June 28, 2018

Operating Engineers Regulatory Review

Risk-Based Regulatory Framework for Plant Rating and Attendance – Path 1

Prepared by the Operating Engineers Risk Task Group
for the Technical Standards and Safety Authority

Preface

In March 2017, the Ministry of Government and Consumer Services (MGCS) and the Technical Standards and Safety Authority (TSSA) collaboratively established the Operating Engineers (OE) Risk Task Group. The task group was established out of recommendations made by a 15 – member panel of experts drawn from the OE Industry. The objective of this panel was to review and provide recommendations for government's consideration to support revisions to the Operating Engineers Regulation (O. Reg. 219/01). The panel submitted a report to the Ministry in June 2017, with the following recommendations:

1. Ontario should adopt a risk-based approach to regulating the OE industry
2. The regulation should include two alternate compliance paths:
    a) Path 1 category-based approach where regulated plants are rated based on their safety risk and attendance requirements assigned
    b) Path 2 approach where regulated plants develop and implement site-specific Risk and Safety Management Plans (RSMP)

The purpose of the OE Risk Task Group is to develop a risk-based framework for implementing the two alternate paths to compliance recommended by the 15 – member panel of industry experts.

The task group membership includes five (5) industry experts with experience in refrigeration, boiler, steam and compressor technology, and process safety management. The task group would like to acknowledge TSSA's contribution made through Jorge Larez, Dwight Reid, Brian Gee and Humphrey Kisembe, as well as the Operating Engineers Advisory Group for the positive contribution to this report. The task group would also like to thank Srikanth Mangalam of the Public Safety Risk Management Institute (PRISM), for facilitating the consultations and for preparing the final report.

This report is the outcome of year-long consultations undertaken by the task group between March 2017 and April 2018. It provides a Path 1 risk-based framework for rating plants and recommends a plant rating and attendance criteria that adopts internationally accepted risk management principles.

Signed by:

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Executive Summary

Changes are being proposed to Ontario's Operating Engineers Regulation (O. Reg. 219/01) of the Technical Standards and Safety Act, 2000. A 15-member panel of industry stakeholders put together to review the operating engineers' regulation has recommended the following key changes:

1. Ontario should adopt a risk-based approach to regulating the OE industry
2. The regulation should include two alternate compliance paths:
    a) Path 1 category-based approach where regulated plants are rated based on their safety risk and attendance requirements assigned
    b) Path 2 approach where regulated plants develop and implement site-specific Risk and Safety Management Plans (RSMP)

The recommendations are designed to modernize the regulation to respond to technological advancements, improve public safety while imposing a minimum burden on business. Details of the full recommendations can be found in the Operating Engineers Regulatory Review Findings and Recommendations Report submitted to the Ministry in June 2017.

Based on these recommendations, a Path 1 methodology has been developed to establish a risk-based semi-prescriptive approach to plant rating. The approach involves the determination of plant risk score based on the following broad plant factors:

- Type of technology – Boilers, refrigeration, steam prime movers and compression
- Plant configuration – design, operating environment and process parameters
- Plant occupancy and type of exposure

The approach adopted in developing the methodology for Path 1 involved identification of hazard scenarios common to the above plant factors that would lead to catastrophic consequences and a probability of fatality resulting from the consequences.

A quantitative risk model is used to estimate the individual risk of fatality, defined as a product of the frequency of occurrence of hazard scenarios and the probability of fatality due to exposure to catastrophic consequences. This product value is adjusted using conditional probability factors (known in the model as modification factors) that would either increase or decrease the estimated risk.

The modification factors are developed based on the technology type, plant configurations and plant occupancy and exposure type. The associated conditional probabilities are estimated based on expert advice and supported by scientific rationale. The estimated risk for a plant (in scientific units of 10^{-1} or lower) is converted into an absolute value using a simple logarithmic conversion. This value is the final plant risk score.

Using the final plant risk scores, the task group recommends the following plant rating and attendance criteria[1]:

- High risk plants would require attendance of a first-class operating engineer at minimum. These are plants with a risk score that is less or equal to 3

[1] The plant rating and attendance criteria adopts the internationally accepted *"As Low as Reasonably Practicable" (ALARP)* principle

- Medium risk plants shall be attended. These are plants whose risk score is between 3 and 5; for such plants the regulator (TSSA Statutory Director) should consider the plant risk score to determine rating and attendance requirements
- Low risk plants would be unattended. These are plants whose risk score is equal to or greater than 5

The Path 1 methodology was tested against a sample of regulated plants to determine how their risk scores would compare with the current plant rating and attendance requirements, using the risk tolerability criteria described above. The risk model results should be interpreted as follows:

- Risk score for which attendance by a 1st class OE is required
- Risk score for which the regulator will prescribe attendance levels
- Risk score for which attendance is not required

Overall, the model test results indicate a marginal shift in the attendance profiles of all categories (attended, unattended and 1st class) of plants. Test results are best interpreted in the context of their technology groups i.e. boilers, compressors, refrigeration and multiple technology plants. Summarized results suggest the following:

- Overall, 117 plants were tested; 93 attended and 24 unattended.
- Out of the 93 attended plants tested, 73 remained in the attended category and 20 shifted to the unattended category.
- Out of the 24 unattended plants tested, 4 shifted to the attended category while 20 remained unchanged.
- There was a shift in the level of attendance required for 1st class plants, where 8 plants shifted to a lower attendance requirement.
- Majority of the plants that shifted to the unattended category are compressor plants whose risk score is driven by their limited population exposure and material type.
- Overall, there’s a net shift (from attended to unattended or vice versa) of 16 plants which represents about 14% of the sample.

To facilitate full implementation of this model and ensure predictability and consistency in the application of the regulation, the task group recommends the following:

- TSSA to develop a user-friendly tool for estimating the risk score of plants
- TSSA to develop a plant attendance schedule that is based on the risk score of plants and other unique factors (if necessary and applicable).

As part of monitoring and continuous improvement, the task group recommends the following ongoing actions:

- Model to be reviewed at least once every three years by TSSA with industry input through means such as risk reduction groups
- TSSA should enhance collection of failure and incident data to enable future availability of Ontario-specific failure rate data. This can be achieved through proactive engagement with relevant stakeholders such as the UK Health and Safety Executive (HSE), ASME and NBBI among others
- Periodically review and update the modification factors and weights using information collected from inspections and audits, incident investigations, observed hazard trends and feedback from regulated clients and inspectors

1. Background

The Ministry of Government and Consumer Services (MGCS) and the Technical Standards and Safety Authority (TSSA) are reviewing Ontario's Operating Engineers Regulation (O. Reg. 219/01) through an industry panel approach.

In November 2016, MGCS and the TSSA brought together a volunteer panel of industry stakeholders with experience related to the operating engineers field. The objective of this panel was to provide recommendations for government's consideration to support revisions to modernize the Operating Engineers Regulation (O. Reg. 219/01) under the *Technical Standards and Safety Act, 2000.*

The industry panel met on seven occasions between November 2016 and February 2017 to discuss the following regulatory challenges to modernize the operating engineers' regulation:

a) Prescriptiveness that places undue regulatory burden on industry
b) Inflexibility to new technology with minimal or no reward for safety innovation
c) Lack of regulatory clarity
d) Regulatory compliance
e) Inadequate labour supply for operating engineers
f) Low public knowledge of the operating engineers' profession

The industry panel made 25 recommendations to modernize the regulation, reaching consensus on 23 recommendations. A key recommendation included the adoption of a risk-based regulatory framework for rating operating plants and determining staffing requirements. The approach would include two paths to regulatory compliance:

1. Path 1 category-based approach where registered OE plants will fulfill staffing and attendance requirements based on plant ratings developed using a scientific risk score.
2. Path 2 site-specific risk-based approach where regulated OE plants will develop and implement a regulator-approved Risk and Safety Management Plan (RSMP).

The Operating Engineers Risk Task Group was commissioned in March 2017 by the Technical Standards and Safety Authority (TSSA), in collaboration with MGCS and the Operating Engineers Industry Expert Panel. The purpose of the OE Risk Task Group was to develop the risk-based regulatory framework for rating operating plants and regulating staffing requirements. The task group consists of nine members drawn from industry, TSSA and an external facilitator. The terms of reference for the task group are attached in Appendix A of this report.

Separately, an Advisory Group, largely comprised of the industry expert panel that made the 25 recommendations was retained to provide feedback and guidance to the work of the task group from a broader industry perspective.

This report presents a risk model for implementing the Path 1 approach as recommended by the task group. It includes an overview of Ontario's operating engineers' industry, the approach taken by the task group to deliver the scope of work, a methodology for estimating the safety risk of plants and results obtained from testing the risk model against a sample of regulated plants obtained from TSSA's database.

Overview of Ontario's Operating Engineers' Industry

Ontario's operating engineers' regulation applies to the management, operation and maintenance of registered plants and the training, examination, and certification of operating engineers and operators. TSSA's Operating Engineers (OE) Safety Program registers, inspects and regulates the safety of plants in Ontario. The program also administers exams and certifies operating engineers, also known as power engineers, ensuring they have the skills and knowledge to run the plants that power Ontario with electricity, refrigeration, heating and cooling. More than 12,000 operating engineers are currently certified under TSSA OE safety program.

Operating engineers/power engineers are professionals who manage, operate and maintain regulated operating plants and related equipment. These include boilers, steam turbines and engines, gas compression plants, refrigeration plants, and associated mechanical and electrical systems in power generation, industrial processes and environmental system plants. Ontario's OE safety program has four certification classes for operating engineer and certifications for compression and refrigeration operators. The program also issues permits for steam turbine operators.

Ontario's OE regulation covers four main types of OE technologies – refrigeration, boiler, compressor and steam prime mover. It also requires plants to be either attended or unattended. A total of 692 out of the current 3,161 registered plants in Ontario require attendance by an operating engineer. Plants require attendance if, among other things, they have a power rating that is above a defined threshold. Plants do not require attendance if they have a power rating (in kW) below a defined threshold.

Attended plants align to one of the four classes of operating engineer. For example, first class plants require a first-class chief engineer, second class plants require a second-class chief engineer, third class plants require a third-class chief engineer and fourth-class plants require a fourth-class chief engineer. Overall, 78% of the registered plants are unattended. Under the current regulatory regime records from 2008 to 2017 indicate 12 incident occurrences that resulted in 3 injuries[2]. No fatalities were recorded during this period.

Rationale for Risk-Based Regulation

To modernize the Ontario Operating Engineers regulation, 219/01, the OE Expert Panel recommended the adoption of a risk-based regulatory framework.

The Task Group has recommended an approach that is expected to provide industry with the flexibility to comply with regulatory requirements, regulatory transparency while reducing burden on industry. It also enables the regulator to meet its safety objectives by focusing enforcement resources to areas where they are most needed.

The basis for the proposed risk-based approach is predicated on the limitations of the current regulatory framework as identified from the review conducted by the OE expert

[2] Annual State of Public Safety Report. 2017 TSSA

panel. The review identified the following factors as limitations of the current regulatory regime:

1. The plant rating system is based on equipment type and total power of the system. A uniform application of requirements across plant types does not consider process safety risks and non-regulatory mitigation measures and controls put in place to manage these risks. As a result, plants with high levels of performance and/or reliable automated controls are rated the same way as those with lower levels of performance if the power rating in kilowatts is the same.

2. The link between plant power ratings and attendance requirements is not supported by evidence of the safety risk posed by plants.

3. Attendance requirements are highly prescriptive and stipulate the precise qualification an operating engineer must have and duration of time they must be present at the plant.

4. The current regulation does not consider changes in technologies to manage safety risk. Such technologies include process safety monitoring systems and automatic shutdown procedures over and above the guarded controls referenced in the current regulation.

A risk-based regulatory framework would address these limitations and is expected to reduce the regulatory burden for industry, while at the same time enable the regulator to meet its safety objectives by focusing enforcement resources to areas where they are most needed.

2. Task Group Discussion and Consensus

2.1. The Path 1 Approach

Path 1 is a category-based approach where registered OE plants will fulfill staffing and attendance requirements based on plant ratings developed using a scientific risk score. To deliver a risk-based framework and methodology for Path 1, the task group held over 200 hours of discussions from April 2017 to March 2018, adopting a topical approach to developing the methodology for estimating the risk of plants. Discussions were guided by the four regulated technologies namely boiler, refrigeration, compressor operations and steam prime mover technologies. The main topics of discussion included the following:

- Hazard identification
- Review of current plant rating
- Review of ACI/SOPEEC plant rating
- Topical presentations from industry experts
- Review of international practices, standards and databases
- Development of modification factors and appropriate weights
- Model formulation and testing

2.2. Hazard Identification

A hazard is a condition or set of circumstances that present a potential for harm. The task group conducted a hazard identification exercise and identified the following as some of the hazards common to operating plants:

- Boilers: Loss of Containment, fire, Boiling Liquid Expanding Vapour Explosion (BLEVE) due to equipment overpressure, mechanical failure or fuel accumulation
- Refrigeration: Loss of Containment, toxic gas release, fire, explosion (due to compressor catastrophic failure, over pressurization of vessels), electrocution
- Compressor operations: Loss of Containment, fire, explosion (due to equipment over pressurization, mechanical failure of compressors due to flammable gas carry over, fuel accumulation), electrocution.
- Possible negative environmental consequences due to the release of flammable and toxic materials to the atmosphere, specially refrigerants.

They validated the hazard analysis output developed by the expert panel and identified hazard scenarios for top/catastrophic events in the four regulated technologies. A unique list of top/catastrophic events and hazard scenarios was also developed for use in estimating plant risk. Refer to Appendices C, D and E for the full list.

2.3. Review of Current Plant Rating

The current plant rating is based on total power rating (i.e. maximum power output) and equipment type (e.g. high pressure or low-pressure power boiler, refrigeration unit, compressor, or steam prime mover) and the consequence of a failure based on the total energy stored is used as a measure of the hazard. The task group reviewed this approach to plant rating and concluded that the kilowatt (kW) rating method is not risk based since power rating alone cannot be used as a primary index for risk. Other factors such as the operating environment of plants and the presence of unique controls or systems plants to manage risk play an equally important role in the safety of plants.

2.4. Review of ACI/SOPEEC Plant Rating

The task group reviewed the Standardization of Plant Staffing and Plant Rating Proposal prepared by SOPEEC for the National Public Safety Advisory Committee (NPSAC). The proposal incorporates some elements of risk but does not fulfill best practices in risk assessment and risk informed decision-making. The proposal adopts a power rating capacity baseline and hazard ranking factors to establish a plant rating by technology type. The factors are summarized as follows:

Boilers
A power rating capacity baseline of 30,000 kW, where a 1st class operating engineer is required and the following four hazard ranking factors:

- Total number of boilers within the plant
- Number of isolated boiler installations within the plant
- Boiler design type
- Fuel type of boiler

Refrigeration
A power rating capacity baseline of 895 kW and the following four hazard ranking factors:

- Plant configuration (Self-contained, built-up indirect, built-up direct)
- Number of compressors
- Number of compressor installations
- Refrigerant type

Compression
A power rating capacity baseline of 671 kW for air compressors and 300 kW for gas compressors and the following two hazard ranking factors:

- Number of compressors
- Number of compressor installations

Steam Prime Movers
A power rating capacity baseline of 1001 kW and the following three hazard ranking factors:

- Number of steam prime movers
- Number of steam prime mover installations
- Steam prime mover type (Steam engine or steam turbine)

The task group reached consensus to adopt some of the hazard ranking factors proposed by SOPEEC but recommended an approach that includes additional risk factors that contribute to the frequency and consequence components of risks common to operating plants.

The task group focused on developing a plant rating approach that utilizes broadly acceptable risk assessment principles while incorporating some hazard ranking factors from the SOPEEC proposal. The proposed Path 1 model utilizes risk modification factors (this includes some of the factors proposed by SOPEEC) in addition to consequence-based factors to estimate the plant risk. These modification factors are described in detail in the frequency and consequence modification factors sections of this report and include the following:

- Design
- Presence of guarded controls
- Fuel type (Relevant only to boilers)
- Number of equipment
- Public Receptors (Building occupancy type)
- Material/fluid type
- Charge, also known as the total volume of storage
- Power rating (in kilowatts for boilers and compressors)

In addition, the Path 1 methodology recommends that the regulator (TSSA Statutory Director) considers the plant risk score and any other unique factors to determine staffing and attendance requirements. Figure 2.1 is the task group's decision criteria recommendation on plant attendance.

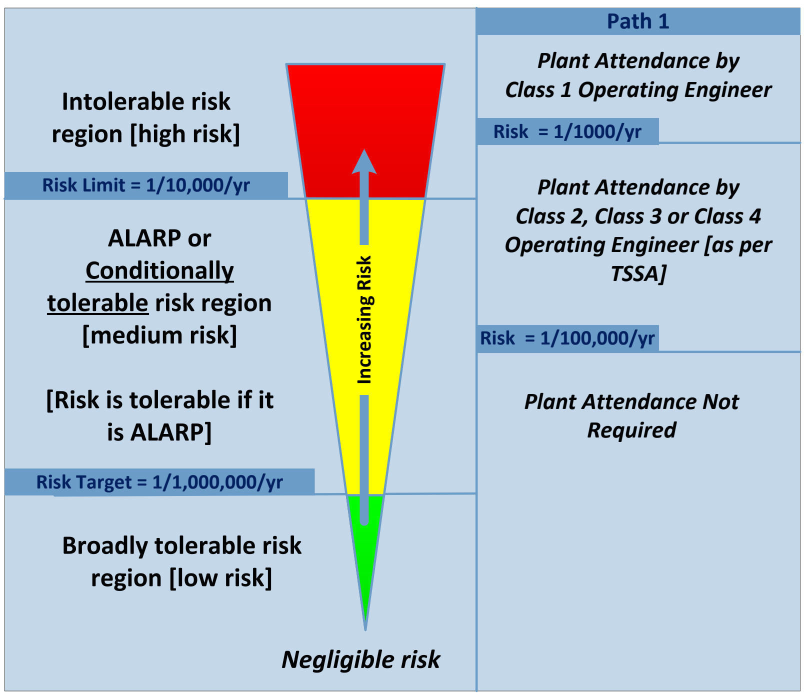

Figure 2.1. Risk Based Plant Rating and Plant Attendance Decision Criteria

Specifically, the task group recommends the following decision criteria for plant rating and attendance:

- High-risk plants (plants in the intolerable risk region) would require attendance of a first-class operating engineer at minimum. These are plants with a risk score that is less or equal to 3
- Medium-risk plants (plants in the conditionally tolerable risk region) shall be attended. These are plants whose risk score is between 3 and 5; for such plants the regulator (TSSA Statutory Director) should consider the plant risk score to determine rating and attendance requirements
- Low-risk plants (plants in the broadly tolerable risk region) would be unattended. These are plants whose risk score is equal to or greater than 5

In their deliberations regarding the decision criteria, the task group considered both public risk and occupational risk. Consensus was reached to use the generally accepted risk tolerance criteria for occupational risk (which are higher than for public risk) for public risk as well. The decision to adopt this approach is based on the following factors:

- The risk analysis methodology for Path 1 is conservatively designed to accommodate a category-based regulatory approach
- Exposure to a catastrophic event such as a boiler explosion, will likely result in a fatality
- Incorporating both sets of risk tolerance criteria in would have significantly increased the model complexity which is considered unwarranted given the conservative risk analysis
- There is no opportunity for industry to take credit for prevention barriers other than control devices on the equipment and guarded controls currently referenced in the regulation
- Failure frequencies often apply to the best in class equipment and the values the model adopts from the referenced international databases apply to all classes of technologies, including non-best in class equipment.
- Recognition of the difficulty of accurately estimating the proximity of the public to the initiating event, viz a viz the magnitude of the potential hazard outcomes.
- The assumption that failure frequencies equate to the largest/catastrophic events, when in fact they represent a range of event sizes, each with a probability of occurrence.

2.5. Industry Expert Presentations

The task group sought the input of industry experts on issues that were beyond the knowledge of the members. Representatives from Clayton Industries made presentations on scientific safety risk-assessments of coil tube, water tube boilers and other boiler technologies. The task group used this information to validate the top events list and the approach to calculating risk.

2.6. Review of International Practices, Standards and Databases

The task group used best practices including international standards such as International Electrotechnical Commission (IEC 31010), Guidelines for Risk Assessment developed by the Canadian Society for Chemical Engineering, TSSA's Risk and Safety Management Plans for Propane Facilities, and others as basis for this review. The proposed risk-based approach is simple, easy to understand and allows for seamless harmonization across all provinces.

The task group used international databases of catastrophic failure rates to develop a unique list of failure scenarios for each technology type. Upon completion of the review, the task group recommended the following international databases to derive the most conservative and relevant failure rate values:

- FRED (Frequency Rate Event Data) database from the UK Health and Safety Executive
- NPRD-2011 database from Reliasoft/Quaternion Software
- National Boiler Inspectors Association (NBIA) database
- Military Standard MIL-STD-1629 and Australian Association of Chemical Engineers

In their considerations, the task group acknowledged the limitations around a lack of failure rate data specific to Ontario but were confident in the validity of the failure rate data from the international databases, since it represents similar technologies and are widely recognized.

2.7. Development of Modification Factors

Conditional probability factors (otherwise known as weights in this model) are used to adjust a plant's risk score by considering the technology type, plant configurations and plant occupancy and exposure type. The factors were developed based on expert advice and supported by scientific rationale.

2.8. Model Formulation and Testing

Based on the approach described above, the task group developed a model for estimating a plant's aggregate individual risk of fatality or injury, estimated as a product of the frequency of credible catastrophic events and the probability of consequence of fatality to the exposed individual resulting from those catastrophic events. This model was tested using a sample of registered plants obtained from TSSA's database and the results indicate marginal changes in plant rating and requirements for attendance. Details of these test results are provided in section 4.2 of this report.

3. Path 1 Methodology

The Path 1 methodology is a risk-based approach for rating operating plants in Ontario. The methodology for estimating risk proposed by the task group aligns with widely accepted risk assessment methods, including risk tolerance criteria. The rating (or risk scores) is determined based on the levels of individual risk posed by plants and a design configuration will inform decisions around plant staffing and attendance. Key assumptions and salient features of the methodology are described in section 3.2 of this report.

The methodology and decision criteria are simple and easily applicable by plant owners (large and small plants) and are designed to promote standardization. In addition to internationally accepted risk assessment methods, the methodology incorporates industry expert advice as well as ongoing standardization initiatives such as the ACI/SOPEEC[3] standardization of plant staffing and plant rating initiative.

3.1. Key Definitions

Individual risk: It is the frequency at which a specific/real individual may be expected to sustain a given level of harm from the realization of specified hazard scenarios leading to adverse impacts. For purposes of this methodology, the level of harm is estimated in terms of probability of a "fatality" and therefore the individual specific individual risk of fatality is estimated. Note that when considering risk to a real individual, this is also known as individual specific individual risk.

Specified hazards: For purposes of the Path 1 methodology, fire, explosion/pressure boundary failure, toxicity, electrical, and heat/temperature induced hazards are considered.

Credible catastrophic events: These are events associated with the technology that have been known to or likely to lead to the realization of the specified hazard scenarios and with the potential to cause fatality to a specific individual. They include consideration of the entire system. Examples of events include Boiling Liquid Evaporating Vapour Explosions (BLEVEs), vessel rupture, toxic releases, piping system leaks etc.

Aggregate individual risk: Total individual risk calculated for all the identified credible catastrophic events and across all specified hazard scenarios for any technology sub-system.

Frequency of Credible Catastrophic Event: It is the frequency of observed credible catastrophic events (sometimes referred to as failure rates) obtained from reliable databases and measured in units of number of occurrences per plant per year. While in most cases the number of plants is inherently assumed in the estimates from the databases, in some circumstances the events may be component-specific and account for design specifications. For example, piping system failure rates are typically represented per unit length of piping and therefore would need to account to specific lengths of piping within each plant. The frequencies assumed for credible catastrophic

[3] Standardization of Power Engineers Examination Committee

events across all technology systems typically reflect system component failure frequencies, modified for design, fluid type, etc.

Probability of Consequence (fatality): The chance that an individual exposed to the specified hazard scenario resulting from the catastrophic event may sustain a level of harm. The level of harm is assumed to be a fatality and the conditional baseline probability of a fatality is conservatively assumed as 1. Path 1 also conservatively assumes that all "occupants" within the vicinity of the plant have an equal probability of fatality of 1. This probability is modified by occupancy and exposure given occupancy.

Modification Factors: These are factors that reflect the variability in safety and risk across and within each of the technology types, and the extent and types of exposure to consequences and would therefore influence the fatal injury frequency from credible catastrophic events. Weights appropriately describing the variability, extent and types of exposure for the modification factors would be used to adjust the frequencies and the probability of consequences.

Levels of Aggregate Individual Risk: The estimated aggregate individual specific risk for each plant assigned using one of the three levels of the *"As Low as Reasonably Practicable (ALARP)"* principle shown in Figure 2.1. The three levels of risk used for Path 1 methodology are described as the intolerable, as low as reasonably tolerable (ALARP) and the tolerable regions of risk.

3.2. Model Assumptions and Salient Features

The key assumptions and salient features of the Path 1 risk assessment methodology are as follows:

- The estimated risk of fatality is adjusted using conditional probability factors known as modification factors
- When estimating individual specific individual risk, the exposure should consider the presence of an individual within or near the plant that could be impacted by the catastrophic event; for example, if an unattended plant has a hospital in the immediate vicinity, then occupancy should be assumed. Exposure is assumed to depend primarily on the fluid and operating conditions.
- Path 1 does not credit any site-specific automations or additional controls that may be in place above and beyond the fail-safe device requirements or guarded controls in the regulations to help reduce risk; these should only be considered within the scope of the Path 2 methodology.
- While it is acceptable to use the initiating event frequencies from national or international databases, these frequencies should be assumed to conservatively apply to the technology system that is being assessed.
- Path 1 methodology should be generic and applicable to all the technology systems and associated sub-systems.
- Path 1 methodology should conservatively measure absolute individual specific individual risk that is comparable to risk tolerability criteria such as ALARP; this creates the ability to link Path 1 and Path 2 methodologies and helps in the possibility positioning Path 1 as a screening methodology.
- Path 1 methodology estimates risk for non-OE workers at the plant and the public. The operating engineer is assumed to be exposed to the plant risk during the times he/she is present.

- Model assumes that the plant is operated and maintained in accordance with acceptable practices and standards.

3.3. Technological Systems and Sub-Systems

The task group discussed and reached consensus on three technological systems with multiple sub-systems for evaluation and inclusion in the Path 1 methodology. The systems and sub-systems include the following:

1. Boilers
    a) Fire Tube
    b) Water Tube
    c) Low Volume
2. Refrigeration Systems
3. Compressors (Compression side for applications including industrial gases, compressed air, CNG storage and dispensing and gas turbines. Does not include compressors used for refrigeration purposes
4. Steam prime movers

3.4. The Model

The proposed mode defines a plant's risk score as the aggregate level of risk to a specific individual in or within the immediate vicinity of the plant. A plant's aggregate individual risk is estimated as a product of the frequency of credible catastrophic events and the probability of consequence of fatality to the exposed individual resulting from those catastrophic events. The risk score is adjusted by the modification factor weights relevant to the technology system, type of occupancy and exposure given the occupancy type, as applicable to plant.

This aggregate individual risk is in the units of 1 fatality/$10^{-x/year}$ and is compared against established risk tolerance criteria. For simplicity and ease of reference, the plant risk score is calculated as the negative log of the aggregate individual risk to give a score. A plant risk score of 3 or less indicates a high-risk plant whereas a plant risk score of 5 or greater indicates a low risk plant.

The equation defining the aggregate individual risk of the plant and the plant risk score is described as follows:

$$Risk_{plant} = \sum(F_{cce} * P_{fd(cce)}) * M_f \qquad (1)$$

$$Plant\ Score\ (P_s) = -log(\ Risk_{plant}) \qquad (2)$$

Where,

- F_{cce}, is the pre-established (reliable database provided) frequency of a credible catastrophic event associated with a technology sub-system, given a system and a sub-system combination.
- $P_{fd(cce)}$ is the probability of fatality associated with the credible catastrophic event adjusted using modification factors.
- M_f is a modification factor that is pre-assigned and reflect the variability in safety

and risk across within each of the technology system, and the extent and types of exposure and occupancy to consequences (described later for each technology system).

To evaluate and test the proposed methodology, the task group prepared a risk assessment tool based on an event-based modeling layout illustrated in figure 3.1 below.

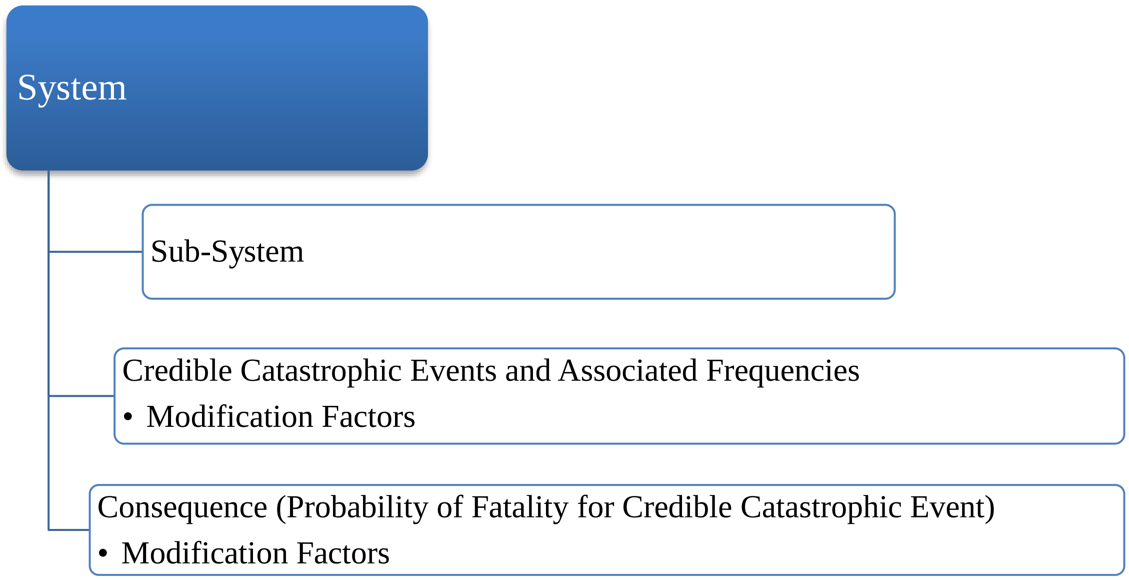

Figure 3.1. Event-Based Modelling Layout

Using a standard hazard identification template and risk assessment methodology, the task group deliberated and arrived at a set of credible catastrophic events for each of the systems and sub-systems. These credible catastrophic events are adjusted to align with failure rates adopted from leading international databases. The task group derived the most conservative failure rate values from the international databases recommended in section 2.6.

A complete list of the credible catastrophic events agreed upon by the task group, their respective frequencies, and the source databases of these frequencies across the three technology systems and sub-systems is presented in the Appendix section.

3.5. Modification Factors

The task group discussed and reached consensus regarding the relevant modification factors for each of technology systems. As discussed in the definitions section, modification factors reflect the variability in safety and risk across technological types and the extent and types of exposure to consequences. They use weights to influence the pre-established frequency of credible catastrophic events and the probability of fatalities.

The base failure frequencies for credible catastrophic events and consequences are based on failure rate databases that are then modified to account for various design features. The modification factors are intended to adjust the risk value based on either the likelihood of failure or the probability of a fatality for each variation. For example, if a refrigeration plant is run using a non-toxic/non-flammable (Class A1) refrigerant, its potential range for fatal exposure (limited to overpressure due to rupture, thermal effects, or asphyxiation due to displacement of air) is much less than it is for a similar sized system using a flammable and/or toxic refrigerant (e.g. ammonia class B2). In this case, the modification factor for ammonia is much higher than for the more benign non-toxic/non-flammable refrigerant to account for the consequence exposure.

The task group identified and reached consensus on the following modification factors:

a) Frequency modification factors
b) Consequence modification factors
c) Weighting modification factors

3.5.1. Frequency Modification Factors

The task group conservatively determined the frequencies of credible catastrophic events using one of two databases (FRED or NPRD-2011) described earlier, by selecting a higher frequency value. The frequency modification factors are meant to increase or decrease the selected top event frequencies based on the design, presence of guarded controls, the type of fuel (if applicable), and the number of equipment on the premises as described below:

Design

This criterion primarily represents the age, adequacy, material type, material length for piping, and/or the state of obsolescence of the design of the equipment as relevant to each of the technology systems. The base frequency for the credible catastrophic event obtained from the databases regardless of the equipment is assumed to apply to most modern, safest design (modification factor of 1) while those representing the other classes are assigned modification factors with higher orders of magnitude indicating higher failure frequencies.

Presence of Guarded Controls

This modification factor simply reflects the presence or absence of guarded controls (less the requirement for being hard-wired) accepted within the current regulation. The absence of a guarded control would have a modification factor reflecting a higher failure frequency.

Fuel Type

Relevant only to boilers, this modification factor assumes the properties of the fuel type (e.g. flammability) increase the probability of the credible catastrophic events related to fuel system/furnace failures. The fuel types considered for the boiler design include:

- Flammable Liquid
- Flammable Gas
- Solid
- Electric
- Black Liquor

3.5.2. Consequence Modification Factors

It is the assumed that, irrespective of the type of credible catastrophic event, the worst-case scenario would always lead to a fatality. The consequence modification factors are therefore set at an upper limit of 1 and reduced based on the type of occupancy of the public receptors and their proximity to exposure, represented in the amount of material or charge and the temperature and/or pressure of the charged fluid. The modification factors agreed upon by the task group as described above include the following:

Occupancy

This factor represents the conditional probability of occupancy within the potentially impacted area for a specified individual. Ontario's OE plants are currently located at locations with the following occupancy types:

- 01 - Power Producers/Utilities
- 02 - Petro/Chemical
- 03 - Production Industries
- 04 - Manufacturing Industries
- 05 - Medical
- 06 - Academic
- 07 - Food Process
- 08 - Public Services
- 09 - Commercial
- 10 - Residential
- 11 - Agriculture
- 12 - Steam Traction

Material/Fluid Type

The material/fluid type may carry the potential risks of scalding, flashing, burn, BLEVE or poisoning depending on type, flammability or toxicity properties or operating temperatures among other properties. Examples of materials considered in the model include water above and below 212°F (100°C), steam, thermal oil, refrigerants, natural gas and organic fluids used in organic rankine cycle systems.

The material/fluid type modifier is a surrogate for a conditional probability of exposure to a hazard for a specified individual that results in a probability of fatality of 1, given occupancy.

Charge

Charge size, also known as inventory refers to the amount of process material that would be released at a point. This suggests that the more process material released, the greater the release duration and the impact range of the hazard and therefore increase the likelihood of an exposure. In the case of boilers, this would equate to the volume of water released, while for refrigeration systems, the total charge (in pounds/kilograms) that could come in direct contact with the exposed individual in the event of a failure. In the case of compressor system leaks, the power rating and storage inventories are used to estimate release.

In addition, where electrical hazards are relevant and apply, the voltage in the system would impact the probability of a fatality largely due to electrical contact or arc flashing.

Power Rating
The power rating of a plant (measured in kilowatts) is the total energy output, represented by operating parameters such as pressure, temperature and volume. The risk model assumes that units with higher power ratings have a greater consequence factor in the event of a catastrophic failure.

Number of Equipment
This represents a complexity factor, which assumes that presence of more equipment on the location increases the chances of the credible catastrophic event by a factor equal to the number of pieces of equipment.

Piping
For piping systems, the length of piping systems containing material posing the specified hazard is considered. The base frequencies are typically in units of occurrences/year/meter. The base frequency for piping is limited to a length of 100 m/328 ft which is assumed to be the maximum length that could create exposure to an individual. The weight for this modification factor is maintained at 1 for all technologies because the consequence is always dependent on the amount of material present within this maximum geographic length and that any material in piping beyond a length greater than 100 m would not directly impact an individual or impair their ability to self evacuate.

3.5.3. Weighting Modification Factors

The task group developed a weighting system for these modification factors based on scientific data, historical evidence, and expert judgement. For example, the weighting factors for the various refrigerant types are based on the concentrations of flammability and/or toxicity.

A substance with a lower flammable limit of 4% has the equivalent of 40,000 parts per million (ppm). Ammonia, which has an IDLH (immediately dangerous to life and health) level of 300 ppm is given a weight that is 40,000/300 of the weight of the flammable substance to account for the range and likelihood of a hazardous exposure. Where sufficient historical data exists, such as insurance claims, it is possible to generate weighting factors based on reported incidents. For each of the modification factors, the weight and justification/rationale as recommended by the task group are presented in the tables in Appendix F.

3.6. Decision Criteria for Plant Attendance Requirements

The risk score of a plant is estimated using the model developed in section 3.4 and compared to the ALARP principle scale which specifies the risk limit and risk practice in accordance with international practices, as shown in figure 3.2 below.

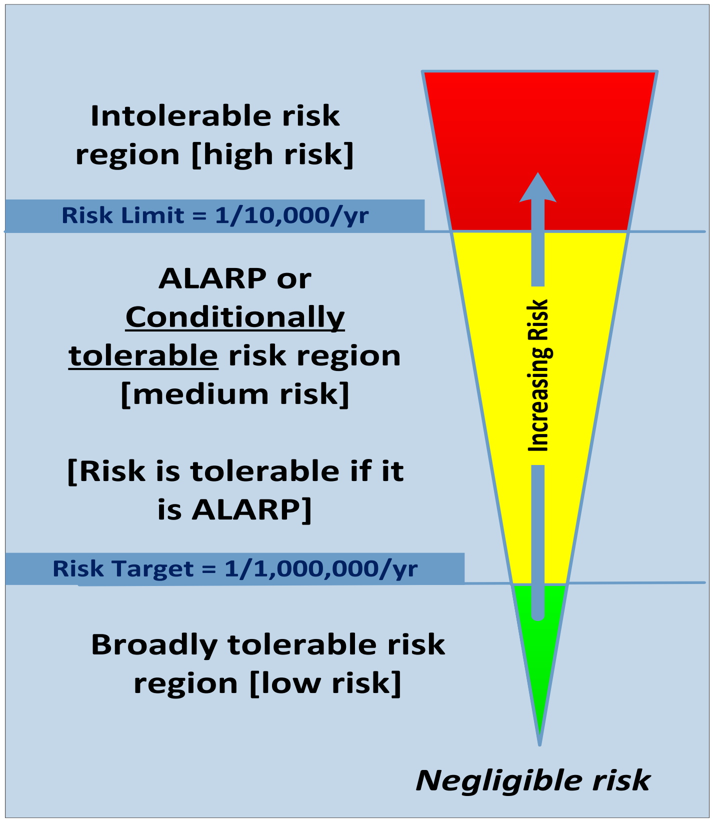

Figure 3.2. Risk Acceptability Using Criteria Using the ALARP Principle

Using the risk scores generated from the model test, the task group recommends the following decision criteria (also summarised in table 3.1) for plant rating and attendance:

- High risk plants (plants in the intolerable risk region) would require attendance of a first-class operating engineer at minimum. These are plants with a risk score that is less or equal to 3
- Medium risk plants (plants in the conditionally tolerable risk region) shall be attended. These are plants whose risk score is between 3 and 5; for such plants the regulator (TSSA Statutory Director) should consider the plant risk score to determine rating and attendance requirements
- Low risk plants (plants in the broadly tolerable risk region) would be unattended. These are plants whose risk score is equal to or greater than 5

RISK MODEL DECISION CRITERIA FOR OE PLANTS			
Risk Limits Description	A plant's individual risk of fatality greater than 1 in 1000/year i.e. risk score of 3.00 or less **(≤ 3.0)**	A plant's individual risk of fatality between 1 in 1000/year and 1 in 100,000/year i.e. risk score between 3.00 - 5.00 **(3.0 ≤ X ≤ 5.0)**	A plant's individual risk of fatality of 1 in 100,000/year or lower i.e. risk score of 5.00 or more **(≥ 5.0)**
Risk Tolerability	Intolerable	Conditional Tolerability	Tolerable
Attendance	Plant requires at minimum, a 1st Class OE	Plant requires attendance, but not necessarily for a 1st Class OE. The regulator shall develop a plant rating and attendance schedule that is informed by the risk score and other site-specific factors, where applicable	Plant does not require attendance

Table 3.1. Recommended Risk Tolerance and decision Criteria

Further to the above recommendation, the task group would like to make known the following critical elements to accompany the decision criteria:

- The methodology does not consider the exposure to the operating engineer from a consequence standpoint; As a result, the operating engineer is assumed to exposed to the residual risk of the plant.
- It cannot be assumed that attendance will reduce the risk to tolerable levels. The presence of the operating engineer will manage the risk and reduce the likelihood of an incident.
- The task group suggests that the regulatory proposal provides the regulator with authority to look at alternative means of demonstrating tolerable levels for plants with very high risks, including the option to use Path 2 methodology.
- The task group also recommends that the “Leadership” elements of the CSA Z767-17 Standard on “Process Safety Management” (which is being considered as the recommended standard for Path 2 methodology) be incorporated into the amended OE regulation and applicable to Path 1 plants as well.

4. Model Testing and Sensitivity Analysis

4.1. The Sample

The risk model was tested against a sample of 117 registered plants obtained from TSSA's database and disaggregated as follows by their current class rating:

Plant Rating	No of Plants
1st class plants	20
2nd class plant	29
3rd class plants	24
4th class plants	20
Unattended plants	24
Total	117

Table 4.1 below categorizes the sample by technology type and the results presented in section 4.2 follow this sequence.

TECHNOLOGY USE/TYPE	COUNT
Boiler-only plants	9
Compressor-only plants	21
Refrigeration-only plants	10
Multiple technology (a combination of two or more technologies	77
Total	**117**

Table 4.1. The Number of Plants Tested by Technology Type

4.2. Test Results

The model test results demonstrate how the risk of plants compare to the risk tolerability criteria described in section 3.6 and how this impacts the attendance profile of plants. The results summary in table 4.2 suggest the following:

- Overall, 117 plants were tested – 93 attended and 24 unattended
- 20 of the 93 attended plants shifted to the unattended category
- 4 of the 24 unattended plants shifted to the attended category
- All the 20 first class plants tested maintained their attendance profiles; however, 8 plants recorded a risk score that is below the task group's recommended threshold for a 1st class plant
- Majority of the plants that shifted to the unattended category are compressor plants whose risk score is driven by their limited population exposure and material type
- Overall, 16 plants had their attendance profile impacted, which represents about 14% of the sample

There is minimal change in the attendance profiles for plants currently classified as 2nd, 3rd, and 4th class plants. The risk scores of such plants mostly fall within the "ALARP" region that requires attendance (but not necessarily for a 1st Class OE). The risk acceptability criteria in section 3.6 provides risk thresholds for unattended plants and plants that require a 1st class OE (i.e. the upper and lower risk score limits).

The model does not propose plant rating criteria for risk scores between these two thresholds and the task group recommends this decision be made by the statutory director. Sixty-one (61) plants had risk scores that fall within this category.

Current Attendance	Risk Model Attendance			Total	
	1st Class	**Attendance**	**Unattended**		
1st Class	8	12		20	
2nd Class	4	23	2	29	**73**
3rd Class		10	14	24	
4th Class		12	8	20	
Unattended		4	20	24	
Total	**12**	**61**	**44**	**117**	

Table 4.2. Overall Test Results

The test results are also presented in a scatter diagram in figure 4.1 below.

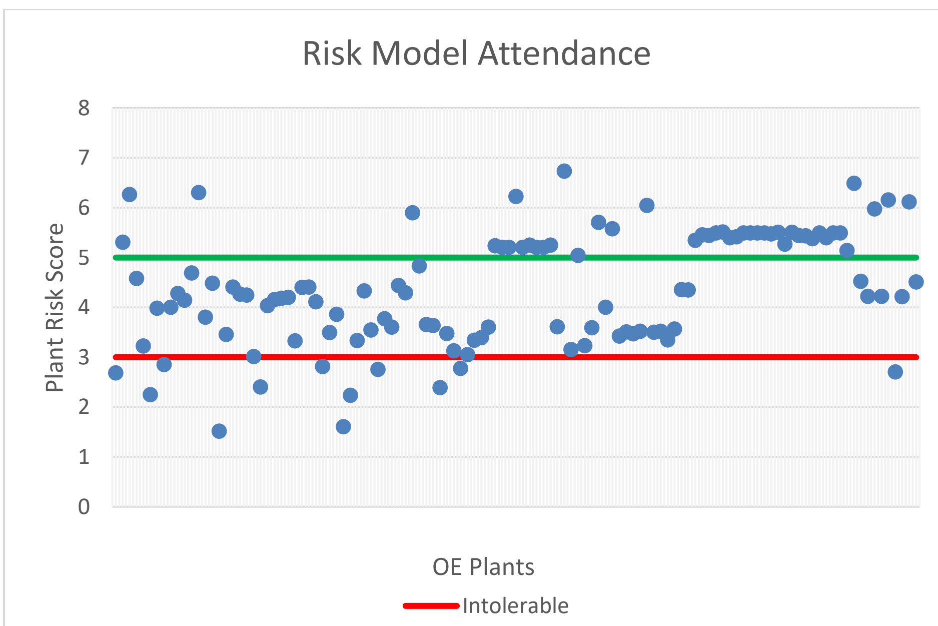

Figure 4.1. Test Results Scatter Diagram

4.2.1. Test Results for Boiler Plants

Nine plants with boiler-only technology with the following attendance profiles were tested:

- Attended – 6 plants (2 first class, 2 second class and 2 fourth class)
- Unattended – 3 plants

Overall, there were no changes in the attendance status of these plants. However, one 1st class plant had a risk score that could not meet the threshold for a 1st class operating engineer but still requires attendance. See table 4.4 below.

Current Attendance	Risk Model Attendance			Total	
	1st Class	Attendance	Unattended		
1st Class	1	1		2	
3rd Class		2		2	**4**
4th Class		2		2	
Unattended			3	3	
Total	**1**	**5**	**3**	**9**	

Table 4.4. Test Results Summary for Boiler Only Technology Plants

4.2.2. Test Results for Compressor Plants

A total of 21 compressor plants with the following attendance profiles were tested:

- Attended – 13 plants (12 third class and 1 fourth class)
- Unattended – 8 plants

The results in Table 4.5 indicate that all 13 attended plants would shift into the unattended category. The sample largely contains compressed natural gas plants.

Current OE Attendance	Risk Model Attendance		
	Unattended	Total	
3rd Class	12	12	**13**
4th Class	1	1	
Unattended	8	8	
Total	**21**	**21**	

Table 4.5. Test Results for Compressor Plants

4.2.3. Test Results for Refrigeration Plants

A total of 10 refrigeration plants with the following attendance profiles were tested:

- Attended – 8 plants (1 second class, 3 third class and 4 fourth class)
- Unattended – 2 plants

The results in Table 4.6 indicate a marginal decrease in the plants that require attendance with 2 fourth class plants shifting to the unattended category.

Current Attendance	Risk Model Attendance		Total	
	Attendance	Unattended		
2nd Class	1		1	**8**
3rd Class	3		3	
4th Class	2	2	4	
Unattended		2	2	
Total	**6**	**4**	**10**	

Table 4.6. Test Results for Refrigeration Plants

4.2.4. Test Results for Multiple Technology Plants

Currently, for multiple technology plants, TSSA makes attendance decisions based on the technology that has the highest power rating. For example, a plant which has a boiler unit of 150 kW and a refrigeration unit of 1200kW, TSSA assigns attendance based on the power rating of the refrigeration unit.

In contrast, the proposed risk model aggregates the individual risk of each unit to obtain a single risk score. In other words, the estimated risk score of the boiler is added to the estimated risk score of the refrigeration plant to obtain a single score which is representative to the overall risk rating of the plant.

Overall, a total of 77 multiple technology (two or more technologies) plants with the following attendance profiles were tested:

- Attended – 66 plants (18 first class, 28 second class, 7 third class and 13 fourth class)
- Unattended – 11 plants

The plant technology combinations are as follows:

a) Boilers and Refrigeration
b) Boilers and Compression
c) Refrigeration and Compression
d) Refrigeration, boilers and compression

Overall the risk model results indicate an increase in the unattended plants from 11 to 15. The number of plants that require a first class Operating Engineer was reduced from 18 to 12. The model only identifies the upper and lower risk score limits (i.e. first class and unattended). Plants with risk scores that fall within these limits shall have the regulator establish a formal process informed by the risk scores to determine plant rating and attendance. For these plants, the model results indicate an increase in the plants that require attendance from 48 to 50. See table 4.3 below for a summary.

<table>
<tr><th></th><th colspan="4">Risk Model Attendance</th><th></th></tr>
<tr><th>Current Attendance</th><th>1st Class</th><th>Attendance</th><th>Unattended</th><th>Total</th><th></th></tr>
<tr><td>1st Class</td><td>8</td><td>10</td><td></td><td>18</td><td></td></tr>
<tr><td>2nd Class</td><td>4</td><td>23</td><td>1</td><td>28</td><td rowspan="3">48</td></tr>
<tr><td>3rd Class</td><td></td><td>5</td><td>2</td><td>7</td></tr>
<tr><td>4th Class</td><td></td><td>8</td><td>5</td><td>13</td></tr>
<tr><td>Unattended</td><td></td><td>4</td><td>7</td><td>11</td><td></td></tr>
<tr><td>Total</td><td>12</td><td>50</td><td>15</td><td>77</td><td></td></tr>
</table>

Table 4.3. Test Results Summary for Multiple Technology Plants

5. Review and Continuous Improvement

To align with Ontario's regulatory policy and best practices in risk management, a framework shall be in place to assess the effectiveness of the proposed risk-based regulatory framework and identify opportunities for continuous improvement. The task group recommends a framework that works in conjunction with TSSA's safety strategy and established safety objectives for the Operating Engineers program.

A range of monitoring and review activities are recommended during the implementation process whose outcome will be used to refine the model inputs to ensure processes are effective and achieve TSSA's desired safety outcomes. Figure 2 outlines these interactions.

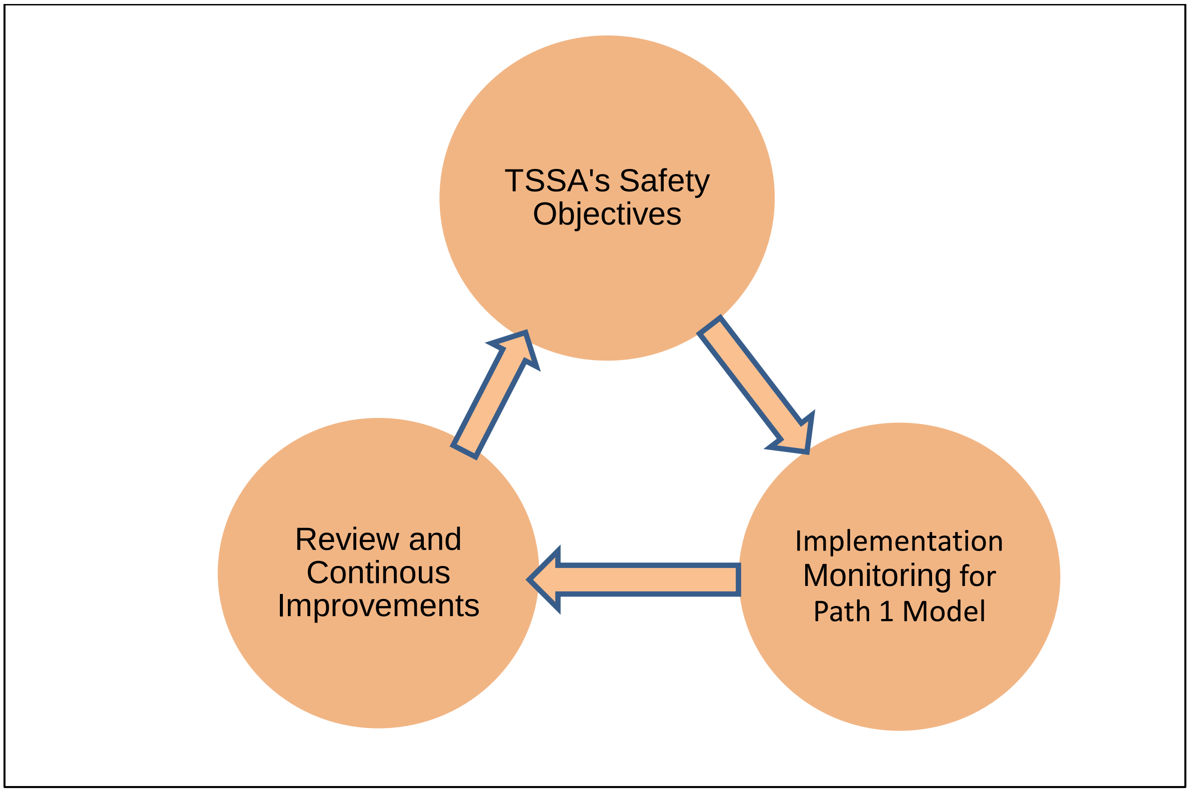

Figure 5.1. Review and continuous improvement process

Review of the Path 1 framework shall be conducted on a regular basis, preferably once every three years, by TSSA's Public Safety Risk Management (PSRM) team, in collaboration with the OE program. The process may involve the following activities:

- Assessment of the emergence of new technologies and systems currently not covered by the Path 1 framework
- Assessing the continuing stability of the model in relation to operations such as inspections and licensing of OE plants
- Assessing the effectiveness of revisions to the model input resulting from previous reviews and the extent with which recommendations from previous reviews are adopted
- Considering actions or recommendations arising from audits, incident investigations and observed hazard trends since the last review

- Identifying any deficiencies or opportunities in the model and developing a plan to remedy these deficiencies or take advantage of the opportunities
- Assessing feedback from regulated clients, industry advisory councils and inspectors on how the model can be improved
- Collecting failure and incident data and applying statistical methods to improve the reliability of failure event frequency data and modifier values.

Continuous improvement will involve acting based on input from the review activities described above. Any change to the path 1 model must be properly assessed using acceptable risk management standards to ensure the changes achieve safety and regulatory objectives set by TSSA and MGCS. Changes made must be approved through established protocols between TSSA and MGCS and must be tracked and documented. They should also undergo peer review and a Quality Assurance process.

6. Conclusion and Next Steps

The Path 1 methodology proposed in this report is a standardized risk-based approach to rating operating plants based on estimated aggregated individual risk of plants. It is a conservative methodology that is primarily focused on informing plant staffing and attendance decisions by the regulator. While the staffing and attendance decisions made as a result of this methodology may not exclusively reduce or maintain the level of risk at acceptable levels, the presence of an operating engineer is assumed to help manage the risk and likely prevent the occurrence of a catastrophic event. The methodology for estimating risk aligns with widely accepted risk assessment methods, including risk tolerance criteria.

The methodology and decision criteria are designed to be standardized, simple and easy to apply for owners of plants, regardless of their plant sizes. In addition to widely accepted risk assessment methods, the methodology anchors on industry expert advice, including recommendations proposed by the Association of Chief Inspectors (ACI) and SOPEEC in the standardization of plant rating proposal. This approach will promote ongoing harmonization initiatives being pursued by Canadian jurisdictions through NPSAC. The Path 1 methodology does not allow for plants to take credit for any specific innovations or modernizations beyond the requirements in the current regulations and adopted standards. The Path 2 RSMP approach will provide this option for plant owners.

The test results generally reflect a minor shift in the staffing profile of plants and the task group expects that this trend will be observed when a full sensitivity analysis is conducted by TSSA. To facilitate full implementation of this model and ensure predictability and consistency in the application of the regulation, the task group recommends the following as the next steps:

- TSSA to develop a user-friendly tool for estimating the risk score of plants
- TSSA to develop a plant attendance schedule that is based on the risk score of plants and other unique factors (if necessary and applicable).

As part of the comprehensive changes proposed to the OE regulation, the task group recommends the mandatory collection and/or reporting of key data relevant to maintaining a robust risk-based regulatory framework. This includes data on failure frequencies specific to Ontario and design factors relevant to currently regulated technologies. The model should be evaluated for accuracy and relevance at least once every 3 years based on new data that may be obtained on frequencies and the weights for the modification factors and reviewed to include new data elements if necessary in the future.

Appendix A. Task Group Terms of Reference and Scope of Work

Purpose

The purpose of the Operating Engineers (OE) Risk Task Group is to develop a framework and methodology for a risk-based approach to regulating staffing requirements for plants, as proposed by the Operating Engineers Expert Panel. The purpose of the Advisory Group is to reflect the voice of the panel and provide input and feedback from a broader industry perspective on public safety, applicability and potential cost implications of the work of the Task Group. The objective of the panel is to review the Operating Engineers Regulation (O. Reg. 219/01) and provide recommendations to improve public safety while imposing a minimum burden on business.

Background

The Ministry of Government and Consumer Services (MGCS) and the Technical Standards and Safety Authority (TSSA) are currently reviewing the Ontario Operating Engineers Regulation (O. Reg. 219/01) ("the regulation") under the Technical Standards and Safety Act, 2000 through an expert panel approach. The Operating Engineers Expert Panel was constituted by MGCS and TSSA, met from November 2016 until February 2017, and will produce a findings report by June 2017.

The expert panel recommended a risk-based approach to regulating the staffing requirements for plants. The approach provides plant owners with two paths for compliance.

1. Path 1 is a risk-based approach that prescribes plant staffing and attendance requirements based on plant ratings determined by a scientific risk score.
2. Path 2 is a risk-based approach that allows plant owners to develop and implement a regulator-approved Risk and Safety Management Plan (RSMP).

MGCS and TSSA have proposed the formation of a Task Group to help establish the framework and the methodology for the risk-based approach that will ensure successful implementation of these two paths for compliance. The framework will be based on best practices in risk management, aligned with Ontario's regulatory policy and designed to promote public safety. This document is intended to serve as the terms of reference and scope of work for the Operating Engineers Risk Task Group.

Scope of Work

The Task Group is tasked to establish a risk-informed decision-making framework and methodology for the two paths for compliance proposed as part of the OE regulatory review.

The key tasks for the Task Group include the following:

1. Develop a risk-informed framework and methodology for Path 1.
2. Develop a risk-informed framework and methodology for Path 2.
3. Develop a plan for addressing operational considerations for implementing the two regulatory approaches.
4. Guide TSSA in the development of tools and assessment of costs for implementation including the development of RSMP templates and guidelines, and implementation plans for the two paths of compliance.
5. Support TSSA and the MGCS in the public consultation process.
6. Develop a framework for monitoring and continuous improvement by TSSA.
7. Identify roles and responsibilities in Path 1 and Path 2 – for example, roles and responsibilities of owners in Path 1 will be very different for those in Path 2.
8. Refine the work plan.

NOTE: The scope of work does not include the actual development of tools and estimation of costs for implementation. TSSA will complete these two tasks and submit them to the Task Group for commentary and feedback.

The Task Group's work will be concluded once it has considered comments obtained through the public consultation facilitated by TSSA. The final output of the Task Group will be the preparation of a report written on behalf of the Task Group by an independent facilitator. This report will be used by TSSA and MGCS to draft and implement the regulation.

Terms of Reference

The following terms of reference have been identified for the formation and operation of the Task Group to ensure that the outputs of the Task Group align with best practices in risk management, achieve public safety outcomes and allow for smooth implementation of the proposed risk management framework. They include:

1. The Task Group and its work shall be coordinated by an independent facilitator with significant knowledge in technical/safety risk management, experience in facilitation and working knowledge of the Operating Engineers regulation and the industry sector.
2. The independent facilitator will be retained by TSSA to coordinate and organize meetings, facilitate risk assessment sessions and discussions, develop risk-based methodology, meet project plan expectations, deadlines and milestones, prepare presentations to stakeholders, and interim and final reports and related documents.
3. The Task Group will report to an Advisory Group whose membership shall be no more than 20 persons, drawn from interested members of the expert panel, broader industry and MGCS.
4. In conducting risk assessments, task group may seek data, information and expertise from external sources up to and including those recommended by the OE Expert Panel members for different technologies, plant categories and sizes.
5. The Task Group shall develop the framework and methodology for both paths such that they are scientific and evidence-based, incorporate expert advice, are clear, easily understandable.
6. Path 1 shall be a risk-based methodology that is limited to determining the staffing requirements for plants.
7. Path 2 shall involve the development of a risk and safety management plan aligned with best practices in process safety management and involves methods that demonstrate acceptable levels of risk.
8. The methodologies for rating plants using Path 1 and Path 2 shall be based on risk assessment methods and measures.
9. Compliance with Path 1 cannot be assumed to meet tolerable risk
10. Compliance with Path 2 must meet tolerable risk as a fundamental requirement
11. Simple and easy to use tools and guidance documents shall be developed for Path 1.
12. Detailed guidelines, templates with example applications, and references to acceptable standards, tools, methods and databases shall be provided for complying with Path 2.
13. The Task Group can seek inputs and feedback from external experts.
14. The Task Group will work collaboratively and where possible seek consensus.

Task Group Deliverables

1. A risk informed framework and methodology for Path 1 prescriptive regulatory approach.
2. A risk informed framework and methodology for Path 2 RSMP regulatory approach.
3. An implementation plan for the Paths 1 and 2 regulatory approaches.
4. Review and provide feedback to TSSA's tools and costs for implementing Path 1 and Path 2 regulatory approaches, including the implementation plans for Path 1 and Path 2.
5. A framework for monitoring and continuous improvement.
6. Final report.

Reporting
For the first four months, the Task Group will provide updates of its work to the Advisory Group on a monthly basis, and for the duration of the project, on a quarterly basis through in-person or teleconference meetings. The Task Group will provide a written status report with updates in advance of these meetings. The frequency of these meetings will be periodically assessed, and the Task Group Secretariat shall coordinate any additional reporting requests.

Terms of Reference – Advisory Group

1. The role of the advisory panel will include the following:
    a) Review reports from the Task Group and provide advice and input to the work of the Task Group.
    b) Provide input and feedback from a broader industry perspective on public safety, applicability and potential cost implications of the work of the task group.
2. Members of the OE Expert Panel who would like to participate in this process can do so through the Advisory Group.

Time Frame
The term of the Task Group shall be 12 months beginning March 2017 to February 2018. See appendix II for the draft work plan.

Appendix B. Task Group Membership

	Name	Company	Position
1	Dave Malinauskas	CIMCO Refrigeration	President
2	Paul Ingham	Thermogenics	Vice President-Sales & Marketing
3	Greg Black	International Union of OEs Local 772	Operating Engineer
4	Marcello Oliverio	Enbridge Gas Distribution Inc.	Process Safety Program Manager
5	David Meston	Change Energy	Safety Engineer
6	Dwight Reid	TSSA	Risk Advisor
7	Brian Gee	TSSA	Technical Advisor
8	Jorge Larez	TSSA	Senior Risk Advisor
9	Humphrey Kisembe	TSSA	Policy Advisor
10	Srikanth Mangalam	PRISM Institute	Facilitator

Appendix C. Failure Frequencies for Boiler Systems

Boiler Sub-System	Credible Catastrophic Event	Event Frequency	Source
Fire Tube	1. Pipe System Failure (Design Modification Factor does not apply, use 1) (per 100m of pipe)	1.65E-04	FRED, UK, HSE p.19, Pressure Vessels (catastrophic)
	2. Tube break/Vessel	1.50E-04	
	3. Shell break/Vessel	4.00E-06	
	4. Furnace (Fuel System) Failure/Vessel	8.97E-06	
	5. Auxiliary (accumulator, high-pressure receiver) system failure/Vessel	5.00E-04	
Water Tube	1. Pipe System Failure (Design Modification Factor does not apply, use 1) (per 100m of pipe)	1.65E-04	FRED, UK, HSE p.19, Pressure Vessels (catastrophic)
	2. Tube break/vessel	1.50E-04	
	3. Drum break/Vessel	4.00E-06	
	4. Furnace (Fuel System) Failure/Vessel	8.97E-06	
	5. Auxiliary (accumulator, high-pressure receiver) system failure/Vessel	5.00E-04	
Low Volume Boilers	1. Pipe System Failure (Design Modification Factor does not apply, use 1) (per 100m of pipe)	1.65E-04	FRED, UK, HSE p.19, Pressure Vessels (catastrophic
	2. Tube break/vessel	1.50E-04	
	3. Drum break/Vessel	4.00E-06	
	4. Furnace (Fuel System) Failure/Vessel	8.97E-06	
	6. Auxiliary (accumulator, high-pressure receiver) system failure/Vessel	5.00E-04	

Appendix D. Failure Frequencies for Refrigeration Systems

Refrigeration	Credible Catastrophic Event	Event Frequency	Source
	1. Pipe System Failure	1.65E-04	
	2. Pressure Vessel Failure	4.00E-06	FRED, UK, HSE p.19, Pressure Vessels (catastrophic)
	3. Electrical Flash/contact (Arc flash from the starter panel assumed)	1.00E-06	Statistics Canada, common risk #84-208
	4. Evaporator failure	4.00E-06	HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)
	5. Condenser Failure	4.00E-06	HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)
	6. Pump Seal Failure	5.00E-05	HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)
	7. Reciprocating compressor failure	1.40E-05	HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)
	8. Rotary compressor failure	2.96E-06	HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)

Appendix E. Failure Frequencies for Compressor Systems

<table>
<tr><th>Compressor Sub-System</th><th>Credible Catastrophic Event</th><th>Event Frequency</th><th>Source</th></tr>
<tr><td rowspan="4">Compression side for Applications including industrial gases, compressed air, gas turbines (does not include refrigeration).</td><td>Pipe System Failure</td><td>1.00E-04</td><td rowspan="4">HSE - Failure Rates and Events Data for use within Risk Assessments (28/06/2012)

Statistics Canada, common risk #84-208</td></tr>
<tr><td>Pressure Vessel Failure</td><td>5.00E-06</td></tr>
<tr><td>Electrical Flash/contact</td><td>1.00E-06</td></tr>
<tr><td>Reciprocating compressor failure</td><td>1.40E-05</td></tr>
</table>

Appendix F. Weighting System and Related Justification

Boiler Modification Factors

Frequency Modification Factors		
Factor	**Weight**	**Justification**
Boiler Design		Based on incident data from NB reports and FRED databases as well has historical data on failure rates and charge.
Safest in class (Low volume coil tube)	1	Forced circulation low volume boilers have never had a waterside explosion, mathematically impossible based on design.
Moderate (Packaged/Field Erected/Water Tube)	10	
Aged Design (Fire Tube - Locomotive)	100	
Fuel Type		
Liquid	1	Only applies to catastrophic failure events, only fuel system failure needs to be considered
Gas	10	
Solid	100	
Indirect Heated	0.1	
Electric	0.1	
Black Liquor	1000	
Number of Equipment		
1	1	This is to capture increased capacity of charge across high water volume boilers as well as potential difficulty in managing multi boiler facilities. Multiple boilers in a plant do present a slightly higher level of complexity to maintain safely.
2	2	
3	3	
4	4	
Presence of Guarded Controls		Fail safe devices as defined in regulations in dependent of specific technologies
None	10	
Fail Safe Devices	1	

Consequence Modification Factors		
Factor	**Weight**	**Justification**
Material/Fluid Type		The more likely hazard is similar to hot water since it remains in liquid form but can degrade to become lighter and decrease its flash point under certain conditions such as presence of moisture.
Water < 212 F (100°C)	0.01	
Water > 212 F (100°C)	1	
Steam	0.1	
Thermal Oil	0.05	
Flammable or toxic fluids such as ORC fluids	1	Currently assumed to be one of cyclopentane (highly flammable) - See TSSA's document for other materials for ORC safety guidelines, the others are considered as of lower flammability and higher toxicity
Proximity to Exposure (Based on the charge identified as volume of water)		This modification factor accounts for inventory or charge, recognizing that a greater charge will produce a larger event and impact a larger region. The task group considered that: • For less than 1000 gallons, the impacts to non-OE workers or the public are not certain – i.e.
<212 F (100°C) (Piping System)	0.01	
>212 F (100°C) (Piping System)	0.1	
Boiler (<75 gallons of water)	0.1	

Consequence Modification Factors		
Factor	**Weight**	**Justification**
Boiler (75 - 1000 gallons of water)	0.5	probability less than 1, and • For piping systems, the rate of release slows the escalation of an event vis a vis boiler vessel failure and the impacts are also not certain.
Boiler (> 1000 gallons of water)	1	
Power Rating		
Boiler - Coil Tube (< 15,000 KW)	0.01	Water side event is restricted to the point where failure is contained in shell and energy is exhausted safely
Boilers - ALL other LWV (< 15,000 KW)	0.01	Water side event is limited to choke point of pipe diameter and restricted to within the boiler shell with minimal release. In the unlikely event of a BLEVE of the mud drum, severe injury could occur in the immediate area.
Boiler (< 600 KW)	0.1	Historically, expert opinion has placed boilers with low kW in the unattended category, pointing to a lesser consequence resulting from an event. The rating for higher kW boilers and the related weights are adopted from the SOPEEC plant rating proposal
Boiler (600 > KW <12,000)	0.4	
Boiler (12,000 > KW < 30,000)	0.7	
Boiler (> 30,000 KW)	1	

Refrigeration Modification Factors

Frequency Modification Factors		
Factor	**Weight**	**Justification**
Automation		
None	10	Fail safe devices as defined in regulations in dependent of specific technologies
Fail Safe Devices	1	

Consequence Modification Factors		
Factor	**Weight**	**Justification**
Refrigerant Type		The ASHRAE 34-2010 standard “Designation and Safety Classifications of Refrigerants” was used as a basis. This standard has a concept called “Refrigeration Concentration Limit” (RCL) which considers the maximum concentration one should be subject to is based on: a) Acute Toxicity Exposure Limit (ATEL). The ATEL is further considered by: • Mortality (LC50) • Cardiac Sensitization • Anexthetic or Central Nervous System Effects • Other Escape-impairing effects and permanent injury b) Oxygen Deprivation Limit (ODL), and c) Flammable Concentration Limit The ASHRAE standard presents this RCL data in terms of ppm. Table 1 of Canada’s refrigeration standard B52-13 identifies commonly used refrigerants based on their type (A1, A2, etc.). We then looked at the RCL for each of these refrigerants within the Refrigerant type category and noted the RCL. These were then pro-rated the weights based on Ammonia being the most dangerous. For example, Ammonia has an RCL of 320. The most dangerous A1 refrigerant listed in B52 is R417a with an RCL of 13,000. The weight for A1 then becomes the ratio of the RCL – in

Consequence Modification Factors		
Factor	**Weight**	**Justification**
		this case 320 / 13,000. This equates to 0.024. This weight is rounded to 2 digits for simplicity.
A1	0.02	Based on RCL of R417a (13000) when compared to RCL of Ammonia (320)
A2L	0.02	Based on RCL of R1234yf (16,000) when compared to RCL of Ammonia (320)
A2	0.03	Based on RCL of R152a (12,000) when compared to RCL of Ammonia (320)
A3	0.06	Based on RCL of Propane (5,300) when compared to RCL of Ammonia (320)
B1	0.04	Based on RCL of R123 (9,100) when compared to RCL of Ammonia
B2L	1	RCL of Ammonia is 320
B2	1	
B3	1	
Charge		Weight is proportional to charge between 0 – 10,000 lbs (4536 Kgs) with the maximum weight being 1 and values for other charges developed using a linear scale. For example, 100 lbs is 0.01. 200 lbs is 0.02 and so on.
100 lbs.	0.01	
1000 lbs.	0.1	
10,000 lbs.	1	
Exposure Impacted by Design (direct v indirect)		Limited exposure to refrigerant should a failure occur. Indirect systems prevent the refrigerant coming in contact with a person should an accident occur
Direct	1	
Indirect	0.1	
Exposure Impacted by Design (Split by electrical voltage)		
Voltage 120 V/240 V	0.001	Common voltages for home wiring and home equipment implies an acceptable level of public (e.g. “safe as houses”). “unqualified” homeowners may do work at this voltage provided it is inspected by ESA Canadian Electrical Code CSA22.1 Safety Standard for Electrical Installations: a) Defines low voltage as 30 up to 750 V. b) 300V or less and 300V up to 600V are used as common divisions to differentiate electrical equipment requirements (e.g. wire size based on “risk”). c) Nominal voltages include 120, 208 and 240 Workplace Electrical Safety CSA Z462: a) defines high voltage as >600V b) uses 300V and 301-750V as common divisions to differentiate electrical risks such as Arc Flash PPE =1 for 240V or less (i.e. lowest risk, typically cotton work clothing only)

Consequence Modification Factors		
Factor	**Weight**	**Justification**
		Ontario Industrial and Construction Regulations under OHSA use 300V as an “implied level” for low risk (e.g. lockout not required if not practical) Electrical utility industry calls this “secondary” voltage and considers this level low risk
240 V to 600 V	0.1	Common voltages for commercial and industrial applications Typically, only “qualified” trades (e.g. industrial electricians) do work at this voltage as there is a lot of energy associated with a 600V system and there is an increased risk of a fatality or serious injury. Canadian Electrical Code CSA22.1 Safety Standard for Electrical Installations: a) Still defined as low voltage up to 750 V, however, other jurisdictions such as the UK use the term “medium” voltage. b) Electrical equipment requirements are greater (e.g. wire size, insulation). c) Nominal voltages include 480 and 600. Workplace Electrical Safety CSA Z462: a) 600 V or less still defined as low voltage b) Higher energy is reflected by Arc Flash PPE =2-4 for 600V or less (i.e. lowest risk, typically special arc flash clothing required) Ontario Industrial and Construction Regulations under OHSA use 301-750 as an implied level for “higher risk” (e.g. lockout required, 2nd person, written procedures, etc. typically required) Electrical utility industry considers this level medium risk but acknowledges the potential high energy levels
Greater than 600 V	1	All documents referenced above consider this high voltage and high-risk work Would typically be performed only by specialized trades (e.g. power maintenance electricians or lines persons) 601-750V not a nominal equipment voltage used by industry in Ontario or Canada

Compressor Modification Factors

Frequency Modification Factors		
Factor	**Weight**	**Justification**
Presence of Guarded Controls	**1**	
None	10	

Frequency Modification Factors		
Factor	**Weight**	**Justification**
Fail Safe Devices	1	Guarded controls as a minimum in current OE Regulation Typical OEM CNG compressors are equipped with gas sensors interlocked to purge fans, heat detectors, oil and vibration monitoring, etc. in each compressor enclosures and equipment E-Stops all leading to safety shutdown. Additional engineering risk controls at the CNG Station level may include smoke detection in electrical supply enclosure, fire alarm pull stations with beacon and annunciator, outdoor locations. Indoor CNG equipment locations have additional Code requirements (e.g. repair garage or bus storage) such as a minimum or 4 air change per hour OR gas detection interlocked to purge fans/openings for fresh air intake AND removal/shutdown of non-hazard rated electrical equipment within 18” of ceiling. Good engineering practice also links the gas detection system to the fire alarm system. Non-CNG compressor applications may or may not have similar typical design or Code requirements depending on the application.

Consequence Modification Factors		
Factor	**Weight**	**Justification**
Material Type (Compressed fluid)		Typically, low probability and low consequence but depends on pressure (e.g. water cutting)
Non-flammable and non-toxic	0.01	
Flammable and non-toxic	0.1	Logically higher risk than the category above hence the higher weighting.
Non-flammable and toxic	0.1	Tradeoff with risk above hence the equivalent weighting.
Flammable and toxic	1	Logically highest risk. Examples include Organic Rankin Cycle materials.
Total Power Rating		
<37 KW	0.01	Total Power Rating in kW (also in HP) is used to estimate the amount of material released in an open system (rupture or major leak) assuming the compressor can’t be tripped. The rating adopts the current regulation categories and the associated weights differentiate the potential for larger consequence associated with larger equipment.
37 to 112 KW	0.1	
112 KW to 299 KW	1	
> 299 KW	1	

Appendix G. Occupancy Modification Factors

Applicable to All Technology Systems

Occupancy	Actual Time at risk (hrs/wk)	Comments for Actual Time at risk	Comments for Probability of being exposed while at Occupancy (assumption)	Proposed modifier
01 - Power Producers/Utilities	45	9 hrs/day at work	Typically, large site, so limiting worker assumed to be near hazard 25% of time at work	0.27
02 - Petro/Chemical	45	9 hrs/day at work	Typically, large site, so limiting worker assumed to be near hazard 25% of time at work	0.27
03 - Production Industries	45	9 hrs/day at work	Industrial	0.27
04 - Manufacturing Industries	45	9 hrs/day at work	Small factor assumed as limiting case, so limiting worker assumed to be near hazard 50% of time at work	0.27
05 - Medical	168	Hospital - worst case	Continuous occupancy for patients, but they won't be near hazard source	1.00
06 - Academic	45	School worst case	Schools not that large, can expect limiting individual to be exposed continuously while at school. However, the risk tolerability threshold at these locations are 3 times lower as per best practices in risk tolerability criteria.	0.81
07 - Food Process	45	9 hrs/day at work	Limiting case ~ small processing facility. Limiting worker exposed 100% of time.	0.27
08 - Public Services	45	9 hrs/day at work	Government offices, public spaces etc. Limiting case ~ small processing facility. Limiting worker exposed 100% of time. However, the risk tolerability threshold at these locations are 3 times lower as per best practices in risk tolerability criteria.	0.81
09 – Commercial	60	10 hrs/day x 6 days/wk e.g. dry cleaners	Small operation – e.g. dry cleaners. Workers assumed to be always in close proximity.	0.36
10 – Residential	168	Continuous exposure	Residential near hazard source. Continuous exposure.	1.00
11 – Agriculture	45	Farm worker in a commercial barn type environment	Typically, large site, so limiting worker assumed to be near hazard 25% of time at work	0.27
12 – Steam Traction				0.01

Appendix H. Background and Use of Failure Rate Data

The UK Health and Safety Executive (HSE) requires failure rate data for the assessment of safety reports and in the implementation of its statutory functions relating to land use planning near major hazard sites. The HSE created a failure rate and event data (FRED) database in 2012 to assist with this need. Many of the existing failure rates used by HSE were derived over 20 years ago but have been subject to periodic review to ensure that they remain appropriate for modern planning enquiries or quantified risk assessments. HSE needs to be assured that its sources of data and their application continue to be fit to support its statutory duties.

Many of the failure rates are based on values derived for RISKAT (RISK Assessment Tool) as detailed in the various parts of the UK's Major Hazards Assessment Unit (MHAU) Handbook (now archived). These generic rates were derived in the early 1980's when MHAU was first formed and have an established pedigree. They were originally derived in the context of assessing risks from chlorine plants. They have been added to and amended as needed to assess different types of plant and operations. The value, type of release and derivation can be found FRED document itself. The assessor needs to decide whether the generic failure rates are appropriate for their assessment; if the generic failure rate is inappropriate then further work is required to derive a suitable specific failure rate.

The application of these generic failure rates to items being used for substances, processes and plant designs that might induce particularly arduous operating conditions or, alternatively, provide for increased reliability is a matter of judgement by the assessor. The greatest difficulty in assigning failure rates is the lack of appropriate industry failure rate data but, in the absence of failure rate data specific to a plant, processes and substances, the generic values given in this section should be used as a starting point. These generic values can be modified to take account of site-specific factors. The specific failure rates are determined by expert judgement, taking account of significant factors along with any specific data available. The figure below provides the structure used and the components for which data is being collected.

HSE has implemented a programme of work to be carried out by the Health and Safety Laboratory (HSL). This includes the development and maintenance of a single source of quality assured failure rate data, ideally accessible from the Internet, bringing together and updating existing failure rate data sources and reviewing new sources not previously available to HSE.

A review of HSE's current failure rate values is being carried out and this will be used to generate a single source of publicly available failure rate data for use by both HSE and the public. This would help industry and HSE move toward a common position or understanding on failure rates. It would also help ensure that HSE professional advice is defensible and transparent.

Appendix I. Sample Model Test Results

Sub-System	Initiating events	Frequency (Y/N)	Top Event Frequency	Frequency Modification Factors			Consequence Modification Factors		Proximity to Exposure		Complexity Factor	Risk Score	Plant Score	Current Status	New Status
				Fuel Type	Presence of Guarded Controls	Design	Material Fluid Type	Occupancy (Public Receptor)	Charge	Power Rating	Number of Equipment				
Two fire tube hot water boilers with combined 2943 KW, <15 psi	1. Pipe System Failure	Y	1.65E-04	1	1	1	0.01	0.27	0.01	1.00	1	4.46E-09		Attended - 3rd Class	Requires Attendance
	2. Tube break	Y	1.50E-04	1	1	100	0.1	0.27	0.1	0.40	2	3.24E-05			
	3. Shell break (Missile)	Y	4.00E-06	10	1	100	0.1	0.27	0.1	0.40	2	8.64E-06			
	4. Furnace Failure	Y	8.97E-06	10	1	100	0.1	0.27	0.1	0.40	2	1.94E-05			
	5. Auxillary system failure	N	5.00E-04	0	0	0	0	0	0	0.00	0	0.00E+00			
	6. Turbine Failure	N	5.00E-04	0	0	0	0	0	0		0	0.00E+00			
Boiler Risk												**6.04E-05**	**4.22**		
Sub-System	**Initiating events**	**Frequency (Y/N)**	**Top Event Frequency**	**Frequency Modification Factors**		**Consequence Modification Factors**					**Number of Equipment**	**Risk Score**	**Plant Score**		
				Presence of Guarded Controls	**Design**	**Total Horsepower**	**Total Volume of Storage**	**Material or Fluid type**	**Occupancy**	**Voltage**					
Two reciprocating compressors, combined 29.83KW with assumed 1000lbs natural gas storage capacity operating at 600V	1. Pipe System Failure	Y	1.00E-04	1	1	0.01	1	0.1	0.27	1	1	2.70E-08			
	2. Pressure Vessel Failure	Y	5.00E-06	1	1	0.01	1	0.1	0.27	1	1	1.35E-09			
	3. Electrical Flash/contact	Y	1.00E-06	1	1	0.01	1	1	0.27	0.1	2	5.40E-10			
	4. Reciprocating Compressor Failure	Y	1.40E-05	1	1	0.01	1	0.1	0.27	1	2	7.56E-09			
	5. Rotary Compressor Failure	N	2.90E-06	1	0	0	0	0	0	0	0	0.00E+00			
Compressor Risk												**3.65E-08**	**7.44**		
Combined Plant Risk												**6.05E-05**	**4.22**		

Appendix J: Guidelines for Completing the Risk Model

Guidelines for Filling the Risk Model Template - Boilers								
	Frequency Modification Factors			Consequency Modification Factors		Probability of Exposure		Complexity Factor
Top Events	Fuel Type	Presence of Guarded Controls	Design	Material Type	Occupancy	Charge	Power Rating	No. of Equipment
Pipe System Failure	Always 1	Always 1	Always 1	Apply material type weights	Apply occupancy weights	0.01<212F 0.1 >212F	Always 1	Always 1
Tube break	Always 1	Apply weights	Apply Design factor weights	Apply material type weights	Apply occupancy weights	Apply Charge weights	Apply Power rating weights	Use total equipment count
Shell break (Missile)	Always 1 except for firetube (For firetube, apply fuel type weights)	Apply weights	Apply Design factor weights	Apply material type weights	Apply occupancy weights	Apply Charge weights	Apply Power rating weights	Use total equipment count
Furnace Failure	Apply the fuel type weights	Apply weights	Apply Design factor weights	Apply material type weights	Apply occupancy weights	Apply Charge weights	Apply Power rating weights	Use total equipment count
Auxilliary system failure	Always 1	Always 1	Always 1	Apply material type weights	Apply occupancy weights	Apply Charge weights	Always 1	Use total equipment count
Turbine Failure	Always 1	Always 1	Always 1	0.1 (this is always steam)	Apply occupancy weights	Always 1 (it is steam)	Apply Power rating weights	Use total equipment count

Guidelines for Filling the Risk Model Template - Compression								
Top Events	Frequency Modification Factors		Consequence Modification Factors					Complexity Factor
	Presence of Guarded Controls	Design	Occupancy	Total Horsepower	Material or Fluid type	Voltage	Total Volume of Storage	Number of Equipment
Pipe System Failure	Always 1	Apply weights based on pipe length to a maximum of 100M	Apply occupancy weights	Always 1	Apply material type weights	Always 1	Always 1	Use a multiplier of 1 for every 100 m of pipe (Always 1)
Pressure Vessel Failure	Always 1	Always 1	Apply occupancy weights	Always 1	Apply material type weights	Always 1	Apply weights based on charge	Use total equipment count
Electrical Flash/contact	Always 1	Always 1	Apply occupancy weights	Always 1	Always 1	Apply voltage weights	Always 1	Always 1
Reciprocating Compressor failure	Apply GC weights	Always 1	Apply occupancy weights	Apply weights based on Horsepower	Apply material type weights	Always 1	Always 1	Use total equipment count
Rotary Compressor failure	Apply GC weights	Always 1	Apply occupancy weights	Apply weights based on Horsepower	Apply material type weights	Always 1	Always 1	Use total equipment count

Guidelines for Filling the Risk Model Template - Refrigeration							
Top Events	**Frequency Modification Factor**		**Consequence Modification Factors**				**Complexity Factor**
	Presence of Guarded Controls	**Design**	**Occupancy**	**Refrigerant Charge**	**Refrigerant type**	**Voltage**	**Number of Equipment**
Pipe System Failure	Always 1	Apply weights based on pipe lengths	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use a multipler of 1 for every 100 m of pipe
Pressure Vessel Failure	Apply weights	Use 1 for self-contained and 2 for field erected	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use total equipment count
Electrical Flash/contact	Always 1	Use voltage based weights	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	Apply Voltage weights	Always 1
Evaporator failure	Apply weights	Use 1 for self-contained and 2 for field erected	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use total equipment count
Condenser Failure	Always 1	Use 1 for self-contained and 2 for field erected	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use total equipment count
Sealed Pump Failure	Always 1	Use weights based on direct or indirect system	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use total equipment count (0 if no refrigerent or hermetically sealed pumps)
Compressor failure	Apply weights	Use weights based on direct or indirect system	Apply occupancy weights	Apply charge weights using a sliding scale (e.g. 0.18 for 1800lbs)	Use Refrigerant Type Weights	N/A	Use total equipment count