

APPENDIX 4

Generic fault trees

Debray B., Piatyszek E., Cauffet F., Londiche H.

Armines, Ecole Nationale Supérieure de Mines de Saint Etienne (France)

Summary

This appendix gives the 14 generic fault trees for the critical events defined in the MIMAH methodology. These generic fault trees can be used as a first tool to build the left part of the bow-tie. The association between fault trees and critical events is shown in Table 1.

Table 1: Association of generic fault trees and critical events

Nr CE	Critical event	Generic fault tree (FT)
CE1	Decomposition	FT Chemical decomposition FT Decomposition tied to a punctual ignition source FT Thermal decomposition
CE2	Explosion	FT Explosion of an explosive material FT Explosion (violent reaction)
CE3	Materials set in motion (entrainment by air)	FT Materials set in motion (entrainment by air)
CE4	Materials set in motion (entrainment by a liquid)	FT Materials set in motion (entrainment by a liquid)
CE5	Start of fire (LPI)	FT Start of fire (Loss of Physical Integrity)
CE6	Breach on the shell in vapour phase	FT Large breach on shell or leak from pipe FT Medium breach on shell or leak from pipe FT Small breach on shell or leak from pipe
CE7	Breach on the shell in liquid phase	FT Large breach on shell or leak from pipe FT Medium breach on shell or leak from pipe FT Small breach on shell or leak from pipe
CE8	Leak from liquid pipe	FT Large breach on shell or leak from pipe FT Medium breach on shell or leak from pipe FT Small breach on shell or leak from pipe
CE9	Leak from gas pipe	FT Large breach on shell or leak from pipe FT Medium breach on shell or leak from pipe FT Small breach on shell or leak from pipe
CE10	Catastrophic rupture	FT Catastrophic rupture
CE11	Vessel collapse	FT Vessel collapse
CE12	Collapse of the roof	FT Collapse of the roof

The limitations of these generic fault trees are given in the main text of this report. It will only be reminded here that these fault trees are not plant-specific, but should preferably be used as a kind of check-list of the different causes leading to a critical event.

It is recommended to have a critical look on these trees to adapt them to the characteristics of the equipment studied. Branches can be freely added or deleted. Especially, the results from other risk analysis (like HAZOP) should be reviewed; and identified causes should be included in the trees.

The reader will then obtain trees adapted to the specificities of the plant.

Generic Fault Trees

CE1 Decomposition (Chemical decomposition)

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient conditions	Critical event
Error ordering the product Delivery error Wilful disobedience Malicious intervention Contamination during transport, delivery or storage Bad quality product delivered	or Wrong product delivered or Right product but not pure Inappropriate choice of the storage place	Normal storage or Abnormal storage	Storage of a reaction sensitive chemical and	Chemical decomposition
Error in labelling the storage place Human error Error in labelling the product Wilful disobedience Malicious intervention	or Inappropriate choice of the storage place			
Error ordering the product Wilful disobedience Malicious intervention Delivery error	or Wrong product delivered Inappropriate choice of the storage place	Abnormal storage, presence of an incompatible reagent in the storage room or	Contact with an incompatible reagent	
Human error Inappropriate labelling of the product Inappropriate labelling of the storage place Error ordering the product Contamination during transport/delivery Manufacturing error	or Inappropriate choice of the storage place Bad quality product delivered			
Design fault (eg. the material constitutive of the equipment is incompatible with the solid stored) Manufacturing error Defective maintenance or cleaning Other human error (forgotten material) Installation error	or Some material present in the storage place is incompatible with the stored solid			
		Leak, entrainment from a nearby pipe or vessel (domino effect)		

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient conditions	Critical event
Lacking or defective maintenance	or	Leak from the roof	or	Contamination by natural elements of the environment (air, water)
Conception error		Door opened		
Installation error				
Human error				
Lacking procedure				
Wilful disobedience				
Plant in flooding risk area	or	Flooding		
Defective protection				
Human error	or	Dropped container	or	Accidental contamination
Obstacles on the way				
Dangerous driving				
		Leak from small container		
Error ordering the product	or	Wrong product delivered	or	Abnormal presence of a catalyst
Delivery error				Presence of a catalyst (if involved)
Wilful disobedience				
Malicious intervention				
Error ordering the product	or	Bad quality product delivered		
Contamination during transport/delivery				
Manufacturing error				
Conception error	or	The material constituting the equipment is a catalyst		
Manufacturing error				
Installation error				
Human error	or	Dropped container	or	Leak, entrainment from a nearby pipe or vessel (domino effect)
Obstacles on the way				Accidental contamination
Dangerous driving				
		Leak from small container		

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient conditions	Critical event
		Fire (domino effect)	Punctual (or permanent) energy source (if required)	
		Chemical energy (domino effect)		
		Furnace, boiler, motor other unshielded hot surface		
Lacking or defective maintenance	or Overheating	or		
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or Abnormal presence			
Installation error				
Lacking or defective maintenance				
Lacking or defective maintenance	or Overheating (regulation failure)	or Heat transport canalisation		
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or Abnormal transport of hot substance			
Installation error				
Conception error	or Abnormal presence	Magnifying glass		
Installation error				
Lacking or defective maintenance	or Overheating (regulation failure, short circuit)	or Resisting electric conductor (resistance, short-circuit)		
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or Abnormal presence			
Installation error				
Conception error	or Abnormal presence	or Friction (conveyers, doors, mechanical devices)		
Installation error				
Human error				
Human error	or Excessive use conditions			
Wrong procedure				
Lacking or defective maintenance	or Lack of lubricant			
Conception error				
Manufacturing error				
Installation error				

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Undesirable event		Detailed direct causes	Direct causes	Necessary and sufficient conditions	Critical event
Lacking or defective maintenance	or	Defective mechanism			
Conception error					
Manufacturing error					
Installation error					
Wilful disobedience	or	Shock between metallic pieces	or Spark		
Manipulation error					
Other human error					
Non respect of licences					
Non respect of procedures					
Wilful disobedience	or	Grinding			
Manipulation error					
Other human error					
Non respect of licences					
Non respect of procedures					
Lacking or defective maintenance	or	Electric system failure	or Electric arc (defect of the electric installation, arc welding)		
Human error					
Maintenance	or	Welding			
Other welding activity					
Friction	or	Static electricity			
dry environment					
lacking or defective maintenance	or	Motor			
Normal presence					
Electrical switch	or	Other electric arc			
Maintenance	or	Hammering	or Impact		
Other hammering					
Dangerous driving	or	impact during transport and handling			
Obstacles on the way					
Manutention error	or	Dropped object			
Broken element from the structure					
		External aggression (plane crash, object lifted by wind)			
		Missile (domino effect)			
		Fall of a structure element (domino effect)			
Maintenance	or	Flame, torch (welding)	or Combustion flame or heat (gas flame welding, smoking)		
Other welding activity					
Non respect of smocking prohibition	or	Smoking			
smoking is not prohibited					
			Natural event (lightening)		
			Hot missile (domino effect)		

Generic Fault Trees

CE1 Decomposition (tied to a punctual ignition source)

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Error ordering the product	Wrong product delivered	Normal storage	Storage of a flammable product	Decomposition tied to a punctual ignition source
Delivery error		Abnormal storage		
Error ordering the product	Bad quality product delivered			
Contamination during transport/delivery				
Manufacturing error				
Human error	Inappropriate choice of the storage place			
Inappropriate labelling of the product				
Inappropriate labelling of the storage place				
		Fire (domino effect)	Punctual (or permanent) energy source	
		Chemical energy (domino effect)		
Lacking or defective maintenance	Overheating	Furnace, boiler, motor other unshielded hot surface		~
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	Abnormal presence			
Installation error				
Lacking or defective maintenance				
Lacking or defective maintenance	Overheating (regulation failure)	Heat transport canalisation		
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	Abnormal transport of hot substance			
Installation error				
Conception error	Abnormal presence	Magnifying glass		
Installation error				

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance or Incorrect command and/or control signal Incorrect sensor signal Interpretation error Transmission error Human error Conception error or Installation error	Overheating (regulation failure, short circuit) or Abnormal presence	Resisting electric conductor (resistance, short-circuit)		
Conception error or Installation error Human error Human error or Wrong procedure Lacking or defective maintenance or Conception error Manufacturing error Installation error Lacking or defective maintenance or Conception error Manufacturing error Installation error Wilful disobedience or Manipulation error Other human error Non respect of licences Non respect of procedures Wilful disobedience or Manipulation error Other human error Non respect of licences Non respect of procedures	Abnormal presence or Excessive use conditions Lack of lubricant Defective mechanism Shock between metallic pieces or Grinding	Friction (conveyers, doors, mechanical devices) Spark		

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance	or	Electric system failure	or	Electric arc (defect of the electric installation, arc welding)
Human error				
Maintenance	or	Welding		
Other welding activity				
Friction	or	Static electricity		
dry environment				
lacking or defective maintenance	or	Motor		
Normal presence				
Electrical switch	or	Other electric arc		
Maintenance	or	Hammering	or	Impact
Other hammering				
Dangerous driving	or	impact during transport and handling		
Obstacles on the way				
Manutention error	or	Dropped object		
Broken element from the structure				
		External aggression (plane crash, object lifted by wind)		
		Missile (domino effect)		
		Fall of a structure element (domino effect)		
Maintenance	or	Flame, torch (welding)	or	Combustion flame or heat (gas flame welding, smoking)
Other welding activity				
Non respect of smocking prohibition	or	Smoking		
Smoking is not prohibited				
				Natural event (lightening)
				Hot missile (domino effect)

CE1 Decomposition (thermal decomposition)

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Human error lacking or defective maintenance Wilful disobedience Malicious intervention	Supply failure	Normal storage Abnormal storage	Storage of a thermal decomposition sensitive chemical	thermal decomposition
Error in labelling the storage place Human error Error in labelling the product Wilful disobedience Malicious intervention Contamination Bad quality product delivered	Inappropriate choice of the storage place Right product but not pure			
		Fire (domino effect) Chemical energy (domino effect) Furnace, boiler, motor other unshielded hot surface	high temperature	
Lacking or defective maintenance Incorrect command and/or control signal Incorrect sensor signal Interpretation error Transmission error Human error Conception error Installation error	Overheating			
Lacking or defective maintenance Incorrect command and/or control signal Incorrect sensor signal Interpretation error Transmission error Human error	Overheating (regulation failure)	Heat transport canalisation		
Conception error Installation error	Abnormal transport of hot substance			

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance or Incorrect command and/or control signal Incorrect sensor signal Interpretation error Transmission error Human error	Overheating (regulation failure, short circuit) or Abnormal presence (of an electric heating element)	Resisting electric conductor (resistance, short-circuit)		
Conception error or Installation error Other human error				
Lacking or defective maintenance or Human error	Electric system failure or Welding	Electric arc (defect of the electric installation, arc welding)		
Maintenance or Other welding activity				
Maintenance or Other welding activity	Flame, torch (welding) or Nearby fire	Combustion flame or heat (gas flame welding, smoking)		
Non respect of fire prohibition or Accidental fire (waste, other combustible substance) Fire is not prohibited				
Non respect of smoking prohibition or Smoking is not prohibited	Smoking			
		Natural event (lightening) Hot missile (domino effect)		

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CE2 Explosion (of an explosive material)

Undesirable event	Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event			
			Normal storage	or	Use of an explosive material	and	explosion	
Error ordering the product	or	Wrong product delivered	or	Abnormal storage				
Delivery error		Inappropriate choice of the storage place						
Wilful disobedience								
Malicious intervention								
Error in labelling the storage place	or							
Error in labelling the product		Right product but not pure						
Human error								
Wilful disobedience								
Malicious intervention								
Contamination during transport, delivery or storage	or							
Bad quality product delivered								
				Fire (domino effect)			or	Ignition source
				Chemical energy (domino effect)				
				Furnace, boiler, motor other unshielded hot surface				
Excessive conditions created by the environment	or	Overheating (regulation failure)		or				
Lack of or defective maintenance								
Conception error								
Manufacturing error								
Installation error								
Incorrect command and/or control signal								
Incorrect sensor signal								
Interpretation error								
Transmission error								
Wilful disobedience								
Manipulation error								
Other human error								
Conception error	or	Abnormal presence						
Manufacturing error								
Installation error								
Wilful disobedience								
Manipulation error								
Other human error								

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Excessive conditions created by the environment	or	Overheating (regulation failure)	or	Heat transport canalisation		
Lack of or defective maintenance						
Conception error						
Manufacturing error						
Installation error						
Incorrect command and/or control signal						
Incorrect sensor signal						
Interpretation error						
Transmission error						
Wilful disobedience						
Manipulation error						
Other human error						
Lack of or defective maintenance	or	Abnormal transport of hot substance				
Incorrect command and/or control signal						
Incorrect sensor signal						
Transmission error						
Interpretation error						
Wilful disobedience						
Manipulation error						
Other human error						
Lack of or defective maintenance	or	Abnormal presence (broken glass,...)		Magnifying glass		
Conception error						
Manufacturing error						
Installation error						
Wilful disobedience						
Lack of or defective maintenance	or	Overheating (regulation failure, short circuit)	or	Resisting electric conductor (resistance, short-circuit)		
Incorrect command and/or control signal						
Incorrect sensor signal						
Transmission error						
Interpretation error						
Wilful disobedience						
Manipulation error						
Other human error						
Lack of or defective maintenance	or	Abnormal presence				
Conception error						
Manufacturing error						
Installation error						

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Wilful disobedience	or	Abnormal presence	or	Friction		
Manipulation error						
Conception error						
Manufacturing error						
Installation error						
Wilful disobedience	or	Excessive use conditions				
Manipulation error						
Other human error						
Excessive conditions created by the environment	or	Defective mechanism				
Lack of or defective maintenance						
Conception error						
Manufacturing error						
Installation error						
Wilful disobedience	or	Shock between metallic pieces	or	Spark		
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Wilful disobedience	or	Grinding				
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Excessive conditions created by the environment	or	Electric system failure	or	Electric arc		
Lack of or defective maintenance						
Conception error						
Manufacturing error						
Installation error						
Incorrect command and/or control signal						
Wilful disobedience	or	Welding				
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Excessive conditions created by the environment	or	Static electricity				
Lack of or defective maintenance						
Conception error						
Manufacturing error						
Installation error						
Incorrect command and/or control signal						

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Excessive conditions created by the environment	or	Motor				
Lack of or defective maintenance						
Conception error						
Manufacturing error						
Installation error						
Wilful disobedience						
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Lack of or defective maintenance	or	Other electric arc				
Conception error						
Manufacturing error						
Installation error						
Wilful disobedience						
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Wilful disobedience	or	Hammering	or impact			
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Wilful disobedience	or	impact during transport and handling				
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Wilful disobedience	or	Dropped object				
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
		External aggression (plane crash, object lifted by wind)				
		Missile (domino effect)				
		Fall of a structure element (domino effect)				

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Wilful disobedience	or	Flame, torch (welding)	or	Combustion flame or heat		
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Wilful disobedience	or	Smoking				
Manipulation error						
Other human error						
Non respect of licences						
Non respect of procedures						
Conception error	or	Other process flames (exhaust gas burners)				
Manufacturing error						
Installation error						
Lack of or defective maintenance	or	Lack of protection (lightning conductor)	or	Natural event (lightning)		
Conception error						
Manufacturing error						
Installation error						
Lack of or defective maintenance	or	Defective protection				
Conception error						
Manufacturing error						
Installation error						
				Hot missile (domino effect)		

Generic Fault Trees

CE2 Explosion (violent reaction)

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
		Normal storage	use of a highly reactive substance	explosion
Human error	Supply failure	Abnormal storage		
Wilful disobedience				
Lacking or defective maintenance				
Malicious intervention				
Error in labelling the storage place	Inappropriate choice of the storage place			
Human error				
Error in labelling the product				
Wilful disobedience				
Malicious intervention				
Contamination during transport, delivery or storage	Right product but not pure			
Bad quality product delivered				
Error ordering the product	Wrong product delivered	Abnormal storage, presence of an incompatible reagent in the storage room	Contact with an incompatible reagent	
Delivery error				
	Inappropriate choice of the storage place			
Human error				
Inappropriate labelling of the product				
Inappropriate labelling of the storage place				
Error ordering the product	Bad quality product delivered			
Contamination during transport/delivery				
Manufacturing error				
Design fault (eg. the material constitutive of the equipment is incompatible with the solid stored)	Some material present on the storage place is incompatible			
Manufacturing error				
Other human error (forgotten material)				
Defective maintenance or cleaning				
Installation error				
		Leak, entrainment from a nearby pipe or vessel (domino effect)		

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance Conception error Installation error Human error Lacking procedure Wilful disobedience Plant in flooding risk area Defective protection Human error Obstacles on the way Dangerous driving	or Leak from the roof Door opened Flooding Dropped container Leak from small container	or Contamination by natural elements of the environment (air, water) Accidental contamination	~	
Error ordering the product Delivery error Error ordering the product Contamination during transport/delivery Manufacturing error Conception error Manufacturing error Defective maintenance Other human error (e.g. the material was forgotten) Installation error	or Wrong product delivered Bad quality product delivered Material present in the storage place is a catalyst	or Abnormal presence of a catalyst	Presence of a catalyst (if involved)	
Human error Obstacles on the way Dangerous driving	or Dropped container Leak from small container	or Leak, entrainment from a nearby pipe or vessel (domino effect) Accidental contamination		
		Fire (domino effect) Chemical energy (domino effect)	Punctual (or permanent) energy source (if required)	

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance	or	Overheating	or	Furnace, boiler, motor other unshielded hot surface
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or	Abnormal presence		
Installation error				
Lacking or defective maintenance				
Lacking or defective maintenance	or	Overheating (regulation failure)	or	Heat transport canalisation
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or	Abnormal transport of hot substance		
Installation error				
Conception error	or	Abnormal presence		Magnifying glass
Installation error				
Lacking or defective maintenance	or	Overheating (regulation failure, short circuit)	or	Resisting electric conductor (resistance, short-circuit)
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Human error				
Conception error	or	Abnormal presence		
Installation error				
Lacking or defective maintenance	or	Shielding, protection failure	or	Friction (conveyers, doors, mechanical devices)
Conception error				
Manufacturing error				
Installation error				
Conception error	or	Abnormal presence		
Installation error				
Human error				
Human error	or	Excessive use conditions		
Wrong procedure				

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance or Conception error Manufacturing error Installation error	Lack of lubricant			
Lacking or defective maintenance or Conception error Manufacturing error Installation error	Defective mechanism			
Wilful disobedience or Manipulation error Other human error Non respect of licences Non respect of procedures	Shock between metallic pieces or Spark			
Wilful disobedience or Manipulation error Other human error Non respect of licences Non respect of procedures	Grinding			
Lacking or defective maintenance or Human error Maintenance or Other welding activity Friction or dry environment lacking or defective maintenance Normal presence Electrical switch or Maintenance or Other hammering	Electric system failure or Welding Static electricity Motor Other electric arc Hammering or Impact	Electric arc (defect of the electric installation, arc welding)		
Dangerous driving or Obstacles on the way Manutention error or Broken element from the structure	impact during transport and handling Dropped object External aggression (plane crash, object lifted by wind) Missile (domino effect) Fall of a structure element (domino effect)			

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Maintenance	or	Flame, torch (welding)	or	Combustion flame or heat (gas flame welding, smoking)		
Other welding activity						
Non respect of smocking prohibition	or	Smoking				
Smoking is not prohibited						
Conception error	or	Lack of protection (lightening conductor) or		Natural event (lightening)		
Lacking or defective maintenance						
Conception error	or	Defective protection				
Lacking or defective maintenance						
				Hot missile (domino effect)		

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CE3 Material set in motion (entrainment by air)

Undesirable event	Detailed direct causes		Direct causes		Necessary and sufficient causes	Critical event		
		Normal state	or	Fragmented material	or	Potentially mobile material	and	material set in motion by air
Lacking or defective cleanup	or	Material crushed by mechanical action (conveyers, doors, ...)		Material susceptible to emit vapours (e.g. solvent)				
Material in doorway								
Normal situation	or	Volatile phase mixed with solid material						
Contamination								
Bad quality material delivered				Part of the material is volatile under ambient temperature and pressure conditions				
Normal situation	or							
Bad quality material delivered								
		Normal functioning	or	Aeration	or	Presence of air vector		
Human error	or	Excessive aeration						
Defective aeration								
Command error								
Open air storage	or	Unprotected material						
Damaged roof or wall				Wind				
Human error	or	Door opened						
Impossible to close								
Closing the door not required by procedures								
Conception error	or	Exhaust gas outlet near the storage spot		or	Exhaust gases			
Installation error								
Lacking or defective maintenance		Leak from exhaust gas pipe						
				Gas escaping from a breach or leak (domino effect)				
				Air projection due to fall, collapse or explosion of a nearby equipment (domino effect)				

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CE4 Material set in motion (entrainment by a liquid)

Undesirable event		Detailed direct causes		Direct causes		Necessary and sufficient causes		Critical event		
		Normal state	or	Fragmented material	or	potentially mobile material	and	material set in motion by liquid entrainment		
Lacking or defective cleanup	or	Material crushed by mechanical action (conveyers, doors, ...)								
Material in doorway										
Normal situation	or	Entirely soluble material (e.g. salt)		Soluble material						
Contamination										
Bad quality material delivered										
Normal situation	or								Partly soluble material	
Bad quality material delivered										
Lacking or defective maintenance	or	Leak or breach on water pipe		or	Liquid escaping from a leak or breach				or	Presence of liquid vector
Impact										
Other leak/breach causes										
		Leak or breach on pipe or vessel (domino effect)								
		Fire				Extinction water				
Normal use of water	or	Water used for extinction								
Inappropriate extinction procedure										
Plant in a flooding area	and	Flooding		or	Natural event					
Unprotected storage										
Damaged roof or wall	or					Rain				
Open air										
Inappropriate procedure	or					Washing		Other water sources		
Normal use of water for washing										
Error	or					Overfilling of water tank				
Command/control failure										

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CE5 Start of fire

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Undesirable event	Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
			Normal storage/use or Abnormal storage/use	Presence of oxidising substance (R7 or R8) and	Start of fire
Error ordering the product	or	Wrong product delivered	or		
Delivery error					
Error ordering the product	or	Bad quality product delivered			
Contamination during transport/delivery					
Manufacturing error					
Human error	or	Inappropriate choice of the storage place			
Inappropriate labelling of the product					
Inappropriate labelling of the storage place					
			Leak, entrainment from a nearby equipment (domino effect)		
			Other accidental contamination		
Human error manipulating the container	or	Dropped container	or		
Obstacles on the way					
Dangerous driving					
Lacking or defective maintenance	or	Leak from small container			
impact					
			Abnormal storage, presence of an incompatible reagent in the storage room		
Error ordering the product	or	Wrong product delivered	or		
Wilful disobedience					
Malicious intervention					
Delivery error					
				Contact with a combustible (reducing) substance	
Human error	or	Inappropriate choice of the storage place			
Inappropriate labelling of the product					
Inappropriate labelling of the storage place					
Error ordering the product	or	Bad quality product delivered			
Contamination during transport/delivery					
Manufacturing error					
Design fault (eg. the material constitutive of the equipment is incompatible with the solid stored)	or	Some material present in the storage place is incompatible with the stored solid			
Manufacturing error					
Defective maintenance or cleaning					
Other human error (forgotten material)					
Installation error					

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Human error	or	Dropped container	or	Leak, entrainment from a nearby pipe or vessel (domino effect)
Obstacles on the way				Accidental contamination
Dangerous driving				
	Leak from small container			
	Normal situation			The reducing substance is part of the stored/used chemical (organic peroxide)

Generic Fault Trees

CE6-CE7 Breach on the shell & CE8-CE9 Leak from pipe (Large)

Undesirable event	Detailed direct causes		Direct causes		Necessary and sufficient causes	Critical event
excessive liquid transfer in batch system (due to human or command error)	or	filled beyond normal level	overfilling vessel causes overpressure	or	internal overpressure (liquid)	or (large) breach on shell or leak from pipe
insufficient capacity available in batch system (design error, defective maintenance)					Size of the leak: Large	
Loss of utilities						
blocked internals leads to overfilling of continuous system (defective maintenance, unexpected reaction)						
blocked outlet leads to overfilling of continuous system (defective maintenance, unexpected reaction (crystallisation))						
Lacking or defective maintenance (not replaced like with like)	or	more flow in than out	and	Pump causes overpressure		
Incorrect command and/or control signal						
Loss of utilities						
Incorrect sensor signal						
Interpretation error						
Transmission error						
Other human error						
Normal situation	or	vessel filled at maximum				
Abnormal situation (errors, failure)						
internal flammable or explosive mixture	and	internal combustion/explosion	combustion/explosion causes overpressure			
ignition source						
wrong substance introduced	or	runaway reaction	runaway (side) reaction causes overpressure			
substance introduced in the wrong form						
substance introduced in wrong ratio/order						
stirrer failure						
primary cooling/ reaction control fails						
substance introduced too rapidly						
vessel filled by design has blocked inlet and outlet	or	filled vessel containing liquid	and	thermal expansion of liquid filled vessel causes overpressure		
vessel left in overfilled condition						
refrigeration fails	or	temperature rise				
warmed up externally						
rapid valve closure	or	sudden blockage	back pressure wave causes overpressure			
sudden sediment blockage						

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance	or stratification potential in vessel (e.g. LNG)	roll-over of vessel contents causes overpressure	Internal overpressure (Gas material)	
Excessive conditions due to process or product lead to failure of the mixing system	no mixing in vessel			
Loss of utilities				
Human error				
Conception error				
Installation error				
Command failure				
evaporating upper layer (gets colder)	or difference in temperature between layers (temperature inversion)			
warmed up lower layer				
filling of a vessel				
Normal presence	or Presence of water in the pipe	and freezing and expansion of aqueous phase	Size of the leak: Large	
Contamination				
Defect in heating	or Low temperature			
Cold weather				
compressor overspeed	or overcompression	overcompression causes overpressure		
blockage in downstream pipework				
pressure regulation fails (e.g. reduction valve)				
Lacking or defective maintenance	or leak/rupture of internal high pressure source e.g. HP steam coil	internal high pressure source causes overpressure		
Excessive conditions created by the process				
Human error	or Wrong connection procedure	external HP source connected causes overpressure		
Badly designed procedure				
Wilfull disobedience	or Source should not be connected			
Human error				
Command/regulation error	or Overpressure in the external HP source			
Human error				
wrong substance introduced	or runaway reaction	runaway (side) reaction causes overpressure		
substance introduced in the wrong form				
substance introduced in wrong ratio/order				
stirrer failure				
primary cooling/ reaction control fails				
substance introduced too rapidly				

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
internal flammable mixture ignition source	and internal combustion/explosion	combustion/explosion causes overpressure		
flammable dust dust put in suspension in air spark Hot spot Friction	and flammable atmosphere or ignition source	dust explosion overpressures enclosure or	Internal overpressure (Solid material) <i>Size of the leak: Large</i>	
Normal storage/use of an instable solid	or solid is unstable	and unstable solid explodes		
Solid has become instable because of physical conditions Solid has become instable because of mixture with incompatible chemical Unstable solid stored/used by mistake High temperature impact Friction	or condition of stability exceeded			
Conception error (insufficient release or mitigation of weight) Installation error Lacking or defective maintenance Wilful disobedience Malicious intervention Manipulation error Other human error	or Natural causes (snow, ice, water, wind) or Loads placed on the equipment	Overloading	Rupture tied to an excessive mechanical stress due to external causes <i>Size of the leak: Large</i>	
Lacking or defective maintenance Installation error Conception error Manufacturing error	or Overfilling Support fails			
Conception error (installation in a known seismic risk zone) Unknown or underestimated seismic risk Lacking or defective maintenance Conception error Manufacturing error Installation error Abnormal use conditions (speed)	or Earthquake or Motor Other source of vibration	High amplitude vibrations		

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Lacking or defective maintenance	Due to external causes (furnace, boilers,...)	Dilatation		
Conception error				
Manufacturing error				
Installation error				
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Wilful disobedience				
Malicious intervention				
Manipulation error				
Other human error				
Lacking or defective maintenance	Due to internal cause (overheating of the content)			
Conception error				
Manufacturing error				
Installation error				
Incorrect command and/or control signal				
loss of utilities				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Wilful disobedience				
Malicious intervention				
Manipulation error				
Other human error				
	Domino effect (fire)			
	Domino effect (explosion)	External overpressure		
Lacking or defective maintenance	Torque	Shear stress		
Conception error				
Manufacturing error				
Installation error				
Conception error	Lacking or defective support			
Installation error				
Lacking or defective maintenance				

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Design error Wrong material ordered Wrong material delivered Human error	Wrong material used	Inappropriate material	Insufficient initial mechanical properties of the structure (below normal use conditions)	
Bad quality resulting from transport or storage conditions Bad quality delivered Lacking or deficient checking procedure Manufacturing error	Bad quality material used		Size of the leak: Large	
Human error Deliberate building out of specifications Design error Transmission/information error	Specifications not met during building Wrong specifications	Inappropriate dimensions		
Design error Transmission/information error	Wrong assembling procedure	Inappropriate assembling		
Human error Impossibility to apply the procedures	Non respect of assembling procedures			
Defective maintenance (not replaced like with like) Design error Manufacturing error Installation error (wrong material used) Wrong material delivered	Low resilience material	Brittle structure	Brittle rupture	
cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Low temperature		Size of the leak: Large	
Hydrogen cracking sensitive material Contamination by hydrogen Wrong material Wrong welding procedure Unauthorized welding	Hydrogen or other chemical causes of embrittlement Embrittlement due to welding			
Sensitive material Heating followed by fast cooling	Embrittlement due to other thermal cycles			

Undesirable event		Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Wilful disobedience	or	Hammering	or	impact	
Malicious intervention		impact during transport and handling			
Manipulation error					
Other human error					
Wilful disobedience	or				
Human error		Dropped object			
Human error	or				
Fall of an object due to vibrations or other cause (wind,...)		impact by a structure element			
High amplitude vibration	or				
Other cause					
		Missile (domino effect)			
		Fall of a structure element (domino effect)			

Generic Fault Trees

CE6-CE7 Breach on the shell & CE8-CE9 Leak from pipe (Medium)

Undesirable event	Detailed direct causes		Direct causes		Necessary and sufficient causes	Critical event
						(medium) breach on shell or leak from pipe
Incorrect or lacking information from the process	or	Bad information	or	Valve opened by mistake	or	Functional opening
Incorrect instruction given by other operator/staff member					Size of the leak: Medium	
Incorrect or lacking procedure						
Incorrect or lacking information from other operator/staff member						
Right information from the process/human environment but misunderstood by operator						
Misunderstanding of the procedure						
Human error : valve operated in the wrong direction	or	Other error				
Human error : wrong valve opened						
Incorrect or lacking information from the process	or	Bad information				
Incorrect instruction given by other operator/staff member						
Incorrect or lacking procedure						
Incorrect or lacking information from other operator/staff member						
Right information from the process/human environment but misunderstood by operator						
Misunderstanding of the procedure						
Human error : valve operated in the wrong direction	or	Other error				
Human error : wrong valve opened						
Corrosive environment	or	Corrosion				
Corrosive product						
Electrical origin						
Stress related corrosion						
Inappropriate material						
Lacking or defective protection						
Internal friction with erosive material	or	Erosion				
Flow pattern favours erosion						
External friction with erosive material (dust, structure)						
Lacking or defective maintenance	or	Electrical failure				
General electrical failure						
External cause (water creates a short circuit, electrical cable is sectioned)						
Defective software						
Defective hardware						
Defective transmission system						

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Undesirable event		Detailed direct causes		Direct causes	Necessary and sufficient causes	Critical event
Excessive conditions created by the environment	or	Aging	or	Seal, joint loss of effectiveness		
Excessive conditions created by the process						
Lacking or defective maintenance						
Wrong material delivered	or	Improper material				
Wrong material used						
Wrong dimension	or	Bad design				
Wrong material						
Not replaced like with like	or	Bad installation or maintenance				
Bad installation or maintenance procedure						
Normal use/storage of aggressive chemical	or	Physical or chemical aggression				
Contamination						
		Normal functioning of the safety valve	or	Safety valve, safety relief device		
Lacking or defective maintenance	or	Too sensitive safety valve				
Design error						
Installation/calibration error						
				fail to clear out contents before opening containment		
Operator error	or	inadequate isolation procedure	or			
Wilful disobedience						
Incorrect procedure						
Lacking or defective maintenance	or	leaking isolation equipment				
Conception error						
Manufacturing error						
Installation error						
		hazardous contents removal procedure failed				
Human error	or					
Blocked outlets						
Human error	or	Disconnected by operator	or	disconnect during filling		
Wrong information about process						
Wilful disobedience						
impact	or	Disconnected by other cause				
Moving part						
		Lacking or wrong information about the content	or	wrong part (containing hazardous material) worked on		
Incorrect sensor signal	or					
Interpretation error						
Transmission error						
Human error						
		Conscious work on part containing hazardous material				
Wilful disobedience	or					
Malicious intervention						

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Incorrect sensor signal Interpretation error Transmission error Human error Incorrect command and/or control signal Incorrect sensor signal Human error	Lacking or wrong information about containment Containment closing procedure failed	operation started when containment open		
Flow stop control not accessible Flow stop control difficult to operate Manipulation error Other human error Lacking information induces delayed action Lacking or defective maintenance Flow stop control not accessible	flow stop control not operated in time flow stop control inoperable	uncontrolled flow during sampling/draining		
Operator error Wrong information on flow stop control	flow stop control operated in wrong direction			

Generic Fault Trees

CE6-CE7 Breach on the shell & CE8-CE9 Leak from pipe (Small)

Undesirable event	Detailed direct causes		Direct causes		Necessary and sufficient causes	Critical event	
fine material present due to process	or	Internal friction with erosive material	or	Erosion	or	Degradation of the mechanical properties leads to incapacity to sustain high pressure	(small) breach on shell or leak from pipe
fine material present due to pollution in product		Flow pattern favours erosion				Size of the leak: Small	
fine material present which came from containment (e.g. due to corrosion) (defective maintenance)							
fluid has too much speed	or						
turbulence		External friction with erosive material (dust, structure)					
Conception error	or						
Installation error							
Erosive material brought by the environment (dust, sand)							
Normal situation							
Conception error	or						
Installation error		Corrosive environment	or	Corrosion			
Lacking or defective maintenance							
Domino effect (nearby leak of corrosive product)							
Corrosive natural environment (sea, salt)							
Normal situation	or	Corrosive product					
Contamination due to human error							
Contamination due to other cause							
Conception error	or						
Lacking or defective maintenance		Electrical origin					
Installation error							
Manufacturing error							
Conception error	or	Stress related corrosion					
Manufacturing error							
Installation error							
Lacking or defective maintenance		Inappropriate material					
Conception error	or						
Manufacturing error							
Installation error		Lacking or defective protection					
Lacking or defective maintenance (not replaced like with like)							
Conception error	or						
Manufacturing error							
Installation error							
Lacking or defective maintenance (not replaced like with like)							

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Conception error	or	Fatigue sensitive material	and	Fatigue
Manufacturing error				
Installation error				
Lacking or defective maintenance (not replaced like with like)				
Conception error	or	Vibration or cyclic loading		
Installation error				
Lacking or defective maintenance				
Vibrating environment (normal situation)				
Human error (thermal protection removed, error setting target temperature)	or	Due to external causes (furnace, boilers,...)	or	Thermal weakening (lowering of the tensile or compressive strength under the effect of high temperature)
Conception error (insufficient protection, wrong material...)				
Installation error				
Lacking or defective maintenance (temperature control or protection not maintained)				
Incorrect command and/or control signal (bad temperature control)				
Incorrect sensor signal				
Human error (e.g. error setting target temperature)	or	Due to internal cause (overheating of the content)		
Installation error				
Incorrect command and/or control signal				
Incorrect sensor signal				
Interpretation error				
loss of utilities				
Design error (wrong regulation system, wrong material...)				
Manufacturing error				
Lacking or defective maintenance				
Installation error				
		Domino effect (fire)		

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Design error (wrong material for a normal presence of the solvent) or Solvent		Other chemical action of the environment (solvent on plastic structure,...)		
Lacking or defective maintenance				
Manufacturing error				
Installation error				
Human error				
Contamination of the product				
Design error (wrong material for a normal presence of the chemical) or Other chemical				
Lacking or defective maintenance				
Manufacturing error				
Installation error				
Human error				
Contamination of the product				
Design error (wrong material or protection) or Direct light on UV sensitive material or Other physical action of the environment (light on plastics,...)				
Lacking or defective maintenance				
Manufacturing error				
Installation error				
Design error (wrong material or protection) or Other physical action				
Lacking or defective maintenance				
Manufacturing error				
Installation error				

Generic Fault Trees

CE10 Catastrophic rupture

Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
excessive liquid transfer in batch system (due to human, loss of utilities or command error)	filled beyond normal level	overflowing vessel causes overpressure	internal overpressure (liquid)	catastrophic rupture
insufficient capacity available in batch system (design error, defective maintenance)				
Loss of utilities				
blocked internals leads to overflowing of continuous system (defective maintenance, unexpected reaction)				
blocked outlet leads to overflowing of continuous system (defective maintenance, unexpected reaction)				
Lacking or defective maintenance (not replaced like with like)	more flow in than out	Pump causes overpressure		
Incorrect command and/or control signal				
Loss of utilities				
Incorrect sensor signal				
Interpretation error				
Transmission error				
Other human error				
Normal situation	vessel filled at maximum			
Abnormal situation (errors, failure)				
internal flammable mixture	internal combustion/explosion	combustion/explosion causes overpressure		
ignition source				
wrong substance introduced	runaway reaction	runaway (side) reaction causes overpressure		
substance introduced in the wrong form				
substance introduced in wrong ratio/order				
stirrer failure				
primary cooling/ reaction control fails				
substance introduced too rapidly				
vessel filled by design has blocked inlet and outlet	contained liquid filled vessel	thermal expansion of liquid filled vessel causes overpressure		
vessel left in overfilled condition				
refrigeration fails	temperature rise			
warmed up externally				
rapid valve closure	sudden blockage	back pressure wave causes overpressure		
sudden sediment blockage				

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Undesirable event		Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event	
		stratification potential in vessel (e.g. LNG)	roll-over of vessel contents			
			and			
Lacking or defective maintenance	or	no mixing in vessel				
Excessive conditions due to process or product lead to failure of the mixing system						
loss of utilities						
Human error						
Conception error						
Installation error						
Command failure						
evaporating upper layer (gets colder)	or	difference in temperature between layers (temperature inversion)				
warmed up lower layer						
filling of a vessel						
compressor overspeed	or	overcompression	overcompression causes overpressure	Internal overpressure (Gas material)		
blockage in downstream pipework						
pressure regulation fails (e.g. reduction valve)						
Lacking or defective maintenance		leak/rupture of internal high pressure source e.g. HP steam coil	internal high pressure source causes overpressure			
Excessive conditions created by the process						
Human error	or	Wrong connection procedure	external HP source connected causes overpressure			
Badly designed procedure						
Wilfull disobedience	or	Source should not be connected				
Human error						
Command/regulation error	or	Overpressure in the external HP source				
Human error						
wrong substance introduced	or	runaway reaction	runaway (side) reaction causes overpressure			
substance introduced in the wrong form						
substance introduced in wrong ratio/order						
stirrer failure						
primary cooling/ reaction control fails						
substance introduced too rapidly						
internal flammable mixture	and	internal combustion/explosion	combustion/explosion causes overpressure			
ignition source						

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
flammable dust dust put in suspension in air spark Hot spot Friction Normal storage/use of an instable solid	and flammable atmosphere or ignition source solid is unstable	dust explosion overpressures enclosure or unstable solid explodes	Internal overpressure (Solid material)	
Solid has become instable because of physical conditions Solid has become instable because of mixture with incompatible chemical Unstable solid stored/used by mistake High temperature impact Friction	or condition of stability exceeded			
Conception error (insufficient relief or mitigation of weight) Installation error Lacking or defective maintenance	or Natural causes (snow, ice, water, wind)	Overloading	Excessive external stress	
Conception error (installation in a known seismic risk zone) Unknown or underestimated seismic risk Defective maintenance (not replaced like with like)	or Earthquake Low resilience material	High amplitude vibrations		
Design error Manufacturing error Installation error (wrong material used) Wrong material delivered cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	or Low temperature	Brittle structure	and Brittle rupture	

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
Hydrogen cracking sensitive material	and	Hydrogen or other chemical causes of embrittlement		
Contamination by hydrogen				
Wrong material	or	Embrittlement due to welding		
Wrong welding procedure				
Unauthorized welding				
Sensitive material	and	Embrittlement due to other thermal cycles		
Heating followed by fast cooling				
Wilful disobedience	or	Hammering		
Malicious intervention		or Impact		
Manipulation error				
Other human error				
Wilful disobedience	or	impact during transport and handling		
Human error				
Human error	or	Dropped object		
Fall of an object due to vibrations or other cause (wind,...)				
High amplitude vibration	or	impact by a structure element		
Other cause				
		Missile (domino effect)		
		Fall of a structure element (domino effect)		

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CE11 Vessel collapse

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) loss of utilities Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Decrease of temperature	Decrease of pressure due to a decrease of the temperature	Underpressure (pressure below the containment limit of the vessel)	or vessel collapse
cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) loss of utilities Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Decrease of temperature below dew point	Condensation		
Lacking or defective maintenance leads to contamination Conception error leads to contact with reactive (contamination) Manufacturing error leads to contact with reactive (contamination) Installation error leads to contact with reactive (contamination) Incorrect command and/or control signal leads to contact with reactive (contamination) Other human error leads to contact with reactive (contamination) Normal situation (current event)	Adsorption (e.g.. By activated carbon) or other gas consuming reaction (ex: absorption of ammonia in water)	Chemical reaction consuming gases		
Human error Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Fast Emptying	Fast emptying of the vessel		

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Collapse of the roof

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Undesirable event	Detailed direct causes	Direct causes	Necessary and sufficient causes	Critical event
cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) loss of utilities Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Decrease of temperature	Decrease of pressure due to a decrease of the temperature	Underpressure (pressure below the containment limit of the roof)	collapse of the roof
cold weather heater fails endothermic reaction Human error (e.g. in setting temperature target) loss of utilities Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Decrease of temperature below dew point	Condensation		
Lacking or defective maintenance leads to contamination Conception error leads to contact with reactive (contamination) Manufacturing error leads to contact with reactive (contamination) Installation error leads to contact with reactive (contamination) Incorrect command and/or control signal leads to contact with reactive (contamination) Other human error leads to contact with reactive (contamination) Normal situation (current event)	Adsorption (e.g.. By activated carbon) or other gas consuming reaction	Chemical reaction consuming gases		
Human error Incorrect command or control signal Incorrect sensor signal Transmission error Normal situation	Fast Emptying	Fast emptying of the vessel or tank		