PLANT SPECIFIC IGNITION PROBABILITY MODEL AND CORRELATIONS FOR USE IN ONSHORE AND OFFSHORE QRA

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The probability of ignition of flammable releases from onshore and offshore installations is a key factor in determining the risks these installations present to people, assets and the environment. Yet, data and practical models available to help assessors assign suitable ignition probability distributions in QRA are lacking.

As part of a programme of initiatives in this area, the United Kingdom Operator's Association (UKOOA), the Energy Institute (EI) and the Health & Safety Executive (HSE) commissioned AEA Technology to review current data and models to assess how these could be used to improve the modelling of ignition in QRA. The review concluded that the commonly applied approach of adopting generic correlations based on the mass release rate for the probability of ignition was overly simplistic, and may lead to unrealistic and very conservative estimates in some situations. It was recognised that there was a need to take better account of the types of plant, substances, process conditions and ignition source characteristics when assigning ignition probabilities to releases of flammable materials.

AEA Technology responded by developing a model that combined recent work on the dispersion of flammable vapours in process areas with the identification of ignition characteristics in offshore and onshore plant areas and other relevant onsite and offsite land use types. The model has been benchmarked against historical ignition probability data, including detailed analysis of the Hydrocarbon Release database [HSE web 2004] operated by the Health & Safety Executive on behalf of the UK offshore industry.

The ignition probability model provides a means to estimate the overall ignition probability and an approximate time/location distribution for a specific release scenario. It can also provide an insight in to the main ignition factors and allows sensitivity

[1]ESR Technology are the former Engineering Safety and Risk Business of AEA Technology divested in October 2005

analysis and 'what-if' analysis, which may help risk analysts and designers to change the plant layout or process conditions to reduce the ignition potential.

It was also recognised that the number of factors taken in to account by the model means it may be too onerous to apply for some risk assessments. Therefore, a series of simple, mass release rate based, ignition probability look-up correlations were developed for a selected range of representative onshore and offshore plant and storage release scenarios. These correlations provide users with a simple and convenient introductory means to incorporate more appropriate ignition probability data in QRAs.

This paper describes the work undertaken and the model developed, with an emphasis on the 'look-up correlations' developed by the project, and their use in QRA. The paper provides a means to promote the use of these ignition probability correlations, which are to be published by the Energy Institute in 2005 on behalf of UKOOA, EI and the HSE.

KEYWORDS: QRA, Ignition Probability, Ignition Probabilities, Ignition Modelling

INTRODUCTION

In Spring 2002, the United Kingdom Operator's Association (UKOOA), the Energy Institute (EI) and the Health & Safety Executive (HSE) commissioned AEA Technology to review current data and models to assess how these could be used to improve the modelling of ignition in QRA: this was considered a priority area given the shortcomings in many commonly used existing ignition models and correlations and the significance of ignition probabilities in determining risk.

The review concluded that the current typical approach of adopting very generic mass release rate based correlations for the probability of ignition was overly simplistic, and may lead to unrealistic or very conservative estimates of risk in some situations. Further, some of the correlations in use do not reflect more up to date historical ignition probability data and knowledge.

A steering group was set up consisting of HSE specialists from the sponsoring industry bodies and Health & Safety Executive, operating companies and consultants to develop a broad specification for a model to assess ignition probabilities for use in QRA, and to indicate what factors the model should attempt to address.

It was generally recognised that there was a need to take better account of the types of plant, substances, process conditions and ignition source characteristics, and recent work on the dispersion of flammable vapours in ventilated areas [BG 2000] and work sponsored by the Health & Safety Executive on ignition source characteristics and overland ignition modelling [HSE 1998] [HSE 2004].

A key expectation was that the model would be able to take account of these factors in a way that would enable inform design and operational decisions to reduce the risk of ignition.

In response to this, AEA Technology developed an ignition probability model, regularly meeting with the steering group to test and direct the development. This included benchmarking the model against historical ignition probability data, including detailed analysis of the Hydrocarbon Release database [HSE web 2004] operated by the Health & Safety Executive on behalf of the UK offshore industry.

The resulting ignition probability model provides a means to estimate the overall ignition probability and an approximate time/location distribution for a specific release scenario. It can also give an insight in to the main ignition factors and allows sensitivity analysis and 'what-if' analysis, which may help risk analysts and designers to change the plant layout or process conditions to reduce the ignition potential.

Initial experience with the model showed that for a given configuration and release type, the ignition probability followed a characteristic relationship against the mass release rate. The general shape of the relationship is shown in Figure 1.

For low release rate scenarios (A), ventilation and dispersion limited the flammable cloud size and the potential for ignition. At medium release rates (B), the flammable cloud size is very dependent on the mass release rate. Eventually, for large release scenarios, the extent of the flammable region becomes limited by the available inventory, regions above the upper flammable limit or other factors such as the isolation of ignition sources or lack of new or active ignition sources, and the ignition probability approaches a limiting value or only increases slightly (C).

It was recognised that this characteristic of the model would allow a series of simple, mass release rate based, ignition probability look-up correlations to be developed for a selected range of representative onshore and offshore plant and storage release scenarios. These would provide users with a simple and convenient means to incorporate more appropriate ignition probability data in QRAs for the majority of situations. This approach also offers advantages in terms of transparency and consistency in model use. The detailed model could still be used in more complex or unusual situations, or where additional insight or analysis was required.

THE IGNITION MODEL

The UKOOA ignition probability model assesses the probability of ignition of hydrocarbon releases for use in offshore and onshore QRA by combining established data and methods on gas build up, gas dispersion, area ignition source characteristics, etc. The model estimates the volume or area of flammable gas or liquid in a given plant area, and then

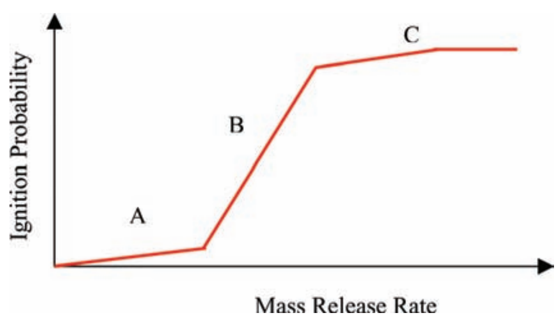

Figure 1. Ignition probability vs release rate relationship

combines this with suitable ignition source densities to calculate the overall ignition probability. The model has been structured to consider the ignition of hydrocarbons within the immediate plant area where the leak occurs, and any additional probability of ignition were the flammable vapour cloud or liquid to spread to adjacent plant areas or beyond.

MODEL STRUCTURE

The model uses a 4 Area structure that represents the ignition source types, which could be reached by any flammable gas/vapour or liquid arising from the release.

The model considers the following areas:

1. Plant Area – where the release originates
2. Adjacent Plant Area – the plant areas around the 'Plant Area'
3. Site Area – the remaining areas within the site or installation boundary
4. Off-site Area – the areas beyond the site boundary

The first three Areas are treated in the model as concentric circles/annuli characterised by radii equivalent to a circular/annular representation of the actual ground footprint area.

The model distinguishes between gaseous and liquid releases. Liquid releases can be treated as pressurised releases prone to mist/aerosol formation with rain-out to form a pool where appropriate, or as simple non-volatile liquids forming a liquid pool. An overview of the model is presented in the Figure 2.

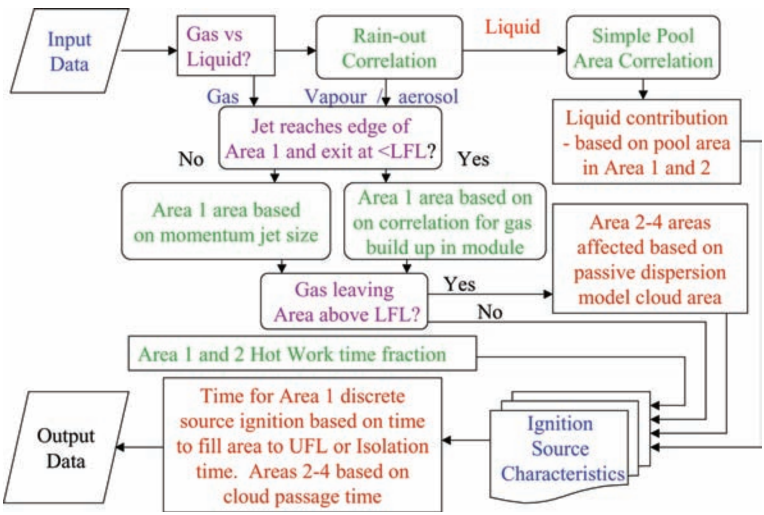

Figure 2. Ignition model structure

INPUT DATA

The model input data consists of basic information on the release, the four 'Areas' being considered and their ignition characteristics, and a number of options for modelling the release and any subsequent dispersion beyond the immediate plant area.

The characterisation of each area's ignition sources is based on selecting one of 17 generic types covering a wide range of plant and onsite and offsite land use types, including areas subject to hazardous area classification and the use of Ex rated equipment. These include various plant module types and equipment levels, and onsite and offsite general areas covering industrial, urban and rural locations.

MODEL OUTPUT

The model provides an estimate of the overall probability of ignition for the scenario, together with contributions to the probability from vapour and liquid components of the release for each of the 4 areas represented in the model. It also provides an approximate time distribution of the ignition probability as it spreads across the four areas.

Selected example model results for a variety of onshore and offshore scenarios are presented in Figure 3 and Figure 4.

MODEL IMPLEMENTATION

The ignition probability model has been implemented as a Microsoft Excel ® workbook, which allows full transparency of the model's input data, calculation methods and results.

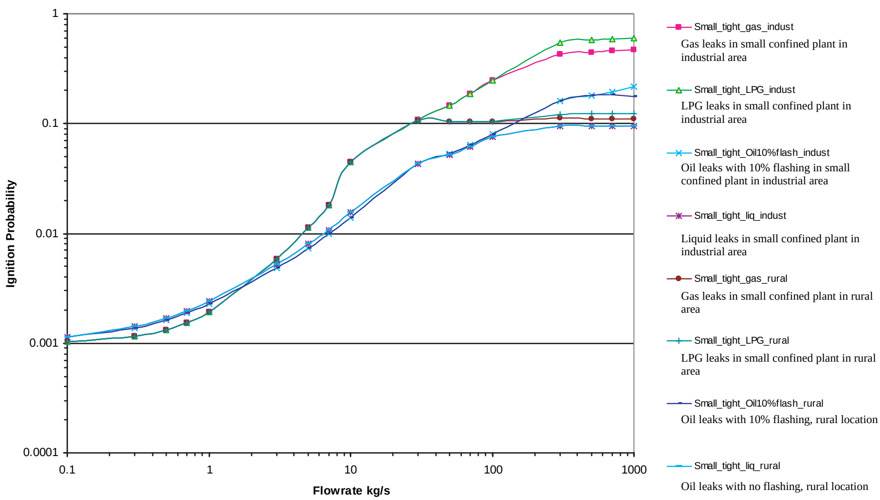

Figure 3. Small onshore plant – confined/congested plant area

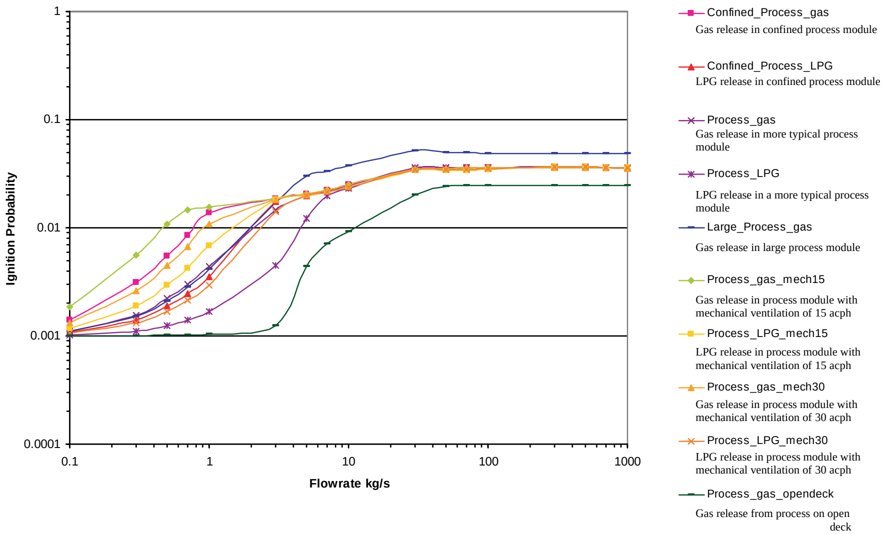

Figure 4. Offshore process module – gaseous releases

The model is available in a "single scenario" analysis version or a "batch" (multirun) version, which includes a macro to run the model for a variety of user defined scenarios and release rates.

All the required input data is entered on a single worksheet, which clearly specifies the data required and provides guidance to the user on data input and values to use, including suitable built in defaults.

A summary output sheet is also provided, which presents all the relevant ignition probability output values and contributions as well as other useful data on the flammable volumes/cloud size and release scenario characteristics.

THE LOOK-UP CORRELATIONS

The objective of this phase of work was to develop 'look-up' tables or correlations for a range of representative scenarios, providing an easy to use reference for ignition probabilities for use in QRA. These tables/correlations would be supported by guidance on how to select a suitable representative scenario, interpret and apply the data, consider sensitivities etc. This is aimed at making the model easier to use. It avoids the need to run the detailed model for every scenario, and also uses AEA Technology's detailed knowledge of the model to provide the most appropriate means to represent the scenarios. The look-up tables should also ensure a more consistent application of the ignition probability model in QRA.

The range of situations addressed by the look-up tables is intended to represent the majority of typical QRA scenarios. This should mean that many QRAs would only need to use the look-up tables to select suitable ignition probabilities for the scenarios being considered. If some of the scenarios being modelled do not fall within the range of representative scenarios in the look-up tables, then the full model can be used to estimate an appropriate ignition probability.

In all cases it was assumed that the plant/process/storage area in which the released occurred, and any adjacent plant/process/storage areas are subject to hazardous area classification and include the use of suitable Ex rated equipment.

The UKOOA Ignition Probability Model (Version D1) was used to model the representative offshore and onshore scenarios to provide a series of simple mass release rate based ignition probability correlations for use in QRA.

The following representative scenarios were assessed. These are based on discussions with various consultants and experts in industry on the scenarios and scenario characteristics required to provide a good representation of most 'major hazard' flammable release conditions:

Release Types:

- Gas releases
- LPG (flashing liquefied petroleum gas) releases, where appropriate
- Pressurised liquid oil releases – leading to a spray release with flashing/evaporation/aerosol formation
- Low pressure liquid oil releases – leading to a spreading pool only (no aerosol formation or flashing)

Release Rates:

- From 0.1 to 1000 kg/s

Onshore Configurations:

- Cross-country pipeline
- Storage facility on plant or stand-alone
- Small Plant on a small manufacturing site
- Large Plant within a refinery or large petrochemical complex

Offshore Configurations:

- Normally Unattended Installation Processing Facility
- Floating Production and Storage – Deck Processing Facility
- Integrated Deck Platform – Open Process Module
- Integrated Deck Platform – Partially Enclosed Process Module
- Integrated Deck Platform – Enclosed Process Module with Mechanical Ventilation
- Integrated Deck Platform – Compression Module
- Wellhead Module
- Riser

- Release Engulfing the Platform (e.g. blowout or massive riser event)

The development of the correlations included extensive sensitivity analysis to establish the robustness of the correlations. A wide range of factors were tested, including:

- Wind speed distribution/variation
- Hot work activity
- Presence of flares vs cold vents
- Liquid bund size
- Electrical isolation time
- Material inventory
- Jet momentum vs passive dispersion within plant areas and beyond

The results of these tests were used to select suitable bases for the look-up correlations.

LOOK-UP CORRELATION CHARACTERISTICS

The results of the scenario ignition modelling have been used to derive a number of representative best-fit curve/correlations, which can be used in QRA to estimate the probability of ignition for a wide range of common scenarios.

The correlations consist of up to three gradients (grad_a, grad_b, grad_c), each of the generic form:

$$\mathrm{Log}_{10}(y) = m \cdot \mathrm{Log}_{10}(x) + k, \text{ rearranged as } y = 10^{[m \cdot \mathrm{Log}_{10}(x) + k]}$$

Where y is the ignition probability, x is the mass release rate (kg/s), m is the 'gradient' of the correlation, and k is the y-axis 'offset' of the correlation.

Gradient a and offset a characterise the correlation between points A and B; gradient b and offset b between points B and C; and gradient c and offset c between points C and D. If an upper point is not specified, the gradient and offset values are used for all values of x (the mass flow rate) above the lower point value. Points A, B, C and D are specified as x values (i.e. mass release rates). Maximum and minimum ignition probability values are also assigned.

The look-up correlations were derived by selecting suitable 'best fit' lines to match, or envelope, the relevant model results. Some examples showing the look-up (BF Best Fit) correlations against the actual model results are presented in Figure 5 and Figure 6.

For convenience, the look-up correlations are also available in a Microsoft Excel ® workbook visual basic function, that returns the relevant ignition probability based on the mass flow rate (kg/s) and an identifier (integer) representing the generic scenario type.

LOOK-UP CORRELATIONS AVAILABLE

There are 27 generic scenario types covered by the look-up correlations, relating to typical offshore and onshore release situations. In addition, the Microsoft Excel ® workbook

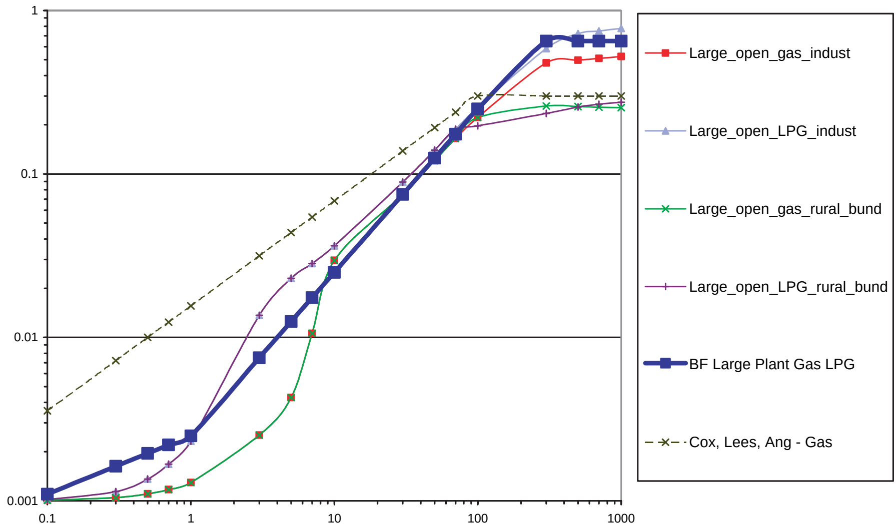

Figure 5. Look-up vs model results for onshore large plant – gas/LPG

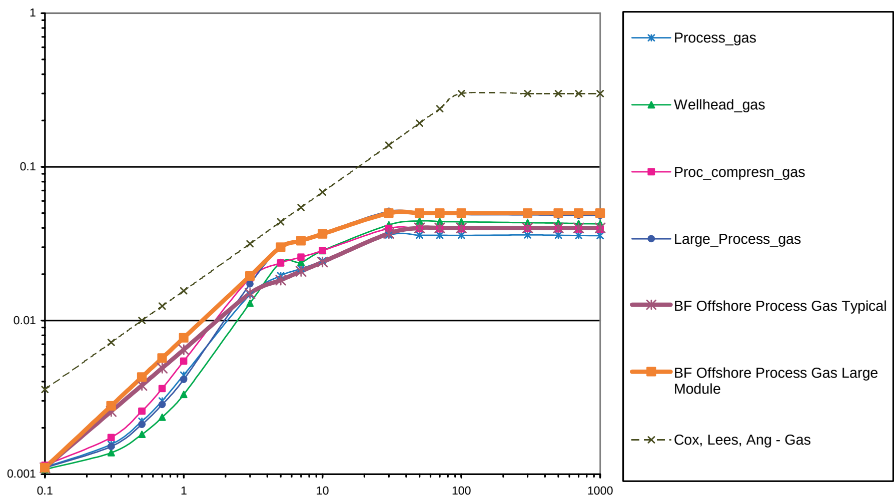

Figure 6. Look-up vs model results for offshore process module – gas

function also offers the commonly used Cox, Lees and Ang ignition probability correlations [Cox 1991] to test sensitivities and for comparison purposes. There is also a special derived correlation for use with low-pressure releases of high flash point liquids such as diesel. The full list of look-up correlations available is given in Table 1.

The look-up correlations are supported by extensive guidance on the selection of the appropriate correlation to use in a given situation, and details of the underlying basis and assumptions used in deriving the correlations. Some examples of the guidance provided is presented in Table 2. The full guidance also offers advice on ignition timing for drifting vapour clouds and estimating the likelihood of an explosion given ignition.

SOME OBSERVATIONS FROM THE WORK

A number of findings arose from the work relating to significant factors in ignition probability assessment.

One of the most apparent findings is that releases offshore, even very large releases, are unlikely to have high ignition probabilities since ignition sources on the platform are generally well controlled with Ex rated equipment maintained in very good condition, and there are negligible sources of ignition 'offsite'. By contrast, for onshore installations, larger leaks can reach offsite areas and the nature of the offsite area and extent of the flammable cloud can significantly affect the probability of ignition. Very large releases in industrial or urban areas are estimated to result in ignition probabilities approaching unity.

The importance of offsite ignition of large leaks tends to be more pronounced for storage facilities than plant, especially those holding flashing liquids where the ignition probability may be heavily dependent on drifting vapour clouds extending offsite and there may be relatively few potential ignition sources on-site. For releases in plant areas, confinement and congestion cause some initial mixing and dilution of the cloud, and there may be a higher potential for ignition on site, limiting the offsite contribution to the ignition probability.

Hot work can be a potential source of ignition, and this is considered within the model. Whilst incidents can arise where hot work is both the source of ignition and the release, these tend to be limited in size due to inventory isolations. The chance of hot work igniting an accidental release caused by some other initiating event is small. In general, if the level of hot working in an area is less than 1 hour per week, then hot work is unlikely to be a significant ignition probability contributor. However, if the level of hot work (the period with open flames, hot surfaces or sparking) exceeds 3 to 5 hours a week, it should be considered more carefully.

The timing of ignition is often used as a basis to determine the nature of the ignited event, for example whether a jet fire or explosion results from ignition of the escaping vapour. However, the data in the Hydrocarbon Release database [HSE web 2004] suggests that this may not be a reliable indication of the resulting event type. This may be due to difficulties in determining the leak and ignition timing, as well as the nature of the leak and its dispersion and the nature of the ignition. It also does not provide a means to estimate whether ignition of a vapour cloud is likely to result in an explosion or a flash fire.

Table 1. Look-Up correlations available

No	Onshore scenarios	No	Offshore scenarios
1	Pipe Liquid Industrial (Liquid release from onshore pipeline in industrial area)	17	Offshore Process Liquid (Liquid release from offshore process module)
2	Pipe Liquid Rural (Liquid release from onshore pipeline in rural area)	18	Offshore Process Liquid NUI (Liquid release from offshore process area on NUI)
3	Pipe Gas LPG Industrial (Gas or LPG release from onshore pipeline in an industrial area)	19	Offshore Process Gas Opendeck NUI (Gas release from offshore process open deck area on NUI)
4	Pipe Gas LPG Rural (Gas or LPG release from onshore pipeline in a rural area)	20	Offshore Process Gas Typical (Gas release from typical offshore process module)
5	Small Plant Gas LPG (Gas or LPG release from small onshore plant)	21	Offshore Process Gas Large Module (Gas release from large offshore process module)
6	Small Plant Liquid (Liquid release from small onshore plant)	22	Offshore Process Gas Congested or Mechanical Vented Module (Gas release from a mechanically ventilated or very congested offshore process module)
7	Small Plant Liquid Bund (Liquid release from small onshore plant where spill is bunded)	23	Offshore Riser (Gas release from typical offshore riser in air gap)
8	Large Plant Gas LPG (Gas or LPG release from large onshore plant)	24	Offshore FPSO Gas (Gas release from typical offshore FPSO process module)
9	Large Plant Liquid (Liquid release from large onshore plant)	25	Offshore FPSO Gas Wall (Gas release from offshore FPSO process module behind a transverse solid wall)
10	Large Plant Liquid Bund (Liquid release from large onshore plant where spill is bunded)	26	Offshore FPSO Liquid (Liquid release from typical offshore FPSO process module)
11	Large Plant Confined Gas LPG (Gas or LPG release from a large confined or congested onshore plant)	27	Offshore Engulf – blowout – riser (Major release which can engulf an entire offshore installation)

(*Continued*)

Table 1. Continued

No	Onshore scenarios	No	Offshore scenarios
12	Tank Liquid 300 m × 300 m Bund (Liquid release from onshore tank farm where spill is limited by a large bund)		Cox, Lees and Ang for Comparison
13	Tank Liquid 100 m × 100 m Bund (Liquid release from onshore tank farm where spill is limited by a small or medium sized bund)	28	Cox, Lees, Ang – Gas
14	Tank Gas LPG Storage Plant (Gas or LPG release from onshore tank farm within the plant)	29	Cox, Lees, Ang – Liquid
15	Tank Gas LPG Storage Industrial (Gas or LPG release from onshore tank farm sited adjacent to a plant or away from the plant in an industrial area)		Special (Derived) Scenario
16	Tank Gas LPG Storage Rural (Gas or LPG release from onshore tank farm sited adjacent to a plant or away from the plant in a rural area)	30	Tank Liquid – diesel, fuel oil (Liquid release from onshore tank farm of liquids below their flash point, e.g. diesel or fuel oil)

An alternative approach is to use historical event data. A review of historical data undertaken as part of the work suggests that for a typical open plant or module, an explosion probability of 0.2 given ignition of a vapour release may be suitable for scoping risk assessments, increasing to 0.3 for confined or congested areas or areas with more widespread or intense potential ignition sources or lower area classification/lower rated equipment. These probabilities probably reflect the variation in leak sources, dispersion conditions, confinement, congestion and ignition characteristics across a range of plant leak scenarios. The 'explosions' probably refer to events where significant overpressures were developed. For QRA purposes, an explosion probability of up to 0.5 may be appropriate for very confined or congested areas.

The overall probability of a jet fire as the initial ignited outcome, based on the historical data, is approximately 0.2 to 0.3 given ignition. It should be recognised that

Table 2. Look-up correlation selection guide (selected examples)

No.	Look-up release type	Application
4	Pipe Gas LPG Rural (Gas or LPG release from onshore pipeline in a rural area)	Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from onshore cross country pipelines running through rural areas
8	Large Plant Gas LPG (Gas or LPG release from large onshore plant)	Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from large onshore outdoor plants (plant area above 1200 m^2, site area above 35,000 m^2)
16	Tank Gas LPG Storage Rural (Gas or LPG release from onshore tank farm sited adjacent to a plant or away from the plant in a rural area)	Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from onshore outdoor storage tanks located in a 'tank farm' adjacent to plants or situated away from plants in a rural area
19	Offshore Process Gas Opendeck NUI (Gas release from offshore process open deck area on NUI)	Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from an offshore process weather deck/open deck on NUIs. Can also be used for open/uncongested weather decks with limited process equipment on larger attended integrated platforms.
20	Offshore Process Gas Typical (Gas release from typical offshore process module)	Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from within offshore process modules or decks on integrated deck/conventional installations. (Process modules include separation, compression, pumps, condensate handling, power generation, etc). If the module is mechanically ventilated or very congested – see 'Offshore Process Gas Congested or Mechanical Vented Module'. If module or deck is very large, greater than 1000 m^2 floor area, see below.
27	Offshore Engulf – blowout – riser (Major release which can engulf an entire offshore installation)	Releases from drilling or well working blowouts or riser failures where the release could engulf the entire installation and reach in to platform areas: applies to partial flashing oil or gas releases. (See also 'Offshore Riser' for riser releases and blowouts with diverters).

an event starting out as an explosion or flash fire can burn back to a jet fire if the release source is a momentum jet and has not been isolated.

However, care must be exercised if applying such assumptions to explosion exceedance analysis. If the exceedance analysis is simply based on a relationship between the release size/flammable cloud volume and the explosion overpressure, then the explosion probabilities referred to above could be applied since the exceedance adjustments are primary being based on the explosion event consequences. However, some more detailed explosion analyses also consider such factors as ignition timing, ignition location and cloud stoichiometry. In these situations, it could be argued that the exceedance modelling is addressing a range of ignited vapour cloud events from worst case explosions to negligible overpressure events – which are essentially what 'flash fires' are. Such analysis may need to use an overall probability of ignition that includes both flash fire and explosion outcomes to be consistent.

CONCLUSIONS

This paper summarises the findings of the second phase of work on a UKOOA/Energy Institute/Health & Safety Executive co-sponsored project to develop a model and guidance for assigning ignition probabilities in quantified risk analysis (QRA). The work was undertaken by AEA Technology and co-ordinated by a joint industry steering group drawn from the United Kingdom Offshore Operators Association (UKOOA), the Energy Institute, the Health and Safety Executive (HSE) and senior risk assessment consultants working in the field of onshore and offshore QRA.

This second phase of work used the UKOOA ignition probability model developed in Phase 1 to generate look-up correlations for use in assigning ignition probabilities in QRA, and to develop guidance for users on the practical application of these look-up tables in QRA.

The look-up correlations provide a convenient and simple means of applying the results of the ignition model to most common onshore and offshore QRA hydrocarbon release scenarios, avoiding the need to run the full model for each release scenario. Extensive guidance is provided on the application of the look-up correlations, including scenario selection, and addressing combined liquid and vapour releases. The report covering the work also offers advice on ignition timing and estimating the likelihood of an explosion given ignition.

However, there will be situations where the nature or complexity of the scenario or the detail of the assessment means that the look-up correlations will not be sufficient. In these cases the full model can be used to estimate the relevant ignition probabilities.

A revised and updated version of the UKOOA ignition probability model has been developed in parallel to the look-up correlation work and this will be issued at Version D1 as part of this project in both the normal and 'batch/multirun' formats provided previously.

A look-up function has also been developed, which allows the look-up correlations to be called using a simple cell function formula linked to a visual basic module in the spreadsheet. This is provided at version D1.

THE WAY FORWARD

We consider that the model and look-up correlations developed by this project provide a more appropriate means to assign ignition probabilities in QRA than the more generic approaches such as that proposed by Cox, Lees and Ang [Cox 1991]. The model and correlations allows the estimation of ignition probabilities to take better account of the release type and plant characteristics, leading to more informative and appropriate assessments of the risks.

The ignition probability model, look-up function and associated documentation are to be published by the Energy Institute in 2005.

It is hoped that the look-up correlations and model will be increasing used in quantified risk assessment for both onshore and offshore major hazard facilities.

The new ignition model and look-up correlations have already been applied successfully to several offshore quantified risk assessments (QRAs) and explosion exceedance curve assessments. The results obtained are significantly more in line with the historical data, including the detailed Hydrocarbon Release database [HSE web 2004], than previous assessment methods, suggesting that the model is providing a more realistic estimate of the ignition probabilities.

As with any novel model or method, there will be a need to consider and justify the use of the model in a given situation, and address any uncertainties or differences compared to other accepted or commonly used methods or data. This will be particularly important where the new model or correlation gives a significantly different probability than 'previous' methods.

It is intended to review experience with the model and look-up correlations at some suitable point in the future to assess its performance and provide additional benchmarking and validation where appropriate.

We would welcome any feedback on the model and look-up correlations or their application as part of our commitment to future development and validation the model.

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