Risk evaluation in Dutch land-use planning

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Risk evaluation in Dutch land-use planning

Nico H.W. van Xanten[a,b,*], *Chris M. Pietersen*[a], *Hans J. Pasman*[a,c], *Pieter van der Torn*[a], *Han K. Vrijling*[a,d], *Ariën J. van der Wal*[a], *Jan G.M. Kerstens*[a,b]

[a] *Hazardous Substances Council, The Hague, The Netherlands*
[b] *Technical University Eindhoven, The Netherlands*
[c] *Texas A&M University, College Station, Texas, USA*
[d] *Technical Univeristy Delft, The Netherlands*

ABSTRACT

In Dutch external safety policy, the acceptance of risk for the population in areas surrounding hazardous substances establishments is based on a limit value for individual risk (IR). Additionally, changes to societal risk (SR) must be justified. A specific software program (SAFETI-NL) with the associated Reference Manual Bevi Risk Assessments (RIVM, 2009) is legally required for the calculation of IR and SR. This prescribed "Bevi calculation method" forms the basis for decisions with important consequences for industry, land use planning and the protection of citizens. It is important that the outcome of calculations made with the prescribed method can be relied upon when making decisions about land use planning that affects both industry and population. This is the subject of this paper.

The prescribed calculation method has been evaluated by performing a case study. The evaluation focussed on risk modelling of a Boiling Liquid Expanding Vapour Explosion (BLEVE) at an LPG filling station, an incident type that plays a significant role in Dutch external safety. The risk modelling of the BLEVE with the prescribed calculation method was found to have a number of serious deficiencies. It is concluded that the prescribed calculation method yields no reliable perspective on the safety of production, use and storage of hazardous substances, nor of possibilities to increase safety.

Decision making should not only depend on quantification of IR and SR. Improving the safety-relevance of the prescribed calculation method requires an increase of the number of dimensions of the outcome of risk calculations in order to make feedback possible. It is recommended to incorporate additional, safety-relevant information into planning and decision-making processes. It is envisaged that a more far-reaching change of Dutch QRA practice is needed (medium to long term). In this context, a number of interesting elements have been noticed in decision-making procedures in other EU Member States.

Keywords: Risk evaluation; Land-use planning; Safety relevance; Relative vs. absolute use of risk calculations; Hazardous substances; BLEVE

* *Corresponding author at*: Hazardous Substances Council, The Hague, The Netherlands. Tel.: +31 6 5259 5099.
E-mail address: nicovanxanten@gmail.com (N.H.W. van Xanten).

http://dx.doi.org/10.1016/j.psep.2014.06.002

1. Introduction

In the Netherlands, the assessment of the acceptability of risks for the population in areas surrounding hazardous substances establishments primarily takes place based on limit values for IR[1] and an evaluation criterion for SR.[2] The competent authority must also justify changes in the level of societal risk, for example if new land use developments are planned in the vicinity of an already-existing establishment. For the determination of the IR and SR from establishments, a calculation method is prescribed in the Netherlands, the "Bevi calculation method", consisting of the SAFETI-NL calculation package in combination with the Reference Manual Bevi Risk Assessments (RIVM, 2009). This prescribed "Bevi calculation method" forms the basis for decisions with important consequences for industry, land use planning and the protection of citizens.

Due to the interests at stake and the reliance of decision makers on the outcomes of risk calculations, the Hazardous Substances Council conducted an evaluation; a paper was presented at the symposium Loss Prevention and Safety Promotion in the Process Industries in May 2013 (Van Xanten et al. (2013)). The technical evaluation was focussed on a case study on risk modelling of a BLEVE at an LPG filling station. A BLEVE is an incident type with great implications for the claims for indirect land use around hazardous establishments (land usage restrictions due to external safety risks). The Council considers the findings with respect to the BLEVE to be characteristic of the deficiencies in the calculation methodology.

Critical observations on the prescribed calculation of risks to the area surrounding hazards should not be confused with criticism of quantitative risk assessment (QRA) as such. The prescribed calculation method is only the *implementation* that has been given in the Netherlands' external safety policy to an otherwise valuable analysis *methodology*. The Netherlands' present approach is restricted to generating risk contours and estimating the SR. With the prescribed risk calculation method, the assessment of the effectiveness of safety measures is either difficult or impossible.

2. Quantitative risk analysis in The Netherlands

In QRAs probabilities and consequences of (known and quantifiable) unwanted events are systematically mapped out, and are expressed numerically. With such analyses, insight can be gained into the severity of risks and the effectiveness of (counter)measures. QRA is being used in many sectors to improve safety, optimise processes and support decision-making, from the chemical sector, the air transportation and aerospace sector to logistics and the medical sector. When developing a QRA instrumentarium for a specific application, the intended use of the instrumentarium is of paramount importance: it determines the required level of detail and the aspects that may or not be left out of consideration.

Important topics in the development of a QRA instrumentarium are the theoretical models used (in the Netherlands, these are based on the "coloured books": PGS1 (2005), PGS2 (1997), and PGS3 (2005)) and the implementation of these models in software. The coloured books have – however – not been updated for some years. The calculation models behind various calculation packages that have been developed since, including the one prescribed in The Netherlands, SAFETI-NL, deviate from the coloured books. As a result, the relationship with the coloured books has faded in recent years. Also, a benchmark exercise demonstrated that the results from the various calculation packages could differ dramatically, despite their shared basis (RIVM, 2001). This may partly be explained by the space left for interpretation that the coloured books give for the development of calculation models, and partly by the space left for interpretation these models offer in the schematic representation of an installation and the selection of parameter values. This illustrates that the quality of a QRA is not solely determined by the quality of the QRA instrumentarium employed, but also by the knowledge and expertise of the user: the schematic representation of an establishment and the assessment of the value of the results of calculations demand knowledge and experience. Each model is a simplification that is only valid within certain limits. The user is responsible for the interpretations he makes.

Although it is impossible in practice to identify one single correct calculation result, the legislature considered it undesirable from the viewpoint of legal certainty that the question of whether a certain limit value was reached should be strongly dependent on choice of model or on expert judgement (Bevi, 2004). In 2006 therefore, a switch was made to the system referred to as "unification", which means that a single calculation package was selected that must be used as standard within the Bevi framework for calculation of IR and SR for establishments: SAFETI-NL. In this calculation package, the parameter values to be used are to a large extent fixed in order to make the calculation results less dependent on assessments made by the risk analyst (see also Uijt de Haag et al., 2008). In this way, the complex reality has been strongly simplified. The prescribed risk modelling, including parameter values and scenarios, is described in the Reference Manual Bevi Risk Assessments (RIVM, 2009). In this paper, the calculation package in combination with the Manual is referred to as "the prescribed calculation method".

3. Methodology for evaluation of the prescribed calculation method

The aim of the evaluation was to investigate the limitations of the prescribed calculation method and to assess the consequences for decisions based on the results of calculations. A complete validation of the prescribed calculation method would be wide-ranging. For this reason, it was decided to use a case study to highlight some remarkable findings. Because of the prominent role of the BLEVE within Dutch external safety policy, a BLEVE at an LPG filling station was chosen for the case study. The BLEVE of an LPG road tanker is determining for the safety distances to be respected around an LPG filling station.

The evaluation focuses at two functions of the QRA instrumentarium: (1) the calculation of IR and SR for land-use

[1] In the Netherlands, individual risk is the probability per year that a person who remains in a certain place in the open air, continuously and unprotected, will die within 24 h as the direct result of an unusual incident within an establishment in which a hazardous substance or hazardous waste is involved. The exposure is considered to take place at a height of 1 m. No information about other types of injury is included in the concept of individual risk.

[2] Societal risk is the cumulative distribution function of the number of fatalities: the probabilities per year that at least 10, 100 or 1000 people will die as the direct consequence of their presence in the area of influence of an establishment and an unusual incident within said establishment in which a hazardous substance or hazardous waste is involved.

planning, and (2) the provision of insight into measures that may increase safety in the specific situation. For the first function, the instrumentarium should be transparent, verifiable and robust, and should contain no deficiencies, considering the role of the IR and SR calculated according to the Decree on External Safety of Establishments (Bevi, 2004) in planning and decision making. With respect to the requirement of lack of deficiencies, it is considered important that the assumptions and starting points for the system description are correct; e.g. that (partial) models have been validated, using field trails or after accidents (validity in terms of correctness). For the second function, it is important that the QRA instrumentarium can be used to gain insight on how to reduce risks and increase safety (validity in terms of safety relevance).

4. Results of the evaluation

The results are summarised in the following five paragraphs, followed by a discussion on the general applicability of the findings for risk modelling of a BLEVE.

4.1. *Transparency*

The theoretical models that are incorporated into the calculation package that is prescribed in the Netherlands, SAFETI-NL, are largely described in the Reference Manual Bevi Risk Assessments (RIVM, 2009). The manual provides an overview of the BLEVE models implemented in SAFETI-NL and thus fulfils the transparency criterion. Still there are disadvantages associated with the obligation to use the Bevi calculation method (see below).

4.2. *Verifiability*

The BLEVE fireball model that is used in the prescribed method is presented comprehensively in the Yellow Book (PGS2, 1997). The same applies to the probit (measure of probability) in the Green Book (PGS1, 2005) that is used to make the connection between the radiation from fires and their lethality. The verifiability is in this regard sufficient.

The verifiability of the failure frequencies is however limited. It is not straightforward and sometimes impossible to derive how the failure frequencies have been established. The Reference Manual Bevi Risk Assessments (RIVM, 2009) is of no help here either. The starting points and assumptions that form the basis of the probability of a BLEVE as used in The Netherlands are not clear. It required an extensive investigation to determine what these are based on. It finally became apparent that the origin of the probability of a BLEVE as used in The Netherlands may be traced back to three studies into the safety of pressure vessels: Phillips and Warwick (1969), Smith and Warwick (1974) and Bush (1975). These old studies primarily concerned steam vessels.[3] Although the many reports that have been issued in The Netherlands since then may give a different impression, the present failure frequencies for pressure vessels are not based on more recent case histories. Such information is indeed available: in the United Kingdom, the failure frequencies used are based on data for pressure vessels of more recent date. Further, it became apparent that the failure frequencies of pressure vessels currently used in the Netherlands were reduced on vague grounds at the very start of activities in the field of risk analysis at the end of the 70s. The failure frequency of a pressure vessel derived from the studies of Phillips and Warwick (1969), Smith and Warwick (1974) and Bush (1975) was reduced by a factor of at least 10 in the COVO study (COVO Commission, 1982). Thorough argumentation for this reduction is absent. This unjustified reduction directly influences the failure frequencies listed in the Reference Manual (RIVM, 2009).

The probability prescribed in the Netherlands for instantaneous failure of a pressure vessel is relatively low, just as is the probability of a BLEVE calculated from this (0.7–2.5 $\times 10^{-7}$ per year). In the United Kingdom the BLEVE probability applied for stationary installations is a factor of 40–140 higher: in HSE (2004), a BLEVE probability of 10^{-5} per year is used.

4.3. *Robustness*

Various comparative studies have demonstrated that the results of risk calculations are strongly dependent on expert judgement (Amendola et al., 1992; RIVM, 2001; Lauridsen et al., 2002). The user of a calculation program may select a model and modify the parameter values and coefficients. The results of calculations may thus differ. The robustness of the risk modelling of a BLEVE according to the Dutch prescribed calculation method is actually very high. This high robustness has been achieved by excluding (further) expert judgement by defining parameter values, coefficients and models in the prescribed calculation method (referred to as unification, Uijt de Haag et al., 2008). In the risk analyses thus, fixed failure frequencies are imposed, and in the modelling of the fireball, only the setting of the safety valve (i.e. the pressure) and the volume of the fireball can be varied. The robustness of the prescribed calculation method for such “standard” installations is thus constructed on a policy decision. It is not a characteristic of the calculation method in itself, as is demonstrated in a sensitivity analysis, of which some examples are presented here.

The pursuit of robustness should not degenerate into insensitivity to essential parameters. After all, reality is almost always different from a “standard” installation. Risk analysis should be tailored to the actual situation. In this study, various risk calculations were performed to analyse the sensitivity of calculation results to assumptions and starting points. This sensitivity analysis reveals that relatively small deviations from the assumptions and starting points as listed in the Reference Manual (RIVM, 2009) may lead to important changes in the indirect land use around LPG filling stations. This means that the risk calculations are (very) sensitive to such deviations. If the model, the parameter values and coefficients would not have been fixed as a matter of policy in the prescribed calculation method, the results of the risk analyses could vary greatly. This may be illustrated by the following examples:

- Variations in the probability of a BLEVE during the unloading of an LPG road tanker
  The position of the 10^{-6} risk contour is strongly dependent on relatively small variations in the probability of a BLEVE

[3] Steam vessels have been in use for more than 150 years to date. It should be observed that there are differences between steam vessels and vessels in chemistry and also that new techniques and standards are used, e.g., for the different types of vessels, the load (pressure) is neither equal nor constant. Vessels used in chemistry often suffer more from contamination and may be subject to corrosion. For this reason, special materials and manufacturing and welding techniques are used. In the past decades, standards for manufacture, maintenance and inspection have also changed.

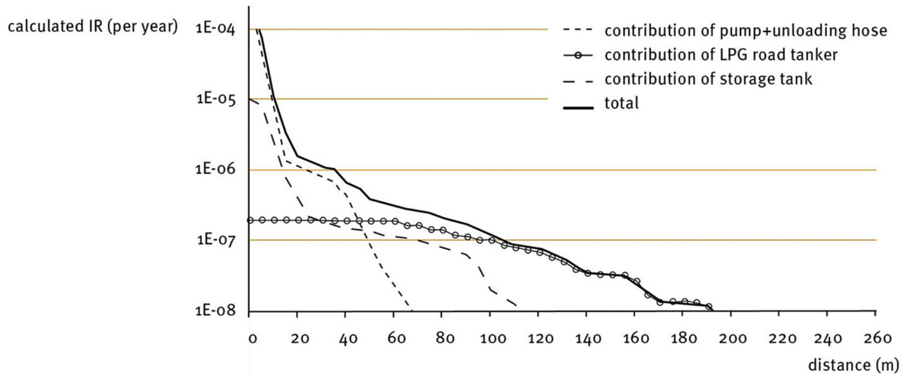

Fig. 1 – Build-up of the IR using the prescribed calculation method for a standard LPG filling station with a throughput of 1000 m^3 and all discharging LPG road tankers with thermal insulation covering.

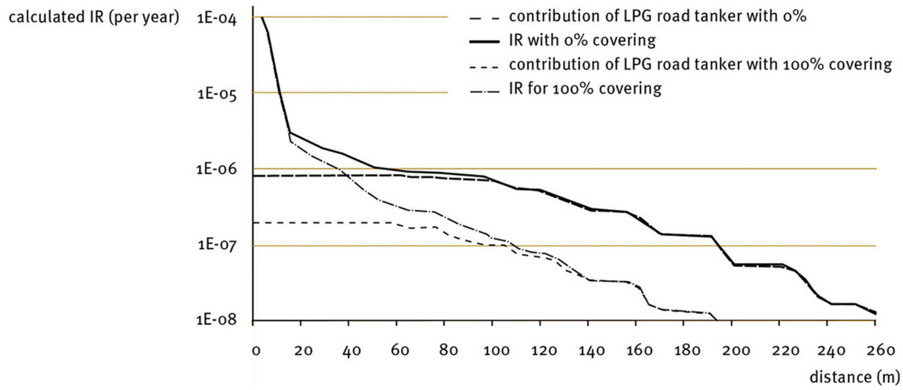

Fig. 2 – The contribution of unloading LPG road tankers with and without thermal insulation covering to the individual risk around an LPG filling station with a throughput of 1000 m^3 per year.

during unloading of an LPG road tanker. This probability is determined by the number of transfers of LPG from a road tanker to the station, the duration of unloading and the probability of a BLEVE per time unit during each transfer. In a standard LPG filling station[4] with a throughput of 1000 m^3 per year,[5] when applying the prescribed calculation method, two accident types determine the level of the individual risk. At a short distance, the pump and unloading hose make a dominant contribution to the IR. At a greater distance, mainly the contributions of the storage tank and road tanker are important. The 10^{-6} risk contour is about 35–40 m from the filling connection. The various partial contributions to the IR are compared to the distance in Fig. 1.

If unloading LPG road tankers are not provided with a thermal insulation covering, the distance from the 10^{-6} risk contour to the filling connection is around 50 m (LPG filling station with a throughput of 1000 m^3 per year), as shown in Fig. 2.

For only a 50% higher probability of a BLEVE during transfer from LPG road tankers not provided with a thermal insulation covering, the distance from the 10^{-6} risk contour to the filling connection increases to 100 m. And for a not unimaginable ten-fold increase in the risk of a BLEVE – see also the verifiability of failure frequencies in the previous section – to 190 m. This is illustrated in Fig. 3.

- Variations in the dose–response relationships

In lethality calculations, relationships are described between exposures on the one hand and probabilities of fatality on the other, using dose–response relationships (probit functions). There is considerable variation between the different probits. The choice of probit thus influences the results of calculations. In a sensitivity analysis, the influence of the choice of the probit for the consequences of a hot BLEVE with fireball was considered. For this, lethality was calculated as a function of distance using different probits for a 26.7 ton LPG road tanker and the thermal radiation according to SAFETI-NL (Fig. 4). Besides the TNO probit that is implemented in SAFETI-NL, other probits have also been used in this evaluation (i.a. HSE, 2004, and Lees, 1996). In the prescribed calculation method, a maximum exposure time of 20 s is used. This exposure time was used for the calculations with the various probits, with the exception of the 'TNO probit including a correction for escape behaviour' (TNO+ escape), where 5 s reaction time was assumed and an escape velocity of 4 m/s, as suggested in the Green Book (PGS1, 2005). It was also assumed that lethality within the radius of the fireball is 100%.

From Fig. 4, it is apparent that the TNO probit is relatively pessimistic. The lethality at the same distance is noticeably lower with the probits according to Eisenberg, Lees, the

[4] According to the prescribed calculation method, by "standard LPG filling station" should be understood an LPG filling station that complies with the requirements applicable in The Netherlands and of which the layout corresponds to the assumptions listed in the Regulation on external safety of establishments (Revi, 2004). I.a. the presence of a thermal insulation covering on the LPG road tanker is required (as per Amendment to Revi, 2007).

[5] According to a survey, in The Netherlands, there are 544 filling stations with an LPG throughput of less than 500 m^3 per year, 1119 with a throughput of between 500 and 1000 m^3 per year and 324 filling stations with a throughput of over 1500 m^3 per year (RIVM communication, 14 December 2009).

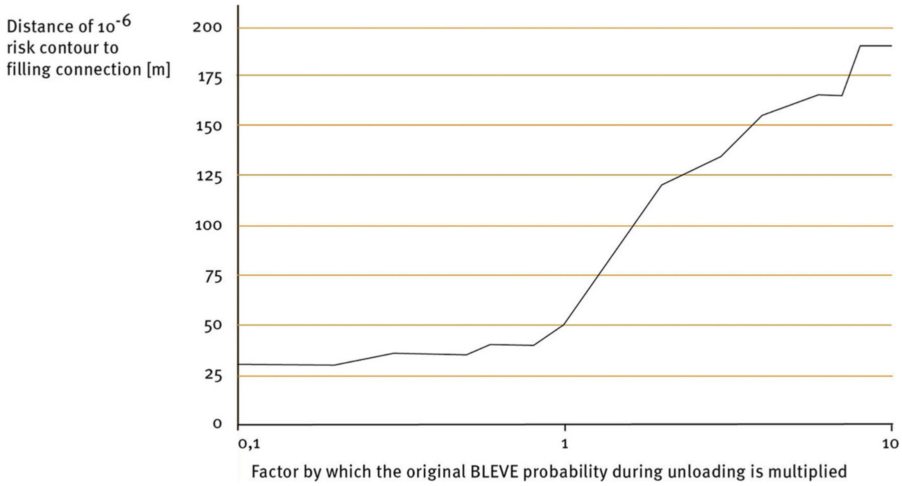

Fig. 3 – Relationship between the position of the 10^{-6} risk contour and the probability of a BLEVE for an unloading LPG road tanker without thermal covering at an LPG filling station with a throughput of 1000 m^3 per year.

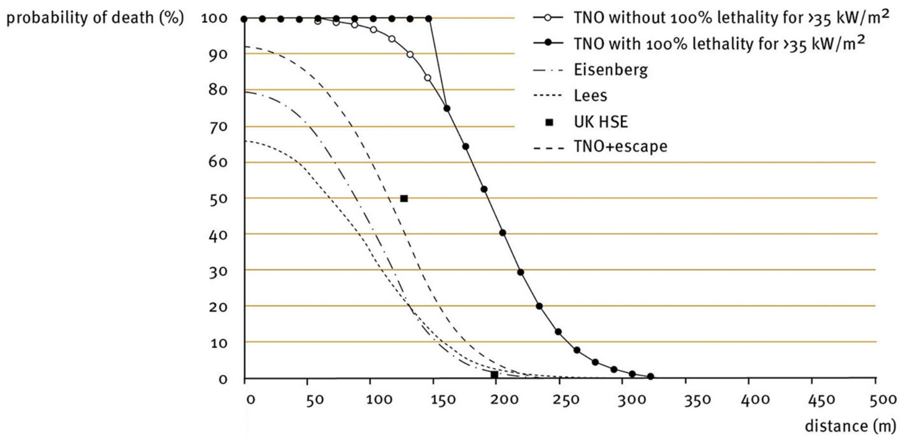

Fig. 4 – Lethality as function of distance for different probits for a hot BLEVE with fireball and an LPG road tanker filled with 26.7 tons of LPG.

HSE in the United Kingdom (2 points) and the TNO probit including a correction for escape behaviour. This study did not include an investigation into the correctness of the different probits. It is indeed clear that a significant variation exists. This underlines the importance of regular validation and of keeping the underlying data up to date.

4.4. *Validity: correctness*

Various points for improvement of the BLEVE risk modelling were observed. These mainly concern the scenarios and (the backgrounds of) the failure frequencies used.

- Leaving out human error and other scenarios
A frequency of 5×10^{-7} per year is used in The Netherlands for the failure frequency of a pressure vessel. It is striking that in the Purple Book (PGS3, 2005: p. 3.3) it is stated that this probability must be increased by a factor of ten – by 5×10^{-6} per year – if standard safety provisions are missing or external impacts (such as collisions for example) and human errors (such as overfilling) cannot be excluded. Conversely, in the Reference Manual Bevi Risk Assessments (RIVM, 2009), the failure frequency contributions of external impacts and human errors are left out on the presumption that standard safety provisions are present: if they were to be absent, they should be implemented immediately. This is not in line with the Purple Book, that requires to increase the failure frequency when external impacts, corrosion and human actions may not be dismissed just like that, even if standard safety facilities are present. HSE shares this judgement. A higher probability must be used if there is reason to do so (HSE, 2004). If the increase by 5×10^{-6} per year mentioned in the Purple Book were used, the probability of catastrophic rupture would increase by around a factor of ten.
- Probability of ignition incorrect
The probability of a BLEVE being accompanied by a fireball is dependent on the probability that the BLEVE is followed by a direct ignition (if the tank contents are flammable, as with LPG). In the Dutch prescribed calculation method, this probability is assumed to be dependent on the release quantity. Physically, this is incorrect. The probability of direct ignition is i.a. dependent on the initial causes of the BLEVE. The probability of direct ignition from a mechanical impact is less than from a fire near the tank. In case of a hot BLEVE, the fire will always cause direct ignition. In the Reference Manual Bevi Risk Assessments (RIVM, 2009), this incorrectness is justified as follows: "It has been opted to retain the distinction in the volume in order to remain in agreement with previous QRAs as much as possible." From this, it may be deduced that the physically incorrect modelling was already recognised, but that it was decided for policy reasons not to allow the final results of the calculation to deviate too far from earlier calculations.

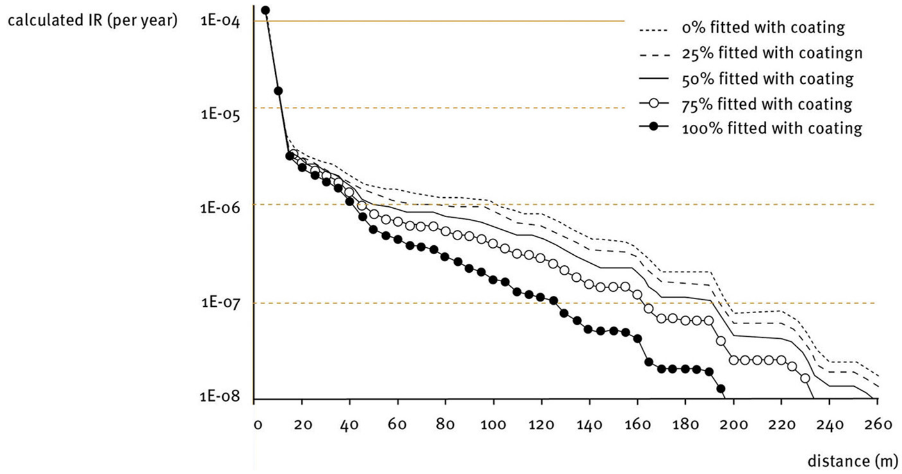

Fig. 5 – Position of the 10^{-6} risk contour for a standard LPG filling station with a throughput of 1500 m^3 per year for different percentages of the transferring tankers that are provided with a thermal insulation covering.

4.5. *Validity: safety relevance*

The safety relevance of the prescribed Bevi calculation method is low: insight cannot be gained (or only very limitedly) into the influence of safety precautions. This applies both to mandatory precautions (that are assumed to be present) and to those that could possibly be taken. The relationship between the safety (or danger) of a specific establishment and the calculated individual and societal risks is thus weak.

- Safety measures not recognised
  The generic nature of the failure frequencies used implies that safety precautions are not recognised or conversely are recognised as standard (and possibly wrongfully) in risk calculations. The prescribed failure frequencies for pressure vessels regard situations without corrosion, fatigue due to vibration, human error or external impacts. This implicitly presupposes the presence of measures, maintenance, inspection and management systems that may well be absent in practice.
- No tailor-made assessment of an establishment
  The modelling according to the Reference Manual Bevi Risk Assessments takes no account of differences in e.g. the expertise, safety management systems or emergency measures present at different (types of) establishments. The probability of a BLEVE with fireball is thus modelled in the same way for a complex industrial process plant as for an LPG filling station.
- No tailor-made assessment of exposure
  In calculating the consequences of heat radiation it is assumed as standard that a person escapes from direct heat radiation after no more than 20 s. This standard escape time does not reflect the possibilities for self-rescue actually present. These may differ greatly from case to case, depending on the characteristics of the population exposed (older people are less able to rescue themselves than young people) and on the characteristics of the surrounding area, such as the building density and the presence of escape routes. The prescribed calculation method is of no help for an analysis of the possibilities of self-rescue and emergency aid.
- Reducing safety distances in advance of realisation of safety measures
  In 2007, the Dutch government wished to introduce technical measures for reducing distances for safety clearances around LPG filling stations, in order to reduce the number of houses within the 10^{-6} contour around LPG filling stations. In The Netherlands, numerous LPG filling stations are situated in densely populated areas. The safety distances were reduced from 110 m to 40 m for "standard" filling stations with a throughput more than 1000 m^3 per year (Revi amendment (Staatscourant 2007, 66)). Particularly, application of a thermal insulation covering to LPG road tankers is of importance. In practice, several years have passed before this thermal insulation covering was applied to the majority of LPG road tankers. Indeed, for LPG filling stations with a throughput of 1000 m^3 per year, the question of whether transferring LPG road tankers are provided with a thermal insulation covering hardly affects the position of the 10^{-6} risk contour (the distance from the filling connection would decrease, according to calculations using the prescribed calculation method, from 50 m to around 40 m, if all LPG road tankers were provided with a covering; see also Section 4.3, Fig. 2). However, the reduced distances also apply to filling stations with a greater throughput. Here, the influence of the thermal insulation covering on the position of the 10^{-6} risk contour is in fact important. From a sensitivity analysis, it becomes clear that reducing the clearance distance in Revi from 110 m to 40 m for LPG filling stations with a throughput of 1500 m^3 per year can only be justified if a large proportion of the transferring tankers are provided with a thermal insulation covering (see Fig. 5). It is noted that the change to the clearance distance in 2007 was in part based on future safety measures. It should be noted that the QRA results for an LPG filling station with a throughput of 1500 m^3 per year are identical to the results for one with a throughput of 1000 m^3 per year if, for the latter filling station, the assumption of a 50% longer duration of stay is made (45 min rather than the 30 min necessary according to the prescribed calculation method to unload the LPG[6]). Deviations from the standard duration of stay may have nothing to do with the

[6] The 30 min duration of stay assumed in the prescribed calculation method is necessary to pump over (an average of) 15 m^3 LPG. Besides this, around thirty actions have to be carried out by the driver of the LPG road tanker. No time is added for this in the prescribed calculation method. The use of only the transfer time and not the duration of stay of the tanker at the LPG filling station would lead to an underestimation of the risk.

unloading of LPG, but do nevertheless influence the level of the risk.

4.6. *The general applicability of the findings for risk modelling of a BLEVE*

Although the evaluation was focused on risk modelling of a BLEVE at LPG filling stations, the findings are considered to be typical for the calculation method prescribed in The Netherlands in a broad sense. The failure frequencies for pressure vessels used in The Netherlands are the same for steam, LPG or chlorine. The mandatory-to-use calculation method is unsuitable for the assessment of safety measures for a specific establishment or for analysing possibilities for self-rescue and emergency aid. The risk modelling (scenario definition, estimation of frequencies, and effect and consequence modelling) for different incident types and types of hazardous properties (flammable, explosive, toxic) features similar difficulties. The uncertainties in each part of the risk modelling are considerable, and this is not only the case for a BLEVE. E.g., the dose–response relationships that define the relation between exposure levels and victim probabilities for toxic substances are at least as uncertain as those for thermal radiation, and the dispersion of toxic substances in a built-up area is very difficult to model.

5. Observations and recommendations

5.1. *Observations from the evaluation*

From the evaluation, the following was observed:

- Transparency: acceptable for the modelling of a BLEVE. The basis for the modelling in the software program SAFETI-NL is indeed explained in the accompanying reference manual.
- Verifiability: the failure frequencies prove to be at least one order of magnitude (a factor of 10) lower than commonly used elsewhere (due to decisions taken at the end of the 70s at the start of activities in the field of risk analysis).
- Robustness: the robustness of the calculation method is artificially high. It is a construct, resulting from the fact that the values of parameters and coefficients have been laid down in the reference manual. In this way it is concealed that small variations in assumptions or starting points often result in large variations in outcome in terms of indirect land use, IR and SR.
- Validity in terms of correctness: the incident scenarios described in the event tree for a BLEVE of LPG are not correctly modelled in the physicochemical sense. Also, human error and similar scenarios are neglected in the risk calculations.
- Validity in terms of safety relevance: use of the calculation method gives no or only limited insight in opportunities to increase safety.

5.2. *Tension between robustness and safety relevance*

The development over the past decades of risk calculation in The Netherlands as an attempt to increase insight, and to corroborate decision making – including safety measures – has set an example to many. However, since 2006 in Dutch external safety policy, QRA results are used in an absolute manner for comparison with the limit value of the IR and the orientation criterion for the SR. The calculation results are, as shown, surrounded by great uncertainties and are based on assumptions and starting points that are not always verifiable or valid. The artificially high robustness of the QRA instrumentarium limits the possibility of taking uncertainty and local circumstances into account in risk analyses. Robustness and safety relevance are difficult to unite in a single QRA instrumentarium.

Uit de Haag et al. (2013) state that any change in the individual risk calculation may have large financial consequences and that the introduction of new knowledge (on existing technologies, but also on new, emerging risks) may be hampered by the potential consequences for land use planning. This indeed is a result of the fact that the prescribed calculation method dictates that outcomes of calculations are used in an absolute manner. To our knowledge, to date there are no other countries that use risk calculations in such way.

A risk associated with the current use of the outcome of calculations is that competent authorities are tempted to accept calculated contour lines as absolute distinctions for safe or unsafe areas. When industry or transportation routes are supplied with supplementary safety measures, the tendency in our small country is to allow for housing to be constructed closer to the industrial activity or transport line than before. An example of this tendency of reducing safety distances has been presented in Section 4.5. A number of observations can be made in this regard. Under the pressure of reducing the number of houses at risk, government had an incentive to reduce safety distances in order not to be confronted with high sanitation cost. A “standard LPG filling station” was introduced and local or site specific circumstances were excluded within the prescribed calculation method. The outcome of the calculations was acceptable to the policy objectives, although realisation of safety measures lagged several years behind.

The limited safety relevance of the QRA instrumentarium does not primarily require further technical development – although further improvement of data collection on e.g. failure frequencies in modern chemical process industry is advocated – but rather adaptation of policy. For this, in broad terms, there are two possibilities: (i) supplementing the results from a robust QRA with safety-relevant information obtained via another route, or (ii) altering the way in which planning and decision making concerning external safety is conducted (less emphasis on an absolute use of QRA results, as is more common practice abroad), in which case a less robust but more safety-relevant QRA instrumentarium can be used. At the same time, an area-oriented approach would allow for more attention for consequences of the choice of a certain location on e.g. transport (inwards and outwards) and location of other establishments in the vicinity (cumulation, escalation and domino effects).

5.3. *Expertise of users*

In The Netherlands, RIVM is held responsible for the distribution of the calculation package SAFETI-NL. RIVM requires that users of the package follow a dedicated training course of four days. Uit de Haag et al. (2013) (RIVM) present in their article some possibilities for improvement that are to be realised, i.a. the inexperience of the users and the varying quality of QRAs presented to competent authorities. RIVM has trained some 300–400 users to date, most of them being consultants; a large new group of consultants with limited knowledge of hazardous substances in industrial practice was attracted to this market. Their number is substantially higher than the approximately 25 recognised consultants in Flanders, Belgium. RIVM has to spend considerable support time in relation to the content of the Reference Manual and in relation to the calculation package SAFETI-NL, due to the large number of users and the inexperience of part of this group. As an example errors in copying scenarios in the software tool are mentioned in their article. The competent Dutch authorities decided in 2013 to concentrate their knowledge and expertise in a few expert groups (Uit de Haag et al., 2013). This appears to be a process solution for a more fundamental problem. As stated in Section 2, knowledge and expertise of the user are of paramount importance.

5.4. *Improvement of the decision making process*

Various possibilities exist to improve the decision making process in land-use planning. Decision making procedures in other EU Member States that also implement the Seveso II Directive (e.g. the French 'Plans de Prévention des Risques Technologiques', PPRT), offer inspiration: (a) By putting emphasis on the dialogue among the stakeholders during planning processes, the results of risk analyses may be used more in a relative sense, to weigh up options and set priorities. In this way, opportunities may be created to remove the limitations of the present QRA instrumentarium, which are associated with the absolute use of QRA results in decision making by competent authorities in The Netherlands. In order to avoid impasses, an authoritative arbiter should be introduced. Also, the introduction of an area-oriented approach could be considered, which would offer opportunities to take safety precautions that are possibly not feasible on a smaller scale; (b) By applying separate probability, effect and consequence classes, more justice can be done to the great uncertainties with which the results of QRAs are surrounded. Currently, in The Netherlands an accuracy is often attributed to numerical risk values which they do not possess. In PPRT, in a first step probability and consequence classes are combined in a matrix to assess the acceptability of risks within a certain study area, which may contain multiple establishments. Then it is decided whether or not further analysis and additional provisions are needed (see under); (c) By making a distinction in the risk analysis between rapid and slow accident progressions, information can be provided to the emergency services that is useful for an assessment of the possibilities for self-rescue and disaster control. In PPRT, if there is sufficient time for emergency aid and self-rescue, a scenario is defined as slow, in other cases as rapid. For the slowly developing scenarios, the extent of the areas within which irreversible consequences are possible are projected on a map. For the rapidly developing scenarios, surrounding area risk levels are determined for each location within the area of the study, based on the (cumulative) probabilities and the intensity of effects. For toxic, radiation and overpressure effects, separate maps are prepared; (d) By showing the vulnerability of the surrounding area on maps, planners will be better able to take account of external safety when preparing land-use plans. In PPRT, the risks for inhabitants, but also for working population, cultural heritage and nature are shown on a map. Further analyses focus on the question whether the vulnerability of objects can be reduced and on the question whether there are costs associated with clearance, sale, reduction of vulnerability and the engineering controls to be taken. The local context is included in further analyses; (e) By also presenting the probabilities and consequences of serious accidents separately, and not combining them directly into a risk measure (such as an IR or a SR curve), valuable information can be provided to planners to reduce the risk to the surrounding area, and also to stakeholders. Besides quantitative methods, also semi-quantitative or qualitative approaches may be used, e.g. when corroborated parameter values are not available; (f) With a Bayesian approach, uncertainties of knowledge and statistics can be incorporated into estimates of the IR and the SR. In this way, fruitless discussions about "the true figure" can be avoided, and the great sensitivity of the position of 10–6 risk contours to the choice of certain calculation parameters and values can be reduced.

5.5. *Transportation*

For transportation (motor, rail, or water way) modelling also a method is prescribed in The Netherlands. Some years ago, it was noted that this method RBM II did not fulfil the criteria of transparency, verifiability and robustness (Hazardous Substances Council, 2006); validity in terms of correctness was not assessed in this study. With regards to safety relevance, some peculiarities in the modelling can be noted, e.g. that risk is calculated for an arbitrary way length (1 km). With this approach risk-prone discontinuities in the transport line are not receiving the attention they may require, e.g. crossings, junctions, and intense traffic zones. By averaging risk per unit length, situations may be acceptable when calculations are made, but locally risk may be quite unacceptable. As in Dutch land use planning, possibilities to increase safety are not identified when using this approach.

References

Amendola, A., Contini, S., Ziomas, I., 1992. Uncertainties in chemical risk assessment: results of a European benchmark exercise. J. Hazard. Mater. 29, 347–363.

Bevi, 2004. Decree on External Safety of Establishments, Staatsblad (The Netherlands' Bulletin of Acts and Decrees) 2004, 250.

Bush, S.H., 1975. Pressure vessel reliability. Trans. AMSE: J. Press. Vessel Technol..

COVO Commission, 1982. Risk analysis of six potentially hazardous industrial objects in the Rijnmond area, a pilot study, A report to the Rijnmond Public Authority.

Hazardous Substances Council, 2006. QRA Modelling of Transport of Hazardous Substances (in Dutch: Adviesraad Gevaarlijke Stoffen, 2006, QRA-modellering vervoer van gevaarlijke stoffen).

HSE, 2004. Planning Case Assessment Guide.

Lauridsen, K., Kozine, I., Markert, F., Amendola, A., Christou, M., Fiori, M., The ASSURANCE project, Final summary report 2002. Assessment of uncertainties in risk analysis of chemical establishments. Risø National Laboratory.

Lees, F.P., 1996. Loss Prevention in the Process Industries – Hazard Identification, Assessment, and Control, vol. 1–3. Butterworth-Heinemann, Oxford, 12/94-98.

PGS1, (in Dutch: Methoden voor het bepalen van mogelijke schade aan mensen en objecten door het vrijkomen van gevaarlijke stoffen) 2005. Methods for Determining Possible Harm to People and Objects Due to Release of Hazardous Substances. Green Book.

PGS2, 1997. Methods for the Calculation of Physical Effects. Yellow Book, Version 3.

PGS3, 2005. Guidelines for Quantitative Risk Assessment, Purple Book, Part I: Establishments, Version 3.

Phillips, C.A.G., Warwick, R.G., 1969. A Survey of Defects in Pressure Vessels Built to High Standards of Construction and

Its Relevance to Nuclear Primary Circuits, UKAEA AHSB(S) R162.

Revi, 2004. Regulation on External Safety of Establishments, Staatscourant (The Netherlands Govt Gazette) 2004, 183, and also the Amendment to Revi, Staatscourant 2007, 66.

RIVM, 2001. Benchmark risk analysis models, RIVM report 610066015.

RIVM, 2009. Reference Manual Bevi Risk Assessments (Handleiding Risicoberekeningen Bevi), version 3.2, dated 1 July 2009.

Smith, T.A., Warwick, R.G., 1974. The second survey of defects in pressure vessels built to high standards of construction and its relevance to nuclear primary circuits, UKAE Safety and Reliability Directorate, SRD R30.

Uijt de Haag, P.A.M., Gooijer, L., Frijns, P.J.M.G., 2008. Quantitative risk calculation for land use decisions: the validity and the need for unification. In: Kao, T.M., Zio, M., Ho, V. (Eds.), International Conference on Probabilistic Safety Assessment and Management PSAM9. May 18–23, Hong Kong, paper 0398.

Uit de Haag, P.A.M., Gooijer, L., Kooi, E.S., Spoelstra, M.B., 2013. Evaluation of the use of the prescribed quantitative risk assessment method for land use planning in the Netherlands. Chem. Eng. Trans. 31, 109–114, http://dx.doi.org/10.3303/CET1331019.

Van Xanten, N.H.W., Pietersen, C.M., Pasman, H.J., Vrijling, H.K., Kerstens, J.G.M., 2013. Rituals in risk evaluation for land use planning. Chem. Eng. Trans. 31, 85–90, http://dx.doi.org/10.3303/CET1331015.