

Development of the Singapore QRA Guidelines

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HSE's Health and Safety Laboratory provided specialist advice to the relevant Singapore government agencies during the development, drafting, piloting and consultation of new QRA Guidelines (which were published in three parts). In Singapore, the QRA Guidelines are used by registered QRA consultants on behalf of companies proposing new major hazard installation developments or major modifications. The QRA results are a key input to land planning decisions and whether to grant "in principle no objection" status to the proposed new development or modification.

The paper describes the process of development and the main features of the new QRA Guidelines including the rationale. Because the QRAs for different developments are being carried out by different registered consultants, it was important to give clear guidance about assumptions, models, inputs and end points so that the QRA results for different proposed developments are consistent. One of the parts of the Guidelines closely specifies the required contents of the QRA report and the electronic files to be provided with it, to aid assessment and use of data by the regulatory agencies to build an overall risk picture. The Guidelines specify the QRA methodology in such a way that it is not dependant on the use of any particular QRA software tool.

Lessons are drawn out for the QRA of major hazard installations in general. These include the need for a consistent methodology taking account of local/national factors; piloting of any new methodology and criteria; use of ALARP demonstration as a criterion; ongoing assurance of risk management over the lifetime of facilities; and use of the QRA as an input to emergency planning.

Keywords: QRA; risk; harm; criteria; footprint; land planning; major accident

Introduction

HSE's Health and Safety Laboratory was contracted by the Singapore Economic Development Board (EDB) between 2012 and 2015 to provide specialist advice to the relevant Singapore government agencies during the development, drafting, piloting and consultation of new QRA Guidelines. The new Guidelines, published in three parts (SRMC, 2015a,b,c), came into force on 1st April 2016 and replaced earlier Guidelines (PCD, 2005).

In Singapore, the QRA Guidelines are used by registered QRA (Quantified Risk Assessment) consultants on behalf of industrial companies proposing new major hazard installation developments or major modifications. The QRA results are a key input to land planning decisions and whether to grant "in principle no objection" status to the proposed new development or modification. This means that it is important that different consultants obtain QRA results that are as consistent as possible so as to give a level playing field. It was also important that the QRA guidelines and criteria were consistent with international practices.

The majority of major hazard installations (MHIs) in Singapore, both fixed sites and pipelines, are situated together on the Jurong Island industrial complex, where land reclamation from the sea continues. The land planning system pre-determines possible types of land-use (e.g. industrial, commercial, residential) for blocks of land, so that risk criteria needed to be set with reference to these land-use types.

The objectives for the new QRA Guidelines included:

- Better health, safety and risk management;
- Consistent decision making;
- Benchmarked with international practice;
- Ongoing sustainable development of the Jurong Island industrial complex:
    - Investor confidence from clarity of QRA requirements;
    - Minimisation of unnecessary sterilization of land;
- Efficient regulation for industry and government;
- Robust against any likely future regulatory development.

The existing QRA guidelines required individual risk calculations and there was a preference to retain this rather than moving to societal risk.

Process of development of the new QRA Guidelines

A number of Singapore government agencies had a key interest in the new QRA Guidelines. The National Environment Agency (NEA) has responsibility for the regulation of toxic major accident hazards. NEA also regulates hazards to the environment but this is covered by separate arrangements from the QRA Guidelines that are concerned with major accident safety. The Singapore Civil Defence Force (SCDF) regulates emergency response planning and flammable major accident hazards, as well as providing Fire and Rescue response. The Ministry of Manpower (MOM) provides the health and safety inspectorate for industrial facilities (both with and without major accident hazard potential). EDB and the Jurong Town

Corporation (JTC) have interests in economic development and a land planning system that does not unnecessarily sterilise land due to major accident hazards but also safeguards the infrastructure through their prevention and control. HSL worked collaboratively with these agencies and perhaps provided a focus for collaboration between them. This was formalised by the creation of the Safety and Risk Management Centre (SRMC) to agree and implement the new QRA Guidelines and whose members are seconded from the interested agencies.

The process of development of the new QRA Guidelines followed the following steps.

Gathering background information

HSL met with the team from the relevant agencies to understand the background, issues and concerns. HSL also provided comments on the existing Guidelines (PCD, 2005). Those Guidelines placed a great deal of emphasis on 'worst credible events' with a frequency greater that 10^{-6} per year. This tended to make the results very sensitive to the detail of the particular frequency analysis that determined whether events were 'credible' or not and furthermore made it difficult to benchmark against internationally used criteria The existing QRA guidelines required individual risk calculations and there was a preference to retain this rather than moving to societal risk criteria.

Meetings were arranged between HSL and industry, often via the Singapore Chemical Industry Council (SCIC), and separately with the QRA consultants. Interviews with the QRA consultants allowed HSL to understand current QRA methodologies and it became evident that different consultants were not using consistent methodologies to calculate risk. HSL signed non-disclosure agreements with a number of industrial companies in order to have sight of existing QRAs and that further indicated that different methodologies and assumptions were in use.

There was also a concern about delays in the assessment process of QRAs. Some of this appeared to be due to the lack of detailed guidance about QRA assumptions to make, leading to the need for discussions with the relevant agencies and potential reworking of the QRA. A particular issue was the use of 'modifiers' on event frequencies due to management factors. Another concern was the handling of potential possible domino effects e.g. an event at one MHI effecting a neighbouring site.

Drafting the QRA Guidelines

Compiled issues that needed to be taken into account in drafting the new Guidelines included:

- Industry issues about the duration of the process, lack of clarity in the methodology and apparent lack of consistency in outcomes;
- The need for better specification of the required QRA methodology because different QRAs had used different input assumptions so that they were not consistent;
- The need to benchmark criteria against international practice;
- Scenario handling problems of frequency cut-offs to determine credible events and frequency modifiers;
- The need for better links with ongoing risk management and ongoing regulatory oversight once MHIs were built and operated. This led to the inclusion of a prioritisation methodology and requirements for ALARP demonstration. This was also addressed separately by the decision of the Singapore government during this project to adopt a safety case regime for major hazard installations, that is currently under development.

The scope of the new QRA Guidelines was threefold: (i) major hazard sites - fixed installations, (ii) pipelines and (iii) bulk transport routes. It was originally intended that there be three separate QRA Guideline documents to cover each of these. However because of significant overlap a single document was drafted that could have subsequently been separated. Otherwise it could have been difficult to ensure consistent requirements for the three types of installation/ bulk transport route.

Drafts of the new QRA Guidelines were developed by HSL, using experience and review of international practices. Written comments from the Singapore agencies were incorporated and there were working sessions in Singapore between HSL and the agencies that allowed issues to be resolved through face-to-face discussion and collaborative working.

Consultation process

The draft QRA Guidelines were agreed at director level by the agencies before consultation. The consultation included pre-consultation with SCIC and QRA consultants before a formal consultation process. HSL made presentations and participated in Q & A sessions with SCIC, industrial companies and QRA consultants. HSL was also involved in drafting detailed written responses to issues raised during the consultation. HSL and the agencies then worked collaboratively to revise the draft Guidelines taking account of issues raised during the consultation.

Piloting

Piloting had not been part of the original plan but the changes from the 2005 Guidelines were significant. Also, because of the unique requirements of Singapore, the proposed QRA methodology, assumptions and criteria did not entirely follow any in use internationally but had some new features. It was therefore important to check that the new Guidelines were usable by the QRA consultants and did not give any unexpected outcomes. A number of industrial companies agreed to take part in a pilot and the results were used to finalise the new QRA Guidelines.

Finalisation of the new QRA Guidelines

Reports on each of the pilot studies were considered by the agencies and HSL. Some of the reports raised specific issues. SRMC took the lead in revising the draft Guidelines to produce a final version, in three parts, and this was done collaboratively with HSL including an extended visit and numerous teleconferences. Opportunity was taken to simplify the criteria to remove overlap, thereby reducing the amount of calculations required. The final version was discussed with SCIC and comments addressed, by email, in face-to-face meetings and teleconferences. Finally this final version was presented to directors of SRMC and the agencies and clarifications provided before approval was granted.

Copies of the new Guidelines were provided on the NEA web-site from November 2015 prior to coming into force on 1 April 2016. Also in November 2016, HSL provided training for agency assessors and presentations to industry and QRA consultants.

Outline of the new QRA Guidelines

Overview

The new QRA guidelines are published in three parts:

- QRA Criteria Guidelines;
- QRA Technical Guidance; and
- QRA Submission Format.

The Criteria Guidelines set out the risk criteria used for land planning decisions. The Technical Guidance provides guidance on input data, assumptions and calculation methodology to be used in the QRA. The Submission Format provides details of the requirements and formats for electronic files and a report that are required to be submitted.

The main changes from the 2005 Guidelines are:

- The requirements are fully risk-based, rather than using the frequency criteria cut-off for worst credible cases;
- There are revised risk criteria and harm levels;
- The Guidelines are customised for fixed installations, pipelines and bulk transport;
- The required methodology and assumptions are much more fully specified (for greater consistency);
- Results can be used for both system level calculations (e.g. cumulative risk from groups of neighbouring sites) and for downstream safety management prioritisation as well as for land planning.

Further details are given below.

Criteria

The QRA criteria document sets out the overall requirements for QRA and the scope (fixed sites, pipelines and bulk transport routes that are within scope) as well as giving the criteria thresholds. Separate criteria are provided for fixed installations (and also apply to clusters of installations covered by the same commercial entity), pipelines and bulk transport routes. Individual risk/ cumulative risk criteria are given for a number of end points that are more fully defined in the Technical Guidance:

- Injury risk criteria to protect sensitive receptors (fully defined in the Technical Guidance and including for example: residential, schools, hospitals, other public buildings with large populations and workers' dormitories);
- Fatality risk criteria to protect other industrial and commercial populations;
- Cumulative escalation criteria to limit escalation beyond the boundary;
- On-site occupied buildings criteria to protect on-site workers;
- Worst-case off-site hazard zone (for bulk transport routes only).

The criteria apply at the boundaries between types of land-use as illustrated in Figure 1. The criteria are summarised in Table 1.

Criteria are lower for pipelines and bulk transport routes than for fixed sites. This is because multiple pipelines run within pipe-racks and pipeline corridors and multiple bulk transport routes for different substances and different operators can run along the same route.

The criteria were benchmarked against international practice. Benchmarking is difficult because there are a range of criteria in use worldwide and those criteria apply to specific QRA methodologies and assumptions, and also to specific regulatory intents. For example, different criteria can be expected to be used by a company controlling risks within its site/pipeline compared with a regulator making land-use planning decisions to allow a new site/pipeline to be built. The company is responsible for the ongoing control of risks, whereas the regulator has to make precautionary decisions that may apply for the lifetime of the site or pipeline. That lifetime may well include a change of ownership over the many years an installation may operate.

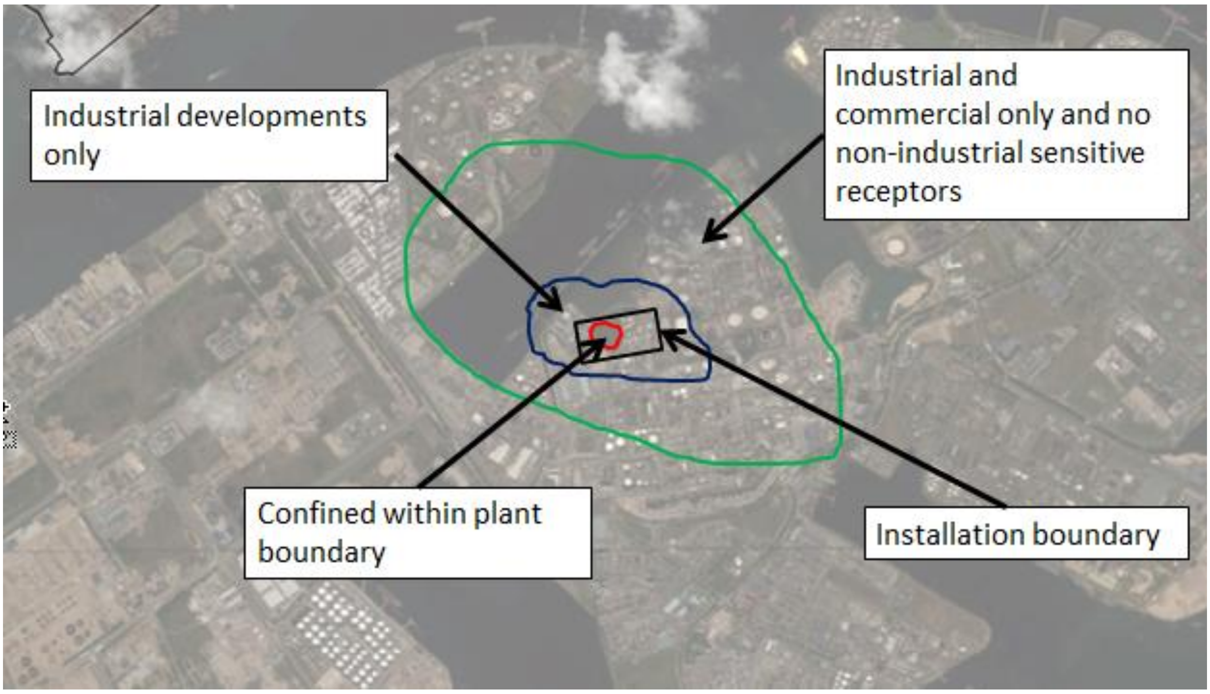

Figure 1: Illustration of QRA criteria to define acceptable land-use within risk criteria contours

Table 1: Summary of Singapore QRA criteria

Risk measure	Criteria	Criteria frequency (per year)		
		Fixed site	Pipeline	Bulk transport route
Location-specific risk of injury	Confined to industrial/ commercial and not reaching sensitive receptors	3E-07	3E-08	3E-08
Location-specific risk of fatality	Confined within boundary	5E-05	5E-06	5E-06
	Confined to industrial	5E-06	5E-07	5E-07
Cumulative escalation risk	Confined within boundary	1E-04	1E-05	1E-05
Individual risk of fatality for on-site occupied buildings	Shall not be exceeded	1E-03	N/A	N/A
Largest injury hazard range beyond boundary	Confined to industrial/ commercial and not reaching sensitive receptors	N/A	N/A	Applies

The injury risk criteria were based on UK criteria for risk-based hazardous substances consents assessments. The fatality risk criteria take account of internationally recognised criteria that range from a ‘broadly acceptable’ risk level of 1E-06 per year to an intolerable risk level for workers who choose employment in the industry of 1E-03 per year (Royal Society, 1983). Escalation risk criteria were based on those recently developed by New South Wales Australia (NSW, 2011). Occupied buildings criteria follow industry guidelines and standards in the UK (CIA, 2010) and USA (API, 2007, 2009).

The viability of the chosen criteria was checked by the piloting stage of the development of the new QRA Guidelines.

Technical Guidance

The Technical Guidance is the most detailed of the three parts. It covers the steps shown in Figure 2. Comments on some of the key stages are provided below.

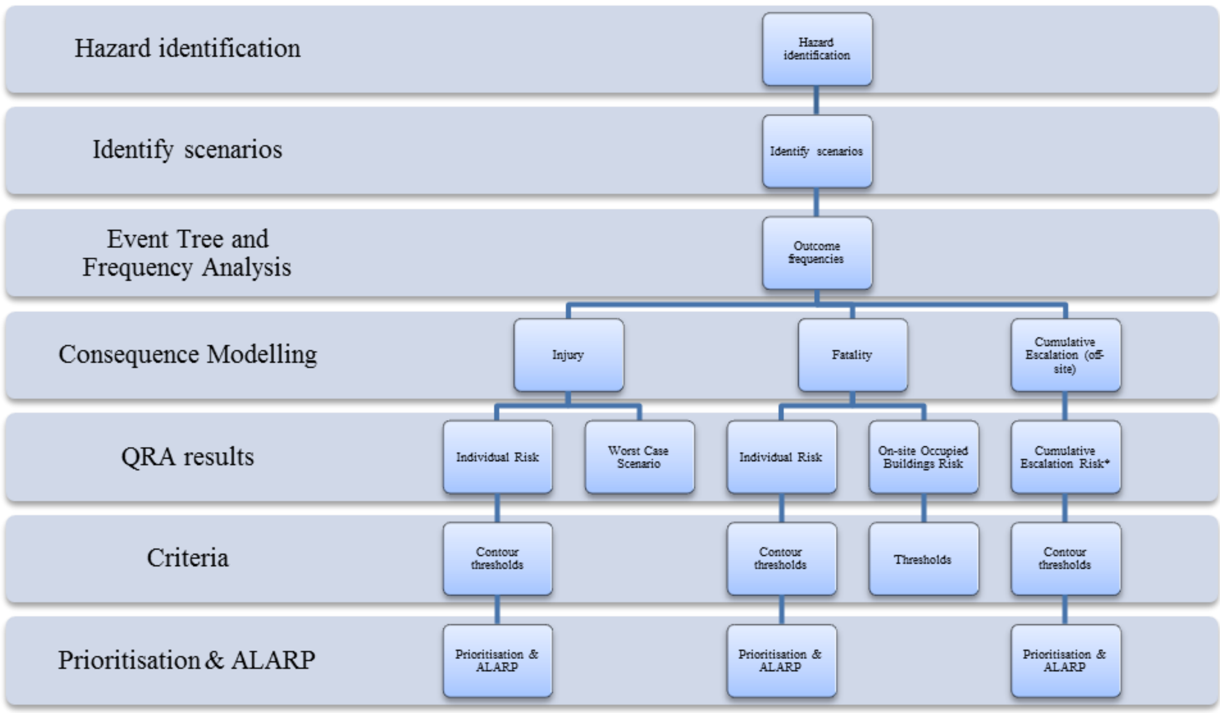

Figure 2: Steps in a QRA study

Scenario identification

It is expected that most scenarios will involve loss of containment of isolatable sections of plant and piping. It is specified that both catastrophic failure and a range of leak hole sizes should be considered. It is also stated that a hazard identification should be carried out to identify any additional process hazard scenarios. Key examples given are failure due to runaway chemical reaction (e.g. the Bhopal, India and Seveso, Italy incidents) and the overfilling of storage tanks so as to result in a severe VCE such as occurred at Buncefield, UK in 2005 (MIIB, 2008). Subsequent analysis showed that similar severe VCEs have occurred in a number of worldwide incidents (Atkinson, 2016). Brief information is given about the modelling of such events, including the guidance of FABIG (2013).

From the scenarios identified, the full range of potential consequence outcomes (e.g. pool fire, jet fire, BLEVE fireball, flash fire, VCE, pressure vessel burst, toxic release) should be calculated in subsequent steps.

Frequency analysis

To promote consistency, sources of historical failure rate data are specified. For example, for fixed installations, the UK HSE FRED database (HSE, 2012) should be used. Leak hole sizes to be used are also specified.

The Technical Guidance contains a lengthy discussion of frequency and event tree modifiers. In general account can be taken of some hardware measures that reduce the frequency of loss of containment, for example design of a pipeline with reduced design stress so as to be resilient to third party activity (e.g. inadvertent impact of a buried pipeline with a mechanical excavator). However 'management factors' are not allowable unless strongly justified because of the possibility of 'double-counting' the effect of risk reduction measures that are already included in the historical failure rate, and the need for any claims of excellent process safety management to be maintained of the lifetime of the installation, including any future change of ownership.

Tables are provided of event tree modifiers (probabilities of failure on demand of mitigation systems) with comments about possible sources of data or conditions under which credit for such a modifier might be justifiable. Ignition probabilities from OGP (2010) are specified. Many Singapore QRAs had previously used a tentative ignition probability model in Cox, Lees and Ang (1990) although the authors had specifically stated that it should not be used. For detection and shut-down systems, it is stated that the probability of failure on demand (PFD) claimed should be justified by the safety integrity level (SIL) to which the system is designed (IEC, 2016). Other mitigation hardware including fire walls, blast walls, toxic refuges etc are also discussed. Generic event trees are provided that make it clear that the QRA needs to consider the risk of failure of the mitigation as well as the risk when the mitigation is successful.

Consequence modelling and harm levels

A number of industry standard software models have been specified as suitable for use, taking into account their specific limits of applicability and the uncertainty in all consequence modelling. The Technical Guidance also makes some comments about input assumptions for source terms, dispersion modelling and flammables modelling. Weather data should apply to Singapore and use F1, B2 and C3 weather conditions, 85% humidity, 30^{o}C ambient temperature and day time solar radiation of 1 kW/m^2. Wind direction bias data for Singapore are provided in the Technical Guidance. It should be noted that the weather conditions to be modelled are different to those typically used for studies in the UK due to the different prevailing weather patterns.

Harm criteria and harm levels have been specified as far as possible for consistency reasons. The QRA calculations (see below) require harm footprints for specified harm levels, summarised in Table 2. As far as possible these harm levels have been specified without the need for harm criteria to be used. This was not possible for toxics and on-site occupied buildings. Recommendations for toxics are probits according to the Netherlands TNO Green Book (TNO, 1992) for % fatality levels, and US Acute Exposure Guideline Level, AEGL-3, (EPA, undated) for injury. AEGL-3 is more appropriate for emergency response and is more suitable for major hazards than IDLH (NIOSH, 1994), that was used in the 2005 Singapore QRA Guidelines. For occupied buildings, harm criteria can be used from sources such as CIA (2010) or API (2007, 2009). Benchmarking of the harm levels included practices from the US, UK, Netherlands, Australia, Hong Kong and France. In common with the 2005 QRA Guidelines, injury and fatality harm levels are for outdoor populations; on-site occupied building harm takes account of the population concerned being in specific buildings.

Table 2: Harm criteria required for QRA

Relevant QRA criteria	**Toxic**	**Thermal radiation**	**Flash fire**	**Overpressure**
Injury	AEGL-3	4 kW/m^2	LFL	1 psi
Fatality	3% fatality 10% fatality 50% fatality	4 kW/m^2 15.3 kW/m^2 * 21.6 kW/m^2 * 37.5 kW/m^2	LFL	5 psi 7 psi 10 psi
Escalation	N/A	20 kW/m^2	N/A	2 psi
Occupied buildings	3% fatality 10% fatality 50% fatality	3% fatality 10% fatality 50% fatality 100% fatality	LFL	3% fatality 10% fatality 50% fatality
* Assuming 30 seconds exposure time				

The output of consequence modelling should be a series of harm footprints, as shown in Figure 3, for all combinations of:

- Scenario outcome;
- Specified harm level; and
- Weather conditions (F1, B2 and C3).

QRA calculations

The use of specified harm footprints with associated frequencies for each scenario is intended to allow risk summation to be carried out using any suitable software. Note this is different to the approach currently taken in the Netherlands where the software is specified by the regulators. The approach in Singapore will still allow the Singapore agencies to calculate multi-installation composite risk contours in future because all QRAs will be carried out on the same basis and also provide results in the same data format.

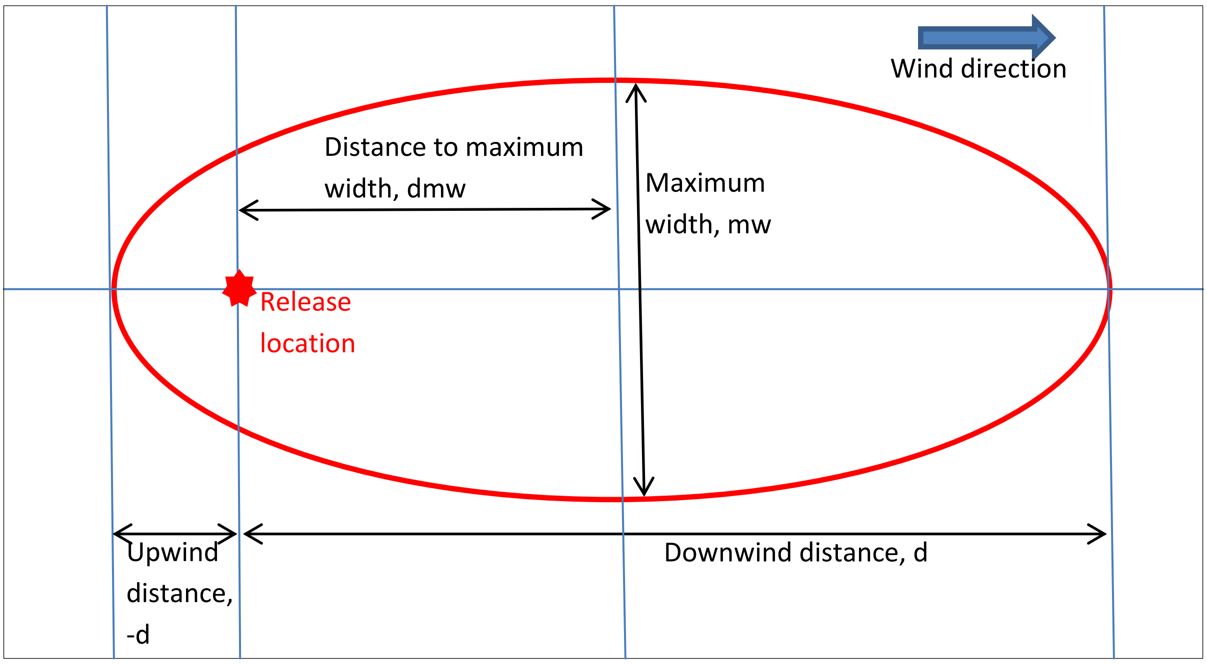

Figure 3: Idealised harm footprint

It is expected that the risk calculation will be carried out at each point in a suitable grid. Modifiers (probabilities) that will need to be included in the calculation are:

- Positional or fractional coverage of footprint at location;
- Weather category split;
- Wind bias at location;
- Weightings of harm effect;
- Delayed ignition probability if not factored in event tree;
- Occupancy (for on-site occupational buildings).

This is in addition to the event tree modifiers already discussed within the frequency analysis.

The 'weightings of harm effect' take account of the different harm levels (see Table 2) specified for calculating individual risk of fatality. In this case, there will be three or four harm footprints for each scenario, corresponding to 3%, 10% and 50% fatality, plus 100% fatality in the case of thermal radiation. A grid point between the 10% and 50% harm footprints should use a total probability of fatality of the average, i.e. 0.3. However the weighting has to be applied to each footprint separately. The 3% footprint will use the average probability between 3% and 10%, i.e. 0.065. The 50% footprint therefore uses a probability of 0.3 – 0.065 = 0.235. Table 3 reproduces the resulting weightings from the Technical Guidance.

Table 3: Weightings for fatality harm footprints

Hazard	**Harm footprint/set**	**Weightings for Individual Risk (Fatality)**
Thermal radiation from fire (e.g. Fireball, Jet Fire, Pool Fire)	4kW/m^2 or 3% fatality (for occupied buildings)	0.065
	15.3kW/m^2 or 10% fatality (for occupied buildings)	0.235
	21.6kW/m^2 or 50% fatality (for occupied buildings)	0.45
	37.5kW/m^2 or 100% fatality (for occupied buildings)	0.25
Toxic	3% fatality	0.065
	10% fatality	0.235
	50% fatality	0.45
Flash Fire	LFL	1.0
VCE	5psi or 3% fatality (for occupied buildings)	0.065
	7psi or 10% fatality (for occupied buildings)	0.235
	10psi or 50% fatality (for occupied buildings)	0.45

Weightings are not required (weighting = 1) for injury and escalation harm levels because only a single level of harm is used. The risk calculated, for example for injury, is therefore the risk of injury or worse.

The QRA calculations have to sum all scenarios and produce iso-risk contours for each of the risk criteria specified (see above). By plotting these on a map, conclusions can be drawn as to whether the criteria have been met.

Prioritisation and ALARP

Guidance is provided on prioritising scenarios for consideration of the potential for further risk reduction and risk reduction as low as is reasonably practicable (ALARP). Although the outputs of the QRA are in terms of individual risk, the prioritisation methodology introduces some societal risk considerations through the use of a risk matrix. The example in Figure 4 is provided and uses estimated number of injuries, based on the number of people within the harm footprint for injury, as an input to societal risk.

Frequency (per year)	1-10 injuries Limited on-site damage < $2M	10-100 injuries Significant on-site/ limited off-site damage $2-100M	100-1000 injuries Catastrophic on-site/ significant off-site damage $100-$2000 M	> 1000 injuries Catastrophic off-site damage > $2000M
1E-6 – 1E-5	1	1	1	1
1E-7 – 1E-6	3	2	2	1
1E-8 – 1E-7	4	3	2	1
< 1E-8	5	4	3	1

Figure 4: Example risk prioritisation matrix

Prioritisation should be based on:

- Harm to humans;
- Significant damage including escalation;
- Impact on sensitive receptors.

For MHIs that are in scope of the new Singapore safety case regime, the requirements for ALARP demonstration within that regime should be followed. For other installations, the QRA Technical Guidance provides guidance on ALARP demonstration, that may be either qualitative or quantitative, as appropriate.

The QRA methodology is largely specified to promote consistency, but even so there will always be uncertainty in QRA results. For example, there may be site-specific conditions and topography that will affect source term modelling; and there are compromises in consequence model assumptions and inputs such as averaging weather conditions into a limited number of categories. The ALARP demonstration, including the qualitative aspects, gives an opportunity to take account of uncertainties. This could include taking credit for existing risk reduction measures not already included in the QRA; or taking account of harm footprints that do not quite reach major populations.

Outcome/ uses of QRA

The Technical Guidance states that the total risk from new/modified units and the existing installation/pipeline needs to be calculated. The QRA for the new/modified units needs to follow the 2016 new QRA Guidelines but the QRA for the existing installation/pipeline may be simplified, using representative scenarios, but these need to cover the geographical coverage of the installation. It is stated that if criteria are not met due to the new/modified units then risk needs to be reduced until they are met. If the criteria are not met due to high existing risk then, subject to pre-consultation with SRMC, the ALARP demonstration may be considered.

There is also a section of the Technical Guidance that discusses use of the QRA as an input in preparing the Emergency Response Plan.

Submission Format

The submission format requires submission of a QRA report and a set of data files. The coordinate system and acceptable file formats for the data files are specified, together with the file naming convention. Electronic data is required so that the regulator can, over time, develop a composite risk picture taking account of multiple sites and pipelines. Data files include:

- Site map;
- Tabulation of scenario outcomes including location, identifier, description, weather, harm footprint dimensions;
- Risk grids for risk values at 10 metre spacing and aligned to Singapore SVY21 geographical coordinate system;
- Shapefiles of risk contours;

- Data about on-site occupied buildings.

Detailed requirements for the structure of the QRA report are provided. This is intended to make the QRA report easier to assess by the regulator as the relevant material will be in a specific section and there are standardised tables of results, facilitating comparisons between assessments. The QRA report structure includes:

- Site information (process description, hazardous materials and inventories, labelled site map, meteorology);
- Hazard identification (including isolatable sections and scenario outcomes/ harm footprints);
- Justification of frequency analysis;
- Justification of consequence analysis;
- Software and approach for risk calculations;
- Worst case consequence harm zones;
- Tabulation of harm footprints and outcome frequencies;
- Confirmation tables that criteria have been met;
- QRA results presented on map(s), including worst case harm zones, fireball zone, risk results;
- Tabulation of events with off-site domino potential;
- Tabulation of top risk contributors (scenarios that contribute most for each type of risk criteria).

Discussion and lessons learned for QRA in general

A QRA that is to be used for regulatory purposes such as land-use planning needs to have consistency between different companies, installations and consultants. In the UK, that is achieved by all hazardous substances consents assessments being carried out by the regulator, using a consistent methodology (HSE, 2015a). Most other international countries make use of QRAs prepared by, or on behalf of, the relevant company. That means that the methodology needs to be sufficiently specified by the regulator to achieve consistency and hence a level playing field between companies, i.e the same level of risk will give rise to the same decision. Without well-specified guidelines, it is possible for different professional risk assessors to interpret them in different ways, leading to inconsistent results.

All international countries have local issues that need to be taken into account in a QRA methodology that is to be used. This can include the regulatory framework, history of land-use planning controls, types and geographical spread of major hazard installations and other developments, and balance between the needs for safety, economic development and new residential housing. This means that there is no ‘one size fits all’ for QRA methodologies and criteria but rather the QRA methodology needs to take account of local factors and existing regulatory systems.

The results of a QRA are sensitive to the methodology and input assumptions. Therefore, although international benchmarking of criteria is useful, criteria need to take account of the particular QRA methodology. Piloting of proposed new methodologies and associated criteria is therefore important to ensure that they are compatible and lead to sensible decisions.

Industrial companies will also need to carry out risk assessment as part of their control of the safety, environmental and business risks of their installations and activities, and a safety case regime is likely to require this. Major hazard installations can be a source of significant business and reputational risk and the cost of a major accident can be so high as to challenge the future viability of a company. A consistent methodology between a company’s different sites and process units will facilitate comparison and prioritisation between them in terms of risk. A company’s self-consistent methodology may not be the same as that required by the regulator, and for multi-national companies dealing with multiple regulators this is unlikely to be possible. All QRA is subject to uncertainty and the requirement to use a specific QRA methodology for installations in a particular country may give useful benchmarking that can highlight the possible range of uncertainty.

Most, if not all, countries have existing historical developments that can give rise to so-called ‘legacy issues’, where the existing developments do not meet standards in terms of risk. It is important for the regulator to have some flexibility in decision-making in such cases. Use of ALARP as a criterion is helpful because it allows account to be taken of uncertainty and of qualitative factors that are difficult to quantify within a QRA. ALARP starts with the inclusion of relevant good practice within the design, and then identifies further potential risk reduction and determines whether it would be reasonably practical to include. In the UK, guidance for existing sites that do not meet current standards/ good practice uses the ALARP test to determining whether updating to current standards is required (HSE, 2014). Under the UK COMAH regulations, for some very high proportionality sites (high potential consequence and/or high risk), best practice may be required (HSE, 2015b).

The Singapore QRA guidelines are concerned with land-use planning for new and major modifications to sites, pipelines and transport routes with major accident hazards potential. It is also important to ensure good ongoing risk management. In Singapore that is being ensured by a new safety case regime. In Europe, the Seveso Directive covers both land-use planning and ongoing risk management.

QRA is an important input to emergency response planning as it identifies the hazard scenarios and provides an estimate of the hazard ranges, casualties and escalation potential that need to be planned for.

Conclusions

New guidelines have been produced in Singapore for QRA, carried out by registered consultants on behalf of companies, as key input to land planning decisions and whether to grant "in principle no objection" status to the proposed new development or modification.

The guidelines were developed collaboratively by the relevant Singapore agencies, with HSL acting as consultant. The process of development involved benchmarking against international practice, initial drafting, consultant with industry and QRA consultants, and piloting.

An outline of the new QRA guidelines has been provided. They comprise three parts: criteria; technical guidance; and submission format. An important requirement was to provide sufficient guidance to promote consistency between different QRAs.

A number of lessons have been drawn out for QRA in general. These include the need for:

- a consistent QRA methodology when the results are to be used as an input to land-use planning decisions or as a means of comparing and prioritising different installations and units within a company;
- any regulatory QRA methodology to take account of local/ national factors;
- piloting of any new methodology and associated criteria to ensure that sensible decisions are reached;
- some flexibility in regulatory decisions, particularly involving existing legacy sites, and that can be provided by making ALARP demonstration part of the criteria;
- link to ongoing assurance of risk management over the lifetime of the facility, pipeline or bulk transport route;
- the QRA to be used as an input to emergency response planning.

References

API, (2007), Management of Hazards Associated With Location of Process Plant Portable Buildings, API RP-753, American Petroleum Institute

API, (2009), Management of Hazards Associated With Location of Process Plant Buildings, API RP-752, American Petroleum Institute

Atkinson, G., Cowpe, E., Halliday, J., Painter, D., (2016), A Review of Very Large Vapor Cloud Explosions, Proceedings of Mary Kay O'Connor Process Safety Center 19th Annual International Symposium, 192- 209, 25-27 October 2016, Texas,

CIA, (2010), Guidance for the location and design of occupied buildings on chemical manufacturing sites, 3rd edition, Chemical Industries Association

Cox, A.W., Lees, F. P., Ang, M. L., (1990), Classification of Hazardous Locations, IChemE, Rugby

EPA, (undated), Access Acute Exposure Guideline Levels (AEGLs) Values, US Environmental Protection Agency, https://www.epa.gov/aegl/access-acute-exposure-guideline-levels-aegls-values#chemicals (accessed 12/12/16)

FABIG, (2013), Vapour cloud development in over-filling incidents, Technical Note 12 (TN 12)Fire and Blast Information Group, http://www.fabig.com/video-publications/TechnicalGuidance# (accessed 11/12/16)

HSE, (2012), Failure Rate and Event Data for use within Risk Assessments, http://www.hse.gov.uk/landuseplanning/failure-rates.pdf (accessed 11/12/16)

HSE, (2014), Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable, http://www.hse.gov.uk/risk/theory/alarp1.htm (accessed 14/12/16)

HSE, (2015a), HSE's land use planning methodology, http://www.hse.gov.uk/landuseplanning/methodology.htm (accessed 14/12/16)

HSE, (2015b), The Control of Major Accident Hazards Regulations 2015: Guidance on Regulations, L111 (Third Edition), http://www.hse.gov.uk/pUbns/priced/l111.pdf (accessed 14/12/16)

IEC, (2016), Functional safety - Safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and application programming requirements, IEC 61511-1:2016, https://webstore.iec.ch/publication/24241 (accessed 11/12/16)

MIIB, (2008), The Buncefield Incident 11 December 2005 The final report of the Major Incident Investigation Board, http://www.hse.gov.uk/comah/buncefield/miib-final-volume1.pdf (accessed 11/12/16)

NIOSH, (1994), Immediately Dangerous To Life or Health (IDLH), US National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh/idlh/idlhintr.html (accessed 12/12/16)

NSW, (2011), Risk Criteria for Land Use Safety Planning, Hazardous Industry Planning Advisory Paper No 4, New South Wales Government, http://www.planning.nsw.gov.au/Policy-and-Legislation/~/media/0D39F08E7889409BBA1FA88D5FB859FD.ashx (accessed 11/12/2016)

OGP, (2010), Ignition probabilities, Report No 434-6, March 2010, International Association of Oil & Gas Producers, http://www.ogp.org.uk/pubs/434-06.pdf (accessed 1/12/16)

PCD, (2005), Guidelines for Quantitative Risk Assessment (QRA) Study (For Installations Which Store, Transport Or Use Hazardous Substances), Singapore Pollution Control Department, http://documents.mx/documents/guidelines-for-quantitative-risk-assessment-qra-study.html (accessed 8/12/16)

Royal Society, (1983), Risk Assessment: Report of a Royal Societal Study Group, Royal Society, London

SRMC, (2015a), QRA Criteria Guidelines, Singapore Safety and Risk Management Centre

SRMC, (2015b), QRA Technical Guidance, Singapore Safety and Risk Management Centre

SRMC, (2015c), QRA Submission Format, Singapore Safety and Risk Management Centre

TNO, (1992), Methods for the determination of possible damage to people and onjects resulting from releases of hazardous materials (Green Book), https://www.tno.nl/en/focus-area/urbanisation/environment-sustainability/public-safety/the-coloured-books-yellow-green-purple-red/ (accessed 12/12/16)

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