

CRITERIA FOR THE FREQUENCY AND MAGNITUDE EVALUATION OF DOMINO EFFECTS

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With the term "Domino Effect" it is assumed the mechanism of propagation of a primary accident scenario (due to heating, overpressure, etc.), generating secondary scenario on other vessels, with a potential increase of damage areas. The secondary scenario could be similar to the primary for type or extension of the effects, or it could produce different events.

For example:

- a Jet-Fire of flammable gas can involve and damage another vessel, containing flammable gas, with the generation of a secondary Jet-Fire;
- a Pool-Fire can involve a vessel containing toxic products causing a toxic substance dispersion.

In order to understand problems correlated with possible domino effects, a study of different types of accident scenarios was implemented, to establish a methodology that allow the definition of frequency and magnitude of secondary scenarios, due to primary event.

The first step is to define fundamental parameters to understand if a vessel, involved in the effects of an accident, can be severely damaged and loss its mechanical properties.

These parameters, which depend directly from the distance of the considered vessel from the centre of the primary scenario, are:

- possibility of involvement of the vessel (in terms of event frequency);
- type of effects of involvement (heat radiation, overpressure, etc.);
- exposure time to the effects;
- presence of protection systems.

These parameters can establish if the vessel can be damaged and the probability of the secondary scenario.

It is also possible to find out "exclusion criteria" in order to exclude the possibility of damage of a vessel.

If it is found that the damage probability of the vessel is not negligible (frequency of the secondary scenario higher than $1 \cdot 10^{-6}$ occ/year), it is necessary to consider other fundamental parameters:

- critical parts of the vessel;
- operation to avoid the damage of the vessel (depressurization, intervention of the fire fighting system on the primary scenario, cooling of the involved vessel, etc.);
- type of damage;
- magnitude of the damage;
- type and magnitude of the consequences of the secondary scenario.

If a secondary scenario and relevant consequences can occur, it is possible to design prevention and protection systems to reduce the risk of damage, for example:

- fast intervention systems for extinguishment of the primary scenario;
- displacement of the dangerous product from involved vessels;
- protection of involved vessel (protection, fire proofing, cooling, etc.);
- intervention of emergency team.

The above mentioned methodology has been applied to many Italian plant (Chemical, Petrochemical and Refineries); we defined:

- possible evolution of scenarios due to domino effect, considering available protection;
- probability of domino effects;
- magnitude of domino effects.

It is possible to conclude that:

- accident scenarios can generate, for domino effect, other different type scenarios;
- even if the type of secondary scenario is different from the primary, in most cases secondary scenarios increase marginally damage areas, without avoiding possibility of intervention of operative personnel and/or emergency team;
- in most cases, the second release increase the depressurization process or increase the vacuum grade of vessels included between the same block valves.

INTRODUCTION

In Italy the interest of Public authorities on "domino effects" is growing, particularly while preparing Territorial Integrated Contingency Plans. The real origin of Domino Effect should be searched in correct process and plant design: in facts a correct design should involve in each phase a detailed Risk Analysis to:

- identify the possibility of severe accidents and subsequent domino effects, and then
- design control system, technical or procedural solutions, hardware protections and so on to prevent the Domino Effect.

A correct risk analysis has to:

1. evaluate all initiator causes;
2. identify all preventive actions to interrupt the accident sequences (alarms, block systems);
3. introduce a first protection level to reduce the released quantity and therefore reduce the magnitude of the primary scenario (for example valves at the bottom of columns and vessels, quick depressurisation systems, displacement of fluids in other vessels or

tanks) in combination with fast detection systems to reveal immediately the leakage (gas, fire and smoke detection);

4. introduce a second protective level or hardware protection systems, which can contrast the effects of the accident in order to avoid the domino effects, such as:
   - fire fighting systems (water, foams,);
   - fireproofing of structures and vessels, steel barriers, double wall pipelines, and so on;
   - concrete bunker or protection walls;
   - water barriers for the dilution of vapours or for protection from heat radiation;
   - use of floating foam;
   - dikes or basins;
   - curbs and efficient drains;
5. revision of the layout after analysis results and evaluation of the vulnerable sites (control rooms, offices, houses and so on) to verify if it is needed to protect them (for example control rooms protected from explosion, fire resistant building);
6. planning the intervention of emergency team, as last protective level, in order to prevent domino effects.

Therefore the possible quantification in terms of frequency and magnitude of the domino effect is the evaluation of an event, which could happen only in case of failure of prevention, protection, control, reduction and intervention Systems.

The procedures usually adopted in the risk analysis already contain criteria and information necessary also to the quantification of the domino effects. Therefore our aim is not to establish a new methodology, but to use consolidated criteria for a particular application.

GUIDE LINES AND REFERENCE NORMATIVES

The Italian Legislation, starting from 1994, began to evaluate domino effects suggesting some criteria, in terms of thresholds to consider.

In particular the first document is the Guide Lines of Civil Protection, "Planning of external emergency for industrial plants subject to important accident risk, GUIDE LINES", January 1994. The reported values are shown in Table 1.

Domino effects from fire scenarios, as reported in Table 1, have to be evaluated according to time exposure. Below the value of threshold of 12,5 kW/m^2 no significant effect is expected.

Similar values of domino effects thresholds are reported in other documents of Italian Legislation concerning the evaluation and analysis of the Safety Reports:

- Ministerial Decree (Environment) 15 May 1996, "Analysis criteria and evaluation of the Safety Reports concerning gas and liquefied petroleum (LPG) storages".
- Ministerial Decree (Environment) 20 October 1998, "Analysis criteria and evaluation of the Safety Reports concerning flammable and/or toxic liquids storages.

Thresholds reported in the two Decrees are similar, and are shown in Table 2.

Table 1. Criteria for domino effects "Planning of external emergency for industrial plants subject to major accident risk, GUIDE LINES", January 1994

Phenomenon	Description	Threshold
Explosion/ UVCE	The value of threshold of 0,3 bar can be considered in order to evaluate material damages due to a possible direct domino effect. This value is relevant for possible damages to heavy structures, process vessels, tanks and piping.	0,3 bar
BLEVE	Typical distances within which the projection of most fragments of significant dimensions can be considered in order to evaluate material damages due to a possible direct domino effect. Those values are equal to 100 meters in case of bottling units and relative storage, 500 meters for spherical tanks and 800 meters for cylindrical tanks.	100 m 500 m 800 m
Fires	The value of threshold of 12,5 kW/m^2 can be considered in order to evaluate material damages due to a possible direct domino effect. This value is relevant to the possible atmospheric tanks damage of the atmospheric tanks or thermal collapse for pressurized tanks, if subject at long exposure.	12,5 kW/m^2

Italian Legislation gives only some suggestion about methodology, but lets the Risk Analyst deepen studies in each case.

EFFECTS QUANTIFICATION

Below are reported some considerations in order to explain how to determine the frequency of domino effects and the possibility of damage.

HEAT RADIATION FROM FIRES

As base reference we remind that the solar heat radiation, in a summer day, can reach intensity between 1 and 1,5 kW/m^2. In order to understand the intensity of heat radiation equal to 12,5 kW/m^2, we can consider the exposure of an iron plate (surface 1 m^2; thickness 0,02 m, similar to the process vessels or tanks thickness). It is assumed that specific heat is equal to 0,5 kJ/(K kg) and it is assumed also that all irradiated heat is absorbed by the plate. In order to achieve an increase of temperature equal to 150°C, with the above assumed data, it is necessary an exposure time of 15 minutes. This calculation does not

Table 2. Ministry Decree 15 May 1996 and Ministry Decree 20 October 1998

Phenomenon	Notes	Threshold
Explosion/ UVCE	The threshold value reported for the possible lethal effects is relevant not only to the direct lethality, due to the collision wave as such (0,6 bar), but also to the indirect lethality, due to falls, projections and impact of fragments and especially, collapse of buildings (0,3 bar). The limits for irreversible and reversible lesions are essentially correlated to the distances which glasses rupture and projection of a significant number of fragments, also light, due to collision wave. The threshold (0,3 bar) value is fixed to consider the average distance of projection of fragments or objects that can damage tanks, vessels and piping due to domino effects.	0,6 (0,3) bar
BLEVE	100 meters from bottle storage, 600 meters for spherical tanks and 800 meters for cylindrical tanks.	100 m 600 m 800 m
Fires		12,5 kW/m^2

consider the fraction of reflected heat and the amount of exchanged heat with the environment and the products inside vessel.

HEAT RADIATION FROM FIREBALLS

In case of the fireball the calculation is simple. Exposure of the plate for two minutes (maximum fireball duration) to 350 kj/m^2 emitted from the fireball causes a temperature increase lower than 5°C, involving no domino effect.

OVERPRESSURE FROM EXPLOSION

Some overpressure values and relevant potential damages are shown in Table 3.

PRELIMINARY CONSIDERATIONS FOR DOMINO EFFECTS

POOL FIRE

This is probably the most representative event for the study of domino effects, as exposure of metal items to fire (engulfed or near flames) can result in severe damage.

In both cases (object in contact with flames or irradiated) the heat transmission and the consequent effects show significant differences.

Table 3. Overpressure values and relevant potential damages[1]

Overpressure effects on plant components	Overpressure (atm)	Effects
Boiler	0.14	Brick cracking
Boiler	0.17	Displacement of the unit and piping rupture
Boiler	0.34	The unit is upset or destroyed
Extraction column	0.44	Displacement of the unit and piping rupture
Extraction column	0.68	Displacement of the unit and piping rupture
Extraction column	0.82	The unit is upset or destroyed
Splitter column	0.37	Deformation of the structure
Splitter column	0.48	The unit is upset or destroyed
Filter	0.14	Damage caused by projection of fragments
Filter	0.65	Displacement of the unit from foundations
Filter	0.82	The unity is upset or destroyed
Electric engine	0.34	Damage caused by projection of fragments
Electric engine	0.61	Displacement of the unit and piping rupture
Electric engine	1.50	Displacement of the unit from foundations
Pump	0.82	Displacement of the unit and piping rupture
Pump	1.90	Displacement of the unit from foundations
Chemical reactor	0.14	Windows and gauges rupture
Chemical reactor	0.27	Displacement of the unit and piping rupture
Chemical reactor	0.44	Deformation of the structure
Chemical reactor	0.61	The unity is upset or destroyed
Horizontal pressurized vessel	0.41	Deformation of the structure
Horizontal pressurized vessel	0.41	Displacement of the unit and piping rupture
Horizontal pressurized vessel	0.41	The unit is upset or destroyed
Vertical pressurized vessel	0.82	Displacement of the unit and piping rupture
Vertical pressurized vessel	0.95	The unity is upset or destroyed
Heat regenerator	0.20	Displacement of the unit and piping rupture
Heat regenerator	0.34	Displacement of the unit and piping rupture
Heat regenerator	0.34	Deformation of the structure
Heat regenerator	0.51	The unit is upset or destroyed
Heat exchanger	0.51	Displacement of the unit and piping rupture
Heat exchanger	0.61	The unit is upset or destroyed
Conic roof tank	0.70	Collapse of the roof
Conic roof tank	0.20	Unit raising (filled 0.5)
Conic roof tank	0.44	Unit raising (filled 0.9)
Floating roof tank	0.20	Unit raising (filled 0.5)
Floating roof tank	0.44	Unit raising (filled 0.9)

(*Continued*)

Table 3. *Continued*

Overpressure effects on plant components	Overpressure (atm)	Effects
Floating roof tank	1.36	Collapse of the roof
Spherical tank	0.54	Displacement of the unit and piping rupture
Spherical tank	0.95	Displacement of the unit and piping rupture
Spherical tank	1.90	The unit is upset or destroyed
Auxiliary instruments: gas meter	0.31	Coating damages
Auxiliary instruments: gas control	0.41	Displacement of the unit and piping rupture
Auxiliary instruments: gas control	0.68	Control systems damage
Auxiliary instruments: gas control	0.68	Coating damage
Auxiliary instruments: trasf.	0.31	Damage caused by projection of fragments
Auxiliary instruments: trasf.	0.51	Displacement of the unit and piping rupture
Auxiliary instruments: trasf.	0.68	The unit is upset or destroyed
Pipe racks	0.24	Deformation of the structure
Pipe racks	0.41	Piping rupture
Pipe racks	0.41	Collapse of the structure
Cooling tower	0.30	Ventilation grates fall between 0.204–0.340 atm
Cooling tower	0.14	Internals damages
Cooling tower	0.24	Collapse of the structure
Steam Turbine	0.82	Control systems damage
Steam Turbine	0.95	Piping rupture
Steam Turbine	1.36	Displacement of the unit from foundations
Air Fin	0.34	Coating damage
Air Fin	0.68	The unit is upset or destroyed

JET FIRE

Geometry is an important parameter of this scenario.

Heat radiation from Jet Fire, that has limited spatial extension, decreases rapidly with distance. Hence, only objects in contact with flame can be damaged.

FLASH FIRE

The short duration of the scenario is the determinant characteristic. Heat radiation due to a Flash Fire scenario can't damage metallic structures or process vessels.

If other inflammable materials are exposed to the Flash Fire, an extension of the fire can be generated.

Accidents can be caused if a Flash-Fire scenario occurs, while a easy flammable liquid release is included in the damage area.

This scenario is not considered in domino effects analysis, because it is assumed that there is no presence of other flammable materials near process vessels containing dangerous products, according to good housekeeping practice and the probability to find a flammable liquid release, included in the damage area of a Flash Fire scenario, is very low.

FIREBALL

The Fireball is a event with a thermic radiation variable in the time and the duration is included between 10 and 40 seconds (considering the amount of flammable substance).

Normally the thermal flux of a Fireball is expressed as kJ/m^2 and considering the duration of the scenario, it is possible evaluate the radiation expressed in kW/m^2.

Although the thermal radiation of a Fireball can be higher than 12,5 kW/m^2 (minimum threshold of Pool Fire Scenarios), because of its short duration it is not probable that damage to structures and vessels involved in the Fireball can be caused.

So as Flash Fire considerations, Fireball scenario is not considered in domino effects analysis, because it is assumed that there is no presence of other flammable materials near process vessels containing dangerous products, according to good housekeeping practice and the probability to find a flammable liquid release, included in the damage area of a Fireball scenario, is very low.

BLEVE (FRAGMENTS PROJECTION)

The possibility of projection of fragments is the major risk of this accident scenario. The Italian Legislation only defines standard distances, considering different typology of vessel and amount of dangerous product. In order to realize a correct risk analysis, a lot of parameters could be considered: for example the amount of involved product and the vessel geometry. It is known that spheres of big dimensions generate few fragments of big dimensions that are thrown to short distance, while long horizontal cylinders can reach relevant distances, due to missing of one of the caps.

The greater risk is the possibility of generation of fragments of small dimensions, with high kinetic energy. Also in this case it is important to estimate the real possibility for fragments to meet process vessels, tanks or metallic structures.

The problem is complex and it can't be solved only defining a limited number of parameters as a Pool Fire scenario (heat radiation and exposure time). A specific analysis is necessary for each case, and will not be analyzed in this paper.

U.V.C.E. (UNCONFINED VAPOUR CLOUD EXPLOSION)

Overpressure waves generation is the principal characteristic of this scenario, which can involve other vessels or structure inside the plant.

It is important define that overpressure waves higher than 1 bar can't be generated by products of Petroleum Industry.

Overpressure values generated by UVCE decrease quickly with distance and in most of the cases values equal to 0.3 ÷ 0.6 bar are reached in the immediate nearness of the centre of scenario.

As shown in table 3, the effects of overpressure waves equal to 0,3 ÷ 0,6 do not cause destruction or severe damage of the equipment, but only little dislocation and damages to structures or connected piping.

Hydrogen can generate overpressure waves higher than 1 bar. It is important to define that if a Hydrogen release occurs from a pipe or vessel, a Jet-Fire is generated, because of immediate ignition.

Hydrogen explosions can occur in battery production sites and electrolytic cells for example, if Hydrogen is confined and a source of ignition is present.

Dispersion of toxic products

In this study only direct effects to the things are considered. In case of release of toxic products the risk of a dangerous situation can increase if personnel is involved during other operations, as for example control filling of a tank lorry.

This particular type of effect is not considered in the study, because some aspects could contemporary occur.

First fundamental criteria for domino effect analysis are reported in table 4.

EXCLUSION CRITERIA

Exclusion criteria are identified in domino effects analysis, in order to distinguish accident scenarios negligible (in term of frequency and probability) from believable scenarios.

Table 4. Fundamental criteria for domino effect analysis

Event	Possibility of domino effects
POOL FIRE	Yes due to heat radiation > 12.5 kW/m^2
JET FIRE	Yes inside the Jet Fire
FLASH FIRE	NOT
FIREBALL	NOT (only possible ignition of flammable materials)
BLEVE (projection of fragments)	Yes specific study for each case
U.V.C.E. (Unconfined Vapour Cloud Explosion)	Yes overpressure > 0.3 bar
Dispersion of toxic products	Excluded

As general rule, frequency and probability of accident scenarios are evaluated with risk analysis criteria. In particular, TRR S.r.l. considers events with a frequency higher than $1 \cdot 10^{-6}$ occ/year not negligible and no further considerations are implemented for events with a frequency lower than $1 \cdot 10^{-6}$ occ/year.

POOL FIRE

As described in the previous chapters, an increase of metallic slab temperature equal to 150°C it is necessary an exposure time of 15 minutes.

In a conservative way, the following exclusion criteria are considered in Domino Effects analysis:

– time of exposure <5 min and vessels inside of flames → Domino effect Probability = 0;
– time of exposure <10 min and heat radiated vessels → Domino effect Probability = 0.

JET FIRE

Jet Fire scenarios occurring at the top of columns or high vessels are not considered in Domino Effect analysis, because it is assumed that Jet Fire can damage no objects.

EVALUATION OF DOMINO EFFECTS FREQUENCY

Probability of domino effects is defined using illustrated criteria reported in table 5.

A further criterion for Jet Fire is added, as shown in table 6.

Monitor number to consider for evaluation of probability of fire fighting systems failure (see note n.3 of previous table) is calculated taking into account monitors so far 40 m from centre of emergency (release point) and outside 12.5 kW/m^2 heat radiation circle.

EFFECTS EVALUATION

If a "secondary" scenario is defined not negligible (in terms of frequency and probability, considering previous criteria), evaluation of relevant effects can be implemented.

The following criteria are used in order to define "secondary" scenario effects.

POOL FIRE

Intervention times are estimated for "primary" scenario. These times are equals to pool fire duration, for not confined pool fire; in fact the released product wets the land surface and it reaches the condition, which the released flow is equal to the consumed flow during combustion.

Table 5. Specific criteria for domino effects due to overpressure and heat radiation scenarios

Domino effects criteria			
Scenario	Primary effect		Domino effect probability[1]
Overpressure	Pressure tanks and piping + Overpressure	$P \geq 1$ bar	1
		0.3 bar $\leq P <$ 1 bar	observation (A)
	Atmospheric tanks + Overpressure	$P \geq 0.6$ bar	1
		0.3 bar $\leq P <$ 0.6 bar	observation (A)
	$P <$ 0.3 bar		0
Heat Radiation	Object inside flames + Exposure time	$T \leq 5$ min	0
		5 min $< T \leq$ 10 min	0,5
		$T >$ 10 min	1
	Heat radiation $>$ 37.5 kW/m^2 + Exposure time	$T \leq$ 10 min	0[2]
		$T >$ 10 min (atm. tanks)	1[3]
		$T >$ 10 min (Pressure tanks and piping)	0,5[3]
		$T \geq$ 20 min	1[3]
	12,5 kW/m^2 $<$ Heat rad. $<$37,5 kW/m^2 + Exposure time	$T \leq$ 10 min	0[2]
		10 min $< T <$ 20 min	observation (B)
		$T \geq$ 20 min	observation (C)
	Heat radiation $<$ 12,5 kW/m^2		0[2]

Obs.: (A) Linear interpolation of probability between respective max and min values of probability.
(B) Linear interpolation of probability between 0 and 0.5.
(C) Linear interpolation of probability between 0 and 1.
[1]It is the probability of involvement of a "secondary" scenario due to damages to structures, vessels caused by a "primary" scenario.
[2]For exception of ignition of flammable materials involved by primary scenario (for example plastic panels, fiber glass piping and tanks).
[3]If automatic or manual fire fighting systems are present in the plant and P is the probability of their failure, domino effect probability is multiplied for P. If passive protection systems (fine proofing, fire walls) are present in the plant, domino effect probability is negligible considering time of exposure of structures and process vessels. If probability of systems failure P is unknown, values of 0.01 (for passive or automatic systems) or 0.1 for manual systems are assumed.

Involved vessels in the fire (inside flames or heat radiated) increase their temperature and flanges and stacks of are the first critical heated components.

A severe failure of coupling flanges (bolt dilation) is assumed for secondary scenario effects evaluation; the quickly emptying of the vessel is assumed also due to the failure.

Table 6. Specific criteria for domino effect due to Jet Fire scenario

Scenario	Primary effect	Domino effect probability
JET FIRE	Jet lenght + Direction	observation (4)

OBS.: (4) Probability calculation is implemented considering the ratio between surface of visible object to damage and semi-sphere surface, with the same centre and radius equal to jet length.

As consequence of the release, the damage areas of primary Pool Fire can increase (if the involved vessel contains flammable products) or toxic products dispersion can be generated.

An isolation of involved vessels in heat radiation is assumed for domino effects analysis, because a long exposure times for domino effects is necessary (temperature increase equal to 150°C of the metal of involved vessel).

As consequence, no additional intervention times are considered in the study for isolation of the damaged vessels.

Maximum amount of released fluid, due to secondary scenario is the vessel hold-up, with assumed above criteria.

An instantaneous release is assumed in order to maximize the domino effects and the following criteria are considered:

– if involved vessels hold-up is lower than source vessel hold-up, secondary scenario effects are assumed similar to first scenario; a translation of damage areas from the primary scenario to secondary is considered;
– if involved vessels hold-up is higher than source vessel hold-up, an unconfined pool is assumed (thickness equal to 5 mm for LPG release and 1 cm for the other products are typical values for low roughness areas by literature and used calculation models) with new damage areas if ignition can occur. Those criteria are conservative and heat radiation is calculated in stationary conditions, not considering the limited duration of the phenomenon.

U.V.C.E.

A quickly emptying of the involved vessels is assumed, due to the overpressure waves generated. Vessel and relevant stacks are considered critical components, involved by caused stress and movements.

Release consequences can be the following:

– Pool Fire generation (if involved vessels contain flammable liquids);
– Jet Fire generation, due to top of the column failure and ignition of released vapours (the considered amount is equal to 110%, taking in account the hold-up included in connected piping);
– toxic product dispersion (if not negligible quantity present in the involved vessels).

JET FIRE
It is assumed an increase of metallic material temperature equal to 400°C, due to involvement of the vessel by Jet Fire scenario. As consequence, a localized failure can occur, due to the material overheating.

A quickly emptying of the involved vessel is assumed, in order to maximize the domino effects.

APPLICATIONS

The described methodology was already applied by TRR S.r.l. to various activities on the Italian territory, as illustrated here below:

Industrial Site in S.Martino di Trecate
Industrial Site in Brindisi
Industrial Site in Viggiano
Industrial Site in Terni
Industrial Site in Augusta/Priolo

APPLICATION AT A REFINERY

The above criteria for domino effects were applied at large Italian Refinery.

Thirty-six accident scenarios have been defined with a possible domino effects and n.9 of them involved process vessels. More than 300 accident scenarios were identified in the Safety Report.

Table 7 show consequences of primary and secondary scenarios (POOL FIRE) for an analyzed case.

Table 7. Example of domino effects analysis

Domino effects analysis results						
Item	Primary scenario	Frequency [occ/year]	Involved vessels[(1)]	Domino effects frequency [occ/year]	Secondary scenario	Damage distances (m) for heat radiation 12,5 kW/m^2
ColumnT8	POOL FIRE	$9{,}5 \cdot 10^{-5}$	E24	$4{,}7 \cdot 10^{-6}$	POOL FIRE	44
			T6	$5{,}9 \cdot 10^{-6}$		44
			T7	$4{,}7 \cdot 10^{-6}$		16
			E7	$4{,}7 \cdot 10^{-6}$		16

[1]Involved objects considered not negligible for domino effects, due to amount of dangerous products, chemical physical data, protection systems and distance from the fire.

CONCLUSIONS

The described methodology allows:

– possible evolution of scenarios, due to domino effect and available protection to avoid the events;
– probability of domino effects;
– magnitude of domino effects.

It is possible conclude that:

– accident scenarios can generate, for domino effect, other different type scenarios (for example Pool Fire can generate Jet Fire);
– even if type of secondary scenario is different than the primary, in most of the cases secondary scenarios increase marginally the damage areas, without avoiding possibility of a plant intervention and intervention of emergency team;
– for most of the cases, the second release increase the depressurization process or increase the vacuum grade of vessels included between the same block valves.

REFERENCES

1. Ministry of the Interiors (Italy), 1986, SIGEM project, *Communication n.6*, Annex 4.