Quantitative Risk Assessment

Final Report

Prepared for:

NW Innovation Works
Port of Kalama, WA

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EXECUTIVE SUMMARY

NW Innovation Works, Inc. (NWIW) contracted AcuTech Group Inc. (AcuTech Consulting) to perform a quantitative risk assessment (QRA) of a proposed methanol plant to be located at the Port of Kalama, in Washington State (Figure A). The plant will be designed to produce 10,000 metric tons per day of AA-grade methanol from natural gas feedstock (5,000 metric tons per day from each of two process trains). The plant will use ultralow emission (ULE) reforming technology licensed from Johnson Matthey, with synthesis gas from a gas heated reformer (GHR) and oxygen blown secondary autothermal reformer (ATR) operating in series.

The QRA was completed to address risks of the proposed plant to onsite employees and the offsite community from an accidental release from the methanol production, storage and vessel loading operations. While the NWIW methanol plant is currently in the design phase, the QRA evaluates the risk assuming the facility is built, in operation and staffed with an onsite workforce.

It should be noted that all observations, conclusions and recommendations contained herein are relevant only to this QRA project and the proposed operations at the NWIW methanol site at the Port of Kalama. These include, and are not limited to:

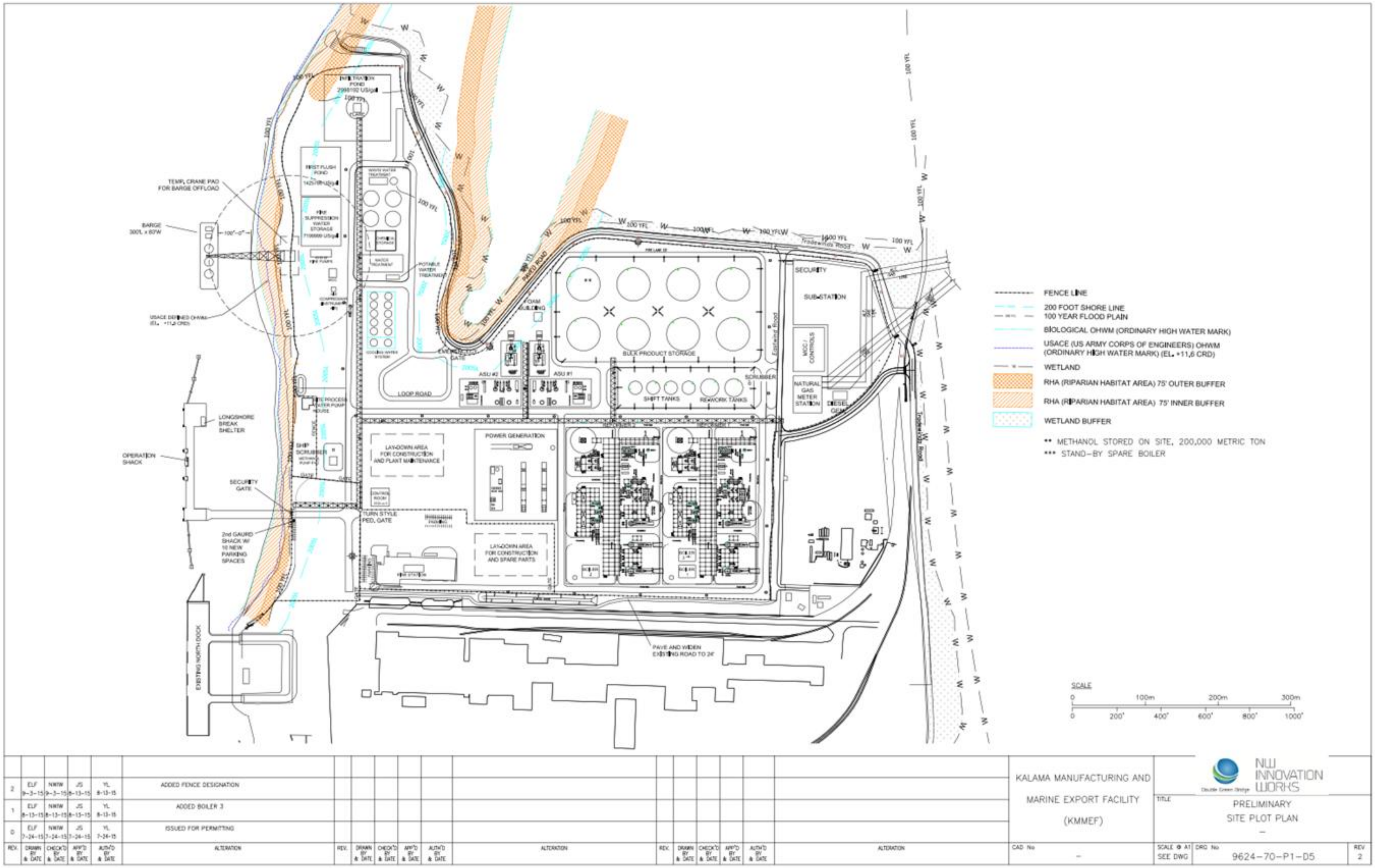
- Facility plot plan
- Heat and material balance
- Equipment and piping sizes
- Safety systems
- Meteorological data
- Onsite staffing
- Onsite building construction and occupancy
- Surrounding offsite businesses and community

Accidental release scenarios defined for this QRA were developed through an initial HAZard IDentification (HAZID) workshop. The HAZID was facilitated by AcuTech and included participation from representatives from NWIW project team, Johnson Matthey Davy Technologies, Worley Parsons, Williams Northwest Pipeline, Endeavour EHS LLC and Port of Kalama. The HAZID considered the process configuration, hazards and facility safeguards designed to mitigate the extent of the hazards and risks.

The detailed HAZID worksheets are provided in Appendix A. As described in the worksheets, potential hazards were identified from:

- Feed gas purification
- Production of synthesis gas
- Crude methanol synthesis
- Production of refined methanol
- Methanol vessel loading
- NOx Package (use of aqueous ammonia for nitrogen oxide emissions reduction)

Figure A - NWIW Plot Plan (Kalama, WA)



Based on the items identified in the HAZID, specific accidental release scenarios were then developed for the following operations and activities, and included in the QRA:

- Natural gas inlet to the plant and gas conditioning
- Saturator
- GHR
- Methanol Loop
- Methanol
- Purification
- Methanol crude, shift and product storage
- Methanol transfer within the site
- Methanol vessel loading (at wharf)
- Aqueous Ammonia storage and truck delivery

The accidental release scenarios were developed systematically, and considered all process equipment for the processing, storage and transfer operations detailed above. The potential consequences (e.g., fire, explosion, toxic exposure) were then evaluated for a range of release sizes (ranging from leaks to ruptures). The consequences/ hazard zones were then used to determine the potential impact(s) to onsite and offsite people. As part of the development of the accidental release scenarios, the process conditions (e.g., composition, temperature and pressure) that may result in more conservative consequences (e.g., larger hazard distances/ hazard zones) were selected, where appropriate.

It should be noted that that **focus of this QRA is on the safety and accidental releases from the NWIW facility**, and the following is not included in the scope of the QRA:

- Security of the NWIW methanol facility
- Safety and security of the methanol vessel

The security of the wharf and vessel will be covered by the Maritime Transportation Security Act of 2002 (MTSA). The wharf and methanol vessels will be subject to United States Coast Guard (USCG) facility security regulations under MTSA listed under the code of federal regulations (CFR):

- 33 CFR Part 101: Marine Security General
- 33 CFR Part 103: Area Maritime Security
- 33 CFR Part 104: Maritime Security Vessels
- 33 CFR Part 105: Maritime Security Facilities

Following 33 CFR 104 and 105, the vessel and wharf will be required to conduct a security assessment and develop a security plan that will be reviewed and approved by the USCG. The wharf also will be subject to the USCG rules at 33 CFR Part 154 which are intended to prevent spills of hazardous materials and prepare for emergency response.

In addition to security at the ship-shore interface, the USCG will be the responsible agency for the safe transit of the methanol vessel. NWIW will work with the USCG to address the safety and security requirements while the methanol vessel in in transit as the project is further developed.

In accordance with internationally recognized guidelines for conducting QRA's, AcuTech developed the consequences, potential impacts, equipment failure rate data and other project/ locations specific inputs to generate the safety risk results.

For the proposed NWIW methanol plant, Individual and Societal risks were calculated:

- **Individual Risk**: Defined as the risk at a specific location to a single person/ individual to a hazard. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). The scale of any incident, in terms of the number of people impacted by an event(s), does not affect the individual risk level a distance from the hazard location(s). Individual risk is presented in this QRA on a geographical basis. The risk contours developed can be used to assess potential risk to the surrounding community, and assist in the land use planning decision for the NWIW site location.

- **Societal Risk**: Defined as the risk to a group of people to a hazard. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). Thus societal risk evaluated the scale of the incident in terms of the number of people that could be impacted from the hazard(s). Societal risk is expressed as the cumulative risk to a group(s) of people who might be affected by accidental release events (for the NWIW QRA societal risk are presented to two groups: onsite population and the offsite community). The calculation for societal risk uses the same consequence and frequency results as the individual risk calculation, but uses information about the number, geographical distribution, occupied building construction and occupancy levels of the population group(s) to determine the risk level.

As the United States does not have prescribed risk criteria to support the evaluation of a quantitative risk assessment, the individual and societal risk results for the proposed NWIW methanol plant have been evaluated against the risk criteria from the Health and Safety Executive of the United Kingdom (UK-HSE), as the comparison basis. The UK-HSE risk criteria have been selected for this project since the UK is unique in that it addresses onsite individual risk for workers, where the other international risk criteria are based solely of offsite impacts.

From the definition above, individual risk contour maps are generated by calculating individual risk at every geographic location assuming that somebody will be present, unprotected (e.g., outdoors), and subject to the risk 100% of the time (i.e., annual exposure of 8,760 hours per year). Individual risk results are associated with a particular location rather than a particular person. For this reason, this risk measure is sometimes referred to as location risk or geographical risk. In this QRA, the individual risk levels are illustrated as an overlay from the NWIW site, and potential risks to the surrounding community and onsite workforce.

The individual risk levels using the UK-HSE risk criteria are classified as follows, and shown visually in Figure B:

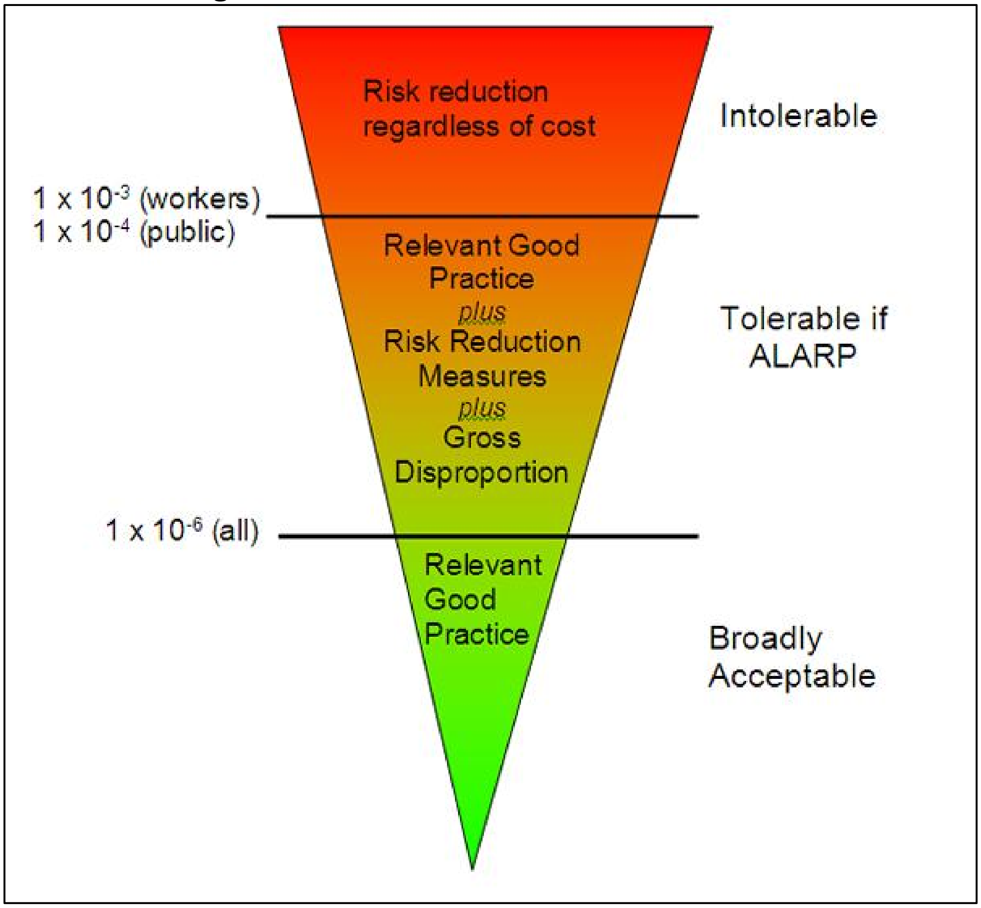
- **Unacceptable** (≥ 1 fatality in 1,000 years)
    - Level where further risk assessment or risk mitigation is required.

- **Broadly Acceptable** (≤ 1 fatality in 1 million years)
    - Level where further risk reduction is not required.

- **Tolerable** (1 fatality between 1,000 and 1 million years)
    - Level where further, prudent risk reduction should be considered. This region is typically referred as the As Low as Reasonably Practicable (ALARP) zone.

While all injuries are of concern, effect models for predicting degrees of injury often include additional uncertainties. To be consistent with the UK-HSE risk criteria, risk to onsite and offsite population is estimated as the risk of fatal injury (death).

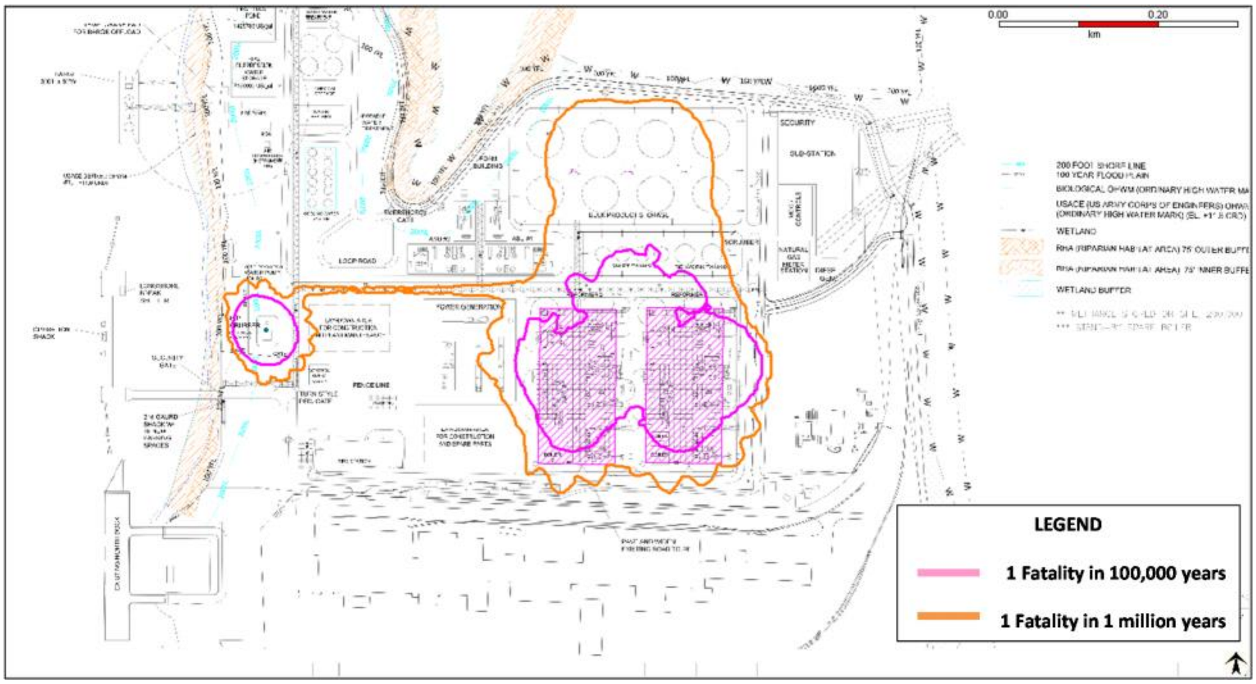
Figure B – UK-HSE Individual Risk Criteria



The individual risk contour for the proposed methanol plant is illustrated in Figure C. As shown, the risk contour illustrating the risk of 1 fatality in 1 million years is maintained within the methanol plant site boundary. As seen in Figure C the risk contour is not illustrated as smooth concentric hazard zones from the NWIW site. This is because individual risk is a measure of risk and not solely a measure of the hazard. The risk contours include all inputs to the QRA (e.g., wind directional probabilities, hazard distances, ignition probabilities, personnel vulnerabilities, etc.).

There are businesses and public areas located in close proximity to the NWIW site boundary, including Steelscape, Air Liquide, the port wastewater treatment facility, the public road and recreational areas (north of the site). When comparing the individual risk results for the NWIW site to the UK-HSE risk criteria, the individual risk is in the broadly acceptable (or negligible) risk level for the offsite public and surrounding community.

Figure C – Individual Risk Contour

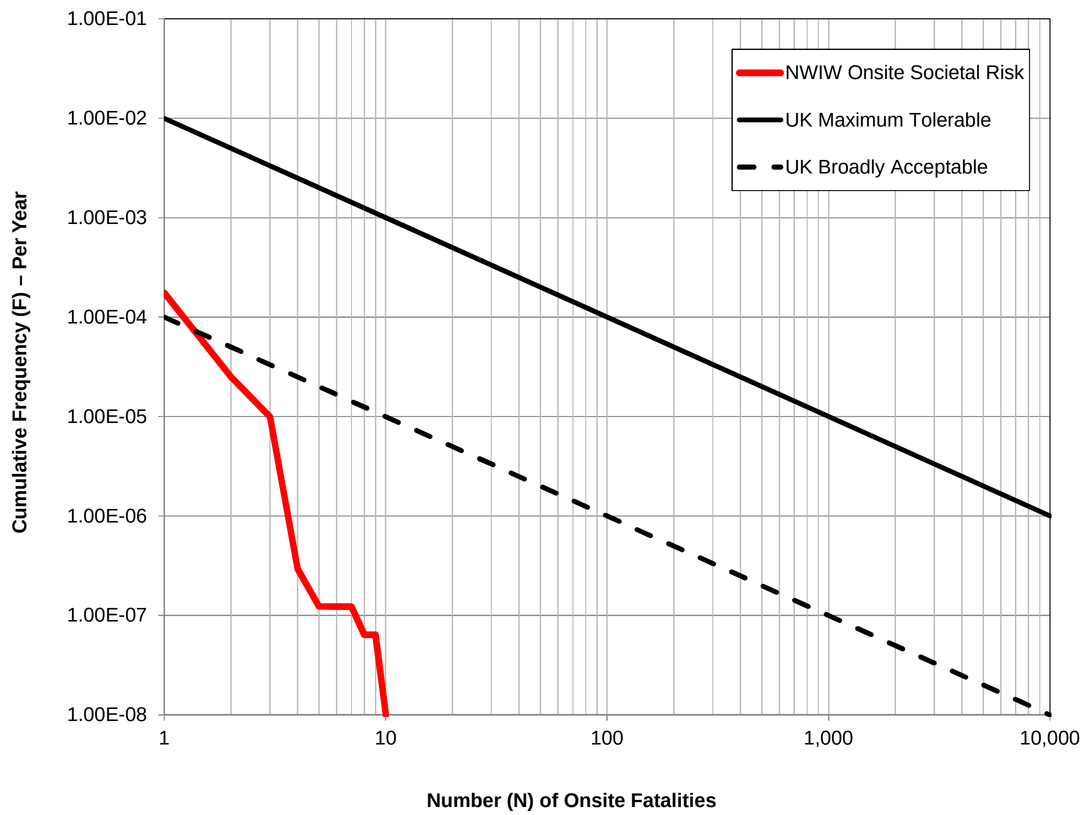


Societal risk measures the potential for impacts to a group of people located in the hazard zone(s) of the range of potential accidental release scenarios. Societal risk estimates include a measure of scale of the accident/ hazard, in terms of the number of people impacted. Societal risk is expressed using an F-N curve, which is the most common method of depicting societal risk results. The F-N curve indicates the expected frequency (F) of release scenarios occurring which result in the number of N or more fatalities. The x-axis of the F-N curve represents the number of fatalities, N. The number of fatalities is depicted on a logarithmic axis with a minimum value of 1. The y-axis of the F-N curve represents the cumulative frequency of the release scenarios with the number of fatalities equal to N or more.

Figure D is the F-N curve, illustrating the societal risk for the proposed NWIW site. The societal risks criteria from the UK-HSE are also shown in Figure D. The following was determined from an evaluation the societal risk results:

- There is no measurable risk of offsite fatalities that were calculated outside the NWIW plant boundary.
- Societal risk is determined for the onsite personnel within the NWIW plant boundary, and the QRA calculated 1 onsite fatality in 5,714 years.

Figure D – F-N Diagram (NWIW Onsite Risk)



The risk to onsite workers can be compared to the fatal injury rates for various occupations. Figure E presents the number and rate of fatal occupational injuries by major occupational group and Figure F present the civilian occupations with high fatal work injury rates (Source: Bureau of Labor Statistics, 2014). From this data, NWIW would be comparable to "Production" in Figure F, which had 206 fatal injuries and a fatal injury rate of 2.4 (per 100,000 full –time equivalent workers). From these national statistics, NWIW employees would have a lower fatal injury rate as compared to structural and iron workers, farming, fishing, forestry, construction, transportation, and logging.

Figure E – Number and Rate of Fatal Occupational Injuries to Civilian Workers by Major Occupation Group, 2014 (Source: Bureau of Labor Statistics, 2014)

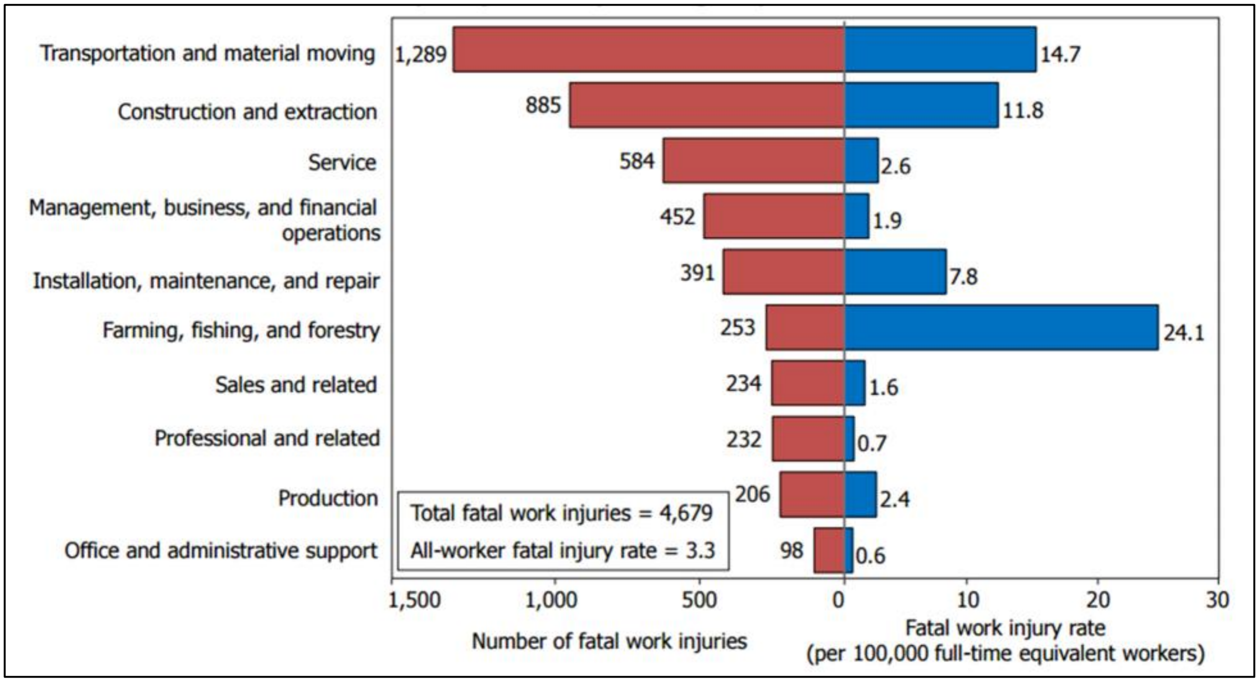
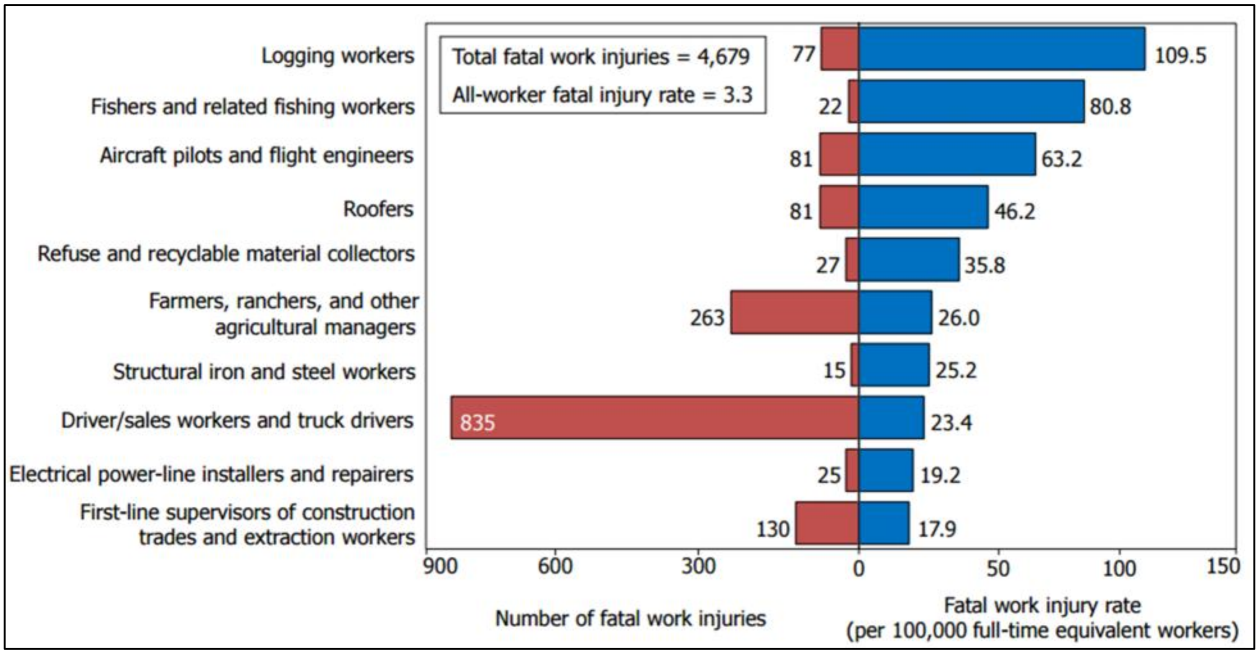


Figure F – Civilian Occupations with High Fatal Work Injury Rates, 2014 (Source: Bureau of Labor Statistics, 2014)



The conclusion of the QRA is that the proposed NWIW methanol plant poses a broadly acceptable level of risk to the offsite public and surrounding community of Kalama, when compared to the HSE-UK risk criteria.

For the NWIW onsite personnel, the risk is in the ALARP range, and from further analysis, the risk is primarily from the potential for accidental releases leading to fires in the methanol production area. While the risk level at the NWIW facility is consistent with the production industry, and has lower fatal injury rates than many other common industries, to address the findings of the QRA, the following recommendations are proposed for NWIW consideration:

- Recommendation 1: Consider further evaluation of the potential consequences of fires in the production area, considering curbing, drainage and impingement of jet fires.

- Recommendation 2: Consider conducting a review of egress pathways from the production area, buildings and other areas where onsite personnel may assemble.

- Recommendation 3: Consider completing a detailed process hazard analysis as part of the project design to fully address all deviations from normal operation, potential consequences, documentation/ evaluation of all safeguards.

1 INTRODUCTION

NW Innovation Works, Inc. (NWIW) contracted AcuTech Group Inc. (AcuTech Consulting) to perform a quantitative risk assessment (QRA) of a proposed methanol plant to be located at the Port of Kalama, in Washington State. The plant will be designed to produce 10,000 metric tons per day of AA-grade methanol from natural gas feedstock (5,000 metric tons per day from each of two process trains). The plant will use ultralow emission (ULE) reforming technology licensed from Johnson Matthey, with synthesis gas from a gas heated reformer (GHR) and oxygen blown secondary autothermal reformer (ATR) operating in series. The process will use two tube-cooled converters in series to carry out the methanol synthesis reaction and a three-column distillation train to produce refined methanol. Methanol is used to make olefin, an ingredient in manufacturing plastics for products such as water bottles and boots.

AcuTech Consulting has expended its best professional efforts in performing this work. It should be noted that this study is based on project information provided by NWIW, including the facility layout, operating parameters and equipment design. While the NWIW methanol plant is only proposed and currently in the design phase, the QRA evaluates the risk assuming the facility is built, in operation and with a staffed onsite workforce.

AcuTech conducted the QRA to determine the potential risks to onsite and offsite populations from accidental releases from the proposed methanol process. As detailed in the report, the offsite population is defined as the nearby businesses and surrounding public areas (e.g., road and recreational area to the north of the NWIW site). The offsite populations included in the QRA were selected due to the close proximity to NWIW, and other locations were screened-out based on the hazard zone distances.

It should be noted that that following is not included in the scope of the QRA, and the focus of this QRA is on the safety and accidental releases from the NWIW facility:

- Security of the NWIW methanol facility
- Safety and security of the methanol vessel

The security of the wharf and vessel will be covered by the Marine Transportation Security Act of 2002 (MTSA). The wharf and methanol vessels will be subject to United States Coast Guard (USCG) facility security regulations under MTSA listed under the code of federal regulations (CFR):

- 33 CFR Part 101: Marine Security General
- 33 CFR Part 103: Area Maritime Security
- 33 CFR Part 104: Maritime Security Vessels
- 33 CFR Part 105: Maritime Security Facilities

Following 33 CFR 104 and 105, the vessel and wharf will be required to conduct a security assessment and develop a security plan that will be reviewed and approved by the USCG. The wharf also will be subject to the USCG rules at 33 CFR Part 154 which are intended to prevent spills of hazardous materials and prepare for emergency response.

In addition to security at the ship-shore interface, the USCG will be the responsible agency for the safe transit of the methanol vessel. NWIW will work with the USCG to address the safety and security requirements while the methanol vessel in in transit as the project is further developed.

The accidental release scenarios included in the QRA were selected by analysis of the process configuration and hazards, and include consideration of facility safeguards designed to mitigate the extent of the hazards and risks. The study considered all process equipment and systematically evaluated a range of accidental release scenarios. Using these inputs, AcuTech conducted this project in accordance with internationally recognized guidelines for conducting QRA's. These guidelines provide the methodologies for:

- Identification of Process Hazards
- Consequence and Impact Analysis
- Likelihood Analysis
- Calculation of Risk
- Presentation of Risk Results

All observations, conclusions and recommendations contained herein are relevant only to this quantitative risk assessment project and the operations at the proposed methanol plant in Kalama, WA. Therefore, **the results should not be applied to any other facility or operation**.

2 QRA METHODOLOGY

AcuTech conducted the quantitative risk analysis utilizing the protocols and methods published by the Center for Chemical Process Safety (CCPS) in their Guidelines for Chemical Process Quantitative Risk Analysis [1] and the Dutch Government in their Guidelines for Quantitative Risk Assessment, known as the TNO Purple Book [2]. These guidelines provide the methodologies for:

- Identification of Process Hazards
- Consequence and Impact Analysis
- Likelihood Analysis
- Calculation of Risk
- Presentation of Risk Results

The scope of work for the QRA included the following steps:

- Division of the process into nodes based on process, as part of an initial HAZard IDentification (HAZID) workshop
- Application of site specific process safeguards, specifically those for detection and isolation of releases
- Development of consequence modeling results using the Phast consequence model
- Analysis of release frequencies for a range of release sizes and release durations
- Development of risk results using the Safeti risk model and site specific data
- Development of geographic individual risk contours
- Development of societal risk results based on onsite and offsite population data
- Comparison of risk results to international risk acceptance criteria
- Development of recommendations to reduce site risk as reasonably practical

The approach was to conduct a site specific analysis, using the commercially available Process Hazards Analysis Software Tool (Phast™) and Software for the Assessment of Fire, Explosion and Toxic Impacts (Safeti™), version 6.7. Phast and Safeti have been selected for this analysis because they are well established, have been validated and are widely used in the oil, gas and chemical industries.

This analysis is performed under site specific conditions for the proposed NWIW methanol plant in Kalama, WA. Therefore, these results are specific to this location and design at the time of the study. **The consequence and risk results should not be applied to any other location**.

2.1 Project Steps

This project was completed following these six (6) main project steps:

- Data Collection
- HAZID
- Release Scenario Development
- Consequence and Impact Analysis
- Frequency Analysis
- Risk Integration and Results

Step 1 – Data Collection

This analysis is performed under site specific conditions collected for the proposed NWIW methanol plant at the Port of Kalama. Therefore, these results are specific to this location and the operations, onsite buildings number and location of onsite personnel and the location of the surrounding community.

The data that was collected provides the basis for the assumptions applied in the QRA. This information includes the following (with section references within the QRA report, which detail the specific assumptions):

- Plant Layout and Equipment Locations (Section 3)
- Loss of Containment Scenarios (Section 4)
- Process Conditions (Section 4)
- Consequence Modeling (Section 5)
- Equipment Failure Rate Data (Section 6)
- Meteorological Data and Surrounding Area Topography (Section 7)
- Onsite Building Construction and Building Occupancy (Section 7)
- Offsite Population (Section 7)
- Vulnerability to fire, explosion overpressure and toxic exposures (Section 7)
- Risk Criteria (Section 8)

Step 2 - HAZID

To develop the accidental release scenarios for the QRA, AcuTech facilitated a HAZard IDentification (HAZID) with personnel from the NWIW project, Johnson Matthey Davy Technologies, Worley Parsons, Williams Northwest Pipeline, Endeavour EHS LLC and Port of Kalama. The goal of the HAZID was to review all proposed processes, storage areas and loading/unloading operations to identify the potential for hazardous material releases that could result in fire, explosion and toxic hazards.

Step 3 – Release Scenario Development

Based on the HAZID, the final set of release scenarios for the QRA were selected by grouping equipment within each plant, into a "node" based on the following factors:

- Type of material being processed (toxic, flammable or both)
- Material phase (gas, liquid, two phase)
- Process conditions (temperature and pressure)
- Type, size and location of equipment

The range of the release sizes (e.g., leak to rupture) applied for each scenario is based on the TNO Purple Book [2], and is based on the equipment component failure rates. The final equipment grouping and the range of release sizes are the main input for the consequence and impact analysis in Step 4 (below).

Step 4 - Consequence and Impact Analysis

Consequence is the measure of the expected outcomes for a given accidental release. In this QRA, consequence is defined as the hazard distance or hazard zone to various fatality endpoints. For the release scenarios developed in Step 3, the consequences were modeled using the Phast model. The specific consequences evaluated include:

- Fire (jet fire, pool fire)
- Boiling Liquid Expanding Vapor Explosion (BLEVE)
- Vapor Cloud Explosion
- Toxic Gas Dispersion

In general, the hazard zones were determined using various parameters. These parameters include:

- Release Quantity
- Duration of Release
- Source Elevation
- Prevailing Atmospheric Conditions and Surrounding Terrain
- Chemical Flammability, Toxicity and Reactivity

Step 5 - Frequency Analysis

Initiating event failure frequencies for each release scenario developed in Step 3 were estimated using the TNO Purple Book [2].

Since the scenarios are based on a grouping of equipment, the initiating event frequencies are the sum of the individual component failure rates of the equipment within the node.

The initiating event frequencies are input in to an event tree analysis to determine the range of possible outcomes. Depending on the process conditions the hazards could range from fire or explosion (if ignited) or toxic release.

Step 6 - Risk Integration and Results

Once the onsite/ offsite population data, consequence modeling results, likelihood calculations and weather data were collected, the information was combined to generate the final risk results, using Safeti. The following results were developed:

- **Individual Risk**: Defined as the risk at a specific location to a single person/ individual to a hazard. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). The scale of any incident, in terms of the number of people impacted by an event(s), does not affect the individual risk level a distance from the hazard location(s). Individual risk is presented in this QRA on a geographical basis. The risk contours developed can be used to assess potential risk to the surrounding community, and assist in the land use planning decision for the NWIW site location.

- **Societal Risk**: Defined as the risk to a group of people to a hazard. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). Thus societal risk evaluated the scale of the incident in terms of the number of people that could be impacted from the hazard(s). Societal risk is expressed as the cumulative risk to a group(s) of people who might be affected by accidental release events (for the NWIW QRA societal risk are presented to two groups: onsite population and the offsite community). The calculation for societal risk uses the same consequence and frequency results as the individual risk calculation, but uses information about the number, geographical distribution, occupied building construction and occupancy levels of the population group(s) to determine the risk level.

- **Overpressure Contours**: Overlay of the overpressure levels on a plot plan of the facility. The contours enable a visual illustration of the vulnerable buildings/ areas within various overpressure damage levels.

3 HAZID

To develop a QRA, an initial list of accidental release scenarios is determined. For this QRA, a HAZID was completed with an extensive list of nodes to evaluate the full range of hazards and potential accidental releases throughout the proposed methanol plant. Nodes are defined by:

- Sectioning the operations at the plant:
- Grouping equipment that operates under consistent or nearly consistent process conditions, with similar hazards or consequences if there were an accidental release;
- Analyzing the failure frequencies and consequences for each node; and,
- Considering a range of release scenarios for each node.

The list of nodes was developed based on HAZID conducted on June 17-18, 2015. The HAZID was facilitated by AcuTech and included representatives from NWIW project, Johnson Matthey Davy Technologies, Worley Parsons, Williams Northwest Pipeline, Endeavour EHS LLC and Port of Kalama. The sectioning of the process, or list of “nodes”, was defined by the HAZID team based on the plot plan, Process Flow Diagrams (PFDs), Heat and Materials Balance and other information provided by NWIW. The boundaries of the nodes are defined based on changes in process conditions (pressure, temperature, or phase).

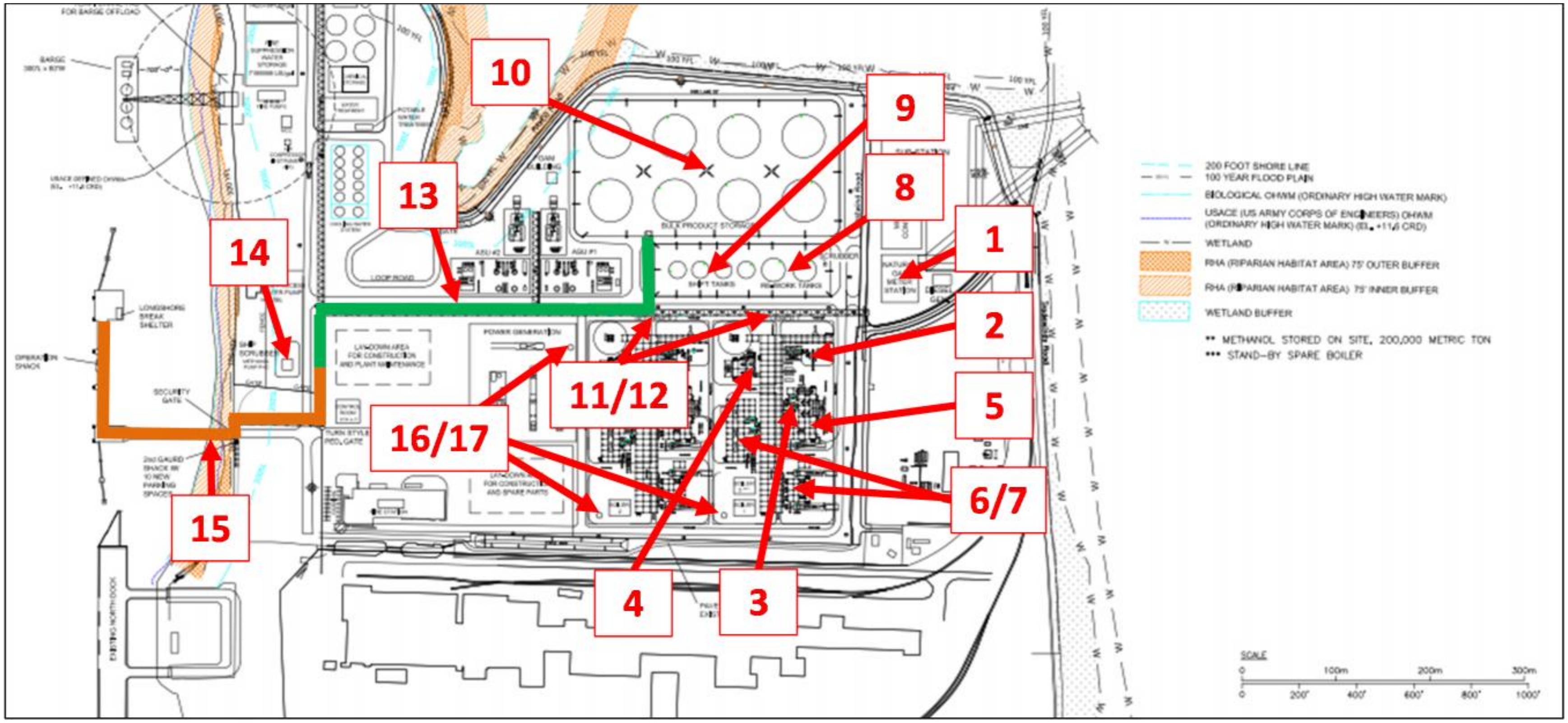
The list of nodes developed for the QRA are provided in Table 1.

Table 1 - Nodes

Node Identification Number	Description
1	Natural Gas Inlet to Plant
2	Natural Gas Conditioning
3	Saturator
4	GHR
5	Methanol Loop
6	Methanol Purification (overhead vapor)
7	Methanol Purification (bottoms liquid)
8	Crude Methanol Storage Tanks
9	Shift Storage Tanks
10	Product Storage Tanks
11	Methanol Transfer (to topping column)
12	Methanol Transfer (shift to product tanks)
13	Methanol Transfer (product tanks to loading pump)
14	Methanol Loading Pump
15	Methanol Loading Line (at wharf)
16	Aqueous Ammonia Storage Tanks
17	Aqueous Ammonia Delivery/ Unloading

Figure 1 depicts the location of the nodes on the NWIW plot plan. While the nodes illustrated are for a single reformer train, both trains are included in the consequence modeling and risk assessment for the proposed plant.

Figure 1 – NWIW Plot Plan with Node Locations (single reformer train)



4 QRA RELEASE SCENARIO DEVELOPMENT

The QRA considers a range of release scenarios for each node from the HAZID. The final accidental release scenarios in the QRA were developed by determining the applicable accidental release or loss of containment scenarios for the equipment within each node.

4.1 Loss of Containment Scenarios

Loss of containment scenarios (LOCs) were completed in accordance with guidance from the TNO Purple Book [2]. A set of LOCs is defined for each type of equipment; therefore, the type of equipment associated with each node defines the LOCs developed for each node. Table 2 indicates the LOCs for each equipment type that was reviewed in the study.

Table 2 - Loss of Containment Events

Vessels/ Reactors	Piping	Pumps	Heat Exchangers
G.1 Instantaneous release of the complete inventory	G. 1 Full bore rupture - outflow is from both sides of the full bore rupture	G. 1 Full bore rupture - full bore rupture of the largest connecting pipeline	G.1 Instantaneous release of the complete inventory
G.2 Continuous release of the complete inventory in 10 min at a constant rate of release	G.2 Leak - out flow is from a leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm	G.2 Leak - out flow is from a leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipeline, with a maximum of 50 mm	G.2 Continuous release of the complete inventory in 10 min at a constant rate of release
G.3 Continuous release from a hole with an effective diameter of 10 mm			G.3 Continuous release from a hole with an effective diameter of 10 mm

In addition to the information provided in Table 2, the following assumptions were applied to this QRA, and were based on the level of design detail available at this stage of the project:

- Scenario 16 and 17 were screened out from further analysis:
  - Selective Catalytic Reduction (SCR) technology is planned to minimize the release of NOx compounds to atmosphere. The SCR technology will utilize aqueous ammonia (19% by weight) which will be injected into the vent streams, which will then pass over a catalyst. The NOx reacts with aqueous ammonia on the catalyst to yield nitrogen and water, which will be safely vented to the atmosphere.
  - Based on the low concentration of aqueous ammonia used for the SCRs, the vaporization rate from an accidental release is low. Based on initial screening modeling using Phast it was determined that the potential hazard zone surrounding a release of aqueous ammonia will be localized to the spill area, with little to no potential for onsite or offsite impacts to people.

- Two release sizes were evaluated for each node:
  - Instantaneous Release - G.1 from Table 2
  - Leak – Combination of G.2 and G.3. Releases from nodes with limited inventory, such as piping, and which may be continually supplied from the upstream portion of the process (such as pump discharges) are limited to a maximum discharge rate of the pump.
  - Unmitigated releases were assumed to have a release with the duration equal to the time required to deplete the unmitigated release inventory, or until a release duration of 30 minutes was reached. The maximum duration of all releases in the model is limited to 30 minutes in accordance with guidance from the TNO Purple Book [2].
  - Methanol plant will have gas detectors, with the signal to close the valve from the control room. For these mitigated release scenarios the time to detect and isolate a release has been assume as 2 minutes.

4.2 Process Conditions

Process conditions for each node were provided by NWIW. Process conditions used to define the release scenarios are defined in Table 3.

Table 3 - Loss of Containment Events

Node	Description	Piping		Process Conditions					Flow Rate (MT/hr)	Comment
		Length (ft)	Diameter (inches)	Inventory (gallons)	Composition (Mole %)	Vapor/ Liquid	Temperature (Celsius)	Pressure (MPa(a))		
1	Natural Gas Inlet to Plant	400	24	N/A	0.47 CO2 0.51 N2 94.04 C1 3.87 C2 0.80 C3 0.24 C4 0.04 C5 0.03 C6+	Vapor	21	2.86 (400 psig)	111.6 (31.0 kg/s)	Heat & Material Balance (HMB) Stream 101
2	Natural Gas Conditioning	400	24	N/A	0.47 CO2 0.51 N2 94.04 C1 3.87 C2 0.80 C3 0.24 C4 0.04 C5 0.03 C6+	Vapor	21	2.86 (400 psig)	111.6 (31.0 kg/s)	HMB Stream 101
3	Saturator	300	36	N/A	63.67 H2O 0.91 H2 0.03 CO 0.24 CO2 0.32 N2 32.69 C1 1.33 C2 0.28 C3 0.08 C4 0.01 C5 0.01 C6+ 0.06 Argon 0.36 MeOH	Vapor	235	5.14 (731 psig)	319.6 (88.8 kg/s)	HMB Stream 201

Node	Description	Piping		Process Conditions					Flow Rate (MT/hr)	Comment
		Length (ft)	Diameter (inches)	Inventory (gallons)	Composition (Mole %)	Vapor/ Liquid	Temperature (Celsius)	Pressure (MPa(a))		
4	GHR	150	36	N/A	38.39 H_2O 42.76 H_2 11.8 CO 6.38 CO_2 0.16 N_2 0.44 C1	Vapor	550	4.19 (593 psig)	259.5 (72.1 kg/s)	HMB Stream 304
5	Methanol Loop	900	24	N/A	1.69 H_2O 58.45 H_2 1.51 CO 3.21 CO_2 8.95 N_2 17.23 C1 4.09 Argon 4.83 MeOH 0.02 Lights	Vapor	112	7.85 (1124 psig)	736 (204 kg/s)	HMB Stream 511
6	Methanol Purification (overhead vapor)	500	68	N/A	100 MeOH	Vapor	128	0.8 (101 psig)	386 (107 kg/s)	HMB Stream 802
7	Methanol Purification (bottoms liquid)	450	20	N/A	72.25 MeOH 27.73 H_2O 0.02 Heavies	Liquid	87	0.858 (110 psig)	57.1 kg/s	HMB Stream 701 1J432A/B (1205 gpm)
8	Crude Methanol Storage Tanks	N/A	N/A	2.3 million	100 MeOH	Liquid	Ambient	Saturated Vapor Pressure (SVP)	N/A	2 Tanks Dike 675' x 170'
9	Shift Storage Tanks	N/A	N/A	1.0 million	100 MeOH	Liquid	Ambient	SVP	N/A	4 Tanks Dike 675' x 170'
10	Product Storage Tanks	N/A	N/A	8.2 million	100 MeOH	Liquid	Ambient	SVP	N/A	8 Tanks Dike 915' x 460'

Node	Description	Piping		Process Conditions					Flow Rate (MT/hr)	Comment
		Length (ft)	Diameter (inches)	Inventory (gallons)	Composition (Mole %)	Vapor/ Liquid	Temperature (Celsius)	Pressure (MPa(a))		
11	Methanol Transfer (to topping column)	400	12	N/A	100 MeOH	Liquid	48	0.6 (72.3 psig)	12.6 (3.5 kg/s)	HMB Stream 602 10% of flow rate
12	Methanol Transfer (shift to product tanks)	400	12	N/A	100 MeOH	Liquid	Ambient	87 psig	366 kg/s	1J452A/B (7574 gpm)
13	Methanol Transfer (product tanks to loading pump)	1600	16	N/A	100 MeOH	Liquid	Ambient	SVP	Calculated	Liquid head of Product Tanks
14	Methanol Loading Pump	N/A	N/A	N/A	100 MeOH	Liquid	Ambient	87 psig	409 kg/s	3J453A-F (8476 gpm)
15	Methanol Loading Line (at wharf)	1000	16	N/A	100 MeOH	Liquid	Ambient	87 psig	409 kg/s	3J453A-F (8476 gpm)

5 CONSEQUENCE ANALYSIS

In the terminology of risk assessment, consequence is a measure of the expected outcome of an event and is measured or expressed as a hazard distance, hazard zone, or a hazard value at a specific location. Consequence analysis is normally carried out using mathematical models and computer software addressing the physical and chemical phenomenon. The results of the consequences modeling are included in an impact analysis (Section 7), which takes into account the presence of people, property and sensitive environments that can be adversely affected by a chemical release from the NWIW site.

Before conducting a consequence analysis, it is necessary to identify events that could follow the release of a hazardous material. The consequence analysis considers a range of potential hazards:

- If an accident involves a flammable liquid spill, ignition and complete engulfment of a flammable tank, a Boiling Liquid Expanding Vapor Explosion, or BLEVE, may occur.
- If the release is a gas or high-pressure liquid, a jet fire will result upon immediate ignition.
- In the absence of immediate ignition, a large flammable vapor cloud may form. A delayed ignition may lead to a Vapor Cloud Explosion or Flash Fire depending on the location of the vapor cloud in relation to obstructed regions.
- The resulting overpressure from a vapor cloud explosion, or BLEVE, can cause significant damage to surrounding processes, control rooms, or other adjacent structures.
- For an unignited toxic release, toxic vapor dispersion with downwind impacts may occur.

In general, a hazardous material release may exhibit one or more of the following types of hazards:

- Flammable exposure (thermal radiation, flame impingement)
- Explosions (blast overpressure)
- Toxic exposure

Specific to the NWIW project, methanol is classified as a flammable liquid. A spill of methanol will result in a liquid pool, and may result in vapor generation at or below ambient temperatures. As these vapors may result in a flammable concentration, and if ignited can flash back resulting in a fire hazard (e.g., pool fire, flashfire). However, if the flammable vapors are confined, the ignition could results in vapor cloud explosion resulting in an overpressure hazard. For the NWIW QRA, no fireball/ BLEVE scenarios were developed as the methanol storage tanks are all designed for atmospheric conditions (i.e., methanol will not be stored in pressurized tanks). If catastrophic tank failure were to occur, the result would be a large pool fire, not a fireball or BLEVE.

A site specific consequence analysis of the accidental release scenarios was conducted using the commercially available Process Hazards Analysis Software Tool (Phast) consequence modeling software, version 6.7. While Phast was used to determine the fire and toxic hazard zones, a combination of the Phast model and the TNO Multi-Energy methodology was used to evaluate vapor cloud explosions. Phast was used to determine the flammable mass of a possible vapor cloud, and the Multi-Energy methodology was used to determine the vapor cloud explosion hazard zones. The Multi-Energy explosion model is incorporated as a module in the Phast software, as such Phast was used for all consequence modeling in the siting analysis.

5.1 Dispersion Modeling

The Phast Unified Dispersion Model (UDM) was used to assess the impacts of the releases, the downwind dispersion distance, the concentration profile and the width of flammable releases.

Dispersion models use an average time to calculate the maximum concentration and the plume width. The value used in this QRA are detailed below and consistent with the Phast default parameters. A short averaging time is usually used for flammable gas dispersion effects since the peak concentration is more important, and a longer averaging time is usually used for toxic dispersion effects since the long-term concentration is more important.

- All flammable dispersion models used an averaging time of 18.75 seconds (Phast default)
- All toxic dispersion models used an averaging time of 600 seconds (Phast default)

5.2 The Consequence Event Tree

Each accidental release scenario in the QRA involves the potential for ignition or no ignition. If ignited, a range of fire and/or explosion consequences could occur. For each release modeled in the QRA, a range of potential outcomes is assessed, each with its own probability of occurrence, and include:

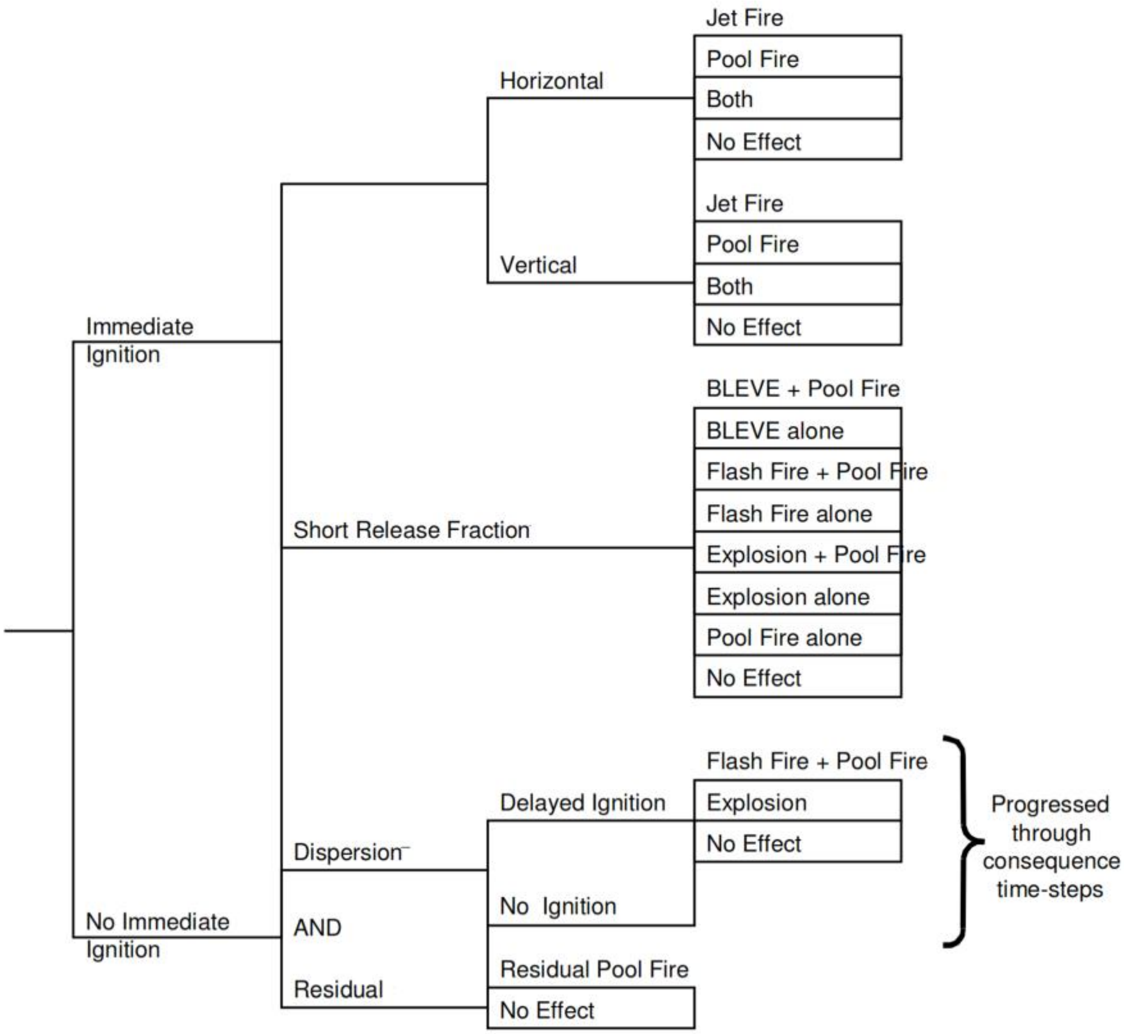
- Jet Fire
- Pool Fire
- Flash Fire
- Boiling Liquid Expanding Vapor Explosion (BLEVE)
- Vapor Cloud Explosion
- Toxic (streams with carbon monoxide or methanol)

The ultimate consequence resulting from an accidental release is determined by the following factors:

- the duration of the release (continuous or instantaneous);
- the phase after release (vapor/liquid/two-phase);
- the time of ignition (immediate or delayed); and,
- the level of obstruction in the area of the vapor cloud.

The generalized event tree shown in Figure 2, illustrates the potential outcomes of an accidental release of a flammable material. Note that there is the potential for multiple distinct consequences (e.g., Flash Fire and Pool Fire) to result from a single release scenario. Delayed ignition events are processed through time steps, to assess potential impacts at various times after the release; this allows the model to account for a range of consequences that may occur, as the cloud drifts downwind, disperses and interacts with different areas of obstruction.

Figure 2 - Generalized Event Tree for Consequences in the Safeti Program



5.3 Vapor Cloud Explosions and Flash Fires

Upon ignition, a flammable vapor cloud may lead to a Vapor Cloud Explosion or Flash Fire. Both events are characterized by the combustion of the flammable vapors, and a single release scenario may result in either consequence depending on the location of the cloud when it is ignited.

As discussed, a spill of methanol will result in a liquid pool, and may result in vapor generation at or below ambient temperatures. As these vapors may result in a flammable concentration, and if ignited can flash back resulting in a fire hazard (e.g., pool fire, flashfire). If the flammable vapors are confined, the ignition could results in vapor cloud explosion resulting in an overpressure hazard.

A Flash Fire is the combustion of a gas/air mixture that produces relatively short term thermal hazards with negligible overpressure (blast wave). Generally, a vapor cloud that is ignited outside of an obstructed region will result in a Flash Fire.

A vapor cloud explosion results from the rapid combustion of a fuel/air mixture with the flame speed approaching sonic velocity, and producing a blast wave. The explosion potential of a flammable hydrocarbon depends on its combustion energy and the energy of the ignition source. In addition, the fraction of the combustion energy converted to explosive energy depends on the nature of the chemical.
Turbulence is required for the flame front to accelerate to speeds required to produce a blast overpressure. In the absence of turbulence, the flame front will burn in a laminar or near-laminar condition, resulting in no appreciable overpressure. This is called a flash fire. Flame turbulence is typically formed by the interaction between the flame front and obstacles such as process structures and equipment. The blast effects produced by vapor cloud explosions vary greatly and are primarily dependent on flame speed. Highly reactive materials (such as ethylene oxide) are much more likely to lead to a vapor cloud than low reactively materials (such as methane).

Confinement of the vapor cloud by obstacles can result in rapid increases in pressure during combustion, Conversely, the absence of confining obstacles allow unlimited outward expansion of the cloud during combustion, limiting the resulting overpressures. Confinement can be expected in structures such as pipe racks or multi-deck process structures.

5.3.1 The TNO Multi-Energy Model

For the modeling of unconfined and confined vapor cloud explosion scenarios, the Phast source term and dispersion modeling was used in combination with the Safeti MPACT risk model using the TNO Multi-Energy (ME) Methodology.

In the MPACT risk model, the ME methodology is used to predict the consequences of vapor cloud explosions in the form of peak overpressure and duration in the region around the explosion using the blast curves developed by TNO. The explosion source is determined in the risk model using the time-varying behavior of the flammable clouds from dispersion modeling and layout of the obstructed regions around the release. The strength of the blast is determined by the degree of confinement and congestion and is input into the ME methodology as a blast strength value ranging between 2 (unconfined) and 10 (maximum confinement and congestion/complete vapor detonation). The obstructed regions defined in the Safeti MPACT risk model for the proposed NWIW methanol plant are described in Section 7.4.

5.4 Pool Fires, Jet Fires, Fireballs and BLEVEs

The fire hazards examined in this study include pool fires, jet fires and fireballs, where impacts to people are the result of thermal radiation generated by the fire. Thermal radiation emanates from the visible portions of the flame. The actual radiation received by a person depends on the distance from the flame surface, location (indoors vs. outdoors), building construction as well as other atmospheric conditions, with sheltering reducing the magnitude of the thermal radiation hazard.

Upon ignition, a spilled flammable liquid will burn in the form of a large turbulent diffusion flame. The size of the flame will depend on the spill surface and the thermo-chemical properties of the hazardous material. If the spill is confined, the confined area will determine the pool size which will then dictate the size of the fire. If the spill is unconfined, the pool dimensions will depend on the amount of liquid released (liquid volume), burning rate of the liquid and the terrain surface characteristics.

A jet fire can result when the material released is a gas or high-pressure liquid that ignites immediately. The size of the jet flame depends primarily on the release rate of the gas or high-pressure liquid. The thermo-chemical properties of the substance are also taken into consideration in determining the size of the jet flame.

A fireball or boiling liquid expanding vapor explosion (BLEVE) can occur from a sudden release of a large mass of pressurized liquid to the atmosphere. A primary cause is an external fire impinging on the shell of a pressurized vessel above the liquid level, weakening the shell and resulting in a sudden rupture. For this QRA no fireball or BLEVE scenarios were developed as the methanol storage tanks are all designed for atmospheric conditions (i.e., methanol will not be stored in pressurized tanks). If catastrophic tank failure were to occur, the result would be a large pool fire, not a fireball or BLEVE.

5.5 Toxic Hazards

The release of a toxic chemical might produce little, if any, equipment damage, but may result in impacts to the surrounding offsite population and onsite workforce. Some chemicals pose acute inhalation hazards, and can result in damage to the respiratory system or other critical functions. In general, toxic vapor dispersion hazard zones are characterized by the following parameters:

- Release Quantity
- Duration of Release
- Source Elevation
- Surrounding Terrain
- Prevailing Atmospheric Conditions
- Chemical Toxicity

Each of the parameters above is discussed below with special emphasis on their influence on estimating downwind dispersion distances.

Release Quantity or release rate refers to the quantity of (or the rate at which) a hazardous chemical is released in the event of an accident. The quantity (or rate) is the single most important parameter in determining the dispersion hazard distances. In general, larger quantities lead to larger dispersion distances. However, the dispersion distance does not increase linearly with quantity or release rate. In fact, an increase in release quantity by a factor of 100 (for example, from 100 gallons to 10,000 gallons) may lead to an increase in the dispersion hazard distance by a factor of 20. For gaseous and high-vapor-pressure liquid releases, the vapor release rate will be the same as the discharge rate. However, for non-flashing liquids, the vapor release rate is governed by the evaporation rate of the liquid and will always be less than the liquid release rate.

Duration of Release is dependent on the release mode. For example, a safety valve release may not last for more than a few minutes whereas a tank puncture may continue to discharge for several hours. For liquids forming evaporating pools, the duration of the vapor release is dependent on the evaporation rate. Simple dispersion models use one of the two extreme cases, i.e., continuous release or instantaneous release. In the case of instantaneous release, the duration of release is very short (e.g., pressurized storage tank rupture) and the total quantity of the chemical released during the accident contributes to the dispersion hazard. Further, the dispersion takes place in longitudinal (along wind), and lateral (across wind) and vertical directions. In the case of a continuous release, the release lasts a relatively long time and the release rate (or evaporation rate) is the most important parameter. The dispersion model used in this study is encoded in Phast and takes into account the actual duration of release.

Source Elevation is attributed to the physical height of the release. For this study, all scenarios have been modeled at a representative release height based on equipment location. A higher source elevation will increase the distance to cloud touchdown. This is particularly important for buoyant and neutrally buoyant clouds.

Surrounding Terrain affects the dispersion process greatly. For example, rough terrains involving trees, shrubs, buildings and structures usually enhance air entrainment. This leads to shorter dispersion distances than that if predicted using a flat terrain. However, rough terrain may lead to localized regions of high concentrations.

Prevailing Atmospheric Conditions include a representative wind speed and atmospheric stability. The neutral or unstable (typical daytime) weather conditions generally leads to shorter dispersion distances than stable (nighttime) weather. For neutrally buoyant releases, increased wind speed reduces the dispersion distance. For heavy gases, dispersion distance increases with wind speed. Since the weather conditions at the time of an accident cannot be controlled, it is important to evaluate the release scenarios for both typical and worst-case weather conditions.

Chemical Toxicity affects the extent of the hazard zone. In this analysis, a probit equation is used to equate the exposure dosage of a toxic chemical to percent fatality. Dosage at a fixed position is the integral of concentration over time at that position. Lower dosage levels leads to larger dispersion distances. As with release quantity, the effect is not linear. In other words, a reduction in dosage by a factor of 100 may result in an increase in the dispersion distance by a factor of 20. The probit equations used in this analysis are in the public domain and were input into the Phast model. Since dosage is a function of concentration and exposure duration, both parameters can significantly alter the calculated hazard zone.

6 FREQUENCY ANALYSIS

An important component of risk analysis is the estimation of the likelihood or frequency of each failure case or release scenario. None of the events considered in this analysis are common and major catastrophic events are very rare. Leak frequencies were developed using a parts count, and event tree analysis was used to evaluate likelihood of success or failure of release mitigation safeguards onsite, specifically the potential for detection and isolation of leaks.

6.1 Parts Count

The frequency of a leak from each node was estimated using a parts count of the equipment in the node. The parts count is a tally of the various pieces of equipment contained in each node. The parts count is combined with the LOC frequencies provided in the TNO Purple Book [2] to determine the likelihood of each release scenario.

Fractional use times were applied to equipment that is not in service at all times (e.g., methanol loading pump and line from pump to wharf). The fractional use time is the portion of time that the equipment is in service, it can be calculated by dividing the time in service over a given period divided by the time period considered. The fractional use time is applied to scale the frequency of equipment failure rates to match the time in service. Therefore, the likelihood of release scenarios is defined by the following equation:

$$f_{LOC} = f_{time} * \sum_{i=0}^{n} P_i * f_i$$

Where:

f_{LOC} = *Frequency of the LOC scenario per annum*
f_{time}= *Fractional Use Time*
P_i = *Tally from the parts count for equipment type i*
f_i= *Failure Frequency for the LOC for equipment type i*

The vessel loading time and fraction usage of the methanol loading pump and line was determined as follows:

- 6 vessels per month
- 36 hours to load a ship
- Fractional usage of 30%

The parts count for each node is detailed in Table 4.

6.2 Loss of Containment Frequencies

The failure frequencies for each LOC equipment type are defined by the TNO Purple Book [2]. The frequencies for each LOC are provided in Table 5.

Table 4 – Parts Count and Scenario

Node	Description	Pressure Vessel	Process Vessel	Reactor Vessel	Atmospheric Storage	Piping (< 75mm)	Piping (75-150 mm)	Piping (> 150 mm)	Pump	Heat Exchanger (shell side)	Heat Exchanger (Shell side – Tube high press.)	Heat Exchanger (Shell side – Shell high press.)	Comments
		Number	Number	Number	Number	meters	meters	meters	Number	Number	Number	Number	
1	Natural Gas Inlet to Plant							121.9					
2	Natural Gas Conditioning		4					121.9				1	
3	Saturator		0.5					91.4		1			
4	GHR		1	2				45.7					
5	Methanol Loop			2				274.3					
6	Methanol Purification (overhead vapor)		1.5					152.5					
7	Methanol Purification (bottoms liquid)		0.5					137.2	1				
8	Crude Storage Tanks				2								
9	Shift Storage Tanks				4								
10	Product Storage Tanks				8								
11	Methanol Transfer (to topping column)							121.9	1				
12	Methanol Transfer (shift to product tanks)							121.9	1				
13	Methanol Transfer (product tanks to loading pump)							487.7					
14	Methanol Loading Pump								1				30% Usage Factor
15	Methanol Loading Line (at wharf)							304.8					30% Usage Factor

Table 5 – Loss of Containment Frequencies

Equipment	Release Frequency (per year)		
	G.1 Instantaneous	G.2 Continuous (10 min)	G.3 Continuous (10 mm)
Pressure Vessel	5.0E-07	5.0E-07	1.0E-05
Process Vessel	5.0E-06	5.0E-06	1.0E-04
Reactor Vessel	5.0E-06	5.0E-06	1.0E-04
Atmospheric Storage	5.0E-06	5.0E-06	1.0E-04
Piping < 75mm diameter	1.0E-06 m^{-1} yr^{-1}	5.0E-06 m^{-1} yr^{-1}	N/A
Piping 75-150 mm	3.0E-07 m^{-1} yr^{-1}	2.0E-06 m^{-1} yr^{-1}	N/A
Piping > 150 mm	1.0E-07 m^{-1} yr^{-1}	5.0E-07 m^{-1} yr^{-1}	N/A
Pump	1.0E-04	5.0E-04	N/A
Heat Exchanger (material on shell side)	5.0E-05	5.0E-05	1.0E-03
Heat Exchanger (material on shell side – Tube higher design press.)	1.0E-05	1.0E-03	1.0E-02
Heat Exchanger (material on shell side – Shell higher design press.)	1.0E-06	N/A	N/A

*G.2 for piping is a leak with an effective diameter of 10% of the nominal diameter, maximum of 50 mm

6.3 Event Tree Analysis

Event tree analysis is used for evaluating the likelihood of release of a hazardous material given the defined plant safeguards in place. The event tree analysis in this QRA determines the likelihood of mitigation working (gas detection and shutdown) or failing to operate on demand.

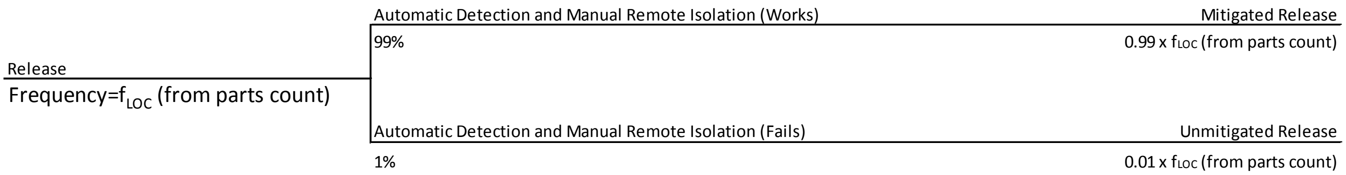
Detection and isolation of an accidental release requires time to complete. Detection and isolation times for the QRA were developed using the detection and isolation times provided in the TNO Purple Book [2]. Table 6 provides the detection and isolation times used in the study.

Table 6 - Detection and Isolation Times

Blocking Type	Time to Detect and Isolate	Failure on Demand
Mitigated Gas Detection and Shutdown from Control Room	2 min	0.01 per demand
Unmitigated	30 min*	N/A
*30 minutes of outflow is the maximum duration defined for the QRA		

The event trees used in the QRA is provided in Figure 3.

Figure 3 - Event Tree for Nodes with Automatic Detection and Manual Remote Installation



Based on the parts counts; equipment Loss of Containment (LOC) frequency and the event tree for mitigated/ unmitigated releases, the failure frequencies for each node are developed. Table 7 details the frequencies applied in the QRA.

Table 7 – Scenario Frequencies

Node	Description	Leak	Rupture (Mitigated)	Rupture (Unmitigated)	Comments
		events/ yr	events/ yr	events/ yr	
1	Natural Gas Inlet to Plant	6.10E-05	1.21E-05	1.22E-07	
2	Natural Gas Conditioning	4.81E-04	3.29E-05	3.32E-07	
3	Saturator	1.15E-03	6.10E-05	6.16E-07	
4	GHR	3.38E-04	3.71E-05	3.74E-07	
5	Methanol Loop	3.47E-04	3.71E-05	3.74E-07	
6	Methanol Purification (overhead vapor)	2.34E-04	2.25E-05	2.27E-07	
7	Methanol Purification (bottoms liquid)	6.21E-04	1.15E-04	1.16E-06	
8	Crude Storage Tanks	2.10E-04	9.90E-06	1.00E-07	
9	Shift Storage Tanks	4.20E-04	1.98E-05	2.00E-07	
10	Product Storage Tanks	8.40E-04	3.96E-05	4.00E-07	
11	Methanol Transfer (to topping column)	5.61E-04	1.11E-04	1.12E-06	
12	Methanol Transfer (shift to product tanks)	5.61E-04	1.11E-04	1.12E-06	
13	Methanol Transfer (product tanks to loading pump)	2.44E-04	4.83E-05	4.88E-07	
14	Methanol Loading Pump	6.00E-04	1.19E-04	1.20E-06	30% Usage Factor
15	Methanol Loading Line (at wharf)	4.57E-05	9.05E-06	9.14E-08	30% Usage Factor

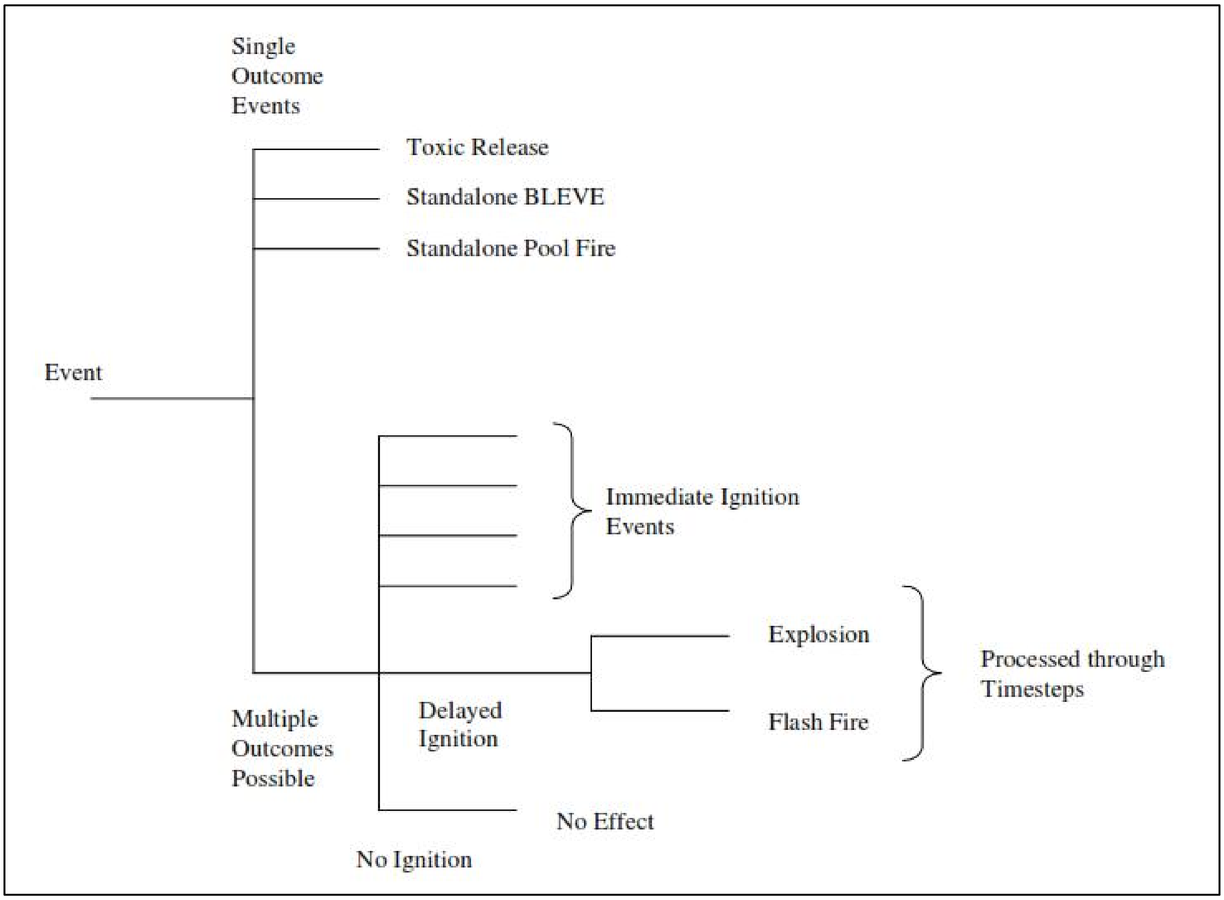
7 RISK ANALYSIS

The consequence model inputs and the frequency analysis results are combined in the risk model to develop the QRA results for the proposed NWIW methanol plant, located at the Port of Kalama. The consequence modeling and the risk modeling are performed in the Safeti program (Phast RISK version 6.7). Once all inputs are defined, the risk results are calculated using the Safeti program's "MPACT" risk model.

7.1 The MPACT Risk Model

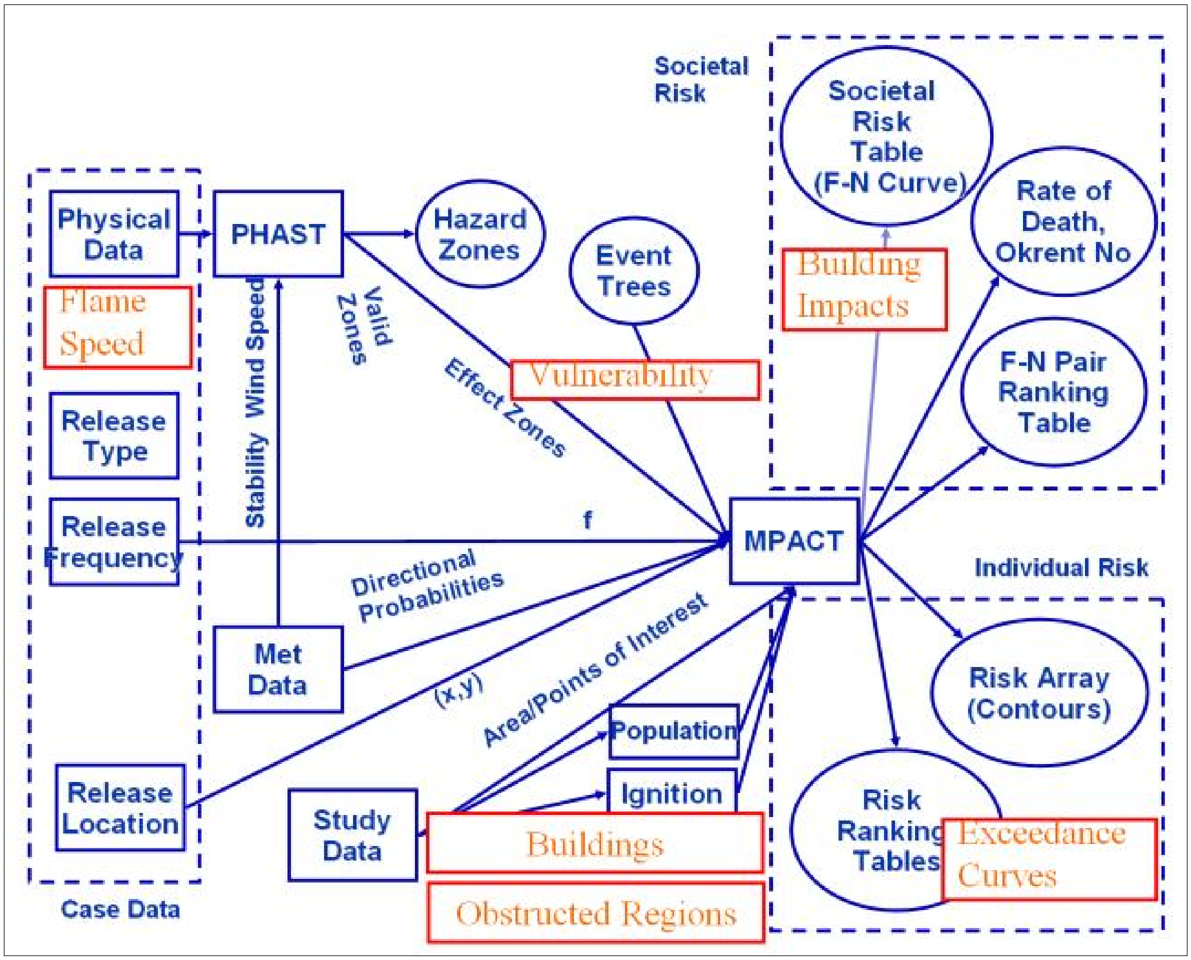
The MPACT risk model is the heart of the Safeti program. The MPACT risk model is the result of decades of development and refinement. It is the most widely used model for developing quantitative and facility siting study risk assessment results. Figure 4 illustrates the generalized event tree logic used in the "MPACT" model.

Figure 4 - The Generalized Event Tree Logic Applied in the MPACT Model



The inputs to the "MPACT" model are numerous, and allow for most advanced and refined modeling results possible. Figure 5 illustrates the inputs and outputs of the "MPACT" model.

Figure 5 - Overall Input and Output Data for the "MPACT" Model



The following site specific information was input into the risk model to develop the likelihoods of the various potential impacts: weather conditions, ignition sources, obstructed regions, onsite buildings/ occupancy and offsite populations. Additional inputs to the risk model included: probabilities of vapor cloud explosion/flash fire, and vulnerability criteria for populations.

7.2 Weather Conditions

The likelihood of the wind directions (16 directions) and eight wind speed and Pasquill stability class combinations were developed from local climactic data. The resulting probabilities were input to the model to determine the probabilities of various wind direction, wind speed and stability class combinations.

Atmospheric stability and wind speed are important factors for consequence analysis. The six most common Pasquill stability classes are given in Table 8. Stability Class F is the most conservative for vapor dispersion distances since there is limited mixing of the released gas with air under these stable atmospheric conditions, and therefore the flammable gas cloud can travel a significantly long distance before it is diluted to the Lower Flammability Limit (LFL), or a toxic concentration of interest. However, stability class does not have a significant effect on fire/ thermal radiation results (jet fire, pool fire).

Table 8 - Pasquill Stability Classes

Stability Class	Description
A	Very Unstable – Sunny light winds
B	Moderately Unstable – Less sunny and more winds than A
C	Slightly Unstable – Very windy/sunny or overcast/light wind
D	Neutral – Little sun and high wind or overcast/windy night
E	Slightly Stable – Less overcast and less windy than D
F	Stable – Night with moderate clouds and light/moderate winds

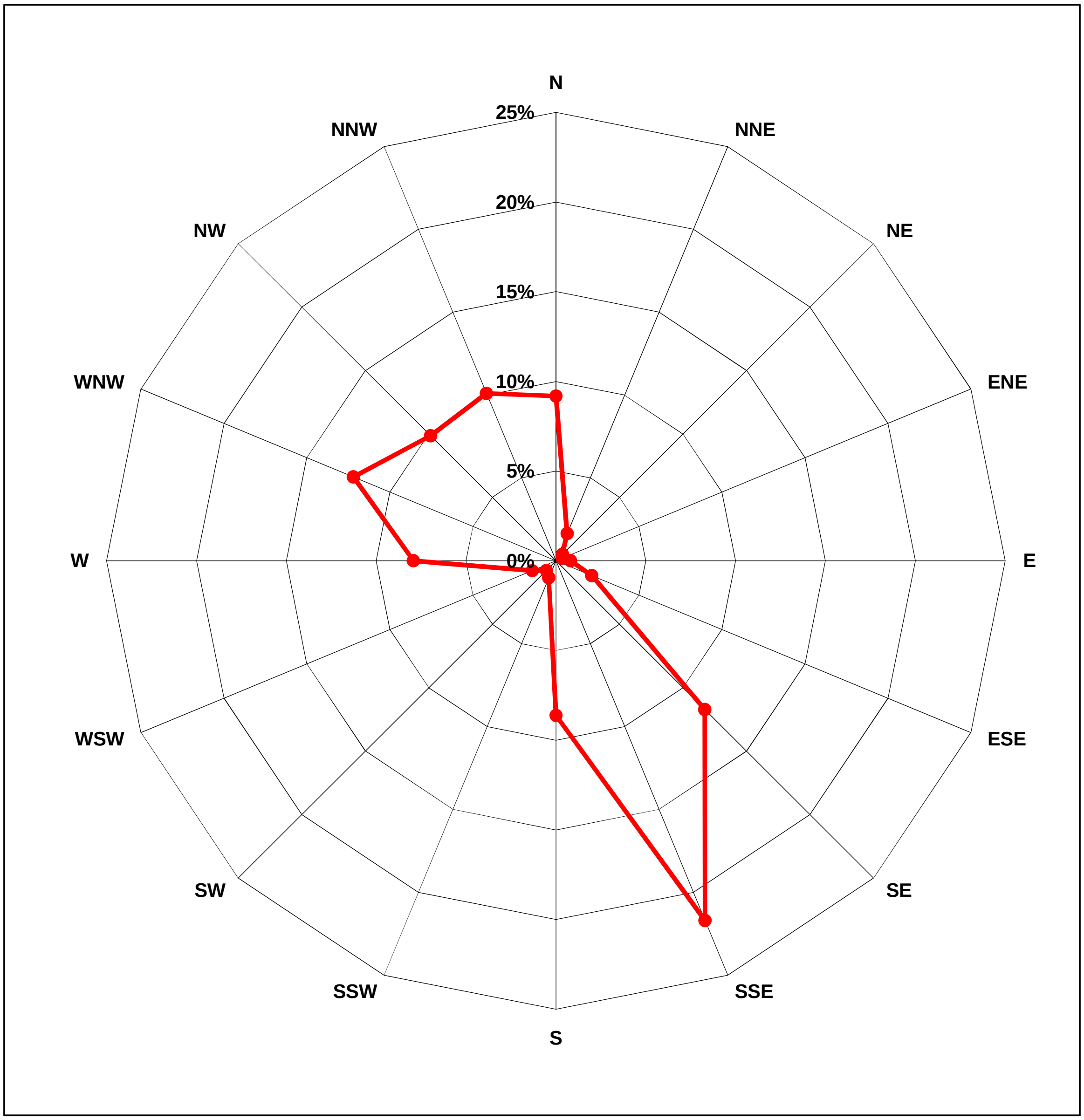
For this analysis, representative meteorological data (for the period 2000 to 2009) was obtained from the National Climatic Data Center (NCDC). Data from the Kelso-Longview station (station number = 727924) was selected since it is the closest weather station (approximately 5 miles) to the proposed NWIW methanol site that provides stability class information from a STAR (STability ARray) Data station. The NCDC meteorological data consists of wind speed, wind direction, and Pasquill stability observations. The wind speed/stability observations have been combined into four representative groups and the probabilities of occurrence summed for day and night time periods. The representative combinations of wind speed and stability class for this location that will be used as input to the Phast model are given in Table 9.

Table 9 – Representative Weather Conditions

Wind Speed	Pasquill Stability	Likelihood of Occurrence	
		Day	Night
m/s	'class'	%	%
1.6	B	12.59%	0%
4.5	C	6.79%	0%
1.6	D	15.58%	15.58%
5.1	D	9.15%	9.15%
1.5	F	0%	31.16%

Figure 6 shows the wind rose data for the Kelso-Longview station. Note that directions indicate the direction from which the wind originates. As shown in the wind rose diagram, the prevailing wind direction at the site is from the South-South East.

Figure 6 - Wind Rose



Other key site specific meteorological parameters used as inputs to the consequence model are:

- Ambient Temperature – 51.5 °F (yearly average 2005-2014)
- Relative Humidity – 71% (yearly average 2005-2014)
- Surface Roughness Length – 1 meter

The surface roughness length describes the surface over which a cloud is dispersing. A surface roughness length of 1m is consistent with regular large obstacle coverage (suburb, forest), and was used for all dispersion modeling.

7.3 Ignition

Flammable releases require ignition to develop into the fire or explosion hazards analyzed in the consequence models employed in the QRA. Not all flammable releases will be ignited, and the time of ignition relative to the time of release affects the potential outcomes of the release. Direct ignition of a release may result in jet fire, pool fire, or fireball hazards, while delayed ignition may result in flash fire or vapor cloud explosion impacts, with the potential for residual pool fire or jet fire impacts. Safeti includes an ignition model to develop the probabilities of each potential outcome based on direct ignition probabilities and defined ignition sources.

7.3.1 Direct Ignition

The probability of direct ignition of an accidental release was defined in accordance with the TNO Purple Book [2]; the guidance is summarized in **Table *2***.

Table 2 - Probability of Direct Ignition for Fixed Installations

Source		Probability of Direct Ignition
Continuous	Instantaneous	
< 10 kg/s	< 1000 kg	0.2
10 - 100 kg/s	1000 - 10,000 kg	0.5
> 100 kg/s	>10,000 kg	0.7

7.3.2 Delayed Ignition

The Safeti MPACT risk model integrates the risk from delayed ignition with time. The risk model calculates the probability of delayed ignition by superimposing the flammable zone of the cloud over ignition sources defined for the site. Ignition sources were defined for the site based a plot plan review of the proposed methanol plant.

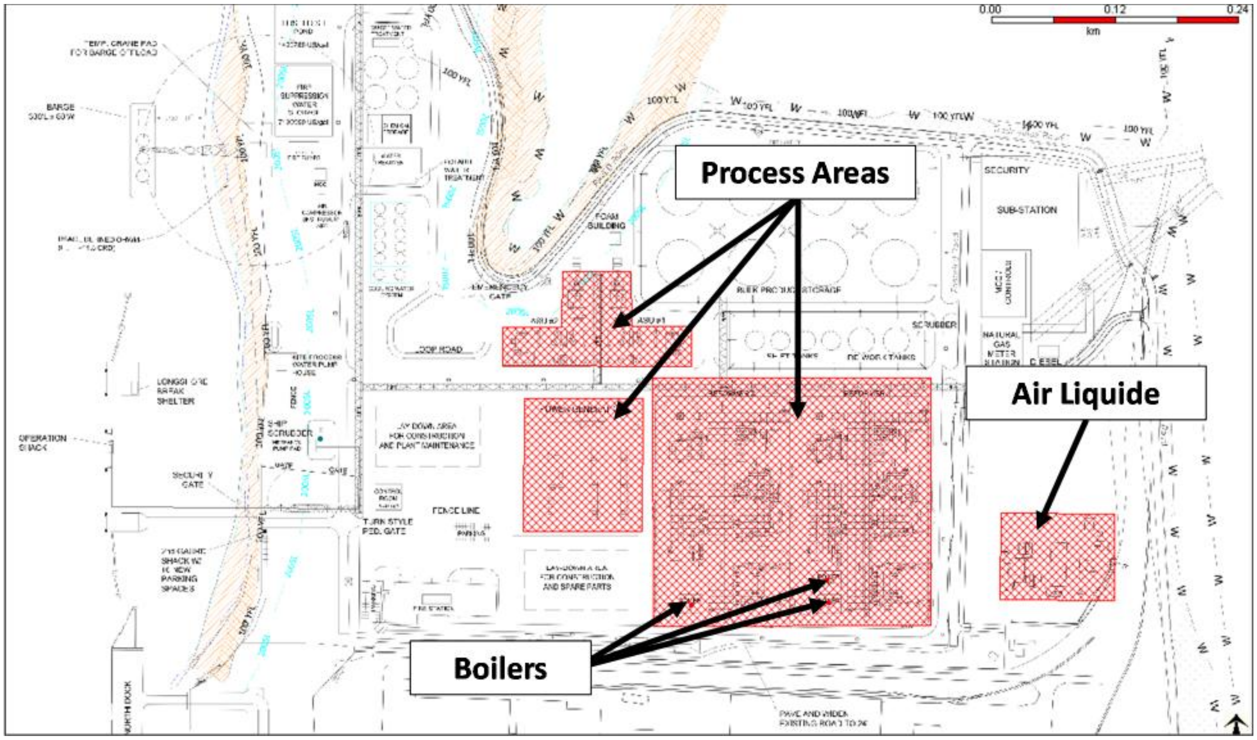
The potential for delayed ignition of a vapor cloud is processed in the MPACT risk model through time steps. For each flammable release a multitude of potential ignition times is assessed to evaluate the full potential of vapor cloud explosions or flash fires which may occur as a result of a delayed ignition. The probability of ignition at each time step is determined by the likelihood of ignition defined for the ignition sources encompassed by the flammable cloud.

Ignition sources are defined based on an ignition source strength, *S* (as defined by TNO and HSE). Ignition source strength represents the probability of a flammable cloud being ignited in that area, if exposed for one minute. The following areas of potential ignition were defined for the QRA (where S is the probability of ignition):

- Onsite
  - Boilers – *S*=0.45
  - Process Areas – *S*=0.9
- Offsite Ignition Sources
  - Air Liquide – *S*=0.9

The ignition sources defined in the study are depicted in Figure 7.

Figure 7 - Ignition Sources Defined in the Risk Model

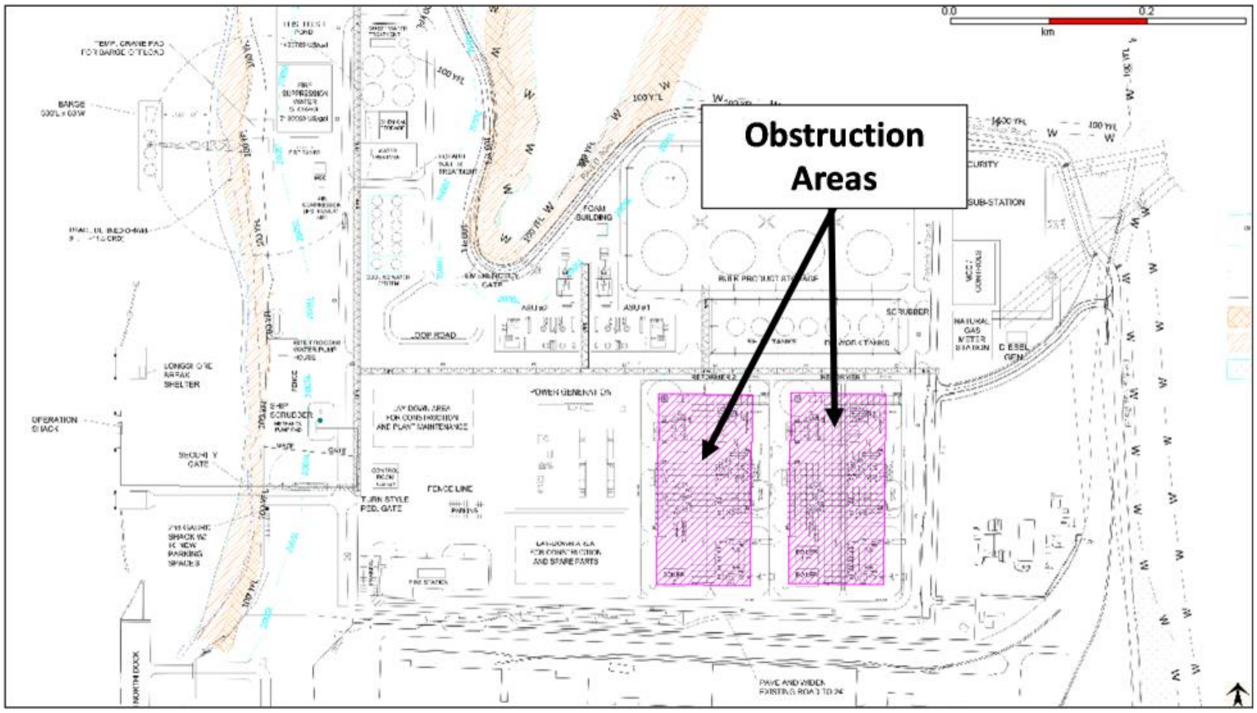


7.4 Obstructed Regions

Areas of confinement and congestion (obstruction) for the proposed methanol plant were defined in the risk model. The presence of confinement and congestion is required for ignited flammable clouds to result in a vapor cloud explosion. The process area and other structures were included in the risk model as obstructed regions.

In accordance with standard industry practice, and guidance from the TNO Purple Book [2], the TNO ME explosion model was used with obstructed regions defined based on guidance in the TNO's "Guidance for the Application of the Multi-Energy method, Second phase" (GAMES) [6]. Obstruction strength values for the TNO ME explosion model range from 1 to 10. The areas of obstruction were defined based on a review of the plot plan, and include the methanol production areas. Figure 8 depicts the areas of obstruction defined in the study. The source strengths defined for the obstructed regions were defined with a multi-energy obstruction Strength = 6.0.

Figure 8 - Obstructed Regions Defined in the Safeti Model



7.5 Onsite and Offsite Populations

7.5.1 Onsite Buildings and Occupancy

A categorization of onsite buildings and their occupancy levels, as well as onsite outdoor populations, were developed with NWIW. The classification of each building was determined, based on the CCPS "Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires" [7]. Definitions for each building classification used in the study are provided in Table 11.

Table 11 - Building Classification Definitions

Building Category	Building Description	Example
A	Wood-frame trailer or shack	Temporary offices.
B	Steel-frame/metal siding pre-engineered building	Workshops, warehouses. This type covers industrial metal-clad buildings only. Brick-clad steel frame-frame buildings are type D.
C	Unreinforced masonry load bearing wall building	Administration building, cafeteria, substation. Single or multistory. Roof of this building type is supported solely by the walls.
D	Steel or reinforced concrete frame with unreinforced masonry infill or cladding	Administration building, cafeteria, laboratory, unit control room, substation. Single or multistory. The roof is supported by a frame, independent of the walls.
E	Reinforced concrete or masonry shear wall building	Substantially designed building but not specifically designed for blast.
F	Blast-resistant building	Central control building designed specifically for blast.

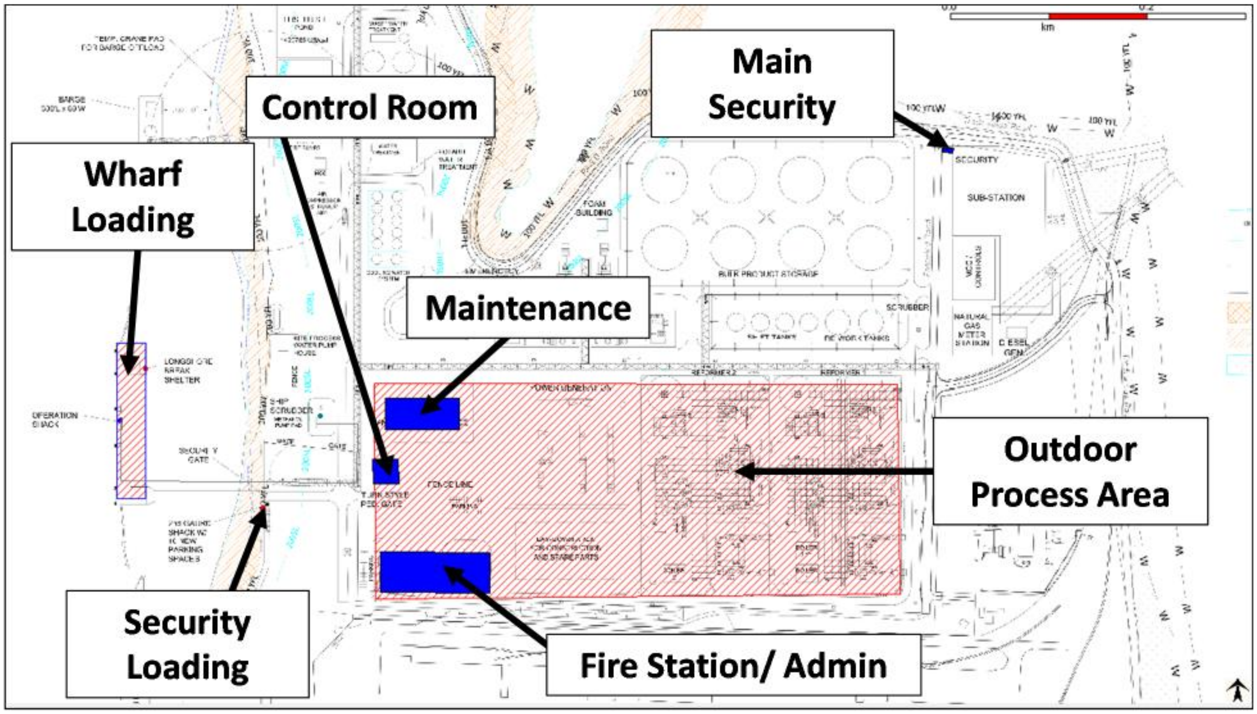
The population data and building classifications used for the proposed methanol plant are provided in Table 12. The locations of populations are illustrated in Figure 9.

Table 12- Onsite Populations and Building Categories

		Number of People			
		Day		Night	
Name	Construction Type	Number of People	Comment	Number of People	Comment
Control Room	D	8.3	- Shift Supervisor (1 @ 75% Indoor) - CR Operator (3 @ 100% Indoor) - Other Operators (9 @ 50% Indoor)	12	- Shift Supervisor (1 @ 90% Indoor) - CR Operator (3 @ 100% Indoor) - Other Operators (9 @ 90% Indoor)
Fire Station/ Admin	D	16	- Admin (12 people @ 100% Indoor) - Warehouse (4 people @ 100% Indoor)	3	- Admin (2 people @ 100% Indoor) - Warehouse (1 person @ 100% indoor)

Name	Construction Type	Number of People			
		Day		Night	
		Number of People	Comment	Number of People	Comment
Maintenance	B	19.5	- Maintenance (39 people @ 50% Indoor)	10.8	- Maintenance (12 people @ 90% Indoor)
Main Security	B	2	- Security (2 @ 100% Indoor)	2	- Security (2 @ 100% Indoor)
Process Area	Outdoors	24.3	- Shift Supervisor (1 @ 25% Outdoor) - Other Operators (9 @ 50% Outdoor) - Maintenance (39 people @ 50% Outdoor)	4.9	- Shift Supervisor (1 @ 10% Outdoor) - Other Operators (9 @ 10% Outdoor) - Maintenance (39 people @ 10% Outdoor)
Wharf	Outdoors	6	Ship Loading Only - 5 Longshoremen - 1 Operator - 1 Security	6	Ship Loading Only - 5 Longshoremen - 1 Operator - 1 Security

Figure 9 - Population Locations Depicted on Plot Plan



7.5.2 Offsite Population

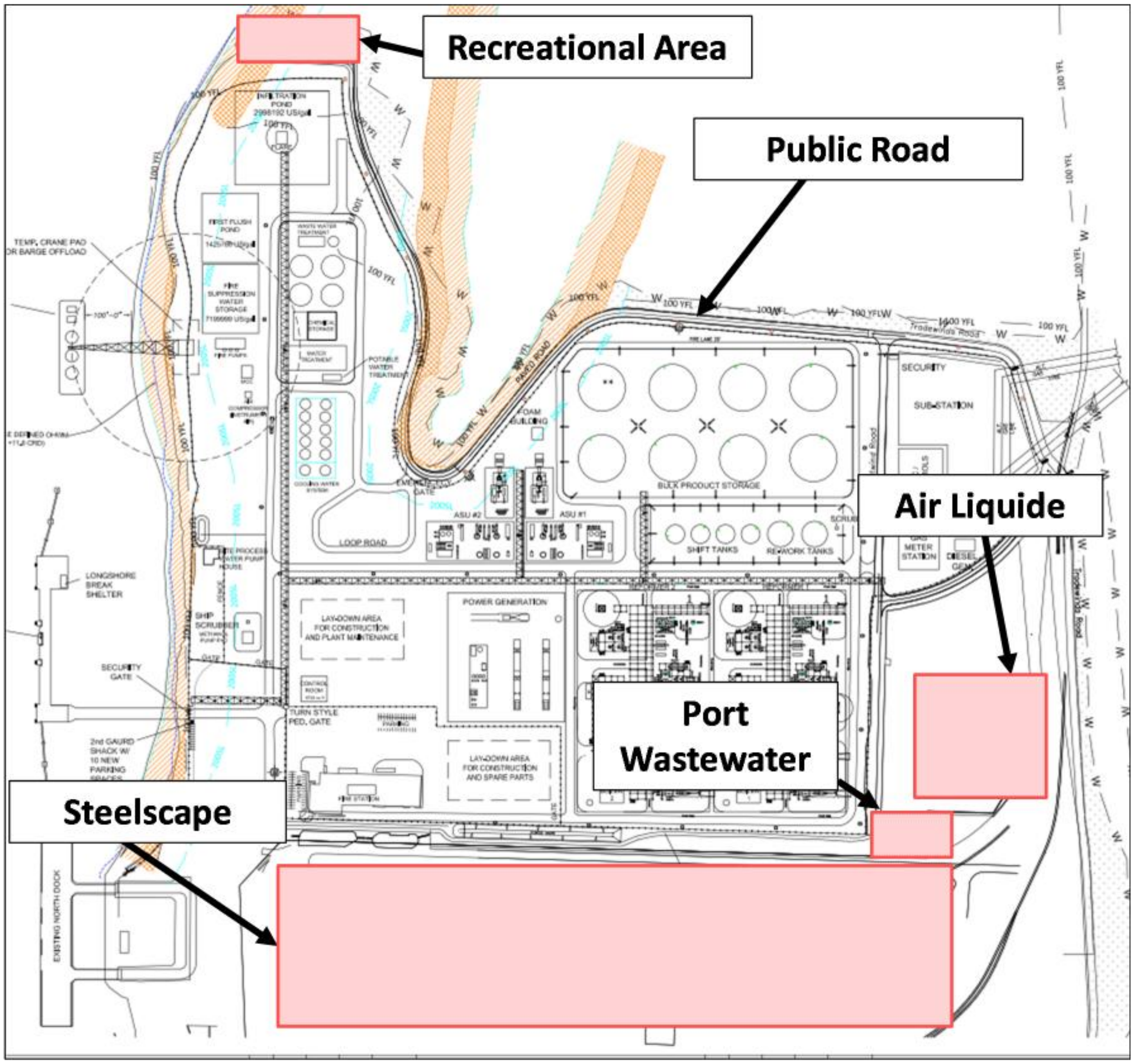
Based on a screening of the potential consequences there are offsite areas considered in the QRA. These include the following businesses and locations illustrated in Figure 10:

- Steelscape, Inc.
- Air Liquide
- Port wastewater treatment facility
- Recreational area to the north of NWIW

The Port of Kalama provided the employment information for the business locations, and the following was assumed:

- Air Liquide: 2 personnel all times
- Port wastewater facility: 2 personnel during the daytime
- Steepscape
  - 155 personnel during weekday shift
  - 30 personnel during weeknight shift
  - 33 personnel during weekend day shift
  - 30 personnel during weekend night shift
  - 4 additional personnel at dock (when moving coils)
- Recreational Area
  - Located outside of the QRA hazard zones (no population data collected)
- General
  - Daytime population: 97% indoors and 3% outdoors (based on TNO Purple Book [2])
  - Nighttime population: 99% indoors and 1% outdoors (based on TNO Purple Book [2])

Figure 10 – Offsite Population Locations



7.6 Vulnerability Criteria and Impact Assessment

To develop the risk results, the consequence modeling results are processed using vulnerability criteria. The vulnerability criteria are used to determine the likelihood of fatality for a given population at a given location. Populations located in buildings are less vulnerable to external fire and thermal radiation hazards, but may be more vulnerable to blast overpressure impacts, depending on the classification of the building. Different vulnerability values are used for populations indoors and populations outdoors. For blast overpressure impacts, the building classification is used to determine the vulnerability of building occupants.

7.6.1 Vulnerability Criteria – Blast Overpressure

Building construction is a major factor in determining damage from blast overpressure. The most severe impact is building collapse, primarily due to diffraction loading of the building walls resulting in roof collapse. Table 13 presents the building vulnerability levels based on guidance from CCPS [7], and have been applied for vapor cloud explosion consequences.

Table 13 - Vulnerability Criteria - Blast Overpressure (Indoors)

Building Category	Building Type	Peak Side-On Overpressure (psi)	Consequences	Vulnerability of Occupants
A	Wood-frame trailer or shack	1.0	Insolated buildings overturn. Roofs and walls collapse.	0.1
		2.0	Near-total collapse.	0.4
		5.0	Buildings completely destroyed.	1.0
B	Steel-frame/metal siding pre-engineered building	1.25	Metal siding anchorage failure.	0.1
		1.5	Sheeting ripped off and internal walls damaged. Danger from falling objects.	0.2
		2.5	Building frame stands, but cladding and internal walls destroyed as frame distorts.	0.4
		5	Building completely destroyed.	1.0
C	Unreinforced masonry bearing wall building	1.0	Partial collapse of walls that have no breakable windows.	0.1
		1.25	Walls and roof partially collapse.	0.2
		1.5	Complete collapse.	0.6
		3	Building completely destroyed.	1.0
D	Steel or concrete frame with unreinforced masonry infill or cladding	1.0	Failure of incident face.	0.1
		1.5	Walls blow in.	0.2
		2.0	Roof slab collapses.	0.4
		2.5	Complete frame collapse.	0.6
		5.0	Building completely destroyed.	1.0
E	Reinforced concrete or masonry shear wall building	4.0	Roof and wall deflect under loading. Internal walls damaged.	0.1
		6.0	Building has major damage and collapses.	0.4
		12	Building completely destroyed.	1.0

For outdoor populations, vulnerability criteria provided in Table 14 is used.

Table 14 - Vulnerability Criteria - Blast Overpressure (Outdoors)

Peak Side-On Overpressure (psi)	Vulnerability
5.0	0.10
3.0	0.05
1.0	0

7.6.2 Vulnerability Criteria – Fire and Thermal Radiation

In the case of fires (pool fire, jet fire), the vulnerability criteria chosen is consistent with the TNO Purple Book [2]. It is assumed that people indoors are protected from heat radiation until the building catches fire. The threshold for ignition of buildings is set at 35 kW/m^2. Table 15 summarizes the vulnerability criteria for pool and jet fires.

Table 15 - Vulnerability Criteria - Pool and Jet Fires

	Fatality Probability	
Thermal Radiation Level	Indoors	Outdoors
35 kW/m^2	1.0	1.0
12.5 kW/m^2	0	0.9
4.0 kW/m^2	0	0

Fireball/ BLEVE impacts are similar to those from pool/ jet fires, however, fireball durations tend to be much shorter. For buildings constructed of combustible materials, type A, ignition of the building is assumed to occur. While fireball/BELEVE are not considered for the NWIW QRA, Table 16 provides the vulnerability criteria applied to fireball impacts, for completeness.

Table 16 - Vulnerability Criteria – Fireball/ BLEVE

Population Location	Description	Fatality Probability
Building Type A	Wood-frame trailer or hack	1.0
Building Type B	Steel-frame/metal siding pre-engineered building	0.0
Building Type C	Unreinforced masonry load bearing wall building	0.0
Building Type D	Steel or reinforced concrete frame with unreinforced masonry infill or cladding	0.0
Building Type E	Reinforced concrete or masonry shear wall building	0.0
Building Type F	Blast-resistant building	0.0
Outdoors	Outdoor Populations	1.0

For flash fires, it is assumed that only people within the fire are impacted by the event, as the thermal radiation impact duration is extremely short there are no impacts outside of the fire. Vulnerability criteria for flash fires are summarized in Table 17.

Table 3 - Vulnerability Criteria - Flash Fire

	Fatality Probability	
Exposure Level	**Indoors**	**Outdoors**
Within LFL Zone	-	0.8

7.6.3 Toxic Probit

Carbon monoxide and methanol pose a toxic hazard at the proposed methanol plant. In dealing with fatality rates for these exposures, the probit equations published in the TNO Purple Book [2], consistent with the default parameters in Phast were used. The probit values have been developed for may toxic chemicals, and can be directly related to a percentage of people expected to be fatally impacted when exposed to a concentration “C” for a time “t”.

The probit equation used in the QRA are:

$$\text{Carbon monoxide: } Y = -7.21 + \ln(C^1\, t)$$

$$\text{Methanol: } Y = -6.347 + 0.664\ln(C^1\, t)$$

Where:
Y = probit value (cumulative normal distribution function of mean 5 and standard deviation 1)
C = concentration in parts per million (ppm)
t = exposure duration in minutes

8 RESULTS

8.1 Risk Presentation

The risks of the proposed methanol plant may be expressed from two perspectives: (1) the risk to individuals and (2) the risk to groups of people. These are referred to, respectively, as individual and societal risk.

This QRA reports individual and societal risk results, and well as the overpressure contours from a vapor cloud explosion.

8.1.1 Individual Risk

Individual risk is defined as the risk to a single person/ individual to a hazard. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). The scale of any incident, in terms of the number of people impacted by an event(s), does not affect the individual risk level at a distance from the hazard location(s). Individual risk is presented in this QRA on a geographical basis. The risk contours developed can be used to assess potential risk to the surrounding community, and assist in the land use planning decision for the NWIW site location.

The risk contours are calculated from the expected frequency of an event capable of causing the specified level of harm at a specified location, regardless of whether or not anyone is present at that location to suffer that harm. Thus, individual risk contour maps are generated by calculating individual risk at every geographic location assuming that somebody will be present, unprotected (e.g., outdoors), and subject to the risk 100% of the time (i.e., annual exposure of 8,760 hours per year). In contrast, other risk measures consider the fraction of the time that individuals are exposed to the risk. Individual risk results are associated with a particular location rather than a particular person. For this reason, this risk measure is sometimes referred to as location risk or geographical risk.

The individual risk results can be expressed as a likelihood (e.g., fatalities per year), or expressed as a recurrence period (e.g., 1 fatality in X years). While all injuries are of concern, effect models for predicting degrees of injury often include additional uncertainties; thus, risk analysts often estimate the risk of fatal injury (death) as a less equivocal measure.

The calculation of individual risk is made with the understanding that the contributions of all incident outcome cases (i.e., event sequences) are additive. For example, the total individual risk to an individual working at a facility is the sum of the risks from all potentially harmful incidents considered separately.

8.1.2 Societal Risk

The societal risk is defined as the risk to a group of people to a hazards. The hazard can be a single incident, or a collection of incidents (e.g., the release scenarios developed for the NWIW site). Thus societal risk evaluated the scale of the incident in terms of the number of people that could be impacted from the hazard(s). Societal risk is expressed as the cumulative risk to a group(s) of people who might be affected by accidental release events (for the NWIW QRA societal risk are presented to two groups: onsite population and the offsite community). The calculation for societal risk uses the same consequence and frequency results as the individual risk calculation, but uses information about the number, geographical distribution, occupied building construction and occupancy levels of the population group(s) to determine the risk level.

Societal risk expresses the cumulative risk to groups of people who might be affected by release events. The calculation uses the same consequence and frequency results as the individual risk calculation, but uses information about the number, geographical distribution, building construction and occupancy levels of the population to determine the level of risk.

Societal risk is expressed using an F-N curve, which is the most common method of depicting societal risk results. The F-N curve indicates the expected frequency (F) of release scenarios occurring which result in the number of N or more fatalities. The x-axis of the F-N curve represents the number of fatalities, N. The number of fatalities is depicted on a logarithmic axis with a minimum value of 1. The y-axis of the F-N curve represents the cumulative frequency of the release scenarios with the number of fatalities equal to N or more.

8.1.3 Overpressure Contours

Overlay of the overpressure levels on a plot plan of the facility. The contours enable a visual illustration of the vulnerable buildings within various overpressure damage levels.

8.2 Risk Criteria

In most locations worldwide, including the United States, there is no legally mandated risk acceptance criteria for facilities handling hazardous chemicals. In lieu of legally mandated criteria, published risk acceptance criteria from foreign governments and trade associations are available for interpreting risk results. As a standard industry practice, risk analysts and facility operators defer to these guidelines in the absence of any legally mandated risk criteria.

From the definition above, individual risk is the level of risk at a distance from a hazard(s). The risk is measured as the risk of fatality to a single person, assuming the person is always present at the location. With the risk levels illustrated as an overlay from the NWIW site, and potential risks to the surrounding community. This QRA uses risk acceptance criteria published by the Health and Safety Executive of the United Kingdom (UK HSE), as the basis of comparison. The UK HSE risk criteria has been selected for this project since UK is unique in that it addresses onsite individual risk for workers, where the other international risk criteria are based solely on offsite impacts. Table 18 details the individual risk criteria, which are illustrated in Figure 11.

Table 18 - Individual Risk Criteria

Individual Risk Criteria	Recurrence Period
Maximum tolerable risk to workers	1 fatality in 1,000 years
Maximum tolerable risk to public	1 fatality in 10,000 years
Broadly acceptable (or negligible) risk to workers and public	1 fatality in 1 million years

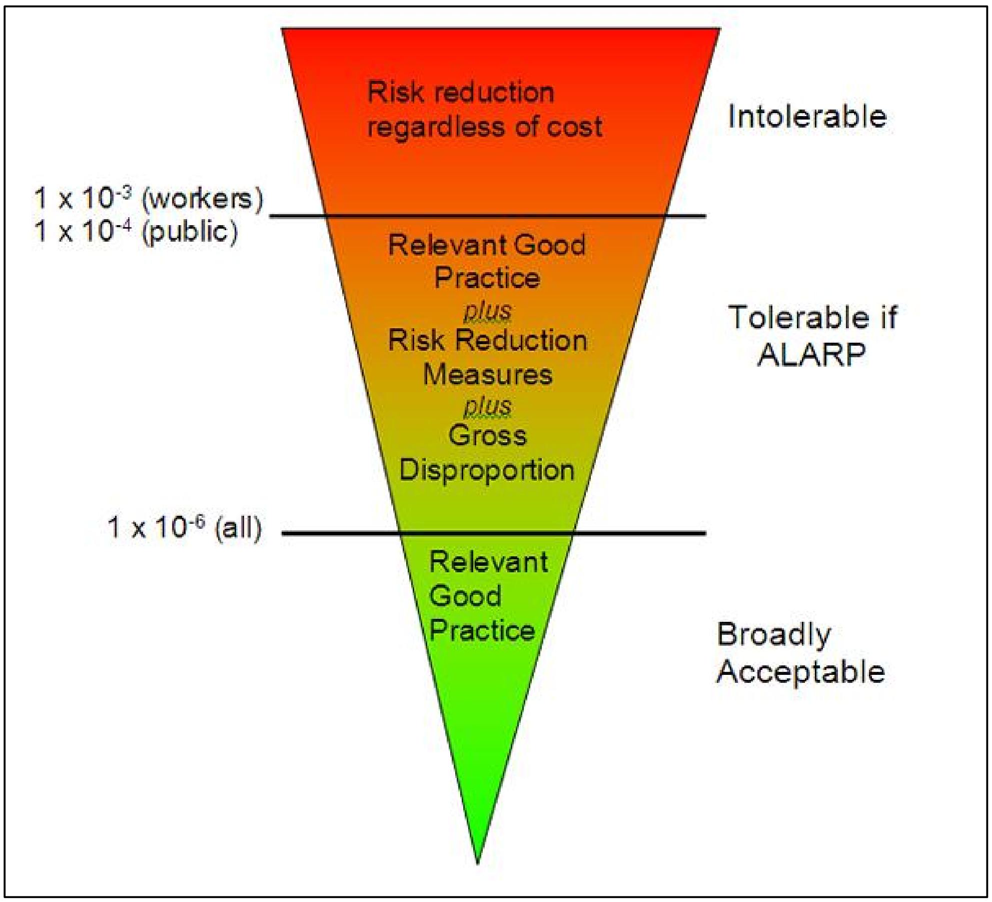
Using the UK-HSE criteria, the individual risk levels for the onsite populations can be classified as follows:

- **Unacceptable** (≥ 1 fatality in 1,000 years)
    - Level where further risk assessment or risk mitigation is required.

- **Broadly Acceptable** (≤ 1 fatality in 1 million years)
    - Level where further risk reduction is not required.

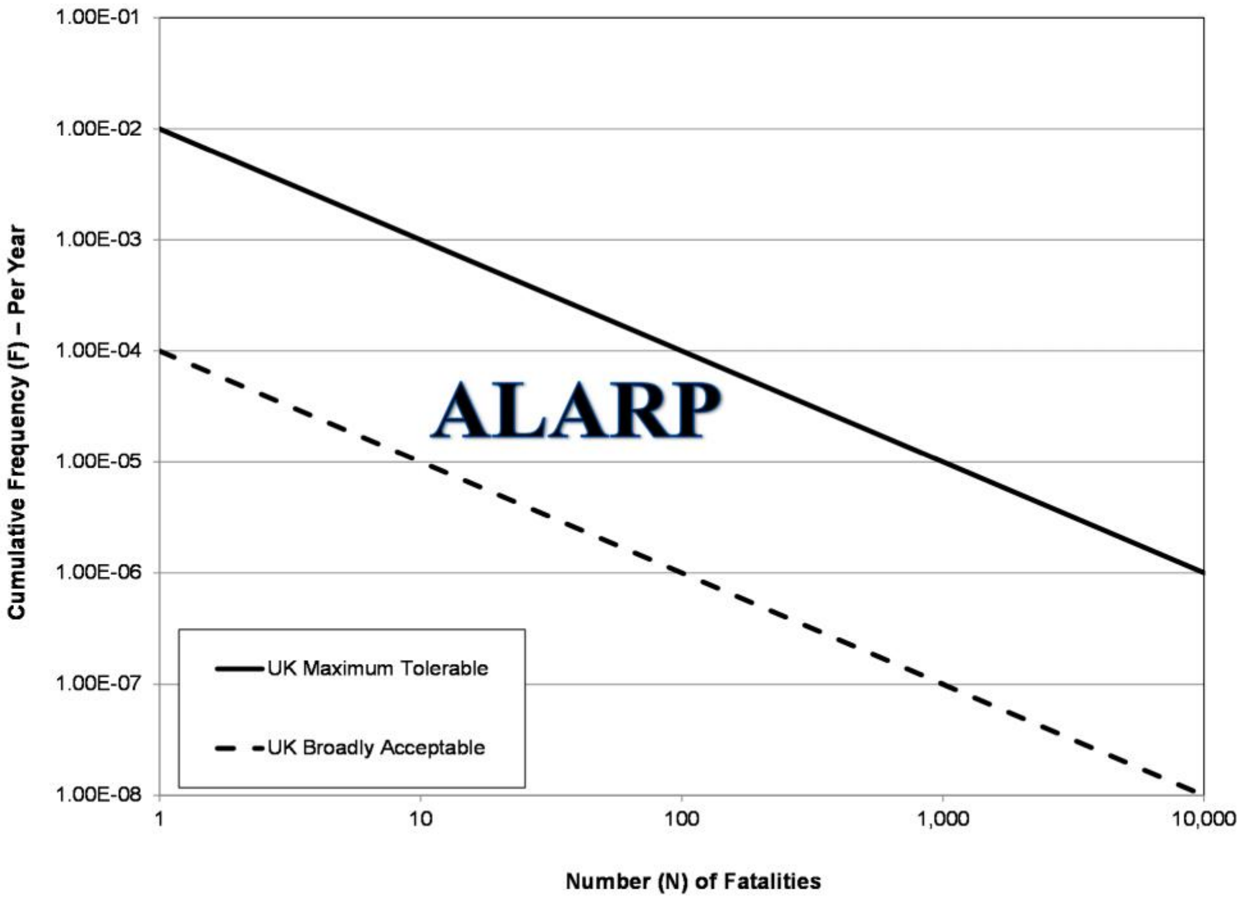
- **Tolerable** (1 fatality between 1,000 and 1 million years)
    - Level where further, prudent risk reduction should be considered. Region is typically referred as the As Low as Reasonably Practicable (ALARP) zone.

Figure 11 – UK-HSE Individual Risk Criteria



Societal risk compares the risk to the onsite and offsite populations to the UK-HSE societal risk criteria. As with individual risk, the societal risk criteria includes a broadly acceptable, intolerable and ALARP regions. Figure 12 depicts the societal risk criteria applied to the F-N diagram

Figure 12 - Societal Risk Criteria



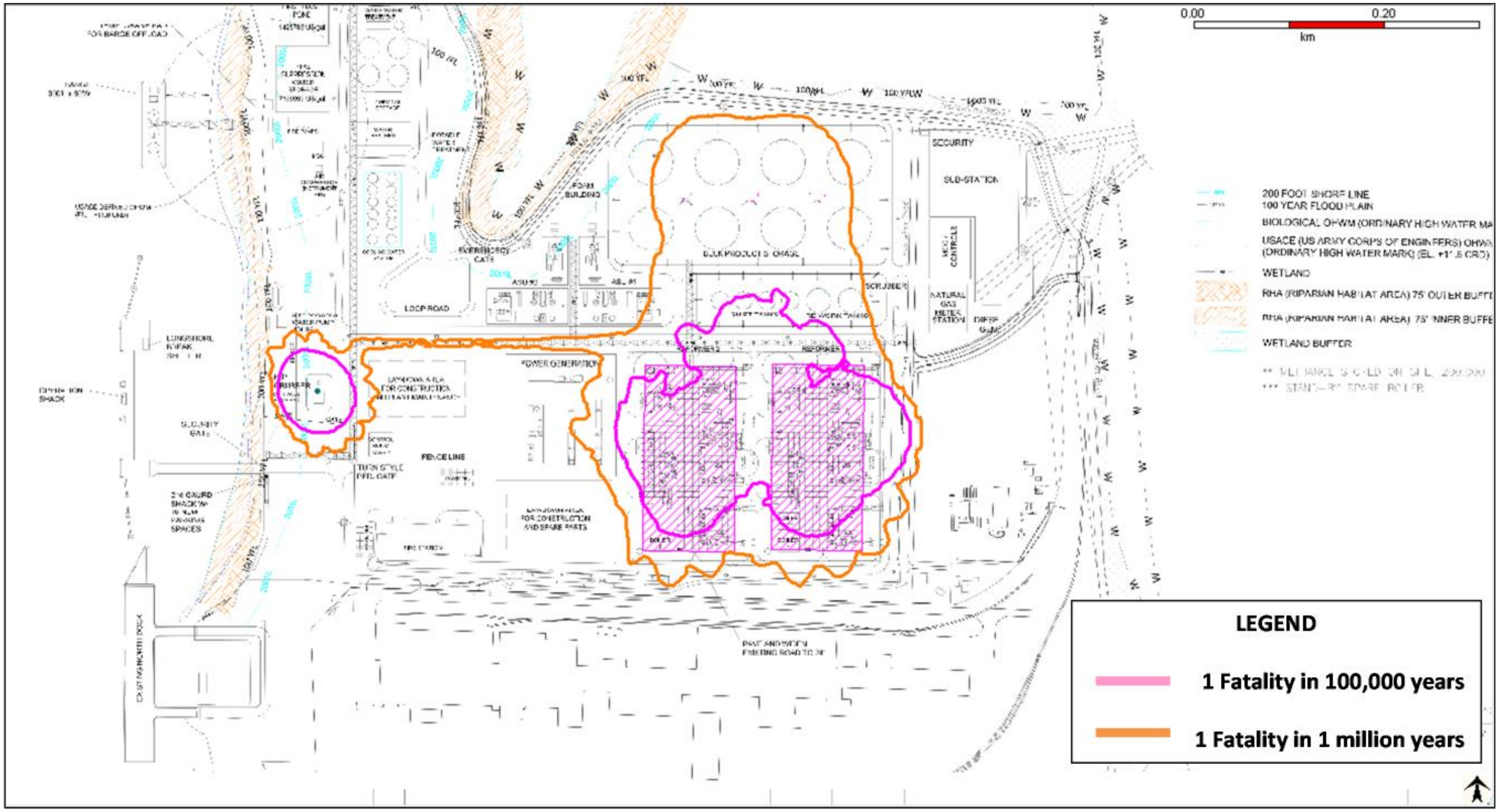
8.3 Risk Results

Risk results for the NWIW methanol plant are detailed below.

8.3.1 Individual Risk Results

Figure 13 illustrates the individual risk contour for the proposed methanol plant. As shown, the risk contour illustrating the risk of 1 fatality in 1 million years is maintained within the site boundary. Therefore, the individual risk is in the broadly acceptable (or negligible) risk level for public impacts. This is the conclusion for the surrounding community as well as Steelscape and Air Liquide, the closest businesses to the proposed NWIW plant.

Figure 13 – Individual Risk Contour

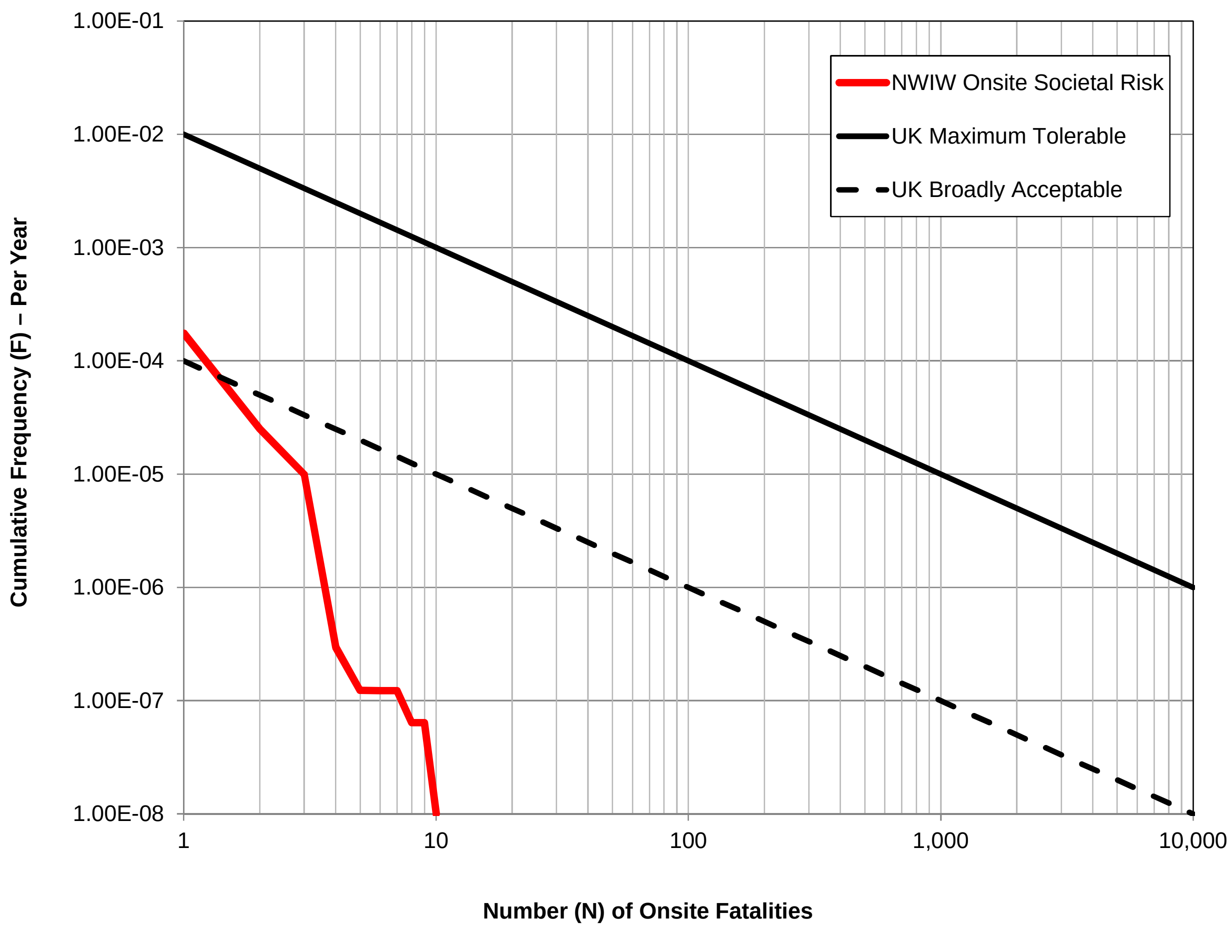


8.3.2 Societal Risk Results

Figure 14 is the F-N diagram, illustrating the societal risk for the proposed methanol plant. The societal risks criteria from the UK-HSE is also illustrated on Figure 14. The following was determined from evaluating the societal risk results:

- There is no measurable risk of offsite fatalities that were calculated outside the NWIW plant boundary.
- Societal risk is determined for the onsite personnel within the NWIW plant boundary, and the QRA calculated 1 onsite fatality in 5,714 years.

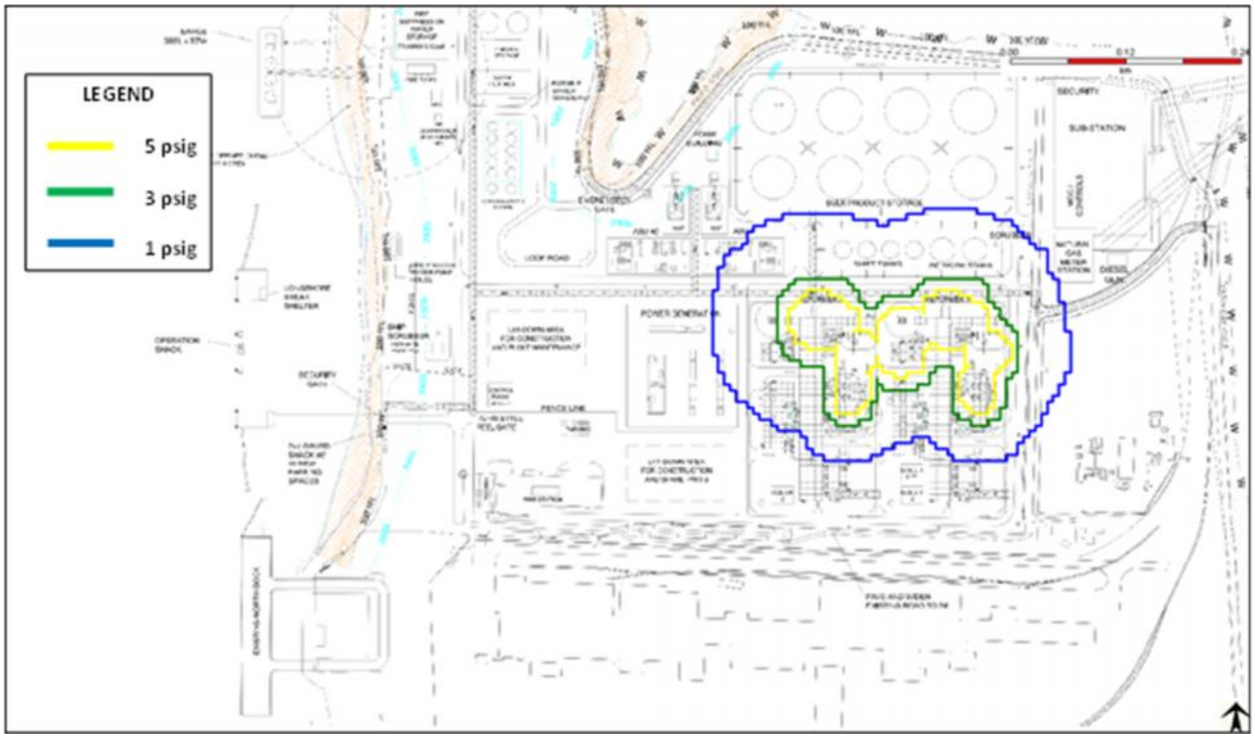
Figure 14 - F-N Diagram (NWIW Onsite Risk)



8.3.3 Overpressure Results

Overpressure contours have been developed for the process area release scenarios, Figure 15. These overpressure contours illustrate three overpressure levels (5, 3 and 1 psig). Regardless of individual risk and societal risk, any buildings within the 5 and 3 psi zone could result in severe damage/ collapse and significant impact to building occupants if exposed to an event with this blast overpressure level. However, as the figure shows, the 5 and 3 psi zone do not extend beyond they process area, and the 1 psi does not impact any onsite buildings or offsite buildings.

Figure 15 – Overpressure Contour



9 CONCLUSIONS AND RECOMMENDATIONS

9.1 QRA Conclusions

This QRA was completed to address risks of the proposed NWIW methanol plant to onsite employees and the offsite community from accidental releases from the methanol production, storage and vessel loading operations. While the NWIW methanol plant is only proposed and currently in the design phase, the QRA evaluates the risk assuming the facility is built, in operation and with an onsite staffed workforce.

It should be noted that all observations, conclusions and recommendations are relevant only to this QRA project and the proposed operations at the NWIW methanol site at the Port of Kalama. These include, and are not limited to:

- Facility plot plan
- Heat and material balance
- Equipment and piping sizes
- Safety systems
- Meteorological data
- Onsite staffing
- Onsite buildings construction and occupancy
- Surrounding offsite businesses and community

In this QRA the level of risk was compared to the risk criteria published by the Health and Safety Executive of the United Kingdom (UK-HSE), which is a widely accepted international authority, and their criteria are utilized by many government organizations and companies to the evaluate risk of similar industries and hazards. The conclusion of the QRA is that the proposed NWIW methanol plant poses a level of risk considered as broadly acceptable to the public and surrounding community of Kalama, as compared to the UK-HSE risk criteria.

For the NWIW onsite personnel, the risk is in the As Low as Reasonably Practicable (ALARP) range. At this risk level prudent risk reduction measures should be considered.

The risk to onsite workers can be compared to the fatal injury rates for various occupations. Figure 16 presents the number and rate of fatal occupational injuries by major occupational group and Figure 17 present the civilian occupations with high fatal work injury rates (Source: Bureau of Labor Statistics, 2014). From this data, NWIW would be comparable to "Production" in Figure F, which had 206 fatal injuries and a fatal injury rate of 2.4 (per 100,000 full –time equivalent workers). From these national statistics, NWIW employees would have a lower fatal injury rate as compared to structural and iron workers, farming, fishing, forestry, construction, transportation, and logging.

Figure 16 – Number and Rate of Fatal Occupational Injuries to Civilian Workers by Major Occupation Group, 2014 (Source: Bureau of Labor Statistics, 2014)

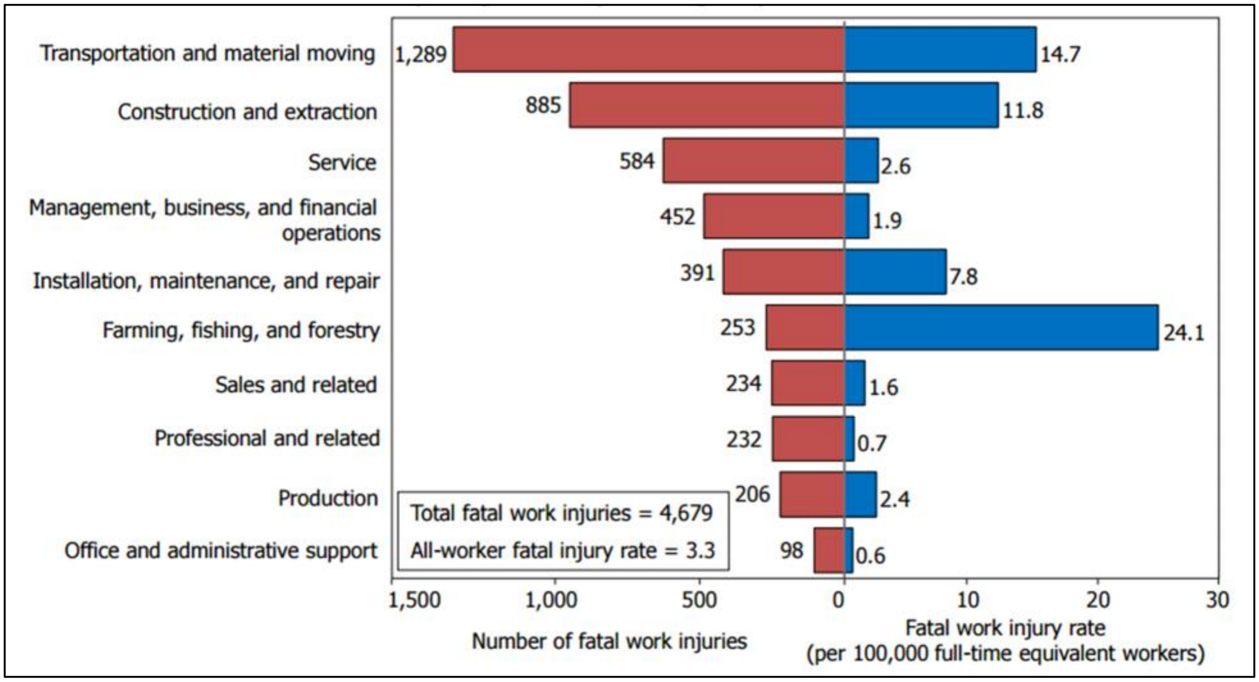
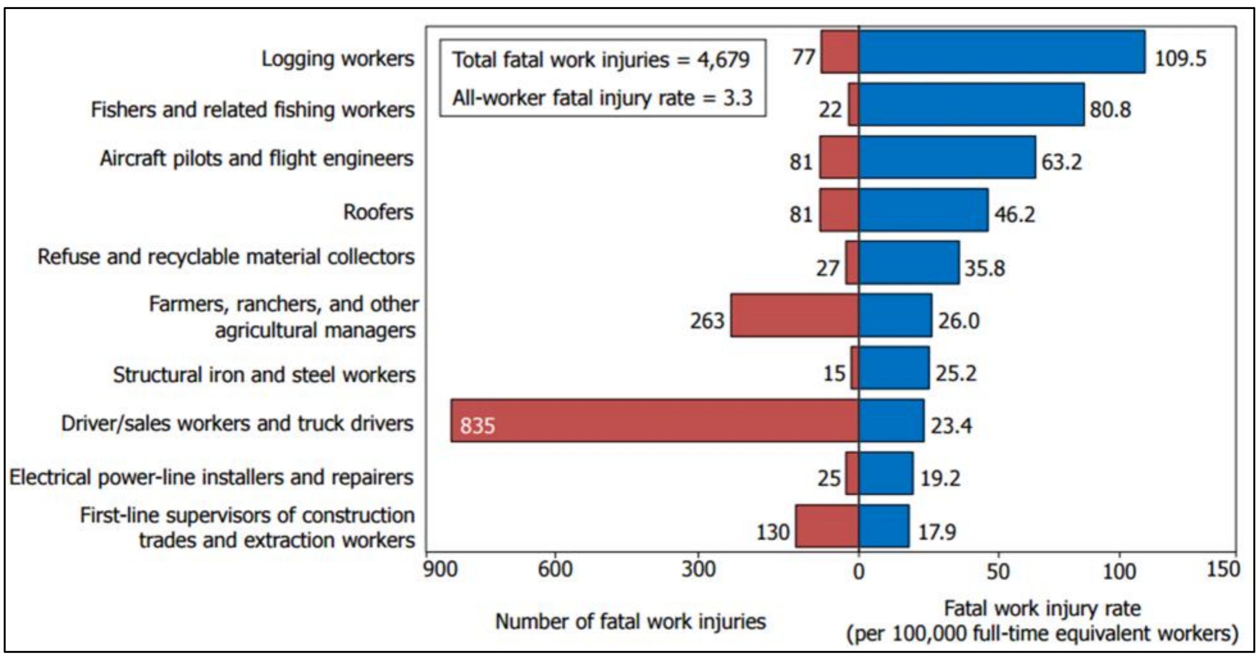


Figure 17 – Civilian Occupations with High Fatal Work Injury Rates, 2014 (Source: Bureau of Labor Statistics, 2014)



9.2 NWIW QRA Recommendations

From further analysis of the results, the onsite risk level is primarily from the potential for accidental releases leading to fires in the methanol production area. To address these findings, NWIW should consider the following recommendations to reduce the onsite risk from ALARP to within the broadly acceptable level:

- Recommendation 1: Consider further evaluation of the potential consequences of fires in the production area, considering curbing, drainage and impingement of jet fires.
- Recommendation 2: Consider conducting a review of egress pathways from the production area, buildings and other areas where onsite personnel may assemble.
- Recommendation 3: Consider completing a detailed process hazard analysis as part of the project design to fully address all deviations from normal operation, potential consequences, documentation/ evaluation of all safeguards.

10 REFERENCES

[1] Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers (AIChE), Guidelines for Chemical Process Quantitative Risk Analysis – 2nd Edition, New York, NY, 2000.

[2] TNO, " CPR 18E Guidelines for Quantitative Risk Assessment," 1999.

[3] International Association of Oil and Gas Producers, Risk Assessment Data Directory-Report No. 434-3, 2010.

[4] The Flemish Governement, Appendix to Handbook Failure Frequencies, 2009.

[5] Center for Chemical Process Safety, Guidelines for Determining the Probability of Ignition of a Released Flammable Mass, New York: John Wiley & Sons, Inc., 2014.

[6] W. A. d. B. a. D. v. L. Mercx, Application of correlations to quantify the source strength of vapor cloud explosions in realistic situations. Final report for the project 'GAMES', TNO Report PML 1998-C53, Rijswijk, The Netherlands, 1998.

[7] Center for Chemical Process Safety, Guidelines for Evaluating Process Plant buildings for External Explosions and Fires, New York, 1996.

[8] National Climactic Data Center, "Stability Array (STAR) Data - Station Number 722400 - Years 2000 to 2009".

[9] United Kingdom Health and Safety Executive, "HSE Hydrocarbons Releases System," UK HSE, 2015. [Online]. Available: https://www.hse.gov.uk/hcr3/.

APPENDIX A

HAZARD IDENTIFCATION (HAZID)