HSE

Health and Safety Executive

An independent review of HSE methodology for assessing societal risk

Prepared by the **Institution of Chemical Engineers** for the **Interdepartmental Task Group on Societal Risk** January 2006

First published 2009

Contents

Appendices

Executive Summary

Following a request from the Interdepartmental Task Group on Societal Risk the Institution of Chemical Engineers (IChemE) undertook a review of the application of Societal Risk Assessment to establishments subject to the Control of Major Hazard Installations Regulations 1999 (COMAH).

The review team was drawn from members of the Institution together with co-opted members, and included members with both academic and industrial backgrounds; the majority with international experience and reputations in both consequence assessment and the application of risk assessment.

Key aspects of the Terms of Reference are given below. (see also Appendix 1)

Purpose

- To provide an independent review of HSE's methodology for assessing societal risk (SR).
- To provide recommendations on how best to assess SR associated with Major Hazard Sites

Terms of Reference

- Are the methods, models and assumptions technically sound?
- Is the approach used by HSE to rank Societal Risk compatible with good practice and 'fit for purpose'?
- To make recommendations on any changes to improve accuracy & robustness

Although the Terms of Reference excluded consideration of criteria the team could not avoid considering the **form** in which the criteria were expressed.

During the course of this review, discussions were held with the UK Chemical Industries Association (CIA) and the UK Petroleum Industries Association (UKPIA). Whilst there is an acceptance of societal risk in the context of COMAH by both of these industry representative bodies, they remain wary of a process that is influenced by political considerations and are concerned that HSE's report "Reducing Risk Protecting People", is unconvincing in this area, i.e. almost any major event will trigger "socio-political" concerns. In addition concerns were expressed that the approach followed in the UK should be consistent with that adopted by other countries (unfortunately the limited time available prevented a full study of this issue).

IChemE's major finding is that the HSE has developed its approach to societal risk in a responsible manner that is, subject to some important concerns noted below, fit for purpose in the context of the current state of knowledge.

IChemE also concludes that it is most important that the engineering profession and industry have a better understanding of HSE's approach to societal risk in order that they can work together to meet the common goal of improved safety. IChemE believes that the following will assist in this aim:

In respect of the first of the Terms of Reference – *are the methods, models and assumptions technically sound?* IChemE finds that:

1. The initial screening tool created by HSE, ARI_{COMAH}, has serious technical limitations and is difficult to understand. In recognising these limitations, HSE has developed a more sophisticated ranking tool QuickFN, which in the Institutions' view should replace $ARI_{COMAH.}$ However, IChemE does not believe that existing ARI_{COMAH} results should be abandoned, and they should continue to be used in deciding the priorities for carrying out QuickFN.
2. In order to improve clarity and transparency, societal risk calculations should be performed without the inclusion of any risk aversion factors and expressed graphically as the cumulative frequency of N or more fatalities occurring at frequency F – called an FN Curve. Any risk aversion should be incorporated into the criteria, and displayed graphically. This will improve clarity and will also enable more direct comparisons with other countries.

The aversion debate needs to be clarified and made explicit. The HSE recognize the need for further discussion with stakeholders on criteria and the way in which risk aversion should be taken into account.

3. The models used by the HSE in QRA and in the calculation of societal risk are technically sound and incorporate many recent developments. In general they are considered 'fit for purpose', although IChemE has some concerns over long distance dispersion.

In respect of the second of the Terms of Reference - *Is the approach used by HSE to rank Societal Risk compatible with good practice and 'fit for purpose'?* IChemE finds that:

4. Quantified Risk Analysis (QRA) is the most effective way to represent the societal risks associated with COMAH installations. However, a full QRA is sufficiently resource intensive to make its application disproportionate for low risk installations and the HSE accepts that such sites may not need to include QRA in their COMAH Safety Reports (this includes those sites with minimal off-site population). The HSE have developed a screening tool, QuickFN, to indicate which sites need to undertake their risk assessments in greater depth. It has also been used by the HSE to indicate where existing off-site development may be a problem. These uses of QuickFN are considered to be wholly appropriate.

5. The HSE uses failure data provided by industry where this has been provided and is seen as credible. In other cases the HSE uses data from its own sources. The 'default' data used by HSE appears to be more pessimistic than that used by other authorities such as those in the Netherlands. Industry bodies have expressed concern that such differences could result in the process industries in the UK being seriously disadvantaged.

   IChemE believes it is in the interests of both the HSE and industry to seek to identify failure rates which have broad support. Frequency data should be urgently reviewed to establish suitable failure rates for equipment engineered and managed to 'best practice'. Alongside the HSE IChemE would recommend the participation of members of other engineering institutions and of industry in this study.

6. Although the dispersion models used by the HSE are comparable with others used in industry there remains great uncertainty about long distance dispersion effects under inversion (stable) atmospheric conditions. This together with current the inclusion of a risk aversion factor in the criteria results in the greatest weight being placed on those parts of the assessment where the uncertainties are the greatest. These technical uncertainties need to be taken into account by those setting criteria.

7. The review team noted the very wide disparity in the calculation of fatalities with different assessments of toxicity. IChemE recognises that this is a difficult area but sees it as one requiring resolution in order to improve compatibility with other European countries using QRA.

8. The calculated risks and effects of accidents should be validated against industry/world experience of accidents associated with handling hazardous materials. For example the predictions of fatalities from chlorine releases appear to be high when set against over 100 years experience in handling this material.

In respect of the third of the Terms of Reference - *to make recommendations on any changes to improve accuracy & robustness,* IChemE believes that:

9. The HSE should bring its guidance on societal risk together into one publication. In addition it should give consideration to the establishment of a process to review its QRA modelling on a regular basis. Such a review should involve both its own staff and members of professional institutions where industry has a voice.

10. The rules used in scenario selection for QuickFN should be clarified. In addition, research should be undertaken to explore methods which could identify those sites where intermediate level events (those affecting the nearby population) could lead to the overall risk being higher than estimated from Quick FN.

The Review Team would like to thank all of those in the HSE, CIA and UKPIA who responded to the many requests for information so quickly. Without their help, IChemE would not have been able to complete its review.

1 Introduction

1.1 The review team comprised members of the Institution together with co-opted members. They were drawn from both academic and industrial backgrounds and all had experience in the application of risk assessment. The team included members with international experience many of whom have published extensively on both consequence assessment and the application of risk assessment.

1.2 The Terms of Reference of the study are attached in Appendix 1. Key aspects of these are

1.3 Purpose

a) To provide an independent review of HSE's methodology for assessing societal risk (SR).

b) To provide recommendations on how best to assess SR associated with Major Hazard Sites

1.4 Terms of Reference:

a) Are the methods, models and assumptions technically sound

b) Is the approach used by HSE to rank SR compatible with good practice and 'fit for purpose'

c) To make recommendations on any changes to improve accuracy & robustness

Note: Although the Terms of Reference excluded consideration of criteria the IChemE team could not avoid considering the **form** in which the criteria were expressed.

1.5 Time constraints did not allow a comparison of HSE's approach to societal risk and those employed by other European countries, although it is recognised that this is an area of concern among industry representative bodies, including CIA and UKPIA.

2 Approach to this review

2.1 The very tight timescale applied to the study precluded any significant original research. The review team therefore asked the HSE to define its approach to the calculation of societal risk. This was subject to critical review by members of the team leading to requests for further information and meetings with HSE technical staff in Bootle.

2.2 In addition, a meeting was held with representatives of the CIA and of UKPIA

2.3 The team were aware that the HSE had prepared a list of the ARI_{COMAH} scores for a number of COMAH establishments. It was decided not to request access to this list in order to concentrate on the methods used in calculating societal risk.

2.4 A list of the documents provided by HSE and used in the study is appended. This indicates which of these are publicly available and which have restricted access.

3 Representation of Societal Risk

3.1 The concept of individual risk is generally well understood and broadly used within the process industries as described in the HSE report 'Reducing Risk, Protecting People (Ref:11). However, individual risk does not, by itself, provide sufficient information to assess those risks where many people could be killed in one incident. This is termed societal risk.

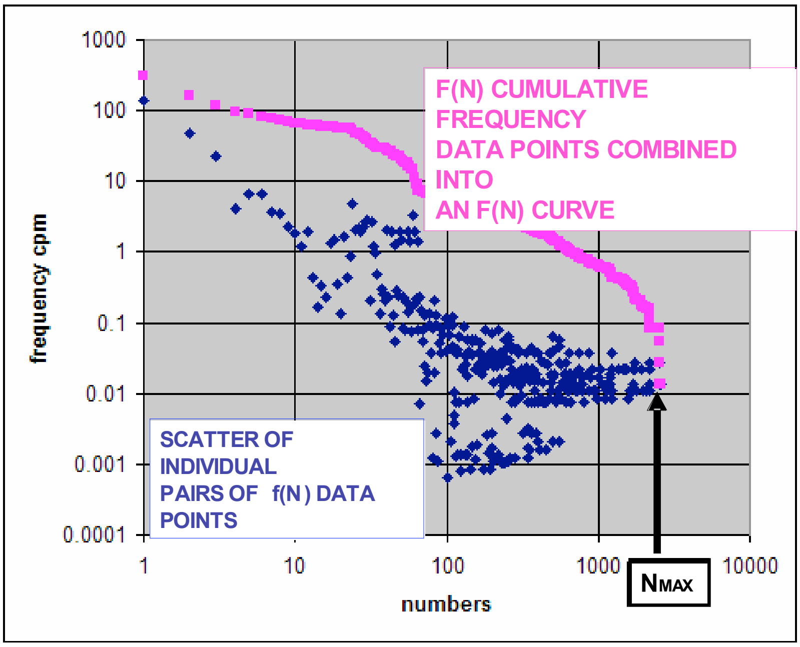
3.2 The most common way, accepted by both HSE and industry, of calculating societal risk is by using methodology based on Quantified Risk Analysis (QRA), with the results expressed graphically or by a Risk Integral (RI).

4 Graphical Representation of Societal Risk

4.1 Two forms of graphical expression can be used:

a) The frequency, f (in chances per million per year – cpm), of an individual event represented by a particular set of circumstances, (release type, wind, weather, etc.) which lead to N fatalities can be plotted. Individual pairs of f-N data are shown graphically on a log-log scale as a scattering of individual points which at the left hand side starts at the frequency of 1 fatality and terminates at its right hand extremity at the frequency of the maximum number of fatalities representing the "worst case" scenario, N_{MAX}.

b) However, to more clearly demonstrate how society in general might regard this concept, the results are more commonly shown graphically, usually on log-log scales, as the cumulative frequency, F (also in cpm), of all circumstances leading to N or more fatalities. Individual F(N) points describe a stepped graph. In practice these are frequently represented as a smooth **FN** curve. This is shown below.



Taken from an internal HSE communication "An Example of the use of Frequency -Consequence Data in Decision Making" David Carter 7.11.05

5 Expectation Values and Potential Loss of Life

5.1 From an individual f(N) point it is possible to calculate the Expectation Value of that event expressed in fatalities per year. The summation of these individual values is the Expectation Value for the whole installation. This is sometimes described as the Potential Loss of Life (PLL) also expressed in fatalities per year. A major use of these values is in determining the cost benefit when implementing risk reduction measures.

5.2 The area under the stepped FN **(**large F**)** curve can also be used to determine the whole installation Expectation Value (EV) or Potential Loss of Life (PLL), expressed as fatalities per year. This produces one figure from the whole curve but in doing so loses much of the information on the changing nature of the risk across the whole spectrum of events.

This single value is also termed the **Risk Integral** by the HSE.

6 Risk Aversion

6.1 If society did not have any aversion to multiple fatality accidents the situation would be described as risk neutral. In other words, society would make no discrimination between the risk of 1 person being killed every year and the risk of 100 people being killed every 100 years.

6.2 However, as can be clearly seen from the public reaction to press and media reports, the outrage generated by road accidents where there are one or two fatalities is generally far less than that generated by a single rail accident event which kills, say, 30 people. IChemE takes the view that, consideration of aversion reflects social concerns and should only be taken into account in setting criteria.

7 HSE Representation of Societal Risk

7.1 HSE has chosen to represent the FN curve in terms of the Risk Integral (RI), a single number that represents the area below the calculated line on the curve, which is used by HSE for ranking of risk and comparison with criteria of acceptability.

7.2 HSE has developed a method in which the weighting for risk aversion is incorporated into the calculation of the RI rather than being represented by a separate criteria line on an FN curve. This approach to including aversion is described by Hirst and Carter [(1),] through the relationship:

$RI_{COMAH} = \sum f(N)\, N^a$, where "a" is a constant used to introduce scale aversion into the RI. If a=1 there is no scale aversion introduced and the value of the RI is exactly the same as that of the EV; if the value of a > 1 then risk aversion is introduced and the RI increases with increasing "a" for a constant EV. The HSE has chosen a value of a=1.4 which they consider to be reasonable in most cases. This is called a **Weighted Risk Integral**.

(The full mathematical justification for this is described by Hirst and Carter [(1)].)

7.3 In developing its approach to societal risk the HSE considered the use of 3 risk bands, Intolerable, ALARP and Broadly Acceptable, similar to those used in R2P2 for individual risk. An official guidance note, SPC/ Permissioning 12, available from the HSE website at the time of the review reflects this 3 band approach.

The HSE have assured us that this is no longer HSE policy.

IChemE believes that the published guidance needs to be clarified as soon as possible.

7.4 IChemE believes that, Risk Integrals, particularly "Weighted Risk Integrals", represent a very complex approach, increasing the possibility of misunderstanding and misinterpretation. The principal advantage of displaying the results of an FN calculation in this form over a graphical representation is that the result is reduced to a single number. However, it is more difficult to explain and understand, it conveys far less information than an FN curve (it cannot, for example, represent medium severity contributions to the curve), it can cloud the link between expert and layman and is unlikely to be followed elsewhere in Europe.

7.5 In safety studies IChemE considers that it is important that those undertaking the work are able to concentrate on the hazards, their causes, the consequences and the way in which they may be controlled. Overcomplicated approaches for risk assessment detract from this and, in addition to taking more time and effort, increase the likelihood of misunderstandings and error.

7.6 IChemE recommends that in order to improve clarity and transparency, societal risk calculations should be performed without the inclusion of any risk aversion factors and displayed in a common form, F (N) curve, not a Risk Integral (RI). Any risk aversion should be incorporated into the criteria and displayed graphically. In addition, IChemE sees benefits in a measure which could be explained and discussed at a site Safety Committee.

8 Societal Risk Tools

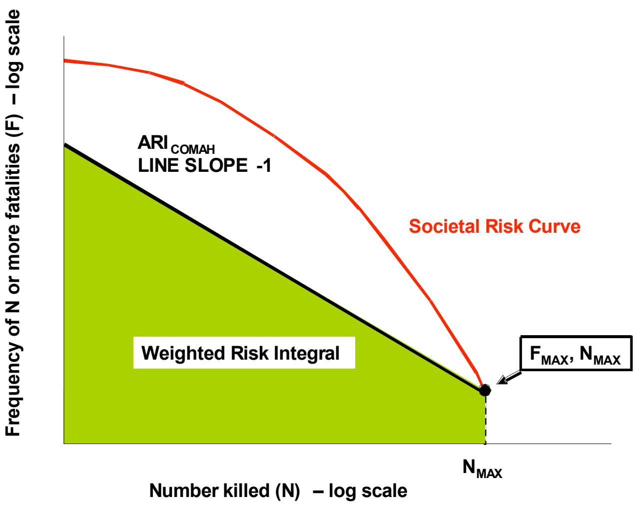
Two methods are used by HSE for ranking and calculating societal risk and comparison with acceptable standards at individual installations.

ARI_{COMAH}

QuickFN

8.1 ARI_{COMAH}

a) ARI_{COMAH}, as described in Hirst and Carter [1] and in the HSE's own ARI_{COMAH} Calculation Workbook. Developed in 2001 it is a simple, approximate 80:20 tool which uses the "single worst case" scenario (the maximum number of fatalities - NMAX at frequency f_{MAX}) together with an assumed slope of -1 from N_{MAX} to describe the whole FN curve. ARI_{COMAH} incorporates a weighted risk integral.



b) On the positive side, it is reasonably simple to calculate and produces one number (Weighted RI) which incorporates risk aversion. However, this approach is seen to have severe technical deficiencies, including:

i) reasons for selection of the "worst case" which can undermine the credibility of the whole approach

ii) this part of QRA is most difficult to estimate with confidence

iii) ARI_{COMAH} is based on assumption that all FN curves approximate to a straight line with a slope of -1. While this may be true for the industry as a whole, it does not reflect reality for a single installation. It does not show "bulges" that may demonstrate a local disproportionate increase in F along a short section of the full FN curve, which may represent the area that is best understood by plant managers for cost effective safety improvements

iv) the way in which risk aversion is incorporated into ARI_{COMAH} is not transparent and is difficult to explain to the non-expert

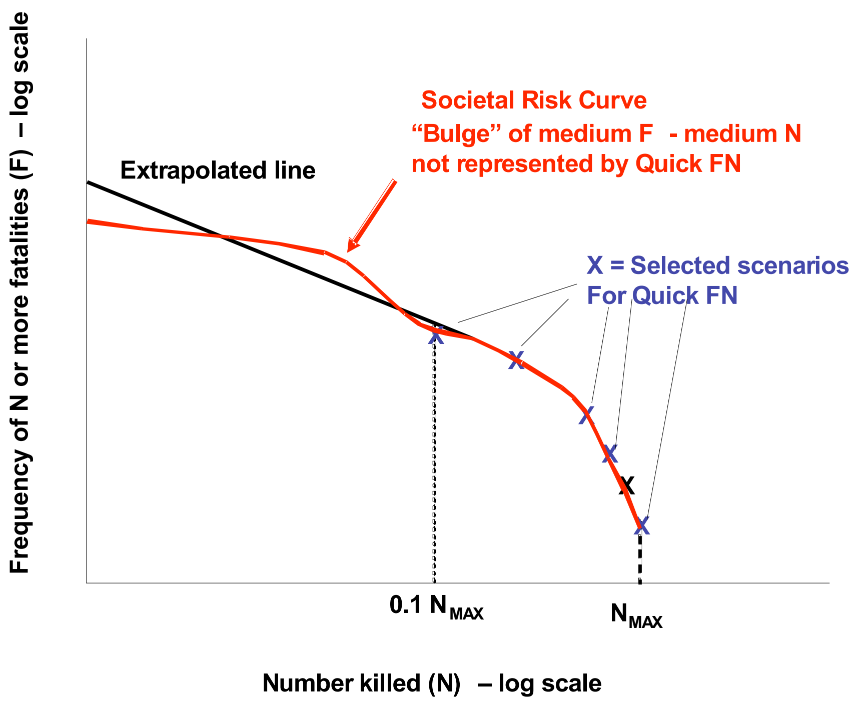
v) it reduces the whole assessment to a single number which only has an indirect reference to criteria

vi) initial time saving in calculation could be outweighed by subsequent discussion

c) IChemE has concluded that the screening current tool, ARI_{COMAH}, has serious technical limitations and is difficult to understand. In recognizing these limitations, HSE has developed a more sophisticated ranking tool called QuickFN, described below, which in IChemE's view should replace ARI_{COMAH}. However, IChemE does not believe that previous work to develop ARI_{COMAH} results should be abandoned, there is sufficient credence in them that they could be used in deciding the priorities for carrying out QuickFN where this is seen to be of value.

8.2 QuickFN

a) QuickFN is a more complex tool than ARI_{COMAH} that is based on detailed QRA's carried out on a number of representative installations. It uses a number of scenarios occurring between N_{MAX} and 0.1 N_{MAX} that are specific to the hazardous material and type of installation (storage, processing) to define the low F, high N part of the FN curve. A line of slope -1 is used to complete the F(N) curve back to the F axis from the tangent of the calculated curve (not the upper point on the calculated curve). This approach is described in the HSE Research Report 283 "Development of an intermediate societal risk methodology" prepared for the HSE by ERM Risk Ltd. In 2004.



On the positive side, QuickFN removes some, but not all, of the uncertainties of ARI_{COMAH}, and is far quicker and less costly than a full QRA. However, it has similar shortcomings to ARI_{COMAH} in relating the result in terms of the shape and slope of the complete F(N) curve, particularly in the area of medium frequency events which may dictate the area of the F(N) curve where managements may find greatest cost effectiveness in making safety improvements (similar point to that made against ARI_{COMAH})

The rules used in scenario selection for QuickFN should be clarified.

IChemE would also recommend that research be undertaken to explore methods which could identify those sites where intermediate level events (those affecting the nearby population) could lead to the overall risk being higher than estimated from Quick FN.

8.3 Full Quantified Risk Analysis

b) A Full QRA considers all scenarios without pre-selection, which removes the uncertainties of ARI_{COMAH} and QuickFN. Full QRA's show the structure of where high F and N conditions exist, and cover both on-site and off-site risks.

c) However, they are far more costly and resource intensive than ARI_{COMAH} or QuickFN, and require skills/expertise which may not be available in smaller companies. In addition, Full QRA may not be appropriate for low hazard and/or low risk installations where the resource requirement is disproportionate to the societal risks presented by the installation.

d) However, a societal risk screening tool based on QRA to assist HSE in deciding where it should direct its efforts to improve safety on COMAH sites is considered to be wholly appropriate.

9 Scenario Selection

9.1 For ARI_{COMAH} only one scenario is selected, either the worst case from the Safety Report or one prepared by the HSE. QuickFN requires between 5 and 14 scenarios (chlorine – 5; LPG distribution – 14).

9.2 It is recommended that the HSE undertake further work to define rules for scenario selection in order that QuickFN can be better understood by industry.

10 Multi-installation sites/Domino effects

10.1 ARI_{COMAH} and QuickFN are applied by HSE on a single installation basis only, i.e. on the "worst case" scenario on the "worst case" installation, with the worst ARI_{COMAH} on a single establishment (site) taken for ranking. No attempt is made to collate risks across multiple installations within a single establishment or to rank a whole industrial complex. Furthermore, the interpretation of "installation" remains unclear.

10.2 HSE state that expert judgment is used where the likelihood of domino effects is significant. IChemE considers this to be a reasonable approach given the inherent uncertainties and complexities.

11 Consequence Modelling

11.1 Having identified a number of scenarios these need to be investigated in order to estimate the consequences. A range of mathematical models are available to assist in this process and IChemE has assessed the models used by the HSE against those developed and used by industry and by consultants.

Consequence models are used for the following steps

a) Source term modelling

b) Jet fire

c) BLEVE

d) Flash fire

e) Vapour cloud explosion

f) Toxic gas dispersion

12 Source Term modelling

12.1 Source term models are used to cover the following steps involved when gases or liquids are released from process equipment

a) the initial release from the equipment

b) creation of vapour by flashing

c) aerosol formation

d) droplet rainout

e) pool formation

f) pool evaporation

12.2 The models used by the HSE incorporate findings from experimental work, such as the RELEASE programme. Evaporation from pools is calculated using a thermodynamic model.

12.3 These are considered ‘fit for purpose’ within the present state of knowledge.

13 Jet Fire

13.1 Jet fires may arise when a gas is released from equipment under pressure and finds a source of ignition. The models used by the HSE are considered ‘fit for purpose’

14 BLEVE (Boiling Liquid Expanding Vapour Explosions)

14.1 BLEVEs, commonly called fireballs, can occur when a pressure vessel storing liquefied flammable gases under pressure fails due to external heating.

14.2 The models used by the HSE to represent the effects of BLEVEs use well established correlations and are considered ‘fit for purpose’.

15 Flash Fire

15.1 Flash fires arise when a flammable gas is released and spreads by dispersion to cover a large area before finding a source of ignition. To model these HSE use a dense gas dispersion model with the limits of the flammable cloud being assessed as the lower flammable limit. A cloud ignition model based on population density is then applied to assess both the likelihood of ignition and the cloud spread at the point off ignition.

15.2 The approach used by the HSE is considered ‘fit for purpose’.

16 Vapour Cloud Explosion

16.1 If the flammable gas cloud formed by a large release is ‘contained’ within a process structure before ignition a vapour cloud explosion may occur. This can lead to substantial overpressures with damage to structures both on and off site.

16.2 The modelling of explosion overpressure by the HSE is based on the Multi Energy method developed by TNO. This is considered a suitable model which recognises the importance of confinement as one of then prerequisites in explosion overpressure.

16.3 The approach used by the HSE is considered ‘fit for purpose’.

17 Dense Gas Dispersion

17.1 Many toxic gases are denser than air, either because of their molecular structure or because of their low temperature following release. Since the 1970’s a number of models have been developed to represent the way in which these clouds behave. As well as the conditions of the release the spread of the cloud is dependent on the weather conditions and wind speed.

17.2 The HSE risk assessment tool Riskat incorporates the models DENZ and CRUNCH which were developed in the 1970’s by AEA technology. Since then updates have been applied.

17.3 The models were validated against the Canvey Island trials.

17.4 A comparison of heavy gas dispersion models for instantaneous releases reported in the ‘Journal of Hazardous Materials in 1994 (Ref 10) noted:

a) In general model predictions of concentration and width are within a factor of 3-5.

b) Differences are more substantial at low wind speeds.

c) Major differences occur for releases at low wind speed and Pasquil stability category F (stable) conditions

17.5 A more recent study carried out by WS Atkins for the HSE (Ref 13) included a review of gas dispersion modelling. A simple chlorine installation was studied and the effects of using different dispersion models explored. See table below

Table 4.3 Societal Risk Measures for Various Dispersion Models

Dispersion Model	N_{max}	PLL	RI_{COMAH}	RI_{LUP}
D1 - HGSYSTEM	2,900	$2.43x10^{-3}$	33,000	1,140,000
D2 - DRIFT	3,860	$2.25x10^{-3}$	34,500	1,390,000
D3 - GASTAR	648	$6.71x10^{-4}$	4,780	60,800
D4 - PHAST	923	$9.81x10^{-4}$	7,660	110,000
D5 - CRUNCH and DENZ	1,580	$1.00x10^{-3}$	10,400	236,000
D6 - SLUMP	914	$1.17x10^{-3}$	10,400	183,000
D7 - SLAB	3,640	$2.51x10^{-3}$	40,700	1,780,000
D8 - TNO Yellow Book (1979)	1,000	$5.18x10^{-4}$	4,550	81,200

One of the principal conclusions was that the simple box models such as SLUMP, CRUNCH & DENZ (used by the HSE) appear to predict lower levels of risk (particularly at medium to high N) than some of the more sophisticated models such as DRIFT & HG SYSTEM.

17.6 In 1994 the EU recognised the importance of dense gas dispersion in safety studies and in 2000 (Ref: 15) authorised an international project SMEDIS to compare model predictions. The HSE contributed to this project but unfortunately the results of the study are still not available

17.7 For Quick FN three envelopes are calculated corresponding to fatal levels of Toxicity of 50%, 10% and 1% which are then combined with information on population density and weather. This is described in more detail in the report produced by ERM (Ref 5).

17.8 The report on the Uncertainty in Societal Risk Calculations (Ref 13) compared this approach with others, both more and less detailed, and concluded that 3 envelope method produces results comparable with others.

17.9 The models used by the HSE are considered ‘fit for purpose’ although IChemE notes that at the present time there is insufficient experimental work and expertise to define with confidence long range heavy gas dispersion under stable conditions.

18 Weather data

18.1 The modelling of gas dispersion requires information on

- Wind direction
- Wind speed
- Atmospheric stability (Pasquil category)

18.2 In the absence of site specific data, information from the nearest airport with full meteorological records is used. A study commissioned by HSE indicated that the use of a greater number of smaller segments to represent the weather data would not result in significant changes to the calculated societal risk.

19 Topography

19.1 The dispersion models assume a flat landscape.

19.2 The HSE reported verbally that tests using Computational Fluid Dynamics (CFD) have shown the effect of topography to be no greater than many of the other variables involved in risk assessment.

19.3 Whilst it may be possible to take topography into account in the future the approach is consistent with that used by others.

20 Vulnerability & Damage

Once the consequences of an incident have been calculated it is necessary to evaluate the effect on people. Such effects could either be directly, through thermal radiation or toxicity or indirectly through the collapse of a building.

20.1 Fire & Explosion

a) The correlations used for effect of thermal radiation from BLEVEs have been reviewed and are seen as fit for purpose.

b) The approach used to estimate the effects on people of being engulfed in a flash fire are seen as fit for purpose.

c) The correlations used by the HSE for the effects of explosion overpressure are seen as fit for purpose.

20.2 Toxicity

a) There have been very few accidents involving large releases of toxic gases. This makes the assessment of toxicity very difficult. Data from a number of sources, including small mammals, has to be combined and then a judgement made on its applicability to man. Probit equations are not used by the HSE.

b) As noted above in QuickFN the HSE use a 3 envelope approach to estimate the effects of toxic gases. Toxicity is represented by ‘cautious best estimates’ of

(i) Lethal Dose,1% LD 1, (Dangerous dose)

(ii) Lethal Dose 10% LD 10 (SLOT)

(iii) Lethal Dose 50% LD 50 (SLOD)

c) The methods used by the HSE have been described in the literature and all values have been published by the HSE

d) A Study by WS Atkins, (ref 13) studied the effect of different representations of toxicity on the societal risks associated with a simple chlorine storage installation. See table below

Table 3.5 Societal Risk Measures for Various Toxicity Approaches

Toxicity Approach	N_{max}	PLL	RI_{COMAH}	RI_{LUP}
T0 - SLOD approach	1,870	1.22×10^{-3}	12,900	318,000
T1 - 3 Envelope approach	2,150	1.21×10^{-3}	13,100	339,000
T2 - TNO Purple Book (1999) probit	594	5.74×10^{-4}	3,910	45,400
T3 - Franks, Harper & Bilo (1996) probit	2,430	1.46×10^{-3}	16,700	468,000
T4 - TNO Green Book (1992) probit	375	5.18×10^{-4}	3,250	31,700
T5 - van Heemst (1990) probit	263	3.76×10^{-4}	2,100	17,500
T6 - ACDS (1991) probit	1,380	1.03×10^{-3}	9,520	186,000
T7 - Zwart & Woutersen (1988) probit	175	2.07×10^{-4}	1,060	7,950
T8 - Withers & Lees (1985) probit	789	7.34×10^{-4}	5,600	77,700
T9 - Eisenberg, Lynch & Breeding (1975) probit	9,200	5.73×10^{-3}	129,000	9,250,000
T10 - IChemE (1989) LC50 dose criterion	219	3.99×10^{-4}	2,280	19,000

e) As can be seen the different values for toxicity have a very pronounced effect on the calculation of fatalities and societal risk. This is accentuated if a weighted criteria is used. There are significant differences between the approach used by the HSE & those used by other authorities, particularly in Holland, which indicate much lower levels of societal risk under similar circumstances.

f) IChemE recognises that this is a difficult area but see it as one requiring resolution in order to increase confidence in QRA. This will be important if industry is required to make significant changes to facilities.

g) The European Union has sponsored a project 'ACUTEX' to determine toxicity values for a range of chemicals. The project has broad support with participants from authorities in a number of countries, from national research organisations and from industry bodies. HSE is a significant partner in this project. The project is expected to report in the next few months. Once available IChemE recommends that the HSE consider the use of AETL approach to assess toxicity

21. Population at Risk

21.1 Population data is obtained from data sources prepared for the HSE and covers

a) Residential population

b) Industrial population

21.2 The following population spread is assumed

a) Day time 10% outdoors, 90% indoors

b) Night time 1% outdoors, 99% indoors

21.3 Special consideration is given to premises such as

a) Schools, hospitals, retail outlets, sports grounds etc

b) The way in which commercial/ industrial populations is handled depends on the data available.

21.4 IChemE endorses the approach followed by the HSE and see it important that Societal Risk calculations should account for **all** exposed populations (residential, public, commercial and industrial).

22 Mitigation

22.1 While on-plant mitigation was not generally taken into account in screening using ARI_{COMAH} and QuickFN, the mitigation provided by fixed water sprays was taken into account in the QuickFN study of an HF Alkylation facility.

22.2 The modelling of toxic gases takes into account the protection offered by being inside a building through a simple infiltration model.

22.3 A 15km cut-off is applied to toxic gas dispersion on the basis that under stable (F2) conditions it would take a cloud 2 hours to cover this distance during which time some protection measures should have been put in place. IChemE is concerned as to whether effective evacuation at this distance can be carried out but recognise that there are problems in modelling at these distances.

22.4 IChemE recommends that for QuickFN the HSE specify under what conditions mitigation measures can be taken into account.

23 Failure Rates

23.1 HSE uses a mixture of historical (generic) and calculated failure rates (derived from fault trees). Both approaches have limitations.

a) The very low failure rates means that generic data has to be prepared from pooled studies of items of different ages, different management regimes etc.

b) Fault trees are critically dependent on assumptions made by the analyst.

c) Generic data often provides more consistent results.

23.2 However HSE has not been prescriptive in the use of this data and has used frequency and consequence data from companies' own safety reports where this was available and appeared to be well-founded, even though a conflict with HSE's own data might be inferred. HSE's own data has been used where the information was not in safety reports.

23.3 The 'default' failure frequencies used by the HSE are defined in its report PCAG, 6K, 'Failure rate and event data for use with risk assessment'. This has not been published but has recently been made available on request under the Freedom of Information Act. IChemE has studied some of the data. It was reported that much of the basic data could be traced back to studies carried out in the 1970's, although some updating has taken place since then.

23.4 Following the preparation of the IChemE teams preliminary conclusions the HSE introduced a review of the failure data carried out by AEA Technology in 2001. IChemE has studied parts of this report, concentrating on the data for the following equipment

a) Pressure vessels

b) LPG pressure vessels

c) Chlorine pressure vessels

(The reason for this is that the studies carried out in the development of QuickFN indicated that pressure vessel failures dominate the high N, low frequency part of the risk curve)

23.5 In its report AEAT noted

a) The recommended generic failure rate values in FRED are for the most part reasonable based on the data available.

b) The comparison of FRED data with data from the AEA Technology Data Centre almost exclusively shows the AEA Technology data to be pessimistic in relation to FRED data. This is more prevalent when comparing FRED data to field specific data from the Component Reliability Databank.

23.6 The specific data on pressure vessels included in the AEA data bank was found to be very limited and the AEA technology conclusions appear to be based on a number of other references which were not quoted in detail and could not be checked. Until the sources can be made available IChemE believes that the AEAT conclusions need to be treated with caution.

23.7 Based on a limited amount of data provided by the HSE on the failure of pressure vessels, the data used by HSE is significantly different to, and on initial inspection more pessimistic, than that used by other authorities, such as those in the Netherlands.

Pressure Vessel Failure Rates

Summary based on figures provided by HSE (Appendix 1)

Failures rates per 10 6 vessel years

	UK	Netherlands	Finland	USA
	Note 1	Note 2	Note 3	Note 4
Catastrophic failure full contents	2	0.5	0.88 to 10000	1.2 to 370
Catastrophic failure half contents	2			
Liquid space 50mm hole	4			
Liquid space 25mm hole	4			
Liquid space 13mm hole	8			
Total	20	0.5	NA	NA

Note 1 : Failures contributing to Quick FN Chlorine storage cases 1 & 2.
Note 2 : Guidelines for Quantitative Risk Assessment. (1999)
Based on exclusion of many specific failure modes.
Frequency with which complete inventory is released should never be less than 1 x 10-7. Higher rates for process vessels and reactors.
Note 3 : Figures from database, based on one referenced study and other anonymous reports..
No indication on figures commonly used.
Note 4: CCPS Guidelines on Process Equipment Reliability Data, (1989)
No indication on figures commonly used.

Industry bodies have expressed concern that such differences could result in the process industries in the UK being seriously disadvantaged. One way of resolving this is would be to publish data with explicit confidence levels.

23.8 In reaching their conclusions both the HSE and AEA technology have necessarily based their conclusions on equipment and records which could be 20 years old or even older.

Since then there have been many changes in the management of process equipment.

a) Improvements

- Improvements in inspection techniques, especially non invasive inspection
- Improvements in the design of relief systems and of other protective systems
- Requirements under COMAH for
  - Rigorous hazard identification
  - Implementation of appropriate preventative and protective measures
  - Implementation of process safety management systems
- Learning from accidents

b) The following changes may have had unintended consequences in offsetting some of the above improvements.

- Reductions in manning
- Greater use of contractors for maintenance

On balance IChemE would expect the positive features to outweigh the negative, the most important change being the introduction of COMAH with its emphasis on improvements in process safety management. Since the HSE has considerable powers under this legislation to insist on improvements it seems reasonable to expect that overall the standards of operations and maintenance will be significantly better than in the past.

23.9 IChemE believes it is in the interests of both the HSE and industry to seek to identify failure rates which have broad support. It is therefore appropriate that industry has an opportunity to participate in a review of the failure rates in order that its own experience can be taken into account.

23.10 Frequency data should be urgently reviewed to establish suitable failure rates for equipment engineered and managed to ‘best practice’. Alongside the HSE, IChemE recommends the participation of members of other engineering institutions and of industry in this study.

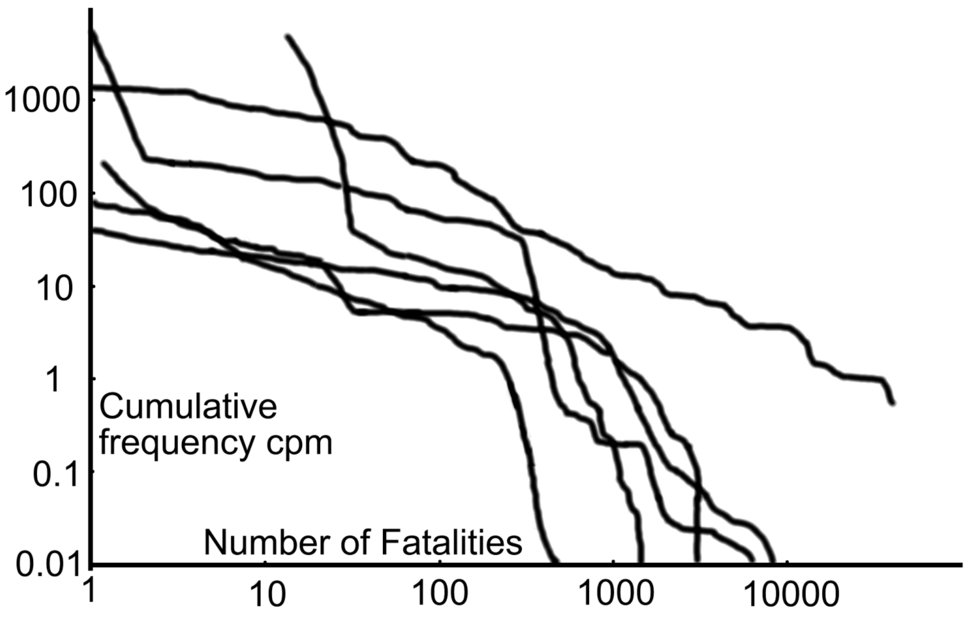
IChemE would also like to see schemes, such as that for offshore data collection OIR12, extended to other industries with failure data being collected, analysed and updated on a regular basis.

24 Benchmarking

24.1 Benchmarking QRA Methods

a) In 1998, the European Union sponsored a benchmarking exercise ‘Assurance’ with teams from seven European countries participating in the study. Each team carried-out a full quantified risk assessment of an ammonia marine offloading and storage facility.

b) The results demonstrate one of the principal weaknesses of QRA with the predicted frequencies of a defined level of fatalities ranging between 2 and 4 orders of magnitude. (see below)



c) The main conclusions drawn by the HSE team participating in this study were:

(i) For both Individual Risk and Societal Risk calculations, the HSE assessments were generally within the range of the results of others and somewhat less cautious than most i.e. Consultation Distances would be smaller

(ii) Uncertainty is a significant factor. Member States need to continue to cooperate to ensure best practice (and emphasizes the importance of continuing to contribute to TWG 5)

(iii) Considering the degree of variability of approach, the inclusion of detailed site specific features is unlikely to be significant in terms of the overall uncertainty of the assessment. This would support a more generic approach to QRA in the UK

d) Unfortunately, apart from noting that the HSE was in the middle of the assessments, the HSE did not feel able to identify which of the FN curves corresponded to the HSE assessment.

e) IChemE believes that other countries using QRA for the control of major hazards have assessment methods which lie towards the lower band of predictions and IChemE would see value in more detailed comparison of the methods used across Europe. In several cases this could be accomplished using published assessment methods.

24.2 Benchmarking of Consequence Assessment Models

a) The HSE have sponsored a study by ERM (Ref 5). Part of this study included the benchmarking of the consequence assessment methods used by the HSE in QRA. The study compared reported consequences and fatalities for a number of selected case studies against those predicted using HSE consequence models.

b) IChemE believes that there would be value in further benchmarking of HSE's methods for calculating the effects of toxic gas releases against industry/world experience of accidents associated with these materials. For example the predictions of fatalities from chlorine releases appear to be very high when set against over 100 years experience in handling this material. This benchmarking should also take account of the large releases which have actually occurred in the transport sector which did not result in large numbers of fatalities.

25 Transparency

25.1 Whilst the terms of reference state that criteria were outside the scope of the review the fact that some parts of the criteria are incorporated into the way in which ARI_{COMAH} is calculated made it impossible to avoid this aspect.

25.2 IChemE found it was difficult to obtain a full view of HSE's approach to societal risk which is spread across several documents.

a) HSE's major report on risk assessment, 'Reducing Risk, Protecting People', (Ref 11) includes limited references to societal risk. It provides one value for the maximum frequency of accidents which could result in 50 or more fatalities. The report also includes a general statement on risk aversion. It does not however provide any detailed guidance on how the HSE takes risk aversion into account in assessing societal risk.

b) The paper prepared by Hirst & Carter (Ref 2) in which ARI_{COMAH} is described also outlines the way in which the criterion for ARI_{COMAH} can be calculated. The paper shows criterion lines on an F(N) diagram and indicates that the ARI_{COMAH} value for the top line is 500,000 and for the lower line 2,000. These are described as '***F-N example criterion lines'*** without any indication as to whether they are definitive figures. The paper was submitted to an academic journal and was not subject to the same degree of study by industry bodies as an HSE consultation document.

c) The COMAH Guidance Note (Ref 14), available from the HSE website, states that the criterion lines for societal risk have a slope of -1 on an FN plot. It includes the figures for ARI_{COMAH} criteria noted above, with the value of 500,000 shown as the boundary between tolerable and intolerable (sites of concern).

IChemE understands that this approach is no longer HSE policy and that ARI_{COMAH} values are used for guidance only

25.3 IChemE found that the degree of mathematical manipulation involved in linking the F(N) curve with the values for the criterion confusing and it took two meetings before the whole review team had a thorough understanding of HSE's approach to societal risk and risk aversion.

25.4 In general the HSE has very high standards of communication but IChemE found that the papers presented to us on this important topic failed to meet these.

25,5 The setting of criteria is an issue which requires support from across a wide range of stakeholders. To avoid misunderstandings IChemE considers that it is important that the issue is described as simply and succinctly as possible.

25.6 In order to carry-out this review of the HSE's approach to societal risk, IChemE consulted documents from a wide range of different sources. These were brought to the teams attention by HSE staff and without this help the review would have been far more difficult and time consuming. Other countries, notably Holland, have brought their guidance on Quantified Risk Assessment together in one place. IChemE recommends that the HSE consider this approach with the production of a document describing:

a) The methods used by the HSE to calculate societal risk

b) The mathematical models used and their availability

c) The assumptions included in the methods

d) The data used and its sources

e) The basis of the criterion

25.7 In addition IChemE recommends that the HSE should give consideration to the establishment of a process to review its QRA modeling on a regular basis, involving both its own staff and members of professional institutions.

26 Views of Industry

26.1 As noted earlier, with the support of the HSE, IChemE held meetings with representatives of the CIA and the UKPIA. Both groups welcomed the review and listed the following concerns related to the application of Societal Risk.

26.2 Those concerns addressed by this review are shown in italics. IChemE sees others as outside the Terms of Reference.

a) Occupational risk (Individual Risk) is well understood and accepted in the process industries.

b) Acceptance of Societal Risk in the context of COMAH, but wary of a process that is influenced by political considerations. Concern that R2P2 could be used as a socio-political statement.

c) General public are more reluctant to accept risks they are unable to control

d) There is a high level of concern over any event that could affect the public.

e) Understanding of risk aversion and societal risk are not well established

f) Concern that the aversion debate is heavily politically driven

g) Dilemma - if the CD (Consultation Distance) is too large it slows the planning process and imposes land blight, if too small it allows encroachment that can lead to future demands for increased risk reduction measures and limitations on future development

h) Clarity is requested – frustrated by a lack of transparency and attempts at validation

i) Societal risk goes beyond safety and must take account of demands on the environment and local employment

j) The ability to know what is required, and to ensure a level playing field (particularly in Europe)

k) Worried about companies being obliged to carry out QRA. QRA is more likely to be acceptable if methods and data are transparent and peer reviewed. Discussion around quality of data and the suggestion on the use of error bars to increase acceptability.

l) *Scenario selection to determine N_{MAX} ; discussion around selection of scenario's for QuickFN between N_{MAX} and 0.1 N_{MAX} as these do not reflect industry experience of major accidents.*

m) Decisions on COMAH need to be compatible with those on LUP.

27 Findings

The following findings, which include recommendations, are aimed at simplifying the way in which societal risk is displayed and seeking greater communication between the HSE, industry and professional bodies.

27.1 It is most important that the engineering profession and industry have a better understanding of HSE's approach to societal risk in order that they can work to meet the common goal of improved safety. IChemE believes that the following will assist in this aim.

27.2 IChemE recognises Quantified Risk Analysis (QRA) as the most effective way to represent the societal risks associated with COMAH installations. However, a full QRA is sufficiently resource intensive to make its application disproportionate for low risk installations and the HSE accepts that such sites may not need to include QRA in their COMAH Safety Reports. The HSE have developed a QRA based screening tool, QuickFN, to indicate which sites need to undertake their risk assessments in greater depth. This has also been used by the HSE to indicate where existing off-site development may be a problem. These uses of QuickFN are considered to be wholly appropriate.

27.3 The initial screening tool created by HSE, ARI_{COMAH}, has serious technical limitations since it extrapolates from the point of maximum uncertainty and is difficult to understand. HSE has recognised this limitation and has developed QuickFN. In IChemE's view, the use of ARI_{COMAH} should be abandoned and replaced by QuickFN, which is believed to be fit for purpose. However, IChemE does not believe that previous work to develop ARI_{COMAH} results should be abandoned, there is sufficient credence in them that they could be used in deciding the priorities for carrying out QuickFN where this is seen to be of value.

27.4 In ARI_{COMAH} risk is represented by an integral which is weighted to incorporate risk aversion. This makes it very difficult to understand and compare with the approaches used in other countries.

a) In order to improve clarity and transparency, societal risk calculations should be performed without the inclusion of any risk aversion factors and displayed in a common form of cumulative frequency of N or more fatalities F(N) curve. Any risk aversion should be incorporated into the criteria.

b) IChemE sees this approach as providing a better appreciation of the risks as well as being more understandable to a range of stakeholders including site safety committees.

c) Whilst risk integrals are of value in cost benefit calculations IChemE does not see them as appropriate for comparison with criteria.

d) The criteria to be applied are outside the TOR of this review but require further discussion covering a range of issues including risk aversion and comparability with other high risk industries.

27.5 The models used by the HSE in QRA and in the calculation of societal risk are technically sound and incorporate many recent developments. In general they are considered 'fit for purpose' although IChemE has some concerns over long distance dispersion (see 27.10 below)

The HSE use failure data provided by industry where these have been provided and are seen as credible. In other cases the HSE uses data from its own sources. The 'default' data used by HSE appears to be more pessimistic than that used by other authorities such as those in the Netherlands Industry bodies have expressed concern that such differences could result in the process industries in the UK being seriously disadvantaged.

IChemE believes it is in the interests of both the HSE and industry to seek to identify failure rates which have broad support. Frequency data should be urgently reviewed to establish suitable failure rates for equipment engineered and managed to 'best practice'. Alongside the

HSE, IChemE recommends the participation of members of other engineering institutions and of industry in this study.

27.6 The review team noted the very wide disparity in the calculation of fatalities with different assessments of toxicity. IChemE recognises that this is a difficult area but see it as one requiring resolution before operators can be expected to make major changes to their installations.(see also item 27.8, re. chlorine, below)

27.7 The calculated risks and effects of accidents should be validated against industry/world experience of accidents associated with handling hazardous materials. For example the predictions of fatalities from chlorine releases appear to be very high when set against over 100 years experience in handling this material.

27.8 The rules used in scenario selection for QuickFN should be clarified & the technique improved through the inclusion of a limited number of points representing the full spectrum of events. This should not necessarily increase the amount of work required to undertake a QuickFN calculation.

27.9 Although the dispersion models used by the HSE are comparable with others used in industry there remains great uncertainty about long distance dispersion effects under inversion (stable) atmospheric conditions. This together with current uncertainties on failure rate data and the inclusion of a risk aversion factor in the criteria results in the greatest weight being placed on those parts of the assessment where the uncertainties are the greatest. These technical uncertainties need to be taken into account by those setting criteria.

27.10 The HSE should bring its guidance on societal risk together into one publication. It should also give consideration to the establishment of a process to review its QRA modelling on a regular basis, involving both its own staff and members of professional institutions

APPENDIX 1 – TERMS OF REFERENCE

SOCIETAL RISK – MAJOR ACCIDENT PREVENTION AND LAND USE PLANNING

These Terms of Reference were amended and agreed by the Cabinet Office.

Purpose of Project

To provide:

- An independent review of HSE's methodology for assessing societal risk (including ARI_{COMAH} and Quick FN processes).
- Recommendations, to be put to the Inter-departmental Task Group on societal risk, on ways in which HSE's existing methodology might be modified to address any shortcomings, and the impact such modifications would have on the assessment of societal risk associated with major hazard sites.
-

Terms of Reference

1. To consider to what extent the methodology, including the analytical tools and the assumptions that underpin it, is technically sound and technically appropriate to the task it is being used for.
2. To consider whether the approach taken by HSE in applying that methodology to rank societal risk and to allow comparison with a standard (itself outside of the terms of reference), is broadly compatible with good practice, and "fit for purpose".
3. If necessary, to consider what changes could be made using currently available information to improve the accuracy of the analysis and/or to improve the robustness of the methodology.

Process:

4. The review should involve the engagement of independent experts to comment on elements of the methodology, and should be carried out in consultation with key stakeholder groups. While the review process should be, and be seen to be, impartial, independent and authoritative, the findings need to generate practical advice to Government.
5. This work should be undertaken under conditions of strict confidentiality, and this should include all those contacted by the review team.

Output:

A report describing the review and containing recommendations to be produced before 31October 2005.

Note: at the time the TOR's were discussed with the Review Team, it was agreed with HSE that the team would present the outputs, as described above, to a meeting of their managers and specialists on 31 October 2005. This presentation as made, after which the HSE stated that the Review Team had met the timing conditions for reporting back. A process of HSE review and feedback prior to finalising the report was agreed.

APPENDIX 2 – TEAM MEMBERS

Dr. Mike Considine

Chairman, Safety & Loss Prevention Subject Group, IChemE; Member of European Federation of Chemical Engineers Loss Prevention Working Party.

Mr. Robin Turney

Chairman, Loss Prevention Panel, IChemE; Member of European Federation of Chemical Engineers Loss Prevention Working Party.

Mr. Richard Gowland

Director of Centre, European Process Safety Centre (EPSC)

Prof. Stephen Richardson

Imperial College

Prof. Nilay Shah

Imperial College

Dr. Geoff Chamberlain

Shell Global Solutions; Visiting Professor Loughborough University.

Mr. John Atherton

Secretary, Safety & Loss Prevention Subject Group, IChemE

REFERENCES

LIST OF DOCUMENTS PROVIDED BY HSE

1. Copy of presentation made by David Cater to the Review Team at HSE Rose Court 29 September 2005
2. A "worst case" methodology for obtaining a rough but rapid indication of the societal risk form a major accident hazard installation, Hirst and Carter, Journal of Hazardous Materials, A92 (2002), 223-237
3. Methods of determining risks from major accident hazard installations, Reston, Maddison, Fowler and Lawton.
4. The ARI_{COMAH} Workbook, HSE, created 08/09/2003
5. Development of an intermediate societal risk methodology – an investigation of FN curve representation, HSE Research Report 283 prepared by ERM Risk Ltd, ISBN 0 7176 2917 1
6. Sensitivity analysis using Quick FN, HSE internal document
7. Quick FN validation exercise, HSE internal document
8. HSE Planning Case and Assessment Guide (PCAG), list of contents and Chapter 6K: Failure Rate Data for use within Risk Assessments.
9. Toxicology of Substances in Relation to Major Hazards, HSE, HMSO for: H2S – 1990, HF – 1993, ammonia – 1990, acrylonitrile – 1989, chlorine – 1990, nitrogen dioxide – 1992, sulphuric acid mist – 1992.
10. Comparison of heavy gas dispersion models for instantaneous releases, Brighton et al, Journal of Hazardous Materials, 36 (1994) 193-208
11. Reducing risks, protecting people (R2P2), HSE Books, 2001, ISBN 0 7176 2151 0
12. A Review of HSE's Risk Analysis and Protection- Based Analysis Approaches for Land-Use Planning, prepared for HSE by Environmental Resources Management, final report 2004.
13. Uncertainty in Societal Risk Calculations, prepared for the HSE by Atkins Process, Issue 01 February 2005.
14. Guidance on 'as low as reasonably practicable' (ALARP) Decisions in the Control of Major Accident Hazards (COMAH), SPC Permissioning/12, HSE, 2004
15. Draft SMEDIS Model Evaluation Protocol, Cambridge Environmental Research Consultants Ltd., Ref. No. SMEDIS/96/8/D, version 2.0 7 December 2000
16. e-mail 13/10 2005 David Cater to Fowler, Painter, Lawton and Maddison SR methodology review.
17. Review of HSE Methodology, chlorine experience. E-mail response to questions raised by the Review Team on 11 October 2005.
18. Comparison and test of models for atmospheric dispersion of continuous release of chlorine, Wheatley et al, HSE Section paper IR/L/HA/86/14, 15 May 1986
19. A Note on F-N criteria lines, DA Carter 27/10/2005 in response to an early draft of the Review Team's presentation to HSE made on 31/10 2005.

DOCUMENTS GENERATED FOR THE REVIEW TEAM OR OBTAINED FROM OTHER SOURCES

1. Implementation of the Fundamental Review of Land Use Planning EU Benchmarking Exercise ASSURANCE: Assessment of Uncertainties in Risk Analysis of Chemical Establishments, DA Carter MSDU HSE, 4 August 2003
2. Land Use Planning – CIA Position Statement, August 2005
3. ACUTEX brochure (draft)

About IChemE

IChemE is the hub for chemical, biochemical and process engineering professionals worldwide. The heart of the process community, IChemE promotes competence and a commitment to best practice, advancing the science and practice of chemical engineering for the benefit of society and supporting the professional development of an international membership totalling 25,000. The Institution has the role of a learned society, publishing books, journals and training packages and organising events and courses including the successful Hazards Symposium Series.

For more information, visit www.icheme.org or contact:

Andrew Furlong
Member Networks Director
IChemE
Davis Building
Rugby
CV21 3HQ

Tel: +44 1788 534484
Fax: +44 1788 560833

Email: afurlong@icheme.org