APPENDIX 3

Method to associate critical events and relevant hazardous equipment

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1. Introduction

This appendix describes the method in order to associate critical events and relevant hazardous equipment. Matrices are used in order to define which critical events must be associated with a given equipment containing a given substance.

The chapter 3 gives the detailed presentation of matrices.

2. Method to associate critical events and hazardous relevant equipment

As a preliminary step, before applying the method, it must be checked if the equipment type and the substance state chosen are compatible. For this, a matrix crossing **the substance state (STAT) and the equipment type (EQ)** was build (see Table 1). A sign "X" in a cell indicates that the association STAT – EQ is possible, and, on the contrary, an empty cell indicates that the top-column equipment type cannot be associated with the top-line substance state. This matrix is only used in order to check the compatibility of the data (equipment type and substance physical state).

Table 1: example of matrix STAT-EQ

	…	EQa	EQb	EQc	EQd	EQe	….
STAT1			X				
STAT2		X		X	X		
STAT3		X		X	X	X	
STAT4		X				X	

Firstly, there exists some possible associations between equipment and critical events, which will be expressed in a matrix crossing **the equipment type (EQ) and the critical events (CE)**, as shown in Table 2.

Table 2: example of matrix EQ-CE

	…	Cei	CEj	CEk	CEl	CEm	…
EQa			X		X		
EQb		X	X	X			
EQc			X		X	X	
EQd		X		X		X	
EQe			X				
…							

Secondly, it has been seen that the event tree must be built according to the equipment type and the substance handled in this equipment. Interesting substances properties in the frame of event trees are the physical state and the hazardous properties.

Hazardous properties will be studied with the issue of dangerous phenomena (DP). As regards physical state, a given one cannot lead to all types of critical events. A matrix crossing **the substance state (STAT) and the critical events (CE)** is then defined, as shown in Table 3.

Table 3: example of matrix STAT-CE

	…	CEi	CEj	CEk	CEl	CEm	…
STAT1			X	X	X		
STAT2		X		X		X	
STAT3		X	X			X	
STAT4			X	X	X		

With these two tables (Table 2 and Table 3), it is possible **to determine which critical events must be associated with a given equipment and a given physical state of the handled substance**.

For example, assuming that an equipment from the type EQd is considered, handling a substance whose physical state is STAT3, the following conclusions can be drawn:

- critical events CEi, CEk and CEm are compatible with EQd
- critical events CEi, CEj and CEm are compatible with STAT3
- thus, only critical events CEi and CEm are compatible with EQd **and** STAT3

This can be better observed in Table 4, where the first line is for the equipment, the second one for the substance physical state and the third one for the combination of the equipment and the substance physical state. In this last line, a sign "X" is present for a given critical event only if it is present in the line of the equipment AND in the line of the substance physical state, for the same critical event.

Table 4: association of CE with EQ and STAT

	...	CEi	CEj	CEk	CEl	CEm	…
EQd		X		X		X	
STAT3		X	X			X	
EQd and STAT3		X				X	

3. Detailed presentation of matrices

3.1 Substance state in the equipment (Matrix Substance state / equipment)

The only purpose of the matrix STAT-EQ is to verify that the substance state and the equipment type chosen for the construction of an event tree are compatible. If not, it is impossible to build an event tree. This check must be carried out before applying the MIMAH methodology.

Table 5: matrix substance state (STAT) – equipment type (EQ)

		EQ1 Mass solid storage	EQ2 Storage of solid in small packages	EQ3 Storage of fluid in small packages	EQ4 Pressure storage	EQ5 Padded storage	EQ6 Atmospheric storage	EQ7 Cryogenic storage	EQ8 Pressure transport equipment	EQ9 Atmospheric transport equipment	EQ10 Pipe	EQ11 Intermediate storage equipment integrated in the process	EQ12 Equipment devoted to the physical or chemical separation of substances	EQ13 Equipment involving chemical reactions	EQ14 Equipment designed for energy production and supply	EQ15 Packaging equipment	EQ16 Other facilities
Solid	STAT1	X	X									X	X	X		X	X
Liquid	STAT2			X		X	X	X		X	X	X	X	X	X	X	X
Two-phase	STAT3			X	X			X	X		X	X	X	X	X	X	X
Gas / Vapour	STAT4			X	X				X		X	X	X	X	X	X	X

Remarks

Cryogenic storage

- It should be noted that 2 substances states are selected for the cryogenic storage: liquid and two-phase. In normal operating conditions, the substance will be in a liquid state in a cryogenic storage, since the material is cooled at boiling temperature under atmospheric pressure. However, the two-phase state is also considered since this state will be obtained as the natural evolution of the system in case of failure of the cooling system.

3.2 Critical events according to equipment type (Matrix EQ-CE)

The matrix linking the critical events and the type of equipment is given in Table 6, here below.

This matrix is used to determine which critical events must be associated with a given equipment type.

Table 6: matrix equipment type (EQ) – critical events (CE)

		CE1 Decomposition	CE2 Explosion	CE3 Materials set in motion (entrainment by air)	CE4 Materials set in motion (entrainment by a liquid)	CE5 Start of a fire (LPI)	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	CE11 Vessel collapse	CE12 Collapse of the roof
Mass solid storage	EQ1	X	X	X	X	X							
Storage of solid in small packages	EQ2					X					X		
Storage of fluid in small packages	EQ3					X	X	X			X		
Pressure storage	EQ4					X	X	X	X	X	X		
Padded storage	EQ5					X		X	X		X	X	
Atmospheric storage	EQ6					X		X	X		X	X	X
Cryogenic storage	EQ7					X	X	X	X	X	X	X	
Pressure transport equipment	EQ8					X	X	X	X	X	X		
Atmospheric transport equipment	EQ9					X		X	X		X	X	
Pipe	EQ10					X			X	X			
Intermediate storage equipment integrated in the process	EQ11	X	X	X	X	X	X	X	X	X	X	X	X
Equipment devoted to the physical or chemical separation of substances	EQ12					X	X	X	X	X	X		
Equipment involving chemical reactions	EQ13					X	X	X	X	X	X		
Equipment designed for energy production and supply	EQ14					X	X	X	X	X	X		
Packaging equipment	EQ15			X	X	X			X	X			
Other facilities	EQ16					X	X	X	X	X	X		

Remarks

Start of fire (LPI)

- It is considered that the start of fire is caused by a Loss of Physical Integrity (LPI). This critical event will only be selected if the risk phrase describes a loss of physical integrity of the substance, leading to a fire (e.g. R7 "May cause fire (organic peroxides)", R8 "Contact with combustible material may cause fire",…. non exhaustive list !). This is not the case for substance having a risk phrase describing its flammability (like R10: Flammable, R11: Highly flammable, …) where no loss of physical integrity is involved.

  Henceforth, it is considered that the "start of fire (LPI)" is a possible critical event for each equipment type without exception. The effective selection of this critical event will depend on the hazardous properties of the substance.

Explosion:

- It is possible to observe an delayed explosion following to a decomposition. The decomposition is then the critical event and the explosion is a secondary critical event. The critical event "explosion" is only valid for violent immediate reaction. (see the definitions of the critical events in the glossary)

- The critical event 'explosion' is only selected for the equipment item 'mass solid storage'. Some gases or liquids may have hazardous properties leading to an explosion (see the substance typology and the risk phrases associated with the explosive substances). These substances are contained in a vessel. Thus, we consider that the explosion must be included in the fault tree, leading to a weakening of the vessel, and to a breach (on a pipe or on the vessel) or a catastrophic rupture, according to the explosion energy. The breach or the catastrophic rupture is the critical event to be considered for these liquid or gaseous substances.

Cryogenic storage

- For cryogenic storage, breaches are considered both in liquid and vapour phase. A leak in vapour phase can lead to a significant release of material, especially if there is a problem with the refrigeration system.

Intermediate storage equipment integrated in the process

- For this kind of process equipment, it is necessary to refer to the storage equipment which presents the same characteristics (mainly pressure, padded or atmospheric storage).

- It should be noted that this kind of equipment is probably more sensitive to a possible contamination by an impurity. This event must be considered as a possible cause, leading to an explosion or a pressure increase for example, and finally giving a breach on the vessel, a breach on a pipe or a catastrophic rupture (which are the critical events).

- For the intermediate storage equipment integrated in the process, it is necessary not to forget the critical events associated to solid products.

Equipment involving chemical reactions

- Among the causes of the different critical events, the runaway can not be forgotten, for a catastrophic rupture as well as for a breach on shell or on pipe.

Runaway - Release of secondary products

The runaway is an uncontrolled or undesirable reaction. This event is a possible cause of a release on an equipment item involving chemical reactions. If the energy of the runaway is sufficient, it may cause a vessel failure or a breach and lead to a release of secondary products. It has been decided

to consider the release of the secondary substances on an equal footing with the original substance present in the equipment item.

When several substances (the stored product and the secondary products) are released in the same time, an event tree will be build for each substance but the fault tree and the critical event are common for all substances released. The phenomena involved in the event trees will depend on the hazardous properties of the different substances.

Runaways have also been observed in some storage. In the same way, this event is a possible cause of a breach (liquid or gas) on the vessel, on a pipe or of a catastrophic rupture. The vessel collapse is not retained as a critical event which may follow a runaway reaction because it supposes a decrease of the pressure. Indeed, the runaway reaction is followed by an increase of pressure or an explosion. The collapse of the roof is either tied to an increase, or a decrease of pressure. So, it can be the consequence of a runaway reaction.

Contact between incompatible substances

The contact between incompatible substances is an undesirable reaction with as consequences, a pressure increase inside the vessel, an explosion, an generation of flammable and / or toxic gases, or a start of fire (LPI).

In a closed equipment, the pressure increase or the internal explosion can lead to a breach on the vessel, a leak on a pipe, a catastrophic rupture or the collapse of the roof. If the undesirable reaction leads to a start of fire (LPI), the critical event will be the start of fire (LPI).

The contact between incompatible substances in an open solid storage or a conveyor belt can lead to an decomposition, an explosion or a start of fire (LPI).

A reaction between incompatible substances is thus classified among the possible causes of the critical events quoted here above. It should be kept in mind that, in this case, the loss of containment can lead to the release of secondary products and the remark made for run-away has to be taken in consideration when several substances are released in the same time.

3.3 Matrix substance state / critical event

The matrix STAT – CE is given in Table 7.

Table 7: matrix substance state (STAT) – critical events (CE)

		CE1 Decomposition	CE2 Explosion	CE3 Materials set in motion (entrainment by air)	CE4 Materials set in motion (entrainment by a liquid)	CE5 Start of a fire (LPI)	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	CE11 Vessel collapse	CE12 Collapse of the roof
Solid	STAT1	X	X	X	X	X	X			X	X		
Liquid	STAT2					X		X	X		X	X	X
Two-phase	STAT3					X	X	X	X	X	X		
Gas / Vapour	STAT4					X	X			X	X		

Remarks

Solid state

- The definition of 'breach in vapour phase' (on the vessel or on pipe) has been extended to equipment containing a solid phase in suspension in air or gas (only process equipment). It should be reminded that, if the gas or the vapour is also a dangerous substance, it is necessary to study the event tree relating to a gas release. In this case, two event trees are built with the same critical event “Breach on shell in vapour phase”: one considering the release of the solid product in suspension in air or in a gas and the other considering the release of hazardous gas or vapour.
- The critical events "material set in motion" (by air or by a liquid) is reserved for a dust / solid exposed to air or water (open storage, conveyor belts).

4. Conclusion

Finally, 2 matrices are used to determine the critical events which must be retained for each relevant hazardous equipment and for the substance handled in the equipment:

- ✓ 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