On the 10^{-4} /yr criterion for blast overpressure – an alternative comparative approach for safer design

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The probabilistic explosion approach outlined in NORSOK Z-013 [1] is now widely used in the oil and gas sector for determining blast loads for design. Several parties within industry have expressed concerns relating to this probabilistic approach (for example, [2, 3]) and, indeed, Abercus shares these concerns. This paper will consider some of the uncertainties in the inputs into the probabilistic methodology and whether the current approach of compiling exceedence data and retrieving the blast load corresponding to an absolute acceptability criterion (typically a frequency of 10^{-4} /yr) is fit for purpose.

Specifically**,** Abercus has recently independently reviewed several probabilistic studies and, depending upon the input assumptions, the design blast load may vary significantly – from several barg to zero, because for the latter the relevant exceedance curve happens to fall entirely below the 10^{-4} /yr criterion. With this level of sensitivity to the underlying input assumptions, the current probabilistic approach based upon an absolute acceptance criterion is simply not credible.

Abercus proposes that instead of using a simple absolute acceptance criterion such as the 10^{-4} /yr criterion that is currently widely adopted, a relative or comparative criterion should be used instead. Such an approach requires the independent consideration of two separate models, a model of the actual asset of interest and a model of a similar notional asset that is used to define the acceptance criterion. This approach has the benefit that any uncertainties associated with the input assumptions will be inherent in both models, so that when they are compared any error will essentially cancel out.

In 2006, a similar comparative approach was introduced into the UK building regulations for the energy performance of new buildings. Despite early skepticism, largely because it was a new approach that perhaps was not well understood by many in industry at that time, the approach has now proven to be very successful for well over a decade. It provides a precedent that could be adapted to drive safer design for blast.

Introduction

The probabilistic explosion approach outlined in NORSOK Z-013 [1] is now widely used in the oil and gas sector for determining blast loads for design. This process involves three steps:

1) CFD simulations: Use computational fluid dynamics (CFD) to simulate a large number of deterministic gas dispersion and explosion consequences to form a database of representative scenarios for pre and post (delayed) ignition behaviour following a loss of containment of flammable material.
2) Probabilistic analysis: Consider the probabilities of release and ignition for each gas dispersion/explosion scenario within the database so that exceedance data can be derived for the explosion blast loads.
3) Determine the design blast loads: From the exceedance data, retrieve the blast load corresponding to the acceptability criterion – typically a frequency of 10^{-4} /yr.

Several parties within industry have expressed concerns relating to this probabilistic approach (for example, [2, 3]) and, indeed, Abercus shares these concerns. This paper will focus on steps 2 and 3 – on how the CFD predictions are interpreted and used for deriving blast loads for design. Specifically, when exceedance data is presented, it is usually only a single set of exceedance data that is provided. The sensitivity of the exceedance data to the uncertainties in the assumptions used to derive it are usually not presented, or may not even have been considered at all. Abercus has previously argued that these sensitivities should be transparent and properly understood [4].

Two important inputs into the probabilistic assessment are the release frequency data assumed for the gas dispersion analysis and the ignition frequency model assumed for the explosion analysis. However, it should be recognised that there may be significant uncertainties relating to both inputs. Abercus has recently independently reviewed several probabilistic studies and, depending upon the assumptions for these input frequencies, which have come from supposedly credible sources, the design blast load may vary significantly – from several barg to zero, the latter because the relevant exceedance curve happens to fall entirely below the 10^{-4} /yr criterion. With this level of sensitivity to the underlying input assumptions, the current probabilistic approach for determining blast design loads is simply not credible.

To address this, Abercus proposes that instead of using a simple absolute acceptance criterion such as the 10^{-4} /yr criterion that is currently widely adopted, a relative or comparative criterion should be used instead. For any assessment, this approach would require independent consideration of two separate models to allow a comparison to be undertaken:

- a model of the actual model of the asset that already exists or as will be built
- a model of a similar *notional* asset that does not and will not exist, but is designed according to certain criteria representative of its age and type.

The notional model will be used to derive blast loads for a representative asset and then, a percentage improvement upon this in terms of reduced blast impact (not just load but also structural response) will be required for the actual model/design. The benefit of this relative approach is that any uncertainties associated with the input assumptions, such as release frequencies and ignition model, will be inherent in both models, so that when they are compared any error will essentially cancel out.

Abercus has experience of a similar shift from an absolute criterion to a relative criterion in another industry, the simulation of energy performance in buildings. When this change in approach was first introduced in the UK in 2006 there was much scepticism – largely because it was a new approach which at that point was perhaps not well understood. However, it is now familiar and has proven to be very successful for well over a decade and will be discussed further in this paper. It provides a precedent that could be adapted to drive safer design for blast.

So long as industry continues to pursue an absolute approach, uncertainties in the inputs will continue to have a significant impact on the exceedance data and the approach will continue to lose credibility. A relative/comparative approach offers a way forward to re-establish confidence in the probabilistic approach.

Probabilistic explosion approach (NORSOK Z-013)

The use of a worst-case design basis for explosion loads, where only large release events are considered, will typically lead to explosion loads that are well in excess of what can be realistically designed for. Since the late 1990s, the offshore industry has progressively moved towards a risk-based design approach based upon the probabilistic methodology for risk and emergency preparedness analysis outlined in NORSOK Standard Z-013 [1]. This approach requires a large dataset of possible events to be simulated using the computational fluid dynamics (CFD) approach at each of the three stages in the sequence leading up to an explosion, as considered in Figure 1:

- the background ventilation pattern under the influence of wind or HVAC during normal operations;
- the dispersion of fuel and the accumulation of a flammable cloud following a loss of containment;
- the explosion dynamics following a delayed ignition of accumulated hydrocarbons.

If the probability of occurrence of each simulated event can be estimated, exceedance curves for the explosion load can be constructed, from which the explosion load corresponding to an allowable level of risk can be determined. This exceedance data is essentially the required output from the probabilistic analysis and is used for determining design explosion loads for subsequent structural design. NORSOK Z-013, however, provides only an outline for the probabilistic approach. There is no comprehensive industry guidance providing a specific detailed approach and, as a consequence, it should be recognized that inevitably there may be variations in the precise approach adopted by different parties.

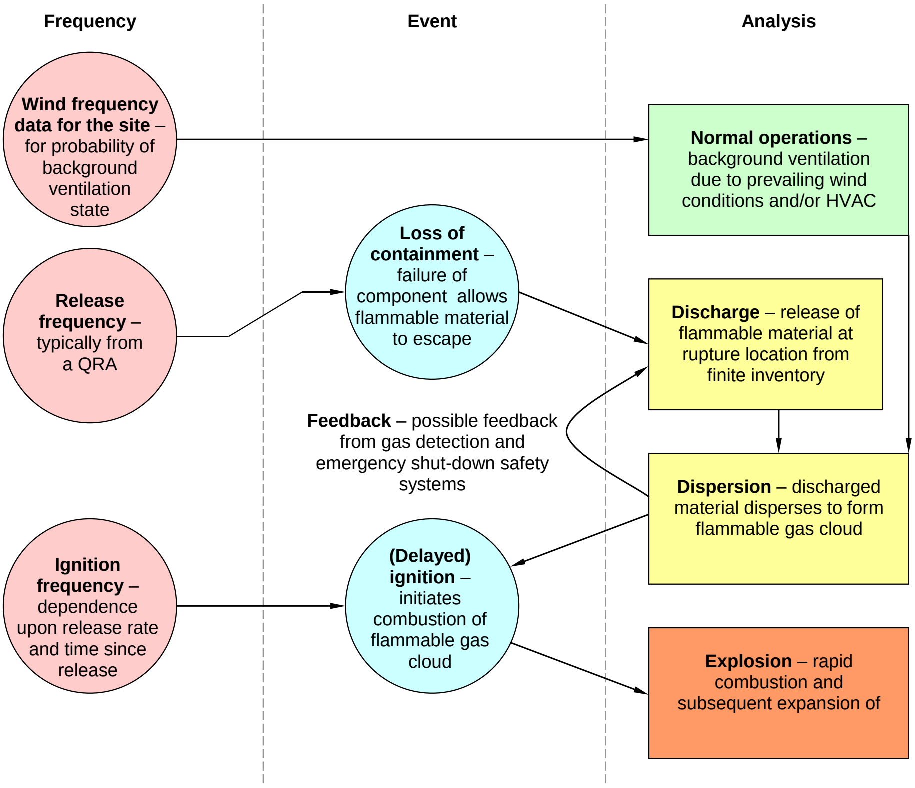

Figure 1: The sequence of events to be considered for the probabilistic approach.

Uncertainties in the inputs to a probabilistic explosion assessment

Two important inputs into the probabilistic assessment are the release frequency data assumed for the gas dispersion analysis and the ignition frequency model assumed for the explosion analysis. However, it should be recognised that there may be significant uncertainties relating to both inputs. Abercus has recently independently reviewed several probabilistic studies and, depending upon the assumptions for these input frequencies, the design blast load may vary significantly.

Release frequencies

One of Abercus recent reviews is discussed here anonymously. Abercus received the assessment and was immediately concerned that the 10^{-4} /yr blast overpressures predicted at the key target of interest seemed rather low. After a review of the CFD model and associated congestion factors, which all looked sensible, focus was turned to the release frequencies assumed for the analysis. The release frequencies assumed for the assessment are presented as *Source 1* in Table 1. As part of the review, Abercus' client independently retrieved release frequency data which is presented as *Source 2* in Table 1. Both Source 1 and Source 2 ultimately derive from the same source data, the HCR database, however there were clearly differences in the data compiled for this project. Most significantly, the data for Source 1 is around one order of magnitude lower than that for Source 2 for releases with a hole size of 75 mm or greater – as highlighted by the red values in Table 1. Without knowing which source was correct (or, indeed, whether either source was correct), Abercus retrieved representative release frequency data from two previous projects for comparison, which are presented as Source 3 and Source 4 in Table 1.

Table 1: Release frequencies for alternative sources of historical frequency data [/yr]*

Hole size [mm]	< 19	19-50	50-75	75-100	100-150	>150	Total
Source 1	1.35×10^{-2}	4.33×10^{-3}	3.49×10^{-3}	**4.59×10^{-5}**	**9.17×10^{-5}**	**2.76×10^{-4}**	2.18×10^{-2}
Source 2	1.62×10^{-2}	1.08×10^{-2}	9.13×10^{-4}	9.13×10^{-4}	1.82×10^{-3}	2.14×10^{-3}	3.29×10^{-2}
Source 3	5.40×10^{-2}	1.15×10^{-2}	3.08×10^{-3}	1.10×10^{-3}	1.78×10^{-3}	5.33×10^{-3}	7.68×10^{-2}
Source 4	1.92×10^{-2}	9.69×10^{-3}	7.81×10^{-4}	7.81×10^{-4}	1.17×10^{-4}	3.49×10^{-4}	3.09×10^{-2}

* The actual numbers presented in this table have been modified from the project report in order to protect the anonymity of the project. They do, however, remain in proportion to those presented in the project report.

The effect of the release frequencies upon the exceedence curves for blast overpressure at the principal target of interest is shown in Figure 2. From this graph it is apparent that 10^{-4}/yr overpressure for the Source 1 was predicted to be around 0.15 barg, whereas for Source 2 it was predicted to be around 0.3 barg, around twice the value.

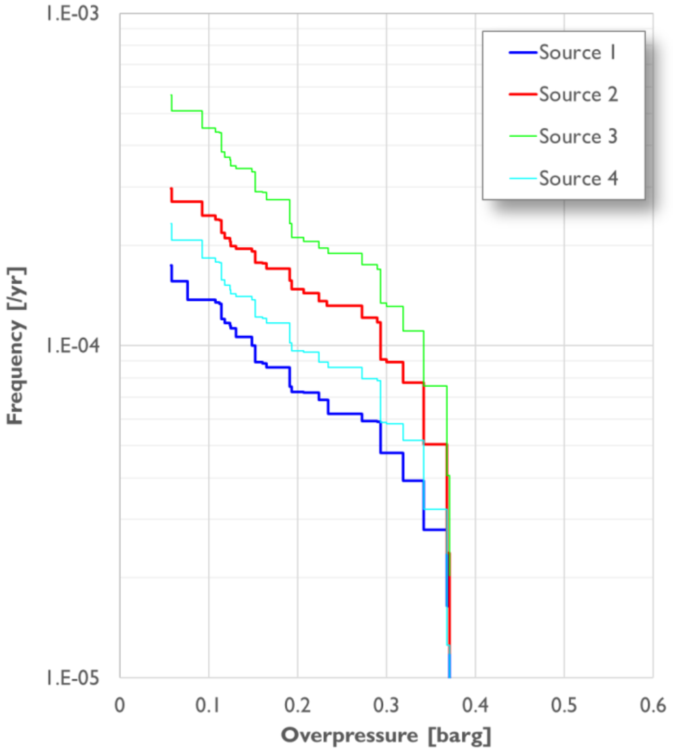

Figure 2: Variation of the exceedence curves at the principal target of interest with release frequency data.

Ignition frequencies

In the UK sector, the input ignition frequencies are often derived from the *UKOOA* ignition model [5]. However, within this model there is scope to interpret aspects of the model differently. The variation of the exceedence curves at the principal target of interest for a previous Abercus assessment is presented in Figure 3 for the six alternative formulations for ignition frequency outlined in Table 2 – each of the six formulations is permissible according to the UKOOA model. For this study, the 10^{-4} /yr blast overpressure at the target was predicted to change from a minimum of 2 barg to more than 4 barg depending upon which formulation is chosen for the ignition frequency.

Table 2: Alternative formulations for the UKOOA ignition model

Ignition methodology	Probability of ignition	Probability of explosion given ignition	Time dependence
A	UKOOA 25	Fixed at 20%	UKOOA
B	UKOOA 25	Cox, Lees and Ang	UKOOA
C	UKOOA 25	Ignored	UKOOA
D	UKOOA 25	Fixed at 20%	Ignored
E	UKOOA 25	Cox, Lees and Ang	Ignored
F	UKOOA 25	Ignored	Ignored

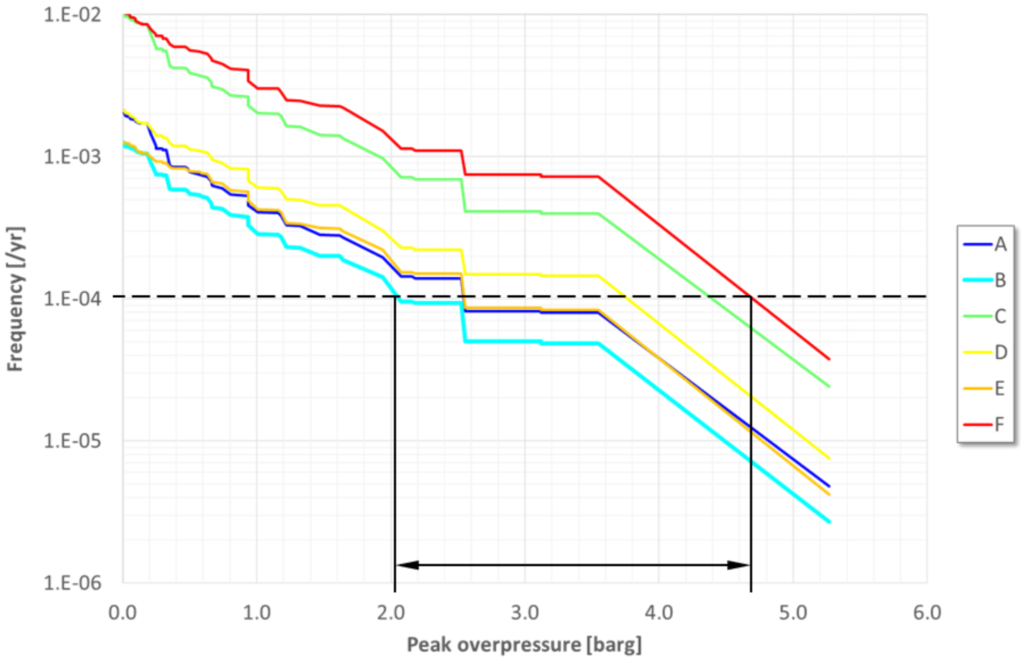

Figure 3: Variation of the exceedence curves at the principal target of interest with ignition frequency data.

Energy performance of buildings and the National Calculation Method (NCM)

Following the adoption of the EU Directive on the energy performance of buildings in 2002, the UK building regulations received a major update for the requirements for energy performance of new buildings other than dwellings (Part L2A in England and Wales, and Section 6 in Scotland) which required the energy performance of such buildings to be calculated according to the National Calculation Method (NCM). The NCM is defined by the Ministry for Housing, Communities and Local Government (MHCLG) in consultation with the devolved administrations and it provides the underlying method and a set of standard data necessary to calculate the annual energy use of a proposed building and the associated Building Emission Rate (BER) for carbon dioxide emissions due to the use of the building [6]. The energy use for a *notional* building of a similar type and under similar circumstances designed to a notional 2002 standard of construction is also calculated to determine the associated Notional Emissions Rate (NER). A Target Emissions Rate (TER) is then derived from the NER by applying two factors:

- an improvement factor (IF) of either 15% or 20%, depending upon whether the actual building is naturally ventilated or mechanically ventilated/air-conditioned
- an LZC (low/zero carbon) benchmark equal to 10%.

Specifically, TER = NER × (1 – IF) × (1 – LZC), so the TER for an air-conditioned building is 28% lower than for the 2002 standard NER. In order to comply with the building regulations, the BER must not exceed the TER.

Notional building

Note that it is the original implementation of the NCM which is described here (2006 for England and Wales, 2007 for Scotland). Over the past decade the NCM has been updated but the philosophy of the approach has remained the same – it is a comparative approach where the notional building does not actually exist, its sole purpose is to determine a relative emissions target, the TER, which is used to demonstrate compliance of the actual building.

A comparison of the notional building for a simple construction is shown in Figure 4 for the 2007 and 2010 editions of Section 6 which described the energy performance requirement for the Scottish building regulations. Note that the shape and size of the notional buildings match that of the actual building, but the notional buildings have a fixed percentage of each external wall defined as glazing (and a fixed percentage of the roof defined as a rooflight for the 2007 notional building). A similar comparison is given in Figure 5 for the 2006 and 2010 editions of Part L2A which described the energy performance requirement for the building regulations in England and Wales.

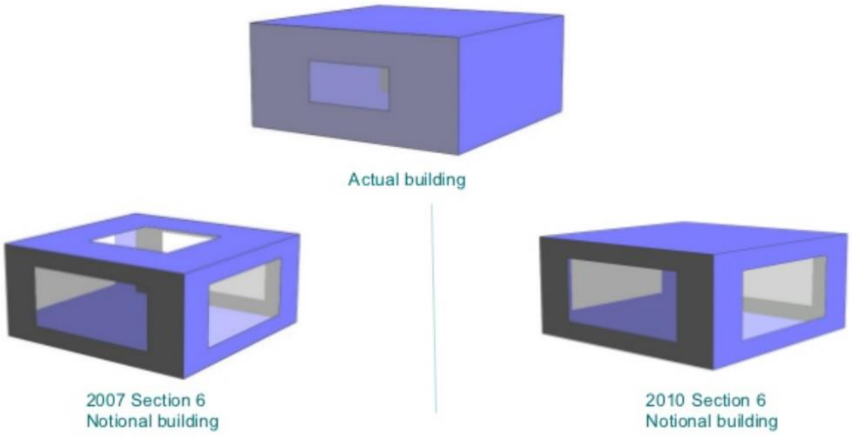

Figure 4: Comparison of the notional building with the actual building for the 2007 and 2010 editions of Section 6 (energy performance requirement for Scottish building regulations) [7].

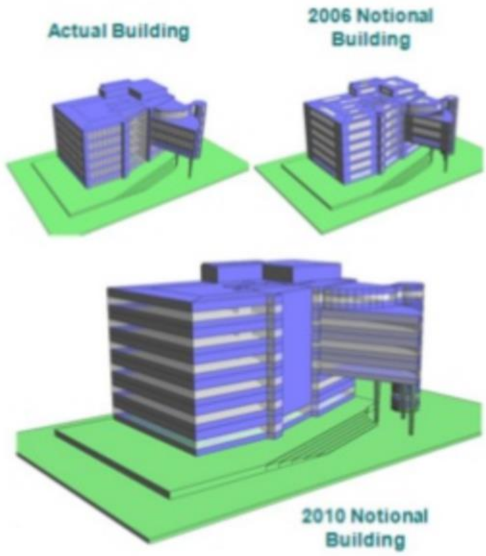

Figure 5: Comparison of the notional building with the actual building for the 2006 and 2010 editions of Part L2A (energy performance requirement for building regulations in England and Wales) [7].

Accredited software and assessors

The NCM methodology is detailed by an independent authority and compliance must be assessed by using an accredited software tool. These tools include a small number (~4) of commercially available physics based dynamic simulation tools that simulate the energy performance of a building in some detail, and a simplified tool called SBEM (Simplified Building Energy Model) developed by MHCLG.

It should be noted that the dynamic simulation tools are themselves independent general-purpose simulation tools that can also be used for building regulation compliance – indeed, some of them significantly pre-date the original 2006 NCM. Essentially the tool must be used within a strictly defined workflow that has been developed by the vendor of the dynamic simulation tool, and it is the combination of the workflow and the dynamic simulation tool that is accredited for the purpose of building regulations compliance. From the perspective of the user, only the model of the actual building is constructed. The model of the notional building is automatically constructed and simulated as part of the workflow – it is a hidden process that cannot be interfered with by the user.

SBEM was developed and released in 2006 specifically for the purpose of building regulation compliance. It is freely available but may be more conservative so that compliance may be more difficult than by the dynamic simulation route. Again, the user constructs the model for the actual building and the SBEM software automatically constructs and simulates the notional building. Dynamic simulation is perhaps analogous to the use of CFD, whereas SBEM is more akin to the use of an integral model.

In addition to the requirement for using an accredited software, compliance can only be achieved if the individual undertaking the assessment is an accredited user of the chosen software. A central database of accredited assessors is maintained and is freely accessible.

A robust comparative approach

The NCM is a comparative approach where compliance is achieved by comparison with a relative criterion, the TER, which depends upon the building under consideration rather than an absolute criterion that applies to all buildings. This was perhaps driven by an early realisation that the dynamic simulation tools that existed pre-2006 were unlikely to yield precisely the same predictions for energy use if applied to the same building due to differences in their underlying algorithms, or indeed if the same tool was applied by two different analysts to the same building due to differences in the modelling decisions that rest with the analyst. Of course, the same is true for the application of CFD.

A major benefit of the NCM approach is that the compliance criterion, the TER, is by simulating the energy performance of the notional building and that simulation uses many of the same input assumptions as the simulation for the actual building. For example:

- the geometry of the envelope of the notional building is identical to that of the actual building, although the proportion of glazing in each external wall and roof, and the construction of each wall (and therefore the U-value) may vary – they are pre-defined in the NCM for the notional building,
- the type of use within each zone of the building (for example, office space, classroom, circulation route) will determine the energy requirement for the building and this is specified by the analyst for the actual building – identical usage is automatically defined for each corresponding zone within the notional building
- the prevailing weather will affect the energy requirement of the actual building so the location is specified by the user as part of the model and an appropriate weather data file for the location, provided as part of the NCM, is used for the simulation – the same weather file is used for the simulation of the notional building too.

The NCM is not perfect. A building may be building regulations compliant using one dynamic simulation tool but it may fail with another. However, the fact that similar assumptions are used for both the actual building and the notional building mean that any errors in the input data or the analysis approach are present in both buildings and therefore, to a large degree, they cancel out. This is a robust approach.

The NCM as a precedent for the probabilistic explosion approach

The NORSOK Z013 standard was first released in the late 1990s at a time when computational fluid dynamics was still a niche technology with relatively few practitioners. It has now been around for 20 years and has not changed significantly since its initial issue. In contrast, during the same period there have been continual advances in both computer hardware and engineering simulation tools, and the use of simulation technologies such as finite element analysis and computational fluid dynamics continues to increase apace.

The NORSOK Z013 standard is perhaps due a review and the NCM could provide a precedent for the probabilistic explosion approach moving forward. Whilst there is certainly merit in considering the development of accredited software and assessor schemes, which is an essential part of the NCM, the driver for this may not be as strong because the number of probabilistic explosion assessments that must be carried out remains relatively small when compared to the number of energy assessments that now need to be undertaken. That said, the consequences associated with explosions are more severe and Abercus believes there is a need to improve the consistency of the approach, so in that sense there is a strong need to adopt something similar to the accredited software and assessor approach of the NCM.

However, perhaps the primary opportunity is for the probabilistic approach to adopt a relative acceptance criterion analogous to the TER, based upon models of an actual asset and a notional asset, rather than sticking to the current approach with an absolute 10^{-4} /yr criterion. By adopting a similar approach to the NCM with a relative criterion, potential errors in the input assumptions including the release and ignition frequencies would essentially cancel out, therefore reducing the sensitivity of the assessment.

Of course, this change in approach would need some thought and the definition of the notional asset for an explosion assessment would require agreement. For example, representative levels of congestion and confinement would need to be agreed for a 2020 notional standard for each type of function – wellhead, process area, utility and so on. Similarly, the energy performance of a building is a single scalar quantity, the amount of energy required by the building for a notional year, so the NCM and building regulations compliance involves the comparison of only two scalar quantities, the BER and TER. For an explosion assessment, how should the blast load for the actual and notion facilities be compared? Should they be compared directly, everywhere across the asset, or is there some overall integrated and quantifiable measure of safety that could be compiled for the entire asset that could allow a simple comparison of two scalars to be undertaken. The former, checking everywhere across the asset, is simplest and most transparent, and this may not have been possible in the past due to the amount of data that would need to be processed to allow this to happen, but with modern computing hardware and using the 3D risk approaches that have emerged over recent years (see, for example, [4]), this could now be feasible.

Abercus believes that the NORSOK Z013 approach is due an overhaul and that the NCM can provide a good model for many aspects of a new probabilistic explosion approach based upon relative acceptance criteria. Abercus also believes that this should be given an urgent focus by industry. The sooner we recognise the concerns that have been raised with the current approach by many different parties, the sooner we can start to address them, improve the consistency of the methodology and produce safer assets.

References

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