. *CALMET* to be run using the NO OBS mode which makes the wind fields the most self-consistent estimate of the flows at all elevations.
2. *CALMET* switch settings are listed in Table 4..

Table 4: Required *CALMET* Switch Settings for Non-Routine Flare Modelling

Parameter	Setting	Description
IWFCOD	1	Usage of prognostic meteorology for initial guess field (1=on)
IFRADJ	1	Computation of Froude number adjustment (1=on)
IKINE	0	Computation of kinematic effects (0=off)
ISLOPE	1	Computation of slope effects (1=on)
ICALM	0	Extrapolation of surface winds even if calm (0=off)

The *ABflare* modelling tool requires the meteorological conditions at the flare stack height at the flare location. The meteorological time series can be extracted from the *CALMET* output or the approved ESRD 5-year mesoscale meteorological data set using the *METSERIES* module of the *CALPUFF* modelling system. The *ABflare* modelling tool graphical interface can be used to assist the modeller in this process.

3.5 Approaches

The link between the source rate category and air dispersion model is outlined in Table 5 and discussed in the following sections. The approach depends upon on the source model used to represent the rate category and upon the air dispersion model to be used. A more complex rate category can be simplified by using a less complex source model. There is no guarantee that doing so will be more or less conservative, therefore the documentation must clearly state the modelling assumptions and reasoning. In a similar way, a more refined dispersion model may better represent the actual flare event, but does not guarantee a lower predicted concentration.

The goal of the air dispersion modelling assessment is to ensure that should a non-routine flaring event occur, the likelihood of exceeding the ambient air quality objectives beyond the facility fenceline will be low.

Table 5: Air Dispersion Modelling Approaches for Non-Routine Flares

Rate Category	Source Model	Dispersion Model	Refinement Level	Source Modelling Requirements	Post Processing Requirements
Long-Term Steady	Continuous	Plume *****	1	The emission rate(s) is modelled as if the source emitted continuously. Use continuous source modelling methodology according to **DETAIL A.**	Post processing for time averages is not required.
		Puff *****	1		
Short-Term Steady	Continuous	Plume	1	Source emission rates are determined based upon the actual duration of the short-term event. Use continuous source modelling methodology according to **DETAIL A.**	Time averages are post processed according to **DETAIL D**.
		Puff	1		
	Finite Duration Puffs	Puff *****	2	Source emission rates are determined based upon the actual duration of the short-term event. The source modelling is conducted according to **DETAIL B**.	Time averages are post processed according to **DETAIL E**.
Exponential or User-Defined Transient Blowdown	Continuous	Plume	1	Source emission rates are determined according to the blowdown exponential transient in terms of a sequence of short-term steady emissions. Use continuous source modelling methodology according to **DETAIL A.**	Each emission is assessed independently and the results of all of the assessments are post-processed according to **DETAIL F**.
		Puff	1		
	Sequence of Finite Duration Puffs	Puff *****	3 or 4	Source emission rates are determined based upon the actual duration of the short-term event. Source emission rates are determined according to the blowdown exponential transient in terms of a sequence of short-term steady emissions. The source modelling is conducted according to **DETAIL C**.	Time averages are post processed according to **DETAIL E**.

***** indicates the recommended modelling approach for the non-routine Source Characterization

3.5.1 Long and Short-Term Steady and Transient Rate Modelled as Continuous Source (DETAIL A)

Assuming a continuous source is the simplest refinement level (1) and can be used for all flaring rate categories described in Section 2.2. Either *AERMOD (using ERCBflare)* or *CALPUFF* (using *ERCBflare* or *ABflare*) can be used to model the non-routine flare release characterized as a continuous release.

The modelling predictions would compare the predicted time averages to the corresponding non-routine risk based criteria. The results are post-processed and combined depending on the rate category and dispersion model used, to determine maximum time averaged statistics, as described later in this document.

3.5.2 Short-Term Steady Rate Modelled as Finite Duration Puffs Source (DETAIL B)

Using a finite duration puff for short-term steady flaring rate, as described in Section 2.2.2, with a puff dispersion model (*CALPUFF*) is the next level of refinement (2). Short-term steady release rate flares can be modelled using either the *ERCBflare* source description or *ABflare* model:

1. To model the short-term steady non-routine flare using the *ERCBflare* source model, the source description information is entered into the *ERCBflare* spreadsheet. The '**DISPERSION MODEL'** page will provide the required source description for input into the *CALPUFF* model. A series of independent sources, species or named sources would be required to track a short-term event starting at each hour of the year. This methodology is identical the *ABflare* model except that the source conditions remain static with changes in meteorology. This methodology does not provide the best scientific description of combustion or representation of plume rise. It is included as a possible modelling methodology for compatibility with existing *CALPUFF* modelling techniques.

2. The recommended practice for short-term steady puff release rate flares is to use the *ABflare* model and tool. *ABflare* assists the user in a three step process to create *CALPUFF* modelling input and provides the best scientific representation of the hour variability of flaring.

    a. Start the *ABflare* model and enter the source description and flare location. *ABflare* will guide the modeller with three steps to create a *CALPUFF* model input:
        i. The flare source location and meteorological configuration is used to extract meteorology at the flare tip height using the *METSERIES* module from the *CALPUFF* tools group.
        ii. The source information entered is used to create an *ABflare* model input file.
        iii. The *ABflare* model is used to create a series of source files for *CALPUFF* using the arbitrary flare source external source description files.

b. *CALPUFF* is run 24-times to represent possible flare events starting at each hour of the day. *CALPUFF* is run 5-times to represent 5-years of meteorology statistic variation.
c. The modelling predictions are post-processed (Section 4.1.2, see DETAIL E).

A puff can be modelled in *CALPUFF* since it has the ability to specify arbitrary source duration. *CALPUFF* can represent the along wind dispersion that will smear out the leading and trailing edge of the puff, which will be of particular importance for short duration flare events or at modelling receptor locations several kilometres from the source. *CALPUFF* is configured by starting a flare event (a puff with duration of the flare event or a sequence of puffs as per a transient release) on each hour of the day (see Figure 4). Each start-hour can be represented by an independent modelling run, an independent species, or individual source (making use of the *CALPUFF* source tracking). In each of these three cases, each start-hour is modelled as a separate flare occurrence of equal probability, resulting in a full year of possible event timings. CALPUFF is executed 24-times, once for each start-hour configuration when configured in a parallel-processing mode or is executed once when configured in a multi-species (or multi-source) mode.

The results are post-processed and combined to determine maximum time averaged statistics, as described in Section 4.1.2, see DETAIL E.

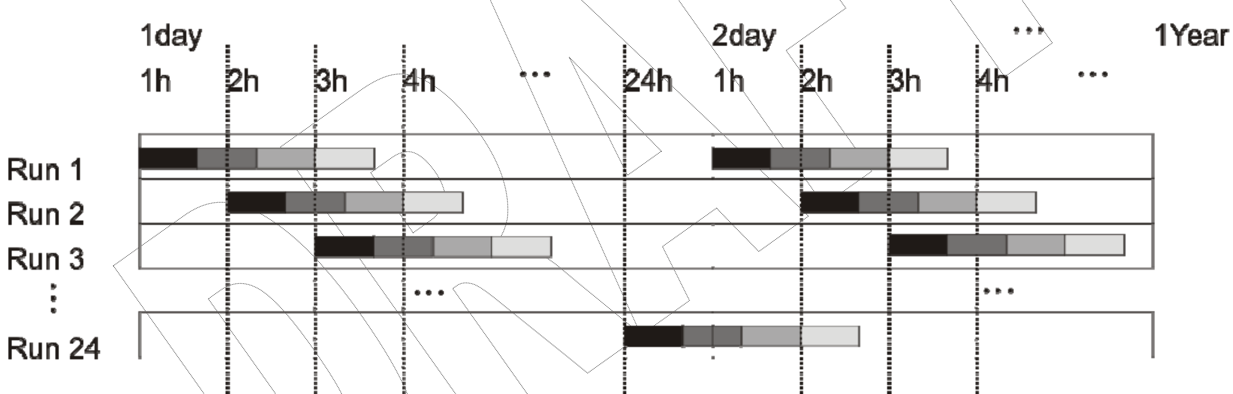

Figure 4: Non-Steady-State Dispersion Model Configuration Showing Puff Sequences Starting on the Hour and Separated by 24-Hours

3.5.3 Transient Blowdown Modelled as Finite Duration Puffs Source (DETAIL C)

Transient release rate non-routine flares modelled with a sequence of finite duration puffs must use the *ABflare* source model with the *CALPUFF* dispersion model because the source emission rates and source characterization changes sub-hourly with the hourly changes in meteorology.

The model configuration is similar to the short-term steady flare release (see Section 3.5.2 and Figure 4) with the exception that instead of a single steady release puff initiated each start-hour, a sequence of puffs are released each start-hour. In practice, this methodology can be used for transient sequences of about 20 hours duration. A gap between the day 1 and day 2 release events is required to allow for travel time of the first flare event out of the domain before starting the second flare event on the same start-hour, next day. If long periods of low-wind speeds or calms persist or the transient sequence extends beyond 24-h, then the methodology would be extended to 48 start-hours and 48-runs would be required.

ABflare assists the user in a three step process to create *CALPUFF* modelling input and provides the best scientific representation of the hour variability of flaring.

1. Start the *ABflare* model and enter the source description and flare location. *ABflare* will guide the modeller with three steps to create a *CALPUFF* model input:
    a. The flare source location and meteorological configuration is used to extract meteorology at the flare tip height using the *METSERIES* module from the *CALPUFF* tools group.
    b. The source information entered is used to create an *ABflare* model input file based upon the modeller specifying the initial pressure, orifice diameter and blowdown duration (or total volume released).
    c. The *ABflare* model is used to create a series of source files for *CALPUFF* using the arbitrary flare source external source description files. Each file contains a non-routine flare transient sequence starting on the hour for that file.
2. *CALPUFF* is run 24-times to represent possible flare events starting at each hour of the day. *CALPUFF* is run 5-times to represent 5-years of meteorology statistic variation.
3. The modelling predictions are post-processed (Section 4.1.2, see DETAIL E).

3.6 Baseline Concentrations and Cumulative Effects

For continuous emissions, a cumulative air quality assessment approach is necessary. However, for non-routine flaring, there is:

- Uncertainty in predicting non-routine source conditions.
- Uncertainty in meteorological related events that may lead to plume over-lap during non-routine flaring.
- Uncertainty in actual operating emissions of other sources.

Therefore, the non-routine flare design air dispersion modelling does not require over-lap modelling of other sources for cumulative effects or baseline concentrations to be added to modelled predictions.

3.7 Post-Event Modelling

If post modelling is required under Directive 060, the actual conditions must be used. If site specific meteorological data during the event is not available, then five years of meteorological data from a standard period is recommended using the ESRD data set. One month per year must be modelled from the data set centred about the month of the event. The maximum predictions must be compared to the AAAQO for SO_2.

4 Output Interpretation

4.1 Post-Processing

The predictions from the air dispersion models requires post-processing to compute appropriate time averages and to generate statistics for comparison to risk-based criteria. The details for doing these calculations are outlined in the following sections.

Post-processing is not required for time averages for long-term steady rate flares modelled as a continuous source.

24-h average predictions are not required as non-routine flaring is infrequent and seldom lasts more than 24 hours.

4.1.1 Short-Term Steady Rate Modelled as Continuous Source (DETAIL D)

For a short-term steady non-routine flare modelled as a continuous source with flaring emissions lasting less than one hour, there are two recommended practices for modelling that give the same result:

1. Adjust the source: The release rate occurs over N-minutes (N<60 minutes) and is modelled at the maximum, medium and low flaring rate. Each input SO_2 emission rate can be multiplied by N/60 when modelled as a continuous source and the resulting prediction can be directly compared with a 1-hour standard.
2. Adjust the predictions: The release is modelled as a continuous source at the maximum, medium and low flaring rate with the corresponding SO_2 emission rate. The resulting concentration is what would actually occur over an N-minute interval of the hour, but for the rest of the hour, the observed concentration would be zero. The hourly average predictions from the model are multiplied by N/60 to obtain the actual 1-hour predicted concentration. This is the method used within *ERCBflare* and *ABflare*.

4.1.2 Short-Term Steady and Transient Rate Modelled as Finite Duration Puffs Source (DETAIL E)

The post-processing for short-term steady and transient events modelled with finite duration puffs is similar. For 1h time averages the post-processing methodology is illustrated in Figure 5. The methodology has 2 basic steps:

1. Merge the individual results of the dispersion modelling from a) having 24-runs to b) being only a single set of data;
2. Using the single set of results in b) to determine the statistics c) at each receptor location for comparison to risk-based criteria.

More details are provided in the *ABflare* User Guide.

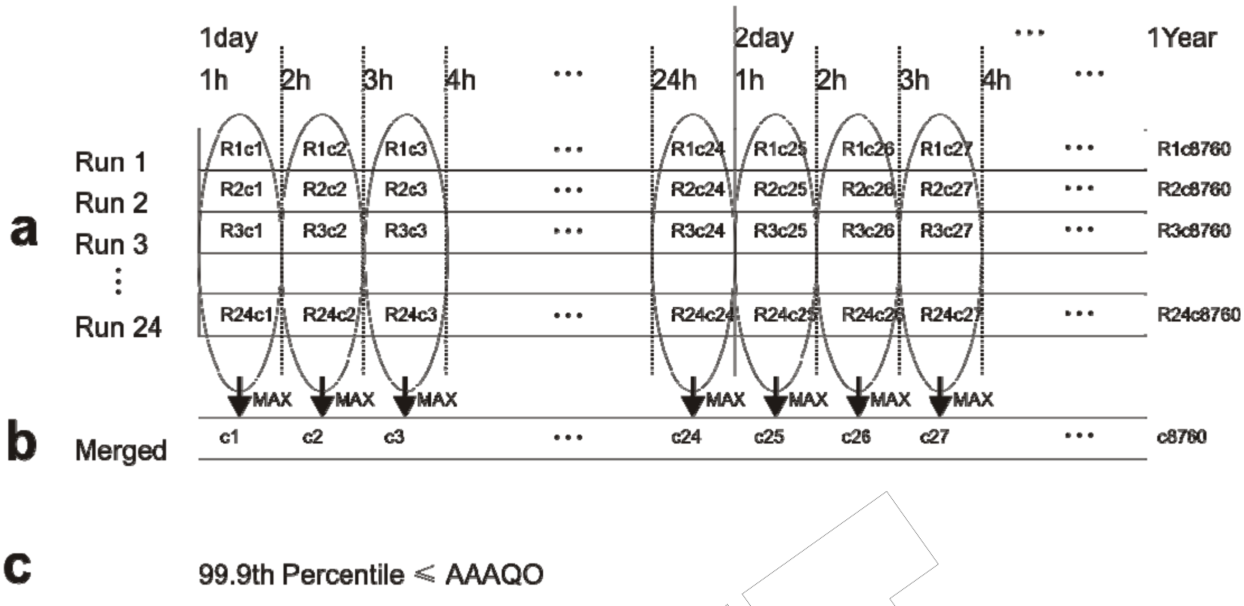

Figure 5: Post-processing Methodology for 1h Time Averages for Short-Term Steady and Transient Puff Source Model Results

4.1.3 Transient Blowdown Modelled as Continuous Source (DETAIL F)

In this case, the transient rate source was defined as a sequence of short-term steady emissions that were modelled as a continuous source. The transient would be discretized to a minimum of a sequence of three steady puffs. Each is modelled as a continuous source for the calendar year. The results are post processed within *ERCBflare* and *ABflare* according to either:

1. If the individual puffs are greater than or equal 1-h duration, then for each hour of the calendar year, determine the maximum concentration at each receptor for the set of puffs ignoring the actual sequence.

$$\mathrm{C(x,y,z,t)} = \text{max of } \begin{cases} \mathrm{C}_{E-max}(x,y,z,t) \\ \mathrm{C}_{E-ave}(x,y,z,t) \\ \mathrm{C}_{E-low}(x,y,z,t) \end{cases}$$

   For example, at each receptor location (*x*,*y*,*z*), the concentration (*C*) at a time (*t*), is equal to the maximum of the predicted concentrations for each of the three modelled flare rates (*E-max*, *E-ave* and *E-low*)

2. If the individual puffs are less than 1-h duration, then for each hour of the calendar year determine the appropriate factored time averages from the results of each hour at each receptor and then take the maximum concentration for each hour.

   For a specific example, if the puff sequence duration was 3-puffs of duration 30-minutes each were used in the modelling, at each receptor location (*x*,*y*,*z*), the concentration (*C*) at a time (t), is equal to the maximum of the predicted concentrations for each of the three modelled flare rates (*E-max*, *E-ave* and *E-low*) according to:

$$C(x,y,z,t) = \text{max of } \begin{cases} \frac{30}{60} \times \left(C_{E-max}(x,y,z,t) + C_{E-ave}(x,y,z,t) \right) \\ \frac{30}{60} \times \left(C_{E-ave}(x,y,z,t) + C_{E-low}(x,y,z,t) \right) \end{cases}$$

The above example is specific to 3-puffs and 30-minute durations each.

This will result in a merged data set containing only the maximum 1-h concentrations for each receptor for the calendar year. Then using typical post-processing methods, determine the appropriate percentile concentrations at each receptor to compare to risk-based criteria.

4.2 Risk Based Criteria

The AQMG provides guidance for the design of stacks with continuous emissions. The endpoint used for continuous emissions is the ninth highest hourly (99.9th percentile), for comparison to the 1-h AAAQO.

Table 6 provides the non-routine flaring air dispersion modelling risk based criteria which are based upon the same design criteria adopted in the AQMG for continuous sources, but takes into consideration the low frequency of non-routine flare events. Similar to the continuous source design criteria, the non-routine flaring source design criteria requires the specified percentile of the predictions to meet the AAAQO for the purposes of designing the flare.

Table 6: Risk Based Criteria for Non-Routine Flare Air Dispersion Modelling

Parameters	Monitoring Criteria Ambient Air Quality Objective	Continuous Source Air Dispersion Modelling	Non-Routine Flare Air Dispersion Modelling	
			Planned	Unplanned
1 h Predictions	100% (0)	99.9% (8)	99% (87)	90% (876)
Annual Flaring Limit (hours)	NA	8760	720	88

Note: number in brackets indicates the number of ranked modelling predictions that can be removed for each year of modeling.

The flaring definitions listed in Table 1 define which criteria are to be used as a function of the design cumulative flaring durations. For example, non-routine flaring for *Planned* flaring (a flare system that cannot have cumulative emissions for more than 720 hours per calendar year) must have modelling results that have the 99% percentile predicted 1-h average concentration being less than or equal to 450 µg/m³

There are several important conditions that must be met in addition to the risk based criteria:

1) The 99.9th percentile hourly modelled predictions for non-routine flares shall not exceed:

a) For unplanned flaring, the SO_2 evacuation limit of 5 ppm for 15 min as per *Directive 71* (ERCB 2009). This is equivalent to 9923 µg/m³ for a 1-hour average.

b) For planned flaring an SO_2 value of 900 µg/m³ for a 1-hour average, as previously used in the ERCB Low Risk Criteria (the Low Risk Criteria is no longer applicable).

2) The AAAQOs cannot be exceeded for all actual ambient monitoring data and time averaging periods.

5 Obtaining Models and Resources

The *ERCBflare* spreadsheet and *ABflare* model can be obtained from the ERCB website for Directive 060.

To be determined

The website contains supporting documentation for the tools.

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Appendix A: Definitions for the Purposes of Non-Routine Flare Modelling

Acid Gas	Gas that is separated in the treating of solution or non-associated gas that contains hydrogen sulphide (H_2S), total reduced sulphur compounds, and/or carbon dioxide (CO_2).
Combustion Efficiency	Is the percentage of the net heating value that is released as heat through combustion.
Conversion Efficiency	Is the relative conversion of carbon and sulphur compounds in the reactants to products of complete and incomplete combustion.
Emergency Flaring	Emergency flaring occurs when safety controls within the facility are enacted to depressurize equipment to avoid possible injury or property loss resulting from explosion, fire or catastrophic equipment failure. Examples of upset flaring include: pressure safety valve overpressure; and emergency shut down.
Non Routine Flaring	"Non-routine" applies to intermittent and infrequent flaring. There are two types of non-routine flaring: planned flaring and unplanned flaring.
Planned Flaring	Flare events where the operator has control over when flaring will occur, how long it will occur and the flow rates. Planned flaring results from the intentional de-pressurization of processing equipment or piping systems. Examples of planned flaring include: pipeline blowdowns; equipment depressurization; loss of normal control during start-ups; facility turnarounds and well tests.
***Pseudo*-Parameter**	An air dispersion model input (e.g., diameter, height, velocity and temperature for a flare) that is based on reverse engineering the model inputs so that the model produces the correct intermediate calculation (i.e., buoyancy and momentum flux).
Refined Assessment	A refined air dispersion modelling assessment is a more complex and data-intensive level of air dispersion modelling. Refined assessments more closely estimate actual air quality impacts by using site-specific meteorological data.
Risk Based Criteria	The Alberta Ambient Air Quality Objectives (AAAQO) provides a basis for determining acceptable air quality. For the purpose of designing flare stack heights and flow rates, a small fraction of event modelling predictions are permitted

	above the AAAQO according to the strict guidance in this document. An example of a risk based criteria is the 1-h time average for a planned non-routine flare; modelling predictions at a receptor must be at or below the 1-h AAAQO 99% of the hourly predictions per year.
Routine Flaring	"Routine" applies to continuous or intermittent flaring that occurs on a regular basis due to normal operation. Examples of routine flaring include: glycol dehydrator reboiler still vapour flaring; storage tank vapour flaring; flash tank vapour flaring; and solution gas flaring.
Screening Assessment	A screening air dispersion modelling assessment is the quickest and simplest dispersion modelling approach. Screening assessment usually provide a conservative (worst-case) estimate of downwind concentrations.
Sour Gas	Natural gas, including solution gas, containing hydrogen sulphide (H2S).
Unplanned Flaring	Emergency or upset operational activities closely associated with facility health and safety. Flare events where the operator has no control of when flaring will occur. There are two types of unplanned flaring: upset flaring and emergency flaring.
Upset Flaring	Upset flaring occurs when one or more process parameters fall outside the allowable operating or design limits and flaring is required to aide in bringing the production back under control. Examples of upset flaring include: off-spec product; hydrates; loss of electrical power; process upset; and operation error.

Appendix B: Non-Routine Flare Modelling Input Information Check List

Non-Routine Flare Modelling
Input Information Check List

1. Source Information
    a. plot plan,
    b. facility fenceline,
    c. site elevation,
    d. stack height,
    e. stack diameter,
    f. ERCB licensed sulphur content or sulphur content sought for approval,
    g. steady / transient modelling assumption,
    h. source model category, and
    i. orifice diameter.
2. Operations Information
    a. scenarios leading to non-routine flaring including: maintenance planned flaring, potential unplanned flaring for operations outside normal control; emergency flaring for principal safety systems such facility depressurization or VRU failure,
    b. gas analysis for each scenario,
    c. flaring duration, contained volume or rates, and
    d. pressures and temperatures of gas to be flared.

Appendix C: Sample Content of a Non-Routine Flare Modelling Assessment Report

Sample Content of a
Non-Routine Flare Modelling Assessment Report

1. Flaring Description:
    a. Purpose of flaring,
    b. Frequency of flaring, and
    c. Summary of management plan for the prevention of flaring.
2. Topography and Terrain:
    a. Map showing the meteorological and modeling domain with contours illustrating topographical features, and land use.
    b. Map showing the meteorological and modelling domain with the terrain land use,
    c. Elevation of stack base.
    d. Elevation minimum and maximum in modelling domain.
    e. Receptor grid resolution.
3. Meteorology:
    a. Data source for meteorology,
    b. AERMET or CALMET switches and assumptions,
    c. AERMET or CALMET Version number,
    d. Summary of meteorology at flare location and stack height:
        i. Wind rose,
        ii. Pasquill-Gifford stability summary,
        iii. Wind speed(s) summary,
        iv. Mixing layer heights, diurnal and seasonal variation, and
        v. Temperature, diurnal and seasonal variation.
4. Source and Emissions:
    a. Physical description of actual source:
        i. Plot plan showing the location of the flare and illustrating the fenceline,
        ii. Stack height,
        iii. Orifice diameter,
        iv. Pressure, and
        v. Volume to be flared and duration of flaring.
    b. Emissions characterization:
        i. As continuous, steady or transient,
        ii. Gas analysis,
        iii. Sour gas composition,
        iv. Assumptions used that make the assessment conservative,
        v. Description of the significant events leading to flaring (note that each event may require independent modelling), and
        vi. Summary table of facility regular sulphur emissions.
    c. Summary of ERCBflare/ABflare output:
        i. Version number,
        ii. Range of conversion and combustion efficiency, and
        iii. Summary of effective stack heights.
5. Model predictions:
    a. CALPUFF or AERMOD version number,

b. AERMOD or CALPUFF switches and assumptions,
c. Summary table of peak prediction and concentration at risk based criteria level for each time average, and
d. Contour map of peak prediction and concentration at risk based criteria level for each time average.

6. Conclusion:
   a. Summary of impact for concentrations.
7. Appendices:
   a. Digital copy modelling input files for ERCBflare/ABflare, CALMET and CALPUFF.