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Advances in Quantitative Risk Analysis

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ABBREVIATED ABSTRACT:

Until recently, the level of detail of a QRA study has been limited by the availability of high speed computing resources. Results for coarse QRA studies were typically presented in terms of overall individual risk, or societal risk, with little opportunity to segment or analyze the risk results in more detail.

This presentation provides an outline of the QRA process, and then goes on to discuss how a basic QRA can now be enhanced to include more detailed segmentation of risk results; or easily expanded to include a detailed facility siting analysis.

KEYWORDS:

Quantitative Risk Analysis, QRA

1. INTRODUCTION

Quantitative Risk Analysis (QRA) as a technique for managing and understanding risks dates back to the 1970s, initially applied in the aerospace, electronics, and nuclear power industries. During the 1980s the technique was refined and applied to the chemical and petrochemical industries.

Until recently, the level of detail of a QRA study has been limited by the availability of high speed computing resources. Results for coarse QRA studies were typically presented in terms of overall individual risk, or societal risk, with little opportunity to segment or analyze the risk results in more detail.

We can now conduct more detailed and accurate QRA studies due to the accessibility, availability, and affordability of high speed computing. For example, using a normal desktop computer, a QRA can now yield risks segmented by hazard type: toxic, flammable, or overpressure; or can filter different population types. Where multiple hazard scenarios may have been combined in the past, each hazard scenario can now be considered individually. Risk results can be assessed in terms of fatalities, dangerous dose, or financial impact. Additionally, a QRA can be expanded upon, to include a detailed facility siting analysis, where building structure, indoor population, and ventilation systems are considered in more detail.

2. THE QRA PROCESS

QRA can be used for a number of different purposes. However, it is most valuable as part of a Risk Management program. Risk Management is the identification and control of hazards, through both technological and management solutions.

Before a QRA is conducted, the purpose of the study must be determined so that the appropriate results are generated. The facilities and risks to be included must also be determined. Any special reporting needs, such as regulatory requirements or local language, should be identified. Finally, QRA methodologies that will provide the required results must be chosen. All of these decisions require management processes and policies to guide the individuals responsible for overseeing and conducting the QRA.

Risk, as it relates to the process industries, has been defined as a measure of economic loss or human injury in terms of both the incident likelihood and the magnitude of the loss or injury. A simplified risk equation could be represented by:

Risk = Consequence x Frequency

A risk analysis is the development of a quantitative estimate of risk, based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies.

A QRA can typically be divided into four primary tasks, and a reporting activity. The primary tasks being:

- Hazard Identification
- Frequency Analysis
- Consequence Analysis
- Risk Determination

The first three primary tasks each have a variety of approaches which can be applied, depending on the scope of the project and the data available. Table 1 lists the approaches and their relative benefits.

Table 1 – Risk Analysis Steps

Risk Analysis Step	Approach	Comment
Hazard Identification	HAZOP	Good for complex systems or new technology
	FMEA	Used where a very detailed assessment is required
	Checklist	Good for simple common facilities with similar designs, for example; pipeline pump stations
	Historical data	Good for simple systems, such as pipelines where one is confident that all possible scenarios will be revealed by historical data
Frequency Analysis	Fault/event trees	Good for complex systems where multiple accident causes exist

Risk Analysis Step	Approach	Comment
	Historical data	Good for transportation studies and simple common systems
	LOPA	Provides a consistent basis for judging whether there are sufficient independent protection layers (IPLs) to control risk
Consequence Analysis	Simple models	Used where the overall risk is not sensitive to the hazard zones or where a quick study is required
	Public models	Required by some regulators (e.g. the Netherlands, California)
	Complex models	Used where the overall risk is sensitive to the hazard zones or where conditions cannot be modeled using simpler approaches (for example, mixtures)

3. CONDUCTING THE QRA

An experienced risk engineer, or team of engineers, should be responsible for the hazard identification and frequency analysis stages. Very broadly speaking a refinery consists of storage and process vessels, process units and pipelines. In this broad breakdown, pumps, compressors, heat exchangers, and some valves are considered to be parts of storage and process vessels or process units. Flanged joints, small bore fittings and some other valves are considered as parts of the pipeline infrastructure.

A two-pronged approach can be utilized during the hazard scenario identification stage – classifying the hazards as either “generic” and “non-generic”. “Generic” scenarios consider loss of containment from piping and equipment – leaks, full-bore piping ruptures, or catastrophic vessel failures. “Non-generic” scenarios consider more unusual failure modes, which are specific to the process being analyzed, such as a refinery operation.

In each case, the purpose of the hazard identification and frequency analysis stages should be to provide a comprehensive list of hazard scenarios, along with all the required data, to be taken to the consequence analysis stage. A comprehensive list of the required data for each scenario is provided below:

- Scenario Name
- Process Flow Diagram / Piping & Instrumentation Diagram
- Fluid Conditions (Temperature, Pressure, Phase, Composition, Explosion Reactivity, Toxicity)
- Release Flowrate
- Release Coordinates
- Equipment Type and Size
- Hole Diameter(s)
- Piping Length (if applicable)
- Release Duration
- Release Geometry (1D, 2D, 2.5D, 3D)
- Degree of confinement
- Release Frequency

The consequence analysis stage should generally include all potential hazards from the materials of interest, usually flammable and toxic hazards. Meteorological conditions which are representative to the site should be applied. Generally two or three sets of wind speed, humidity and atmospheric stability data are selected. Usually at least two sets of conditions are chosen: one to represent daytime and the other night-time conditions. In many cases complete wind rose data spanning 8, 12, or 16 directions are used.

Hazard levels must also be selected for:

Radiant heat from fires. Generally levels for injury and fatality are required and are set by considering an exposure time based on how long it might take someone to escape or reach a safe haven. Typical values are $5 kW/m^2$ for injury and $12.5\ kW/m^2$ for death. Thermal radiation damage probits are also used routinely.

Radiant heat dose from BLEVEs. Typical values are 80 kJ/m2 for injury and 160 kJ/m2 for fatality. Thermal damage radiation probits are also used routinely.

Overpressure. Overpressure must take into consideration how injuries could be sustained. Very low overpressures can shatter standard windows potentially causing injury to anyone inside the building. It requires a higher overpressure to cause structural damage that could result in building collapse and potentially fatal injury. Very high levels of overpressure are required to directly cause fatal injury, but lower levels can throw a person against equipment causing serious or fatal injury. Typical values are 0.1 bar for injury and 0.3 bar for fatality, these are based on failure of windows and conventional brick or concrete buildings. There are also several published overpressure probits that we routinely use to determine the potential for damage to objects and humans based on peak pressure and/or impulse.

Toxic exposure. The toxic response of humans is extremely complex and difficult to model. For a limited number of materials probit equations have been developed that relate exposure time and concentration to a probability of injury. A number of simple concentration dependent data also exist, for example IDLH (Immediately Dangerous to Life and Health) and ERPG (Emergency Response Planning Guidelines) limits are published by a number of authorities, including several regulators. Other available data include Lethal Concentration (LC) and Lethal Dose (LD) data, usually expressed in terms of a particular percentage of fatality for specified exposure duration. All of these data are based on some extrapolation of test or theoretical data and are further impaired by assumptions on the average response of the human body to the toxic material. In reality every individual reacts differently and different populations may be more or less sensitive. The most commonly used data are probit equations and ERPG values.

4. RISK DETERMINATION

Typically, both Individual and Societal Risk results are modeled. Onsite and Offsite effects can be calculated, with results presented for daytime population, night-time population and a combined average.

5. ADVANCES IN COMPUTING

QRA was originally developed in the late 1970s and early 1980s, when computing power was very limited. The level of detail of a QRA study was limited by the availability of high speed computing resources. As computing capabilities have advanced, QRA studies can now consider a larger number of hazard scenarios, risk results segmented by hazard type: toxic, flammable, or overpressure; or different population types filtered. Where multiple hazard scenarios may have been combined in the past, each hazard scenario can now be considered individually. Risk results can be assessed in terms of fatalities, dangerous dose, or financial impact. Additionally, a QRA can be expanded upon, to include a detailed facility siting analysis, where building structure, indoor population, and ventilation systems are considered in more detail.

For example, ioMosaic recently conducted a QRA study of an oil refinery which identified over 7,000 potential release scenarios with each release scenario having multiple hazard outcomes including toxicity, thermal radiation from fires, and overpressure from explosions. The actual number of hazard scenarios considered in this QRA study was approximately 21,000 (three different meteorological data sets/conditions were used for each relevant scenario). The actual number of consequence outcomes considered was approximately 100,000. All these calculations were conducted on typical desktop computers. Such an enormous QRA study would not have been possible until recently.

One of the best ways of understanding how computing power has increased, is to consider Moore's Law, which describes a long-term trend in the history of computing hardware. Since the invention of the integrated circuit in 1958, the number of transistors that can be placed inexpensively on an integrated circuit has increased exponentially, doubling approximately every two years. The trend has continued for more than half a century and is not expected to stop until 2015, or even later.
Almost every measure of the capabilities of digital electronic devices is linked to Moore's law: processing speed, memory capacity, sensors and even the number and size of pixels in digital cameras. All of these capabilities are improving at approximately exponential rates.

The law is named for Intel co-founder Gordon E. Moore, who introduced it in a 1965 paper. It has since been used in the semiconductor industry to guide long term planning and to set targets for research and development. Figures 1a and 1b provides an illustration showing how computing capacity and CPU transistor counts have grown over time.

Figure 1a: Moore's Law Applied to Computing Capacity

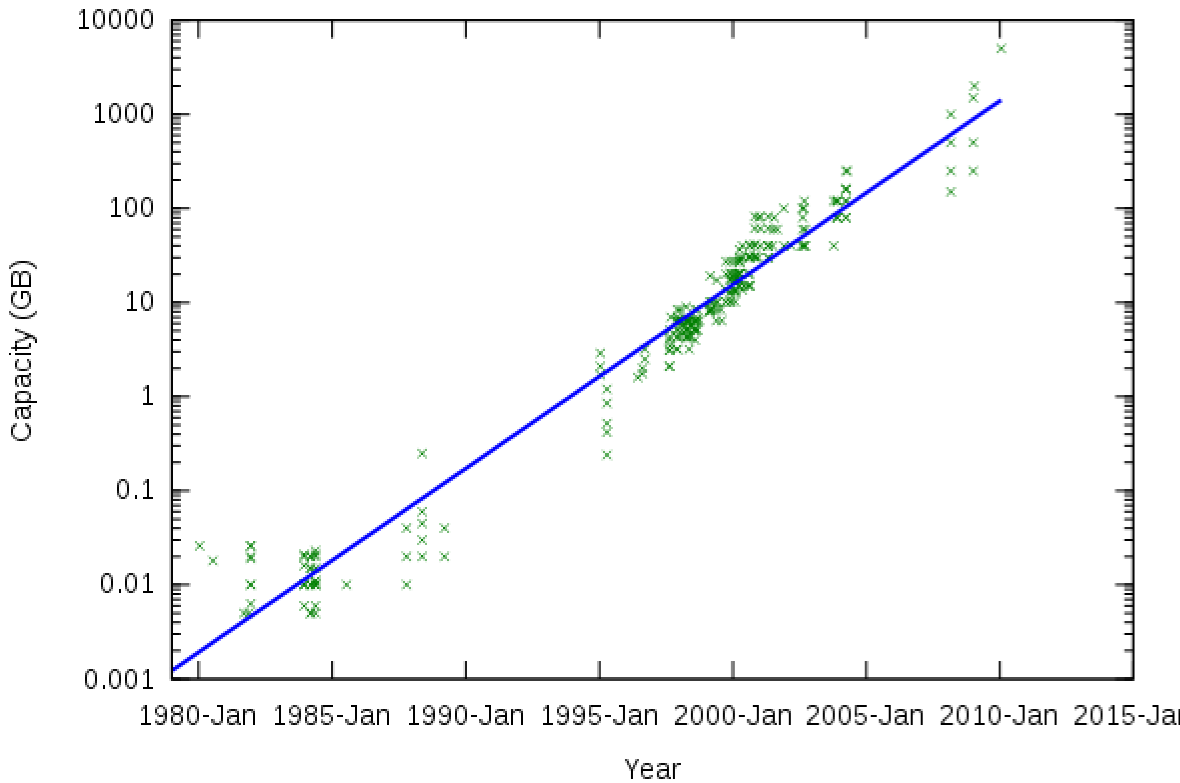
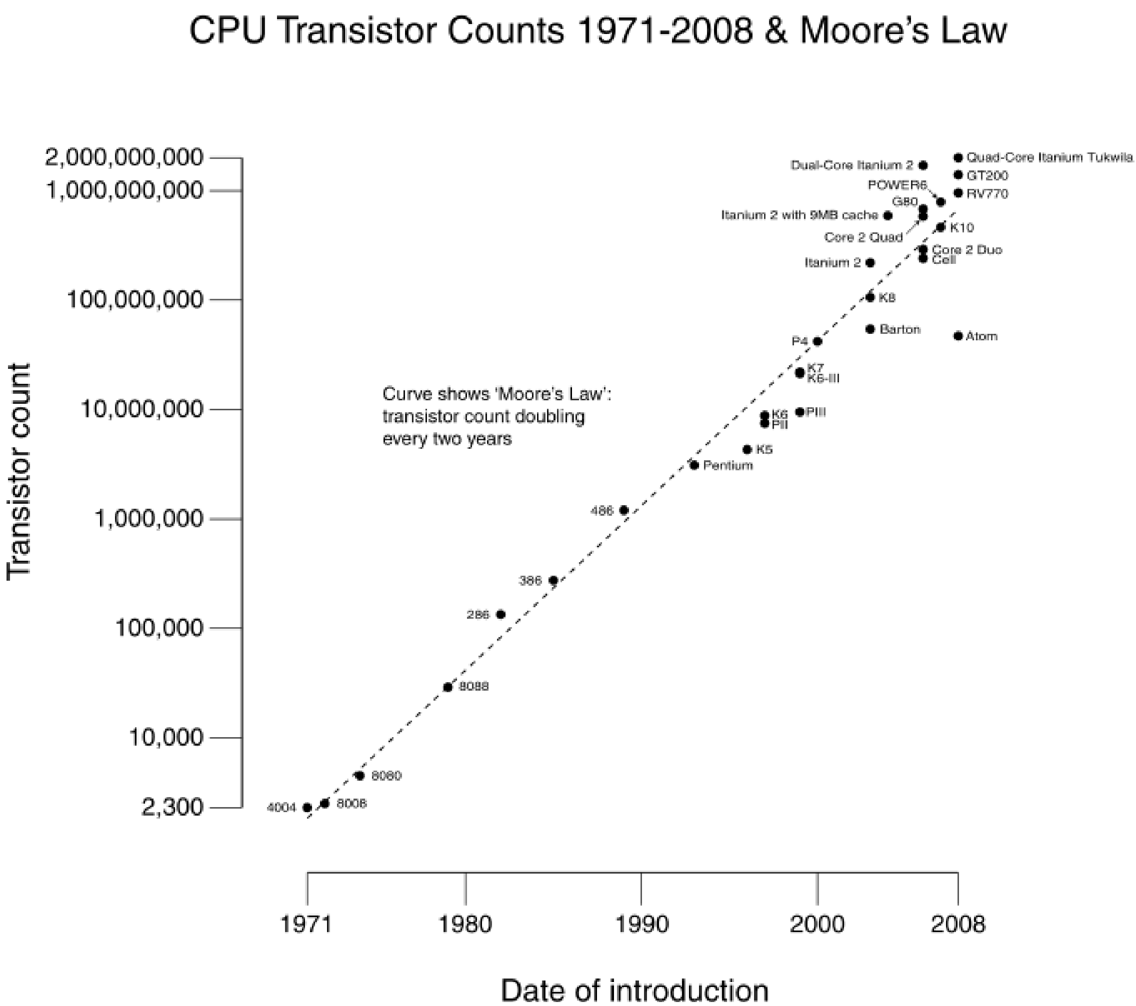


Figure 1b: Moore's Law Applied to Transistor Counts



6. ADDITIONAL RISK REPORTING OPTIONS

With the increased computing capabilities, additional onsite risk statistics can also be calculated showing the highest individual risk, average individual risk, fatal accident rate, and rate of death.

Individual Risk: "The risk to a person in the vicinity of a hazard. This includes the nature of the injury to the individual, the likelihood of the injury occurring, and the time period over which the injury might occur".

Average Individual Risk: "The average of all individual risk estimates over a defined population".

Fatal Accident Rate (FAR): is calculated from the average individual risk, and is normally used as a measure of employee risk in an exposed population. This is the number of fatalities occurring during 1000 working lifetimes (10^8 hours).

Average Rate of Death (ROD): is the estimated average number of fatalities in the population from all potential incidents.

QRA has traditionally considered populated areas being outdoors, twenty-four hours per day. With the increased focus on facility siting, it is becoming more necessary to consider occupied building populations, building type, and any safeguards which a building may be fitted with. There is a lot of overlap between a QRA study, and a detailed facility siting study. The additional computing capabilities available, now make it make easier to integrate the two approaches.

As shown in Figure 2, a QRA study can now include:

- Allowances for toxic or flammable gas detectors, and air handling shut-off
- Allowances for different building types (based on API or CCPS building types)
- Consideration of indoor population compared with outdoor population
- Consideration of amount of windows on each building

Figure 2 - Sample SuperChems Expert Building Infrastructure Data Form

	A	B	C	D	E	F	G	H
1	InfraStructure GUID	4D262681-9EEA-11DE-9FE9-001DD9E78187						
2	Map File	NONE						
3								
4	X1 Coordinate. m	199.000	Area. m2	176.000				
5	Y1 Coordinate. m	760.000						
6	X2 Coordinate. m	207.000						
7	Y2 Coordinate. m	782.000						
8								
9	InfraStructure Location or Unit	Unit 22 control room						
10	InfraStructure Description, Function, or Service	Building 122-B-12						
11	InfraStructure Type	Building - Control Room		<<< Press F12 for list				
12	InfraStructure Structural Class	CCPS-F		<<< Press F12 for list				
13								
14	☐ InfraStructure is a sensitive receptor							
15								
16	InfraStructure Building Characteristics [If Applicable]							
17								
18	☑ Flammable or toxic detectors will automatically shutdown air handling s							
19	☑ InfrStructure administration can shutdown the air handling system							
20	☑ InfraStructure operates under positive pressure							
21								
22	Number of toxic detectors	1						
23	Number of flammable detectors	1						
24	Fraction of InfraStructure surface covered by windows	0.000						
25								
26	InfraStructure Population Statistics [If Applicable]							
27								
28	Overall Population	Number	Presence Factor		Risk ?		Ignition ?	
29	Contractor	1	1		☑ Yes		☑ Yes	
30	Employee	10	1		☑ Yes		☑ Yes	
31	Public	0	1		☑ Yes		☑ Yes	
32	Sensitive	0	1		☑ Yes		☑ Yes	
33	Visitor	0	1		☑ Yes		☑ Yes	
34	Other	0	1		☑ Yes		☑ Yes	
35								
36	Fraction Present Outdoor	0.075						
37								
38	Daytime Population	Number	Presence Factor		Risk ?		Ignition ?	

Additionally, the outputs can now include:

- Risks segmented by Toxic, Flammable, or Overpressure hazards
- Risks segmented by Population Type (Employee, Contractor, Visitor, etc)
- Risks segmented by Building Type (based on API or CCPS building types)
- Risks reported in terms of Fatality, Dangerous Dose, or Financial Impact
- Risk of a specific hazard level (e.g. risk contour for specific overpressure level)

Some examples are shown in Figures 3 to 6.

7. CONCLUSIONS

The high performance computing capabilities readily available to a risk engineer today did not exist when the QRA technique was originally developed.

The potential for generating more detailed and more accurate QRA studies continues to grow. The tools that are available to a risk analyst provide a variety of choices and affords the analyst a greater understanding of the risks and major contributors contributors to risks more than ever before.

With the wealth of information and tools available, it is important for the risk analyst to define in advance, the scope, intended inputs and desired outputs. The ability to conduct a QRA study and a facility siting study simultaneously provides opportunities for cost savings, as well as offering consistency of calculations and results.

Figure 3: Overall Risk Contours

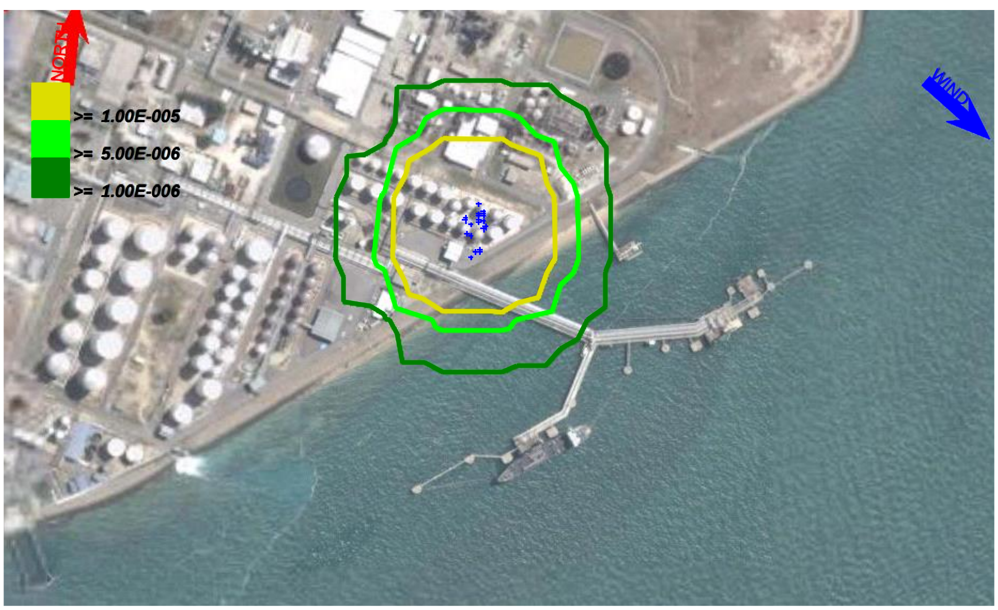


Figure 4: Risk Contours to Specific Hazard Level (1 psi overpressure)

Figure 5: Risk Contours Showing Just Toxic Risk

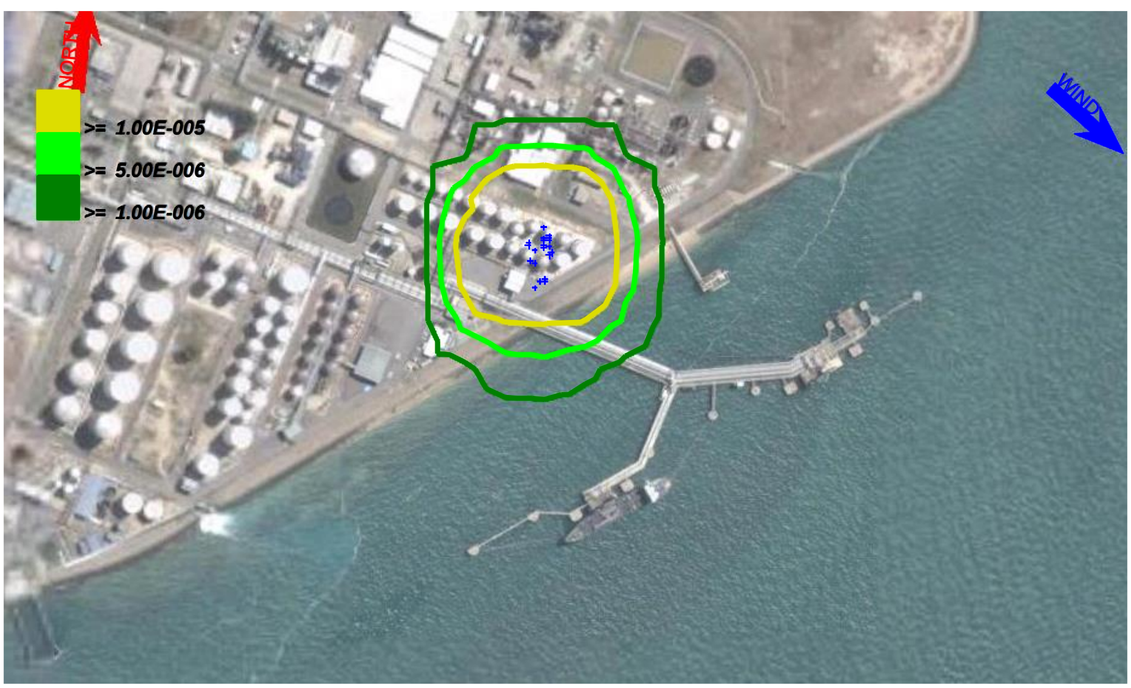
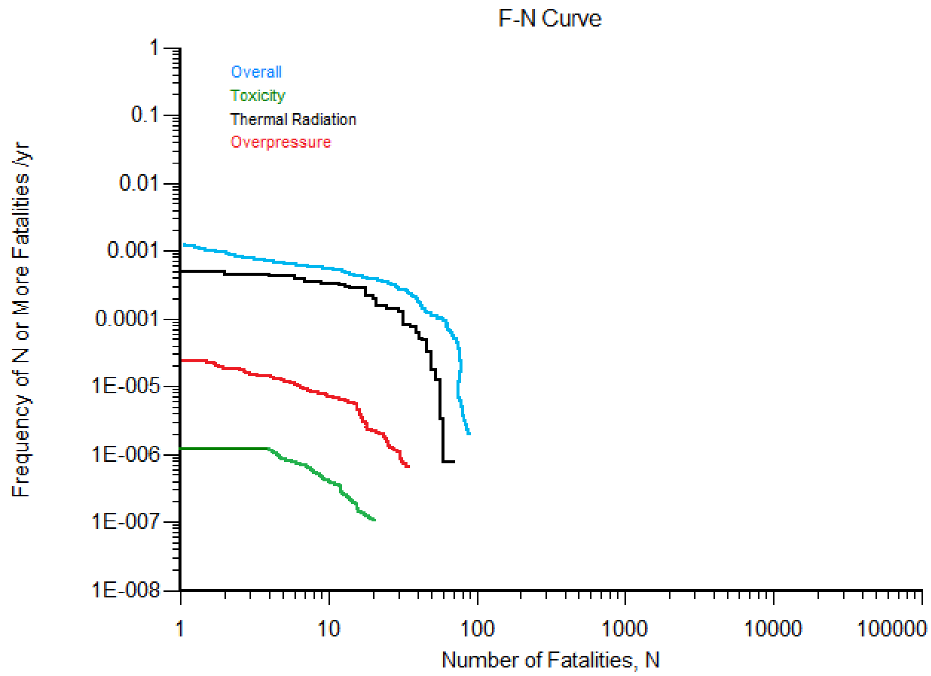


Figure 6: Societal Risk Curves Segmented by Hazard Type



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