THE EXPLOSION OF THE DISPLAY FIREWORKS ASSEMBLY PLANT "MS VUURWERK" ON FEBRUARY 14, CULEMBORG, THE NETHERLANDS

25th DoD Explosives Safety Seminar
18-20 August 1992, Anaheim, California

W.P.M. Mercx and H.H. Kodde

1 INTRODUCTION

On February 14 1991, a heavy explosion completely destroyed the assembly plant for display fireworks 'MS Vuurwerk' in Culemborg, the Netherlands.
An investigation was carried out in order to determine the strength of the explosion on the basis of damage caused to the buildings in the vicinity.
Furthermore an investigation was carried out of the crater and its direct vicinity to find the cause of the explosion.

Results of the investigations performed by the TNO Prins Maurits Laboratory were presented in a report (in Dutch): 'Report from the Prins Maurits Laboratory TNO concerning the explosion of the 'MS Vuurwerk' assembly plant for display fireworks at Culemborg on Thursday 14 February 1991.
This paper gives a summary of that report.

2 LOCATION

The assembly plant for fireworks 'MS Vuurwerk' is situated 5 km outside the built-up area of the town of Culemborg in south-west-west direction. Culemborg itself is situated about 15 km south of the city of Utrecht in the centre of the Netherlands. Heart of the plant was a bunker from World War II. This bunker is situated at the foot of a dike which was part of the 18th century water defense system of Holland. The dike starts at the river 'Lek' and passes the plant in south-south-west direction (see Figure 1A).

The plant is situated at a distance of 50 m from the dike. A number of houses and farms are situated against the other side of the dike. The dike itself has a height of 5.8 m. At the plant side of the dike, only a couple farms are present, the nearest building at a distance of about 200 m.
The landscape is very flat and open. The dike is the only elevation present (see Figure 1B).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
AUG 1992		**00-00-1992 to 00-00-1992**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The Explosion of the Display Fireworks Assembly Plant 'MS WURVYERK' on February 14, Culemborg, The	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Vitro Corporation,45 West Gude Dr,Rockville,MD,20850-1160**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA260984, Volume I. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**15**	

Figure 1A Culemborg and surroundings

Figure 1B The location of the assembly plant

Two buildings were present on the premises (see Figure 2).

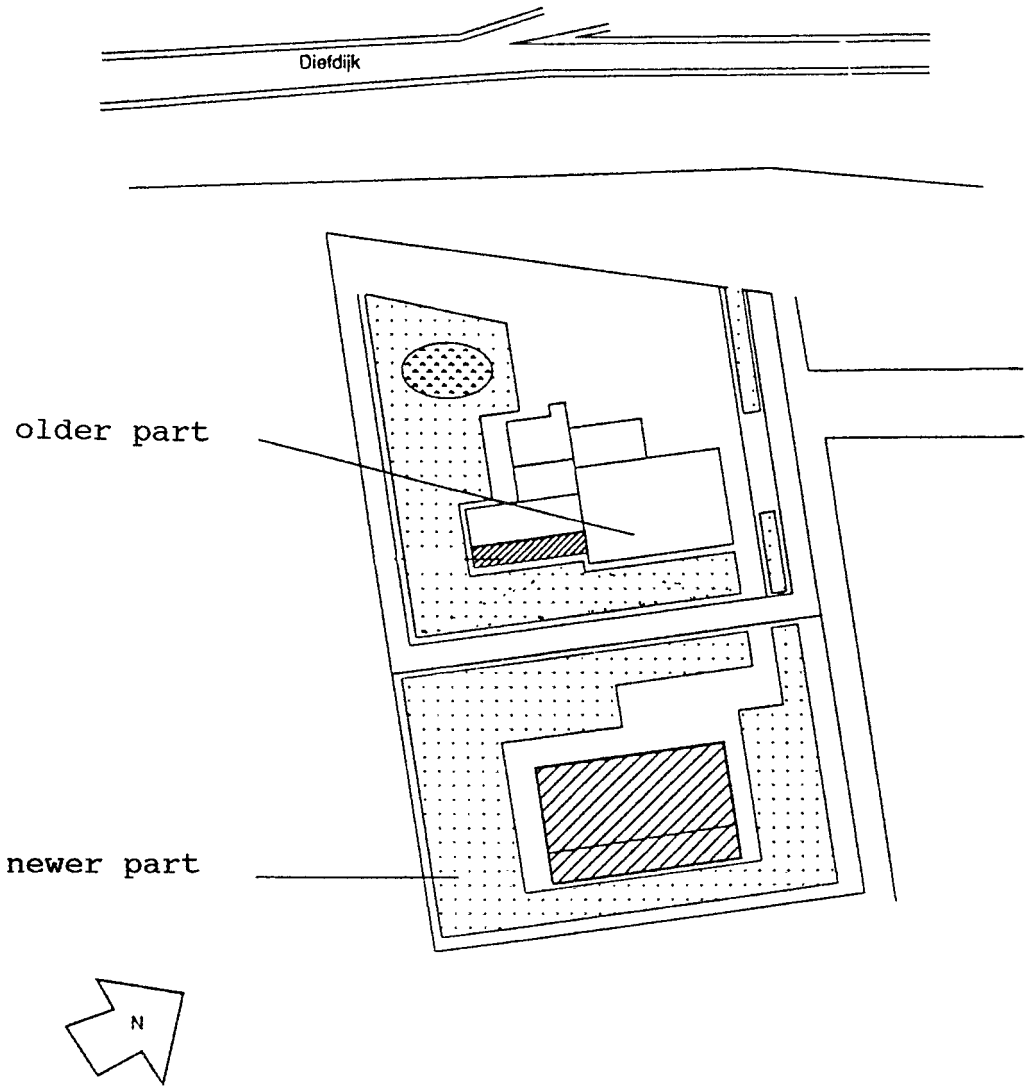

Figure 2 Lay out of the assembly plant

The first one consisted of the old bunker, an administration office, an assembling hall of 25 by 16 square meters and 5 small storage rooms. The other building 20 m east of the first one was built in 1990 and in service since a couple of months. It consisted of an assembling hall of 20 by 12 square meters, four storage rooms and two workrooms (see Figure 3). Figure 4 shows a section of the building. The walls of the storage rooms were made of 0.2 m thick unreinforced concrete blocks while the ceiling was made of concrete hollow core slabs. The inner wall of the cavity walls were also concrete blocks while the outer

wall was masonry. The assembly hall was composed of steel trusses covered with asbestos plates.

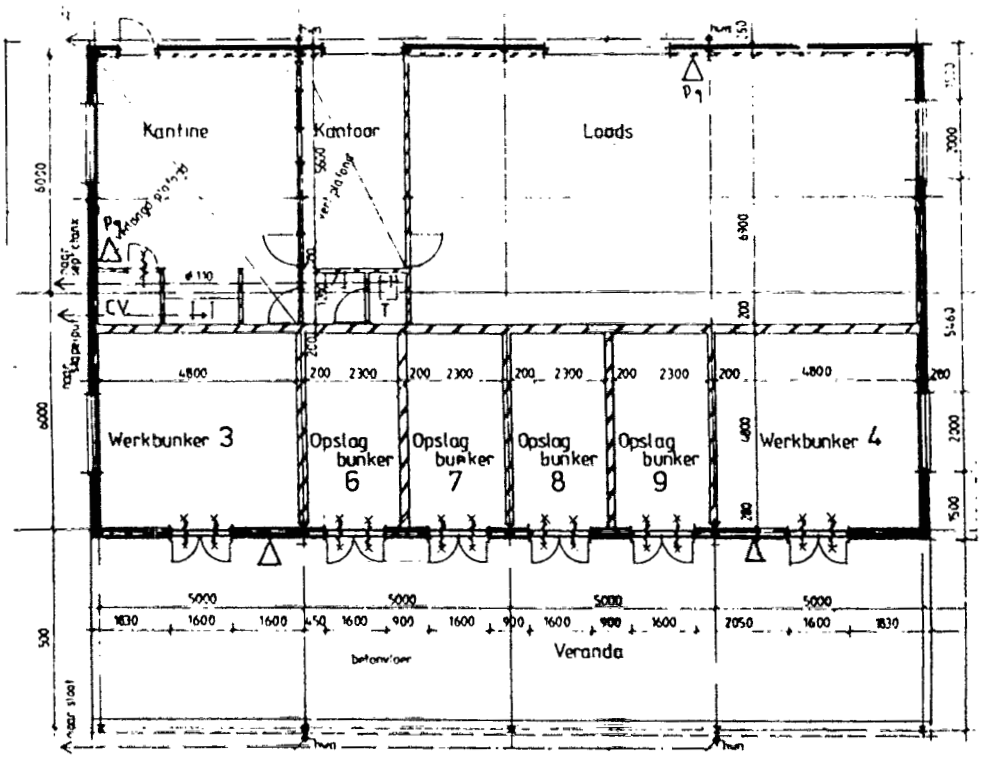

Figure 3 Lay out of the exploded building

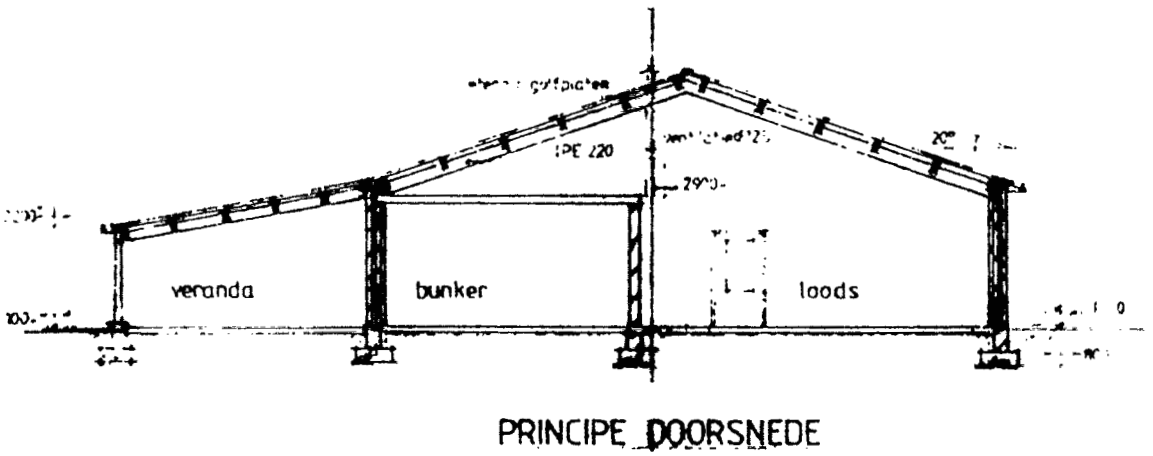

Figure 4 Section of the building before the explosion

3 THE EXPLOSION

At about 11.50 hours in the morning of 14 February a big bang was heard by the farmers and the inhabitants of the town Culemborg. Initially it was thought that something like an aeroplane had crashed. Although it was not confirmed by all witnesses and therefore not generally accepted, a second much stronger explosion occurred within 20 seconds. As pieces of concrete and wood started to fall from the sky, people realised that the explosion occurred within the fireworks plant.

It appeared that the new building was completely vanished and that only a large crater was left. The crater dimensions where 10 by 5 meters with a depth of more than two meters (see Figure 5).

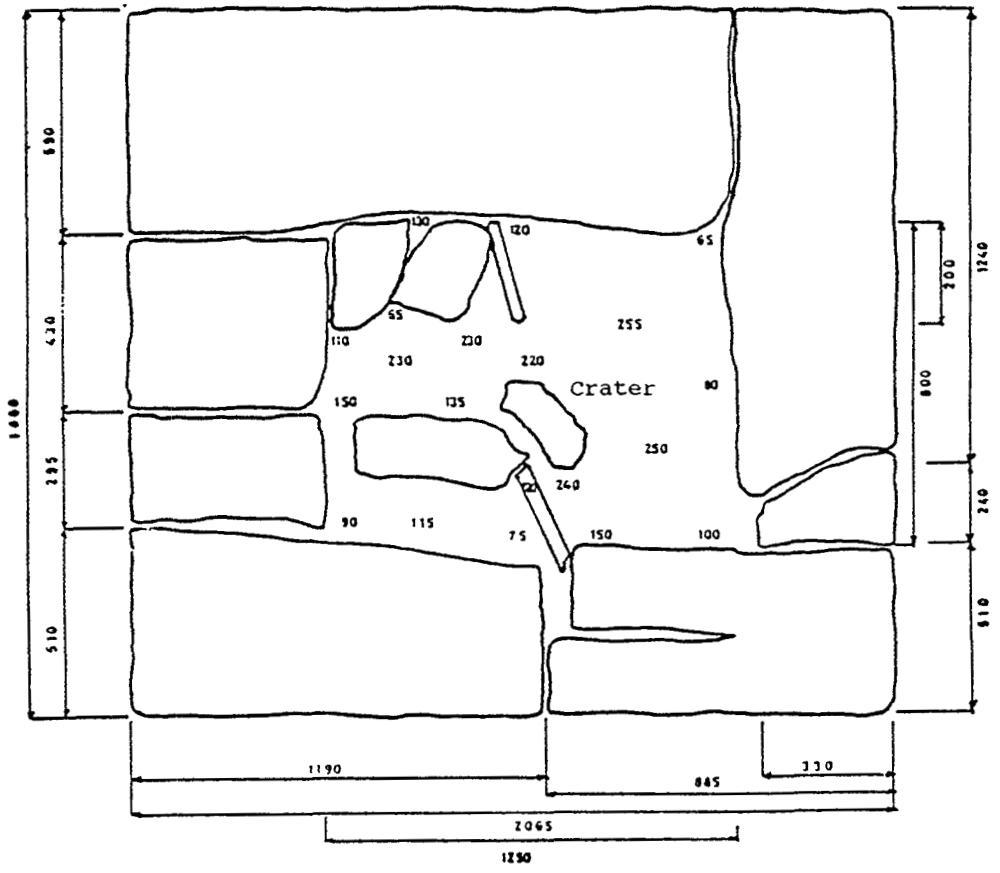

Figure 5 Overview of the crater

The old building was set on fire and minor explosions occurred during the rest of the day in the storage area where firework articles were ignited.

4 DAMAGE

Only a brief overview of the damage can be given here. One of the annexes to the report [1] gives an extended overview.
The nearest buildings were situated directly behind the dike. Although no house was collapsed, there was a lot of damage: roofs were pushed in and walls were heavily cracked. Most of the window panes were broken. Window and door frames were broken. Corrugated panels of barns were pushed in.
Up to 500 m behind the dike window pane breakage was observed.

The same pattern was visible on the eastern side of the dike: At 500 m large wooden doors of 3 by 4 meters were lifted and pushed in. Most of the masonry of the houses within 900 m were found to be cracked.
At 900 m some frames of the double window panes were pushed in, roofs of large barns were lifted and wooden trusses were cracked.

Beside damage caused by the blast there was considerable damage caused by flying debris. The largest range over which debris was thrown was found on the eastern side. The storage rooms were situated on the eastern side of the assembling hall.
Up to 650 m east of the plant large pieces of concrete weighting 10 to 20 kg and parts of steel girders (length approx. 4m) were found.
Table 1 gives an overview of the large steel girders that were found and Figure 6 gives the location of these pieces of steel. All IPE's box girders and steel strips were parts of the steel truss of the exploded building.

Table 1: Overview of large steel girder parts found in the vicinity (location numbers refer to Figure 6)

Location	Type
1	I-beam IPE 180 length 4 m
2	box girder 5.5 x 5.5 cm^2 length 3 m
4	I-beam IPE 160 length 3.5 m
5	box girder 5.5 x 5.5 cm^2
8	IPE 180, 4 m
9	IPE 180, 4 m
10/11	box girder 5.5 x 5.5 cm^2 with steel strip 8x0.5 cm^2
12	strip length 1.5 m
13	IPE 180, 4 m
14	strip
15	steel cylinder, length 0.88 m, diameter 0.32 m
16	IPE 160, 4 m
17	strip
18	IPE 180, 4 m
19	box girder, 2 m

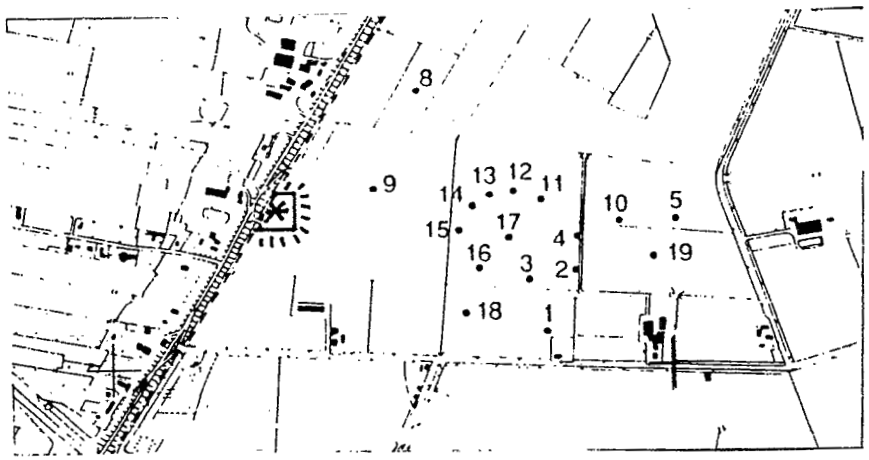

Figure 6 Location of the large steel girder parts

Most of the debris consisted of bricks or parts of bricks and concrete pieces with dimensions comparable to bricks. At a distance of 300 to 550 m in eastern direction, the distance between the pieces of debris was about 50 m.

To get an overview of the debris distribution around the explosion centre the near vicinity was divided in square sections of about 10 by 10 square meters (see Figure 7).

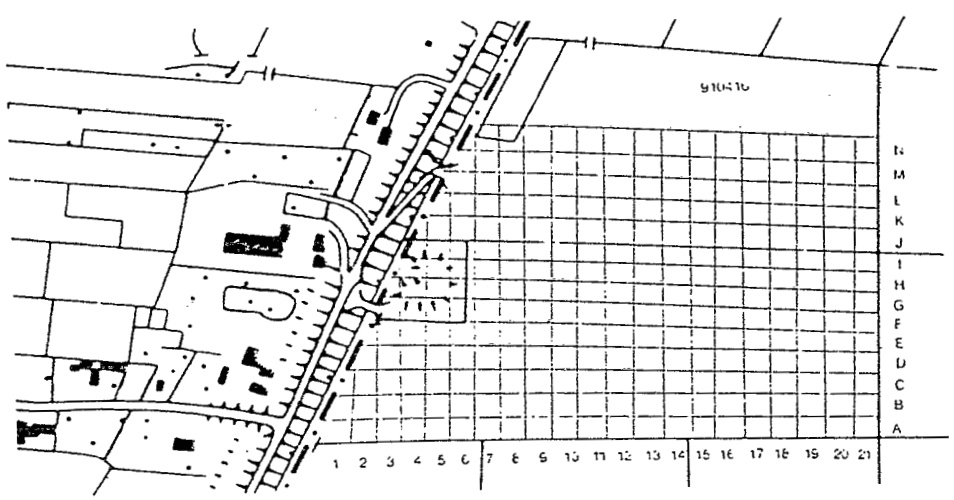

Figure 7 Sections for fragment and debris recovery

Each section was searched by a team of police and army men and every piece of debris weighting over 0.5 kg was gathered. Table 2 gives the total weight of the debris found in each section.

Table 2: Total weight (kg) of debris per section

row	section													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	143	0	43	183	215	175	0	0	0	0	0	0	0	0
2	147	165	175	104	45	177	0	0	0	0	0	0	0	0
3	70	146	158	238	99	1220	0	0	0	0	16	0	0	0
4	57	302	172	70	0	1550	0	0	0	0	0	0	0	0
5	48	175	239	230	995	1816	0	0	0	243	0	14	0	0
6	199	321	393	475	543	674	0	0	0	83	80	48	51	47
7	28	119	125	144	0	124	129	0	0	165	21	27	68	14
8	99	78	95	118	87	94	66	80	82	102	20	23	62	0
9	150	113	116	92	44	46	19	121	87	175	212	64	25	0
10	93	54	47	25	61	50	50	61	95	63	74	145	74	0
11	66	37	51	83	55	55	0	105	58	88	65	54	41	0
12	39	25	26	33	20	72	113	109	164	0	35	84	27	0
13	38	17	17	43	0	58	249	148	133	104	55	42	16	13
14	26	9	20	27	31	0	245	149	100	125	26	23	17	0
15	17	30	7	22	113	621	120	177	85	40	38	14	20	0
16	31	22	39	25	14	13	144	19	87	44	42	151	30	0
17	33	42	42	45	34	71	29	34	324	31	20	26	34	0
18	24	7	26	12	11	39	8	8	14	44	51	36	60	0
19	22	36	25	31	15	12	77	35	20	81	40	17	22	0
20	50	38	32	18	20	12	40	35	21	32	14	12	0	0
21	37	63	36	21	16	1	121	8	18	4	55	8	9	0

There was also considerable damage within the town of Culemborg itself. Large window panes were broken and chimneys were damaged. Roofs of showrooms were lifted causing damage to ceilings and goods stored inside.
It was reported that some minutes after the explosion a window pane at a location 50 km away broke due to a strong wind gust. The explosion was observed by seismological instruments more than 100 km away.

The estimate of insurance companies on the total costs of the damage was 50 million Dutch guilders so about 30 million US dollars.

5 EXPLOSION STRENGTH

Initially it was tried to estimate the strength of the explosion by the amount of damage of the buildings in the vicinity. It was however very difficult to distinguish zones with different levels of damage. Therefore two other approaches were applied.

First an estimate was based on window pane breakage. Based on the number of broken panes at certain distances and the dimensions of the panes and orientation with respect to the explosion, a rather accurate estimate could be made of the shock wave pressures at certain distances [2,3]. Applying the relation of overpressure versus distance for free field surface explosions gave un upper limit of 5000 kg TNT and a lower limit of 1000 kg TNT with a best average value of 2000 kg TNT.
The second approach was to compare the debris patterns and the crater dimensions with data from literature. For this data from the phases two and three of the joint Australian/UK fragmentation trials were applied [4]. These trials were performed with amounts of 500, 1800 and 5600 kg of explosives in structures very comparable to the ones present in the firework assembly plant. Although the comparison of data was very rough because of different ways of gathering and presenting data, it appeared that the debris pattern and crater dimensions of the 1800 kg trials matched best with those from the accident.

6 STORED QUANTITIES AND CLASSES OF FIREWORKS

Maximum quantities and types of fireworks to be stored in the plant are described in the Nuisance Act for the plant. This Act allowed the storage of Hazard Division (HD) 1.3 and HD 1.4 articles only. HD 1.1 and HD 1.2 articles were explicitly excluded with the single exception of 200 kg black powder, HD 1.1, to be stored in the World War II concrete bunker only.

An amount of 1000 kg gross fireworks was allowed to be stored in each of the four storage rooms of the exploded building. This weight is without the weight of the packaging material like wooden boxes. The fireworks should be stored within the transportation packaging. A maximum amount of 200 kg gross was allowed in each of the two workrooms.
The total allowed amount in the building that exploded was therefore 4400 kg gross which roughly implies an amount 1500 to 2000 kg explosive substances.
From data presented by the Ministry of Transport it could be concluded that 8000 to 10000 kg of fireworks were present in the plant, that is including the storage in the old building of the plant. This total amount of firework articles is about the maximal amount permitted by the Nuisance Act to be present at the plant

Based on the quantities present at the moment of the explosion and the estimated explosion strength it was concluded that a mass explosion occurred of the total quantity of fireworks present in the new building.
As only HD 1.3 articles were allowed to be stored this explosion effect was not expected at all. The outside quantity distances

were based on HD 1.3 distances and were not sufficiently large to protect against a mass explosion. Beside the need to find the cause of the explosion it was therefore very important to find the cause of the mass explosion of the storage of HD 1.3 articles.

7 INVESTIGATION TO THE CAUSE OF THE EXPLOSION

The investigation into the cause of the explosion was carried out in the direct surroundings within a radius of about 20 meters of the crater.
The investigation was focussed on:
- display firework articles or packages which probably do not belong to HD 1.3
- other explosive articles than display firework articles or packages which could be the cause of a mass explosion. For instance very fine grained black powder, special pyrotechnic mixtures or even high explosives
- packaging other than fibreboard or wood
- parts of the wooden doors of the storage rooms. This might give an indication whether a deflagration to detonation transition occurred.

The following types of display firework articles were found:

- Cardboard report shells
They had a diameter of five and eight cm. During the explosion the shells functioned properly. Some were found in the original state. A chemical analyse of the pyrotechnic mixture showed an aluminium/perchlorate mixture.
These pyrotechnic mixtures might give a mass explosion. This was demonstrated during trials performed in 1989 by TNO-PML as a mass explosion occurred during a bonfire test [5].

- Knätter vulcano
They had a height of about 25 cm and a ground diameter of 8 cm. They have all functioned properly. No vulcano was found in its original state.
These display firework articles showed no divergence of the HD 1.3.

- Silver Gerb from Le Maitre GB
Fragments of a pertinax like casing were found. The dimensions of the fragments were in the range of a few cm^2 up to a ten decade cm^2. These fragments indicate that the Gerbs did not functioned properly. The dimensions of the Gerbs casing were: diameter eight cm, length forty cm and thickness 0.6 cm. The weight of the explosive contents was about three kg and consisted of a mixture of black powder and titanium.

On May 14, 1991, bonfire experiments were carried out according to the UN test series 6C. The Gerbs however did not show a mass explosion. They ignited and functioned as they should

- Spheres made in Japan
The cardboard shells with a diameter of about eighteen cm were found in the original state. They were blown away and the shell was broken in two parts, due to the impact on the ground or due to the influence of moisture on the glued seam.
The explosive content consisted of black powder, saw dust and grains of seed.
These display firework articles showed no divergence of the HD 1.3.

- Roman Candles made in Russia
A few of them, about 5 %, were found totally intact, including the electrical ignitor. From the ruptured cardboard tubes it was concluded that most of the other 95 % were exploded. The wooden boxes, in which they were packed, were partially fragmented and splintered.

The materials which were found other than the firework articles or packaging were mainly building materials. An interesting material which was found were green plastic fragments of about a few cm^2. They belonged to a domestic wastes mini container. These fragments were also found underneath the concrete parts of the floor, in the direct surrounding of storage room 6.

The crater consisted of two parts, one part underneath storage room 6 and the other part underneath storage rooms 7, 8 and 9. The concrete floor plates of storage room 7 and 8 were partially shoved over the floor plates of storage room 6.
A reasonable explanation for this is that the explosion probably started in storage room 6, immediately followed by an explosion in storage room 7, 8 and 9. The latter was responsible for shoving the concrete floor plates over each other. This sequence of events is also in agreement with the locations where some of the green plastic fragments were found.

A second fact to support the theory of an initial explosion immediately followed by a second one, is the crack pattern in the concrete floor plates in front of the storage rooms (see Figure 8).

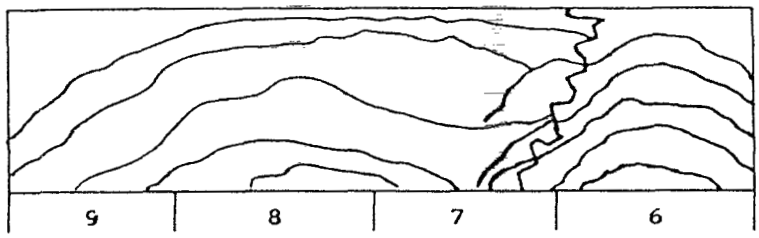

Figure 8 Cracks in concrete floor in front of the storage rooms

This pattern showed two circular crack zones, one in front of storage room 6 and one in front of the storage rooms 7, 8 and 9 and a large cross crack perpendicular to the storage rooms. The circular cracks in front of storage room 6 were not interrupted by the cross crack while the circular cracks in front of 7, 8 and 9 were. This indicates that the cracks in front of rooms 7, 8 and 9 were created after the formation of the cracks in front of room 6.

In summary:
- no display fireworks were found with a HD other than HD 1.3
- no articles or projectiles were found other than originating from the display fireworks or packages
- the domestic wastes mini container fragments and the crack pattern both indicate that there were two explosions, the second immediately occurring after the first one
- there was no deflagration preceding the detonation as no large parts of the wooden doors were found

8 CONCLUSIONS

It was concluded that:

- the damage caused by the explosion was comparable to a surface explosion of at least 1000 kg TNT. A best average value of the explosion strength is 2000 kg TNT
- the explosion started in one of the storage rooms of the new building which caused a sympathetic explosion in the three adjacent storage rooms
- the explosion could only by caused by an amount of explosives which acted as belonging to the HD 1.1

An amount of explosives with HD 1.3 can produce a mass explosion if:
- stored with a small amount of HD 1.1
- the classification of at least one type was wrong
- the storage conditions differed from transportation conditions
- assemblage of fireworks changes the nature of the article and thus influences the hazard division.

All these conditions could be present:
- although the presence of 200 kg black powder was confirmed by the owner, it was not found in the old bunker where it should be. In fact black powder was not found at all except within the recovered items.
- test performed by TNO-PML on display fireworks articles with similar pyrotechnic substances as were recovered indicate a HD 1.1 hazard rather than a HD 1.3 hazard.
- recovered items were similar to items responsible for an explosion of a fireworks factory in the UK.

Definite indications for the direct cause of the explosion were not found.

It is recommended to make an evaluation of the damage caused by the explosion in relation of the criteria of the quantity distances as recommended by the AC/258 storage group. This should be done especially for the fragment and debris criterion for HD 1.1 as large pieces of steel girders were thrown far beyond the 400 m circle.

It is recommended to require classification procedures for display fireworks. Not only for transport conditions but for fabrication, assembling and storage conditions also. The application of classification results for transport conditions to other circumstances as is usual presently must be strongly rejected.

9 REFERENCES

1 W.P.M. Mercx et al.
'Report from the Prins Maurits Laboratory TNO concerning the explosion of the 'MS Vuurwerk' fireworks factory at Culemborg on Thursday 14 February 1991.
PML 1991-C35,
TNO Prins Maurits Laboratory, May 1991, The Netherlands.

2 Committee for the Prevention of Disasters due to Hazardous Materials
Methods for the determination of possible injuries and damage to persons and goods doe to the release of hazardous substances (in Dutch)
'Green Book', Directorate-General of Labour, Voorburg 1990

3 Norville, H.S., Minor, J.E.
Glass Failure Prediction for Arnold Engineering Development Centre
AEDC, AEDC-TR-87-32, Arnold AFB, TN, 1987

4 Henderson J
Joint AUS/UK stack fragmentation trials, Phase 3
ESTC/Report No. 2/90, Ministry of Defence UK
London, November 1990

5 Amelsfort van, R.J.M.
Preliminary experiments with some types of display fireworks
PML 1990-28 (in Dutch)
TNO Prins Maurits Laboratory, May 1990, The Netherlands

ABSTRACT

On February 14 1991 a heavy explosion completely destroyed the assembly plant for display fireworks "MS Vuurwerk" in Culemborg, The Netherlands.

An Investigation was carried out in order to determine the strength of the explosion on basis of damage caused to the buildings in the vicinity.
The damage was severe and extended a large area.
Therefore. an investigation was performed to determine the kind of articles involved and the Hazard Division they belong to.

The paper describes the accident, the damage analysis and the remaining doubts and questions.
Special attention will be paid to the relation between the (possible) differences between transport and storage classification.