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# ANALYSIS OF THE LPG-DISASTER IN MEXICO CITY

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## ABSTRACT

In November, 1984, an enormous disaster involving an LPG installation occurred in Mexico City and resulted in the deaths of over 500 people. A TNO team went to Mexico shortly afterwards to conduct an investigation. This article reflects on their findings and draws some preliminary conclusions.

## INTRODUCTION

TNO's Department of Industrial Safety in Apeldoorn has published an in-depth accident analysis of the LPG-disaster that took place in the early morning of Monday, 19 November, 1984 in one of the northern quarters of Mexicc City.

The accident analysis has been carried out within the framework of a number of past and present activities, conducted by TNO in the field of industrial safety, such as:

- The maintenance of a data base of disasters involving hazardous materials ("FACTS") and matching accident analyses.
- The conduct of risk assessment analyses and safety studies concerning the handling of hazardous materials (e.g., "LPG, a study" (ref. 1).
- The development of models for the benefit of disaster fighting.

The objective of the Mexico City disaster analysis is in fact two-fold. Firstly, it serves to test existing effect- and damage models, used in safety studies, which predict the amount of damage and the area where damage is likely to occur. Secondly, it examines the way in which the disaster fighting was conducted as well as the specific difficulties that are encountered in the case of disasters such as the one in Mexico City.

The execution of the accident analysis went thus: On TNO's initiative the Dutch authorities together with Dutch industry (which operates large LPG-storage) participated in a joint investigation team.

The team visited Mexico City approximately two weeks after the disaster, and was, through mediation of the Dutch embassy, formally received by the State Oil Company Pemex (Petroleo Mexicana) who operate the LPG-storage depot where the disaster occurred. Three representatives from Industry and one from the Ministry of Home Affairs (Fire Inspectorate) made up the team together with a Mexican national from Mexico City University who was engaged in a term of probation with TNO at the time of the disaster. The person in question was of major importance during the information-gathering meetings through his local connections and his command of the language. The team was controlled by TNO, with the undersigned serving as its project and team leader. The investigation was financially sponsored by the Ministries of Home Affairs, Social Affairs, and Housing, Physical Planning and Environment.

The report of the analysis has been written and published under the auspices of TNO. The team members have contributed to the report by way of discussions and comments. The representative of the Fire Inspectorate has contributed with analysis of the aspects to the disaster fighting. This article does not elaborate his findings.

A great amount of factual information is given in the report, which also calculates, on the basis of existing effects and damage models, damage distances and compares them with the actual situation. A survey of case histories of comparable accidents is also included together with scores of photographs and drawings and comprehensive summaries of reports from Mexican newspapers and magazines relevant to the disaster.

The articles gives an initial description of the location of the disaster, the disaster itself and it also supplies a damage analysis.

Additional data analysis, particularly the comparison of the actual damage with existing effects and damage models can be found in the TNO report.

## The LPG-installation and surroundings

The LPG-installation is situated in San Juan Ixhuatepec, Mexico City. Housing in the vicinity of the installation did not materialize until after the construction of the installation had begun in 1962, a fact that has been established through examination of aerial photographs dating back from a number of years. Housing is simple: brick walls between concrete pillars, occasionally with a second storey added. There are also a number of plainer houses made of wood and corrugated roofing. The build-up area begins already at a distance of 130 meters from the storage tanks.

The lay-out of the Pemex LPG-storage and distribution centre is given in Fig. 1. The storage consisted of four spheres with a volume of 1,600 $m^3$ and two spheres of 2,400 $m^3$. There were an additional 48 horizontal cylinders of various dimensions present (Fig. 1). At the time of the

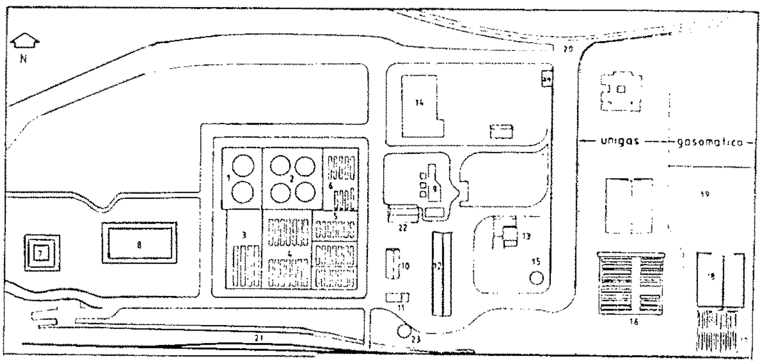


Figure 1. PEMEX LPG installation, San Juan Ixhuatepec, Mexico City. Scale 1:2200

LEGEND

1 2 spheres of 2,400 $m^3$, ø = 16.5 m
2 4 spheres of 1,600 $m^3$, ø = 14.5 m
3 4 cylinders of 270 $m^3$, 32x3.5 m ø
4 14 cylinders of 180 $m^3$, 21x3.5 m o
5 21 cylinders of 36 $m^3$, 13x2 m ø
6 6 cylinders of 54 $m^3$, 19x2 m ø
7 flare pit (2nd flare pit)
8 pond
9 control room
10 pumphouse
11 fire pumps
12 road car loading
13 gas bottle store
14 pipe/valve manifold
15 watertower
16 LPG storage Unigas
17 LPG storage Gasomatico
18 bottling terminal
19 depot of cars with bottles
20 entrance
21 railcar loading
22 store
23 watertank
24 garrison

disaster the complete storage may have contained 11,000-12,000 $m^3$ of LPG. According to Pemex the set pressure of the pressure relief valves amounted to approximately 10.3 bar. The wall thickness of the larger spheres was 37 mm. The wall thickness of the cylinder that was actually measured by the team was found to be approximately 28 mm. The storage location was divided into separate sections through concrete walls about 1 m high (Fig. 2).

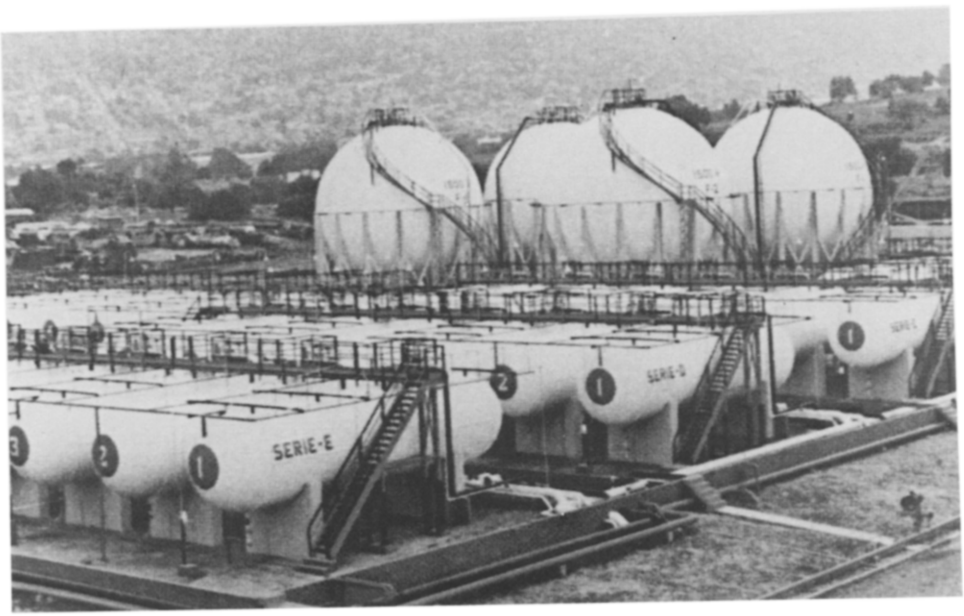


Figure 2. Storage tanks before the disaster took place.

The storage distribution centre was fed through three underground LPG-pipelines from refineries at distances of hundreds of kilometers. The LPG was distributed through underground pipelines to two adjacent gas companies (Unigas and Gasomatico) (Fig. 1). Further away another five companies were supplied via tank cars and gas cylinders. The installation accommodated transshipment facilities for tank cars and railway tank cars as well as a gas bottling plant.

There were also two ground flare pits, a fire protection system complete with pond, pumps and waterspray distribution.

## The disaster

In the early morning (about 5:45) on Monday, 19 November, 1984, a chain of events at the LPG-storage in San Juan Ixhuatepec led to one of the major disasters in the history of industrial activities.

LPG-leakage followed by ignition caused a number of explosions which almost completely destroyed the storage. Five people were killed and two were injured at the Pemex site. The effect in the built-up area south of the storage was truly dramatic. Approximately 500 people were killed and over 7,000 were seriously injured. The majority of people were surprised in their sleep. Later, about 200,000 people were evacuated. Fig. 3 shows one of the many BLEVEs (Boiling Liquid Expanding Vapour Explosion) which occurred. The various explosions were registered on the seismograph of

Figure 3. A "BLEVE"

Mexico City University situated some 20 miles away. Altogether nine explosions were registered, the initial one at about 5:45, the final one at about 7:01. The second and seventh explosions were the most severe with an intensity of 0.5 on the Richter Scale. The second explosion occurred already one minute after the initial one.

The way the disaster developed

It has not yet been possible to establish exactly the direct cause of the accident, although from information gathered through various sources and eye witness accounts, a picture of the way the disaster developed can be given: In the early morning of 19 November, 1984, large quantities of LPG leaked from a pipeline or tank in one of the walled-in, approximately 1 m high sections of cylinders. The (heavy) LPG-gas dispersed over the wall into the surroundings. Guards tried to warn people to take refuge. The vapour cloud had reached a visible height of about 2 m when it ignited, probably through coming into contact with a flare pit at the bottling plant. A flash fire resulted, its flame front, subject to the degree of confinement of the vapour cloud, sometimes accelerating, a process that caused local overpressures. Eye witnesses mentioned explosions in various places in the vicinity.

The cylindrical storage tank area had a relatively large degree of confinement. Overpressure caused by vapour cloud ignition may have been such that additional damage was sustained by the pipelines over there.

On the basis of a number of reflections, it appears to be an impossibility that tanks were already thrown off their supports at this time. The vapour cloud is assumed to have penetrated houses which were consequently destroyed through internal explosion (Fig. 4).

Figure 4. Devastated house.

The vapour cloud explosion was probably the first out of a series of nine registered by the University. It caused a huge sea of flames in the storage area, probably fed by damaged pipelines. Already after one minute a violent explosion (BLEVE) occurred. The explosion is likely to have involved various storage tanks. A number of reports stated that one of two cylinders were thrown about over large distances. Two spheres may also have exploded at the same time.

Heating and/or penetration by fragments or other tanks were responsible for the complete number of BLEVEs. The very short interval between the vapour cloud explosion and the initial BLEVE (if combined with information gathered through reasonably reliable sources) justifies the tentative supposition that overfill may have occurred in the case of one or more tanks with the possibility of a high pump pressure on the cylinders and pipelines.

The damage that was sustained

The four smaller spheres were completely destroyed, their fragments scattered about the area. The largest spheres remained intact although their legs had buckled from the heat, which caused them to fall to the ground (Fig. 5). Four out of 48 cylinders were left on their original concrete supports. Twelve cylinders came down at distances of over 100 m. The greatest measured distance amounted to 1,200 m. Forty-four out of 48 cylinders were located by the team. The remained four fragmented into smaller parts.

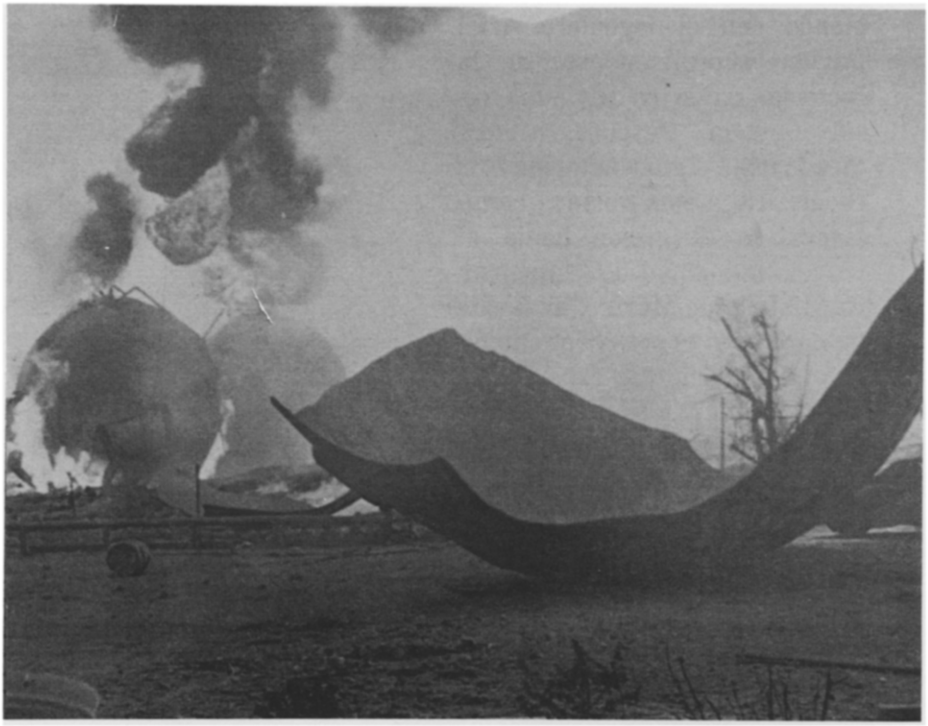

Figure 5. Fragment of a small sphere and 2 large spheres on fire.

A great fire raged inside the pump house. Various other buildings and constructions at the company site sustained damage or collapsed from the heat. As has already been mentioned, the damage to the built-up area was of dramatic proportions. The exact locations where the 500 dead and over 7,000 injured were found are not (yet) known. TNO is hoping to obtain additional information in this respect. However, our own observations, video tapes, conversations, etc., enabled us to establish quite accurately the area in which housing was for the greater part destroyed. The majority of casualties occurred within this area which stretches out to roughly a distance of 300 m away from the centre of the storage location.

This particular disaster area is indicated in Fig. 6,

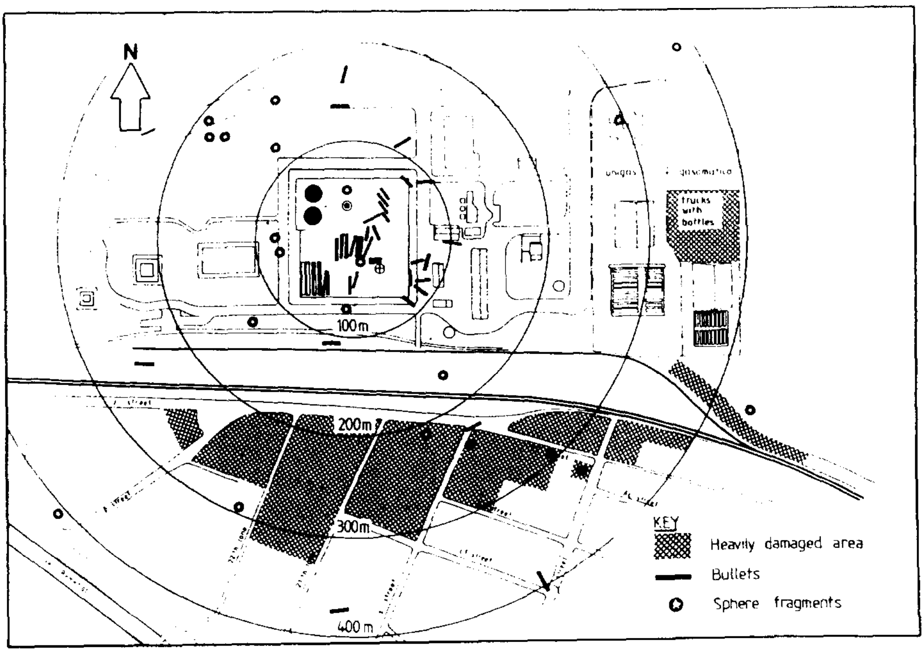


Figure 6. Reproduction of the area in which damage occurred.

which also gives the positions of the various cylinders after the disaster, except for the couple that came down at distances of over 1,000 m and the one sphere fragment that landed at a distance of about 700 m. The cylinder at the corner of J. Street and LT. Street (a distance of 400 m) is given in Fig. 7.

Figure 7. "End tub" crashed at a distance of about 400 m.

Damage in relation to the physical effects

The damage sustained by housing was probably only partly due to the vapour cloud explosion and for the greater part due to explosions inside the houses. It has furthermore been concluded that overpressure effects were negligible in contributing to the damage in the case of this disaster. However, it is a fact that overpressure effects caused by the BLEVEs (physical explosion) did throw various cylinders off their supports. The "earthquakes", reported by almost every eye witness, accompanying the second explosion may also have caused damage to housing. This "earthquake" was set off by the physical explosion which is liable to supply high overpressures at the location of the explosion. This particular overpressure quickly decreases as a function of distance in relation to that particular location.

The investigation team failed to notice glass breakage on the spot. The breakage that was later reported (and photographed), at a distance of approximately 600 m north and south of the LPG-storage, probably originated from heat radiation combined with small overpressures. The physical explosions managed to cause some overpressure damage in the residential area. It has been assumed that the major part of the damage was caused by the intense heat and the groundlevel fireballs penetrating the areas on a number of occasions. Constructions such as the ones in the San Juan Ixhuatepec tend to lose their strength within 30 minutes in situations like the one that has been described.

## Comparison with effect and damage models

The TNO report has examined the way in which the actually sustained damage relates to the damage predicted by existing effect and damage models. The analysis has not yet been completed. The amounts of data that have become available present an opportunity for additional research. The investigation is to be continued and relevant information will be published at a later stage.

A number of preliminary conclusions have already been formulated. Important to the analysis of the damage caused by this disaster are two developments of the disaster:

- a vapour cloud explosion which may cause overpressure effects,
- a BLEVE

## A LPG vapour cloud ignition

The vapour cloud was formed by dispersion of LPG into the atmosphere. LPG is a heavy gas in relation to air and spreads out close to the ground into the surroundings, subject to weather conditions. At the time of the San Juan Ixhuatepec accident, hardly a breeze was felt and the temperature was about 7$^{o}$C.

The calculation of the dimensions of the flammable part of a vapour cloud, in cases of a slight wind or no wind at all, remains a problem where existing models are concerned.

Using the heavy-gas-dispersion model as it was applied in ref. 1, it can be stated that such a vapour cloud (in the case of LPG-leakage from a 4" pipeline) reaches a distance of at least 200 m away from the point of release. From experiments (ref. 2) and case histories (ref. 3), it appears that overpressure effects which may occur are to a great extent subject to the degree of confinement of the vapour cloud. However, a single determining factor has not yet been found. The degree of confinement in some sectors of the residential area and in the storage location (between and underneath the cylinders) may indeed by instrumental in causing significant overpressures. Yet, the picture of the damage shows that such overpressures cannot have been determining the damage in the residential quarter. Many relatively fragile partitions and walls have been left standing as they were.

Ignition of a vapour cloud inside a building is bound to cause extensive damage to that building. Internal explosions appear to have occurred in many damaged buildings. A number of these explosions probably took place at the time of the initial vapour cloud explosion. Internal explosions may also have occurred later, on penetration of partly unburnt LPG that was dispersed by the physical explosions of one or more larger storage tanks (BLEVEs). Case histories supply examples hereof which have been included in the report. People inside an igniting vapour cloud stand only a small chance of survival (case history). Direct flame contact, the intense heat and lack of oxygen see to this. Accounts from people at distances of over 300 m at the time of ignition indicate that ignitions took place locally, although only at small heights (< 1 m), which enabled these people to survive.

BLEVEs

As has been stated before, a BLEVE develops through heating of the tank wall in the vapour space (weakening of material through insufficient cooling), through overpressures (excessive pump pressure, blow off safeties which do not work properly or insufficiently), or through mechanical penetration (by fragments of other tanks that have exploded). The reports points out that penetration will indeed occur at the calculated fragment velocities.

A BLEVE involves a physical explosion: overpressures due to expanding gas and/or "flash" evaporation of the liquid. Calculations incorporated in the report show that vapour expansion is the determining factor where the extent of the damage is concerned. Models determining the occurring overpressures on the basis of an adiabatic flash evaporation tend to overestimate the overpressure effects to a great extent. The models in question only become valid over and above a specific temperature of the liquid. In the case of LPG the ceiling is probably around 55$^{o}$C.

The overpressure effects may have caused some damage to housing, albeit indirectly. The "earthquakes" that were reported are more likely to have been responsible. Some damage to glass, such as was reported (at 600 m) may (in combination with heat radiation) have been caused by these effects.

The physical explosions have been responsible for the shift of a great number of cylinders. Calculations support the feasibility in this respect.

The fireball

The dimensions of a fireball originating from a BLEVE of flammable material in fire situations are generally calculated by means of empirical relations derived from experiments. "LPG, a study" (ref. 1) describes a relation using coefficients which are the average results of six experiments:

- diameter of the fireball: $D = 6.48\ W^{0.325}$ (m)
- duration of the fireball: $t = 0.85\ W^{0.26}$ (sec)

W = amount of LPG in fireball (kg)

In calculating the quantity of LPG participating in the fireball the complete content of the tank is generally taken into account. Safety studies assume in general that devastation will occur within the fireball's projection and that nobody will survive the disaster.

The maximum diameter in the case of this particular accident amounts to approximately 500 m (a 1,600 $m^3$ sphere filled to a 90% capacity). With a view to the area in which damage occurred it gives a slight under-valuation. Fireball dimensions such as seen on photographs and video have an (estimated) small dimension (ranging from 200-300 m). It must be taken into account that the initial (and probably damage-determining) BLEVE was not registered.

From accounts of, among others, the fire brigade it appears that in the case of BLEVEs the groundlevel fire expanded enormously. In cases of other accidents "groundlevel fireballs" throwing quantities of unburnt material about have been mentioned. This particular mechanism may have played a major part in these cases. In ref. 4, it has been stated that the development of a fireball has not yet been adequately described in the models. Especially in cases concerning great quantities of LPG, the damage distance may be influenced by the above mechanisms. This article does not elaborate on the heat radiation damage outside the devastated area. Relevant data may be found in the report.

Fragmenting

Upon rupture tanks containing LPG usually fragment into a number of parts. Case histories of spherical tanks such as were present in San Juan Ixhuatepec show that the number of fragments will amount to 10-20.

In the case of cylindrical tanks, the amount is a great deal less. Energy released upon rupture of an LPG-tank is partly (60% according to the TNO "Yellow Book" (ref. 5) converted into kinetic energy of the fragments. As a result the fragments may be scattered about over great distances. Fig. 6 shows the positions of the larger fragments up to distances of about 400 m. At least four large fragments came down at even greater distances of 600, 750, 1,100 and 1,200 m.

A preferential direction can be detected from the way the cylinders are positioned. These "fragments" are so-called "end tubs". They were predominantly launched in a southward direction, a fact caused by the original south-north positioning and the pipeline connection north of the tanks. A fire resulting from a split or a leak of the pipeline connection initiates a circumferential rupture of the tank, its spherical front bursts off in a northerly direction, whereas the major part of the cylinder will be jettisoned southward.

This particular directionality is also found in case histories (ref. 6). Fig. 8 indicates this effect in the case of the San Juan Ixhuatepec disaster.

In the report the fragmenting in San Juan Ixhuatepec has been compared in a general fashion with fragmenting in cases of comparable accidents of the past.

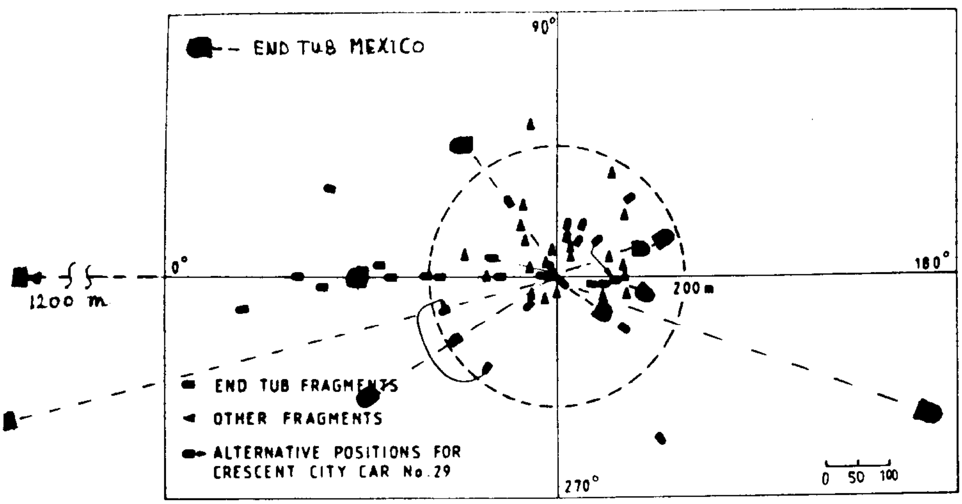


Figure 8. Reproduction of the directional preference.

Evaluation

An in-depth analysis such as this particular one which involves the authorities, industry as well as a research organization supplies interesting facilities for the benefit of the testing of installation design with regard to safety, governmental safety policy, disaster fighting and effect and damage models.

Although TNO's investigation concerning San Juan Ixhuatepec is to be continued a number of conclusions can already be drawn. This particular article limits its conclusions to an effect and damage analysis.

Where the installation is concerned two remarks may already be made:

- From a space consideration the installation lay-out was very much confined. The cylinders were situated very close to one another and were walled-in. Ventilation problems may occur in this respect, and in the case of disasters the high degree of confinement may cause overpressures which may occasion additional damage.
- The built-up area was too close to the installation. When the installation was built, this adjacent area was only waste land.

Additional research is being carried out in the case of effect and damage models. The following can already be stated:

- Although the vapour cloud had a dimension with the potential to cause enormous damage, the damage from overpressure effects may have been limited. Adequate models to predict effects of overpressure have still not become available. TNO is one organization engaged in research in this particular field.

- In view of the minor damage outside the 300 m area (hardly any glass breakage noted) it can be concluded that a model for the calculation of overpressures resulting from flash evaporation results in an overestimation of the effect. The vapour expansion appears to have been the determining factor in this case.
- The current models for the prediction of the fireball dimensions of a BLEVE produce damage distances somewhat smaller than those observed in San Juan Ixhuatepec. There are also indications that the maximum damage distance is not determined by the fireball dimension but by LPG that is scattered about the surroundings resulting in groundlevel fires in the affected areas.
- The positioning of the cylinders and the location of the pipeline connection to the cylinders determine the direction in which they were scattered.

<u>The report</u>

An English version of the TNO report comprising a great amount of information and an analysis of the distance and may be obtained from: TNO Department of Industrial Safety, Mrs. M. Ruys-Keijzer, P.O. Box 342, 7300 AH Apeldoorn, The Netherlands (telephone: (0)55-773344; telex: 36395 tnoap nl)

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