APPENDIX 11

AND and OR gates, and notations in the event tree

Delvosalle C., Fiévez C., Pipart A.

Faculté Polytechnique de Mons, Major Risk Research Centre (Belgium)

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1. Introduction

This appendix gives some precisions for the calculation of the frequencies in the event tree (calculation of the frequencies of Dangerous Phenomena, MIRAS step 5).

Chapter 2 will show that, in the event trees built with the MIMAH methodology, they are in fact "AND" and "OR" gates which are included. This chapter explain how these gates are placed and how to take them into account in the calculation of frequencies.

Chapter 3 gives information about the notation of the different probabilities encountered in the event tree.

Chapters 4 to 7 shows the generic event trees of MIMAH on which the AND and OR gates, as well as notations, have been explicitly expressed.

2. "AND" gate and "OR" gate

In event trees built by the MIMAH methodology, "AND" and "OR" gates and probabilities are placed on the branches of event trees, between the different levels of events.

For example, if we consider a catastrophic rupture of an equipment storing a liquid substance with all imaginable hazardous properties (fictitious example), the event tree, with the "AND"/"OR" gates and the probabilities associated with each branch (**when there are no safety barriers**), is shown in Figure 1.

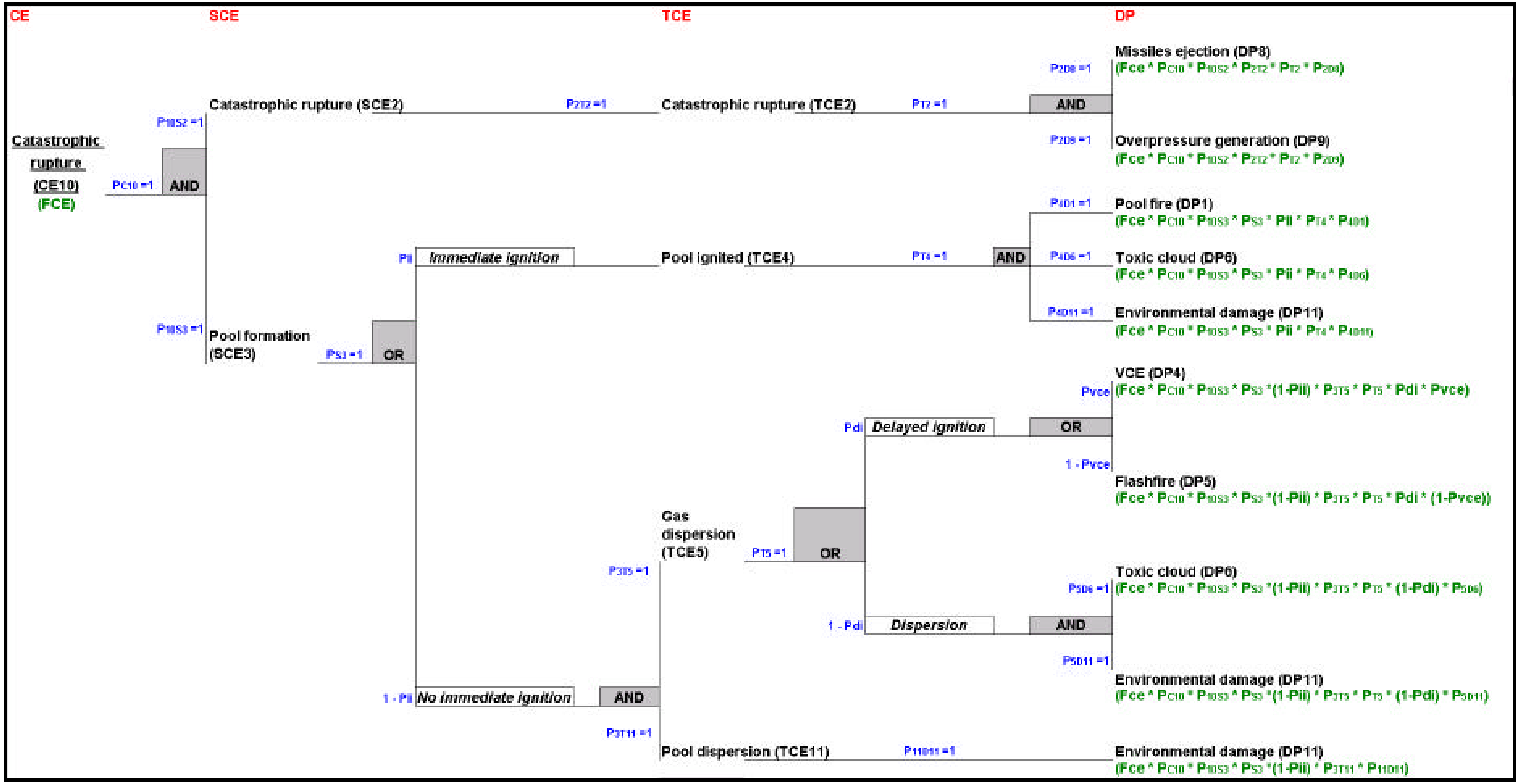


Figure 1: example of addition of AND and OR gates in the event tree

In the generic event trees built with the MIMAH methodology, there is no AND / OR gates explicitly drawn. In fact, these gates are implicitly included in the event trees.

AND gates are located between an event and its simultaneous consequences (for example a breach on a two-phase storage, under the liquid level, has two consequences occurring simultaneously – a two-phase jet and a pool formation). These outcomes are linked by a AND gate.

If the events are tied by an "AND" gate, the frequency upstream the "AND" gate is transmitted to all the branches downstream.

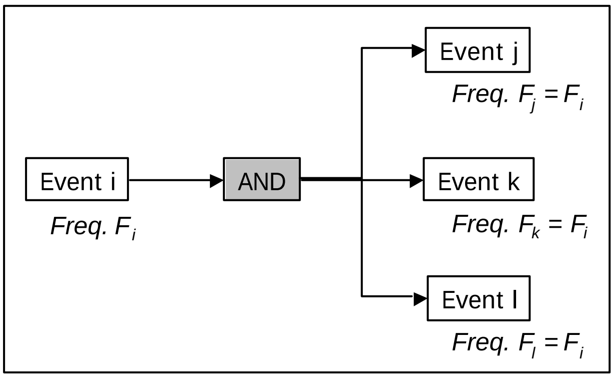


Figure 2: "AND" gate

OR gates appear downstream an event if one of the consequent events may occur and the others not. For example, if we consider the pool formation, a direct ignition can occur and we have then the "pool ignited" phenomenon, and in the other case we have the dispersion of the gas. Events linked by a OR gate are mutually exclusive.

The frequency of each event downstream a OR gate may be determined by multiplying the upstream event frequency by the "transmission" (conditional) probability along the path leading to that outcome. Thus the probabilities associated with each branch must sum to 1.

For instance, if there are only two downstream events, the transmission probability of one branch may be P_1 and the transmission probability of the other branch, P_2, is equal to $1-P_1$. This is illustrated in Figure 3.

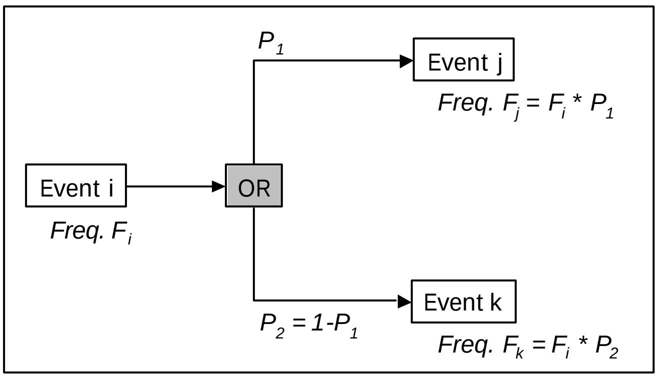


Figure 3: "OR" gate

3. Notations in trees

- The probability which ties two events or the probabilities between an "AND" gate and an event, is noted as follow: **P_{iLj}**

where i is the number associated to the upstream event

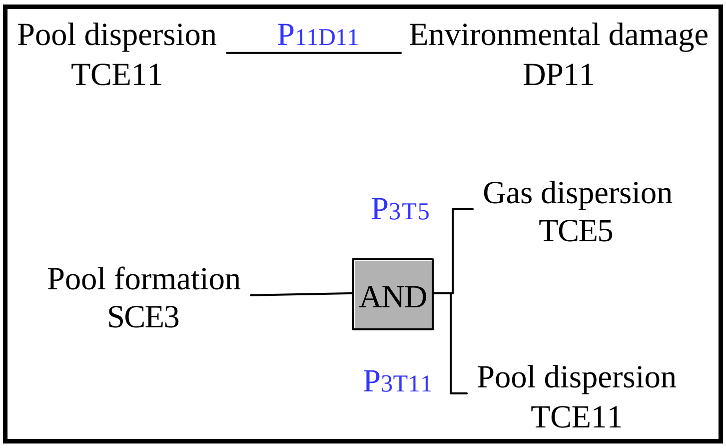
j is the number associated to the downstream event

L is "S" when the downstream event is the secondary critical event

"T" when the downstream event is the tertiary critical event

"D" when the downstream event is the dangerous phenomenon

Examples:



- The probability upstream of a gate is noted as follow: **P_{Li}**

where i is the number associated to the upstream event

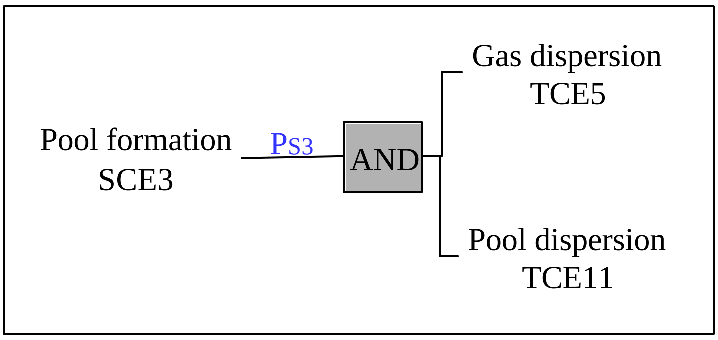
L is "C" when the upstream event is the critical event

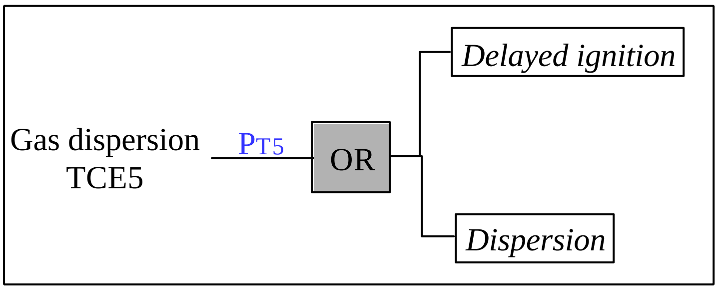
"S" when the upstream event is the secondary critical event

"T" when the upstream event is the tertiary critical event

"D" when the upstream event is the dangerous phenomenon

Examples:





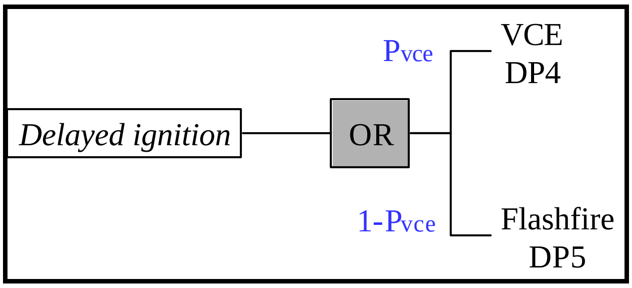
- The other probabilities between an "OR" gate and an event are tied to ignition probabilities

  P_{ii} means "probability of immediate ignition"

  P_{di} means "probability of delayed ignition"

  P_{vce} means "probability of VCE"

  Example:



- In the following paragraphs, abbreviations are used. Their signification are given here.

  F_{CE} means "frequency of critical event"

  P means "probability"

  Pi means "probability of ignition"

  Pii means "probability of immediate ignition"

Pdi means "probability of delayed ignition"

Pvce means "probability of VCE"

Prain-out means "probability of rain-out"

Pexpl means "probability of explosion"

- In the event trees, the calculation to obtain the frequency of a dangerous phenomenon associated to the critical event, with a frequency F_{CE}, is put between brackets next to the dangerous phenomenon.

4. Substance state = Liquid

The table below gives the critical events associated to the substance state "LIQUID"

		CE 1 Decomposition	CE 2 Explosion	CE 3 Materials set in motion (entrainment by air)	CE 4 Materials set in motion (entrainment by a liquid)	CE 5 Start of a fire (LPI)	CE 6 Breach on the shell in vapour phase	CE 7 Breach on the shell in liquid phase	CE 8 Leak from liquid pipe	CE 9 Leak from gas pipe	CE 10 Catastrophic rupture	CE 11 Vessel collapse	CE 12 Collapse of the roof
Liquid	STAT2					X		X	X		X	X	X

4.1 CE5 : Start of fire

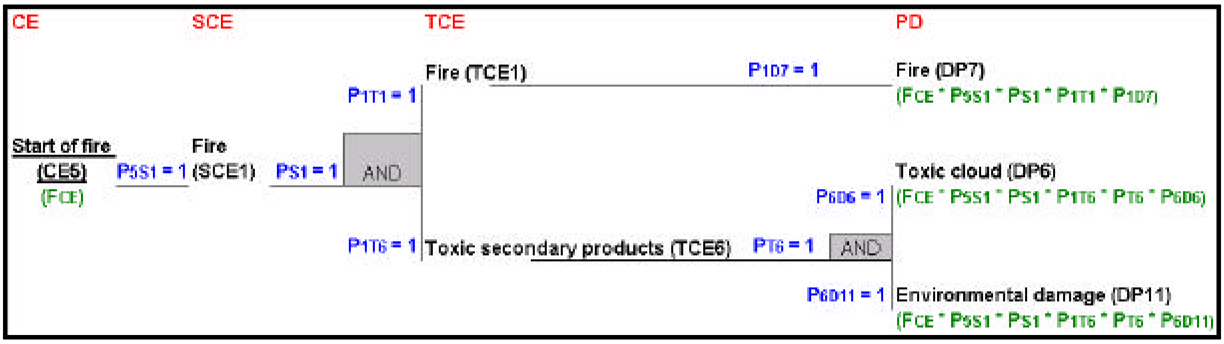


Figure 4: Event tree of "CE5 Start of fire" with a liquid substance

In Figure 4, if there are no safety barriers, the frequencies of dangerous phenomena are known if the frequency of the critical event "Start of fire" is known for the given equipment type.

4.2 CE7: Breach on the shell in liquid phase; CE8: Leak from liquid pipe; CE11: Vessel collapse

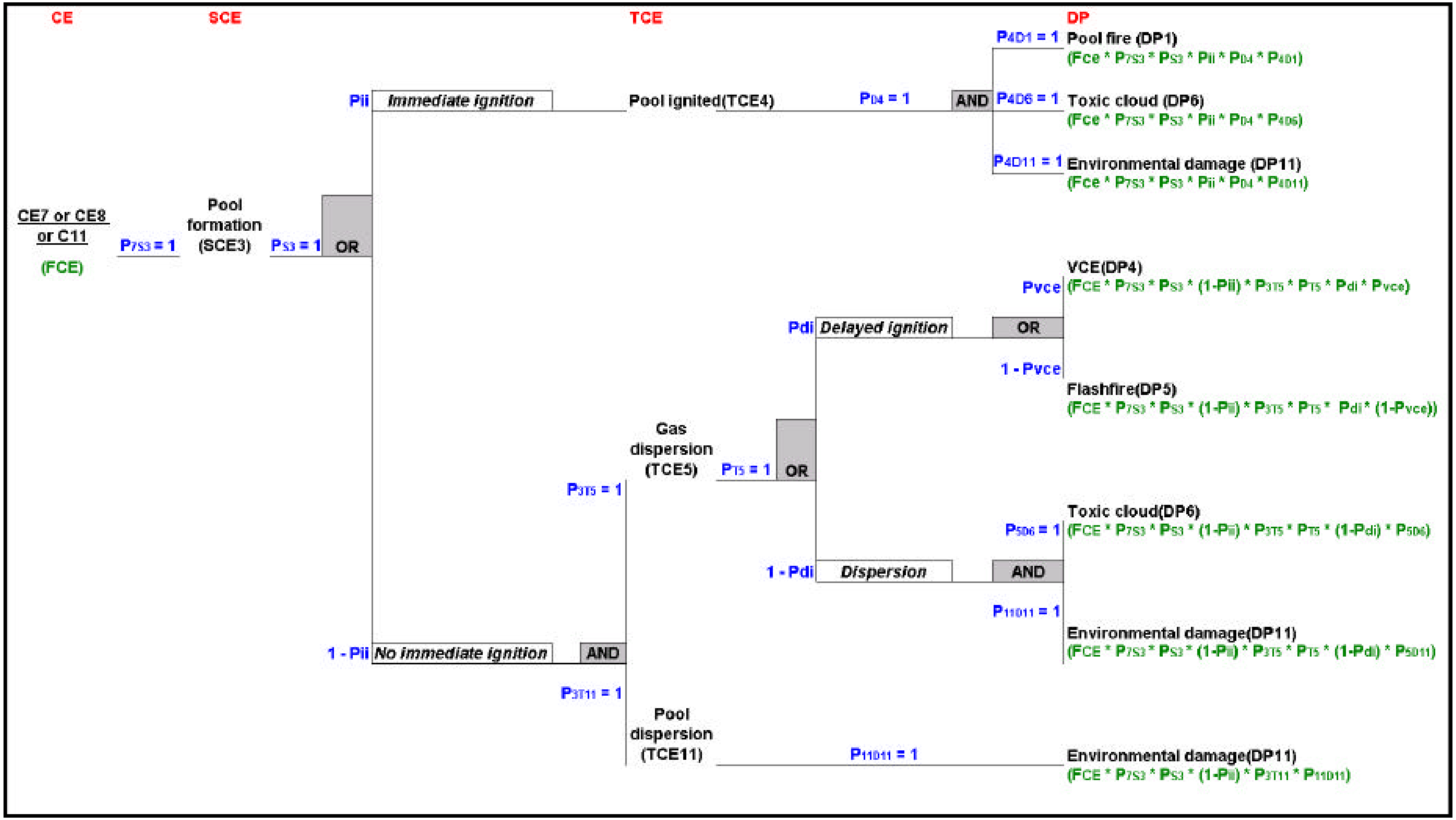


Figure 5: Event tree of CE7, CE8 or C11 with a liquid substance

In Figure 5, if there are no safety barriers, the data needed for the calculation of frequencies of the dangerous phenomena are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of immediate ignition of a pool from a continuous release of liquid, Pii
- Probability of delayed ignition of the gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

4.3 CE10: Catastrophic rupture

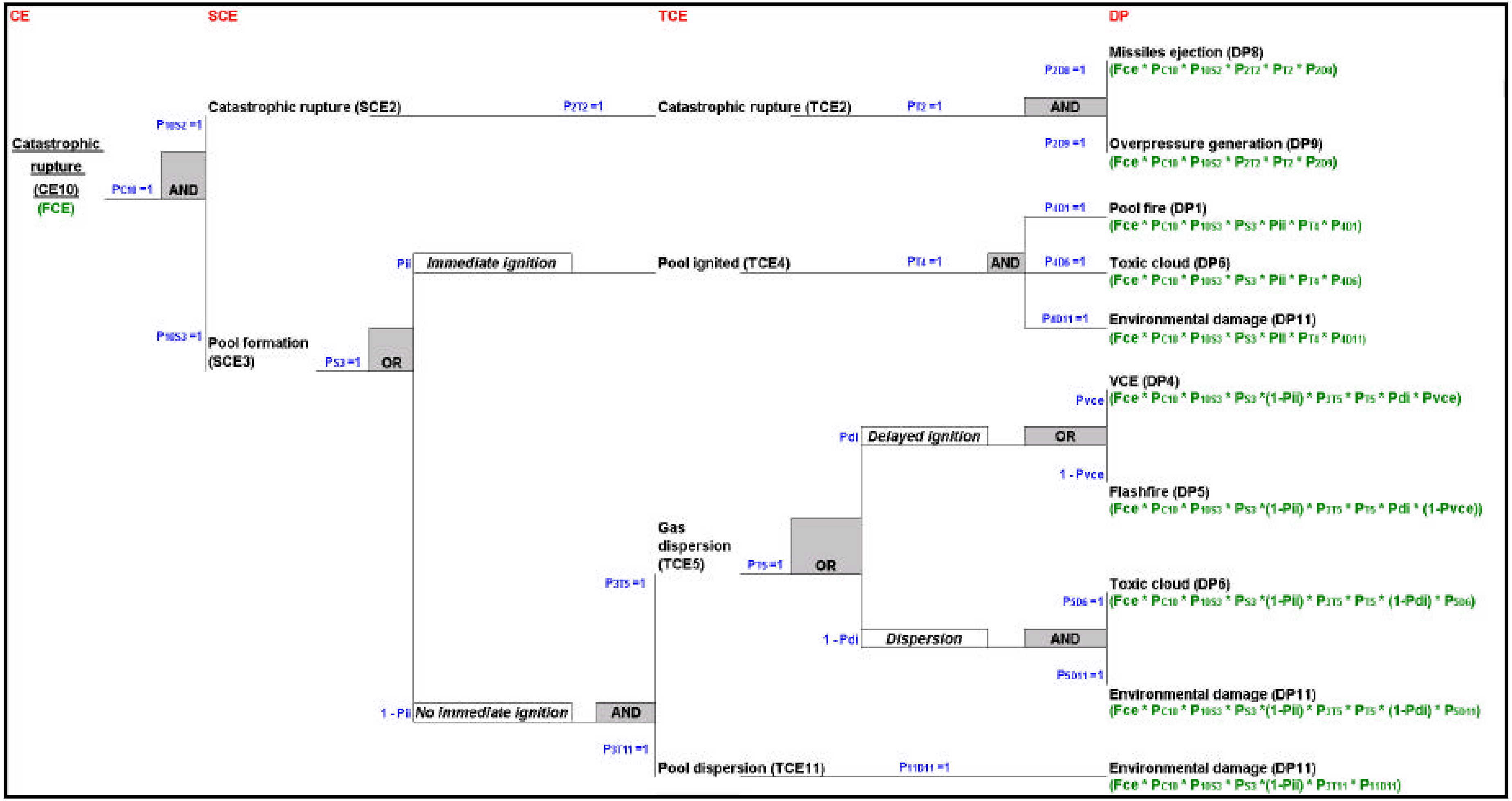


Figure 6: Event tree of "C10 Catastrophic rupture" with a liquid substance

In Figure 6, if there are no safety barriers, the data needed for the calculation of frequencies of the dangerous phenomena are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of immediate ignition of a pool from an instantaneous release of liquid, Pii
- Probability of delayed ignition of the gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

4.4 CE12: Collapse of the roof

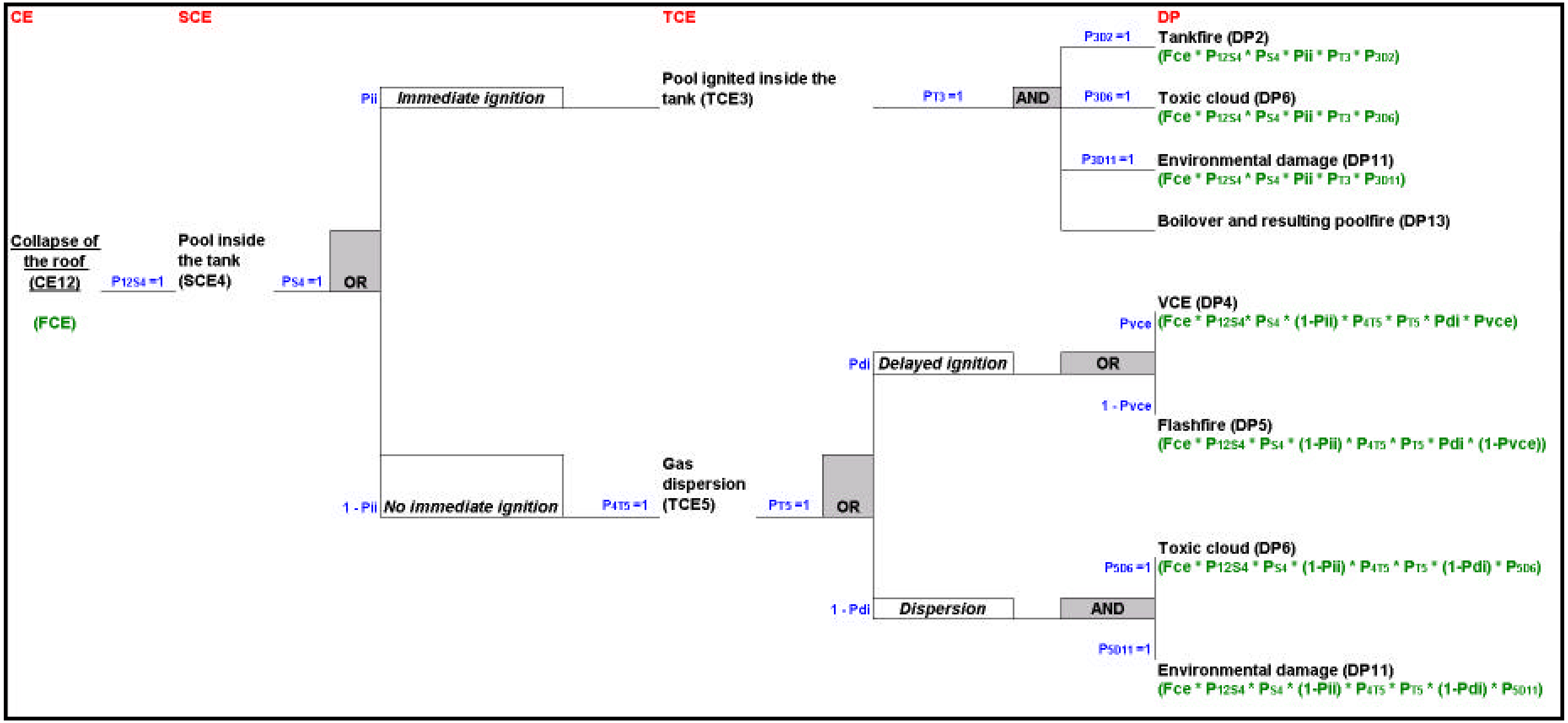


Figure 7: Event tree of "CE12 Collapse of the roof" with a liquid substance

In Figure 7, if there are no safety barriers, the data needed are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of immediate ignition of a pool inside a tank, Pii
- Probability of delayed ignition of the gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

Remark:

The occurrence of a boilover is function of substance type. This event is very rare

5. Substance state = Gas/vapour

The table below gives the critical events associated to the substance state "GAS/VAPOUR"

	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
Gas / Vapour STAT4					X	X			X	X		

5.1 CE5: Start of fire

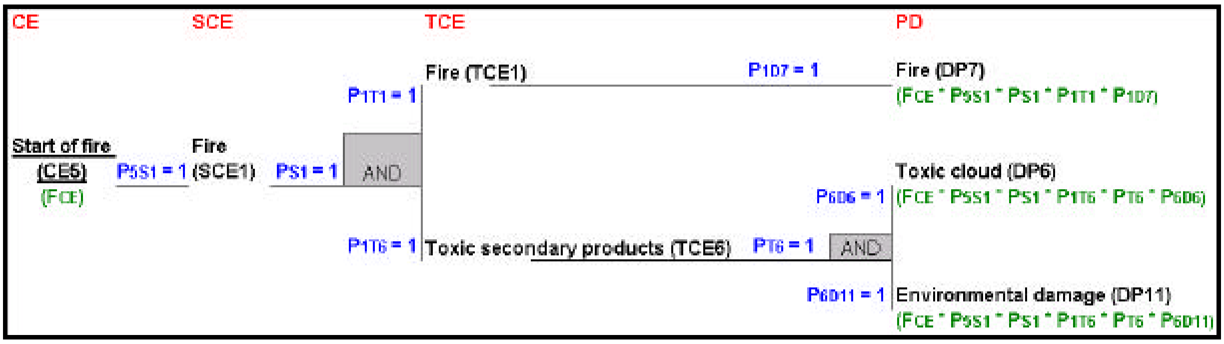


Figure 8: Event tree of "CE5 Start of fire" with a gas

In Figure 8, if there are no safety barriers, the frequencies of dangerous phenomena are known if the frequency of the critical event "Start of fire" is known for the given equipment type.

5.2 CE6: Breach on the shell in the vapour phase; CE9: Leak from gas pipe

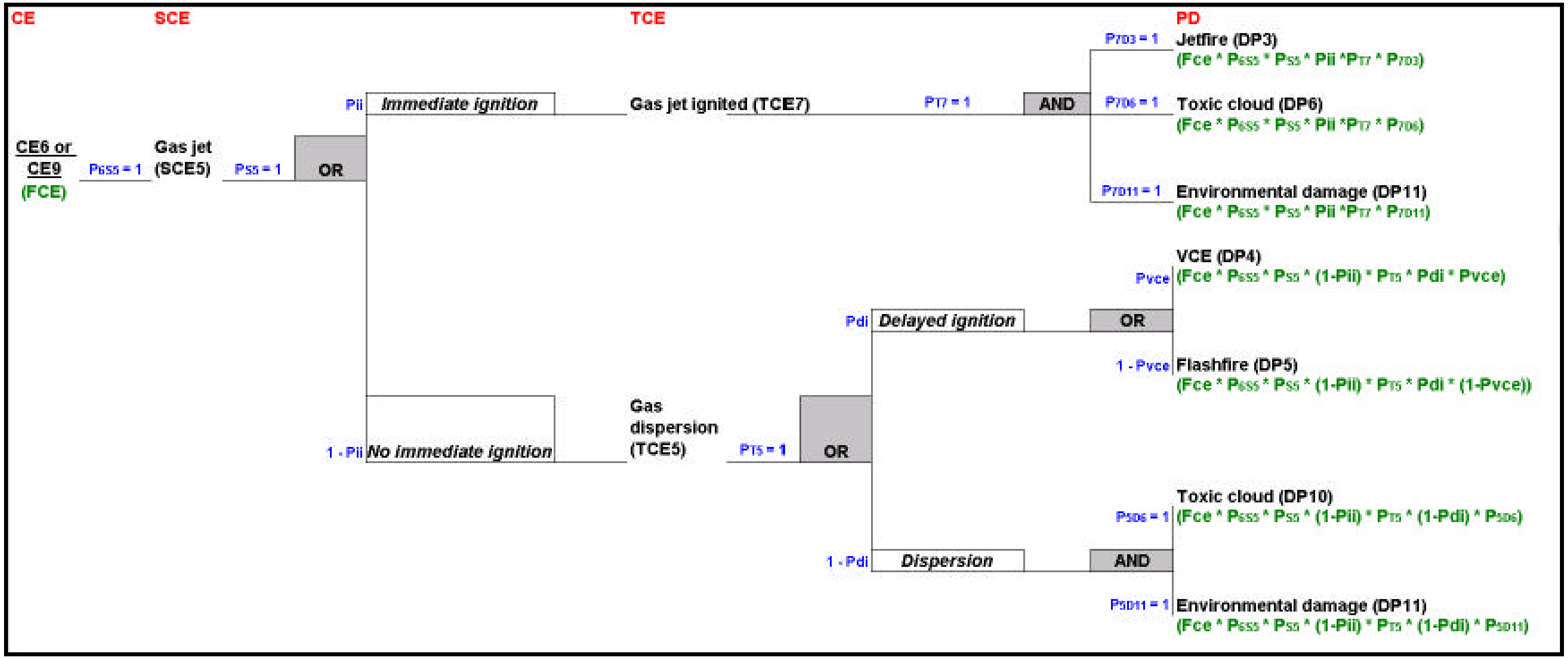


Figure 9: Event tree of CE6 or CE9 with a gas

In Figure 9, if there are no safety barriers, the data needed for the calculation of frequencies of dangerous phenomena are:

- Frequency of critical event for the given equipment type, FCE
- Probability of immediate ignition of a gas jet, Pii
- Probability of delayed ignition of a gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

5.3 CE10: Catastrophic rupture

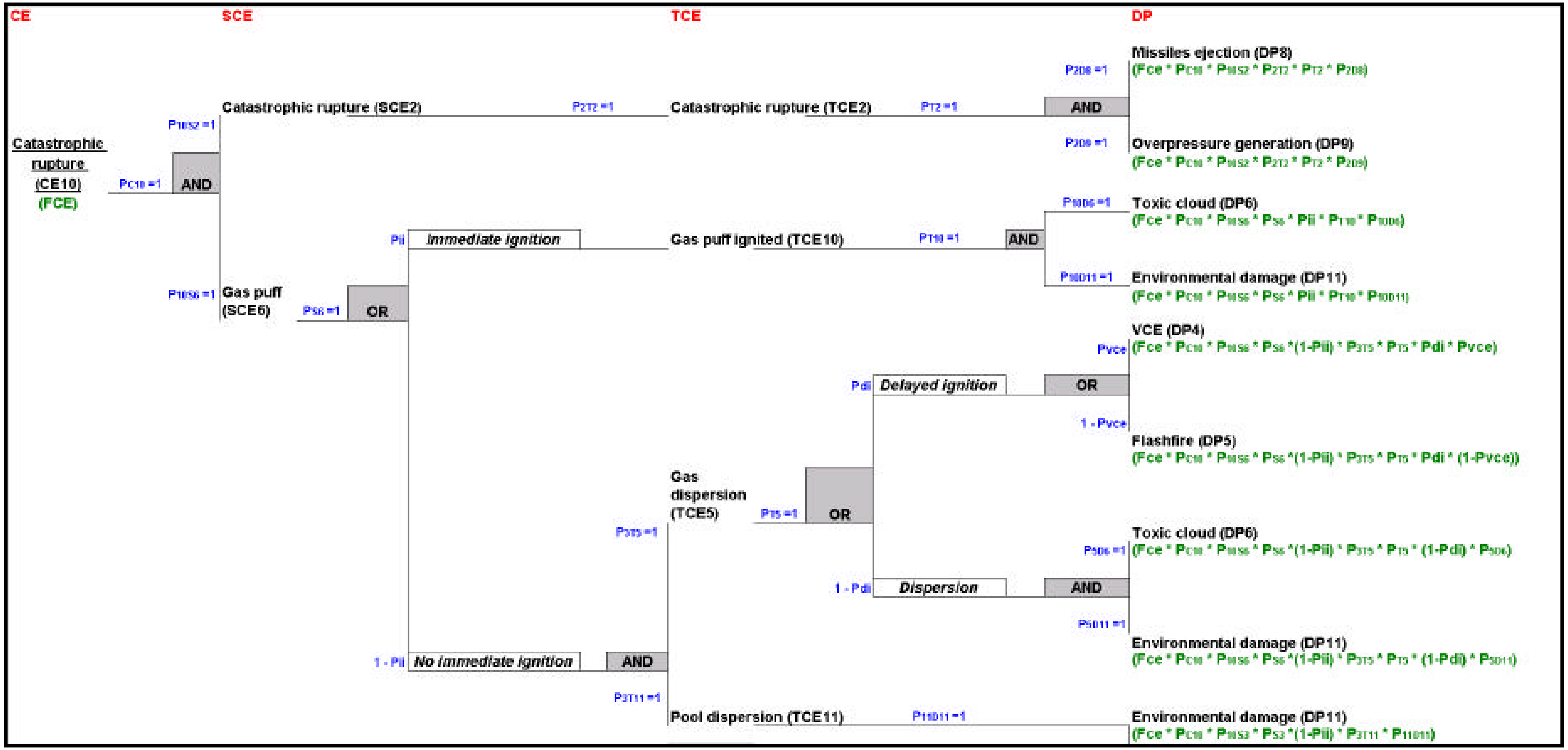


Figure 10: Event tree of "C10 Catastrophic rupture" with a gas

In Figure 10, if there are no safety barriers, the data needed for the calculation of frequencies of dangerous phenomena are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of immediate ignition of a gas jet, Pii
- Probability of delayed ignition of a gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

6. Substance state = Two-phase

The table below gives the critical events associated to the substance state "TWO-PHASE"

	CE 1 Decomposition	CE 2 Explosion	CE 3 Materials set in motion (entrainment by air)	CE 4 Materials set in motion (entrainment by a liquid)	CE 5 Start of a fire (LPI)	CE 6 Breach on the shell in vapour phase	CE 7 Breach on the shell in liquid phase	CE 8 Leak from liquid pipe	CE 9 Leak from gas pipe	CE 10 Catastrophic rupture	CE 11 Vessel collapse	CE 12 Collapse of the roof
Two-phase STAT3					X	X	X	X	X	X		

6.1 CE5: Start of fire

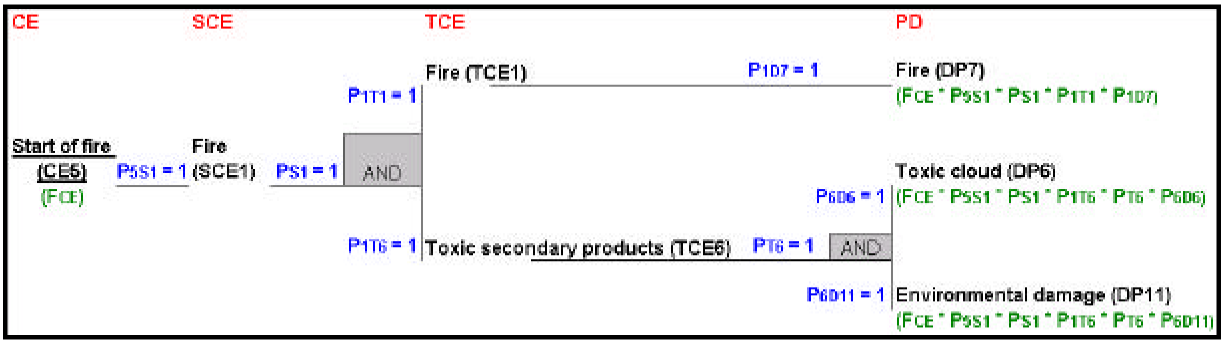


Figure 11: Event tree of "CE5 Start of fire" with a two-phase substance

In Figure 11, if there are no safety barriers, the frequencies of dangerous phenomena are known if the frequency of the critical event "Start of fire" is known for the given equipment type.

6.2 CE6: Breach on the shell in vapour phase; CE9: Leak from gas pipe

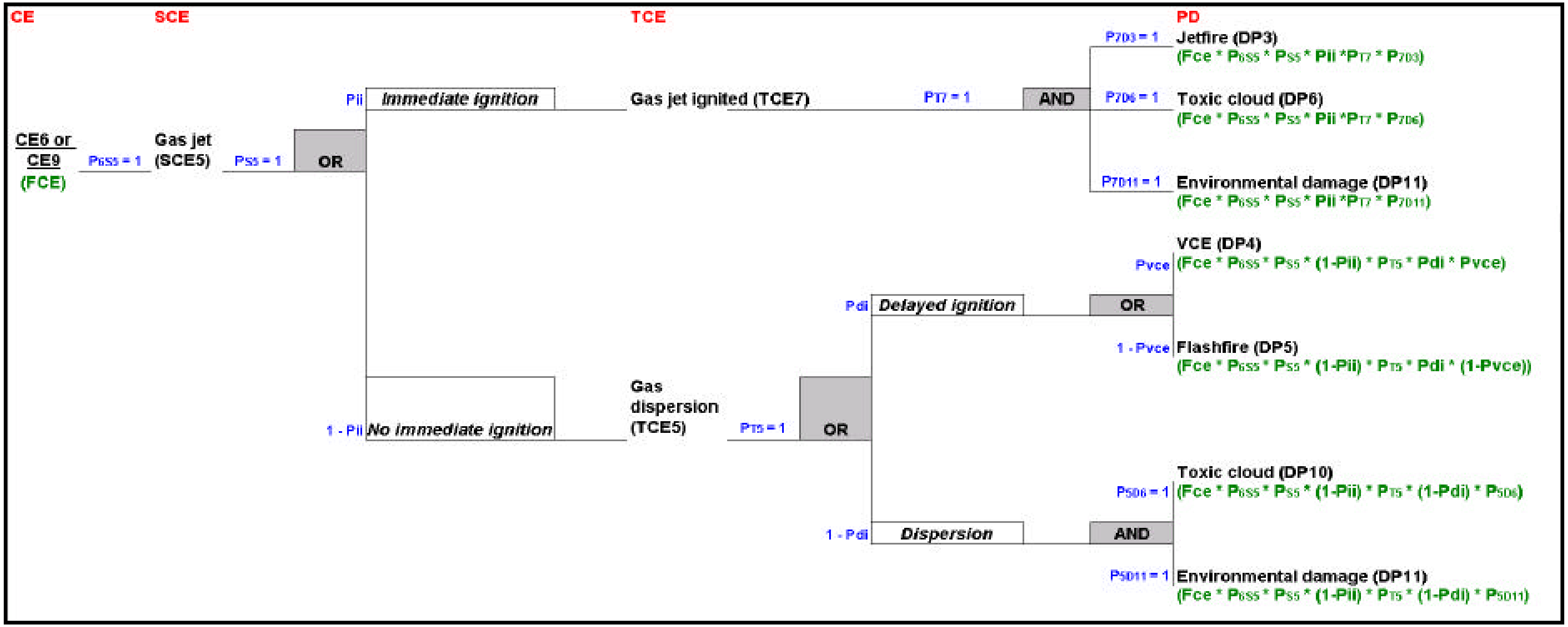


Figure 12: Event tree of CE6 or CE9 with a two-phase substance

In Figure 9, if there are no safety barriers, the data needed for the calculation of frequencies of dangerous phenomena are:

- Frequency of critical event for the given equipment type, FCE
- Probability of immediate ignition of a gas jet, Pii
- Probability of delayed ignition of a gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

6.3 CE7: Breach on the shell in liquid phase; CE8: Leak from liquid pipe

In Figure 13 (see below), if there are no safety barriers, the data needed for the calculation of frequencies of dangerous phenomena are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of rain-out, this probability is tied partly to the probability that the jet is turned toward an obstacle. So this probability is tied to the position of the leak on the equipment, to probabilities of wind directions, to the presence of an obstacle in this direction. If the two-phase jet meets an obstacle, the rain-out is 100%.
- Probability of immediate ignition, Pii
- Probability of delayed ignition of a gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

Remark:

The probability Pii is often the same for the branch "Pool formation" and for the branch "Two-phase jet".

The probability Pdi is the same for the branch "Pool formation" and for the branch "Two-phase jet". Indeed, the gas dispersion comes from the pool (vaporization of the pool) and from the jet.

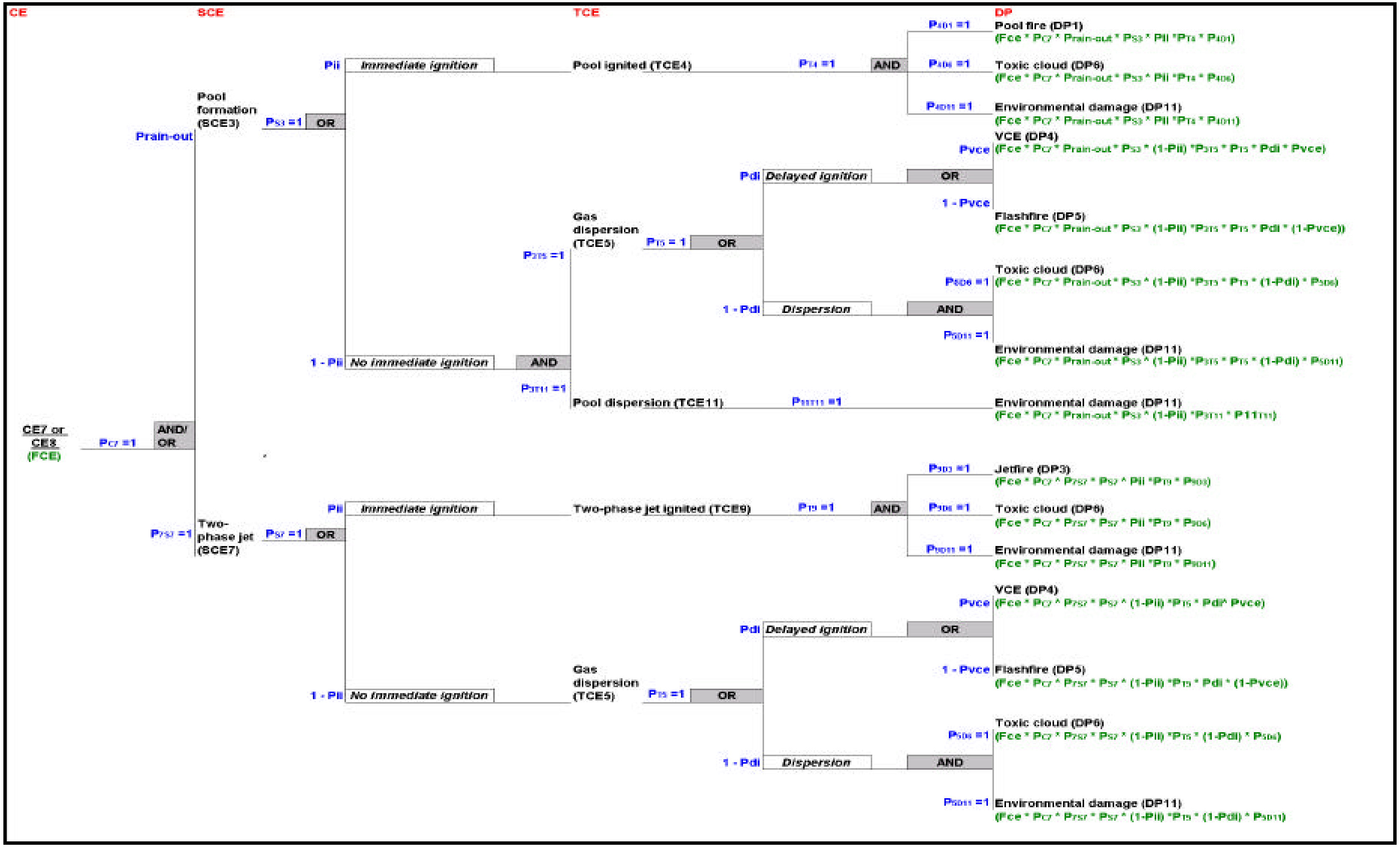


Figure 13: Even tree of CE7 or CE8 with a two-phase substance

6.4 C10: Catastrophic rupture

In Figure 14 (see below), if there are no safety barriers, the data needed for the calculation of frequencies of dangerous phenomena are:

- Frequency of critical event for the given equipment type, F_{CE}
- Probability of immediate ignition, Pii
- Probability of delayed ignition of a gas dispersion, Pdi
- Probability of VCE, Pvce, in relation with the probability of a flashfire

The other probabilities are equal to 1.

Remark:

If there is immediate ignition of the aerosol puff, there will be also immediate ignition of the pool or if there is immediate ignition of the pool, there will be also immediate ignition of the aerosol puff.

So, the probability Pii is the same for the branch "Pool formation" and for the branch "Aerosol puff".

The probability Pdi is the same for the branch "Pool formation" and for the branch "Aerosol puff". The gas dispersion comes from the pool (vaporization of the pool) and from the puff.

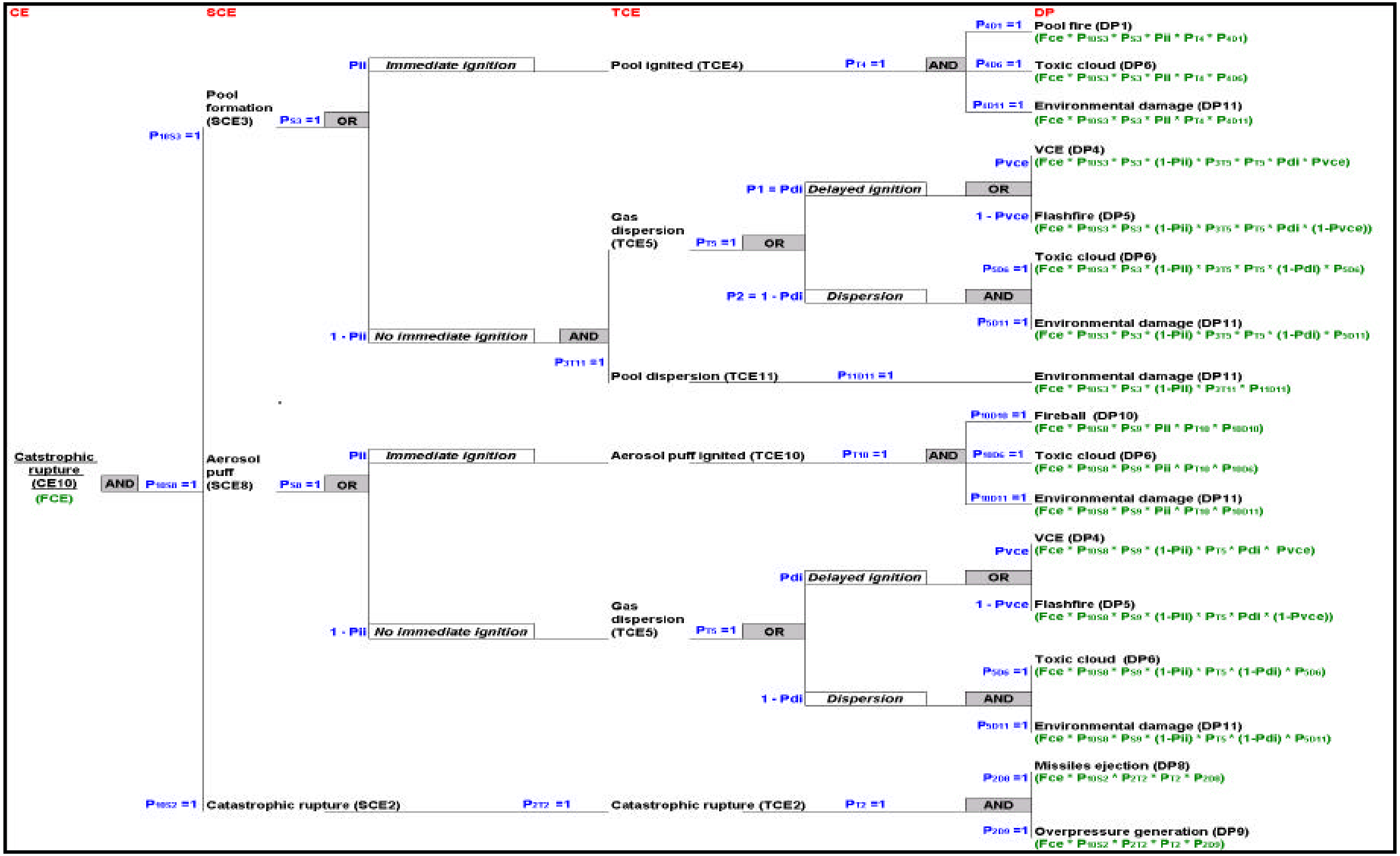


Figure 14: Event tree of "CE10 Catastrophic rupture" with a two-phase substanc

7. Substance state = Solid

The table below gives the critical events associated to the substance state "SOLID"

		CE 1 Decomposition	CE 2 Explosion	CE 3 Materials set in motion (entrainment by air)	CE 4 Materials set in motion (entrainment by a liquid)	CE 5 Start of a fire (LPI)	CE 6 Breach on the shell in vapour phase	CE 7 Breach on the shell in liquid phase	CE 8 Leak from liquid pipe	CE 9 Leak from gas pipe	CE 10 Catastrophic rupture	CE 11 Vessel collapse	CE 12 Collapse of the roof
Solid	STAT1	X	X	X	X	X	X			X	X		

7.1 CE1: Decomposition

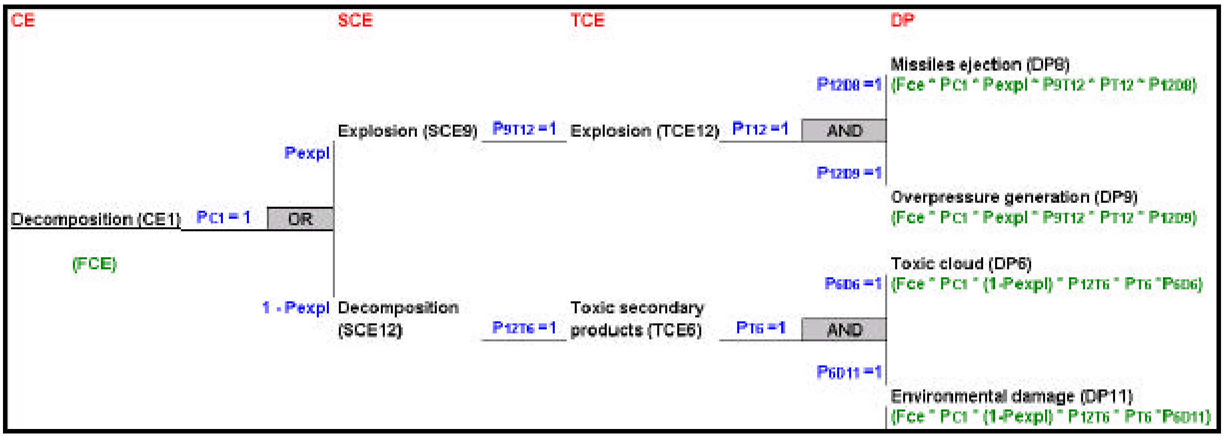


Figure 15: Event tree of "CE1 Decomposition" with a solid substance

In Figure 15, if there are no safety barriers, the necessary data to know for the calculation of frequencies of dangerous phenomena are:

- The probability of explosion, probability to have an explosive decomposition, Pexpl

The other probabilities are equal to 1.

7.2 CE2: Explosion

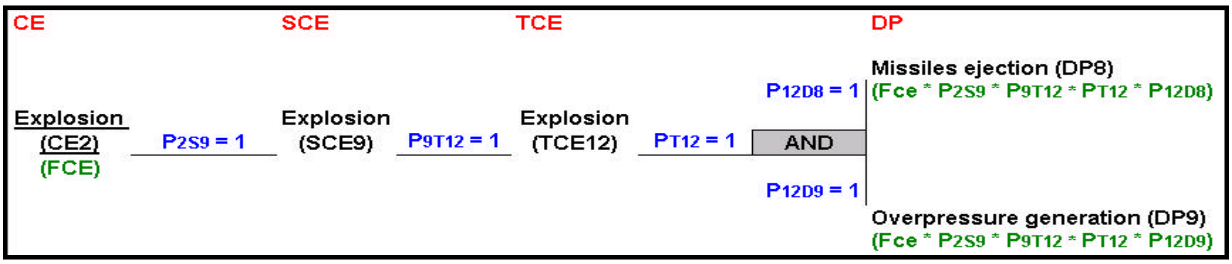


Figure 16: Event tree of "CE2 Explosion" with a solid substance

If there are no safety barriers, the frequencies of dangerous phenomena are known if the frequency of the critical event "Explosion" for a Mass Solid Storage is known.

7.3 CE3: Materials set ın motion (entrainment by air)

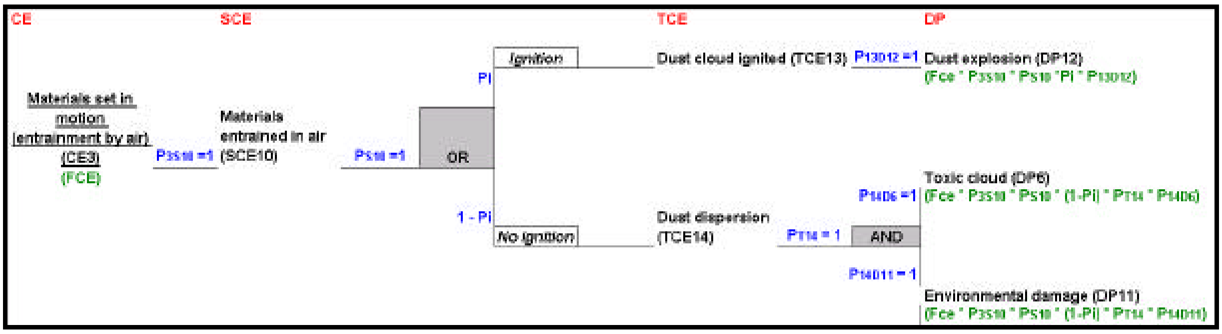


Figure 17: Event tree of "CE3 Materials set in motion (entrainment by air) with a solid substance

In Figure 17, if there are no safety barriers, the necessary data to know for the calculation of frequencies of dangerous phenomena are:

- The probability of ignition of a dust cloud, Pi

The other probabilities are equal to 1.

7.4 CE4: Materials set in motion (entrainment by a liquid)

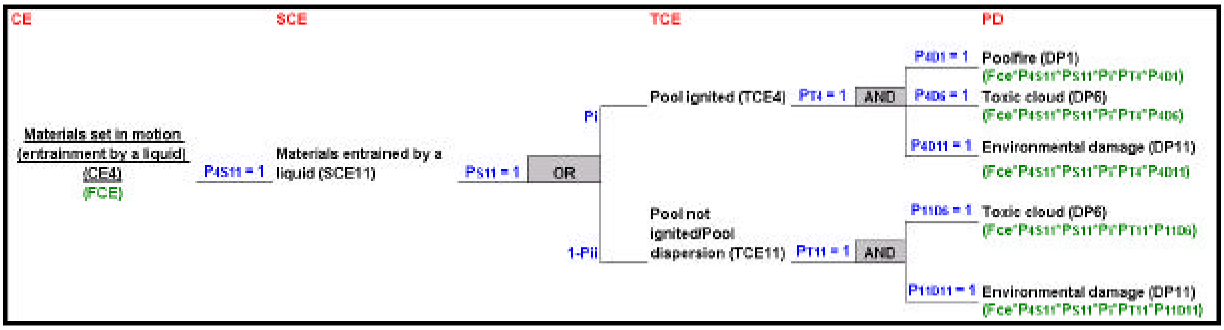


Figure 18: Event tree of "CE3 Materials set in motion (entrainment by a liquid) with a solid substance

In Figure 18, if there are no safety barriers, the necessary data to know for the calculation of frequencies of dangerous phenomena are:

- The probability of ignition of the pool dispersion, Pi

The other probabilities are equal to 1.

7.5 CE5: Start of fire

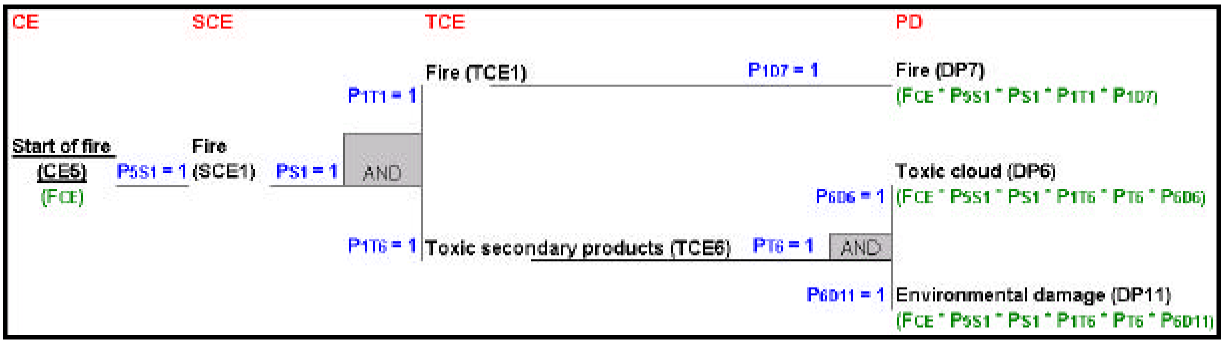


Figure 19: Event tree of "CE5 Start of fire" with a solid substance

In Figure 19, if there are no safety barriers, the frequencies of dangerous phenomena are known if the frequency of the critical event "Start of fire" is known for the given equipment type.

7.6 CE6: Breach on the shell in vapour phase; CE9: Leak from gas pipe

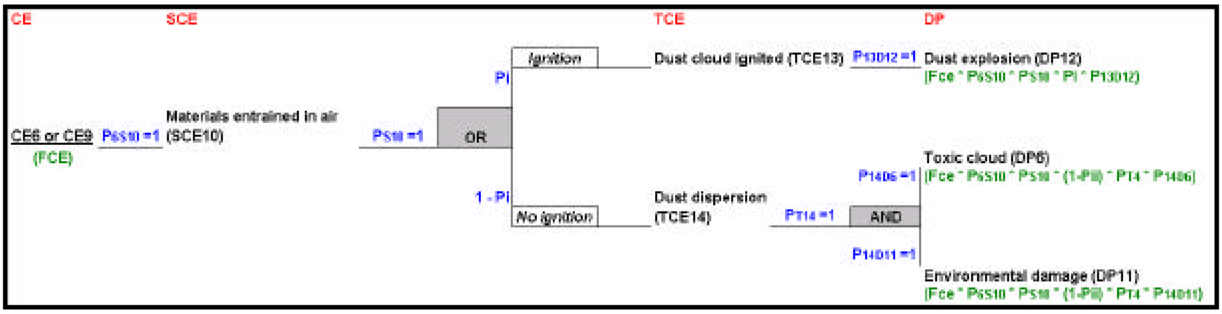


Figure 20: Event tree of CE6 or CE9 with a solid substance

In Figure 20, if there are no safety barriers, the necessary data to know for the calculation of frequencies of dangerous phenomena are:

- The probability of ignition of a dust cloud, Pi

The other probabilities are equal to 1.

7.7 CE10: Catastrophic rupture

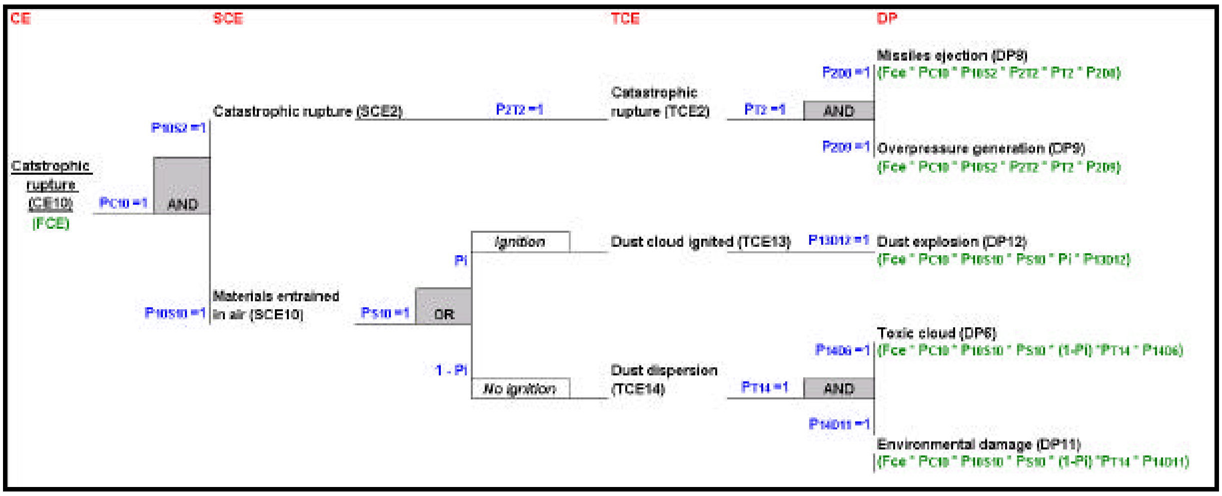


Figure 21: Event tree of "CE10 Catastrophic rupture" with a solid substance

In Figure 21, if there are no safety barriers, the necessary data to know for the calculation of frequencies of dangerous phenomena are:

- The probability of ignition of a dust cloud, Pi

The other probabilities are equal to 1.