INDUSTRIAL RISK ANALYSIS OF STORAGE, BOTTLING AND DISTRIBUTION OF LIQUEFIED PETROLEUM GAS

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Abstract: The purpose of this study is to describe the possible major accident scenarios and their probability, as well as the conditions under which they occur in the case of an site that handles, stores, bottles and distributes liquefied petroleum gas.

Keywords: risk, location, storage matrix, assessment, scenario

1. GENERAL CONSIDERATIONS

The study deals with particular aspects of relevant site identification, hazardous substances, identifying the major risks, their qualitative analysis, determining the individual scenarios, quantitative analysis of individual scenarios and highlighting the consequences of their conduct. The conclusions drawn from the analysis are absolutely necessary for developing internal and external emergency plans, as well as for spatial planning, issues that are not detailed in the content of this study. It is noted that all the approaches presented in the study must be an integral part of the safety report promoted by the economic operator.

2. ANALYSIS OF INDIVIDUAL SCENARIOS AND HIGHLIGHTING THE CONSEQUENCES

Selecting the scenarios is done in order to provide data for the intervention on site, for external emergency planning and spatial planning.

2.1. The total destruction of the tank park by terrorist attack or air attack

It is assumed that a terrorist attack or air attack would occur with explosive

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means: explosive charges placed on tanks, remote explosive throwing devices, air attack bomb etc. Such an event would cause damage by tearing the tanks body followed immediately by the explosion of the tanks (BLEVE type).

The probability of occurrence is very low for the air attack, because the objective has no strategic importance, the trigger of such an attack usually requires the existence of a previous conflict (state of war) and therefore the anticipation of such an event, which provides the necessary time to stop the activity, emptying the tanks and transporting the dangerous goods in safe places or a possible evacuation of the population from that area.

The terrorist attack is a very low probability event (even if it's bigger than the air attack), but since it cannot be predicted will surely produce great effects, especially if it consists of a simultaneous explosion in several points of the objective.

2.2. The explosion of a LPG tank

Explosion can be caused at LPG tanks by the formation of explosive gas-air mixtures and the explosions by decompression of the tank and occurrence of BLEVE type over-pressurization.

Formation of explosive mixtures in LPG tanks is possible where tanks are empty, insufficiently cleaned and degassed, especially during the intervention works, in contact with a source of fire or a spark. Such intervention works are performed regularly during interior revisions. The most common sources of ignition are electrostatic discharge through use of protective clothing made of synthetic fibers, sparks caused by ferrous metal tools or accessories, sparks through electrical discharge from tools or lamps in normal construction or defective etc. To avoid such incidents is imperative, before and throughout the conduct of interventions, to make a rigorous explosimetry examination inside the tanks. The probability of occurrence of such explosions depends on the safety measures applied during such interventions.

In case of a tank explosion, it can cause a chain explosion of the tanks (Domino effect). Successive explosion is possible because of the explosive blast with materials throwing and because of the fire (fireball) at the previous tank. These will produce on the nearby tanks, a material weakening by hitting it with great power, increasing the pressure and weakening of the material due to fire and finally cracking the tank, producing a new explosion.

The probability of occurrence is very low, given that the access of large machines that would hit a tank, except the vehicles that are carrying LPG, occurs only in conditions of carrying out large works: replacement or installation of new tanks, when special protective measures are taken. Striking the tanks by lightning is unlikely, because there are massive metal parts in the building, they are protected and in addition there is a lightning protection system that is checked regularly.

The BLEVE type accident explosions history, at LPG tanks and tanker trucks showed that most accidents occurred due to corrosion in the connections area at the top of the vessel.

2.3. The explosion of LPG tanker truck

The explosion of an LPG tanker truck may occur under the same conditions as the explosion of a tank. In addition to the tanks, the tanker trucks during parking for unloading are more vulnerable, being placed outside the site and being exposed either due to wrong maneuvers resulting in tearing or breaking the hoses, either hitting other equipment or vehicles.

However, the likelihood of damage to tanker trucks during unloading or loading, followed by the explosion, remains very small because during the presence of the tanker truck at the ramp, any other activity in the area is forbidden.

2.4. Fire in the storage tanks park

A fire in the storage tanks area is possible through the ignition of some combustible or flammable materials existing in the area. Combustible materials present are normally represented by polystyrene insulation of tanks, the electrical system supply of pumps and automation equipment and vehicles.

The possibility of fire at the electrical installation is very low, this being explosion proof constructed for explosive environments, respecting the regulations in force. A fire at the electrical system may occur due to the use of improvisations or protection system malfunction fuses, protective relays, etc.

The ignition of vehicles can be produced especially by short-circuit at the electrical system. The ignition of the vehicles that are being used has a low probability, because the tanks used for transporting LPG have a special design, complying with ADR rules for the class of products that they are carrying. The risk of fire occurrence at transport tanks is the one assumed at the dangerous goods transport operation, both for vehicles and railway tanks. Possibility to ignite other combustible materials in the area is possible if their storage is in the tanks area. The existence of such materials in the area is forbidden. At the occurrence of combustible materials, for example oil spills from pumps and/or fuels from vehicles equipment, they must be removed immediately, being possible sources of ignition.

Flammable substances that may be present in the LPG tanks area are represented by LPG, a highly flammable product. The ignition of LPG is possible in case of leakage (leaks) and contact with a source of fire, represented by open flames or spark.

LPG leakage can occur through:

- leaks: flanged joints or other connections, glands at pumps and valves, cracks or pores on the equipment or pipeline (including flexible hoses for unloading), defective valves or other fittings;
- actions of unauthorized persons;
- incorrect handling of valves;
- super-pressurizing with triggering the safety valves on the tanks.

Pipeline cracks may occur due to corrosion, high mechanical stress by hitting, snatching for unloading-loading connections (by failing to ensure the tank), vibration through the pump.

Super-pressure of the tanks can occur by:

- heating when involved in a fire, or during the summer at high temperatures and insolation. This phenomenon is more likely in the case of propane which has a higher vapor pressure. Super-pressurizing by heating in an environment is much diminished because of the thermal insulation of tanks;
- over-filling (over 80%) without leaving sufficient space for expansion of vapors;
- not coupling or closing equalization circuit when transfusing from tanker trucks.

Ignition sources can be: unauthorized open fire, short-circuits at the electrical equipment, static electricity, sparks produced by striking with hard objects, sparks from the exhaust of motor vehicles, lightning. A peculiarity of the possibility of gas leaks ignition is that they can light themselves up from remote ignition sources, even outside the objective, in the dispersion area of a gas in concentrations above the flammability limit. Since the gases are accumulating in closed spaces, the ignition will be with explosion.

The probability of LPG leakage occurrence is medium, they may be present in small amounts, especially in coupling nozzles at the tanker trucks and at pumps glands. The probability of leakage ignition is reduced given that the leaks may be present, especially during loading and unloading the tanks, when any other activity is stopped, unloading-loading routes are controlled regarding the leaks, are being taken measures for discharging the electrostatic charges. Also, the exhaust of the tanker trucks is explosion proof constructed, there is a lightning protection system, is used the intervention and explosion protection equipment, electrical installations are explosion proof, open fire in the tanks area is allowed in very special circumstances, by taking all the safety measures. Leakage ignition is possible by not complying with one of the protective measures mentioned.

2.5. Leakage of LPG at the storage tanks

LPG leak in the storage tanks area is dangerous because of its potential to cause fire and staff intoxication. Intoxication of the staff surprised by gas leaking is possible especially if there are interventions made without taking the necessary safety measures. Due to placing the tanks outdoors, it’s considered that an accident resulting in staff intoxication cannot lead in normal circumstances to death and thus causing a major accident.

2.6. Explosion in the bottling hall

An explosion in the bottling hall can occur where there is a LPG leak, forming an explosive atmosphere, in contact with a source of fire or spark. The explosion of a mixture, within the explosive limits, gas-air in a confined space (constrained) is CVE type, “Confined Vapor cloud Explosion“, vapor explosion in a confined space.

Leakage of LPG in the bottling hall can occur by:

- leaks in the flanged joints of other types of joints of the bottling plant;
- cracks due corrosion or high mechanical stress;
- defects to valves or other closures at tank or filling facility;
- action of unauthorized persons;
- incorrect handling.

Sources of ignition include: short-circuit on electrical systems, electrostatic discharge, sparks produced by striking with hard objects, sparks from normal or defective electrical equipment.

The possibility of producing LPG leakage at the bottling hall and subsequent to ignition with explosion is reduced, taking into account that:

- there are continuous detection of gas leakage sensors in the hall;
- the hall is equipped with a ventilation system that prevents the accumulation of gas and formation of explosive mixtures;
- during bottling, there are taken specific safety measures for hazardous environments: forbidding the unauthorized access, periodically tested and trained operating personnel, use of anti-sparking tools and equipment, explosion proof electrical equipment, completely forbidding the use of open fire etc.

Power of explosion depends on the quantity of LPG existing inside the hall. A major explosion in the bottling hall could damage the storage tanks and finally it could lead to their chain explosion (Domino effect). The present tanks involved in the explosion of the hall will be damaged and explode themselves. The staff within the objective could be seriously injured, even to death. People caught close to the objective can be injured seriously. Seismic waves and sound will cause panic among the surrounding population.

2.7. Leakage of LPG in the bottling hall

LPG leaks are dangerous because they can cause fire or explosion and can intoxicate the operating personnel. Serious intoxication of the operating personnel that would lead to a major accident can only occur if there’s a leak inside the hall of a very big quantity of LPG (much above the explosion limit) and a lack of exhaust ventilation. Intoxication can occur in case of high local concentrations of LPG, for example if the staff is surprised (possibly immobilized by accident) by a jet of pressurized gas.

Probability of massive leaks of LPG in the bottling hall is very low.

2.8. Fire in the bottling hall

A fire in the bottling hall can be produced by ignition of LPG leaks. If LPG leakages are in the form of a pressurized gas jet it will cause a jet of fire (jet fire). The power of the jet depends on the pressure of the gas and the surface to be discharged. The size of the affected area is limited in the first instance to the size of the hall, the jet being stopped and turned to the wall. The possibility of LPG leak ignition has been dealt with in the previous scenarios. The probability of fire in the bottling hall is low, but higher than in the tanks area, mainly due to the large number of manual maneuvers to be made at the filling heads.

2.9. Explosion in the hall‘s tank testing and painting area

An explosion in the hall‘s tanks testing and painting area may occur if there‘s an accumulation of large quantities of LPG, which ensure the existence of an explosive gas-air mixture within the explosive limits, or by the explosion of a tank during test operations. The accumulation of a quantity of LPG that would cause an explosion may occur in case of repeated leaks of LPG from the tanks that weren‘t emptied enough.

The accumulation of a quantity of LPG that would cause an explosion may occur in case of repeated leaks of LPG from the tanks that weren‘t emptied enough. The probability of such accumulations followed by the explosion is very low due to prior emptying of cylinders before testing.

The explosion of a cylinder during the test operation is possible by forming an explosive mixture inside the cylinder (i.e. in the case of internal verification or preparation for disposal), in contact with a source of fire or spark. Sources of ignition may be lighting equipment, cleaning tools, etc.

The possibility of producing an explosion in the testing and painting hall is reduced if there’s a proper emptying and cleaning of cylinders before performing these operations.

2.10. LPG leaks in the repair shop

LPG leaks in the repair shop can occur if repairs are being made especially at the filled LPG cylinders, for example when changing faulty valves after filling. Also, there may be minor leaks at the cylinders that were brought for repairing that were poorly drained. Leaks are dangerous because they can cause fire and explosions later. In case of massive leakage the operating personnel can be severely intoxicated. Likelihood of massive leakages that would cause a major accident in the repair shop is extremely low due to the small number of filled cylinders that are being handled and training of operating personnel that performs such operations.

2.11. Fire in the repair shop

A fire in the repair shop may occur in the case of ignition of existing combustible and flammable materials. Combustible materials are maintenance materials, furniture, wiring, lubricants that, although they exist in small amounts, can be a source of fire.

Flammable products are represented by the possible leakage of LPG from the cylinders that are being brought to the repair shop.

Ignition sources may be short-circuits on the electrical system, sparks caused by electrostatic discharge, especially from the equipment that is used, sparks caused by improper tools and devices.

2.12. Explosion in the repair shop

An explosion of repair can occur if there's an accumulation of a quantity of LPG, which ensure the existence of an explosive gas-air mixture within the explosive limits in contact with a source of fire or spark, or the explosion of a cylinder during the repairing operation. The accumulation of a quantity of LPG that would form an explosive atmosphere in the repair shop can occur when handling filled cylinders with LPG leakage and degassing of LPG cylinders that were insufficient emptied. Probability of occurrence is low due to the very low frequency of leaking cylinders and the extremely low period of time for this operation.

The explosion of a cylinder during the repair operations is possible by forming an explosive mixture inside the cylinder (e.g. when changing gaskets, valves, rectification of threads etc.) in contact with a source of fire or spark. Sources of ignition may be lighting equipment, tools used in the repairing, etc. The possibility of producing an explosion in the repair shop is reduced if there's a proper emptying and cleaning of cylinders before performing these operations.

An explosion in the repair shop can produce damage in the bottling hall with massive leaks of LPG and possible subsequent fires and explosions (Domino effect).

2.13. The explosion of LPG cylinders

The explosion of LPG cylinders may occur inside the objective during storage and handling operations. A cylinder explosion occurs relatively similar to the explosion of a tank (the major difference lies in the amount of LPG involved): BLEVE type explosion caused by super-pressurization of a LPG leaking.

BLEVE type explosion may occur at pressure cylinders, in case of crack of the cylinder wall due to high mechanical stress: hard hits with hard objects, slamming the cylinders, super-pressurizing by involvement in a prior fire, corrosion, material defects, damage to the valves. In the case of large enough cracks that would cause a rapid depressurization, will occur the BLEVE type explosion.

A feature of the cylinders involved in a fire is that, if they are not sufficiently immobilized, the valve usually fails at super-pressurization producing a rocket effect and then the explosion may take place.

An explosion of a cylinder is very dangerous and can cause damage to neighboring cylinders and their chain explosions. An explosion of cylinders is unlikely because they are subject to checks being under ISCIR regulations and special safety measures existing within the objective, through the specifics of activity conducted.

2.14. Suicide attempt by gassing with LPG

It is highly unlikely due to security and control measures, general security measures of the objective; the staff of the company is subject to psychiatric control, both at employment and periodically.

3. THE RISK ASSESSMENT MATRIX

For a suggestive presentation of conclusions resulted from accidental risks analysis specific for the activity, further is presented the risk quantification matrix, based on possible accident scenarios. For this was proceeded to assigning numerical values for each level of probability of occurrence (P) and the severity of the consequences (G). Associated risk (R) of each scenario is the product between the two assigned values.

Significance of the assigned or calculated values is as follows:

- Probability (P): 1 – unlikely; 2 – less likely; 3 - average probability; 4 - high probability; 5 – most likely.
- Severity (G):

1. minor effects, negligible (work accidents without hospitalization, reduced discomfort produced to population, small damage in the objective, LPG leaks with no effect on personnel, short-term disruption of activity on the objective);
2. moderate short-term effects (work accidents with more than five people hospitalized among the employees, increased discomfort produced to population by stress, limiting the movement, or releasing gas at detectable but non-toxic concentrations, damage in the objective, LPG leaking in large quantities in the objective without reaching outward, medium term activity interruptions of the objective);
3. significant effects on the short or moderate term (employment injury with hospitalization of over five people among the employees and/or for longer than 24 hours, injuring or intoxicating a person outside the objective with hospitalization, preventing automobile and pedestrian traffic, release of gas at toxic concentrations, particularly large damage within the objective and/or minor damage to the goods outside the objective, dangerous leaks of products outside the objective, short-term activity interruption of other objectives, interrupting the drinking water supply services, electricity, gas or telephone on short term);
4. significant effects or significant on long-term (injury or intoxicating one or more persons outside the objective with average term hospitalization, blocking the traffic for a long period of time, particularly important damages within the objective and/or major damages to the goods outside the objective, long term leaks of hazardous products and high concentrations of hazardous substances far beyond quality requirements,

long term activity interruption of other objectives, long term interruption of electricity supply services or telecommunications, damage, causing victims of disaster of moving some people for a short period of time);

5. very serious effects, disasters (deaths, injuring a number of people and hospitalizing them for prolonged periods of time, producing significant damage to public or private goods, halt the company's activities for long periods of time, causing victims of disaster or moving a large number of people for a long period of time).

- Risk:

- under 5 - insignificant risk, in the normal range;
- 5-9 – acceptable risk, needs regular monitoring and implementing a rigorous operating system
- 10-15 – tolerable risk, safety facilities are necessary and equipment for operation and permanent monitoring
- over 16 – high risk, special protection measures and an intervention system and amenities are needed

All faults or events with severity level 4 and 5 present a major accident hazard, and the others represent a potential danger, by the extent of damage to other areas, worsening the situation through failure to eliminate damage on time. In determining the values associated with probability and risk levels was taken into account the existence of management and technical facilities for safety.

Risk matrix is presented in table 1.

Table 1. **Risk assessment matrix**

Scenario no.	Danger	Probability	Severity	Risk
1	The total destruction of the tank park by terrorist or air attack	1	5	5
2	The explosion of a LPG tank	2	5	10
3	The explosion of a LPG tanker truck	2	4	8
4	Ignition in storage tanks park	2	3	6
5	Leakage of LPG at the storage tanks	4	2	8
6	Explosion at the bottling hall	3	4	12
7	Leakage of LPG at the bottling hall	4	2	8
8	Fire at the bottling hall	3	3	9
9	Explosion in the hall‘s tank testing and painting area	1	4	4
10	LPG leaks in the repair shop	2	2	4
11	Fire in the repair shop	1	3	3
12	Explosion in the repair shop	1	4	4
13	Explosion of GPL cylinders	1	4	4
14	Suicide attempt by gassing with LPG	1	4	4

From risk assessment results that the risk of a major accident in the objective is tolerable, requiring a continuous monitoring and a rigorous system of operation.

The highest risk of producing a major accident and fire explosion within the objective is the bottling hall. This is due to the relatively large number of people working in the hall and the large number of manual maneuvers performed. There is in these circumstances the possibility of local accumulation of LPG leaks and their explosion or ignition before being detected by the alarm device. A future upgrade of the bottling system in these conditions is welcomed. A significant risk is represented by the leakage of LPG from the storage tanks due to the lack of a continuous detection system in this area and quantity of LPG leaks (present on the elastic hose) at every filling and unloading of tankers.

The explosion of a LPG tank is also a significant risk, especially because of the seriousness of such an accident. The relatively low risk of explosion of a tank is justified by the low number of people in the area, and a rigorous ISCIR control applied during the inspections at maturity.

Risk of leaks and fires at bottling hall and tanks is equal, in the hall being increased the number of people who may be injured in the first instance, but "compensated" at the tanks by the serious consequences that could have place by extension. Fire severity of jet fire was not considered major (4 or 5) because their range of action is limited and can be easily extinguished by stopping the gas supply.

In areas with high mortality is considered that 50% of the unsheltered population dies. In this area, the property damage is major. At the outer limit of the area with damage effects on the population, the property damage is minor. Effects on people and property damage decreases with the increasing distance from the center of the explosion. In carrying out the scenarios, the following assumptions were used:

- at the explosions in enclosed spaces (hall, workshops) was considered that the gas-air mixture is at the explosive upper limit throughout the entire room's volume and the entire amount of gas is involved in the explosion (worst case). It is possible, however, depending on the dispersion of the gas in the room, that the explosion won't be full, a part of the gas being burnt in a violent fire, but limited by the amount of gas immediately after explosion;
- at the cylinders explosion was simulated the explosion of a single cylinder;
- at jet fires were simulated two cases at 5 bar (normal pressure on paths) and 8 bar the discharge pressure of relief valves. Were only simulated outside fires because in the rooms, the fires are limited by their size;
- while performing the simulations it was not taken into account the existence of some obstacles that limit the damage. At jet fire where the jet's section is limited, its length is strongly influenced by the existence of obstacles: buildings, concrete fences, being practically stopped (and „returned") by them. At explosion, the obstacles will absorb some of the shock wave strength and thermal radiation, being possible staff's sheltering in buildings.

It is mentioned that both thermal radiation and shock wave will break the windows and sometimes the walls too and it can injure the personnel. However the explosion and fire effects are much diminished by sheltering. The results of explosion simulations were graphically represented on the scale map of the objective area and they are being shown in Figures 1, 2 and 3.

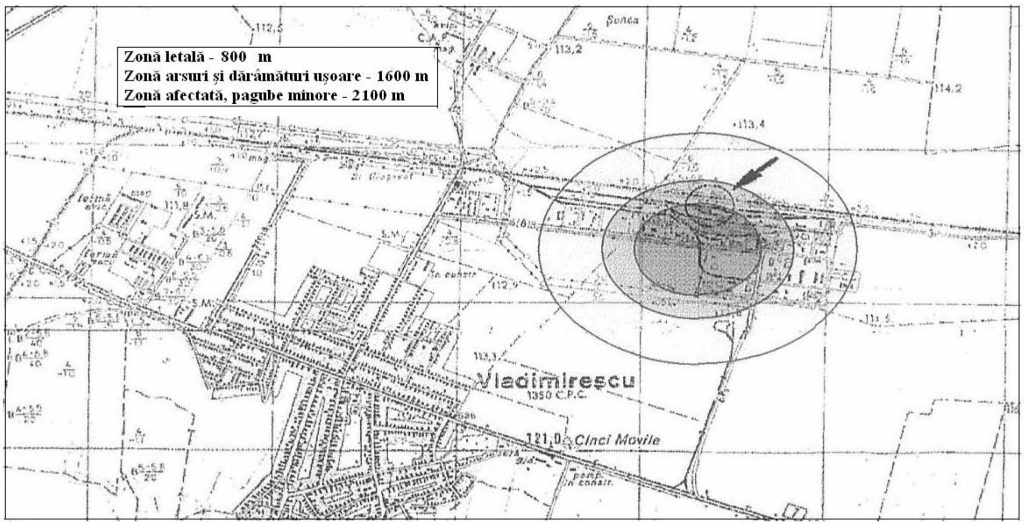

Fig. 1. Simulations with explosion scenarios

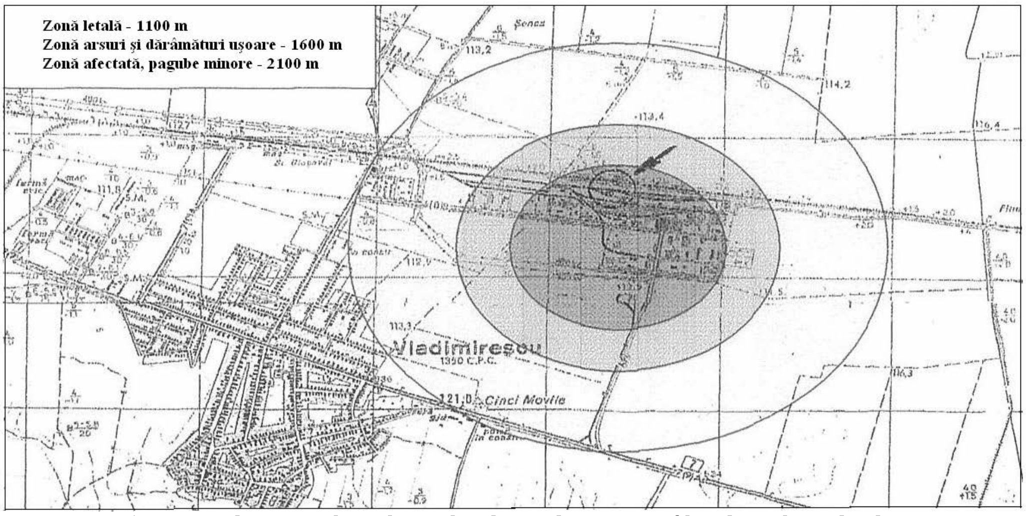

Fig. 2. Explosion risk in the technological process of bottling the cylinders

Analyzing the scenarios presented in Figures and taking into account the substances that are used and the technological process that goes on across the objective, results that, in exceptional cases, accidents may occur on site and with effects outside the site, on the ranges: lethal area - 1100 m; burns and light debris area - 1600 m; affected area, minor damage - 2400 m. Analyzing the distances resulted from calculations, it appears that the effects with minor damages would be felt up to the industrial area of Arad and a part of Vladimirescu locality.

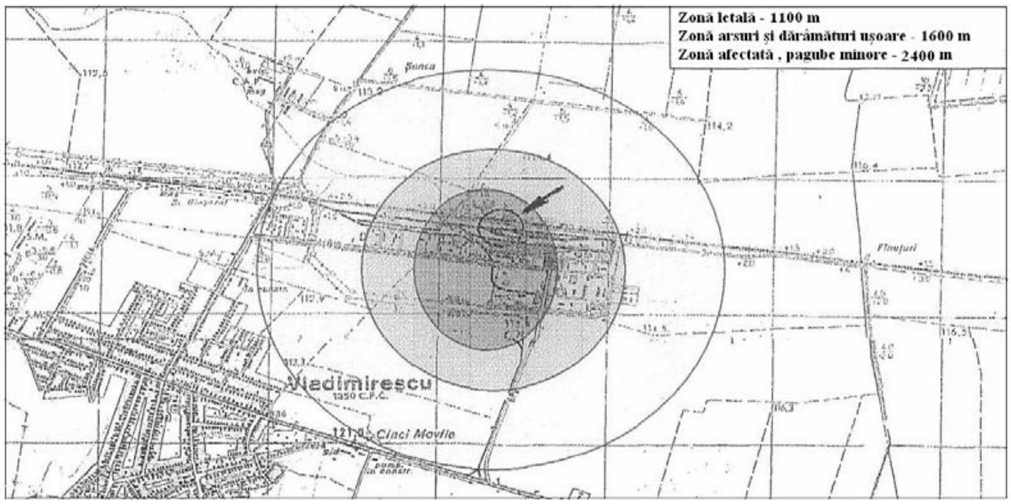

Fig. 3. Explosion risk in transporting LPG on pipelines, valves and pumps, which ensures the transport from rail ramp to the tank park and from the park to the technological loading line

4. CONCLUSIONS

Following the qualitative assessment performed have resulted 14 individual scenarios that were analyzed using the LOPA quantitative methodology.

The analysis of individual scenarios leads to the conclusion that of the 14 scenarios, 13 of them fall within acceptable limits, with the incidence in the acceptable risk area (green area) where not required additional measures to reduce the risk are.

The explosion in the bottling hall is the event that has the frequency of occurrence at the limit between intolerable risk and acceptable risk areas, which implies the need for additional safety measures. Analyzing the technology of LPG bottling, which involves many manual actions, involving a large number of human operators, there is the obvious need to upgrade the bottling plants, especially for eliminating the losses of gas. The highest risk of producing a major accident and fire explosion in the objective is the bottling hall. This is due to the relatively large number of people working in the hall and the large number of manual maneuvers performed. In these circumstances there is the possibility of local accumulation of LPG leaks and their explosion or ignition before being detected by the alarm device.

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