

## **APPENDIX 5**

# **Methodology for the building of generic event trees (MIMAH)**

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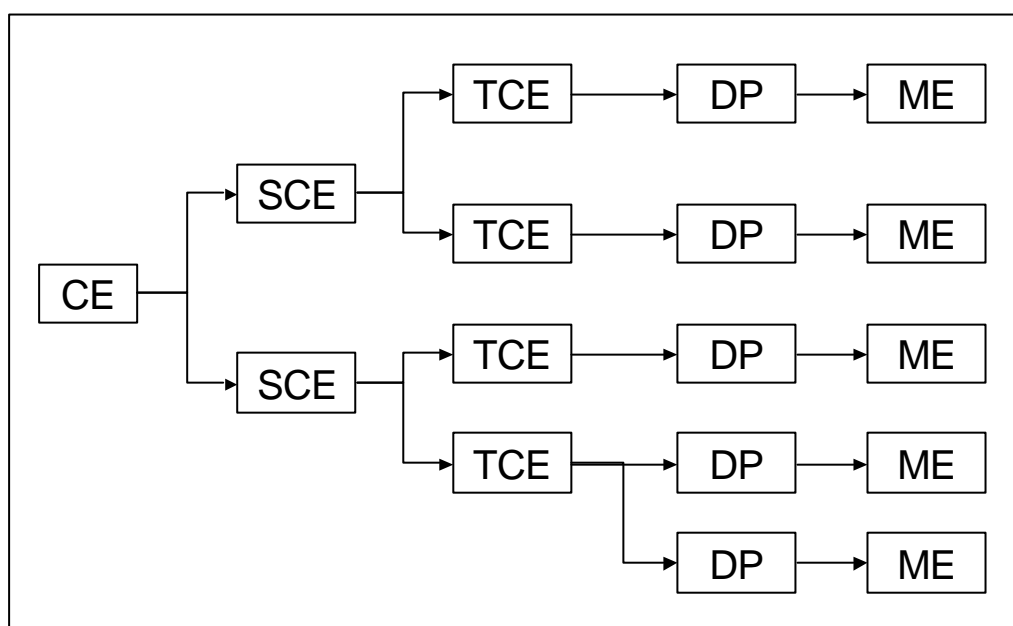
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## 1. Introduction

This appendix will explain the methodology used to build the event tree. All the methodology can be applied manually, but a "mimah" file is also available on the ARAMIS web site, allowing an automatic generation of the event trees on the basis of three set of data: the type of equipment, the physical state of the substance and the risk phrases considered.

First of all, it is useful to remind the structure of the event tree, presented in Figure 1. The signification of the acronyms is given in Table 1.



**Figure 1: Event tree**

**Table 1: acronyms in the event tree**

CE	Critical Event
SCE	Secondary Critical Event
TCE	Tertiary Critical Event
DP	Dangerous Phenomenon
ME	Major Event

## 2. General overview of the methodology

The methodology must serve to build generic trees, in an algorithmic form (with logical links). It has been chosen to work with matrices.

The methodology will be explained here according to its main principles. Detailed developments and actual matrices are given in section 3.

**Firstly**, let us remind that the critical events to be selected according to the MIMAH methodology have already been identified. As explained in appendix 3, two matrices have been used **to determine which critical events must be associated with a given equipment and a given physical state of the handled substance**:

- ✓ 1 matrix crossing the type of equipment and the 12 potentials critical events
- ✓ 1 matrix crossing the physical state of the substance considered and the 12 potentials critical events

**Secondly**, it is necessary to know which secondary critical event(s) occur(s) after a given critical event. A same critical event can give rise to different secondary critical events, depending on the physical state of the handled substance.

A matrix linking **the critical events (CE), the substance state (STAT) and the secondary critical events (SCE)** is thus built. An example is shown in Table 2. It can be observed that some cells are hatched: this means that the critical event and the physical state concerned are incompatible (as showed in the matrix STAT-CE in appendix 3) and thus cannot lead to a secondary critical event.

Table 2: example of matrix CE-STAT-SCE

		...	SCEo	SCEp	SCEq	...
...						
CEi	STAT1					
CEi	STAT2		X			
CEi	STAT3		X		X	
CEi	STAT4					
CEj	STAT1		X		X	
CEj	STAT2					
CEj	STAT3			X	X	
CEj	STAT4				X	
CEk	STAT1		X			
CEk	STAT2				X	
CEk	STAT3					
CEk	STAT4		X		X	
CEl	STAT1		X	X		
CEl	STAT2					
CEl	STAT3					
CEl	STAT4			X		
CEm	STAT1					
CEm	STAT2		X		X	
CEm	STAT3			X		
CEm	STAT4					
...						

We will use the same example as in the appendix 3. For the equipment EQd containing a substance in physical state STAT3, it was shown that the critical events CEi and CEm are possible.

In Table 2, from the lines marked by arrows, it can be concluded that, for this physical state, the critical event CEi will lead to the secondary critical events SCEo and SCEq, and also that the critical event CEm will lead to the secondary critical event SCEp.

So, the first part of the event trees can be drawn as shown in Figure 2.

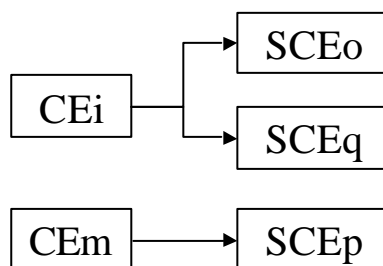


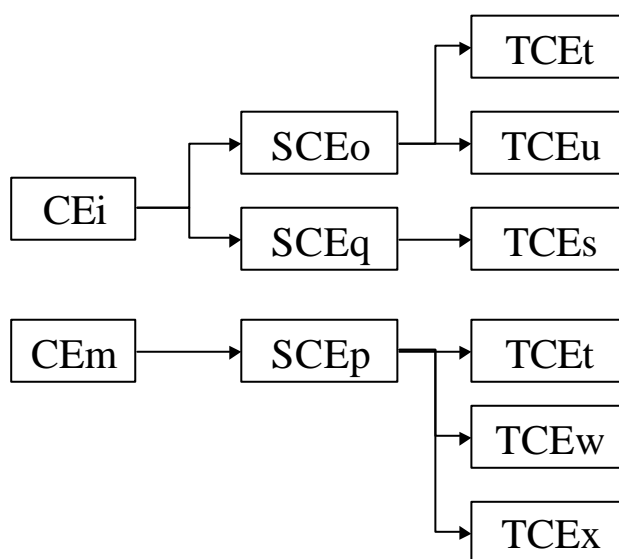
Figure 2: example of construction of an event tree (till SCE)

**Thirdly**, it is necessary to define a matrix crossing the secondary critical events (SCE) with the tertiary critical events (TCE). The crossing is independent of the physical state of the substance. An example of such a matrix is presented in Table 3, and the event tree corresponding to our example is shown in Figure 3.

It is worth noticing that the substance physical state is not a parameter for this matrix. TCE are directly linked with SCE, and the influence of the substance state is fully included in the choice of the SCE. For example, a substance state "liquid" will influence the choice of the SCE "pool formation" rather than the SCE "gas jet". But for the SCE "pool formation", the fact that the substance is in a liquid state does not affect the linked TCE (e. g. "pool ignited", "pool not ignited").

**Table 3: example of matrix SCE-TCE**

	...	TCEs	TCEt	TCEu	TCEv	TCEw	TCEx	...
...								
SCEo			X	X				
SCEp			X			X	X	
SCEq		X						
...								



**Figure 3: example of construction of an event tree (till TCE)**

**Fourthly**, the same reasoning must be conducted about a matrix linking **tertiary critical events (TCE)** and **dangerous phenomena (DP)**. An example of such a matrix is presented in Table 4, and the event tree corresponding to our example is shown in Figure 4.

Table 4: example of matrix TCE-DP

	...	DPa	DPb	DPc	DPd	DPe	DPf	DPg	DPH	...
...										
TCEs			X			X				
TCEt								X		
TCEu		X								
TCEv				X	X					
TCEw		X							X	
TCEx							X			
...										

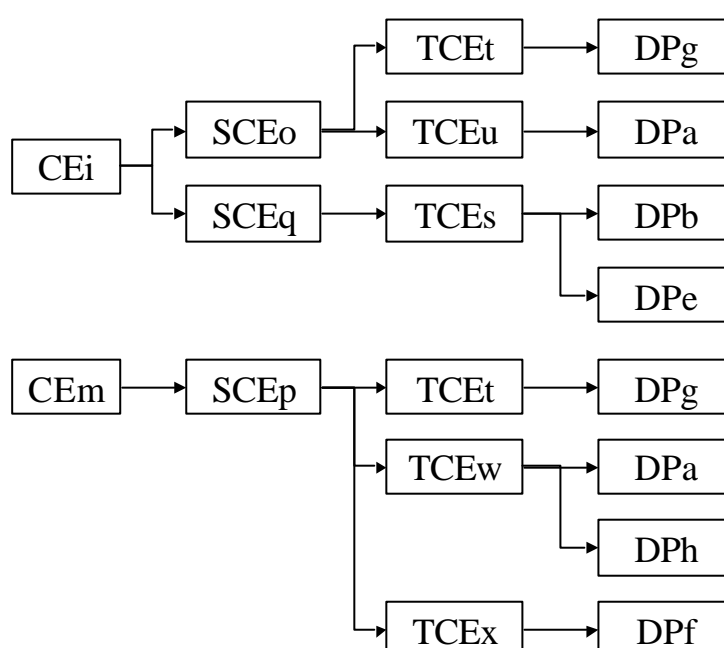
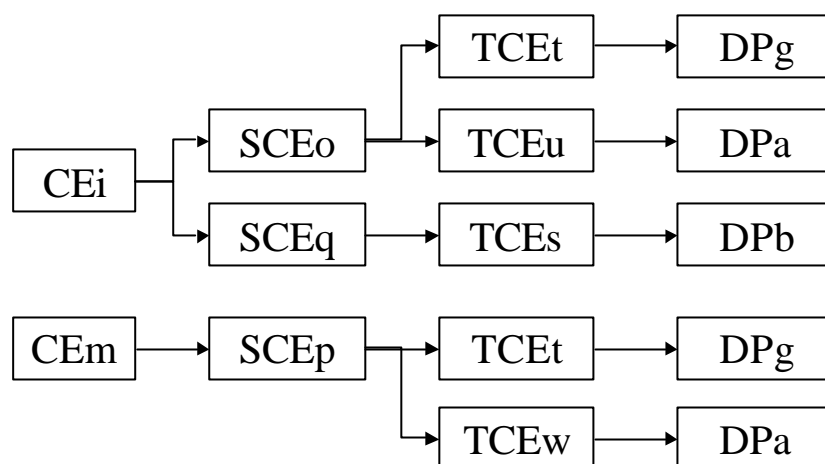


Figure 4: example of construction of an event tree (till DP)

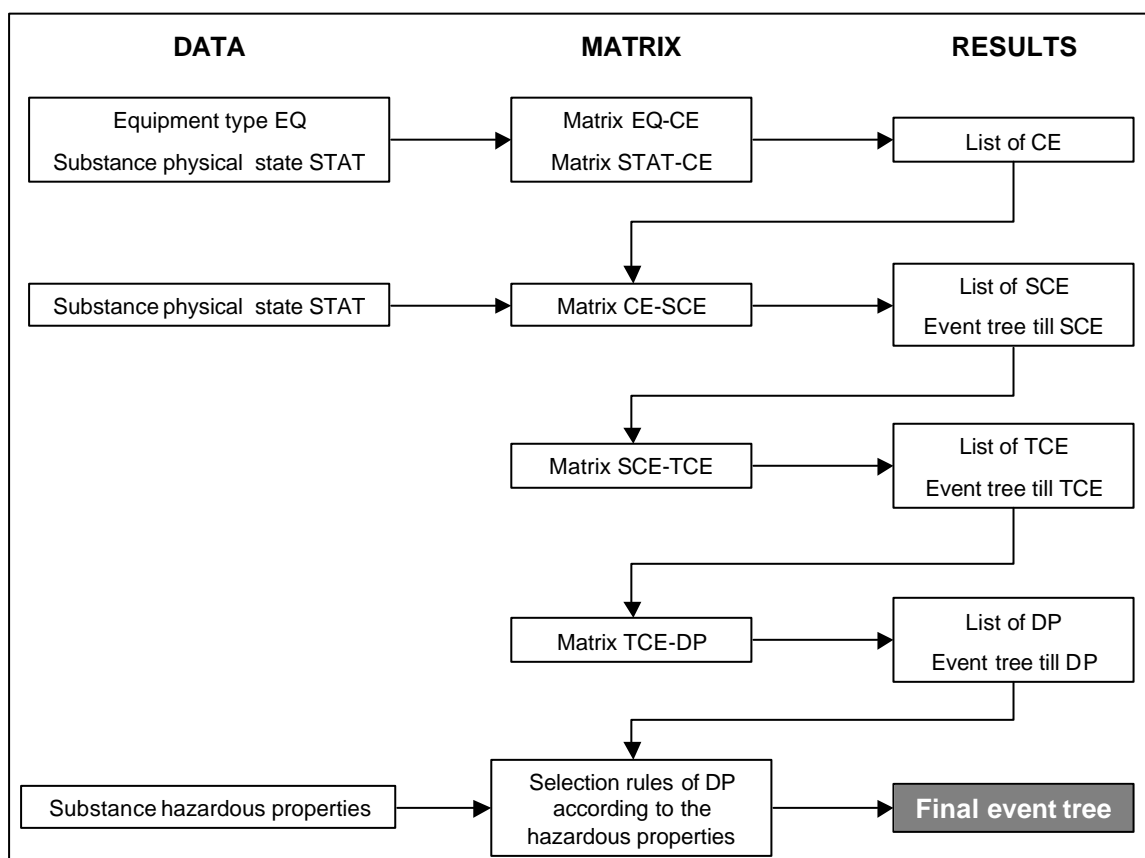
Lastly, the hazardous properties of the handled substance must be taken into account for selecting appropriate dangerous phenomena. Detailed rules will be explained in section 4. This selection will lead to the deletion of some branches of the event tree. In our example, if the hazardous properties of the substance are only compatible with dangerous phenomena DPe, DPf and DPh, the event trees will be less extended, as shown in Figure 5. In this final tree, all branches which do not end with the above-quoted dangerous phenomena (DPe, DPf or DPh) are deleted.



**Figure 5: final event tree (including selection of DP according to hazardous properties)**

**Remark:** The major events are not included in the automatic construction of event trees. This will be explained in section 3.4.

As regards the part "event tree", the MIMAH methodology can thus be summarised as shown in Figure 6.



**Figure 6: summary of the steps followed by MIMAH (part "event tree")**



### **3. Detailed presentation of matrices**

#### **3.1 Matrix Critical event / substance state / secondary critical event**

The matrix CE - STAT - SCE is given in Table 5.

As previously explained, empty lines indicate that the critical event and the physical state concerned are incompatible, and no secondary critical event can be selected. The compatibility between the substance physical state and the critical event is indicated by a sign "X" in the second column of Table 5.

Table 5: matrix crit. events (CE) – subst. state (STAT) - secondary crit. events (SCE)

Compatibility CE-STAT			SCE1	SCE2	SCE3	SCE4	SCE5	SCE6	SCE7	SCE8	SCE9	SCE10	SCE11	SCE12
			Fire	Catastrophic rupture	Pool formation	Pool inside the tank	Gas jet	Gas puff	Two-phase jet	Aerosol puff	Explosion	Materials entrained in air	Materials entrained by a liquid	Decomposition
Decomposition	CE1	X	STAT1 Solid								X			X
			STAT2 Liquid											
			STAT3 Two-phase											
			STAT4 Gas / Vapour											
Explosion	CE2	X	STAT1 Solid								X			
			STAT2 Liquid											
			STAT3 Two-phase											
			STAT4 Gas / Vapour											
Materials set in motion (entrainment by air)	CE3	X	STAT1 Solid									X		
			STAT2 Liquid											
			STAT3 Two-phase											
			STAT4 Gas / Vapour											
Materials set in motion (entrainment by a liquid)	CE4	X	STAT1 Solid										X	
			STAT2 Liquid											
			STAT3 Two-phase											
			STAT4 Gas / Vapour											
Start of a fire (LPI)	CE5	X	STAT1 Solid	X										
		X	STAT2 Liquid	X										
		X	STAT3 Two-phase	X										
		X	STAT4 Gas / Vapour	X										
Breach on the shell in vapour phase	CE6	X	STAT1 Solid									X		
			STAT2 Liquid											
		X	STAT3 Two-phase				X							
		X	STAT4 Gas / Vapour				X							
Breach on the shell in liquid phase	CE7		STAT1 Solid											
		X	STAT2 Liquid		X									
		X	STAT3 Two-phase		X			X						
			STAT4 Gas / Vapour											
Leak from liquid pipe	CE8		STAT1 Solid											
		X	STAT2 Liquid		X									
		X	STAT3 Two-phase		X			X						
			STAT4 Gas / Vapour											
Leak from gas pipe	CE9	X	STAT1 Solid									X		
			STAT2 Liquid											
		X	STAT3 Two-phase				X							
		X	STAT4 Gas / Vapour				X							
Catastrophic rupture	CE10	X	STAT1 Solid	X								X		
		X	STAT2 Liquid	X	X									
		X	STAT3 Two-phase	X	X				X					
		X	STAT4 Gas / Vapour	X				X		X				
Vessel collapse	CE11		STAT1 Solid											
		X	STAT2 Liquid		X									
			STAT3 Two-phase											
			STAT4 Gas / Vapour											
Collapse of the roof	CE12		STAT1 Solid											
		X	STAT2 Liquid			X								
			STAT3 Two-phase											
			STAT4 Gas / Vapour											

### 3.2 Matrix secondary critical event / tertiary critical event

The matrix SCE – TCE is given in Table 6.

**Table 6: matrix secondary critical events (SCE) – tertiary critical events (TCE)**

		TCE1 Fire	TCE2 Catastrophic rupture	TCE3 Pool ignited inside the tank	TCE4 Pool ignited	TCE5 Gas dispersion	TCE6 Toxic secondary products	TCE7 Gas jet ignited	TCE8 Gas puff ignited	TCE9 Two-phase jet ignited	TCE10 Aerosol puff ignited	TCE11 Pool not ignited / Pool dispersion	TCE12 Explosion	TCE13 Dust cloud ignited	TCE14 Dust dispersion
Fire	SCE1	X					X								
Catastrophic rupture	SCE2		X												
Pool formation	SCE3				X	X						X			
Pool inside the tank	SCE4			X		X									
Gas jet	SCE5					X		X							
Gas puff	SCE6					X			X						
Two-phase jet	SCE7					X				X					
Aerosol puff	SCE8					X					X				
Explosion	SCE9												X		
Materials entrained in air	SCE10													X	X
Materials entrained by a liquid	SCE11											X			
Decomposition	SCE12						X								

### 3.3 Matrix tertiary critical event / dangerous phenomena

The matrix TCE – DP is given in Table 7.

**Table 7: matrix tertiary critical events (TCE) – dangerous phenomena (DP)**

		DP1 Poolfire	DP2 Tankfire	DP3 Jetfire	DP4 VCE	DP5 Flashfire	DP6 Toxic cloud	DP7 Fire	DP8 Missiles ejection	DP9 Overpressure generation	DP10 Fireball	DP11 Environmental damage	DP12 Dust explosion	DP13 Boilover and resulting poolfire
Fire	TCE1							X						
Catastrophic rupture	TCE2								X	X				
Pool ignited inside the tank	TCE3		X				X					X		X
Pool ignited	TCE4	X					X					X		
Gas dispersion	TCE5				X	X	X					X		
Toxic secondary products	TCE6						X					X		
Gas jet ignited	TCE7			X			X					X		
Gas puff ignited	TCE8						X				X	X		
Two-phase jet ignited	TCE9			X			X					X		
Aerosol puff ignited	TCE10						X				X	X		
Pool not ignited / Pool dispersion	TCE11											X		
Explosion	TCE12								X	X				
Dust cloud ignited	TCE13												X	
Dust dispersion	TCE14						X					X		

### 3.4 Major events (ME)

The matrix linking dangerous phenomena and major events is shown in Table 8. Major Events (ME) are defined as the possible effects on targets (human beings, structure, environment,...) due to the identified Dangerous Phenomena.

It has been decided to not include this level in the event tree, because it is quite obvious and will weighs unnecessarily the event tree with a supplementary level.

**Table 8: matrix dangerous phenomena (DP) – major events (ME)**

		ME1 Thermal radiation	ME2 Overpressure	ME3 Missiles	ME4 Toxic effects
Poolfire	DP1	X			
Tankfire	DP2	X			
Jetfire	DP3	X			
VCE	DP4	X	X	X	
Flashfire	DP5	X			
Toxic cloud	DP6				X
Fire	DP7	X			
Missiles ejection	DP8			X	
Overpressure generation	DP9		X		
Fireball	DP10	X			
Environmental damage	DP11				X
Dust explosion	DP12		X	X	
Boilover and resulting poolfire	DP13	X			

## 4. Links between Risk Phrases and Dangerous Phenomena

The objective is here to delete some dangerous phenomena from the generic trees built, depending on the risk phrases of the substance considered. For example, for a toxic substance, inflammable, all branches related to poolfire, VCE, flashfire, etc will be deleted, in order to keep only the DP "toxic cloud".

Risk phrases are treated here by generic category, as explained in the main report (typology of hazardous substances). For each risk phrase, the dangerous phenomena (DP) likely to be encountered are mentioned.

It has first been tried to build a matrix linking risk phrases and dangerous phenomena. This solution was not workable because it appears that links with dangerous phenomena are not sufficient. Thus, additional conditions have been defined when needed. These conditions are explained here after.

It should be worthy to use the mimah.xls tool to built the trees.

## 4.1 Very toxic substances

*R 26 - Very toxic by inhalation.*

DP: toxic cloud

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "toxic cloud" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R26, the substance is toxic by itself and not a secondary product resulting from a fire, and thus the DP "toxic cloud" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE14 (dust dispersion).

*DP6 if TCE5 or TCE14*

*R 100 - Emit very toxic vapours when it is in a fire.*

DP: toxic cloud or environmental damage

These DP will be selected only in the following cases:

- if the critical event concerned is "start of a fire"
- OR if the product is flammable (condition on the risk phrase) and effectively in fire (TCE: fire, pool ignited inside the tank, pool ignited, gas jet ignited, gas puff ignited, two-phase jet ignited, aerosol puff ignited).

*DP6 if CE5 or {(RP10 or RP11 or RP12 or RP 17 or RP18 or RP30) and (TCE1 or TCE3 or TCE4 or TCE7 or TCE8 or TCE9 or TCE10)}*

*DP11 if CE5 or {(RP10 or RP11 or RP12 or RP 17 or RP18 or RP30) and (TCE1 or TCE3 or TCE4 or TCE7 or TCE8 or TCE9 or TCE10)}*

## 4.2 Toxic substances

*R 23 - Toxic by inhalation.*

DP: toxic cloud

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "toxic cloud" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R23, the substance is toxic by itself and not a secondary product resulting from a fire, and thus the DP "toxic cloud" must only be selected if a release and dispersion of a toxic substance is

considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE14 (dust dispersion).

*DP6 if TCE5 or TCE14*

*R 101 - Emit toxic vapours when it is in a fire.*

DP: toxic cloud or environmental damage

These DP will be selected only in the following cases:

- if the critical event concerned is "start of a fire"
- OR if the product is flammable (condition on the risk phrase) and effectively in fire (TCE: fire, pool ignited inside the tank, pool ignited, gas jet ignited, gas puff ignited, two-phase jet ignited, aerosol puff ignited).

*DP6 if CE5 or {(RP10 or RP11 or RP12 or RP 17 or RP18 or RP30) and (TCE1 or TCE3 or TCE4 or TCE7 or TCE8 or TCE9 or TCE10)}*

*DP11 if CE5 or {(RP10 or RP11 or RP12 or RP 17 or RP18 or RP30) and (TCE1 or TCE3 or TCE4 or TCE7 or TCE8 or TCE9 or TCE10)}*

### 4.3 Oxidising substances

*R 7 - May cause fire (organic peroxides).*

DP: fire

This DP will be selected only in the following case:

- in the causes, appears a contact with an incompatible substance
- AND the CE is "start of fire"

*DP7 if CE5 and {remark: in the fault tree, there is a contact with an incompatible substance }*

*R 8 - Contact with combustible material may cause fire.*

DP: fire

This DP will be selected only in the following case:

- in the causes, there appears a contact with an incompatible substance
- AND the CE is "start of fire"

*DP7 if CE5 and {remark: in the fault tree, there is a contact with a combustible material }*

*R 9 - Explosive when mixed with combustible material.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears a contact with an incompatible substance

*DP8 and DP9 if CE2 and {remark: in the fault tree, there is a contact with a combustible material}*

*DP8 and DP9 if CE10 and {remark: in the fault tree, there is a contact with a combustible material}*

For the risk phrase R9, a remark must be added in the bottom of the event trees: "The possibility of an internal explosion should be considered in the fault tree. The critical event is then one of the following: CE6 breach on the shell in vapour phase, CE7 breach on the shell in liquid phase, CE8 leak from liquid pipe, CE9 leak from gas pipe, CE10 catastrophic rupture. The nature of the substance released should be determined (it can be the substance with the risk phrase R9 or a secondary product resulting from the explosion) and an event tree should be build for the critical event and the substance retained".

## 4.4 Explosive substances

For all explosive substances, the same remark as for R9 should be taken in account: "The possibility of an internal explosion should be considered in the fault tree. The critical event is then one of the following: CE6 breach on the shell in vapour phase, CE7 breach on the shell in liquid phase, CE8 leak from liquid pipe, CE9 leak from gas pipe, CE10 catastrophic rupture. The nature of the substance released should be determined (it can be the explosive substance or a secondary product resulting from the explosion) and an event tree should be build for the critical event and the substance retained".

*R 2 - Risk of explosion by shock, friction, fire or other sources of ignition.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears any ignition source

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there appears any ignition source}*



*R 3 - Extreme risk of explosion by shock, friction, fire or other sources of ignition.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears any ignition source

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there appears any ignition source}*

*R 102 - Pyrotechnic substance (not defined in the 67/548/EEC Directive)*

DP: fire

This DP will be selected only in the following case:

- the CE is a start of fire

**AND**

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture

*DP7 if CE5*

*AND DP8 and DP9 if CE2 or CE10*

*R 1 - Explosive when dry.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, the material becomes dry

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, the material becomes dry }*

*R 4 – Forms very sensitive explosive metallic compounds.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears the formation of explosive metallic compounds

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there appears the formation of explosive metallic compounds }*

*R 5 - Heating may cause an explosion.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears an uncontrolled heating

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there appears an uncontrolled heating }*

*R 6 - Explosive with or without contact with air.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture

*DP8 and DP9 if CE2 or CE10*

*R 16 - Explosive when mixed with oxidising substances.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, appears a mixing with an oxidising substance

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there is a mixing with an oxidising substance }*

*R 19 - May form explosive peroxides.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, there appears a formation of explosive peroxides

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there appears a formation of explosive peroxides }*

*R 44 - Risk of explosion if heated under confinement.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, appears a heating under confinement

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there is a heating under confinement }*

## 4.5 Flammable substances

Remark: For all risk phrases related to flammable, highly flammable or extremely flammable substances, the Dangerous Phenomenon DP7 (fire) has not been selected. The fire as DP is only possible if the Critical Event "start of fire (Loss of Physical Integrity)" is selected, which occurs only for substances having risk phrase R7, R8, R102.

*R 10 - Flammable.*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball, boilover

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10 and DP13*

It should be noted that the risk phrase R10 is the only one with which the dangerous phenomenon DP13 (boilover and resulting poolfire) is associated. This is because this phenomenon has only been previously observed on heavy hydrocarbons, and the risk phrase R10 is for heavier substances.

*R 18 - In use, may form flammable/explosive vapour-air mixture*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

## **4.6 Highly flammable substances**

*R 17 - Spontaneously flammable in air.*

DP: poolfire, tankfire, jetfire, fireball

*DP1 and DP2 and DP3 and DP10*

Remark: The VCE and flashfire are not selected here because the substance is spontaneously flammable in air. Thus there is no possibility of cloud formation, the ignition is immediate.

*R 10 - Flammable (in particular conditions of temperature and pressure).*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball, boilover

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10 and DP13*

*R 11 - Highly flammable.*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

*R 30 - Can become highly flammable in use*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

## **4.7 Extremely flammable substances**

*R 12 - Extremely flammable.*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

*R 10 - Flammable ( $T > T_{éb}$ ).*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

*R 11 - Highly flammable ( $T > T_{éb}$ ).*

DP: poolfire, tankfire, jetfire, VCE, flashfire, fireball

*DP1 and DP2 and DP3 and DP4 and DP5 and DP10*

## **4.8 Substances which react violently with water**

*R 14 - Reacts violently with water.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, appears a contact with water

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there is a contact with water }*

*R 15 - Contact with water liberates extremely flammable gases.*

For substance having the risk phrase R15, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of flammable gases due to a contact between the substance and water (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a flammable one.

*R 29 - Contact with water liberates toxic gas.*

For substance having the risk phrase R29, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of toxic gas due to a contact between the substance and water (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a toxic one.

*R 14/15 - Reacts violently with water, liberating extremely flammable gases.*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, appears a contact with water

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there is a contact with water }*

For substance having the risk phrase R15, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of flammable gases due to a contact between the substance and water (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a flammable one.

*R 15/29 - Contact with water liberates toxic, extremely flammable gas.*

For substance having the risk phrase R15/29, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of flammable and toxic gases due to a contact between the substance and water (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a flammable and toxic one.

## **4.9 Substances which react violently with an other substance**

*R 103 - Contact with an other substance liberates toxic gas*

For substance having the risk phrase R103, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of toxic gas due to a contact between the concerned substance and an incompatible substance (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a toxic one.

*R 104 - Contact with an other substance liberates very toxic gas*

For substance having the risk phrase R104, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of very toxic gas due to a contact between the concerned substance and an incompatible substance (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a toxic one.

*R 105 - Contact with an other substance liberates flammable gas*

For substance having the risk phrase R105, no dangerous phenomenon is selected. A special event tree must be created, supposing the release of flammable gases due to a contact between the concerned substance and an incompatible substance (contact to be mentioned in the fault tree). The bow-tie is centred on a critical event "release" (on vessel or on pipe, or a catastrophic rupture), and the substance released is a flammable one.

*R 106 - In case of contact with an other substance, can explode*

DP: missile ejection, overpressure generation

These DP will be selected only in the following cases:

- the CE is an explosion or a catastrophic rupture
- AND in the causes, appears a contact with an incompatible substance

*DP8 and DP9 if CE2 or CE10 and {remark: in the fault tree, there is a contact with an incompatible substance}*

## 4.10 Substances which present a risk for the environment

### Aquatic environment

*R 50 - Very toxic to aquatic organisms (96h CL50 (fish) £ 1 mg/l*

*or 48h CE50 (daphnia) £ 1 mg/l*

*or 72 h CL50 (algae) £ 1 mg/l)*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R50, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

*R 51 - Toxic to aquatic organisms (96h CL50 (fish): 1mg/l < CL50 £ 10 mg/l*

*or 48h CE50 (daphnia): 1mg/l < CE50 £ 10 mg/l*

*or 72 h CL50 (algae): 1mg/l < CL50 £ 10 mg/l).*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R51, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

#### Non-aquatic environment

*R 54 - Toxic to flora*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R54, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

*R 55 - Toxic to fauna*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R55, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic



substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

*R 56 - Toxic to soil organisms*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R56, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

*R 57 - Toxic to bees*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100). Here, for the risk phrase R57, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

*R 59 - Dangerous for the ozone layer*

DP: environmental damage

This DP will be selected only in the following case:

- it should be noted that, in the event trees, the DP "environmental damage" can occur after a release of a toxic substance, or as a consequence of a fire if the substance is likely to emit toxic vapours when it is in a fire (R101 – R100).

Here, for the risk phrase R59, the substance is a toxic one and not a secondary product resulting from a fire, and thus the DP "environmental damage" must only be selected if a release and dispersion of a toxic substance is considered. It means that the TCE must be either TCE5 (gas dispersion) or TCE11 (pool dispersion) or TCE14 (dust dispersion).

*DP11 if TCE5 or TCE11 or TCE14*

## 5. Additional rules

Some chains of events must be selected independently of the risk phrases, but obviously only if they are pre-selected after the analysis of the different matrices leading to the event trees which do not take into account the risk phrases.

- The secondary critical event "catastrophic rupture" (SCE2), which can only occurs after the CE10 (catastrophic rupture) must always be selected. It leads to a missile ejection and an overpressure generation, which always go with a catastrophic rupture. In terms of DP, this rule means that the DP "missiles ejection" and "overpressure" resulting from the SCE "catastrophic rupture" must always be selected.

## 6. About domino effects (BLEVE and Boilover)

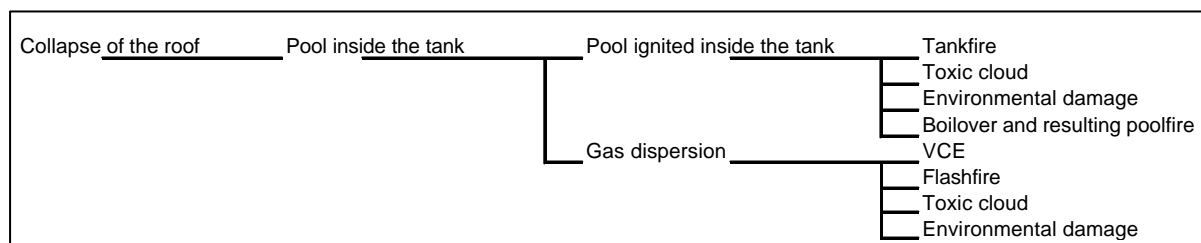
Some accidents are typically domino effects, for example the **BLEVE** and the **boilover**. These accidents can only occur as a result of a previous accident (e.g. poolfire, jetfire, tankfire).

It may be a problem to put these accidents in the event trees. The poolfire, tankfire, etc are at the level "dangerous phenomena". So it is difficult to imagine adding levels after the level DP, in order to take account of domino effects like BLEVE and boilover (which are followed by effects like fireball or missiles ejection), because of the risk of obtaining too long trees.

It has been chosen to consider the **BLEVE** as a special type of catastrophic rupture, with own causes and occurrence conditions (in particular the superheat temperature). For example, the poolfire, which is a dangerous phenomenon, may be the cause of the catastrophic rupture (BLEVE) of a pressure vessel. **Thus, some domino effects resulting from a dangerous phenomenon may be the cause of some critical events, in a second bow-tie.**

It has been difficult to include the **boilover** in a critical event previously defined for atmospheric storage. The following reasoning has been made: the boilover is a possible consequence of a tank

fire, which is a dangerous phenomenon which may occur after the critical event "collapse of the roof". A dangerous phenomenon "boilover and resulting poolfire" is added, it may occur after the TCE "pool ignited inside the tank". The "resulting poolfire" it is spoken about is the consequence from the ejection of burning liquid during the boilover. It should also be noted that the boilover is only selected if the substance has the risk phrase R10 (flammable liquids with a relatively high flash point). The event tree including the boilover phenomenon is shown in Figure 7.



**Figure 7: event tree including boilover**

Other cases of domino effects accidents can be imagined. For example, a dust explosion could be an ignition source for a fire of solid materials, this one can lead to an explosion, ...

**In fact, domino effects resulting from a dangerous phenomenon are naturally included in the causes of other bow-ties.**

## 7. Example – application of MIMAH to build an event tree

An example is given in appendix 15. This one shows the complete application of the ARAMIS methodology for the identification of accidents scenarios, including the part related to MIMAH.

## 8. Conclusion for the event trees

The objective of the method explained in this appendix is to build event trees on the basis of three data: the type of equipment, the hazardous properties of the substance handled and its physical state.

It has been shown how the use of matrices leads to the choice of critical events according to the equipment type and the substance physical state. Other matrices lead to the full construction of event trees for every critical event. Lastly, rules about hazardous properties of the handled substance give final event trees, taking into account the hazardous properties.

It is not possible to show here all trees obtained with MIMAH. The appendix 6 contains the list of critical events retained for each combination "equipment type" – "substance state" and shows the generic event trees obtained. Event trees taking into account risk phrases are not printed because there are many possible combinations of risk phrases, leading to a very great number of pages. The reader will use the rules explained in section 4 to build his own trees.

AND and OR should be present in the event tree but at this stage they are not drawn to simplify the tree. These gates will be introduced in the MIRAS part of the ARAMIS method.