PD ISO/TR 16732-3:2013

BSI Standards Publication

Fire safety engineering — Fire risk assessment

Part 3: Example of an industrial property

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National foreword

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Part 3: Example of an industrial property

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Partie 3: Exemple d'un complexe industriel

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 16732-3 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO 16732 consists of the following parts, under the general title *Fire safety engineering — Fire risk assessment*:

— *Part 1: General*

— *Part 2: Example of an office building* [Technical Report]

— *Part 3: Example of an industrial property* [Technical Report]

Introduction

This part of ISO/TR 16732 presents an example of the application of ISO 16732-1, prepared in the format of ISO 16732-1. It includes only those sections of ISO 16732-1 that describe steps in the fire risk assessment procedure. It preserves the numbering of sections in ISO 16732-1 and so omits numbered sections for which there is no text or information for this example.

This example is intended to illustrate the implementation of the steps of fire risk assessment, as defined in ISO 16732-1. Only steps that are considered as relevant in this example are well detailed in this annex.

Risk assessment is preceded by two steps – establishment of the context, including the fire safety objectives to be met, the subjects of the fire risk assessment to be performed and related facts or assumptions; and identification of the various hazards to be assessed. (A “hazard” is something with the potential to cause harm.)

Assumptions made in the present document have been chosen to illustrate, in a simple manner, how the fire risk assessment methodology proposed in ISO 16732-1 can be applied to an industrial facility. These assumptions must be regarded as examples only, and not be applied to other cases without verifying they are representative of the considered cases.

Fire safety engineering — Fire risk assessment —

Part 3: Example of an industrial property

1 Scope

This part of ISO/TR 16732 deals with a fictitious propane storage facility dedicated to the reception of propane transported by tank wagons, the storage of propane in a pressurized vessel and the bulk shipment of propane by tank trucks. The fire risk assessment developed in this part of ISO/TR 16732 is not intended to be exhaustive, but is given as an example to illustrate the application of ISO 16732-1 to an industrial facility.

The scope of this part of ISO/TR 16732 is further limited to design-phase strategies, including changes to the layout of the facility and selection of relevant fire safety strategies (implementation of risk reduction measures). Not included are strategies that operate during the operation phase, including process modifications.

This part of ISO/TR 16732 illustrates the value of fire risk assessment because multiple scenarios are analysed, and several design options are available, which may perform well or not depending on the considered scenario. Risk estimation is needed to determine the result of these different combinations, and overall measures of performance that can be compared between design options. If there were only one scenario of interest, or if the options all tended to perform the same way on all the scenarios, then a simpler type of engineering analysis would suffice.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16732-1:2012, *Fire safety engineering — Fire risk assessment — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16732-1 and the following apply.

3.1
BLEVE
Boiling Liquid Expanding Vapour Explosion
phenomenon which occurs when a vessel containing a pressurized liquid substantially above its (atmospheric) boiling point is ruptured, releasing the contents explosively

Note 1 to entry: Taken from Reference [1].

Note 2 to entry: A more detailed description of phenomena involved during a BLEVE is given in 5.3.

3.2
flashing vaporization
rapid transformation into vapor that is released when a saturated liquid stream undergoes a reduction in pressure

3.3
LPG
Liquefied Petroleum Gas
flammable mixture of propane and butane mainly used as a fuel in heating appliances and vehicles

3.4
LOC
Loss of containment
release of product, such as a leak of product on a pipe, an instantaneous release of product due to a vessel rupture, etc.

3.5
end-cap
curved end part of a pressurized cylindrical vessel shell

3.6
ERS
Emergency Release System
special mechanical device designed to break when a locked loading arm is accidentally displaced, and which isolates the leak by the automatic closing of two valves on each side

4 Applicability of fire risk assessment

ISO 16732-1 lists some examples of circumstances where it is important to give due consideration to scenarios with low frequency but high consequence and hence, fire risk assessment is useful.

The example in this part of ISO/TR 16732 was conducted to support an analysis of different designs for a propane storage facility, where the main risk is a BLEVE of the pressurized storage vessel (which is a spherical storage tank). A BLEVE particularly fits well with the definition of a high consequences and low frequency event where fire risk assessment is useful.

5 Overview of fire risk management

5.1 General

This clause specifies the different design options to be assessed.

5.2 Overall description of the industrial facility

The facility chosen for this example is a propane storage facility, due to its simple process and generic character. The propane storage facility activities include

— reception of propane transported by tank wagons: a compressor sucks up the pressurized storage vessel gaseous atmosphere and compresses it into a tank wagon vapour space to push the liquid into the storage vessel,

— storage in a pressurized vessel,

— bulk shipment of propane by tank trucks: a pump sucks up the pressurized storage vessel liquid and injects it in a tank truck, for delivery to privates or companies.

The following main types of equipment are used: a pressurized storage vessel (with a diameter of 12.5 m for a volume of about 1 000 m^3), tank wagons and tank trucks, pumps, compressors and pipes.

This example focuses on the influence of the truck loading area layout and risk reduction measures upon the pressurized storage vessel BLEVE frequency.

5.3 Phenomenology of a BLEVE

According to the Center for Chemical Process Safety, a BLEVE is defined as “a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapor and flashing liquid. The release of energy from these processes (expanding vapor and flashing liquid) creates a pressure wave”[2].

The overall phenomena involved in a BLEVE (see Figures 1 to 3) have been extensively described in Reference [3].

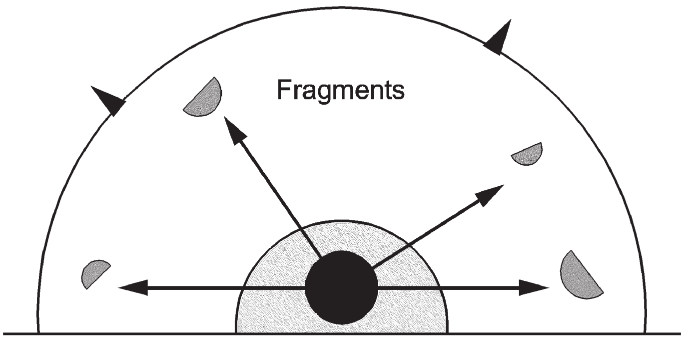

Figure 1 — Vessel failure (dark grey), fireball (light grey), ejection of fragments (black semicircles) and pressure wave (outer circular line)[3]

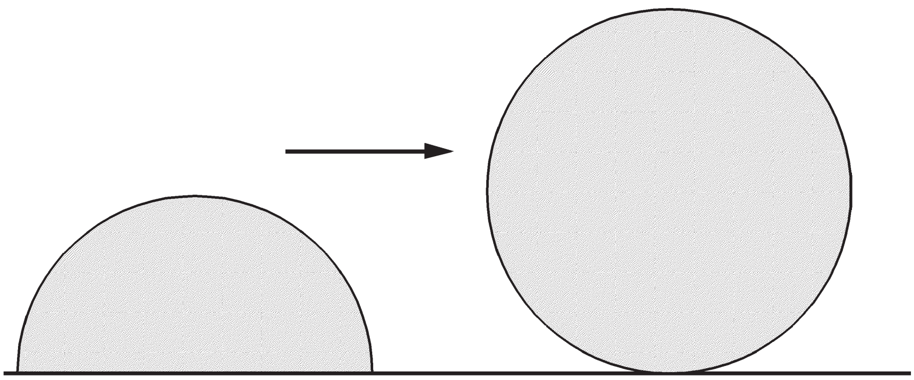

Figure 2 — Fireball lift-off[3]

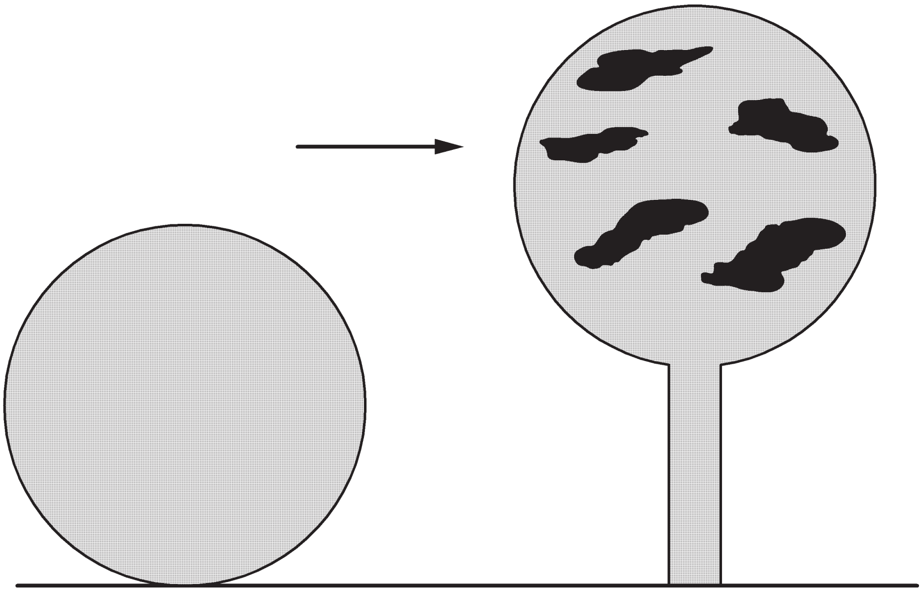

Figure 3 — Fireball apogee[3]

Numerous BLEVEs of stationary storage tanks, tank wagons and tank trucks occurred during the last decades, leading to large disasters and loss of hundreds of lives. Shalif[4] has listed 74 BLEVEs in the period 1926-1986, resulting in 1,427 fatalities and 635 injuries. The catastrophic failure of a pressurized vessel is a sine qua non condition for a BLEVE to occur: it can be provoked by either mechanical or thermal threats with a sufficiently high energy. Table 1 illustrates the different causes leading to a BLEVE.

Table 1 — Past accidents involving BLEVEs and corresponding causes[5]

Causes	BLEVEs
Fire	25
Impact	19
Vessel overfilling	11
Vessel over pressurization	3
Fatigue	2
Explosion	2
Corrosion	1
Earthquake	-
Flood	-
Lightning	-
Others (runaway, overheating, etc.)	25

This survey shows that fire and impact events are the most common causes leading to a BLEVE. Therefore, if the scope of the example is limited to effects of an adjacent fire, BLEVE or explosion, the scope will include roughly half of the circumstances leading to past BLEVE accidents.

According to Roberts et al.[6], “if a pressurised vessel is attacked by fire, its temperature rises and this reduces the strength of the vessel. This, combined with the pressure within the vessel, may lead to failure of the vessel with catastrophic consequences”.

The global heat transfer mechanisms involved during thermal threat on a pressurized vessel are described in Figure 4. When a fire engulfs a vessel, the total incident flux (due to radiation and convection) is absorbed by the vessel, the liquid and the gas. It causes the evaporation of the liquid phase, and hence both a pressure increase as well as the decrease of the liquid level. Thus, absorption capacity is decreasing with time. Safety valves are commonly used to delay the occurrence of a BLEVE by discharging a part of the vessel content. The rapid rise of pressure inside the equipment due to boiling combined with the drop of material strength due to external heating of the envelope will lead to the catastrophic rupture of the vessel.

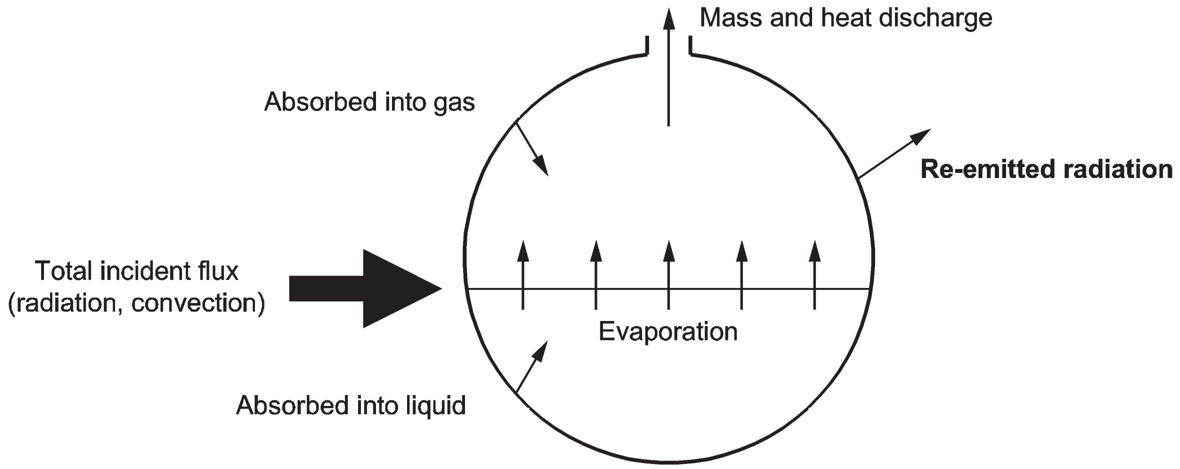

Figure 4 — Heat transfer mechanisms involved during thermal threat on a pressurized vessel[6]

5.4 Risk reduction measures

Table 2 lists risk reduction measures that can be used to prevent or delay a BLEVE, based on a review provided by Fulleringer.[7]

Table 2 — Examples of common risk reduction measures against BLEVEs

Risk reduction measures	Function
Layout (distance)	Increases separation distances to decrease accidental loads on the vessel
Layout (orientation)	Decreases the probability that a thermal/mechanical event threatens the vessel
Isolation of leak (emergency release system)	Isolates loading arm in case of tank truck displacement
Isolation of leak (automatic pump shutdown)	Shutdowns feeding pumps in case of pressure drop (i.e. a leak)
Containment/evacuation of the product (bund, slope)	Prevents liquid accumulation under the vessel/Increases separation distances to reduce thermal loads on the vessel
Safety valve	Discharges product outside the vessel and hence reduces the stress induced by increase of internal pressure
Passive fire protection (protective coating, thermal shielding)	Reduces heat transfer rate to vessel wall
Active fire protection (water deluge, water curtain)	Protects the vessel as it absorbs part of the heat produced by a fire/a jet fire[a]
Concrete wall around the vessel or mounding	Protects the vessel against thermal and mechanical loads

[a] Several tests and studies[8] have shown that a typical water deluge system on a LPG storage vessel cannot maintain a water film over the whole vessel surface if a jet fire impinges on the vessel. API 2510A[9] indicates that "...effective cooling of a vessel shell that is exposed to jet flames is difficult to achieve. The velocity of the jet stream may deflect a water spray pattern or fog pattern from a fire hose." So the current example assumes water deluge is only efficient for radiant jet fires, not impinging jet fires.

5.5 Presentation of design options

In the present example, several alternative designs are considered, differing in

— the separation distances between the pressurized storage vessel and the truck loading area,

— the orientation of the truck loading area, and

— the risk reduction measures implemented relative to the storage vessel (emergency release system on loading arms, automatic feeding pump shutdown system and water deluge on the pressurized storage vessel[1)]).

Table 3 summarizes the six different design options studied in the present document.

Table 3 — Fire protection design options considered

Design option	Additional separation distance	Truck loading area orientation	Emergency relief system (ERS)	Pump shut down	Water deluge
			(99 % reliability assumed)	(99 % reliability assumed)	(90 % reliability assumed)
1	No	North-to-South	No	No	No
2	Yes	North-to-South	No	No	No
3	No	West-to-East	No	No	No
4	No	North-to-South	Yes	No	No
5	No	North-to-South	Yes	Yes	No
6	Yes	North-to-South	Yes	Yes	Yes

"North-to-South" means that a line through the bays of the truck loading area will be perpendicular to the shortest line from pressurized vessel to truck loading area (Figure 5).

"West-to-East" means that the shortest line from pressurized vessel to truck loading area, if extended, will also run through the bays of the truck loading area (Figure 6).

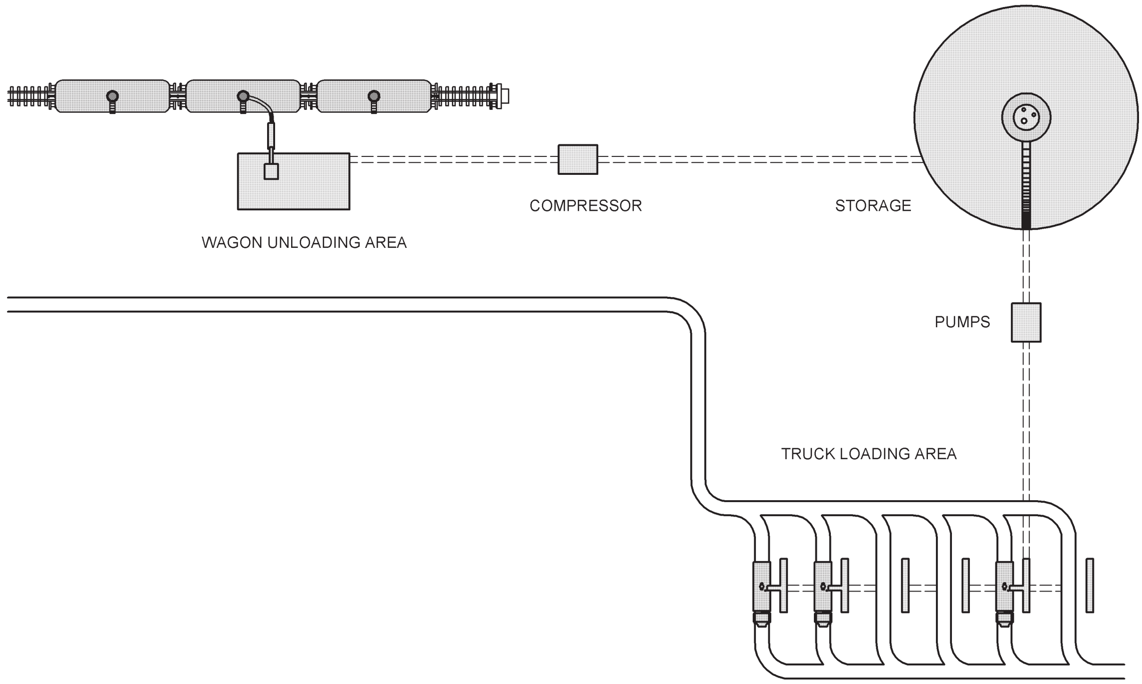

Figure 5 — Option 1

1) Note that pressure safety valve action is not considered in this example.

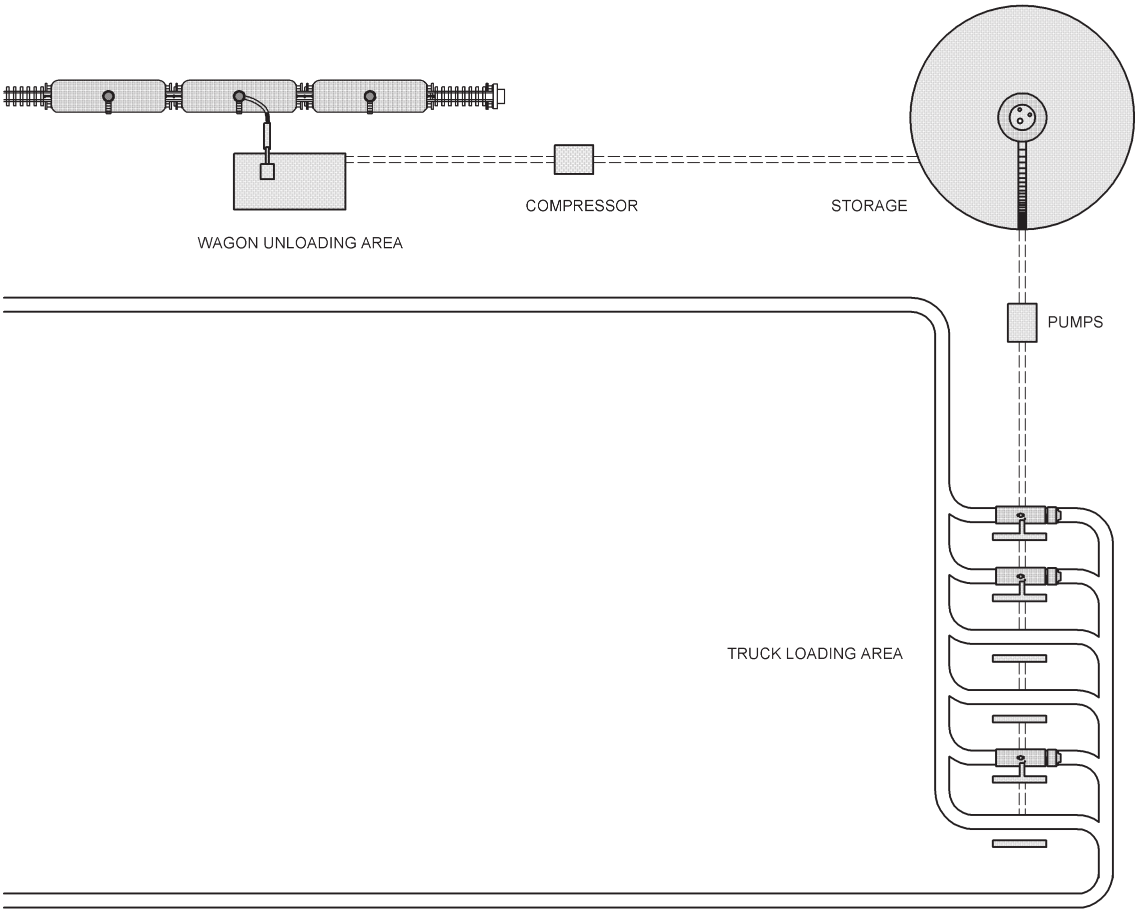

Figure 6 — Option 3

a) Option 1 has the closest point of the truck loading area located 25 m from the storage vessel and has no other risk reduction measures (Figure 5).

b) Option 2 is the same as Option 1 but with a separation distance of 50 m between the storage vessel and the nearest point in the truck loading area. Option 2 also has no risk reduction measures.

c) Option 3 is the same as Option 1 but with a different orientation of the truck loading area. Option 3 also has no risk reduction measures (Figure 6).

d) Option 4 is the same as Option 1 but with an emergency release system on each loading arm. An ERS is efficient for a loading arm rupture, but not for leaks. For simplification purposes, it is assumed that the only cause of a loading arm rupture is an accidental tank truck displacement. ERS is then assumed to prevent all LPG large releases due to a loading arm rupture.

e) Option 5 is the same as Option 4 but with an additional automatic feeding pump shutdown system activated by both a gas detection system covering the truck loading area and a low pressure detection system.

f) Option 6 is the same as Option 2 but with risk reduction measures (ERS, automatic feeding pump shutdown system, and also a water deluge activated by an infrared detection system on the pressurized storage vessel and designed to protect LPG storage tanks in the event of a fire).

6 Steps in fire risk estimation

6.1 Overview of fire risk estimation

Fire risk estimation begins with the establishment of a context. The context provides a number of quantitative assumptions, which are required with the objectives and the design specifications, to perform the estimation calculations.

The objective for this example is to prevent the pressurized vessel to BLEVE. The focus is on a BLEVE of the pressurized storage vessel, because of its potentially devastating effects[2)]. Reducing the probability of a BLEVE is also expected to reduce the potential for harm to third parties located outside the propane storage facility.

For simplification purposes, this example only focuses on the influence of the truck loading area layout and risk reduction measures upon the storage vessel BLEVE frequency.

6.2 Use of scenarios in fire risk assessment

6.2.1 Overview of specification and selection of scenarios

The number of distinguishable fire scenarios is too large to permit analysis of each one. Therefore, any fire risk assessment must develop a scenario structure of manageable size but must also make the case that the estimate of fire risk based on these scenarios is a reasonable estimate of the total fire risk. The principal techniques to achieve these goals are identification of hazards, combining of scenarios into clusters and exclusion of scenarios with negligible risk.

The following steps define how the scenarios are selected in this example.

6.2.2 Identification of hazards

The present example studies a BLEVE of the pressurized storage vessel in a propane storage facility.

As explained in 5.3, a BLEVE is the direct consequence of the catastrophic rupture of a vessel, which can be caused by several types of events.

These events can be classified in two main categories or families of hazards and related initiating events (see Figure 7, see Reference [10]):

— internal (to the facility) hazards, caused by the activities of the facility itself; for the example, there are three main families of internal hazards and related initiating events, which are

  — mechanical failure of the storage vessel itself by over pressurization, overfilling, corrosion or fatigue,

  — BLEVE of other pressurized vessels on the site (wagons and trucks in our example), conducting to overpressures and ejection of fragments (BLEVE associated thermal radiation is not considered to be able to provoke a BLEVE because of the short duration of the fireball[3)]) that may lead to mechanical damage on the pressurized fixed storage vessel,

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2) According to the CCPS book relationship[2], the BLEVE of a 1 000 m^3 vessel storing propane would give a fireball maximum diameter of: $D = 5.8\ M^{1/3} = 5.8 \times (582 \times 1{,}000)^{1/3} = 485$ meters.

3) According to the CCPS book relationship[2], the BLEVE of a 1 000 m^3 vessel storing propane would give a fireball duration of: $t = 2.6\ M^{1/6} = 2.6 \times (582 \times 1{,}000)^{1/6} = 24$ seconds.

  - propane releases from other equipment on the site conducting to fires, jet fires or explosions that may also lead to mechanical damage on the pressurized storage vessel.
- external (to the facility) hazards, caused by the surroundings of the facility; for the example, there are three main families of external hazards and related initiating events, which are:
  - natural events such as earthquake and lightning,
  - transportation accidents outside the facility (airport, railways, highways, river traffic),
  - hazardous material release in nearby facilities such as petrochemical facilities, factories, and pipelines.

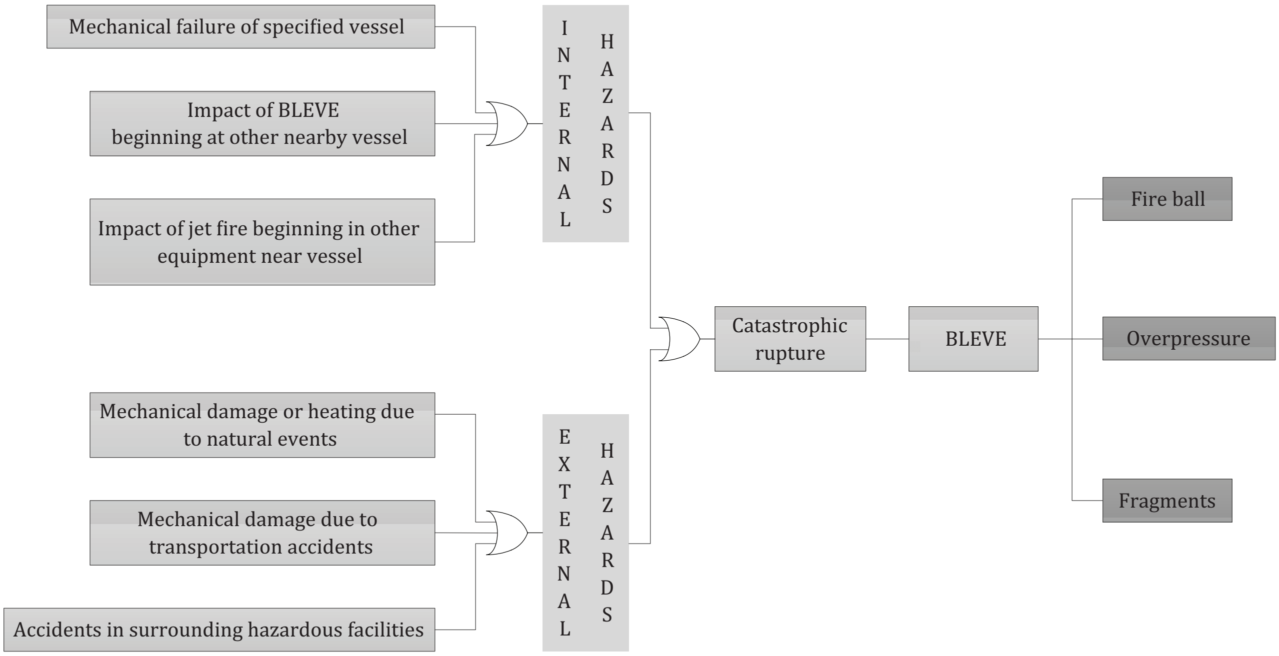


Figure 7 — Generic fault tree (bow-tie format) for catastrophic rupture and BLEVE (without risk reduction measures)

Figure 7 describes the six families of initiating events and related hazards that can lead to the catastrophic rupture of a pressurized vessel. As noted, the scope of this example is limited to BLEVE due to adjacent fires, BLEVEs or explosions, and also to risk reduction strategies focused on the truck loading area. Internal-hazard scenarios involving mechanical failure of specified vessel are therefore not relevant for the example. External-hazard scenarios such as natural events or transportation accidents outside the facility, also are not relevant for the example. Explosions also are not considered here for simplification purposes: it is assumed in the example that the truck loading area congestion level is too low to give sufficient high overpressures to provoke a BLEVE of the pressurized storage vessel.

Therefore, in this example, the six families of initiating events and related hazards are reduced to only two families: impact of BLEVE beginning at other nearby vessel and impact of jet fire beginning in other equipment near vessel.

These two families can be further reduced to two groups of more specifically defined loss of containment initiating events that are the only hazards considered capable of initiating a BLEVE of the storage vessel:

- jet fires from truck loading arms, considered the only fire resulting from a nearby leak that can have sufficient impact at a distance; and
- tank truck BLEVEs, considered the only nearby source of a BLEVE.

Some past incidents have been identified in the ARIA database[11] that particularly well illustrate these two families of initiating events and related hazards. Several cases of leaks (or malfunctions likely to lead to a leak) occurring in LPG tanker loading facility were noticed that would have been able to initiate a jet fire and thus impinge a LPG pressurized storage vessel:

— October 23, 1989, Le Blanc, France: LPG release in the LPG road-tanker loading facility of a LPG depot;

— January 14, 2002, Cournon d'Auvergne, France: LPG release due to a nozzle rupture in the LPG road-tanker loading facility of a LPG depot;

— April 23, 2004, Germany: LPG release and flash in the LPG road-tanker loading facility of a refinery;

October 7, 2004, Le Blanc, France : malfunction of an ERS in the LPG road-tanker loading facility of a LPG depot;

— March 21, 2005, Donges, France: release of LPG at a railcar tank loading station of a LPG depot.

Also several cases of tank truck BLEVEs (on industrial sites or LPG filling stations) were noticed:

— February 9, 1972, Tewksbury, Massachusetts, United States of America: BLEVE of a tank truck during unloading operation;

— July 5, 1973, Kingman, Arizona, United States of America: BLEVE of a wagon truck during unloading operation after disconnection of an unloading arm;

September 11, 1998, Buncheon, South Korea: BLEVE of a tank truck in a LPG filling station after leak of an unloading arm;

May 7, 2007, Dagneux, France: BLEVE of two tank trucks parked on an industrial site;

August 10, 2008, Toronto, Canada: BLEVE of a tank truck parked on an industrial site during a transfer operation between two tank trucks.

6.2.3 Combining scenarios into scenario clusters

The two narrowly defined families of hazards and initiating events defined at the end of 6.2.2 constitute an initial structure consisting of two scenario clusters. In this case, scenario clusters have been developed from families of hazards, as opposed to the normal sequence in ISO 16732-1, wherein scenarios are developed from hazards and are then grouped into scenario clusters.

This initial scenario structure can be improved by subdividing the jet fire scenario cluster into three narrower scenario clusters based on the size of the initiating leak. Frequency of occurrence, as well as consequence, can then be directly estimated for each of these smaller scenario clusters. The three sizes of leaks are defined qualitatively and each is represented by a specific size of leak, as indicated.

Minor leaks, represented by a 1 % diameter leak: such leaks can be the result of corrosion, and they can be omitted from the analysis because they do not support a jet fire large enough to cause a BLEVE,

— Medium leaks, represented by a 10 % diameter leak: such leaks can be the result of a gasket leak or a pipe connection leak for instance,

— Major leaks, represented by a full-bore rupture: such leaks can be the result of a steam hammer, a vehicle impact or an arm failure, for example.

The final scenario structure therefore consists of three scenario clusters – a tank truck BLEVE, a jet fire caused by a medium leak (represented by a 10 % diameter leak), and a jet fire caused by a major leak (represented by a full-bore rupture).

6.2.4 Exclusion of scenarios with negligible risk

In this example, it is assumed that each loading area is fitted with a drainage system that enables to collect fuel and oil leaks, thus preventing truck fires that could otherwise lead to a BLEVE. Note that tire/break fires are also supposed to be extinguished by truck drivers before leading to an aggravated fire.

6.2.5 Demonstrating that the scenario structure is appropriate and sufficient

As stated in 6.2.2, the scenario structure for the present example requires only scenarios that begin with tank trucks on the facility or with equipment that interacts with tank trucks on the facility, which together represent all scenarios falling within the scope of the example. Based on the experience with past BLEVEs, the two types of scenarios identified in 6.2.2 are considered as the only ones capable to produce a BLEVE of the pressurized storage vessel.

6.2.6 Fire risk assessment without explicit scenario structures

Subclause 6.2.6 of ISO 16732-1:2012 is not relevant in this example.

6.2.7 Behavioural scenarios

For simplification purposes, this example does not consider human behaviour explicitly. However, human error is inherently taken into account in the frequencies of loss of containment used for the present fire risk assessment. Fire brigade is assumed to be unable to control the fire after several minutes because of its dimensions, which is a conservative assumption.

6.2.8 Fire risk assessment for selecting design fire scenarios for deterministic analysis

Subclause 6.2.8 of ISO 16732-1:2012 is not relevant in this example.

6.3 Estimation of frequency and probability

6.3.1 Frequencies of loss of containment

The scenario clusters selected in 6.2 all involve loss of containment events (LOCs) – either a truck loading arm leak resulting in a jet fire or a tank truck BLEVE.

In this example, the “Purple Book”[12] database was used to quantify LOC frequencies.

6.3.2 Frequency that a loading arm leak produces a jet fire that provokes a BLEVE of the pressurized storage vessel

The frequency that a loading arm leak produces a jet fire that provokes a BLEVE of the pressurized storage vessel can be estimated by multiplying

— the frequency of a loading arm LOC (/hour),

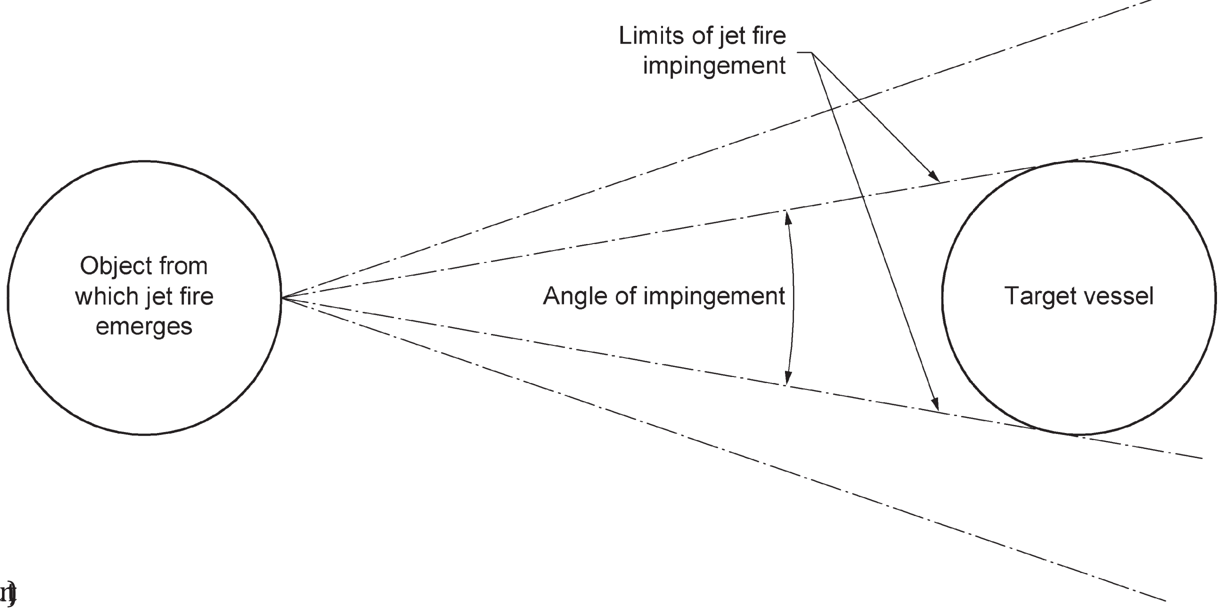
— the annual number of hours of loading (assumed to be 1,000 h in our example for the six loading arms, corresponding to 1,000 loading operations of one hour per year),

— the probability of immediate ignition (that a leak produces a jet fire), which is assumed to be 1 in the example,

— the probability that the jet fire is oriented in the direction of the pressurized storage vessel (orientation factor) and that it can impinge the vessel or generate sufficiently high radiation level on the vessel to provoke a BLEVE of the pressurized storage vessel[4)] (critical radiation level is fixed at 16 kW/m^2, which is a conservative assumption compared to Health and Safety Executive recommended value

4) Considering a constant jet fire length is conservative. In a real situation, the jet fire length decreases as a result of the depressurisation of the leaking equipment.

of 37,5 kW/m2[13]). Orientation factor can be calculated, for example, using the approach proposed by Pettitt et al. (see Figure 8, see Reference [14]). In this approach, leak frequency density is assumed to be constant over the total area of the loading arm (i.e. singularities are not taken into



account)

Figure 8 — Example of “angle of impingement” between two vessels

— the probability of failure of risk reduction measures (if existing), and

— the probability that impinging jet fire damages the vessel, which is assumed to be 1 in this example. Note that only a jet fire that lasts long enough can provoke a BLEVE of the pressurized storage vessel. In this example, it is assumed that an impinging jet fire will last enough to provoke a BLEVE of the pressurized storage vessel.

6.3.3 Frequency that a tank truck BLEVE leads to an overpressure that provokes a BLEVE of the pressurized storage vessel

The frequency that a tank truck BLEVE leads to an overpressure that provokes a BLEVE of the pressurized storage vessel can be estimated by multiplying

— the frequency of a tank truck instantaneous release (/year)5),

— the probability of immediate ignition (that an instantaneous release results in a BLEVE), which is assumed to be 1 in this example6),

— the probability that an overpressure level greater than 38 kPa7) can reach the pressurized storage vessel, and

— the probability that the overpressure damages the vessel sufficiently to cause a BLEVE.

5) In this example, it is assumed that tank truck BLEVEs are independent events.

6) In this example, the BLEVE frequency is equal to the tank truck catastrophic rupture frequency.

7) In this example, a 38 kPa overpressure is assumed to provoke a BLEVE of the pressurised storage vessel. It corresponds to the *“overpressure of partial damage on a pressure vessel”*[16].

6.3.4 Frequency that a tank truck BLEVE leads to a vessel fragment impact that provokes a BLEVE of the pressurized storage vessel

The frequency that a tank truck BLEVE leads to a vessel fragment impact that provokes a BLEVE of the pressurized storage vessel can be estimated by multiplying

— the frequency of a tank truck instantaneous release (/year),

— the probability of immediate ignition (that an instantaneous release results in a BLEVE), which is assumed to be 1 in this example,

— the probability that the BLEVE results in effective ejection of fragments, which is assumed to be 1 in this example,

— the probability that a vessel fragment travels a sufficient distance to reach the pressurized storage vessel, which is assumed to be 1 in all options of this example because of the small distance separating the tank truck loading zone and the pressurized storage vessel (which is a conservative assumption comparing to the recommendations in Reference [13]): this factor can be more precisely estimated using a probabilistic approach; see References [15],[16],[17],

— the probability that the vessel fragment travels in the direction of the pressurized storage vessel (orientation factor). Orientation factor can be calculated using the approach proposed in Reference [14]. In this example, it is assumed that only end-caps have sufficient energy and mass to provoke a BLEVE of the pressurized storage vessel. A 60° angle is considered for end-cap according to Holden et al.,[15] and

— the probability that the fragment damages the vessel sufficiently to cause a BLEVE is assumed to be 1.

6.4 Estimation of consequence

In the example, consequence is defined as the occurrence of a BLEVE in a storage vessel and is not measured on a scale. Therefore, consequence estimation is not required for the example.

6.4.1 Consequence estimation from loss experience

Subclause 6.4.1 of ISO 16732-1:2012 is not relevant in this example.

6.4.2 Consequence estimation from models

Subclause 6.4.2 of ISO 16732-1:2012 is not relevant in this example.

6.4.3 Consequence estimation from engineering judgment

Subclause 6.4.3 of ISO 16732-1:2012 is not relevant in this example.

6.5 Calculation of scenario fire risk and combined fire risk

Calculations in 6.5, and generally in every part of this example, are done solely to provide a realistic illustration of the general procedures applied to this application. As such, the parameter estimates and other calculations cannot be validly used as a realistic representation of this application or a basis for decision-making among these options. A real application of the procedures would require substantiation for all parameter values and other decisions, and would also require a detailed discussion of statistical significance of the calculated differences in point estimates of risk among the several options.

Here are the results of the conducted Fire Risk Evaluation. The following values of LOC frequencies are used. Radiation distances have been arbitrarily chosen, and are representative of LPG leaks.

Table 4 — Types of releases, LOC frequencies, corresponding jet-fire flame lengths, and radiation distances

Equipment	Type of failure	Frequency	Flame length	16 kW/m²
Unloading arm	Full-bore rupture	3.10^{-8}/h	80 m	100 m
	10 % leak	3.10^{-7}/h	40 m	60 m

Table 5 — Tank truck BLEVEs' frequency and overpressure distances

Equipment	Frequency per truck	38 kPa
Tank truck	5.10^{-7}/year	30 m

Option 1: 25 m distance, North-to-South orientation, without risk reduction measures

Both full-bore rupture and 10 % leak jet fires can impinge the pressurized storage vessel and provoke a BLEVE. The BLEVE of a tank truck generates both overpressure and fragments. In this Option 1 configuration, an overpressure level greater than 38 kPa can reach the pressurized storage vessel in case of the BLEVE of a tank truck. According to the truck loading area orientation, one end-cap of each tank truck can reach the pressurized storage vessel.

The orientation factors are taken equal to 0.18 for a jet fire (both for full-bore rupture and 10 % leak) and to 0.22 for a vessel fragment. So the BLEVE frequency due to the truck loading area is given by: $(3.10^{-8} \times 10^3 \times 1.8.10^{-1}) + (3.10^{-7} \times 10^3 \times 1.8.10^{-1}) + (5.10^{-7} \times 6 \text{ trucks}) + (5.10^{-7} \times 6 \text{ trucks} \times 2.2.10^{-1}) = 6.10^{-5}$/year.

The BLEVE frequency due to the truck loading area is quite high without safeguards for such a facility.

Option 2: 50 m distance, North-to-South orientation, without risk reduction measures

For this option, only full-bore rupture jet fire can impinge the pressurized storage vessel, but radiation levels for the 10 % leak are assumed to be sufficient to provoke a BLEVE (16 kW/m²). In this Option 2 configuration, the BLEVE of a tank truck cannot lead to an overpressure level greater than 38 kPa on the pressurized storage vessel because of the 50 meters separation distance. According to the truck loading area orientation, one end-cap of each tank truck can reach the pressurized storage vessel.

The orientation factors are taken equal to 0.13 for a jet fire (both for full-bore rupture and 10 % leak) and to 0.15 for a vessel fragment. So the BLEVE frequency due to the truck loading area is given by: $(3.10^{-8} \times 10^3 \times 1.3.10^{-1}) + (3.10^{-7} \times 10^3 \times 1.3.10^{-1}) + (5.10^{-7} \times 6 \text{ trucks} \times 1.5.10^{-1}) = 4.10^{-5}$/year.

Additional separation distance does not reduce the BLEVE frequency due to the truck loading area in a significant manner.

Option 3: 25 m distance, West-to-East orientation, without risk reduction measures

Both full-bore rupture and 10 % leak jet fires can impinge the pressurized storage vessel and provoke a BLEVE. Trucks are 5 m spaced. So only the two first trucks (25 m and 30 m) can provoke a BLEVE of the pressurized storage vessel by overpressure effects in case of instantaneous release. Moreover, given the trucks' orientation, end-caps cannot reach the pressurized storage vessel.

Regarding the perpendicular orientation of the trucks, each jet fire has its own orientation factor OF (OF = 0.18 for the first truck, 0.17 for the second truck, 0.16 for the third truck, 0.15 for the fourth truck, 0.14 for the fifth truck and 0.13 for the last truck). So the BLEVE frequency due to the truck loading area is given by: $\sum (3.10^{-8} \times (10^3/6) \times OF_i) + \sum (3.10^{-7} \times (10^3/6) \times OF_i) + (5.10^{-7} \times 2 \text{ trucks}) = 5.10^{-5}$/year.

The BLEVE frequency due to the truck loading area is only slightly reduced compared to Option 1 thanks to a different orientation of the truck loading area.

Option 4: 25 m distance, North-to-South orientation, ERS

Both full-bore rupture and 10 % leak jet fires can impinge the pressurized storage vessel and provoke a BLEVE. But this time, ERS can isolate loading arm ruptures. An overpressure level greater than 38 kPa can reach the pressurized storage vessel in case of the BLEVE of a tank truck. According to the truck loading area orientation, one end-cap of each tank truck can reach the pressurized storage vessel.

The orientation factors are those considered for Option 1 (same distances). So the BLEVE frequency due to the truck loading area is given by (see also Figure 10): (3.10^{-8} x 10^3 x $1.8.10^{-1}$ x 10^{-2}) + (3.10^{-7} x 10^3 x $1.8.10^{-1}$) + (5.10^{-7} x 6 trucks) + (5.10^{-7} x 6 trucks x $2.2.10^{-1}$) = 6.10^{-5}/year.

The influence of ERS is not significant in the present case because of the major contribution of the 10 % leaks jet fires which cannot be isolated by ERS.

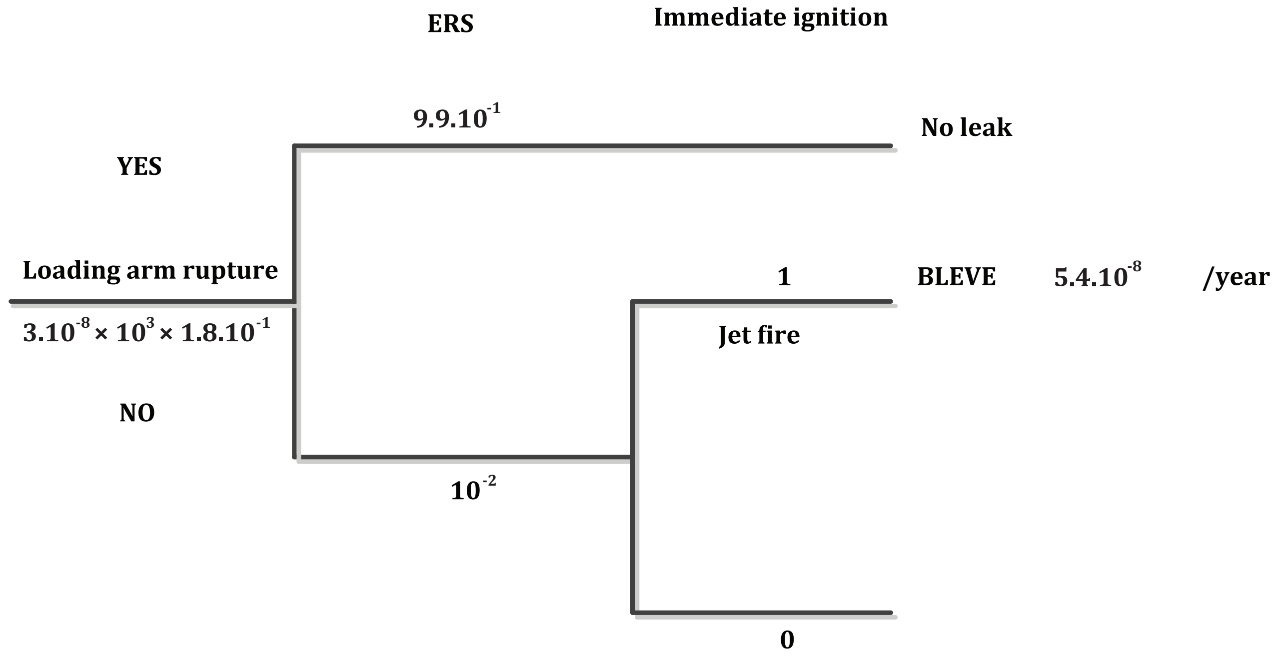


Figure 9 — Event tree for a full-bore rupture jet fire (Option 4)

Option 5: 25 m distance, North-to-South orientation, ERS and automatic pump shutdown system

Both full-bore rupture and 10 % leak jet fires can impinge the pressurized storage vessel and provoke a BLEVE. ERS and an automatic pump shutdown system can isolate both loading arm ruptures and 10 % leaks. An overpressure level greater than 38 kPa can reach the pressurized storage vessel in case of the BLEVE of a tank truck. According to the truck loading area orientation, one end-cap of each tank truck can reach the pressurized storage vessel.

The orientation factors are those considered for Option 1 (same distances). So the BLEVE frequency due to the truck loading area is given by (see also Figures 10 and 11): (3.10^{-8} x 10^3 x $1.8.10^{-1}$ x 10^{-2} x 10^{-2}) + (3.10^{-7} x 10^3 x $1.8.10^{-1}$ x 10^{-2}) + (5.10^{-7} x 6 trucks) + (5.10^{-7} x 6 trucks x $2.2.10^{-1}$) = 4.10^{-6}/year.

The BLEVE frequency due to the truck loading area is greatly reduced comparing to Option 4, by the use of an automatic pump shutdown system.

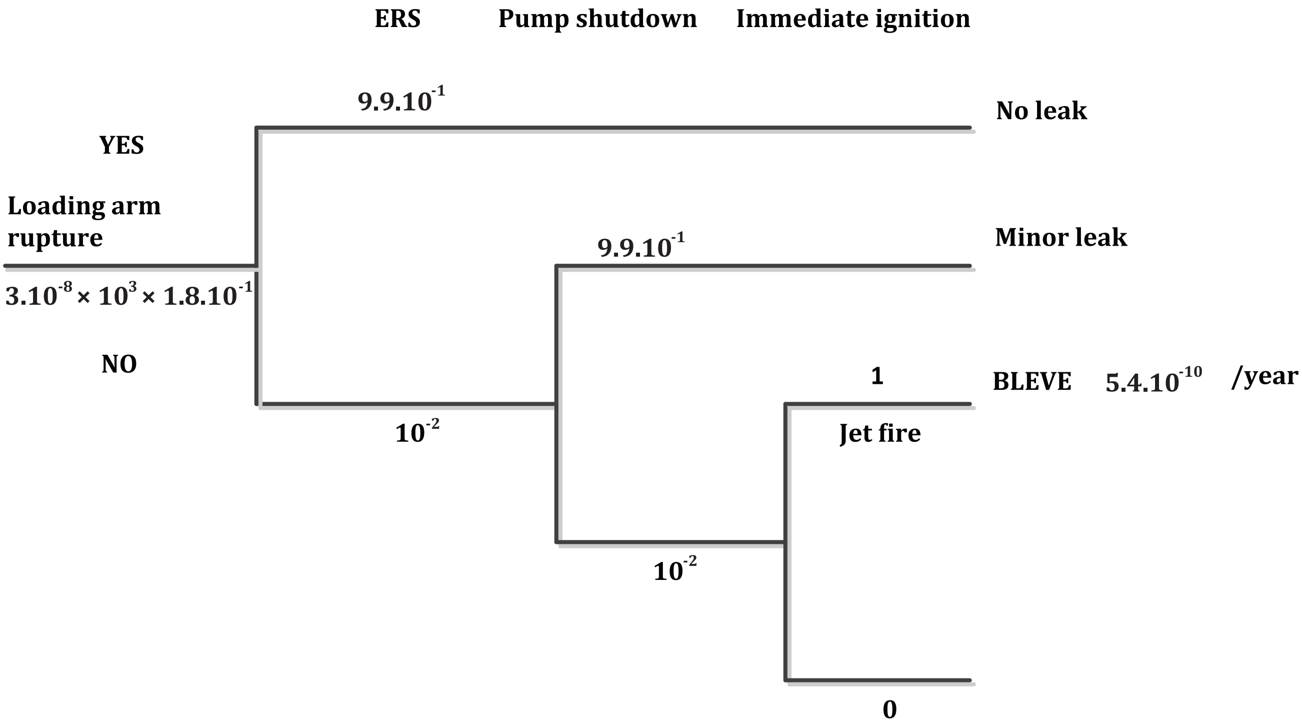


Figure 10 — Event tree for a full-bore rupture jet fire (Option 5)

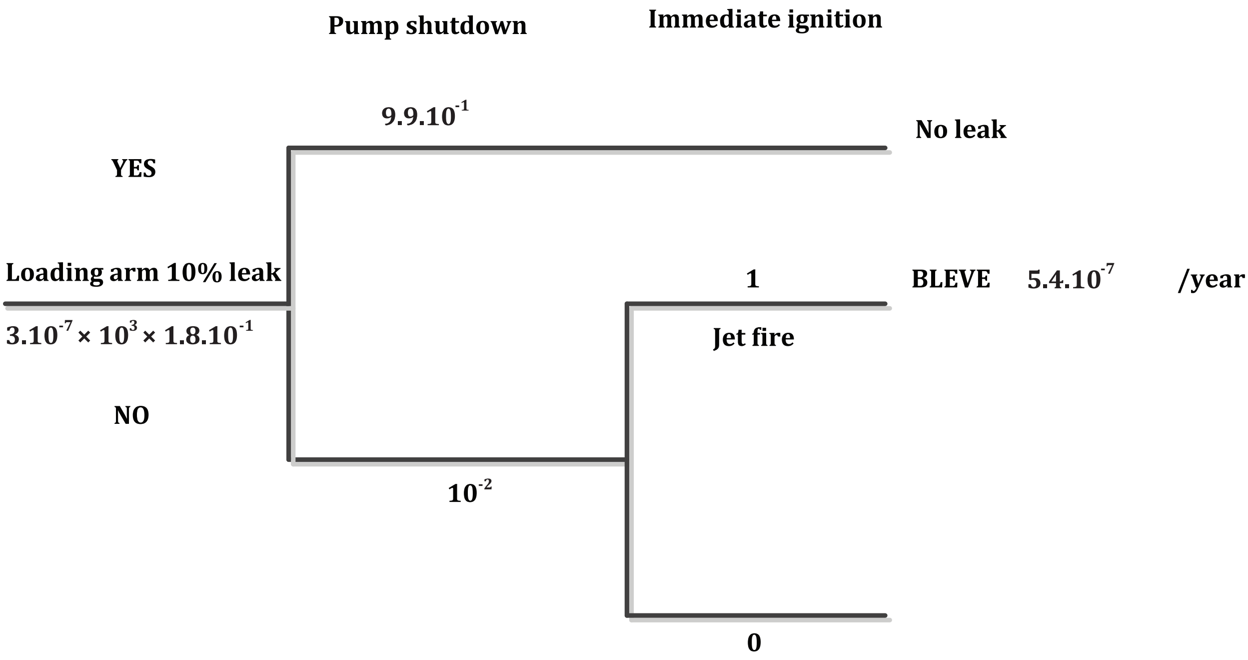


Figure 11 — Event tree for a 10 % leak jet fire (Option 5)

Option 6: 50 m distance, North-to-South orientation, ERS and automatic pump shutdown system and water deluge

Only full-bore rupture jet fire can impinge the pressurized storage vessel, but radiation levels for the 10 % leak are assumed to be sufficient to provoke a BLEVE (16 kW/m^2). This time, ERS, an automatic pump shutdown system and a water deluge (only efficient for radiant jet fires, in our case 10 % leaks jet fires) are installed. An overpressure level of 38 kPa cannot reach the pressurized storage vessel because of the 50 meters separation distance. According to the truck loading area orientation, one end-cap of each tank truck can reach the pressurized storage vessel.

The orientation factors are those considered for Option 2 (same distances). So the BLEVE frequency due to the truck loading area is given by (see also Figures 12 and 13): $(3.10^{-8} \times 10^{3} \times 1.3.10^{-1} \times 10^{-2} \times 10^{-2}) + (3.10^{-7} \times 10^{3} \times 1.3.10^{-1} \times 10^{-2} \times 10^{-1}) + (5.10^{-7} \times 6 \times 1.5.10^{-1}) = 5.10^{-7}$/year.

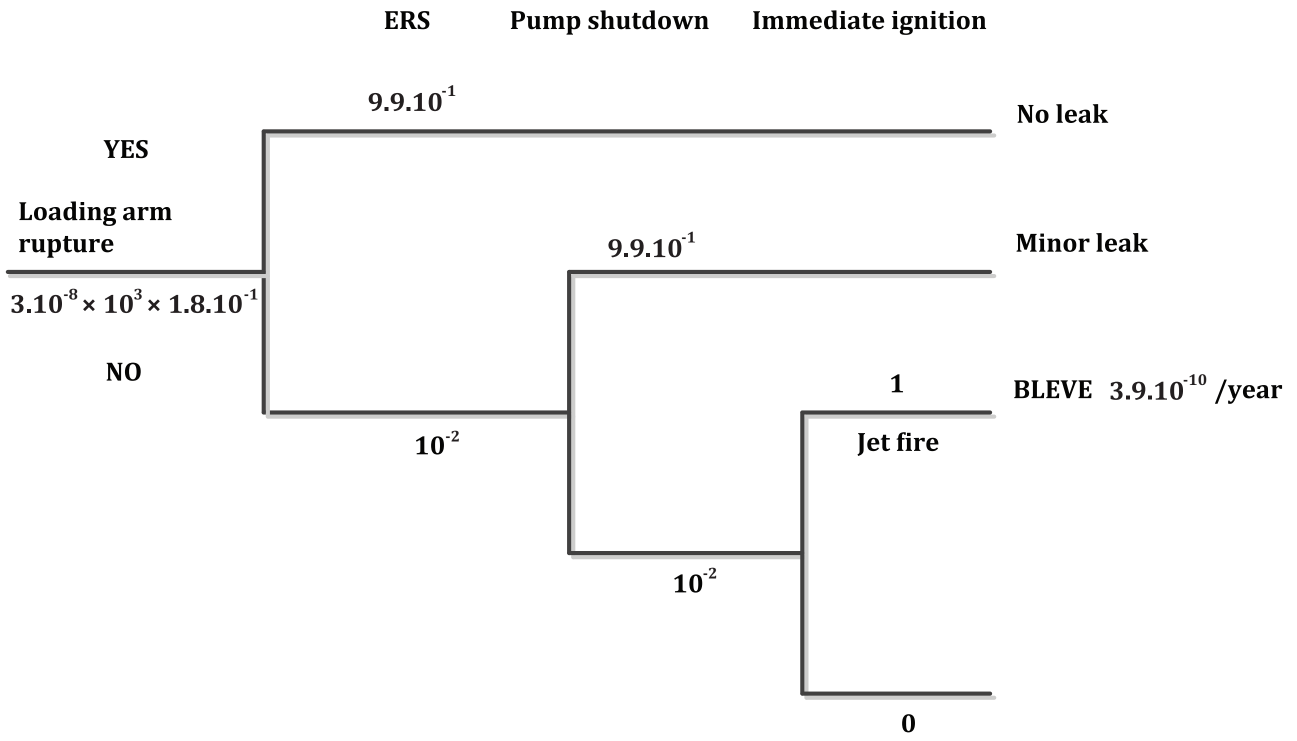


Figure 12 — Event tree for a full-bore rupture jet fire (Option 6)

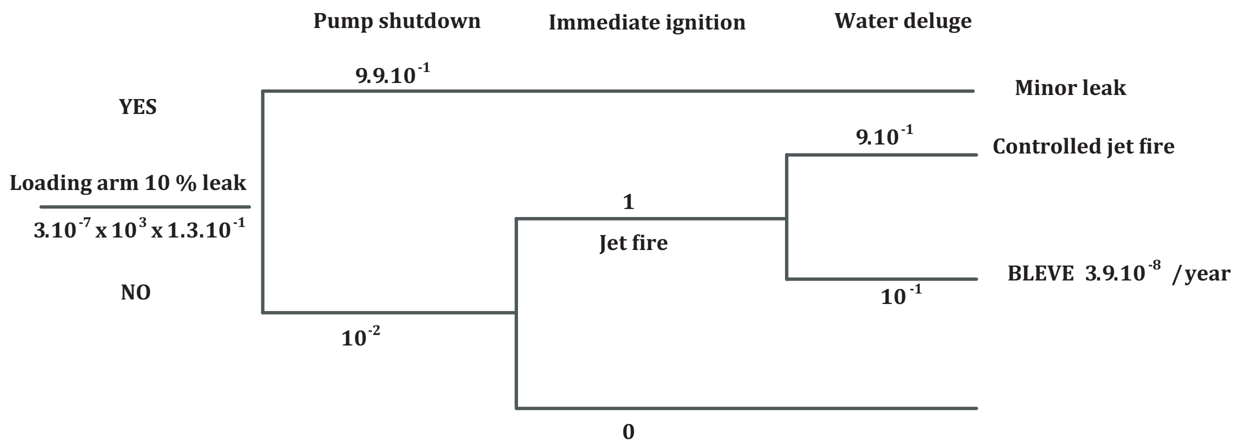


Figure 13 — Event tree for a 10 % leak jet fire (Option 6)

Figure 14 and Table 6 give a summary of calculations' results.

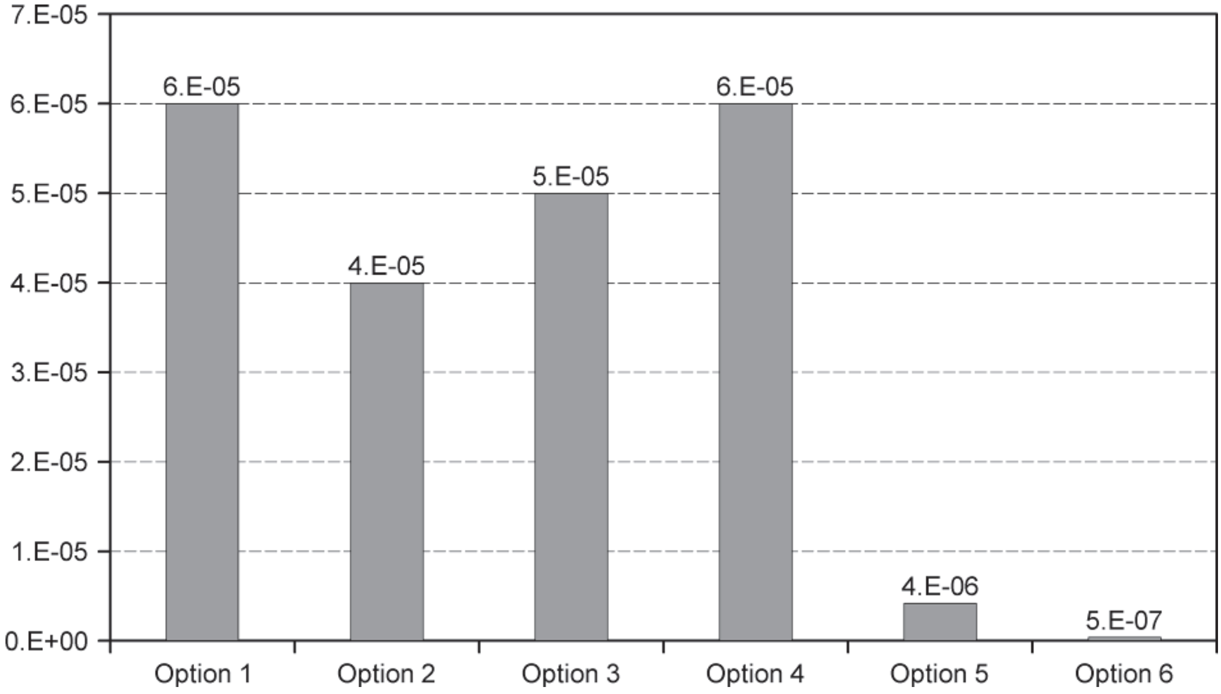


Figure 14 — BLEVE frequency for each option

Table 6 — Relative contribution of events to BLEVE frequency

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Full-bore rupture jet fire	$5.4.10^{-6}$ *(9 %)*	$3.9.10^{-6}$ *(9 %)*	$4.65.10^{-6}$ *(9 %)*	$5.4.10^{-8}$ *(<1 %)*	$5.4.10^{-11}$ *(<1 %)*	$3.9.10^{-10}$ *(<1 %)*
10 % leak jet fire	$5.4.10^{-5}$ *(85 %)*	$3.9.10^{-5}$ *(90 %)*	$4.65.10^{-5}$ *(89 %)*	$5.4.10^{-5}$ *(94 %)*	$5.4.10^{-7}$ *(13 %)*	$3.9.10^{-8}$ *(8 %)*
Tank truck BLEVE overpressure	3.10^{-6} *(5 %)*		10^{-6} *(2 %)*	3.10^{-6} *(5 %)*	3.10^{-6} *(71 %)*	
Tank truck BLEVE fragments	$6.6.10^{-7}$ *(1 %)*	$4.5.10^{-7}$ *(1 %)*		$6.6.10^{-7}$ *(1 %)*	$6.6.10^{-7}$ *(16 %)*	$4.5.10^{-7}$ *(92 %)*
TOTAL	$6.3.10^{-5}$	$4.3.10^{-5}$	$5.2.10^{-5}$	$5.8.10^{-5}$	$4.2.10^{-6}$	$4.9.10^{-7}$

This example shows that isolating systems (ERS, automatic pump shutdown system) can greatly reduce the pressurized storage vessel BLEVE frequency because they reduce the release duration and hence the capacity of a jet fire to provoke a BLEVE. Modifying the layout (separation distances and orientation) is a less efficient safeguard in our example.

This example also shows the importance of the identification of the main contributing events to implement adequate risk reduction measures: for example, there is a very small difference between Option 1 and Option 4, because ERS are not effective for 10 % leak jet fires (main contributing event).

From Table 6, contributing events weight largely differs from Option 1 to Option 6. In all cases, loading arm full bore ruptures are not predominant events because of their low initial frequency.

Lastly, when comparing Option 1 and Option 6, note that the pressurized storage vessel BLEVE frequency is greatly reduced by the use of an additional separation distance (50 m), ERS, automatic pump shutdown system and water deluge.

7 Uncertainty, sensitivity, precision, and bias

The example does not include a formal analysis of uncertainty or sensitivity.

Formal uncertainty analysis would require development of distributions for the values of parameters used in the calculations. A simpler sensitivity analysis could be performed using conservative engineering value estimates at every stage. This simpler analysis would indicate how high the calculated risk values could be for each design option, but this analysis could not be reliably used to determine with confidence that the estimated risk values for two design options are significantly different.

8 Fire risk evaluation

8.1 Individual and societal risk

Subclause 8.1 of ISO 16732-1:2012 is not relevant in this example.

8.2 Risk acceptance criteria

For the purpose of this study, an acceptable frequency of 10^{-5}/year is used as an example.[18]

Figure 15 shows that both Options 5 and 6 complete this criterion.

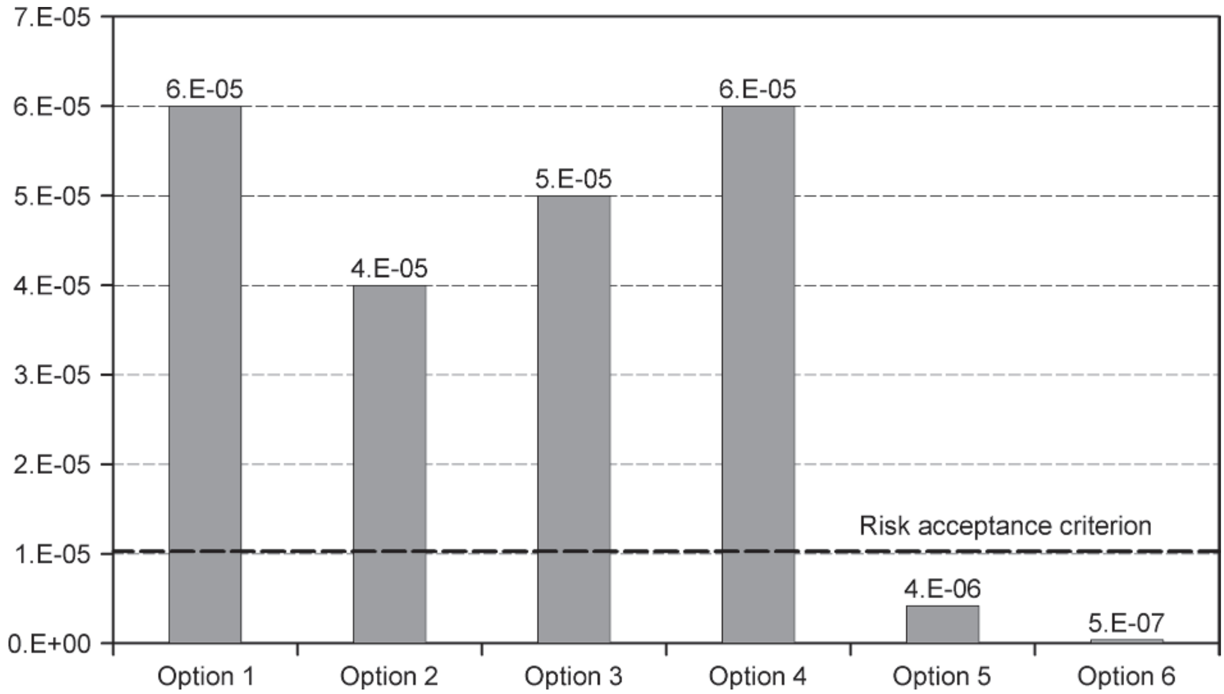


Figure 15 — BLEVE frequencies compared to risk acceptance criteria

8.2.1 Baseline from defined recent experience

Subclause 8.2.1 of ISO 16732-1:2012 is not relevant in this example.

8.2.2 Establishing criteria based on baseline

Subclause 8.2.2 of ISO 16732-1:2012 is not relevant in this example.

8.2.3 Acceptable frequency and revised criteria for multiple-death events

Subclause 8.2.3 of ISO 16732-1:2012 is not relevant in this example.

8.2.4 Acceptance based on ALARP

Subclause 8.2.4 of ISO 16732-1:2012 is not relevant in this example.

8.3 Safety factors and safety margins

Subclause 8.3 of ISO 16732-1:2012 is not relevant in this example.

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