Gas Transmission
Network Innovation Allowance

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Above Ground Installation Integrity Decision Support Tool

NIA Final Report

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Pressure Reduction Installation Decision Support Tool

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Executive Summary

National Grid operate pressure reduction installations (PRI) on the transmission system in the UK and the US. These installations are predominantly maintained and operated to generic procedures which do not fully take into account location or site specific risks. National Grid has initiated work to develop decision support tools (DSTs) which take into account location and site specific risks

This report describes the PRI DST risk ranking model and scoring logic. The model development has been informed by Take and Regulator Station models and advice provided by the National Grid US operator. The PRI DST provides a qualitative assessment of the supply and safety risks associated with PRI design based on factors which affect the ability to continue to supply gas under fault conditions and the installation's reliability, integrity and condition. The qualitative risk model assigns numeric scores to each factor and calculates an overall risk score which reflects the likelihood of a supply failure or a loss of containment incident. The qualitative risk model will enable an assessment of the sites which are most vulnerable to failure against consistent criteria and allow these sites to be prioritised for more detailed consideration.

Ranking of risk scores will enable efficient and reliable sites to be identified, and the learning obtained can be applied to new sites and sites targeted for investment.

The use of qualitative risk models in the development of maintenance requirements is established good practice, but it is recognised that the availability and access to data can be problematic and can limit the use and application of such models. To address this, the tool is structured to efficiently use the experience and knowledge of National Grid operational personnel and accessible data.

Conclusions

The conclusions of the work described in this Report are:

1. The PRI DST model has been developed to calculate site risk scores based on an assessment of the equipment specified by National Grid. The quality of individual items of equipment is scored, these scores, which are used in calculating the site risk score, are presented in the results table to enable addition interrogation of the factors contributing to the site risk.

2. The development of the model has been informed by models and information provided by the National Grid US operator, and the scoring is based on principles taken from the standard IGEM/TD/13 and the National Grid maintenance management procedures.

3. The model is populated using data recorded through site surveys, and if required, additional data obtained through desk studies to obtain asset maintenance, inspection and fault data.

4. The model has been verified using data recorded during specific site surveys.

Recommendations

It is recommended that:

1. Sensitivity studies be carried out to review and challenge the equations and weightings used in the scoring logic to ensure the significance of the influence of specific equipment and facilities on the risk score likelihood is correct.

2. The model verification is extended to include desk studies to obtain additional data for the surveyed sites, and the desk study scoring logic modified as required.

3. A range of good and worst case site study scenarios reflecting the range National Grid PRI sites are constructed in order to identify the risk scores which confirm sites are low risk or high risk. Desk studies should then be carried out for sites with high risk scores to improve the accuracy of the score, and the results used to identify the scope for further investigations.

4. A PRI DST handbook similar to those provided by the US operator is developed to describe the scoring process and provide illustrative and photographic examples of typical equipment scores.

5. Consideration is given to the value of developing a US version of this calculator in order to obtain feedback from the US operator.

Contents

1 Introduction

1.1 Background

National Grid operate pressure reduction installations (PRI) on the transmission system in the UK and the US. These installations are predominantly maintained and operated to generic procedures which do not fully take into account location or site specific risks. National Grid has initiated work to develop decision support tools (DSTs) which will address these issues.

This report describes the PRI DST risk ranking model and scoring logic. The model development has been informed by Take and Regulator Station models and advice provided by the National Grid US operator. The PRI DST provides a qualitative assessment of the supply and safety risks associated with PRI design based on factors which affect the ability to continue to supply gas under fault conditions and the installation's reliability, integrity and condition. The qualitative risk model assigns numeric scores to each factor and calculates an overall risk score which reflects the likelihood of a supply failure or a loss of containment incident. The qualitative risk model will enable an assessment of the sites which are most vulnerable to failure against consistent criteria and allow these sites to be prioritised for more detailed consideration.

Ranking of risk scores will enable efficient and reliable sites to be identified, and the learning obtained can be applied to new sites and sites targeted for investment. The use of qualitative risk models in the development of maintenance requirements is established good practice, but it is recognised that the availability and access to data can be problematic and can limit the use and application of such models. To address this, the tool is structured to efficiently use accessible data and the experience and knowledge of National Grid operational personnel.

A risk ranking model which uses a points scoring system has been developed by Pipeline Integrity Engineers Ltd (PIE). The purpose of this model is to:

i) Calculate a score for a PRI site which represents the risk posed by the site due to the likelihood of equipment failure, causing loss of supply and or loss of containment consequences;
ii) Calculate multiplication factors using data obtained through an additional office based desk study which can reduce and improve the accuracy of the site's likelihood of failure score;
iii) Calculate a maintenance workload score;

The benefits that can be expected from applying this model include:

i) Comparison and ranking of different sites based on equipment design, condition and performance, and site security and condition;

ii) Identification of sites with high calculated risk scores for which a detailed review of potential risk reduction measures would be of value;
iii) Identification of sites with low risk scores and high maintenance workload scores for which a detailed review to justify maintenance reductions would be of value.

The model, which is available in a simple, non-interactive form, is described in this report.

1.2 Scope

A PRI DST has been developed to provide risk ranking for PRIs. The tool uses a model based upon the allocation of point scores for the risk of loss of supply and loss of containment events and the consequences of failure. A working version of the model is available, and has been populated with data recorded during site surveys carried out to verify the application of the model. The logic and application of the model are described in this report.

The tool applies to sites including the following equipment:

- Inlet, outlet valves
- Pigtraps
- Pipework (above and below ground)
- Electrical, control and instrumentation
- Filters
- Metering
- Chromatograph and other gas quality equipment
- Preheating
- Pressure reduction equipment (regulators, flow control valves, tight shut off valves, slamshuts)
- Small bore regulator (instrumentation and control) systems
- Non return valves
- Odorant plant
- Telemetry

1.3 Report Structure

The report is structured as follows:

Section 2 Summarises Take and Regulator Station risk assessment models developed by the US operator.

Section 3 Describes the development of the PRI DST model.

Section 4 Presents the application of the model to site surveys.

Section 5 Draws conclusions from the study.

Section 6 Lists recommendations from the study.

Section 7 Lists references.

Appendix 1 Presents details of the US Take Station Risk Model scoring logic

Appendix 2 Presents details of the PRI DST Model scoring logic

2 Review of the National Grid US Operator's Risk Assessment Models

The National Grid US operator has developed a risk scoring model for application to Take and Regulator stations. These models are in use, and have been used to calculate risk scores which are used to rank the risks posed by installations the models have been applied to. These models were provided as input to the development of the PRI DST model, and in addition, the US experts involved in the development and application of the models provided advice.

2.1 Risk Ranking Guidelines and Data Requirements

The US models are described in references [1 – 6]. The risk assessment considers the following three areas or modules:

i. Impact to company;

ii. Effectiveness of technical controls;

iii. Effectiveness of location specific controls.

A scoring system of between 1 (good) and 5 (poor) is used to assess a number of issues under each heading. In general, the assessment involves judging arrangements and equipment condition during a site visit. The risk assessment guidelines [1,2] for the models note that some assessments are of a more specialist nature, and are to be performed by engineers or by an engineering services company. The risk assessment guidelines documents include useful photographs and diagrams to indicate how scores should be assigned, and the assessment and work scope document [3] includes notes on the need to ensure that equipment name plates are identified and data from them obtained; or that the ownership of equipment is recorded.

The use of a consistent scoring logic of 1 (good) to 5 (poor) for all factors allows personnel collecting to develop and apply practical judgements. The Excel based model then applies weighting factors to the scores recorded for different equipment and site facilities, to reflect their differing significance and contribution to the total site risk. The weightings applied have been developed by the engineering experts who have developed the models.

For the Health and Safety, Reliability and Strategic factors the score range is increased to 7. These factors are used to assess the impact to the company using quantitative data. The impact to company and the effectiveness of location specific controls assessments are as described in section 2.

2.2 Risk Ranking Model – Structure and Scoring

The risk ranking model is presented in an Excel document which includes: the scoring for each factor; the weighting applied to the factor score; and the calculation of the total risk score. The scoring of each factor is between 1 (good) and 5 (poor). For the Health and Safety, Reliability and Strategic factors the score range is increased to 7, as described above.

The influence or significance of each factor is determined by an assigned weighting. The specific reasons for each weighting have been assigned using expert engineering judgement. The weightings for each factor within a particular module add up to 100%.

Once individual scores are obtained for each of the three modules, a likelihood score is applied to calculate the total risk ranking score. The model includes a "Sort" button, which when selected resizes the columns to their default width and sorts the populated spreadsheet based on the "Risk Score" in column F, so that the stations with the highest risk score are at the top of the worksheet.

The model structure showing the scoring and weighting for each factor is given in Figure 1. The assessment requirements are described in [6] and summarised in Appendix 1, Section A1.1, and modifications developed for the effectiveness of technical controls assessment are given in Appendix 1 Section A1.2.

2.3 US Operator Experience Applying the Risk Ranking Model

The US operator has provided Regulator Station and Take Station risk scoring tools which have been used to assist in the development of a PRI DST for application on National Grid UK sites. The US operator advised that significant effort has been invested in the last 3 years in implementing and populating these tools. The US operator also advised that the tools were set up by engineering experts, and the site models are populated using data defined in checklists completed by technicians during site visits. The operator applies an audit process to check the accuracy and consistency of the site data. Expert engineering judgement is required to interpret the site data and input scores into the models. The implementation of the tools is assisting the operator in the development of electronic asset registers which record the status, condition and compliance of the installations.

Impact to Company

Factor	Description	Score	Weighting
IC1	H&S	1 - 7	25%
IC2	Environmental	1 - 5	25%
IC3	Reliability	1 - 7	25%
IC4	Reputational	1 - 7	25%

→ Sum (IC score x weighting)

Technical Controls

Factor	Description	Score	Weighting
TC1	Access Conditions	1 - 5	4%
TC2	Vault/building condition	1 - 5	4%
TC3	Access ladder	1 - 5	4%
TC4	Above ground structure	1 - 5	3%
TC5	Vault penetration - control lines	1 - 5	4%
TC6	Vault penetration, gas main	1 - 5	4%
TC7	Regulator age	1 - 5	4%
TC8	Operational factors - monitoring	1 - 5	10%
TC9	Control line integrity	1 - 5	10%
TC10	Odorisation	1 - 5	5%
TC11	Operational factors - bypass operation	1 - 5	10%
TC12	Pipe - atmospheric corrosion	1 - 5	2%
TC13	Component - atmospheric corrosion	1 - 5	2%
TC14	Regulator separation - overpressurisation	1 - 5	10%
TC15	Venting	1 - 5	12%
TC16	System station feeds	1 - 5	8%
TC17	Station security	1 - 5	2%
TC18	Station alarming	1 - 5	2%

→ Sum (TC score x weighting)

Location Specific Controls

Factor	Description	Score	Weighting
LS1	Weather related impact	1 - 5	50%
LS2	Area type	1 - 5	50%

→ Sum (LS score x weighting)

Likelihood

Likelihood	Score
Time to Asset Failure & Coincident Event or Time to Certain Event & Coincident Event	1 - 5

→ Likelihood score

Risk score = (Technical Control Score + Location Specific Control Score) x Impact Score x Likelihood Score

Figure 1 – US Risk Ranking Model – Structure and Scoring

3 Development of the PRI DST

The PRI DST was developed in two stages. The first stage was based on the US operator's Take and Regulator station models, and enabled an understanding of and comparison with the US operator's models. The second stage involved increasing the scope of the model to address the scope required by National Grid, i.e. the equipment listed in Section 1.2, and more detailed modelling of desk or office based studies which can be applied to sites with higher risk scores.

The tool takes into account factors influencing the consequences of failure, in terms of security of supply and loss of containment; as well as location, site specific risks and site condition.

The development of the stage 1 and stage 2 models is described below.

3.1 Stage 1 PRI DST Development

The stage 1 model was developed based on the Regulator and Take station models provided by the National Grid US operator [1-5]. Like the US operator models, the aim of the stage 1 model [7] was to provide an efficient, effective and influential assessment of a population of UK PRIs. A range of complex and diverse factors is included, but these are assessed in a way that allows ranking scores to be allocated using operational knowledge and judgement, rather than through data analysis. It was envisaged that this model would be applied to a population of PRIs and used to generate the population risk ranking, identifying problems associated with the reliability of supply and the likely causes of these problems.

A simple scoring logic based upon the system used in the US models [1-6] incorporating operational experience, and assumptions made by National Grid relating to security of supply, was included.

The stage 1 model structure and scoring is shown in Figure 2.

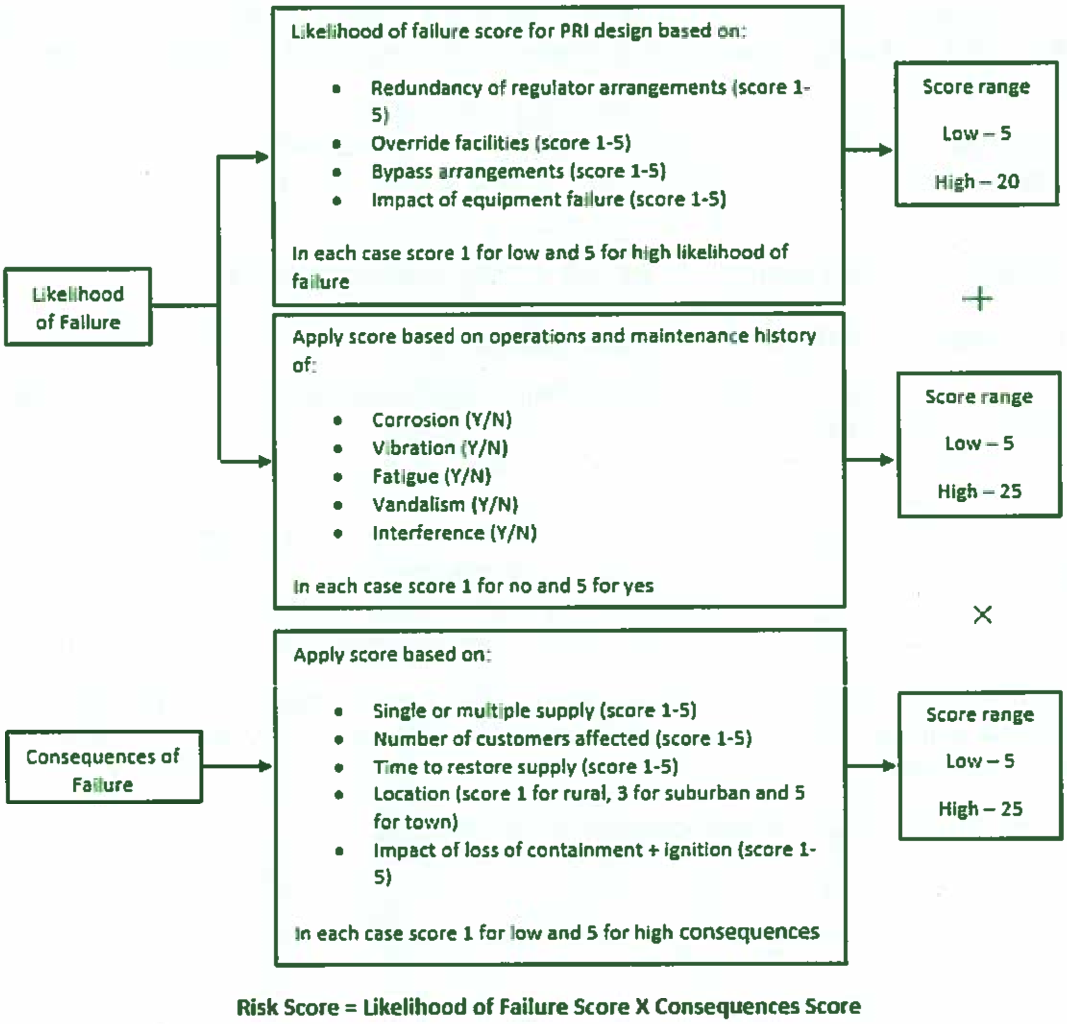

Figure 2 Stage 1 PRI DST Development - Structure and Scoring

It was intended that the simple scoring logic be applied using readily available advice/information/results and input from someone with operational experience. This approach enabled a series of questions to be developed, for scoring either in a workshop situation or during a site visit.

Results from the model would indicate which aspects of the PRI have high scores, thereby identifying which data should be prioritised for further investigation. The model was designed to identify the reason for the site risk prioritisation, so that sites for further consideration could be selected based upon the pressure control design arrangements, integrity concerns or gas supply consequences.

The development of the stage 1 model allowed the model logic to be compared with the US operator's model, and the essential requirements for the stage 2 model to be identified. As previously stated, the stage 1 model was to be used to risk rank a population of PRIs, so that the development of stage 2 model could address the sites with higher risk scores. However, obtaining sources of data to populate the model proved problematic, so the development of the stage 2 model was revised as described below.

3.2 Stage 2 PRI DST Development

It was proposed that a more detailed modelling approach would enable further consideration for sites with high risk scores, and allow the maintenance requirements of sites with low risk scores to be revised. The intention was to review and challenge the stage 1 model to investigate whether such an approach was feasible, and to determine the appropriate level of detail and data required.

The model was to be applied to all UKD and UKT PRI sites, of which there are over 850 for UKD and over 250 for UKT. A number of potential sources of the data required to populate the model for all sites were considered. Enquiries and discussions initiated by the Safety Sustainability and Resilience (SSR) Team confirmed that site asset registers and inspection and maintenance records are held in National Grid's SAP database. It was indicated however that this data is not readily accessible, and therefore could not provide a practical route to populating the model. This position is very similar to that of the US operator. It was therefore suggested that the approach applied by the US operator to model development be used to inform development of the UK model. On this basis, the planned development of the PRI DST was revised as follows:

i) Develop the scoring logic for the stage 2 model to calculate the total risk score for PRI sites.
ii) Develop the excel score calculator for the stage 2 model as a checklist for completion using a combination of available data, knowledge, and site surveys in the same way as the US model.
iii) Carry out a series of site surveys to verify the application of the model, and identify and implement changes as required.

The above approach enabled work on the model development to continue without the need to initiate a major work programme to access and extract asset details and maintenance and inspection records from the SAP database. The stage 2 model was developed to calculate a site risk score as described above, using likelihood of failure factors for site equipment, desk study multipliers, and consequence of failure factors for loss of supply and safety (i.e. loss of containment). An overview of this model is shown in Figure 3.

In addition to the risk score, the model also calculates a maintenance workload score. This score is based upon the quantity of equipment and the difficulty of access to that equipment, and thus provides a relative measure of the time required to perform routine maintenance. The maintenance workload score is separate from the likelihood and consequences of failure scores, and can be used to identify sites with low risk scores and high maintenance scores, for which there may be value in reviewing the site maintenance requirement.

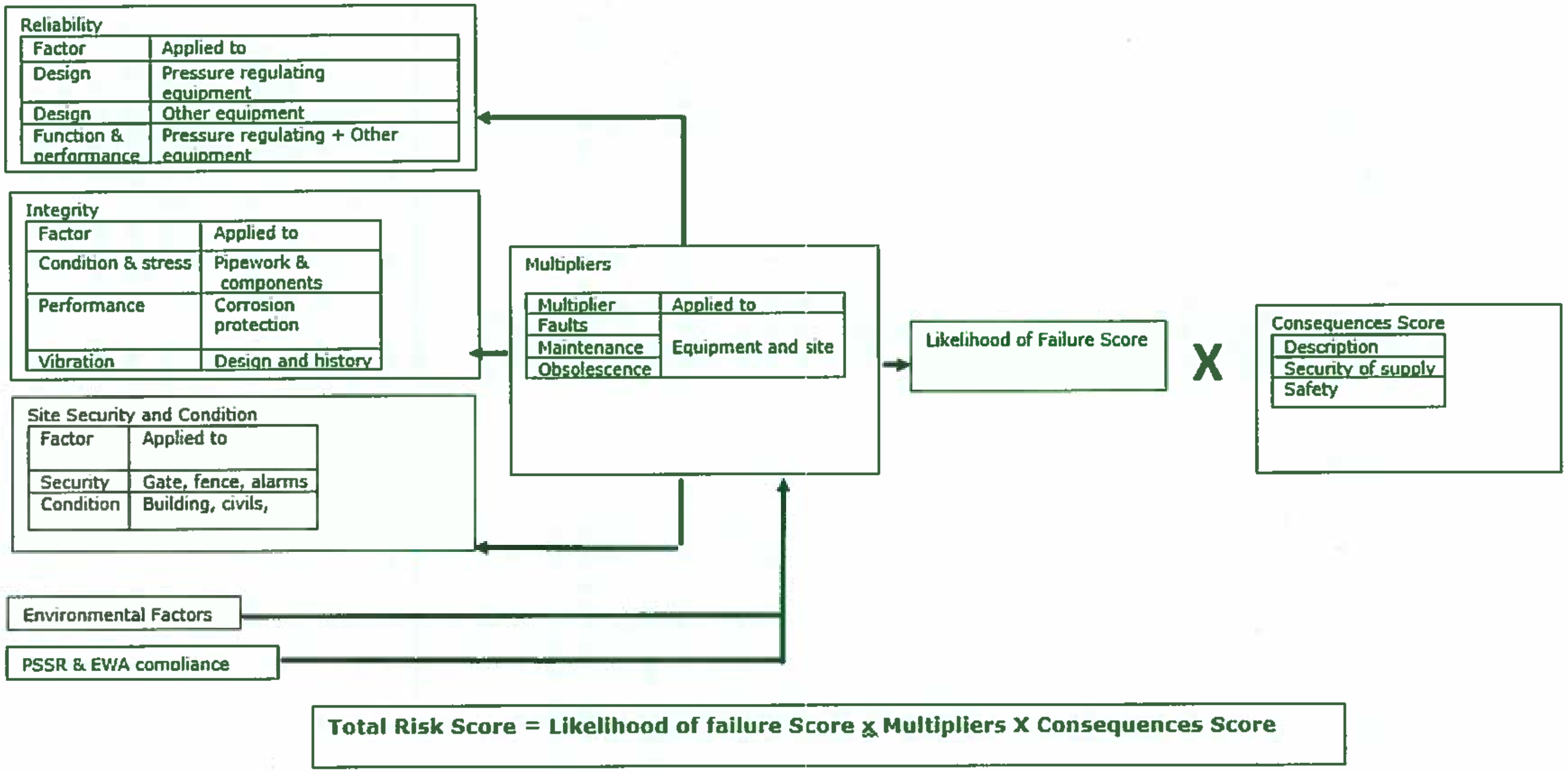

Figure 3 Stage 2 Model - Overview of Structure and Scoring Logic

3.2.1 Likelihood of Failure Factors

The factors affecting the likelihood of failure take into account the reliability of the design and performance of site equipment in avoiding failure to supply gas, and the impact of equipment integrity. The scoring has been developed using the US model score conditions 1 (low) to 5 (high).

The likelihood of failure score is based upon the type and variety of different equipment used on the site and the condition and reliability of that equipment. It is also affected by the security and condition of the site itself.

Experience applying the model during site surveys confirmed that while a significant volume of information on the type and configuration of equipment, asset condition and site security and condition can be collected from the survey, data relating to faults, equipment obsolescence, fatigue cycling, CP functionality and PSSR compliance (which can be used to develop multipliers for the likelihood of failure scores) will require an office based desk study.

The likelihood of failure score was therefore developed to comprise of two parts:

- A site study; and
- A desk study

The scoring logic was developed based on principles derived from IGEM/TD/13 [8], and the National Grid maintenance procedures [9-11].

Data required for the site study is obtained from a visit to the site itself, while the desk study requires checks of site and equipment records and certification. Completion of the desk study is not required to calculate a relative risk score for the stream/site, but can be used to improve the site study score and its accuracy. It is therefore intended that the desk study be used as a follow up analysis to the site study to potentially reduce and improve the risk score for sites for which the calculated risk score is high.

The Site Study

The site study is broken down into four individual scores:

- The pressure regulation score;
- The mechanical equipment score;
- The electrical equipment (including instrumentation and telemetry) score; and
- The site security & condition score.

These scores are used to provide assessments of three different categories of equipment used on the PRI, and an assessment of the site's condition and level of security. The three categories of equipment are the pressure regulation, mechanical and electrical (including instrumentation, control and telemetry), detailed as follows:

- Pressure regulation equipment
  - Pressure regulation equipment
  - Pressure regulation safety
- Mechanical equipment
  - Pigtraps

- Filters
- Heating system
- Meters
- Other pipework
- Chromatograph
- MEG
- Odourant

- Electrical equipment
    - Instrumentation, telemetry & control equipment
    - Cathodic protection

The list of equipment is as specified by National Grid. Details of the likelihood of failure site study scoring logic are given in Appendix 2.

The Desk Study

As previously noted, it is intended that the desk study be used as a follow up analysis to the site study to modify and improve the accuracy of the calculated relative risk score. Completion of the desk study is therefore not required to calculate a relative risk score for the site. However, if the desk study is not completed, then the maximum possible desk study scores are applied to the site risk score. The desk study is broken down into four individual scores covering the same categories as the site study:

- The pressure regulation score;
- The mechanical equipment score;
- The electrical equipment score; and
- The site security & condition score.

In the calculation of the likelihood of failure score, the desk study scores for each of the above categories are applied as factors to their site study equivalents.

Full details of the likelihood of failure desk study scoring logic are given in Appendix 2.

3.2.2 Consequence of Failure Factors

The consequences of failure score is comprised of two parts:

- The pressure stream loss of supply score; and
- The safety score

The consequences of failure, both in terms of the loss of supply and loss of containment, are dependent upon the quantity of gas flowing into the site.

Loss of Supply

The loss of supply consequences score is calculated according to:

- Whether the PRI is a single supply to a downstream network
- The criticality of the site

Maximum loss of supply consequence scores are allocated where the site is a single supply, and the maximum criticality of the site, where a pressure regulation stream provides the maximum pressure reduction (i.e. very high pressure to intermediate pressure). The criticality modelling in terms of the pressure reduction per stream is based upon the models developed by the US operator and the methodology included in the UKD RIIO 2014 report [12].

Safety

The safety consequences score is based on the risk posed to people outside the site boundary, and is calculated according to:

- The nearby population density
- The inlet pipeline diameter and pressure

The population density is determined from the area classification: rural, suburban and town. The maximum score is allocated to town areas, in which the population density and infrastructure complexity is maximum.

The inlet external pipeline diameter and inlet pressure are used to define a danger score. This gives an estimate of the size of the hazard area in the event of a loss of containment.

Based on engineering judgement, the danger score is normalised to a value of 1 for a site with a 30 inch diameter inlet pipe (762 mm) at a pressure of 70 barg. The danger score is calculated using the following expression:

$$Danger\ \mathrm{Score} = \frac{PD^2}{f}$$

Where P is the inlet pressure in barg, D is the inlet pipe diameter in mm and f is a normalising factor (with a value of 40645080 barg.mm^2).

It is noted that the US model includes a number of occupational health and safety issues. These factors are dealt with differently in the UK, and are not included in the UK model.

Full details of the consequences of failure scoring logic are given in Appendix 2.

4 Site Survey Results

A series of site surveys were carried out to obtain the data required to populate the stage 2 PRI DST model and calculate risk scores for the sites.

Surveys of the sites detailed in Table 1 were carried out. The results, including the likelihood of failure and consequence scores for loss of supply and safety (loss of containment) for each site's pressure reduction stream, the site risk score and the site maintenance score are given in Table 2. The format of the model results output is shown in Figure 4. This shows the detailed breakdown of the individual equipment item scores which are used in the calculation of the site likelihood of failure score, and the factors which are used to calculate the site consequence score. These details allow the user to identify the key factors which influence the overall site risk score.

Site Name	Inlet Pipe Diameter (mm)	Inlet Pressure (Barg)
Worsley	215	30
Cadishead	457	30
Padgate	209	30
Monks Heath	168	30
Wilmslow	324	30
Altringham	324	30
Dane Road	168	30
Partington (1)	762	70
Partington (2)	610	38

Table 1 Sites Surveyed to Obtain Data for Input to the PRI DST

Site	Likelihood of Failure	Consequences		Stream	Site	Maintenance
		Supply	Safety			
Worsley	49	25	6	1518	1518	29
Cadishead - Stream 1	53	25	9	1792	2998	40
Cadishead - Stream 2	51	15	9	1205		
Padgate	48	20	6	1242	1242	19
Monks Heath - Stream 1	55	20	6	1410	2118	36
Monks Heath - Stream 2	57	20	6	1459		
Wilmslow	52	20	7	1408	1408	34
Altringham	47	20	7	1266	1266	31
Dane Road	51	20	16	1811	1811	21
Partington (1)	55	25	30	3038	3038	42
Partington (2) - Stream 1	52	25	14	2010	8360	72
Partington (2) - Stream 2	53	25	14	2060		
Partington (2) - Stream 3	56	25	14	2184		
Partington (2) - Stream 4	54	25	14	2106		

Table 2 PRI DST Results - Calculated Site Scores

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risk sum

Site Name	Monks Heath	Monks Heath	Partington NTS	Partington LTS	Partington LTS	Partington LTS	Partington LTS
Stream Name	Stream 1	Stream 2	Stream 1	Stream 1	Stream 2	Stream 3	Stream 4
Likelihood of Failure Scores							
Pressure Regulation Equipment	[illegible]	[illegible]	0.262	0.156	[illegible]	0.200	[illegible]
Pressure Regulation Safety	0.344	[illegible]	0.372	[illegible]	0.167	[illegible]	0.311
Pressure Regulation Desk Score	1.083	1.083	[illegible]	1.063	1.083	1.083	[illegible]
Pressure Regulation Score	19	21	25	19	20	23	21
Pigtraps	0.013	0.013	[illegible]	[illegible]	0.013	0.013	0.013
Filters	0.043	0.041	0.055	0.045	[illegible]	0.073	[illegible]
Heat Exchangers	0.074	0.074	0.043	0.000	0.000	[illegible]	0.000
Heating System	[illegible]	0.048	[illegible]	0.067	[illegible]	0.067	[illegible]
Meters	[illegible]	0.079	0.085	0.083	0.067	[illegible]	0.047
Other Pipework	[illegible]	[illegible]	0.083	[illegible]	0.054	0.054	0.054
Chromatograph	0.000	0.000	[illegible]	[illegible]	[illegible]	0.000	0.000
MEG	[illegible]	0.000	0.000	0.000	0.000	0.000	[illegible]
Odourant	[illegible]	0.000	0.358	0.000	0.000	0.000	0.000
Mechanical Equipment Desk Score	1.219	1.219	1.219	1.219	[illegible]	1.219	[illegible]
Mechanical Equipment Score	7	7	13	6	7	7	6
Instrumentation, Control & Telemetry Equipment	[illegible]	0.309	0.213	[illegible]	[illegible]	0.303	0.303
Cathodic Protection	0.367	0.362	[illegible]	0.326	[illegible]	[illegible]	[illegible]
Electrical Equipment Desk Score	1.173	1.173	1.173	1.173	[illegible]	[illegible]	[illegible]
Electrical Equipment Score	16	16	10	13	13	13	13
Site Security & Condition	0.681	0.681	0.356	0.751	0.751	0.751	0.751
Site Security & Condition Desk Score	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Site Security & Condition Score	13	13	7	14	14	14	14
Likelihood of Failure Total	55	57	55	52	53	56	54
Consequences of Failure Scores							
Criticality	[illegible]	0.3	[illegible]	0.4	0.4	0.4	0.4
Single Supply	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pressure Stream Score	20	20	25	25	25	25	25
Danger	0.010	0.010	0.500	0.174	0.174	0.174	0.174
Population	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Safety Score	6	6	30	14	14	14	14
Consequences of Failure Total	26	26	55	39	39	39	39
Stream Risk Score	1410	1459	3033	2010	2060	2184	2106
Total Site Risk Score	2869	2869	3038	8360	8360	8360	8360
Stream Maintenance Workload	19	17	42	19	17	17	19

Figure 4 Format of Model Results Output

5 Conclusions

The conclusions of the work described in this Report are:

5.1 The PRI DST model has been developed to calculate site risk scores based on an assessment of the equipment specified by National Grid. The quality of individual items of equipment is scored, these scores, which are used in calculating the site risk score, are presented in the results table to enable addition interrogation of the factors contributing to the site risk.

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5.4 The model has been verified using data recorded during specific site surveys.

6 Recommendations

It is recommended that:

6.1 Sensitivity studies be carried out to review and challenge the equations and weightings used in the scoring logic to ensure the significance of the influence of specific equipment and facilities on the risk score likelihood is correct.

6.2 The model verification is extended to include desk studies to obtain additional data for the surveyed sites, and the desk study scoring logic modified as required.

6.3 A range of good and worst case site study scenarios reflecting the range National Grid PRI sites are constructed in order to identify the risk scores which confirm sites are low risk or high risk. Desk studies should then be carried out for sites with high risk scores to improve the accuracy of the score, and the results used to identify the scope for further investigations.

6.4 A PRI DST handbook similar to those provided by the US operator is developed to describe the scoring process and provide illustrative and photographic examples of typical equipment scores.

6.5 Consideration is given to the value of developing a US version of this calculator in order to obtain feedback from the US operator.

7 References

1 Take Station Inspection Handbook – Risk Assessment Guidelines (Final) (PowerPoint format)

2 I&R Inspection Handbook – Regulator Station Risk Ranking Guidelines (Final – New Model) (PDF of PowerPoint document)

3 Gate Station/Take Station Assessment & Work Scope (Excel format)

4 I&R Handbook Risk Ranking Input Data Form (PDF format)

5 Reg Station Corp Risk Assessment_2013 - 2014

6 PRI_DST PN1 -Description of the National Grid US Risk Assessment Guidelines and Regulator Station Risk Assessment. PIE. April 2015.

7 PRI_DST PN2 - PRI Decision Support Tool – Development of Risk Ranking Model J Haswell and C Lyons PIE. April 2015.

8 IGEM/TD/13 Pressure regulating installations for Natural Gas, Liquified Petroleum Gas and Liquified Petroleum Gas/Air. Edition 2. Communication 1755 Institution of Gas Engineers and Managers 2011.

9 T/PM/MAINT/2 Management Procedure for Maintenance of Pressure Reduction Installations Part 3Installations with Inlet Pressures Above 7 Barg. 01/13.

10 T/PM/MAINT/11 Management Procedure for Maintenance of Fixed Electrical Systems and Equipment. June 2010.

11 T/PM/MAINT/12 Management Procedure for Maintenance of Instrumentation Systems and Equipment. January 2012.

12 Manual for Assessing Health and Criticality of Gas Distribution Assets Parts 1 and 2. RIIO- GD1 NOM Health and Risk Reporting Methodology. G Robinson, J Madden, S Skipp, I Foster. December 2014.

Appendix 1 - US Operator Model

A1.1 Risk Ranking Guidelines

Section Title	Detailed contents	Scoring	Comments
	Impact to Company		
1 Impact to Company	1.1 Health and Safety	1 - 7	Hazard radius – proximity to nearest structure
	1.2 Environmental Impact	1 - 5	No oil seal – odorant & asbestos present
	1.3 Reliability	1 - 7	Minimal loss of customers – major loss and high costs
	1.4 Strategic	1 - 7	Station rebuild duration Regulator station – 21 days, regulator station – 42 days Relight time 1800 customers 3 days/48 hours 1
	Effectiveness of Technical Controls		
2 Station Documentation	2.1 P&D IDs	1 - 5	On site – none
	2.2 One line diagrams	1 - 5	On site – none
	2.3 Material records	1 - 5	Material test reports, mill inspection reports
	2.4 Hydrostatic test records	1 - 5	Pressure & temperature charts,
	2.5 Weld records	1 - 5	NDE reports, X rays, UT
3 Station Design	3.1 Inlet/outlet valves	1 - 5	Marking, accessibility
	3.2 Vibration	1 - 5	% time occurring
4 Station Access	4.1Access to gate stations	1 - 5	Accessible, not accessible
5 Overpressure Protection	5.1 Relief or control monitor	1 - 5	ROV, no ROV
	5.2 Ownership	1 - 5	National Grid or others
6 Heater Controls	6.1 Age	1 - 5	0 – 10, 11 – 20, > 25 years
	6.2 Capacity BTU/hr	1 - 5	100%, 75-90%, peak, >75% peak

Section Title	Detailed contents	Scoring	Comments
	6.3 Redundancy	1 - 5	None – 75% peak capacity
	6.2 Isolation valves available	1 - 5	None – all heaters + bypass
7 Heater Controls	7.1 NFPA 86/ASME CSD 1 compliant	1 = yes, 5 = no	
	7.2 Redundant Fuel Gas Isolation	1 = yes, 5 = no	
	7.3NFPA 54 compliant venting air infiltration	1 = yes, 5 = no	
	7.4 Wiring and compliance to NFPA 70	1 = yes, 5 = no	
	7.5 Personal Insulation protection on stack	1 = yes, 5 = no	
8 Back up Generators	8.1 Condition	1 – 5	None – available with auto start
9 UPS	9.1 Capacity & condition	1 - 5	24 hrs + - less than 12 hours
10 RTU & Telemetry	10.1 Type & points monitored	1 - 5	Hard wired, cellular link
11 Station Controls	11.1 Check metering	1 – 5	UT - none
	11.2 Tubing, supports	1 - 5	condition
12 Motorised Pilots	12.1	1 - 5	One or both lines contain motorised pilot
13 Motorised Valves	13.1 Condition	1 - 5	Clean – not functional
	13.2 Position indication	1 - 5	None – local + remote
	13.3 Functionality tests	1 - 5	Untested – Annual test
14 Manual Station Valves	14.1 Type	1 - 5	Plug - ball
	14.2 Condition	1 - 5	Non-operational – clean & lubricated
	14.3 Valve sealing ability	1 - 5	Untested – class IV shutdown
	14.4 Position indicators	1 - 5	None – local indication

Section Title	Detailed contents	Scoring	Comments
15 Scrubbers	15.1 Age		
	15.2 Metal condition/ corrosion, tank contents, environmental etc	1 - 5	
	15.3 Drip Tank Contents	1 - 5	No debris – hazardous liquids
	15.4 Maximum Drip Tank Volume (Gal)	1 - 5	< 51 gals – 99,999 gals
	15.5 Mechanical Safety Design	1 - 5	Safety relief – no safety relief or spares
	15.6 Design and Construction	1 - 5	AG & inside – BG no CP
	15.7 Spill Containment Design	1 - 5	Double containment - none
16 Filters	16.1 Age	1 - 5	< 10 years - > 40 years
	16.2 Condition	1 - 5	Good - damaged
17 Chromatographs	17.1 Age	1 - 5	< 15 year, > 15 years
	17.2 Tubing condition	1 – 5	Copper – stainless steel
	17.3 Heated gas test	1 = yes, 5 = no	
	17.4 Cylinders secured	1 = yes, 5 = no	
	17.5 Chromatograph well maintained, clean, calibrated	1 = yes, 5 = no	
18 Safety Devices	18.1 Gas Detection	1 - 5	Has maintenance records - none
	18.2 fire detection	1 – 5	Has maintenance records - none
	18.3 Fire extinguisher	1 – 5	At entrance with current inspection - none
	18.4 Fire alarm	1- 5	Yes with remote monitor - none
19 Security	19.1 Fence	1 - 5	Barbed/razor wire – breached, messy
	19.2 Gates	1 – 5	Motorised with card access – damaged manual
	19. 3 Perimeter alarm	1 - 5	Electronic - none

Section Title	Detailed contents	Scoring	Comments
	19.4 Intrusion alarms on cabinets	1 = yes on critical cabinets, 5 = no	
	19.5 Intrusion alarms on vaults	1 = yes, 5 = no	
20 Odorant System	20.1 Spill Containment Design	1 – 5	Full - none
	20.2 Odorization Equipment	1 – 5	New with monitoring – no odoriser but required by code
	20.3 Storage Tank Condition	1 – 5	Good - >50% wall loss
	20.4 Tubing, supports	1 – 5	Well supported - unsupported
	20.5 Probes, site gauges	1 - 5	Available - none
21 Buildings	21.1 Roof	1 - 5	Transite - steel
	21.2 Roof condition	1 - 5	Water tight – missing panels
	22.3 Building separation of electrical classifications	1 - 5	Separated, mixed
	22.4 Exterior siding	1 - 5	No damage - damaged
	22.5 Doors	1 - 5	Steel, locked – needs replacement
	22.6 Steps/ramps	1 - 5	Concrete steps – no steps
	22.7 Lighting	1 - 5	Explosion proof - none
	22.8 Support system	1 - 5	Full load design – inadequate & damaged
	22.9 Windows	1 - 5	Good – damaged/missing
	22.10 Sound insulation	1 - 5	External noise < 65 dB – external noise > 80 dB
22 Cathodic protection	22.1 Atmospheric corrosion	1 - 5	Piping coated/good condition – pitted/poor condition
Effectiveness of Location Specific Controls			
23 Weather related	23.1 Humidity/wet/dry	1 - 5	Dry in all conditions – affected by weather

Section Title	Detailed contents	Scoring	Comments
24 Plant location	24.1 Adjacent neighbours	1 - 5	Located on company property – near to high risk neighbours
25 Asset Failure	25.1 Call outs	1 - 5	None – 4+ for regulator/station equipment

A1.2 Revised Technical Controls Assessment Requirements given in Risk Ranking Guidelines

Number	Details	Comments
5	Access Conditions	Location of and access to equipment
6	Vault/building condition: walls and cover	signs of deterioration of walls, cover, roof etc
7	Access ladder	design and condition of ladder and mounting brackets
8	Above ground structure - building condition	Walls/roof/doors in good condition – showing deterioration
9	Vault penetration - control lines	Coating, protection/ embedded in concrete, link seals
10	Vault penetrations, gas main	Coating, protection/ embedded in concrete, link seals
11	Equipment age - monitor/ control regulators	0-5 years, 5 - 20 years, 20 - 40 years, exceeding 40 years, Obsolete
12	Operational factors - Ops performance monitoring	monitoring, alarms, info in gas control
13	Control line integrity	CP, age
14	Odorisation	(no details)
15 - 19	Operational factors - bypass operation	No bypass - duplicate line
20	Pipe - atmospheric corrosion	no action - integrity concerns
21	Component - atmospheric corrosion	no action - integrity concerns
22	Regulator separation - overpressurisation	no overpressurisation will occur/ incident would not affect both regulators - single incident affects both regulators and safety relief causing overpressurisation
23	Venting	discharge to atmosphere above ground or in vault

Number	Details	Comments
24	System station feeds	Integrated system - single supply
25	Station security	Security device restricts entry - no security
26	Station alarming	alarm + gas detection - no alarm, no gas detection

Appendix 2 - PRI DST – Scoring

The model calculates scores for the relative risk of pressure reduction sites on the basis of the equipment installed, the operating conditions, and the site location, criticality and condition.

Risk scores are calculated by considering the functionality of the site's pressure reduction streams. The risk score for an individual pressure reduction stream is calculated by combining separate scores for the likelihood of failure and the consequences of failure of the stream together. The likelihood of failure and consequences of failure scores are combined according to the following expression:

$$\text{Stream Risk Score} = \text{Likelihood of Failure Score} \cdot \text{Consequences of Failure Score}$$

In the case of pressure reduction sites which consist of only one pressure reduction stream the stream risk score represents the overall risk score that particular site. It is noted that certain pressure reduction sites may consist of more than one pressure reduction stream. In these cases the overall site risk score is calculated by summing the risk scores from each pressure reduction stream on site:

$$\text{Site Risk Score} = \sum_{i=1}^{n} \text{Stream Risk Score}_i$$

In addition to the risk score, a maintenance workload score for each pressure reduction stream is also calculated. This score is based upon the quantity of equipment comprising the pressure stream; and the difficulty of access to that equipment; and thus provides a relative measure of the time required to perform routine maintenance for the stream. The maintenance workload score is separate from the likelihood and consequences of failure scores of the pressure reduction stream.

Consequences of Failure Score

The consequences of failure score is based upon the criticality of the pressure reduction stream with respect to a potential interruption in the gas supply (i.e. the number of consumers affected by such an incident); and the potential number of casualties in the event of a failure of the stream.

The consequences of failure score is comprised of two parts:

- The pressure stream score; and
- The safety score

Each of the above scores receives an equal weighting with regards to the makeup of the consequences of failure score.

Safety Score

The safety score is broken down further into scores for population and danger. Each of these scores receives an equal weighting with regards to the makeup of the safety score.

The population score is calculated using the area classification of the site from IGEM/TD/13 [8] which is defined in accordance with the local population density. A score ranging from 1 to 5 is assigned to the pressure reduction stream on the basis of the area classification, with sites located in Type R (rural) areas receiving the lowest score and sites located in Type T (town) areas receiving the highest score. This score is then expressed as a fraction of the maximum possible score. The final population score is produced by applying a safety score weighting:

$$Population\ Score = \frac{Area\ Score}{Maximum\ Area\ Score} \cdot 0.5$$

The danger score is defined using the inlet pressure and inlet external pipe diameter, and gives an estimate of the quantity of gas flowing into the site. The danger score is normalised to a value of 1 for a site with a 30 inch diameter inlet pipe (762 mm) at a pressure of 70 barg which expresses the score as a fraction of the maximum possible. The danger score is calculated using the following expression:

$$Danger\ Score = \frac{PD^2}{f} \cdot 0.5$$

Where P is the inlet pressure in barg, D is the inlet pipe diameter in mm, f is a normalising factor (with a value of 40645080 barg.mm^2), and 0.5 is a safety score weighting.

The overall safety score is calculated by adding the population and danger scores, expressing this value as a percentage of the maximum possible safety score and applying a consequences of failure score weighting:

$$Safety\ Score = (Population\ Score + Danger\ Score) \cdot 100 \cdot 0.5$$

Pressure Stream Score

The pressure stream score is broken down further into scores for criticality and single supply. Each of these scores receives an equal weighting with regards to the makeup of the pressure stream score.

The criticality score uses the magnitude of the site pressure reduction to assess the site supply criticality The scoring is based upon the site criticality scoring logic presented in the Gas Distribution Assets RIIO 2014 report [12]. Five different categories are used in the criticality score, from which the pressure reduction for the stream can be defined. These are:

- Very High Pressure (VHP) – Intermediate Pressure (IP)
- Very High Pressure – High Pressure (HP)
- High Pressure – Low Pressure (LP)
- High Pressure – Medium Pressure (MP)
- High Pressure – Intermediate Pressure

The above list is ranked by criticality from highest to lowest. It is therefore assumed that streams with VHP-IP pressure reduction supply the largest number of consumers whereas streams with HP-IP supply the fewest. A score ranging from 1 to 5 is assigned depending upon which of the above category the stream fits into. This score is then expressed as a fraction of the maximum possible score. The final criticality score is produced by applying a pressure stream score weighting:

$$Criticality\ Score = \frac{Criticality}{Maximum\ Criticality} \cdot 0.5$$

The single supply score is used to indicate a high probability that gas supply would be interrupted for any consumers supplied by a given stream in the event of an incident on that stream. The score records whether consumers are supplied by that stream exclusively or whether other sites on the network have the capability to maintain the gas supply to those consumers in the event of a shutdown. A score ranging from 1 to 5 is assigned to a stream on the basis of an affirmative or negative as to whether it is single supply, with single supply sites receiving the highest score. The score is then expressed as a fraction of the maximum possible score. The final single supply score is produced by applying a pressure stream score weighting:

$$Single\ Supply\ Score = \frac{Yes/No}{Yes} \cdot 0.5$$

The overall pressure stream score is calculated by adding the criticality and single supply scores, expressing this value as a percentage of the maximum possible pressure stream score and applying a consequences of failure score weighting:

$$Pressure\ Stream\ Score = (Criticality\ Score + Single\ Supply\ Score) \cdot 100 \cdot 0.5$$

Consequences of Failure Calculation

The overall consequences of failure score is calculated by adding the safety and pressure stream scores:

$$Consequences\ of\ Failure\ Score = Safety\ Score + Pressure\ Stream\ Score$$

Likelihood of Failure Score

The likelihood of failure score is based upon the type and variety of different equipment used in the pressure reduction stream and the condition and reliability of that equipment. It is also affected by the security and condition of the site itself.

The likelihood of failure score is comprised of two parts:

- A site study; and
- A desk study

Data required for the site study can be readily obtained from a visit to the site itself by experienced and knowledgeable personnel. The desk study however, requires checks of previous site and equipment records and certification, and therefore may require separate office time to interrogate available documentation. Completion of the desk study is not required to calculate a relative risk score for the stream/site. Individual scores calculated as part of the desk study are used as multipliers to those calculated as part of the site study. It is therefore intended that the desk study be used as a follow up analysis to the site study to potentially reduce the calculated relative risk score.

The Site Study

The site study is broken down into four individual scores:

- The pressure regulation score;
- The mechanical equipment score;

- The electrical equipment (including instrumentation and telemetry) score; and
- The site security & condition score.

These scores are used to provide assessments of three different categories of equipment used on the pressure reduction stream, and an assessment of the site's condition and level of security.

The Pressure Regulation Score

The pressure regulation score covers equipment in the stream explicitly relating to the pressure reduction process and any associated pipework. Pressure reduction equipment is scored separately to the other mechanical equipment in the stream because of its importance to the pressure reduction process.

The pressure regulation score is based upon the functionality and the safety of the pressure reduction equipment and pipework. The score is split into separate equipment and safety scores which have equal weighting with regards to the makeup of the pressure regulation score.

The equipment score provides a measure of the likelihood that the pressure reduction equipment will fail, and the ability of the stream design to cope with that failure. The score is calculated summatively and includes terms rating the bypass arrangement, the condition of the equipment and the condition of standard and small bore pipework. The latter terms, relating to condition, are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the four terms in the equipment score has equal importance and therefore they each receive a weighting of 1/4. The equipment score is calculated using the following expression:

$$\begin{matrix}Equipment\\Score\end{matrix} = \frac{\begin{matrix}Bypass\\Arrangement\end{matrix}}{4\cdot Max} + \frac{\left[\begin{matrix}Equipment\\Condition\end{matrix}\cdot\begin{matrix}Pressure\\Protection\end{matrix}\cdot\begin{matrix}Noise\\Level\end{matrix}\cdot Location\right]}{4\cdot Max} + \frac{\left[\begin{matrix}Pipework\\Condition\end{matrix}\cdot\begin{matrix}Redundant\\Stabbings\end{matrix}\cdot\begin{matrix}Pipework\\Supports\end{matrix}\right]}{4\cdot Max} + \frac{\left[\begin{matrix}Small\ Bore\\Condition\end{matrix}\cdot\begin{matrix}Control\\Cabinet\end{matrix}\right]}{4\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The safety score provides a measure of the safety of the pressure reduction equipment. It considers the likelihood of an accidental overpressure, the potential for escape and dangers from venting and noise level. As with the equipment score, the safety score is calculated summatively and includes terms for regulator arrangement, regulator type, pressure drop per regulator, pressure protection devices, relief valves, non-return valves, venting method, noise level and location. The factors used in the calculation are assigned a score ranging from 1 to 5. Each of the terms is presented as a fraction, where the score of the factors within that term is divided by the maximum possible score. The terms are then weighted with respect to their importance to the calculation. Each of the nine terms in the safety score has an equal importance and therefore they each receive a weighting of 1/9. The safety score is calculated using the following expression:

$$\begin{matrix}Safety\\Score\end{matrix} = \frac{\begin{matrix}Regulator\\Arrangement\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Regulator\\Type\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Pressure\\Drop\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Pressure\\Protection\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Relief\\Valve\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Non-Return\\Valve\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Venting\\Method\end{matrix}}{9\cdot Max} + \frac{\begin{matrix}Noise\\Level\end{matrix}}{9\cdot Max} + \frac{Location}{9\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The overall pressure regulation score is produced by first applying pressure regulation score weightings of 0.5 to both the equipment and safety scores, the scores are then added and the value is expressed as a percentage of the maximum possible pressure regulation score:

$$Pressure\ Regulation\ Score = [(Equipment\ Score \cdot 0.5) + (Safety\ Score \cdot 0.5)] \cdot 100$$

The Mechanical Equipment Score

The mechanical equipment score covers any other mechanical equipment and associated pipework in the stream which is not explicitly part the pressure reduction process. The score is split into separate scores for different equipment types which have equal weighting with regards to the makeup of the mechanical equipment score. The equipment covered by this score is:

- Pigtraps;
- Filters;
- Heat exchangers;
- The heating system;
- Meters;
- Other pipework;
- Chromatographs;
- Monoethylene Glycol (MEG); and
- Odourant

Pigtraps

The pigtrap score provides a measure of the likelihood that an on-site pigtrap will fail. The score is calculated summatively and includes terms rating the pigtrap setup, the condition of the pigtrap and the condition of the associated pipework. The latter terms, relating to condition, are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the three terms in the pigtrap score has equal importance and therefore they each receive a weighting of 1/3. It is noted that if there are no pigtraps on the site, the pigtrap score will be zero. The pigtrap score is calculated using the following expression:

$$\begin{matrix}Pigtrap\\Score\end{matrix} = \frac{\begin{matrix}Pigtrap\\Type\end{matrix}}{3 \cdot Max} + \frac{\left[\begin{matrix}Pigtrap\\Condition\end{matrix} \cdot \begin{matrix}Pressure\\Vessel\\Plate\end{matrix}\right]}{3 \cdot Max} + \frac{\left[\begin{matrix}Pipework\\Condition\end{matrix} \cdot \begin{matrix}Redundant\\Stabbings\end{matrix} \cdot \begin{matrix}Pipework\\Supports\end{matrix}\right]}{3 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Filters

The filters score provides a measure of the likelihood that the filters will fail, and the ability of the stream design to cope with that failure. The score is calculated summatively and includes terms rating the filter bypass and layout, the condition of the filters and the condition of the associated pipework. The latter terms, relating to condition, are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the three terms in the filters score has equal importance and therefore they each receive a weighting of 1/3. The filters score is calculated using the following expression:

$$\begin{matrix} Filters \\ Score \end{matrix} = \frac{\left[\begin{matrix} Filter \\ Arrangement \end{matrix} + \begin{matrix} Isolation \\ Valves \end{matrix}\right]}{3 \cdot Max} + \frac{\left[\begin{matrix} Filter \\ Condition \end{matrix} \cdot \begin{matrix} Pressure \\ Vessel \\ Plate \end{matrix}\right]}{3 \cdot Max} + \frac{\left[\begin{matrix} Pipework \\ Condition \end{matrix} \cdot \begin{matrix} Redundant \\ Stabbings \end{matrix} \cdot \begin{matrix} Pipework \\ Supports \end{matrix}\right]}{3 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Heat Exchangers

The heat exchangers score provides a measure of the likelihood that heat exchanger equipment will fail, and the ability of the stream design to cope with that failure. The score is calculated summatively and includes terms rating the bypass arrangement, the condition of the heat exchangers and the condition of the associated pipework. The latter term, relating to pipework condition, is affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of the heat exchanger condition. In line with other condition scores this has been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the term. Factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the three terms in the heat exchangers score has equal importance and therefore they each receive a weighting of 1/3. It is noted that if there are no heat exchangers on the site, the heat exchanger score will be zero. The heat exchangers score is calculated using the following expression:

$$\begin{matrix} Heat \\ Exchangers \\ Score \end{matrix} = \frac{\begin{matrix} Heat \\ Exchanger \\ Arrangement \end{matrix}}{3 \cdot Max} + \frac{\begin{matrix} Heat \\ Exchanger \\ Condition \end{matrix}}{3 \cdot Max} + \frac{\left[\begin{matrix} Pipework \\ Condition \end{matrix} \cdot \begin{matrix} Redundant \\ Stabbings \end{matrix} \cdot \begin{matrix} Pipework \\ Supports \end{matrix}\right]}{3 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The Heating System

The heating system score provides a measure of the quality of the heating system, the likelihood that the system will fail, and the ability of the design to cope with that failure. The score is calculated summatively and includes terms rating the type and bypass of the heaters, the condition of the heaters and the condition of any associated pipework. The latter terms, relating to condition, are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. In the heating system score the term rating the condition of the heaters is given extra weight to account for streams which do not have a separate heat exchanger system. The condition of heaters term receives a weighting of 1/2 with the other two terms receiving a weighting of 1/4. The heating system score is calculated using the following expression:

$$\begin{matrix}Heating\\System\\Score\end{matrix} = \frac{\left[\begin{matrix}Heater\\Type\end{matrix} + \begin{matrix}Heater\\Arrangement\end{matrix} + \begin{matrix}Water\\Pump\end{matrix}\right]}{4 \cdot Max} + \frac{\left[\begin{matrix}Heater\\Condition\end{matrix} \cdot \begin{matrix}Heater\\Location\end{matrix}\right]}{2 \cdot Max} + \frac{\left[\begin{matrix}Pipework\\Condition\end{matrix} \cdot \begin{matrix}Redundant\\Stabbings\end{matrix} \cdot \begin{matrix}Pipework\\Supports\end{matrix}\right]}{4 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Meters

The meters score provides a measure of the quality of metering, the likelihood that meters will fail, and the ability of the stream design to provide metering when bypass systems are in use. The score is calculated summatively and includes terms rating the meter arrangement, use and type; the condition of the meters and the condition of the associated small bore pipework. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of meter condition and small bore condition. In line with other condition scores these have been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the terms. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the three terms in the meters score has equal importance and therefore they each receive a weighting of 1/3. It is noted that if there are no meters on the site, the meters score will be zero. The meters score is calculated using the following expression:

$$\begin{matrix}Meters\\Score\end{matrix} = \frac{\left[\begin{matrix}Meter\\Arrangement\end{matrix} + \begin{matrix}Meter\\Type\end{matrix} + \begin{matrix}Meter\\Use\end{matrix}\right]}{3 \cdot Max} + \frac{\begin{matrix}Meter\\Condition\end{matrix}}{3 \cdot Max} + \frac{\begin{matrix}Small\ Bore\\Condition\end{matrix}}{3 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Other Pipework

The other pipework score relates to any pipework which is part of the stream but not directly related to specific equipment. The score provides a measure of the likelihood that the pipework will fail. The score includes only one term, rating the condition of the pipework. This term is affected by several individual factors which are multiplied to provide a compounding effect. The factors are assigned a score ranging from 0.9 to 1.5. The calculation is presented as a fraction, where the combined score of the individual factors is divided by the maximum possible combined score. The other pipework score is calculated using the following expression:

$$\begin{matrix}Other\\Pipework\\Score\end{matrix} = \frac{\begin{bmatrix}Pipework \\ Condition\end{bmatrix} \cdot \begin{matrix}Redundant \\ Stabbings\end{matrix} \cdot \begin{bmatrix}Pipework \\ Supports\end{bmatrix}}{Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Chromatograph

The chromatograph score provides a measure of the likelihood that the chromatograph equipment will fail. The score is calculated summatively and includes terms rating the presence of a chromatograph, and the condition of the chromatograph and its location. The latter term, relating to condition, is affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the two terms in the chromatograph score has equal importance and therefore they each receive a weighting of 1/2. It is noted that if there is no chromatograph on the site, the chromatograph score will be zero. The chromatograph score is calculated using the following expression:

$$\begin{matrix}Chromatograph\\Score\end{matrix} = \frac{\begin{matrix}Chromatograph\\Installed\end{matrix}}{2 \cdot Max} + \frac{\begin{bmatrix}Chromatograph \\ Condition\end{bmatrix} \cdot \begin{matrix}Chromatograph \\ Location\end{matrix} \cdot \begin{bmatrix}Chromatograph \\ Cabinet\end{bmatrix}}{2 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

MEG

The MEG score provides a measure of the likelihood that the MEG equipment will fail. The score is calculated summatively and includes terms rating the presence of MEG on site, and the condition of the MEG. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of MEG condition. In line with other condition scores this has been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the term. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the two terms in the MEG score has equal importance and therefore they each receive a weighting of 1/2. It is noted that if there is no MEG on the site, the MEG score will be zero. The MEG score is calculated using the following expression:

$$\begin{matrix}MEG\\Score\end{matrix} = \frac{\begin{matrix}MEG\\Installed\end{matrix}}{2 \cdot Max} + \frac{\begin{matrix}MEG\\Condition\end{matrix}}{2 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Odourant

The odourant score provides a measure of the likelihood that the odourant equipment will fail. The score is calculated summatively and includes terms rating the presence of odourant on site, and the condition of the odourant. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of odourant condition. In line with other condition scores this has been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the term. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the two terms in the odourant score has equal importance and therefore they each receive a weighting of 1/2. It is noted that if there is no odourant on the site, the odourant score will be zero. The odourant score is calculated using the following expression:

$$\begin{matrix} Odourant \\ Score \end{matrix} = \frac{\begin{matrix} Odourant \\ Installed \end{matrix}}{2 \cdot Max} + \frac{\begin{matrix} Odourant \\ Condition \end{matrix}}{2 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Mechanical Equipment Calculation

The overall mechanical equipment score is produced by first applying mechanical equipment score weightings of 1/9 to the pigtrap, filters, heat exchangers, heating system, meters, other pipework, chromatograph, MEG and odourant scores. The scores are then added and the value is expressed as a percentage of the maximum possible mechanical equipment score:

$$Mechanical\ Equip.Score = \left[\frac{\begin{matrix} Pigtrap \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Filters \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Heat \\ Exchangers \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Heating \\ System \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Meters \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Other \\ Pipework \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Chromatograph \\ Score \end{matrix}}{9} + \frac{\begin{matrix} MEG \\ Score \end{matrix}}{9} + \frac{\begin{matrix} Odourant \\ Score \end{matrix}}{9} \right] \cdot 100$$

The Electrical Equipment Score

The electrical equipment score covers any electrical equipment associated with the stream. The score is split into separate scores for different equipment types which have equal weighting with regards to the makeup of the mechanical equipment score. The equipment covered by this score is:

- Instrumentation, control & telemetry equipment; and
- Cathodic protection

Instrumentation, Control & Telemetry Equipment

The instrumentation control & telemetry score rates the ability of the site to monitor and control the pressure reduction stream. It provides a measure of the quality and functionality of the instrumentation, telemetry and control systems, the likelihood that these systems will fail and the ability of the systems to cope in the event of power outage. The score is calculated summatively and includes terms rating the standby power arrangement, the condition of the electrical units and cables, the control and telemetry types, the condition of the telemetry equipment and the condition of the small bore control and instrumentation pipework. The latter two terms, relating to condition, are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of the condition of electrical units and cables. In line with other condition scores this has been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the term. Factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. In the instrumentation control & telemetry score the term rating the control and telemetry types is given extra weight to emphasise the risk to streams which do not have a telemetry system. The control and telemetry type term receives a weighting of 1/3 with the other four terms receiving a weighting of 1/6. The instrumentation control & telemetry score is calculated using the following expression:

$$\begin{gathered}\textit{Instrumentation}\\ \textit{Telemetry \& Control}\\ \textit{Score}\end{gathered} = \frac{\begin{gathered}\textit{Standby}\\ \textit{Power}\end{gathered}}{6\cdot Max} + \frac{\begin{gathered}\textit{Units \& Cables}\\ \textit{Condition}\end{gathered}}{6\cdot Max} + \frac{\left[\begin{gathered}\textit{Control}\\ \textit{Regime}\end{gathered} + \begin{gathered}\textit{Telemetry}\\ \textit{Specification}\end{gathered} + \begin{gathered}\textit{RTU Comms}\\ \textit{Type}\end{gathered}\right]}{3\cdot Max} + \frac{\left[\begin{gathered}\textit{Telemetry}\\ \textit{Condition}\end{gathered} \cdot \begin{gathered}\textit{Telemetry}\\ \textit{Location}\end{gathered} \cdot \begin{gathered}\textit{Telemetry}\\ \textit{Cabinet}\end{gathered}\right]}{6\cdot Max} + \frac{\left[\begin{gathered}\textit{Small Bore}\\ \textit{Condition}\end{gathered} \cdot \begin{gathered}\textit{Control}\\ \textit{Cabinet}\end{gathered}\right]}{6\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Cathodic Protection

The cathodic protection score provides a measure of the likelihood that the cathodic protection system will fail and the ability of the cathodic protection system to cope in the event of power outage. It also emphasises the risk to streams which do not have a cathodic protection system. The score is calculated summatively and includes terms rating the standby power arrangement, the condition of the electrical units and cables, the presence of a cathodic protection system and the condition of the cathodic protection system. The latter term, relating to condition, is affected by several individual factors which are multiplied to provide a compounding effect. It should be noted that the condition terms in the site study score for cathodic protection are based on appearance only and do not measure the performance of the cathodic protection system, this must be ascertained from records as part of the desk study. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, with the exception of the condition of electrical units and cables. In line with other condition scores this has been given a score ranging from 0.9 to 1.5 despite the fact that in this case, only one factor affects the value of the term. Factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. In the cathodic protection score the term rating the presence of a cathodic protection system is given extra weight to emphasise the risk to streams which do not have a cathodic protection system. The presence of a cathodic protection system term receives a weighting of 2/5 with the other three terms receiving a weighting of 1/5. The cathodic protection score is calculated using the following expression:

$$\begin{matrix}Cathodic\\Protection\\Score\end{matrix} = \frac{\begin{matrix}Standby\\Power\end{matrix}}{5\cdot Max} + \frac{\begin{matrix}Units\,\&\,Cables\\Condition\end{matrix}}{5\cdot Max} + \frac{2\cdot\begin{bmatrix}Presence\\Cathodic\\Protection\end{bmatrix}}{5\cdot Max} + \frac{\begin{bmatrix}Cathodic & & Cathodic\\Protection & \cdot & Protection\\Location & & Cabinet\end{bmatrix}}{5\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Electrical Equipment Calculation

The overall electrical equipment score is produced by first applying electrical equipment score weightings of 0.5 to the instrumentation, telemetry & control, and cathodic protection scores. The scores are then added and the value is expressed as a percentage of the maximum possible electrical equipment score:

$$Electrical\ Equip.Score = \left[\left(\begin{matrix}Instrumentation\\Telemetry\,\&\,Control\\Score\end{matrix}\cdot 0.5\right) + \left(\begin{matrix}Cathodic\\Protection\\Score\end{matrix}\cdot 0.5\right)\right]\cdot 100$$

The Site Security & Condition Score

The site security & condition score covers aspects of the site design and layout not directly related to the pressure reduction stream, for example the fencing, gate, buildings, civils and alarms. The score provides a rating of the general condition of these aspects in addition to a measure of the security of the site. The score is calculated summatively and includes terms for the fence type, gate type, condition of buildings, condition of civils, alarm arrangement and presence of vehicle impact protection. The terms relating to condition are affected by several individual factors which are multiplied to provide a compounding effect. Factors used in isolation in the calculation are assigned a score ranging from 1 to 5, and factors used as part of compound multipliers are assigned a score ranging from 0.9 to 1.5. Each of the terms in the calculation is presented as a fraction, where the combined score of the factors within that term is divided by the maximum possible combined score. The terms are then weighted with respect to their importance to the calculation. Each of the six terms in the site security & condition score has equal importance and therefore they each receive a weighting of 1/6. The final site security & condition score is expressed as percentage of the maximum possible. The site security & condition score is calculated using the following expression:

$$\begin{matrix}Site\ Security\\\&\ Condition\\Score\end{matrix} = \left(\frac{\begin{matrix}Fence\\Type\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}Gate\\Type\end{matrix}}{6\cdot Max} + \frac{\begin{bmatrix}Buildings & \cdot & Buildings\\Condition & & Locks\end{bmatrix}}{6\cdot Max} + \frac{\begin{bmatrix}Civils & \cdot & Cable\ Ducts\\Condition & & Condition\end{bmatrix}}{6\cdot Max} + \frac{\begin{matrix}Alarm\\Arrangement\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}Vehicle\\Impact\\Protection\end{matrix}}{6\cdot Max}\right)\cdot 100$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The Desk Study

As previously noted, it is intended that the desk study be used as a follow up analysis to the site study to improve and potentially reduce the calculated relative risk score. Completion of the desk study is therefore not required to calculate a relative risk score for the stream/site. However, if the desk study is not completed, then the maximum possible desk study scores are applied to the stream/site risk score. The desk study is broken down into four individual scores covering the same categories as the site study:

- The pressure regulation score;
- The mechanical equipment score;
- The electrical equipment score; and
- The site security & condition score.

In the calculation of the likelihood of failure score, the desk study scores for each of the above categories are applied as factors to their site study equivalents.

In the same way as the site study the desk study scores for three of the above four categories are broken down further to address specific types of equipment and aspects of the risk:

- The pressure regulation score
    - Pressure regulation equipment
    - Pressure regulation safety
- The mechanical equipment score
    - Pigtraps
    - Filters
    - Heating system
    - Meters
    - Other pipework
    - Chromatograph
    - MEG
    - Odourant
- The electrical equipment score
    - Instrumentation, telemetry & control equipment
    - Cathodic protection

In all of these sub-scores the score is calculated summatively. The terms used vary slightly between each calculation, however common factors include a history of faults or incidents, obsolescence of equipment parts and compliance with the relevant certification. Certain scores include equipment specific terms, for example an up to date Close Interval Protection Survey for the cathodic protection score or fatigue records for the pipework. The factors used in each term are assigned a score ranging from 1 to 5 and the terms in each calculation are presented as fractions, where the score of the factor comprising that term is divided by the maximum possible score for that factor. The terms in each calculation are weighted equally with respect to each other. The overall scores for each category are calculated by applying further weightings to each of the sub-scores and then adding. The outcome is then multiplied by 0.625 and added to 0.625. This final step is performed in order to produce a factor ranging between 0.75 and 1.25 which can be applied to the site study score. This section provides a summary of the expressions used to calculate each desk study score.

The Pressure Regulation Score

The pressure regulation equipment score is calculated using the following expression:

$$\begin{matrix}Equipment\\Score\end{matrix} = \frac{\begin{matrix}PSSR\\Compliance\end{matrix}}{3 \cdot Max} + \frac{\begin{matrix}Equipment\\Obsolesence\end{matrix}}{3 \cdot Max} + \frac{\begin{matrix}History\ of\\Faults\end{matrix}}{3 \cdot Max}$$

The pressure regulation safety score is calculated using the following expression:

$$\text{Equipment Score} = \frac{\text{PSSR Compliance}}{3 \cdot Max} + \frac{\text{Equipment Obsolesence}}{3 \cdot Max} + \frac{\text{History of Faults}}{3 \cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The overall pressure regulation score is calculated using the following expression:

$$\text{Pressure Regulation Desk Score} = ([(\text{Equipment Score} \cdot 0.5) + (\text{Safety Score} \cdot 0.5)] \cdot 0.625) + 0.625$$

The Mechanical Equipment Score

The pigtrap score is calculated using the following expression:

$$\text{Pigtrap Score} = \frac{\text{PSSR Compliance}}{4 \cdot Max} + \frac{\text{Fatigue Records}}{4 \cdot Max} + \frac{\text{Equipment Obsolesence}}{4 \cdot Max} + \frac{\text{History of Faults}}{4 \cdot Max}$$

The filters score is calculated using the following expression:

$$\text{Filters Score} = \frac{\text{PSSR Compliance}}{4 \cdot Max} + \frac{\text{Fatigue Records}}{4 \cdot Max} + \frac{\text{Equipment Obsolesence}}{4 \cdot Max} + \frac{\text{History of Faults}}{4 \cdot Max}$$

The heating system score is calculated using the following expression:

$$\text{Heating System Score} = \frac{\text{Equipment Obsolesence}}{2 \cdot Max} + \frac{\text{History of Faults}}{2 \cdot Max}$$

The meters score is calculated using the following expression:

$$\text{Meters Score} = \frac{\text{Equipment Obsolesence}}{2 \cdot Max} + \frac{\text{History of Faults}}{2 \cdot Max}$$

The other pipework score is calculated using the following expression:

$$\text{Other Pipework Score} = \frac{\text{Fatigue Records}}{3 \cdot Max} + \frac{\text{Pipework Obsolesence}}{3 \cdot Max} + \frac{\text{History of Faults}}{3 \cdot Max}$$

The chromatograph score is calculated using the following expression:

$$\text{Chromatograph Score} = \frac{\text{Equipment Obsolesence}}{2 \cdot Max} + \frac{\text{History of Faults}}{2 \cdot Max}$$

The MEG score is calculated using the following expression:

$$\text{MEG Score} = \frac{\text{Equipment Obsolesence}}{2 \cdot Max} + \frac{\text{History of Faults}}{2 \cdot Max}$$

The odourant score is calculated using the following expression:

$$\begin{matrix}\text{Odourant}\\\text{Score}\end{matrix} = \frac{\begin{matrix}\text{Equipment}\\\text{Obsolesence}\end{matrix}}{2\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Faults}\end{matrix}}{2\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The overall mechanical equipment score is calculated using the following expression:

$$\begin{matrix}\text{Mechanical}\\\text{Equipment}\\\text{Desk Score}\end{matrix} = \left(\left[\frac{\begin{matrix}\text{Pigtrap}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Filters}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Heating}\\\text{System}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Meters}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Other}\\\text{Pipework}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Chromatograph}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{MEG}\\\text{Score}\end{matrix}}{8} + \frac{\begin{matrix}\text{Odourant}\\\text{Score}\end{matrix}}{8}\right]\cdot 0.625\right) + 0.625$$

The Electrical Equipment Score

The instrumentation, telemetry & control score is calculated using the following expression:

$$\begin{matrix}\text{Intrumentation}\\\text{Telemetry \& Control}\\\text{Score}\end{matrix} = \frac{\begin{matrix}\text{EAWR}\\\text{Compliance}\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}\text{Electrical}\\\text{Equipment}\\\text{Obsolesence}\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Electrical}\\\text{Faults}\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}\text{Telemetry \& Instru.}\\\text{Regulation}\\\text{Compliance}\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}\text{Telemetry \& Instru.}\\\text{Equipment}\\\text{Obsolesence}\end{matrix}}{6\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Telemetry \& Instru.}\\\text{Faults}\end{matrix}}{6\cdot Max}$$

The cathodic protection score is calculated using the following expression:

$$\begin{matrix}\text{Cathodic}\\\text{Protection}\\\text{Score}\end{matrix} = \frac{\begin{matrix}\text{EAWR}\\\text{Compliance}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{Electrical}\\\text{Equipment}\\\text{Obsolesence}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Electrical}\\\text{Faults}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{Cathodic}\\\text{Protection}\\\text{Function}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{CIPS}\\\text{Survey}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{Cathodic}\\\text{Protection}\\\text{Obsolesence}\end{matrix}}{7\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Cathodic Protection}\\\text{Faults}\end{matrix}}{7\cdot Max}$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

The overall electrical equipment score is calculated using the following expression:

$$\text{Electrical Equipment Desk Score} = \left(\left[\left(\begin{matrix}\text{Instrumentation}\\\text{Telemetry \& Control}\\\text{Score}\end{matrix}\cdot 0.5\right) + \left(\begin{matrix}\text{Cathodic}\\\text{Protection}\\\text{Score}\end{matrix}\cdot 0.5\right)\right]\cdot 0.625\right) + 0.625$$

The Site Security & Condition Score

The overall site security & condition score is calculated using the following expression:

$$\begin{matrix}\text{Site Security}\\\text{\& Condition}\\\text{Desk Score}\end{matrix} = \left(\left[\frac{\begin{matrix}\text{History of}\\\text{Theft}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Trespassing}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{History of}\\\text{Vandalism}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Site}\\\text{Safety}\\\text{Incidents}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Pipework}\\\text{Location}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Landslide}\\\text{Susceptibility}\end{matrix}}{11\cdot Max}\right.\right.$$

$$\left.\left. + \frac{\begin{matrix}\text{Seismic}\\\text{Susceptibility}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Mining}\\\text{Impact}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Cold}\\\text{Susceptibility}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Flooding}\\\text{Susceptibility}\end{matrix}}{11\cdot Max} + \frac{\begin{matrix}\text{Lightning}\\\text{Susceptibility}\end{matrix}}{11\cdot Max}\right]\cdot 0.625\right)$$

$$+ 0.625$$

Where "Max" denotes the maximum value of the combined factors in the numerator.

Likelihood of Failure Calculation

The overall likelihood of failure score is calculated by adding the individual scores for the four different categories appearing in both the site study and the desk study:

- The pressure regulation score;
- The mechanical equipment score;
- The electrical equipment score; and
- The site security & condition score.

The site study score for each category must be multiplied by its corresponding desk study score and a likelihood of failure score weighting before the addition can take place. In the likelihood of failure calculation the pressure regulation score is given extra weight to emphasise its importance to the pressure reduction process. The pressure regulation score receives a weighting of 0.4 with the other three scores receiving a weighting of 0.2. The likelihood of failure score is calculated according to the following expression:

$$\begin{aligned}&\textit{Likelihood of Failure Score}\\&=\left(\begin{matrix}\textit{Pressure}\\\textit{Regulation}\\\textit{Site Score}\end{matrix}\cdot\begin{matrix}\textit{Pressure}\\\textit{Regulation}\\\textit{Desk Score}\end{matrix}\cdot 0.4\right)+\left(\begin{matrix}\textit{Mechanical}\\\textit{Equipment}\\\textit{Site Score}\end{matrix}\cdot\begin{matrix}\textit{Mechanical}\\\textit{Equipment}\\\textit{Desk Score}\end{matrix}\cdot 0.2\right)+\left(\begin{matrix}\textit{Electrical}\\\textit{Equipment}\\\textit{Site Score}\end{matrix}\cdot\begin{matrix}\textit{Electrical}\\\textit{Equipment}\\\textit{Desk Score}\end{matrix}\cdot 0.2\right)\\&+\left(\begin{matrix}\textit{Site Security}\\\textit{\& Condition}\\\textit{Site Score}\end{matrix}\cdot\begin{matrix}\textit{Site Security}\\\textit{\& Condition}\\\textit{Desk Score}\end{matrix}\cdot 0.2\right)\end{aligned}$$

Maintenance Workload Score

As previously note, a maintenance workload score for each pressure reduction stream is also calculated in addition to the stream/site risk score. This score is based upon the quantity of equipment comprising the pressure stream; and the difficulty of access to that equipment, and thus provides a relative measure of the time required to perform routine maintenance for the stream. The maintenance workload score is separate from the likelihood and consequences of failure scores of the pressure reduction stream.

The score is calculated summatively and includes terms addressing the pressure reduction equipment, pigtraps, filters, heat exchangers, heaters, meters and chromatograph, MEG and odourant equipment. For the pressure reduction equipment term, the type and amount of equipment present is compounded by the location, which can affect the difficulty of access. Factors used in the calculation are assigned either a score ranging from 1 to 5 (e.g. for different equipment types), or a score with a value equal to the number of units present. Additionally, the location of the pressure reduction equipment is used as a multiplier and therefore is assigned a score ranging from 0.9 to 1.5. The maintenance workload score is calculated using the following expression:

$$\begin{aligned}\begin{matrix}\textit{Maintenance}\\\textit{Workload}\\\textit{Score}\end{matrix}&=\left(\left[\begin{matrix}\textit{Number of}\\\textit{Regulators}\end{matrix}+\begin{matrix}\textit{Isolation}\\\textit{Valve}\\\textit{Arrangement}\end{matrix}+\begin{matrix}\textit{Number of}\\\textit{Protection}\\\textit{Devices}\end{matrix}+\begin{matrix}\textit{Isolation}\\\textit{Valve}\\\textit{Type}\end{matrix}\right]\cdot\textit{Location}\right)+\begin{matrix}\textit{Pigtrap}\\\textit{Type}\end{matrix}+\begin{matrix}\textit{Number of}\\\textit{Filters}\end{matrix}+\begin{matrix}\textit{Number of}\\\textit{Heat Exchangers}\end{matrix}\\&+\begin{matrix}\textit{Number of}\\\textit{Heaters}\end{matrix}+\begin{matrix}\textit{Number of}\\\textit{Meters}\end{matrix}+\begin{matrix}\textit{Chromatograph}\\\textit{Installed}\end{matrix}+\begin{matrix}\textit{MEG}\\\textit{Installed}\end{matrix}+\begin{matrix}\textit{Odourant}\\\textit{Installed}\end{matrix}\end{aligned}$$

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