

DEMONSTRATING THE TOLERABILITY OF RISK FROM MAJOR ACCIDENTS

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A risk assessment framework for major accidents that meets the requirements of the Control of Major Accident Hazards (COMAH) Regulations is presented. The framework has salient features that link directly to the requirements of the regulations and the interpretation of law by the Competent Authority for COMAH. A scheme for categorising risk levels based upon a realistic approach to consequence analysis was developed within the framework, with methods for demonstrating that risks are tolerable. The risk assessment framework and the supporting methods are applicable to new developments as well as existing establishments, and can be used during conceptual design to assess the relevance or adequacy of proposed risk reduction measures. The framework has been applied to an LNG production and storage facility in the UK, and has allowed the completion of the assessment of the facility's safety report by the Competent Authority for COMAH.

KEYWORDS: COMAH, risk, tolerability, ALARP

INTRODUCTION

Transco LNG Storage owns and operates five LNG production and storage facilities in the UK, storing between 21,000 and 84,000 tonnes of LNG each. In addition, the facilities have inventories of LPG (liquid ethylene, propane and butane) and high-pressure natural gas. Safety reports for each of the facilities have been produced previously to meet the requirements of the former CIMAH Regulations in the UK. The introduction of the Control of Major Accident Hazards (COMAH) regulations meant that the existing safety report format needed substantial revision to meet more stringent requirements.

Three safety reports for LNG storage facilities were submitted in February 2000, and the remaining two were submitted in February 2001. The reports passed initial assessment by the Competent Authority for COMAH (the Health and Safety Executive, the Environment Agency and the Scottish Environmental Protection Agency SEPA). However the risk assessment methods employed were subsequently found to require further development.

As a result of development work and discussions with the Competent Authority, a risk assessment framework was developed to meet the requirements of UK regulation and the Competent Authority. The framework has allowed the successful completion of the assessment of the exemplar safety report from Transco LNG Storage.

PRINCIPLES ADOPTED FOR RISK ASSESSMENT

One of the key regulations in COMAH[1] states that operators of establishments must demonstrate that they have taken all measures necessary to prevent, or reduce, the consequences of major accidents. This demonstration is an important part of the safety reports for establishments such as the LNG storage facilities, and a very strong emphasis is placed by the Competent Authority on the assessment of this demonstration. It is essential that the demonstrations made reflect UK Government policy and its interpretation by the Competent Authority when this is available via guidance documents or other publications. Where no guidance is available, company policy may be used provided it is supported by a justification.

The Competent Authority for COMAH has published guidance documents which cover the preparation of safety reports[2] and the tolerability and control of risk[3]. Two principles are contained within these documents that can be used to derive a framework for risk assessment for major accidents:

- Demonstration that all necessary measures have been taken to reduce risk can be:
    - Utility-based (meeting the minimum levels of protection expected)
    - Equity-based (showing that further improvements are not beneficial in terms of cost)
    - Technology-based (showing that state-of-the-art technology is applied)
- Demonstration must be proportional to the magnitude of the hazard or risk

The revised basis of demonstration for the LNG storage sites was essentially equity-based. Technology-based demonstrations are usually hard to achieve, as the best practice available is often well in excess of requirements for acceptable working in a specific situation (e.g. the use of clean-room technology for painting); Even so, demonstration of the use of appropriate codes and standards for the design, operation and modification of the facilities was still seen as essential. The use of utility-based demonstrations was felt to lack depth based on the initial risk assessments in the original safety reports. These showed that none of the individual risks from major accidents at the facility were intolerable.

An additional concept that arises from the guidance documents[2,3] is that of "broadly acceptable" risk. This represents levels of risk that would be of no concern to workers at the facilities or the general public. If a major accident scenario has a broadly acceptable level of risk assigned to it, then no further demonstration is needed that all measures necessary have been taken to reduce risk. Nevertheless the facility is still obliged to adopt risk reduction measures that are simple and cheap to implement. This is consistent with "going the extra mile" for safety[3].

The guidance for preparing safety reports[2] indicates that for major accidents, societal risk is usually more relevant than individual risk. To assess the tolerability of risks from major accidents at the LNG storage installations, the suggested upper limit for societal risk (a frequency of not more than 1 in 5000 years for any major accident producing 50 or more fatalities) from HSE guidance[3] was therefore adopted. Figure 1 shows the resultant societal risk plot for a typical scenario; a line with a slope of –1 on the logarithmic scale has been constructed through the HSE recommended point, in line with published information[4]. As there was little published guidance available regarding the lower boundary for tolerability, below which societal risks were regarded as broadly acceptable, a decision was made to set a limit four orders of magnitude below this, based on suggested published values[5]. Risks that fall below this value are regarded as broadly acceptable. Risks that are up to two orders of magnitude below the intolerable level are regarded as tolerable if "As Low As Reasonably Practicable" (ALARP), and are subject to an equity-based demonstration to establish that this is the case. As an interim measure, risks that are in the two orders of magnitude below this are regarded as though they are in a border region between broadly acceptable and tolerable if ALARP. Subsequent discussion documents published by HSE suggest that these risks are more likely to be regarded as broadly acceptable.

Proportionality in equity-based demonstrations needs to apply to both the identification and the assessment of risk reduction measures. This was achieved by assigning stringent methods (e.g. detailed cost-benefit analysis) to the major accidents with the greatest risk in the tolerable if ALARP region, and assigning progressively simpler and more qualitative methods to accidents with lower risks.

The use of cost-benefit analysis for demonstration needs to follow UK Government practice to be acceptable to the Competent Authority. An acceptable method is defined in the HM Treasury "Green Book"[6]. An additional requirement is the demonstration of "gross disproportion" between costs and benefits, with greater disproportion for more severe consequences of accidents (e.g. greater offsite effects, greater numbers of fatalities).

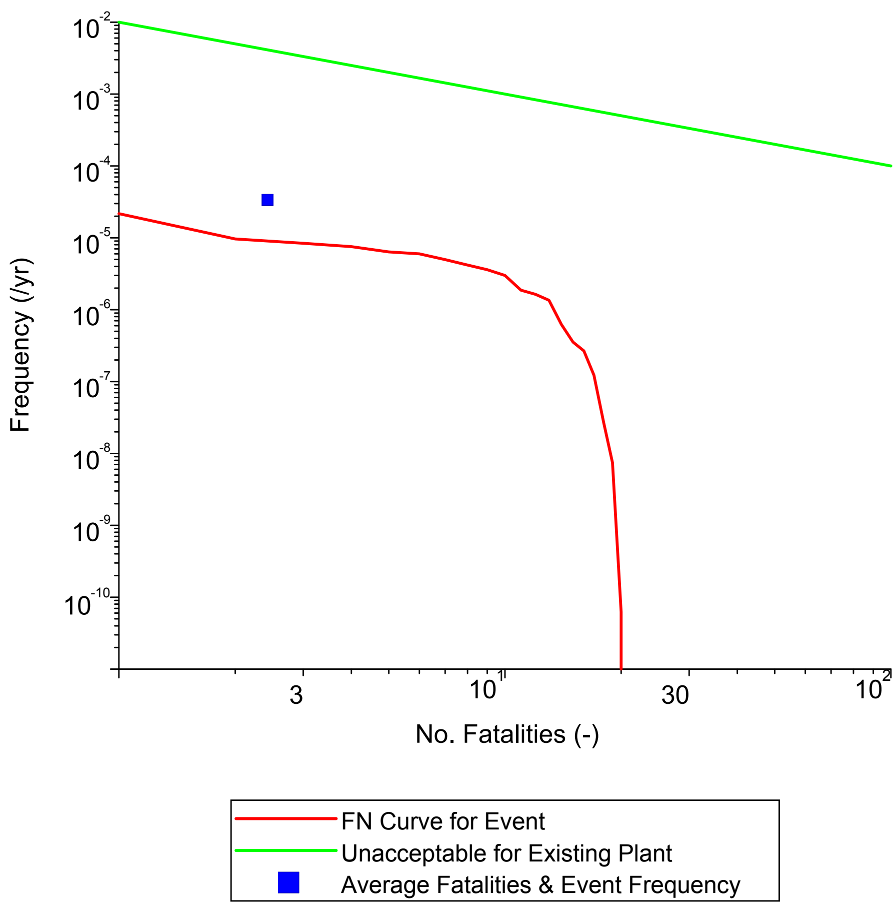

Figure 1. Typical F-N plot for a major accident scenario

RISK ASSESSMENT FRAMEWORK

Given the principles outlined above, together with specific requirements from the COMAH regulations and guidance documents[1,2,3], a framework for demonstrating that all necessary measures have been taken to control risks from major accidents was developed. Useful feedback was obtained from the Competent Authority for COMAH during its development.

The key steps in the framework are as follows:

1. Identify all major accidents, and select a representative set of major accident scenarios for detailed analysis.
2. Determine the consequences and frequency of occurrence of the major accident scenarios, for a range of realizations.
3. Assign an appropriate "Risk Category" to the scenario, based on the magnitude of the risk. (This is expressed numerically through the "potential loss of life per year" i.e. the product of the frequency of the event and the expected number of fatalities it produces.)

   Then for each scenario:

4. Identify risk reduction measures using a method appropriate for the risk ranking, and rank the measures qualitatively in order of perceived cost-benefit.
5. Examine the benefits of top risk reduction measure using a method appropriate for the risk ranking.
   a) If the measure is not of benefit, then it is assumed that all necessary measures have been applied.
   b) If the measure is of benefit, adopt the measure, re-evaluate the risk ranking and examine the next risk reduction measure using a method appropriate for the new risk ranking. Continue until no further measures are found to be worthwhile.

The outcome of this work will either be a demonstration that no additional risk reduction measures are worthy of application, or a list of risk reduction measures to be implemented to an appropriate timescale. Once any worthwhile measures are implemented, all necessary measures will have been taken to prevent, or reduce the consequences of, major accidents as the risks from the scenario are demonstrated as ALARP.

APPLICATION TO AN LNG STORAGE FACILITY

The framework described above was applied to the Transco LNG Storage facility at Partington, near Manchester. This facility has four LNG storage tanks, each with a capacity of 21,000 te, and storage for liquid ethylene, propane and butane for use as refrigerants in its two liquefaction plants. The facility also stores gas oil (Diesel fuel) to drive firewater pumps. In the past, it used to store odorant to odorise exported natural gas from vaporised LNG, although this has now been removed.

Details on each of the steps and how they were applied within Transco LNG Storage are given below. The process is shown as a diagram in Figure 2.

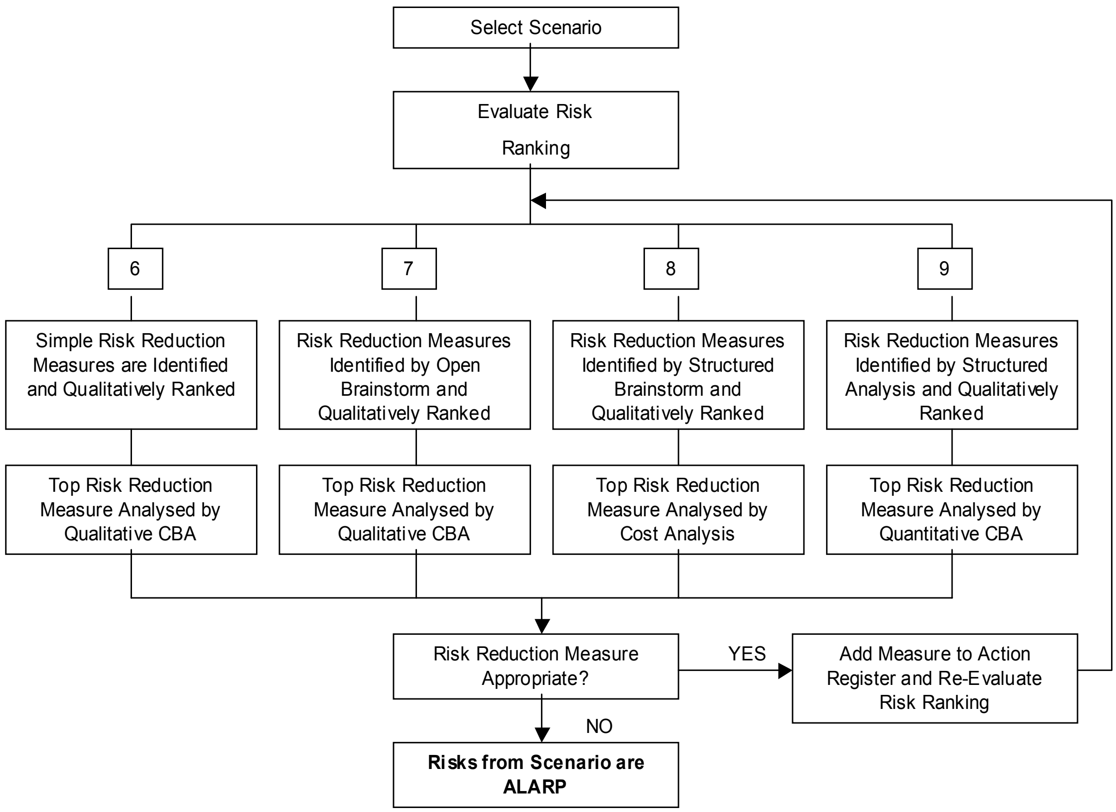

Figure 2. Identification and analysis of risk reduction measures

MAJOR ACCIDENT IDENTIFICATION

The major accident identification had already been completed as part of the development of the original safety reports.

The identification was achieved using a panel of experts, covering the following expertise:

- Chairman (experienced in similar study leadership e.g.HAZOP)
- Engineering (process, mechanical, control & instrumentation, electrical)
- Process safety (major hazards)
- Operations (representative from shift operations team and/or the facility Safety Representative)
- Management (representative from facility management team)

The facility was divided into functional areas based on a combination of activity, dangerous substance stored and location, and keywords representing initiating events for major accidents were applied to each area. The consequences of the initiating event being realised (the major accidents) were agreed, and a summary of the control and mitigating measures for the initiating event was recorded to assist in the development of the safety report. In conducting the panel discussions, best practice for HAZOP studies was found to work well.

After all areas were analysed, scenarios were selected that represented releases from the largest sources of dangerous substance or specific events occurring in sensitive locations. In the case of the LNG storage installation at Partington these covered:

- The LNG storage tanks
- The major LNG pipelines (fill and export)
- The LPG storage tanks and pipelines
- The largest natural gas pipeline
- The odorant storage tank
- The largest pressure relief valves for each dangerous substance
- The gas oil storage tank
- The most significant congested or confined volumes

In this particular case, the resultant set of major accident scenarios had already been assessed by the competent authority as acceptable.

CONSEQUENCES AND FREQUENCY OF MAJOR ACCIDENTS

Consequence analysis of the major accident scenarios was carried out using models developed by Advantica Technology. These models are generally based on experimental data, often obtained at large or full scale using LNG, LPG and high-pressure natural gas[7]. Major accidents with high consequences were analysed over a range of realisations using methods discussed elsewhere[8]; this ensured that the worst-case realisation was identified. The output from these analyses was an estimate of the expectation value for fatalities and a corresponding frequency of occurrence for each scenario, obtained from the integration of a societal risk plot for the more severe major accidents. An example of such a plot is shown in Figure 1.

Although none of the major accident scenarios for the LNG storage facilities could lead to a Major Accident to the Environment (MATTE), a method was developed to obtain a severity term for such events. This involved comparing the likely response of the media to an environmental accident with the response for fatalities. Table 1 shows the anticipated responses of the media for fatalities, derived from published information[9]. The likely response of the media to an environmental accident would be based on local knowledge and recent articles in the press and this would be used to obtain an equivalent number of fatalities using Table 1.

Table 1. Guide to media response in the event of a major accident

Acute effects	Typical media attention
>5 Fatalities on-site Fatalities off site	International news. Outcry threatens to close operation.
1–5 Fatalities, injuries off-site	Headline National news. Continuing local attention.
Low Probability of 1 Fatality	Considerable local, some National attention. Local outcry.

RISK CATEGORY DETERMINATION

Given a slope of –1 for the upper bound on tolerable risk (Figure 1), the product of the number of fatalities and frequency is constant for events lying on this line. Given also that the lower limit of tolerability has been set four orders of magnitude below the upper bound, categories of risk emerge based on the product of the number of fatalities and the frequency of occurrence as shown in Table 2. Risks at Category 10 are deemed to be unacceptable, and if ever encountered an action plan would be created immediately to reduce risk. Risks that fall below Category 5 are deemed to be broadly acceptable and the scenario is not subject to analysis for risk reduction measures (unless a measure becomes known that is simple and cheap to implement).

As a result of this work, the number of scenarios falling into each category was as follows:

Category 9: 0
Category 8: 2
Category 7: 3
Category 6: 4

Risks for the remaining scenarios were judged to be broadly acceptable.

IDENTIFICATION AND ANALYSIS OF RISK REDUCTION MEASURES

To determine appropriate risk reduction measures for each scenario, an expert panel was set up similar to the one used for the identification of major accidents described above. To ensure proportionality in determining measures, four methods were used corresponding to the four relevant risk categories in Table 2:

- *Structured Analysis*: the initiating events for the scenario were examined in turn to highlight additional controls or mitigation measures that could be adopted.
- *Structured Brainstorm*: this was a less structured discussion than the analysis above, focussing on prevention, protection and mitigation measures in turn.
- *Open Brainstorm*: The panel was free to propose measures in any order
- *Open Brainstorm (Operations)*: This was similar to the brainstorm above, but only operations staff were involved. The brainstorm focussed on operational improvements.

Table 2. Risk categories for major accidents

Product, P (in units of fatalities per year)	Risk ranking number
$<10^{-6}$	4 or 5
10^{-6}–10^{-5}	6
10^{-5}–10^{-4}	7
10^{-4}–10^{-3}	8
10^{-3}–10^{-2}	9
$>10^{-2}$	10

To ensure proportionality in examining the cost-benefit of risk reduction measures, four methods were developed corresponding to the four relevant risk categories in Table 1:

- *Cost-Benefit Analysis*: A method was developed by Advantica Technology based on principles in the HM Treasury "Green Book"[6]. A key requirement of the cost-benefit method developed was to ensure that appropriate "gross disproportionality" was achieved when comparing costs against benefits. The method increased the magnitude of the quantified benefits with increasing total risk of fatalities, increasing number of offsite fatalities and increasing difference between expected and maximum fatalities over the range of realisations.
- *Cost Analysis*: The panel decided on a sum that would be appropriate for the risk reduction measure, and an assessment was then made of the actual cost of implementation either by knowledge of similar work or from an independent assessment by a quantity surveyor. If the assessed sum was less than the sum decided by the panel, then the measure would be implemented.
- *Qualitative analysis*: The relative costs and benefits of the risk reduction measures were discussed qualitatively by the panel.
- *Qualitative Analysis (Operations)*: As above, but using operations staff only.

The panel discussions to determine risk reduction measures were generally successful, once the panel had the "feel" for what was required. It became apparent that proportionately more time was spent on scenarios with higher risk, as intended to achieve proportionality in identifying measures.

Determining costs for risk reduction measures where necessary was also straightforward. An idea that was proposed was to obtain quotations from contractors for the work. However, this was rejected on the grounds that contractors would lose patience with the facility if too many requests for quotations were made without business necessarily being generated. A quantity surveyor was employed to provide an independent, realistic assessment of costs in the absence of other information such as the costs of previous similar projects.

RESULTS OF APPLYING THE FRAMEWORK

Once the methods described above had been applied, certain risk reduction measures dealing with inspection issues were found to be worthy of adoption, and are currently being included in maintenance regimes. A modification to an enclosure to reduce the risk of explosions was shown by consequence modelling to have negligible benefit compared to the cost of the modification. As a result, risks from major accidents at the Partington LNG storage facility have been shown to be ALARP.

The results of the work were submitted to the Competent Authority in December 2001, and in March 2002 the Competent Authority stated that the safety report for the Partington LNG storage installation meets the minimum requirements of the COMAH regulations.

CURRENT AND FUTURE WORK

At present (2002), work is underway to apply the framework to the remaining LNG storage facilities belonging to Transco LNG Storage. The automated models for consequence analysis are allowing the work to proceed at a faster pace.

In addition, plans are being developed to convert the Isle of Grain LNG storage facility to allow importation of LNG from ships, via a new jetty and a 3.5 km LNG pipeline. The framework presented above has been used to assess the risks from major accidents involving the new jetty and the pipeline, and to assess the cost-benefits of risk reduction measures proposed as part of the conceptual design. So far, risk levels from the jetty and pipeline have been shown to be relatively low, and a number of worthwhile risk reduction features have been examined and assessed. As a result, the project is being developed in the knowledge that an appropriate level of expenditure will be allocated to ensure that the risks are as low as reasonably practicable.

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