The Development of Improved Risk Assessment Methods for Use in Industrial Environmental Management Systems

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ABSTRACT

Industrial sites that store or use chemicals are controlled in the UK under the COMAH (Control Of Major Accident Hazards) Regulations 1999 [1] based on their holdings of “Dangerous Substances”. The COMAH Regulations [1] came into force in 1999 and are the UK’s response to the European Union’s Seveso II Directive. The purpose of these Regulations [1] is to:

- Identify Major Accident Hazards (MAH);
- Ensure that control measures are in place to prevent a MAH;
- Ensure that mitigatory measures are in place to limit effects if MAH do occur.

The UK’s Health and Safety Executive (HSE), and the Environment Agency (EA) jointly enforce the Regulations [1]. The fundamental requirement is given in the statement below, which is taken directly from the Regulations [1].

> *“Every operator shall take all measures necessary to prevent major accidents and limit their consequences to persons and the environment”*.

This paper describes the development of a six-step screening methodology designed to identify Major Accidents To The Environment (MATTE) and improved consequence definitions that can be used in risk matrices to define the severity of an environmental fault. The method has been designed to be compatible with existing Environmental Management Systems (EMS) used in the chemical and nuclear industry.

INTRODUCTION

The six-step screening processes presented in this paper is a development of that proposed by Patterson [2], which was based on a review of potential environmental faults from a large chemical / industrial nuclear facility in the UK.

The application of risk assessment in hazardous industries is now widespread. In the nuclear industry the concept of risk assessment is central to regulation and licensed sites are required to justify continued operation by submission of a risk assessment as part of a Safety Case. The purpose of the risk assessment is to demonstrate that risks from operations are tolerable. Risks are identified, screened and assessed as part of the demonstration of their tolerability.

The consequence analysis, which is a component of risk assessment seeks to calculate the severity of the event if it were realised and for environmental analysis, evaluations are made concerning the following three parameters:

Source. This is where the contaminants originated from and information can be gathered on its size, its form (powder, liquid, gas or solid) and toxicity;

Pathway. This is the route by which the pollutant or burdens can move within the environment either through natural features including streams, groundwater's, air masses or man made feature including, pipes, ducts, surfaces. Pathway can also include ingestion routes and respiratory airways through which pollutants can travel into the organs and tissues of various species.

Receptor. This is the area where pollutants accumulate and this can be a protected species, a lake, river or the tissues of human or animal populations.

SIX-STEP MATTE SCREENING METHODOLOGY

Patterson’s screening process has been refined and developed into a new six-step process. The approach to MATTE identification is based on a review as follows:

1. Desktop review of appropriate documentation:
    - The facility chemical inventory;
    - The approved schedule of faults, for a nuclear licensed site this is found in the Safety Case;
2. Walk-through audit of the facility using the inventory as a guide to identify further environmental hazards.
3. Screening and assessment of identified faults. Fault scenarios that are not screened out are carried forward and the next step applied.

Screening Step 1

Screen out those scenarios that do not impact directly on the environment. The purpose is to remove all scenarios that are non-environmental in consequence. For example a spillage of a chemical in a laboratory that results in the substance remaining contained inside the building is screened out. Although internal spills will result in additional clean-up waste that will have an environmental impact, this should be screened out, as it will not cause immediate damage. Similarly any faults with a safety consequence only (physical injury etc.) are also screened out. If it is not possible for the chemical substance to reach the environment in that particular fault sequence, it should be screened out.

Screening Step 2

Screen out those scenarios that do not involve “dangerous substances”. A definition of dangerous substances is given in Schedule 1, Parts 2 and 3 of the COMAH Regulations [1]. By definition this means that a dangerous substance must be involved somewhere in the fault sequence (initiator, partaker, product, bi-product or pre-cursor).

Screening Step 3

Screen out those substances involving radioactive substances. It is important to note that this step can only be applied to faults that involve radioactive materials and no other hazardous substances. In the UK radioactive substances are covered by other Regulations [3].

Screening Step 4

Assess the chemical inventory involved in the accident to determine if the quantity released could constitute a MATTE or not. Screen out using qualitative arguments those scenarios that do not have the potential to impact on the nearest conservation receptor.

Screening Step 5

Screen out using a more detailed analysis of the accident by characterising the fault in terms of consequence and frequency.

A return frequency of 1 x 10^{-6} yr^{-1} is the likelihood of fault occurring once in 1,000,000 years. This is not considered to be a credible return frequency for classification as a potential MATTE. Any faults that can be shown to have return frequency of <1 x 10^{-6} yr^{-1} are therefore screened out. Consequences are also evaluated in this step, where the frequency is determined to be > 1 x 10^{-6} yr^{-1}. A simple unit release model [4] based on the modelling tool Aermod [5] is considered to be appropriate for assessing atmospheric releases.

For aquatic releases this step evaluates the nature of the fault in detail to determine the amount of material released. Dilution factors are then be applied to calculate receptor concentrations based on worse case assumptions.

For consequence assessment the predicted concentration can be compared with Environmental Quality Standards (EQS) or Environmental Assessment Levels (EAL). In the UK these are published by the Environment Agency (EA) and can be used as a benchmark to assess damage to the environment. Current UK guidance [6] gives figures for routine contributions whereby a release can be considered insignificant if:

Concentration < 0.01 EAL.

This guidance also gives a value for accidental releases. The actual word 'major' is used in the guidance to describe scenarios where the concentration at the receptor site is > 10 x EAL. This value is used in step 5 to evaluate consequence. Scenarios which have a return frequency of > 1 x 10^{-6} yr^{-1} and/or a receptor concentration > 10 x EAL are considered to be potential MATTE.

It is important to note that the purpose of step 5 is to carry out enough analysis to determine that whether the scenario is a potential MATTE. Detailed quantitative consequence modelling is not carried out in this step (see step 6). Organisations operating many sites may have a considerable number of facilities to assess and it is not possible to justify the cost or time necessary to model all scenarios. It is not always necessary to know the exact effects on the environment in order to make a valid judgment about acceptability and industry must be able to prioritise resources for decision-making.

Screening Step 6

This step is used selectively to check the validity of previous scenario assessments by dispersal modelling. Quantitative analysis, using aquatic and atmospheric dispersal modelling software is applied to a selected number (5 – 10 %) of scenarios to validate by consequence that screened scenarios are MATTE.

Prioritisation

Once MATTE faults have been identified, emergency response arrangements can be reviewed for adequacy. As large nuclear/chemical sites have many buildings and facilities, some form of prioritisation over which ones represent the most importance to the site, as a whole is required. The qualifying quantities in the Regulations [1] are used to give a determination of relative harm. The Regulations [1] specify upper and lower limits for the named substances and categories given in Schedule 1 Parts 2 and 3. If the site total holding exceeds one of these limits then it is classed as a lower or upper tier site and specified Regulations [1] apply. The limits reflect the Regulators interpretation on what substances are most harmful. For example the lower tier limit for substances classed as flammable is 5000 Te, whereas for substances classed as explosive this limit is 10 Te and for some particularly dangerous substances including dioxins and carcinogens this limit is only 0.001 Te.

Relative harm is calculated based on these limits for each of the substances, assuming that for the maximum lower tier limit (5000 Te) the corresponding harm index value is equal to one. Therefore by dividing this maximum limit by the other lower tier limits a relative harm value can be calculated. Care must be taken when using these figures to assess risk. The wide-ranging relative harm index suggests a dramatic difference in importance, which, could be misinterpreted and some MATTE faults perceived to be a far greater risk. The relative harm index should therefore be further refined into weighting bands as given in Table I.

Table I. Suggested Scores
For Relative Harm Index Values

Relative Harm Index Range	Harm Score
Above 50000	10
10000-50000	5
1000-9999	4
100-999	3
10-99	2
1-9	1

The application of these harm scores is given in

Table **II** for named substances and

Table **III** for specific categories.

Table II. Relative Harm Scores for Named Substances

Named COMAH Substance	Notification Limit (Te)	Relative Harm Index	Harm Score
Ammonium nitrate	350	14	2
Ammonium nitrate conforming to Fertilizer Regulations 1991.	1250	4	1
Arsenic pentoxide, arsenic (V) acid and/or salts	1	5000	4
Arsenic trioxide, arsenious (III) acid and/or salts	0.1	50000	5
Bromine	20	250	3
Chlorine	10	500	3
Nickel compounds in inhalable powder form (nickel monoxide, nickel dioxide, nickel sulphide, nickel disulphide, nickel trioxide)	1	5000	4
Ethyleneimine	10	500	3
Fluorine	10	500	3
Formaldehyde (concentration $\geq$ 90%)	5	1000	4
Hydrogen	5	1000	4
Hydrogen chloride (liquefied gas)	25	200	3
Lead alkyls	5	1000	4
Liquefied extremely flammable gases (including LPG) and natural gas (whether liquefied or not)	50	100	4
Acetylene	5	1000	4
Ethylene oxide	5	1000	4
Propylene oxide	5	1000	4

Named COMAH Substance	Notification Limit (Te)	Relative Harm Index	Harm Score
Methanol	500	10	2
4, 4-Methylenebis (2-chloraniline) and/or salts in powder form	0.01	500000	10
Methylisocyanate	0.15	33333	5
Oxygen	200	25	2
Toluene diisocyanate	10	500	3
Carbonyl dichloride (phosgene)	0.3	16667	5
Arsenic trihydride (arsine)	0.2	25000	5
Phosphorus trihydride (phosphine)	0.2	25000	5
Sulphur dichloride	1	5000	4
Sulphur trioxide	15	333	3
Polychlorodibenzofurans and Polychlorodibenzodioxins (including TCDD), calculated in TCDD (Tetra Chloro Dibenzo p Dioxin) equivalent	0.001	5000000	10
Specific CARCINOGENS.	0.001	5000000	10
Automotive petrol and other petroleum spirits	5000	1	1

Table III. Relative Harm Scores for Categories of Substances

Specific COMAH Category	Notification Limit (Te)	Relative Harm Index	Harm Score
Very Toxic	5	1000	4
Toxic	5	1000	4
Oxidising	50	100	3
Explosive plus pyrotechnics or explosives contained in an article	50	100	3
Explosive	10	500	3
Flammable	5000	1	1
Highly Flammable Flash point less than 55^{o}c	50	100	3
Highly Flammable Liquids Flash point less than 21^{o}c	5000	1	1
Extremely Flammable	10	500	3
Dangerous to the environment Very toxic to the environment	200	25	2
Dangerous to the environment Toxic to the environment	500	10	2

Reacts violently with water	100	50	2
Liberates toxic gas on contact with water	50	100	3

Once the six-step screening methodology has been applied across the relevant facilities *all* potential MATTE faults for a complete site or facility can be prioritised using these values as a guide. For faults that have been fully characterised in terms of frequency and consequence a 3 dimensional expression of the fault can be mathematically calculated thus:

MATTE Fault Risk = Frequency x Consequence Score x Relative Harm Score

Where frequency is either estimated or modelled in likelihood per year (y^{-1}) and a consequence score given to reflect severity as defined in Table V.

Table IV. Suggested Consequence Scores

Consequence Severity Classification	Score
Catastrophic	5
Critical	4
Marginal	3
Minor	2
Negligible	1

DEVELOPMENT OF CONSEQUENCE DEFINITIONS

Consequence assessment can be based on value judgments or quantitative methods that use mathematical models to work out contaminant migration and the fate of various pollutants in the environment. These models have become very sophisticated using computer programs to predict pollutant dispersal and deposition based on weather patterns. Qualitative methods use various severity classifications to grade consequence based on the extent or the reversibility of environmental damage. An example of these severity bands is given in the Table VI [7].

Table V. Consequence Definitions

Consequence Severity Classification	Definition
Catastrophic	Severe widespread long-term environmental damage (not reversible). Major release of radioactive or chemically toxic material. Radioactive dose to humans, which may result in fatalities.
Critical	Severe localised environmental damage (not reversible). Large release of radioactive or chemically toxic material to the environment. Radioactive dose to humans.
Marginal	Local environmental damage reversible in the short term. Small spillage of radioactive material to the environment. Radioactive dose to humans.
Minor	Minor environmental disruption, minor spillage. Non-Radiological spillage.
Negligible	Trivial damage, no long-term environmental consequence.

These consequence definitions [7] are based purely on the severity of environmental impact and can be used with the screening methodology (screening step 5). A problem with the consequence definition given above is that it is often very difficult to judge if a release of toxic or radioactive material will result in a reversible damage without applying expensive modelling. Also under the critical and marginal classifications, radioactive dose to humans is given as a definition, however even small discharges can give a dose and it is the magnitude of the dose that is important. Again modelling is required to accurately predict dose to critical groups (human or otherwise).

A more sophisticated consequence definition is proposed based on environmental aspects used in management systems. This will link the risk assessment with the EMS with the wider definition of consequence based on business issues (monetary), societal preference (stakeholder concerns) as well as environmental impact.

Environmental accidents result in impacts from either:

- Accidental Releases to Air
- Accidental Releases to Water
- Additional Waste Generation

These are in the main as a result of spillages, fires or explosions.

It is normal practice to apply a significance weighting to environmental aspects in an EMS based on stakeholder concerns, business issues and environmental impact. A typical significance application for a chemical / nuclear site is shown in Table VII.

Table VI. Aspect Significances

Environmental Aspect	Corporate Significance
Releases to Air – Radioactive	High
Releases to Air – Acids	Low
Releases to Air – Volatile Organic Compounds	Low
Releases to Air – Ozone Depleting Substances	Medium
Releases to Air – Beryllium	Low
Releases to Air – Lead	Low
Releases to Air - Combustion by Products	Medium
Releases to Water – Radioactive Effluent	High
Releases to Water – Trade Effluent	Medium
Releases to Water – Domestic Effluent	Low
Releases to Water – Engineered Surface Water	High
Releases to Water – Un-engineered surface Systems	High
Releases of Waste – Radioactive	High
Releases of Waste - Trade Waste	Low
Releases of Waste – Domestic Waste	Low

Based on the information given in the table above more meaningful definitions can be derived for accidental releases, which match the corporate importance placed on different substances.

The revised consequence definitions, are presented in Table VIII.

Table VII. Revised Consequence Definition

Environmental Aspects	Corporate Significance	Definitions	Consequence Severity Classification
Releases to Air – Radioactive	High	Accidental discharge of radioactive material to air, resulting from a fire or explosion. An engulfing fire would need to breach containment systems and result in catastrophic collapse of the building structure.	Catastrophic
Releases to Water – Radioactive	High	Accidental release of water contaminated with radioactive effluent to the surface water systems from a fire or explosion (see footnote).	
Releases to Air – Radioactive	High	Accidental release of radioactive material to air (other than from a fire or explosion).	Critical
Releases to Water – Radioactive	High	Accidental discharge of water contaminated with radioactive effluent to the engineered or un-engineered surface water system.	
Releases of Waste – Radioactive	High	Accidents, which result in the generation of additional R/A waste.	
Releases to Air – ODS & Combustion by Products	Medium	Accidental release of ODS to air from a spillage. Release of combustion by products from a fire or explosion in a building containing chemicals classed as dangerous by the COMAH.	Marginal
Releases to Water – Trade Effluent	Medium	Accidental release of water contaminated with trade effluent to the engineered or un-engineered surface water system.	
Releases to Air – Acids, Volatile Organic	Low	Accidental release of acids, volatile organic compounds, beryllium or lead to air.	Minor

Environmental Aspects	Corporate Significance	Definitions	Consequence Severity Classification
Compounds, Beryllium and Lead. Releases to Water – Domestic Effluent Release of Waste- Trade or Domestic Waste	 Low Low	 Accidental release of water contaminated with domestic effluent to the un-engineered surface water system. Accidents, which result in the generation of additional trade or domestic waste.	
Releases to Water – Domestic Effluent	Low	Accidental release of water contaminated with domestic effluent to the engineered surface water system.	Negligible

A release of radioactive effluent to the un-engineered system (stream, ditch etc.) is considered to be worse than the engineered system (drain, duct etc.) as there is much reduced chance of mitigating the effects by intercepting the contamination in the on-site (engineered) drainage system. Although in a fire situation it is likely that both the engineered and un-engineered systems would be affected by firewater run-off.

CONCLUSIONS

The screening methodology provides a logical sequence for identifying potential MATTE faults. The prioritisation methodology ranks potential MATTE faults by the relative harm posed by the substance involved. Contingency plans can then be developed for these fault scenarios as part of environmental management arrangements. The screening methodology is for the most part qualitative and modelling is only used to confirm by sampling that scenarios are potential MATTE.

The consequence definitions reflect importance and concerns based on business (cost), societal preferences and environmental impact. It is important to note that physical quantities have not been used to differentiate between categories as this is very difficult to calculate without recourse to modelling. It is recognised that as greater quantities of say radioactive material are released to the environment in an accident, the more serious the potential consequence. It is the political reaction however, to any uncontrolled release (even relatively small ones) that will determine overall consequence. This methodology takes account of these concerns. Modelling is very time consuming and expensive and is not considered to be economically viable or indeed necessary for most accident scenario assessment.

The six-step screening method described in this paper will give a transparent and traceable method of identifying potential MATTE faults. The process relies primarily on a review of existing fault schedules and is therefore ideally suited to sites that use risk assessment techniques for hazard identification.

Collectively the application of screening including prioritisation and the improved consequence definitions can be used to give a three dimensional expression of a fault thus:

Fault Risk =Frequency x Consequence Score x Relative Harm Score

The methodology presented in this paper is complimentary to techniques already employed in industry giving refinement in assessing environmental faults.

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