Recent advances in software for modelling the risks associated with gas explosions in congested spaces using the Multi Energy Method

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1. Introduction

When calculating risks from explosions, accurate prediction of the effects of congestion on overpressure has a significant impact. In addition, the protection offered by buildings is also an important factor. The TNO Multi Energy (ME) Method, integrated with source term discharge and dispersion models to assess the extent of flammable clouds, is often used for predicting overpressures (Van Den Berg, 1985). Developed as a more accurate alternative to the TNT-equivalence model, it could initially only be applied in a general manner using conservative assumptions. However, since then, a number of initiatives have been undertaken to improve its usability. The GAME project in 1995 provided correlations to help select appropriate curves based on parameters such as volume blockage ratio, equipment diameter, flame length and laminar burning velocity. This was extended by the GAMES project in 1998 which gave guidance on combining multiple explosion sources and validated the model against CFD predictions. Further research published in 2002 (RIGOS) provided guidance on when equipment separated by finite distance should be treated as single obstructed regions.

This paper describes the recent implementation of the ME method in a software model for Process QRA (see for example Cavanagh et al, 2009) which can be used to predict the risks to people from VCEs and takes account of the guidance from the GAME, GAMES and RIGOS projects. The software allows graphical definition of a plant and selects the most appropriate ME curve based on a number of user defined parameters. It enables the definition of explosion sources, areas of congestion, population distributions, buildings and appropriate vulnerability levels on a GIS map. The paper also presents a simple case study for a typical installation with a number of buildings, each offering different levels of protection to their occupants, and describes the risks calculated using the built in guidance described above. Results are presented as traditional F/N curves to illustrate the effects of vulnerability modelling on the resulting risks.

2. Explosion Modelling

1.1 The Multi Energy Method

The ME method is based on experimental research which indicated that only the combustion energy generated in obstructed and/or confined regions results in lethal overpressures. An obstructed region is an area where obstacles are present generating turbulence which accelerates the flame if a cloud is ignited within it. To apply this model, each obstructed region is treated separately as an explosion source if the separation distance is sufficiently large. Otherwise, obstructed regions are combined to form larger confined sources which will be discussed further below. The ME blast curves were derived from modelling the effects of idealised ground level explosions and provide important information on blast effects, such as side-on overpressure, represented by a sequence of curves where the effects depend on distance from the explosion centre (see TNO Yellow Book (1997)). Because of the complexity of real process plants, it is not trivial to apply this model to represent typical accident scenarios. A particular issue is that analysts may make different assumptions about the division of a plant into regions with varying degrees of congestion. This can lead to dissimilar results for essentially the same plant which has led to further research comparing the results of the ME method with measurements and more rigorous CFD models to produce guidance on applying the method. Between 1993 and 1995 a JIP investigated ways to provide “Guidance for the Application of the Multi-Energy Model”, the ‘GAME’ project (Eggen, 1998). This research produced correlations for peak side-on overpressures at the explosion centre for 2D and 3D confinement which can then be used to select the most appropriate blast curves.

However, determining parameters for the correlations from the GAME project is not a straightforward task and a further JIP followed to investigate the practical application of the guidance to specific example scenarios. In this work the Multi-Energy results were compared with detailed information provided by measurements and CFD predictions. This was published in 1998 under the project acronym ‘GAMES’ (Werex et al, 1998). In parallel the Yellow Book was updated so some of the findings are reflected in the 1997 version.

1.2 Critical Separation Distance

An important aspect of applying the method is determining explosion sources. This is difficult if a vapour cloud engulfs more than one obstructed region separated by open spaces. If the open spaces are sufficiently large, the VCE flame front will slow down while travelling across them and the explosion will develop multiple separate blasts. However if the spaces are small, the explosion should be modelled as one single blast with summed energy for all obstructed regions. This is of sufficient concern that a further JIP (RIGOS) was initiated to investigate this phenomenon (Van den Berg et al, 2002). The critical separation distance between obstructed regions is the criterion that enables the determination of explosion sources for each scenario. The Yellow Book (1997) and RIGOS give complimentary guidance on this which is implemented within the software model.

1.3 Obstructed Regions and Explosion Sources

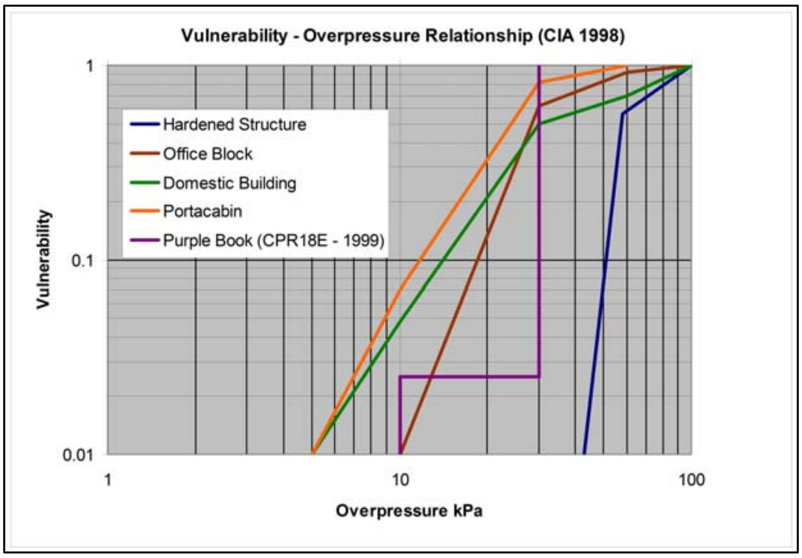
The method for dividing a plant into obstructed regions has to be decided upon by the analyst. This process usually starts with the definition of a bounding box that encloses all the relevant obstacles, followed by further refinement. How this is done in practice depends on the experience of the analyst and is open to interpretation. To aid the process, the TNO Yellow Book has a “recipe” to help define obstructed regions which has been used in this example. Explosion sources can then be specified directly or determined by the software using the critical separation distances mentioned earlier.

2. Vulnerability Modelling

Once the behaviour of a release of flammable material has been predicted, its effects on the population need to be assessed. Converting harmful effects into fatality rates is referred to as “vulnerability modelling” and there are a number of published models for explosion effects (e.g. Bevi Reference Manual, 2009). Of interest for QRA is estimation of probability of death from explosion strength and guidance is provided by a number of sources including CIA (1998) and API (2003 and 2007). Recent extension to the model described here allows buildings to be defined with specific vulnerability properties, thus providing a much more accurate picture of the risks to those indoors. A brick structure offers greater protection than a similarly positioned timber structure and the recent extensions therefore take account of buildings offering specific levels of protection at given levels of blast overpressure. For example, the CIA guidelines specify vulnerability characteristics for 4 different building types, as shown in Table 1.

Table 1: CIA Building Vulnerability Characteristics:

Building Type	Description
Type 1 - Hardened structure	Special blast proof construction – no windows
Type 2 – Typical office block	Four storey, concrete frame and roof, brick block wall panels
Type 3 – Typical domestic building	Two storey, brick walls, timber floors
Type 4 – Portacabin	Single storey, timber construction



For each type there is a correlation between overpressure and vulnerability, as illustrated in Figure 1. The provision for different building types each with its own vulnerability (conditional probability of death) as a function of overpressure provides a far more rigorous analysis. In fact, since this has been implemented in a generic way and any pressure-vulnerability relationship can be associated with any building type, the methodology supports other guidelines on the design and location of occupied buildings subject to explosion hazards (e.g. API RP 752 and API RP 753).

3. Case study – Chemical Plant

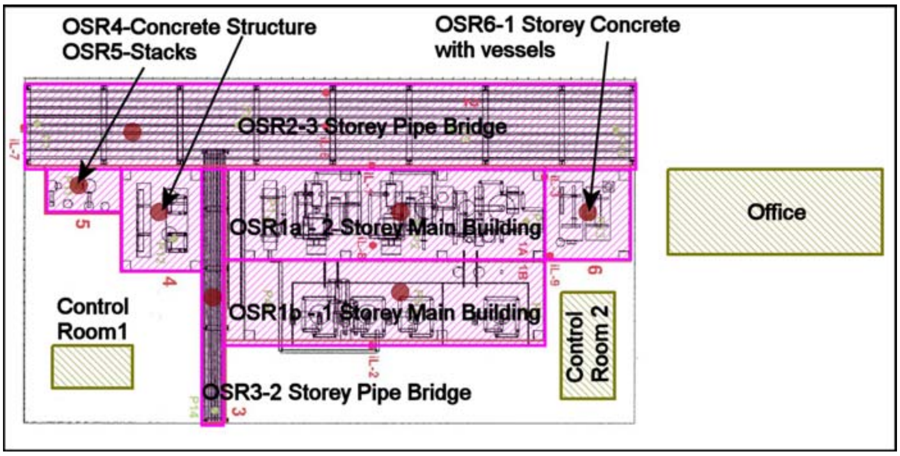


Figure 2 – Typical chemical Plant from GAMES

This case study, based on an example from GAMES, represents a typical Chemical Plant. In GAMES, a CFD model of the plant was created against which the ME method was validated. This model was divided into a number of obstructed regions and has been recreated in our software model to exemplify the importance of combining accurate prediction of over-pressure with building vulnerability modelling. As shown in Figure 2, control rooms and an office building, with associated population, have been included to show the influence of vulnerability on societal risk. By using different building types with appropriate vulnerability properties for buildings we can assess the overall societal risk against some suitable acceptance criteria. Figure 3 shows F-N curves for 4 different building configurations along with some typical “ALARP” acceptance criteria.

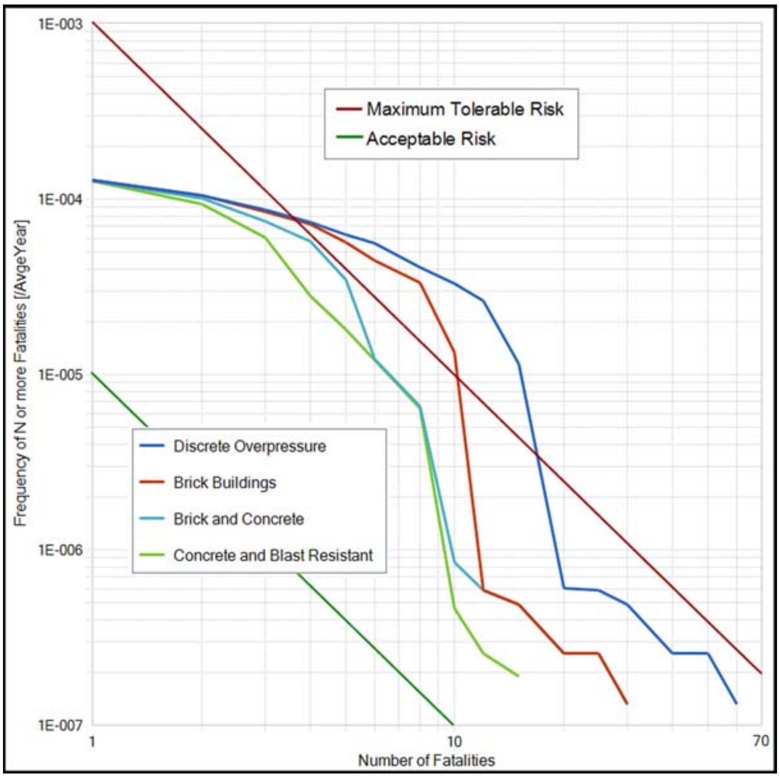


Figure 3: F-N Curves for 4 Building Configurations

The first F-N curve is for a discrete overpressure vulnerability model and we can see that the criteria shown are not satisfied. Moving to an interpolated overpressure vulnerability model and using data appropriate to typical brick buildings, we can see from the second curve that, although the overall societal risk has reduced, it still exceeds the criteria in the 4 to 10 fatality range. By replacing the control rooms with stronger concrete structures, we can see that the overall societal risk reduces further and is now within the ALARP region. The final curve illustrates how, by replacing the control rooms with blast resistant structures and the office block with concrete structures, further risk reduction can be achieved. Of course this is a very simplified example intended to illustrate the relevant concepts, particularly the effect of refining vulnerability models to take account of use of different building types to improve protection to personnel.

4. References

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