

Using Quantified Risk Assessment (QRA) in Feasibility Design

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Quantified Risk Assessment (QRA) is a sensitive and powerful tool which can be used to assess the risks posed by potentially hazardous installations to workers, offsite populations, the environment and assets. But QRA can also be complex, time consuming and costly to undertake and is generally the preserve of specialist practitioners.

Not surprisingly, operating and design companies delivering major projects may only undertake a QRA when there is a compelling reason to do so or only when the design is well characterised and there is confidence in the chosen solution and plenty of input data available. However, this potentially misses an opportunity to harness the benefits of QRA very early in the project lifecycle where the relative risks of different technologies or operating regimes or plant configurations can be assessed. Such side by side comparison can be done in several ways but in early design it is often qualitative in nature. However, early phase quantitative analysis can be hugely beneficial to decision making, giving greater confidence in the safety of the final design and thereby avoiding the chances of unacceptable risks being revealed later in the project.

The Feasibility Design for the redevelopment of a National Grid gas compression station presented a challenge to Costain to upgrade the site whilst not exposing local populations to unacceptable risk levels. Site space constraints meant the redevelopment required new land purchase that would place potentially hazardous plant closer to offsite populations. Costain developed a number of design options based around the proposed land purchase and to aid optioneering Costain decided to use a Coarse QRA to assess the differences in risk profile between each scheme.

The Costain Design Safety team built a Coarse QRA model using Event Tree Analysis to develop scenarios and apply appropriate probabilities, whilst consequences were assessed using PHAST modelling software, which was combined with the event tree data to produce F-N curves for the different options under consideration, allowing the design team to screen out unfavourable solutions.

Later in the project Costain was able to validate its Coarse QRA results against the output from a full QRA carried out by National Grid, and by comparison with the planning consultation zones set out in the Health and Safety Executive's (HSE) Planning Advice for Developments Near Hazardous Installations (PADHI). Correlation between all three sources was very good and confirmed the value of the original assessment.

What Costain learnt is that QRA can, and should, be used much earlier in projects to build confidence into the design of potentially hazardous installations; and that this can be done using basic tools. Being able to compare results with other sources and techniques has shown the accuracy of early phase QRA to be good and demonstrated the robustness of the approach. So whilst detailed / full QRA does remain a specialist area, designers and operators should consider incorporating a Coarse QRA in to their Feasibility Design decision making toolkit.

Keywords: QRA, Feasibility, Optioneering, Gas, Off-site and Populations

Introduction

Companies operating high hazard installations such as may be found in the oil and gas or chemical industries, face a balancing act with regard to protection of their workers and the public from potentially catastrophic hazards whilst at the same time maintaining commercial success so that they can continue to provide the societal benefits that result from their activities.

Of course the safest position is not to expose local populations to the risks associated with high hazard processes at all, and sometimes this is indeed the case. For example it would not typically be considered acceptable to build a new refinery alongside a housing estate or a school, as the associated social risks are simply not tolerable or too costly to manage.

However, placement of high hazard facilities in total isolation from local residents and delicate, valuable or sensitive environments is generally not possible, and as such we need to understand whether the associated risks are acceptable with respect to the benefit realised.

National Grid operates the National Transmission System (NTS), which transports natural gas around the UK at high pressure in a network of buried pipelines. Due to the large distances (7,654 km of pipeline in total) the pressure in the lines needs to be boosted at intervals to maintain flow, and this is the job of the NTS compressor stations. Relative to a refinery or chemical plant, gas compression sites are considerably less complex operations however they transport natural gas in pipes of up to 1.2m diameter and at operating pressures of up to 94barg, and therefore failure of a pipeline, whilst extremely unlikely, can be potentially catastrophic. The UK has not seen any significant failures of the main gas pipelines that make up the NTS but the consequences of such an incident would be high energy gas release, which if ignited could result in flash fire and or a jet fire, which at NTS pressures and line sizes could result in jet flame of hundreds of meters in length.

More than 99% of the NTS network is buried, which offers general protection from impact and interference and in the event of a release the consequences to local populations will be lessened due to ground shielding effects. However, in compressor stations these lines must surface to pass through the gas separators, compressors and other process equipment, which make

up the Above Ground Installation (AGI), and consequently for these sites there is a potentially increased risk to receptors from the NTS pipelines.

Historically gas compression sites have been kept away from densely populated areas, and go largely unnoticed by the public given most of the infrastructure is buried. However, over time populations have increased around and or migrated closer to compressor sites either as part of planned housing development or creeping / organic growth. So when Costain began working on a Feasibility Design study for the upgrade to one of National Grid's older compressor stations, preserving the safety of local populations and the environment was of prime importance.

The redevelopment of the forty year old compressor site allowed for the installation of two new low emission gas turbine driven compression systems, and associated Balance of Plant (BOP), which would significantly improve the environmental performance of the site and would also re-life the installation for the next generation. A major constraint for the project was that the existing compressor station could only be shut down during the summer months, when gas demand is low, meaning 'like-for-like' replacement in the same location was not viable. It became clear early in the Feasibility Design that the new compression capacity and BOP could not physically be accommodated within the existing site layout and boundary and so plans were drawn up by National Grid to purchase land directly adjacent to the site for expansion. Costain developed a number of layout schemes considering practical issues such as flood zones and the position of existing pipelines and other infrastructure.

At the Feasibility Design stage it would typically be sufficient to carry out scheme development on the basis of practicability and relative risk analysis e.g. closer / further from receptors, smaller / bigger capacities i.e. qualitative analysis. However, in order to meet the project's long term programme dates National Grid needed to progress with land purchase ahead of completion of the Feasibility Design and subsequent more detailed engineering. Because of the early stage of the design the land purchase requirement presented a commercial risk for National Grid; if it subsequently came to light that locating new compression capacity on the purchased land presented an unacceptable risk to local populations then the capital investment would have been wasted.

To make robust planning and investment decisions for high hazard installations, operators and regulators must fully understand the risks, i.e. the nature of the associated hazards and their consequences and likely frequency of occurrence. There are a number of ways in which such complex risks can be measured, with Quantified Risk Assessment, alternately known as Probabilistic Safety Assessment (PSA) or Probabilistic Risk Assessment (PRA), one of the most widely used. QRA is able to take estimated consequence and frequency data for different hazards to determine each scenario's risk which can then be aggregated to generate an overall risk profile for a site.

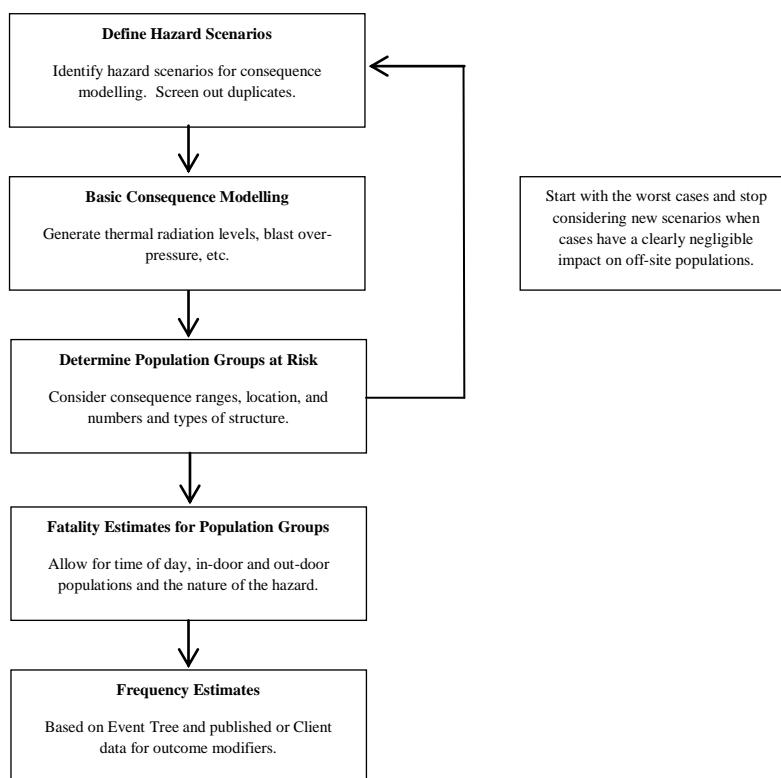
However QRA can be complex, costly and time consuming to deliver, requiring a detailed understanding of the plant design and operation, and the associated hazards and failure rate data. The benefit of the investment in QRA is a robust and focused assessment of risks, which ensures sufficient risk reduction and mitigation measures are provided without being overly conservative, as may be the case with simpler analysis techniques. QRA is typically carried out using specialist software and considerable experience can be required to undertake it and interpret the results. Consequently QRA is not generally a task undertaken by facility owners in-house or which is routinely used early in the project lifecycle e.g. Feasibility Design or Optioneering, where insufficient information is generally available or where too many design options are still being considered to make the use of QRA practical or economic.

To mitigate the land purchase risk National Grid asked Costain to undertake an assessment to determine the suitability of the proposed site extension for the use with new the compression plant. Because of the feasibility stage of design and the very specific terms of reference Costain determined that a full detailed QRA was not appropriate but rather a Coarse QRA was required and so Costain set about building a QRA model specifically for the task of considering the risk to off-site populations from the new installation.

Methodology

The objective of the Coarse QRA model was to determine whether the new compressors and associated BOP would represent an unacceptable increase in risk to receptors in relation to their current risk exposure or would exceed generally acceptable norms as laid down by the HSE and industry. The degree of accuracy required only needed to be such that National Grid could be broadly confident that the purchase of new land at such an early phase of the project would not turn out to be a costly mistake.

Figure 1 Summary of Approach to Coarse QRA



The land which was identified as most suitable for the site expansion was a field of permanent pasture directly to the eastern boundary of the existing site. This area of land represented the best expansion option as it allowed for a sensible process and infrastructure layout and it was not affected by potential flood issues (as is the case for the land immediately adjacent to the west and south of the site). However, placing the new compressors and associated BOP in the field to the east of the site would locate potentially high hazard pipework and equipment closer to the main populations associated with the site than for the current installation. This would inevitably lead to some increase in hazard and risk for these population groups whilst other receptors may be beneficially affected (This would be on the basis that the existing compression kit would no longer be operated except for back up purposes, thereby reducing the potential initiating event frequency).

As well as determining the risks specifically associated with the new compressor installation the Coarse QRA looked at the risks associated with the existing compression provision (Not including BOP) to allow a side by side comparison of the old and new installations to determine if there was any significant change in overall risk levels.

The QRA start point was to determine the extent and location of vulnerable populations by inspection of the local area using on-line maps and aerial photographs. The site is in a greenfield environment but there are up to thirty properties within a 500m radius, which also includes a service station and fast food restaurant. Around 750m to the west is a main line railway, and 550m to the north there is a busy dual carriageway with a link road 150m to the east. The nearest densely populated areas lay around 800m to the north east and 750m to south east.

Populations which were identified for consideration in the QRA were as follows (Refer to Figure 2)

- Area 1 360m to the North West - Single dwelling.
- Area 2 300m to the East - Scattered group of fifteen houses centred to the east of the existing site whose risk exposure will be most significantly affected by the proposed development. Although considered as a single group not all properties would necessarily be affected to the same degree by an event due to their distribution.
- Area 3 750m to the South East - Large residential estate.
- Area 4 650m to the North East - A farm.
- Area 5 820m to the North East - A residential unit / school housing approximately fifteen residents and an assumed equal number of staff by day and a lesser number of staff at night. Beyond the school is a residential housing estate.
- Area 6 500m to the North East - A service station with associated shopping facilities and fast food restaurant serving a busy dual carriageway.

Figure 2 Principal Population Locations Considered by the Coarse QRA



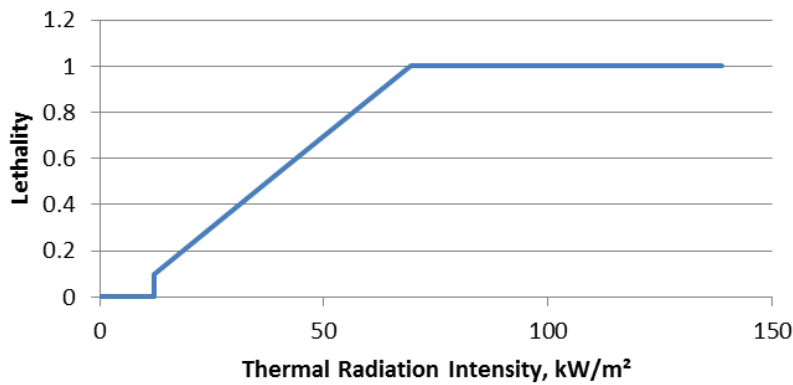
After determining the populations likely to be affected by a major site incident the potential impacts of such events were calculated using PHAST consequence modelling software which is able to model multiple effects including thermal radiation levels, flash fire envelope and blast over-pressure.

A range of scenarios were modelled with the most significant consequences arising from full bore and partial rupture of the new 1,050mm diameter gas lines where they come above ground, to enter and leave the compressors, which would have the potential to generate significant blast overpressure and high thermal radiation intensities associated with a flash fire or jet fire. Vulnerability factors were applied taking into account the protection provided by buildings, time of day, and escape speed of individuals, to calculate the likely number of fatalities for each scenario.

For outdoor populations lethality was determined based up on thermal radiation exposure expressed in terms of Thermal Dose Units (TDU) $((\text{kWm}^{-2})^{4/3}\text{s})$ using a Probit equation calibrated to give 1% lethality at a thermal dose of 1,060 TDU (Value specified by National Grid).

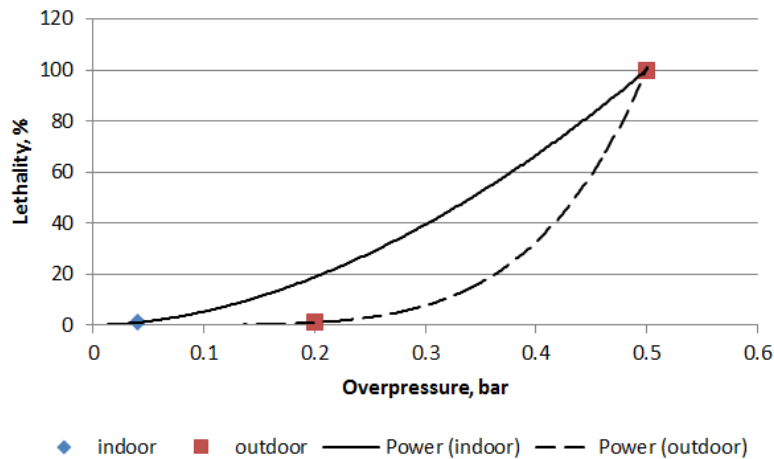
The thermal lethality effects to indoor populations were based upon thermal radiation intensity allowing for the protection that may be offered by buildings. The curve shown in Figure 3 attempts to take account of both direct thermal radiation (via windows) and the likelihood of a building catching fire and the occupant(s) being unable to evacuate to a safe location. A minimum threshold value of 12 kWm^{-2} was assumed; this represents the intensity at which someone in a building would either feel the effects of thermal radiation through a window (bearing in mind they can quickly reach the shade of a solid wall) or at which a building may start to burn, up to around 70 kWm^{-2} , which represents a thermal intensity level high enough to cause immediate fire in unprotected structures; under which circumstances all occupants would be considered to become fatalities.

Figure 3 Thermal Radiation Lethality to Indoor Populations



The lethality due to overpressure resulting from a compressor enclosure explosion was modelled as two curves, one for indoor populations and one for outdoor populations [Figure 4]. The curve for indoor populations rises at lower overpressures reflecting the greater risk to individuals from missiles / shattered glass / falling objects / collapsing structures. The curves were calibrated at National Grid’s 1% fatality levels of 40mbar and 200mbar for indoor and outdoor populations respectively, and 100% fatality at 500mbar overpressure in both cases.

Figure 4 Lethality Due to Blast Overpressure - Indoor and Outdoor Populations



Flash fires consequences were determined by setting the limit of the fire based upon the Lower Flammability Limit (LFL) for natural gas (Approximately 5%). Anyone within this zone, indoors or outdoors was considered to become a fatality.

The consequence modelling output was presented as bounding case contours, overlaid on a map of the site and surrounding areas, representing the limits associated with 1% thermal or blast lethality and the maximum extent of a flash fire. As the Coarse QRA was only considering off site impacts initiating events that did not result in any consequence contours extending beyond the site boundary were not carried forward.

Fatality data is not really informative without knowing what the potential frequency of each scenario occurring is, i.e. the initiating event frequency. This data can be difficult to source or apply to a particular situation but in this case Costain was able to draw upon National Grid’s extensive library of failure rate data. The failure rate for pipework, expressed as ruptures per meter per year, was used in combination with the length of above ground pipeline to determine the initiating event frequency for major pipe failure / full bore rupture.

Of course there are a number of outcomes that can result from major pipe failure such as flash fire, blast overpressure or jet fire. The likely frequency of each of these outcomes was determined using Event Tree Analysis, as shown in Figure 5, which allowed Costain to consider an event following different paths due to consequence modifiers such as ignition probability and delay, degree of release confinement, directionality etc.

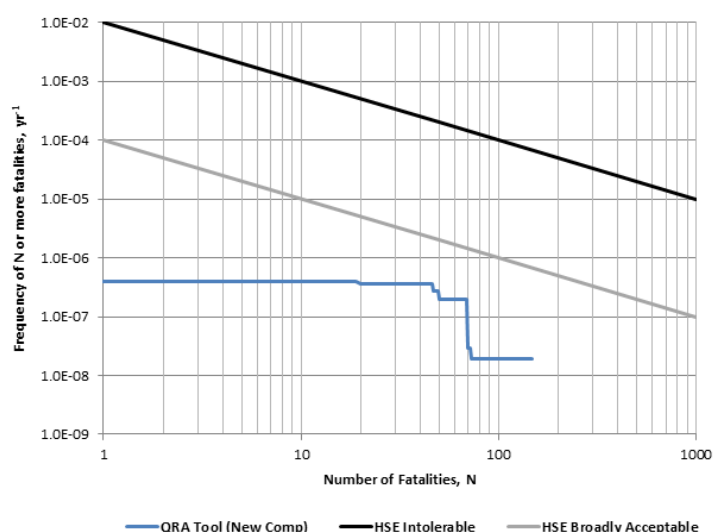
A simple approach was taken to releases that were expected to be highly directional, i.e. jet fire and flash fire. The likelihood of fatality was reduced by a factor of ten to account for the highly directional nature of jet and flash fire and the possibility that they could occur in any direction. Due to the population locations and the wind rose for the site location this remained a conservative assumption for flash fire.

Figure 5 Event Tree Analysis for Full Bore Pipe Rupture

Initiating Event		Ignition			Ignition Timing / Unignited Release Type			Confinement/Release Type			Intermediate Event Outcome	
Scenario	Init. Event Frequency	Event	Ignition Probability	Intermediate Frequency	Toxic Release/Delayed Ignition	Probability	Intermediate Frequency	State	Probability	Intermediate Frequency	Description	Intermediate Frequency
	yr ⁻¹		(fraction)	yr ⁻¹		(fraction)	yr ⁻¹		(fraction)	yr ⁻¹		yr ⁻¹
1050mm diameter above ground pipe rupture												
S1	1.60E-06	No Ignition	0.4	6.40E-07	Non-toxic	1	6.40E-07				No hazardous consequence	6.40E-07
					Toxic	0	0.00E+00				Toxic release	0.00E+00
		Ignition	0.6	9.60E-07	Immediate	0.3	2.88E-07	Jet	1	2.88E-07	Jet Fire	2.88E-07
								Pool	0	0.00E+00	Pool Fire	0.00E+00
					Delayed	0.7	6.72E-07	Confined	0.25	1.68E-07	Vapour Cloud Explosion	1.68E-07
								Unconfined	0.75	5.04E-07	Flash Fire	5.04E-07

Aggregating the fatality data resulting from each initiating scenario with the frequency results for each potential outcome allowed a graphical representation of the overall level of societal risk from the new development to be represented in the form of a F-N curve as shown in Figure 6.

Figure 6 F-N Curve for the New Compressor Installation



Results and Validation

The Coarse QRA clearly indicated that the new compressors, if located in the proposed location directly to the east of the existing site, would not present an unacceptably high societal risk with the results falling within the ‘Broadly Acceptable’ region on the F-N curve. It was found that the largest number of potential casualties would arise from a jet fire at night due the associated high thermal radiation levels impacting houses in Area 3 causing them to burn at a time of day when escape would be compromised.

The results also highlighted that in the event of a jet fire Area 6 would also see significant casualties due the presence of a fast food restaurant and a service station, although in this case fatalities would be likely to be higher during the day when drivers would be most likely to use the facilities.

Figures 7 and 8 show the 1% Thermal Lethality distances for a jet fire and the distances to the LFL for a flash fire, calculated by the Coarse QRA, for both the existing compressors and the new compression plant. These hazard ranges show the zone of effect has grown for the new compressor installation, reflecting an increase in pipeline size from 900mm to 1,050mm, and how the area of effect has shifted east with the new installation. The changes in size and position of the zone of effect only have an impact on the more outlying populations (for a jet fire case), which the consequence data showed would now contact the fringes of the large residential estates at Areas 3 and 5. It was also shown that the new compressors would not result in additional fatalities for a flash fire event as no new population groups were encompassed by the revised flash fire zone associated with the new plant.

Figure 7 Existing Compressors (900mm Pipe) & New Compressors (1,050mm Pipe) – Distance to 1% Thermal Lethality (Full Bore Rupture Jet Fire)

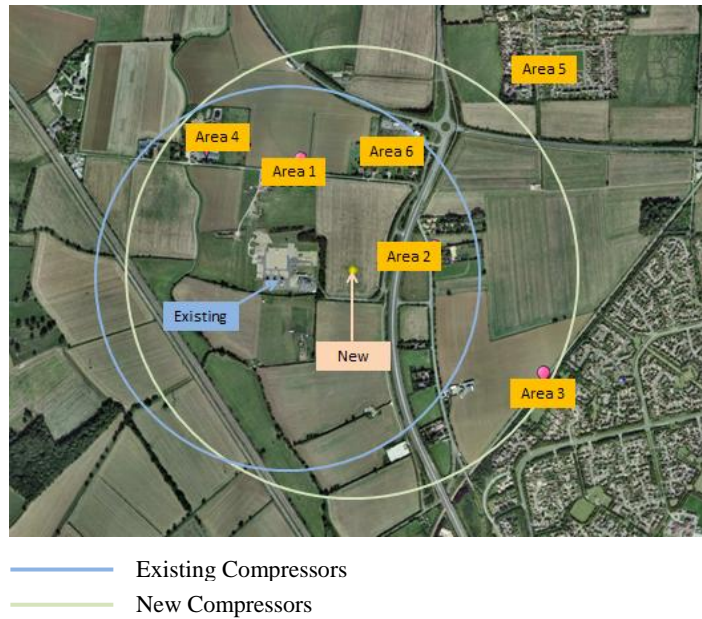
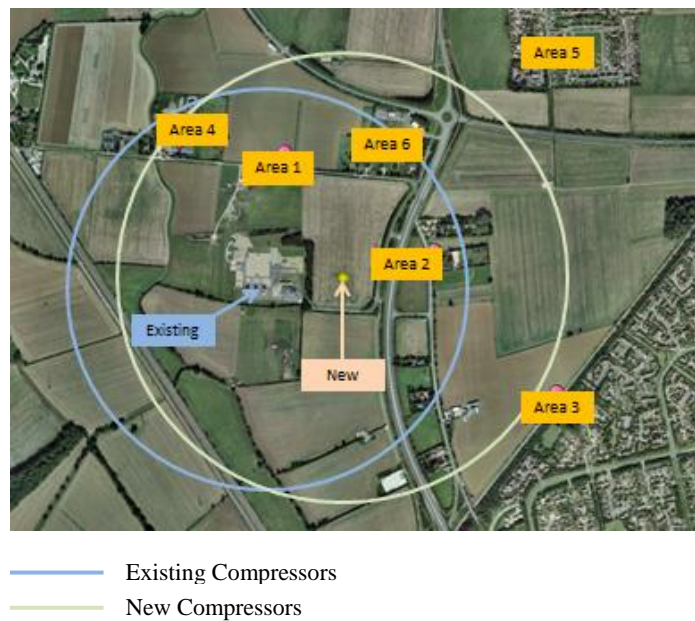


Figure 8 Existing Compressors (900mm Pipe) & New Compressors (1,050mm Pipe) – Distance to Lower Flammability Limit (Full Bore Rupture Flash Fire)



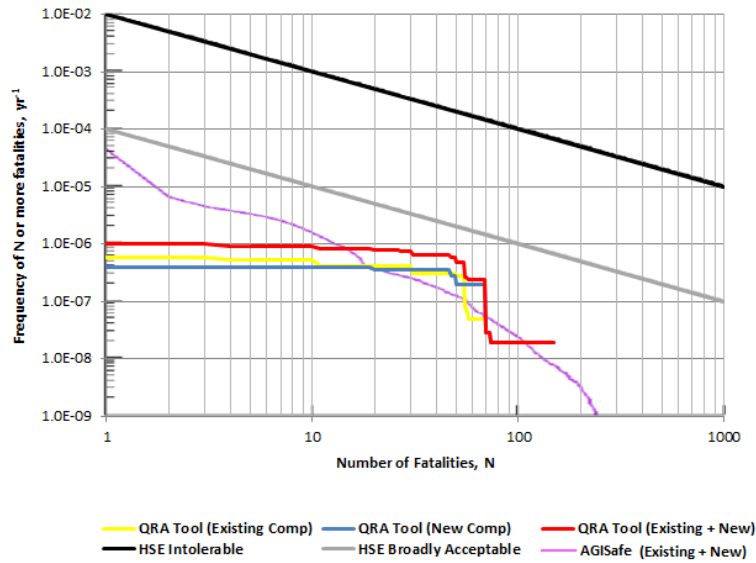
As the results of the Coarse QRA, were clear and positive, National Grid were able to enter into negotiations to purchase the land to the east of the site and the more detailed design stages of the project were able to proceed upon this basis. However, later in the project National Grid commissioned a full QRA assessment to validate the findings of the Coarse QRA model and to quantify the on-site risks, which were not assessed in the coarse study. The full QRA study was carried out using AGISafe [DNV-GL, 2014], a risk assessment software package specifically designed for assessment of National Grid assets.

Comparison of the F-N curves produced using Costain’s Coarse QRA tool and AGISafe both predicted overall societal risk would fall within the HSE ‘Broadly Acceptable’ risk region. The correlation of the two methods for high consequence / low frequency events (i.e. $N > 10$) was very good, both in terms of frequency (likelihood of event) and severity of the event. The Coarse QRA tool does in general predict more fatalities, as illustrated in Figure 9, as would be expected due to more conservative assumptions being applied in the assessment.

As the Coarse QRA tool was specifically developed to quantify low frequency higher consequence events, and on-site workers were excluded from the assessment, the results predict much lower frequencies for lower consequences high

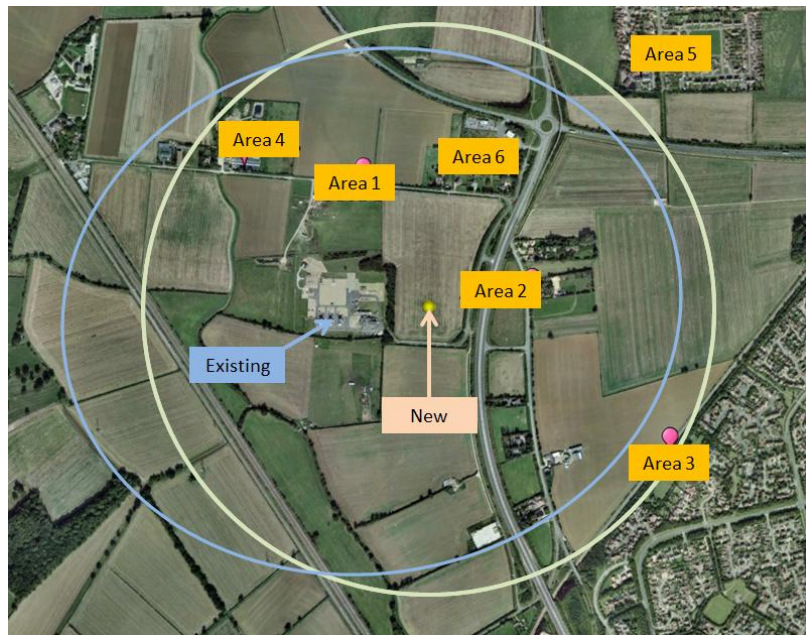
frequency events ($N \leq 10$) than AGISafe. For major events offsite casualty rates would dominate and the difference between the two studies then becomes much smaller.

Figure 9 Comparison of Coarse QRA and AGISafe F-N Curves



As well as outputting an F-N curve AGISafe can also calculate location specific risk which can be overlaid around the site to show the societal risk that the installation presents to local populations. The methodology used for the Coarse QRA is less sophisticated and requires hazard consequence results to be linked to an event tree to generate the F-N curve. This approach doesn't lend itself easily to displaying location specific risk as contours on a site map. However it is possible to compare the AGISafe risk contours with the risk levels calculated through the Coarse QRA Event Tree Analysis for specific locations. For example at Area 2 and Area 4 the Coarse QRA tool predicts location specific risk of approximately 8×10^{-7} and $7 \times 10^{-7} \text{ yr}^{-1}$ respectively. Risks produced by AGISafe are of a similar order of magnitude; Area 2 being between the 10^{-7} and $3 \times 10^{-7} \text{ yr}^{-1}$ contours and Area 4 being approximately $3 \times 10^{-7} \text{ yr}^{-1}$. Again the Coarse QRA tool is slightly conservative with respect to AGISafe.

Figure 10 Lowest Risk AGISafe Contour for Existing Site & New Compressors Compared to the Coarse QRA Distance to 1% Thermal Lethality (1,050mm Full Bore Rupture Jet Fire)



- Approximate Line of AGISafe Lowest Risk Contour (Equivalent to a Societal Risk of $1 \times 10^{-10} \text{ yr}^{-1}$) – Based on Whole of Existing Plant and New Compressors
- 1% Thermal Lethality (Equivalent to 1,060 TDU at a Frequency of $3 \times 10^{-8} \text{ yr}^{-1}$) - New Compressors Only

A third source of validation of the Coarse QRA output was possible by comparing against the HSE Consultation Distances or zones associated with the HSE's Planning Advice for Developments Near Hazardous Installations (PADHI) [HSE, 2007]. Consultation zones advise planning authorities on statutory consultation requirements with the HSE for any developments which impinge on predefined risk zones around high hazard facilities.

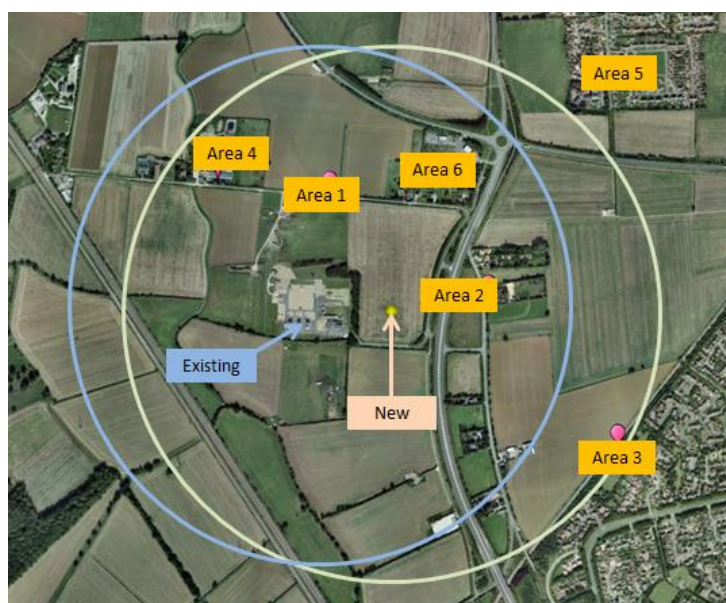
The Consultation distances defined under PADHI can be described in terms of thermal dose as follows:

- Inner Zone (IZ): Thermal Dose of 1,800TDU or above
- Middle Zone (MZ): Thermal Dose of 1,000TDU or above
- Outer Zone (OZ): Thermal Dose of 500TDU or above

On completion of the Coarse QRA it was possible to compare the hazard distances with the site's existing PADHI consultation distances. Comparing the 1% Lethality radius (1,060TDU) calculated by the Coarse QRA against the roughly equivalent PADHI MZ (1,000TDU), shows the zone of effect to be of similar size and area to the MZ but obviously shifted east to allow for the position of the new compressors (Refer to Figure 11). The new zone is in fact a little larger, which can generally be attributed to the larger pipe size associated with the new installation i.e. 1,050mm compared to 900mm.

It is noted by the authors that PADHI has been updated to the HSE's Land Use Planning Methodology, which instead of hazard consequence distance uses risk contours to establish the size of Consultation Zones. In the case of the MZ this would equate to a risk of '1 in 1,000,000 yr⁻¹ that a typical resident would be exposed a dangerous dose or worse' (HSE, 2015).

Figure 11 PADHI MZ Consultation Distance for Existing Compressor Site Compared to the Coarse QRA Distance to 1% Thermal Lethality (1,050mm Full Bore Rupture Jet Fire)



- Approximate PADHI MZ (Equivalent to 1,000TDU) for the Existing Compressor Installation (Including Balance of Plant)
- Coarse QRA 1% Thermal Lethality (Equivalent to 1,060TDU) - New Compressors Only

Sensitivity and Limitations

The Coarse QRA is sensitive to the vulnerability of indoor populations to thermal radiation, and the density of their associated dwellings, because of the basic thermal radiation calibration used as per Figure 3. Factors such as the nature of the buildings, density and screening will all affect fatality rates in Areas 3 and 5 for a jet fire resulting from a full bore rupture of a 1,050mm diameter pipe. However, analysis of the F-N curve indicates that a significant increase in the number of fatalities or the initiating event frequency would need to occur in order to bring the F-N curve in to the 'Tolerable if ALARP' (As Low As Is Reasonably Practicable) risk region, which make the results conservative.

A certain degree of conservatism was built into the original Coarse QRA model. The effects of jet fires or flash fires were considered to be uniform in all directions when in reality they are highly directional and will therefore affect some populations directly whilst others will be relatively untouched, even if nearer to the point of release, leading to an overestimate of the total number of fatalities. Further development of the Coarse QRA tool now allows the option to calculate the consequences of jet fires or flash fires in twelve directional segments to improve the accuracy of future studies.

Another inherent conservatism of the Coarse QRA tool is that for people caught by a flash fire (extent defined by the Lower Flammable Limit for natural gas) the fatality rate was considered to be the same whether indoors or outdoors. Arguably

buildings will provide some degree of protection against flash fire; the degree of protection offered will depend on the integrity of the structure and or the degree of gas built-up over time in the building. While on-site buildings can be designed with specific fire resistance and automatically operating ventilation dampers, it is not realistic for domestic or light industrial buildings close to hazardous installations to meet such requirements; therefore it was considered reasonable for the purposes of the Coarse QRA to apply the same fatality rates for all individuals, whether sheltered or unsheltered, in population areas within a flash fire envelope.

Conclusions

The Coarse QRA served its intended function which was to determine, allowing for reasonably conservative factors, whether the operation of new compression plant in an area to the east of the existing compression installation would be considered safe with respect to current off-site population levels and distribution. The Coarse QRA showed that the societal risk posed by the new compressors was not significantly different than from the existing installation and was well within the 'Broadly Acceptable' range as defined by the HSE. As a consequence of the positive Coarse QRA results National Grid was able to agree a contract to purchase the land to the east of the existing site and was subsequently able to maintain an ambitious project programme, which will result in consumers and the local population benefiting from improved system reliability and environmental performance sooner than they otherwise might have done.

The subsequent commissioning of a full QRA study and comparison against the sites HSE planning consultation zones supported the validity and value of the Coarse QRA output, albeit that the latter was, as might be expected, slightly more conservative.

The use of a Coarse QRA in project phases as early as Feasibility Design and Optioneering has shown to Costain and National Grid the benefits and confidence, especially important for non-technical stakeholders, that can be realised by a more quantitative than qualitative analysis. As a result of the success of the project Costain have continued to develop the Coarse QRA tool with the intent of working with our clients to be able to provide more informed decision making for front end design projects we deliver in the future.

Assumptions and Inputs

- The site worker population was set at four in normal circumstances up to a maximum of ten, and these individuals were only considered to be vulnerable during normal workday hours. Consequently, onsite population risks could be demonstrated to be reduced to tolerable and ALARP levels by means of the normal design and review process, and were not included in the Coarse QRA.
- Below ground pipe failure consequences were bounded by (i.e. were considered no worse than) the consequences of failure of the above ground pipework. Failure of below ground pipelines is considerably less likely than failure of above ground pipe, and would be mitigated by ground shielding effects.
- Gas releases were assumed to be in the horizontal as this would result in bigger zones of effect.
- Weather Conditions were defined as:
 - Air Temperature: 7.85°C
 - Normal Relative Humidity: 0.88
 - Wind Speed: 5ms⁻¹ with neutral conditions (Pasquill Stability Class D)
- Population numbers in specific locations were based on estimates taking account of the type of property.
- The gas release is not toxic, and asphyxiation was not considered to be a significant long range hazard.
- The probability of ignition occurring was set at 0.6 and the probability of that ignition being delayed was set at 0.7. Other input parameters were taken from published sources or estimated from first principles.
- The Coarse QRA did not assess the risk to road or rail users from the new compressors. The new compressor plant would be expected to marginally increase the risk to road users whilst offering an equivalent decrease in risk for rail travellers.
- For indoor populations at Area 3 only housing in a limited area within an arc extending approximately 100m from the edge of the estate was considered. This totals around one hundred and twenty houses lying in a zone defined by thermal radiation intensities between 6 to 20kWm⁻².

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