Preliminary modelling of the vapour release from LG Polymers, Visakhapatnam on 7 May 2020

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INTRODUCTION

The LG Polymers plant is located in Venkatapuram, a suburb of Visakhapatnam city. The plant stores and uses styrene monomer for making plastic products. A toxic vapour was released from the plant at about 2.30 am on 7 May 2020, and vapour emission continued for many hours. The precise sequence of the accident and the exact constituents of the release, such as presence of other gaseous compounds if any, is unknown at this point of time. Over 1,000 persons were hospitalized on 7 May morning due to toxic vapour inhalation and about 400 are still under treatment. Eleven persons died on 7 May and one more person died subsequently.

SITE INFORMATION

The area around the LG Polymers plant is thickly populated on all sides except towards the Northeast where the Simhachalam hills lie, and the Southwest.

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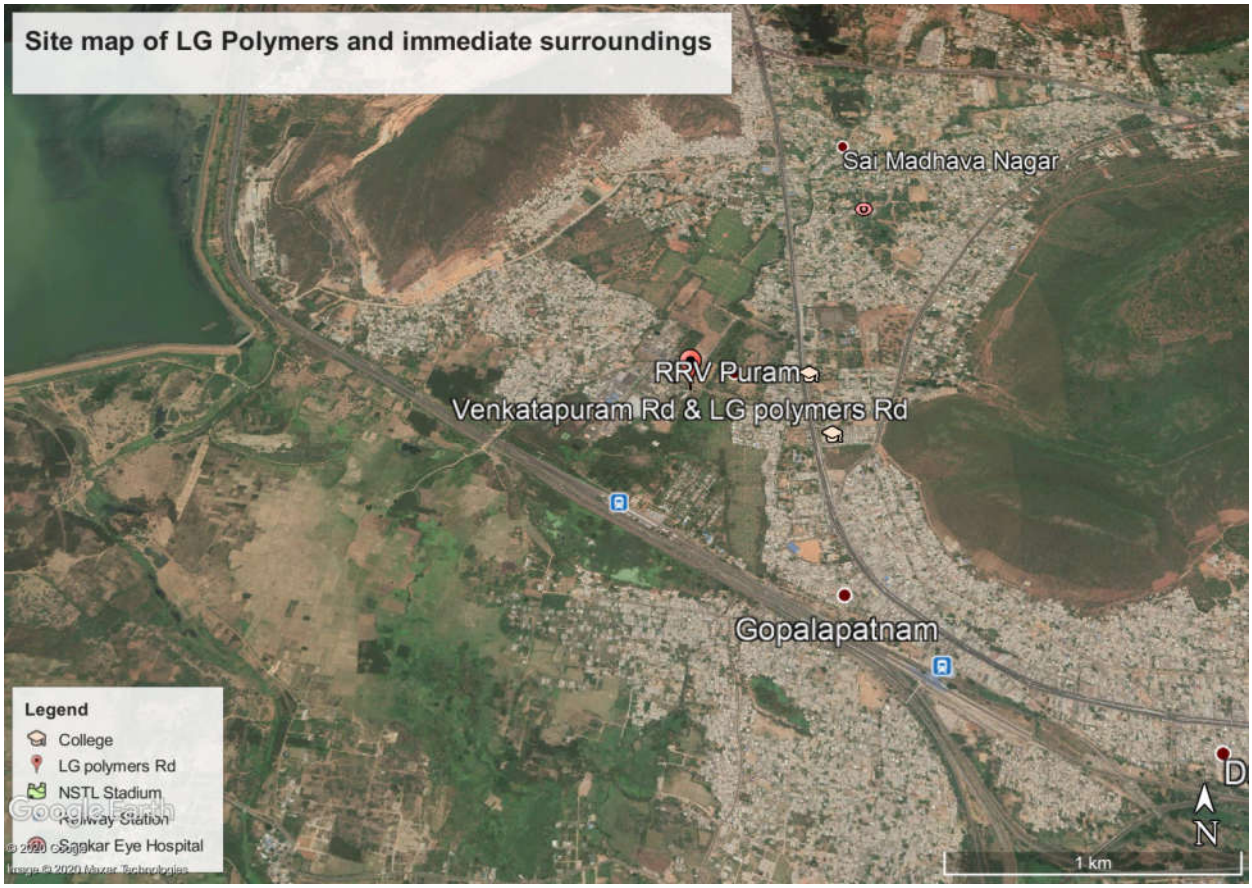


SOURCE INFORMATION

Released chemicals: Commercial styrene consists of 99.93% styrene, the remaining 0.07% being constituted by 18 hydrocarbon compounds. The precise composition of the release from LG Polymers is not known. Besides styrene, other hydrocarbons in styrene and some degradation by-products of styrene may also have been in the released vapours.

Tank details: From the information provided by Dr S Bala Prasad, Environmental Engineering Division, Civil Engineering Department, Andhra University, the dimensions of the tank from where the release occurred were: height-12 m, diameter-18 m, relief valve diameter-6 inches, material in the tank at the time of the release-1,900 T.

Since styrene should be kept at low temperatures (<18ºC) to minimize the occurrence of self-polymerization, the tank has a cooling system with a refrigeration unit attached to it. To prevent a polymerization reaction, an inhibitor, TBC, is added to styrene.

Meteorology: The meteorological conditions at the time of the release are not known. As Visakhapatnam is a coastal city, and the release happened at night, it would be safe to assume that at the time of the accident the wind speed would have been low, i.e., <1 m/s and would have been towards the sea, somewhere in the Northeast to Southeast arc.

PROBABLE ACCIDENT SEQUENCE

From anecdotal information, it appears that the long COVID-19 lockdown period may have reduced the inhibitor concentration in the tank, or no inhibitor was added for a considerable period, and the refrigeration system was either not working or was working insufficiently for some time before the accident. This may have led to an increase in the temperature of the tank contents and increased the rate of polymerization reaction, thus increasing the temperature inside the tank to 180º C, leading to the relief

valve popping and releasing some of the tank's contents to the atmosphere. The vapours released seem to have formed an aerosol cloud in the atmosphere, which then carried with the wind. The cloud behaved like a dense gas, which is why people on the second story of houses were relatively less affected.

MODELLING METHOD

ALOHA, a screening model based on DEGADIS, was used to model the release. ALOHA provides reasonably accurate information on the expected vulnerable zones (areas that will be affected) under various release conditions. The input data used for the modelling was as follows:

Chemical: Styrene monomer behaving as a dense gas.

Meteorology: Wind direction—East, Wind speed—0.62 m/s, Atmospheric stability class—F- stable.

Release modelling: Modelling was done for styrene monomer released from the tank through a 6" diameter valve.

Vulnerable zones: The results of the modelling were mapped onto a google map as red, orange, and yellow zones. These zones are defined as areas that may cause the following impacts:

Red zone: Has styrene monomer vapour concentrations of >1,100 ppm. Exposure for up to 60 minutes to such concentrations may have life-threatening health effects or may cause death.

Orange zone: Has styrene monomer vapour concentrations ranging 130-1,100 ppm. Exposed persons could experience serious adverse health effects or an impaired ability to escape in a 60 min exposure period to these concentrations.

Yellow zone: Has styrene monomer vapour concentrations ranging 20-130 ppm. Exposed persons may experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of a 60-minute exposure to these concentrations.

The red, orange, and yellow vulnerable zone definitions are from US Environment Protection Agency's Acute Exposure Guideline Levels[3] (AEGLs) for acute exposure[4] to styrene monomer concentrations by public.

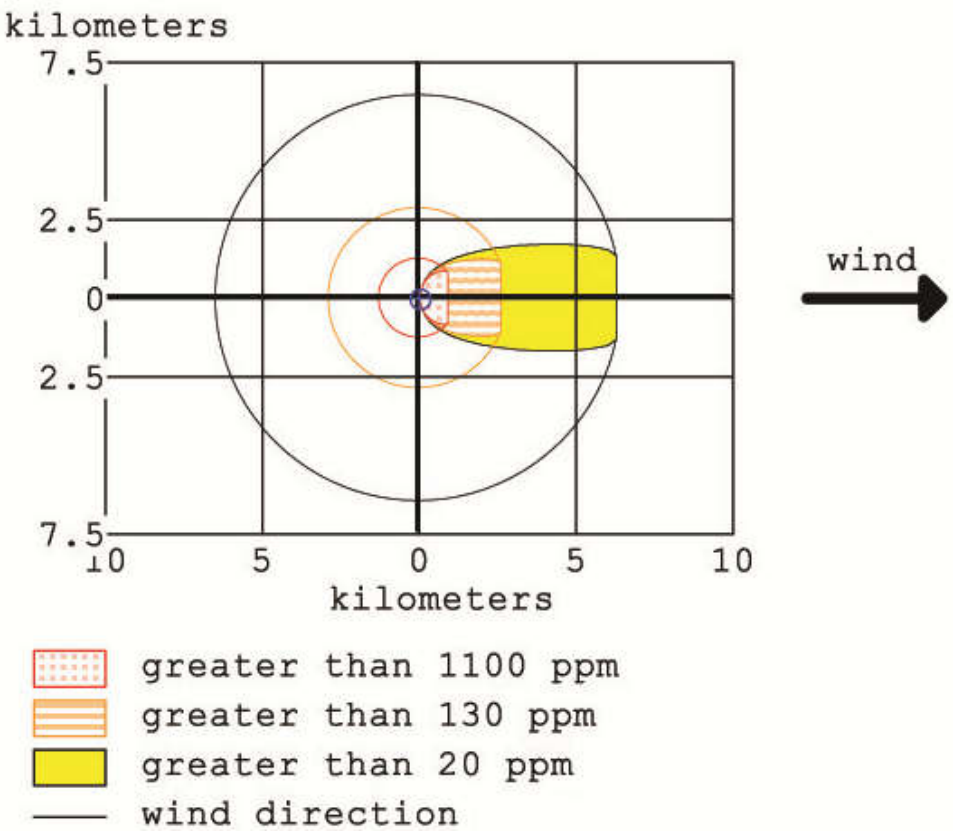
Since the release continued for well over one hour, wind direction shifts would have occurred during this period. The red vulnerable zone therefore constitutes the entire area enclosed by the radius from the styrene tank up to the point where the vapour concentration drops to 1,100 ppm. The other two zones constitute the entire area of the annuli between the concentrations 1,100-130 ppm (orange zone) and 130-20 ppm, respectively.

This study was done under constraints of not having all the necessary source data. Assumptions had to be made to obtain a first approximate picture of the toxic vapour cloud spread. As more information becomes available, the model will be re-run to obtain results which provide a more accurate understanding of the toxic vapor release from LG Polymers.

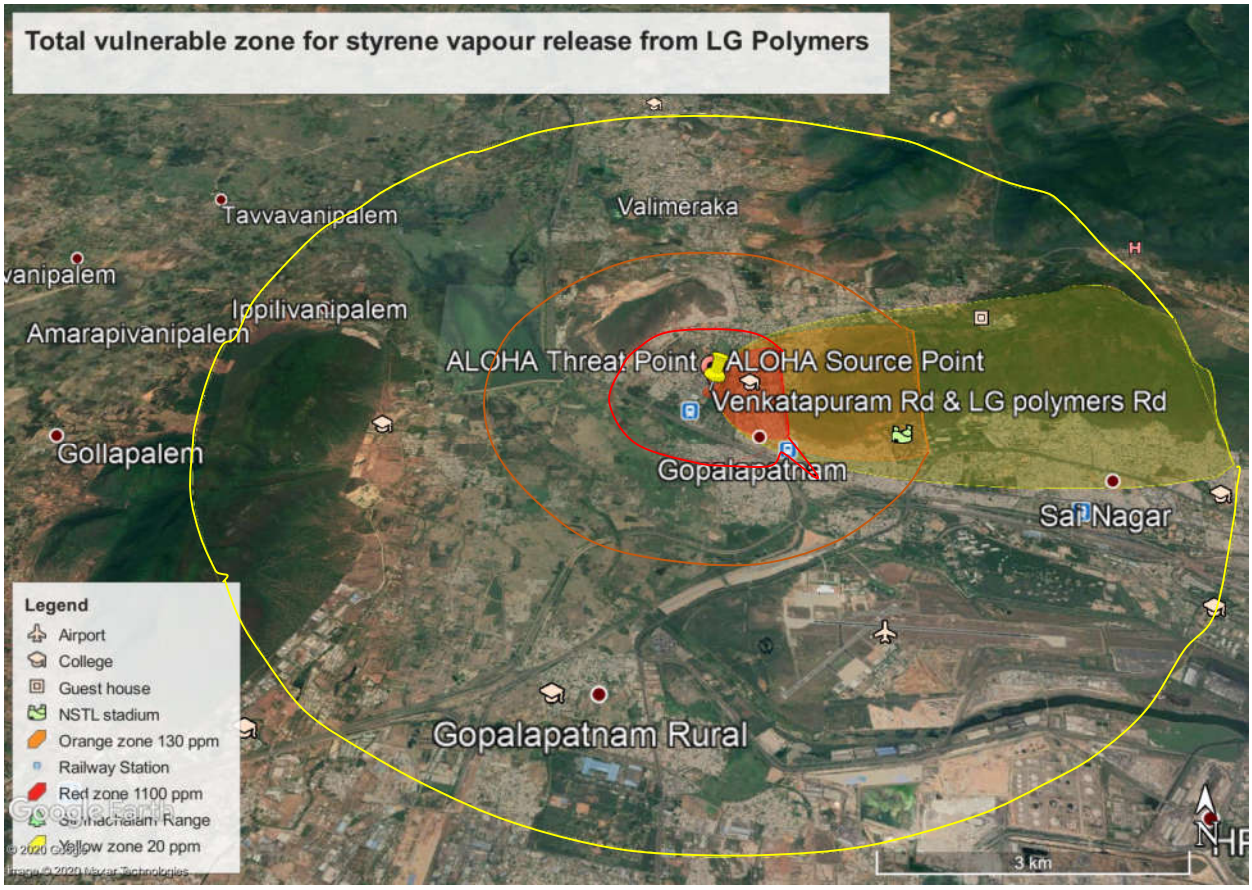
RESULTS

The radii of the various vulnerable zones computed by the model are: Yellow zone = 6.3 km from the source, Orange zone = 2.6 km from the source, Red zone = 1.0 km from the source (see figs below).

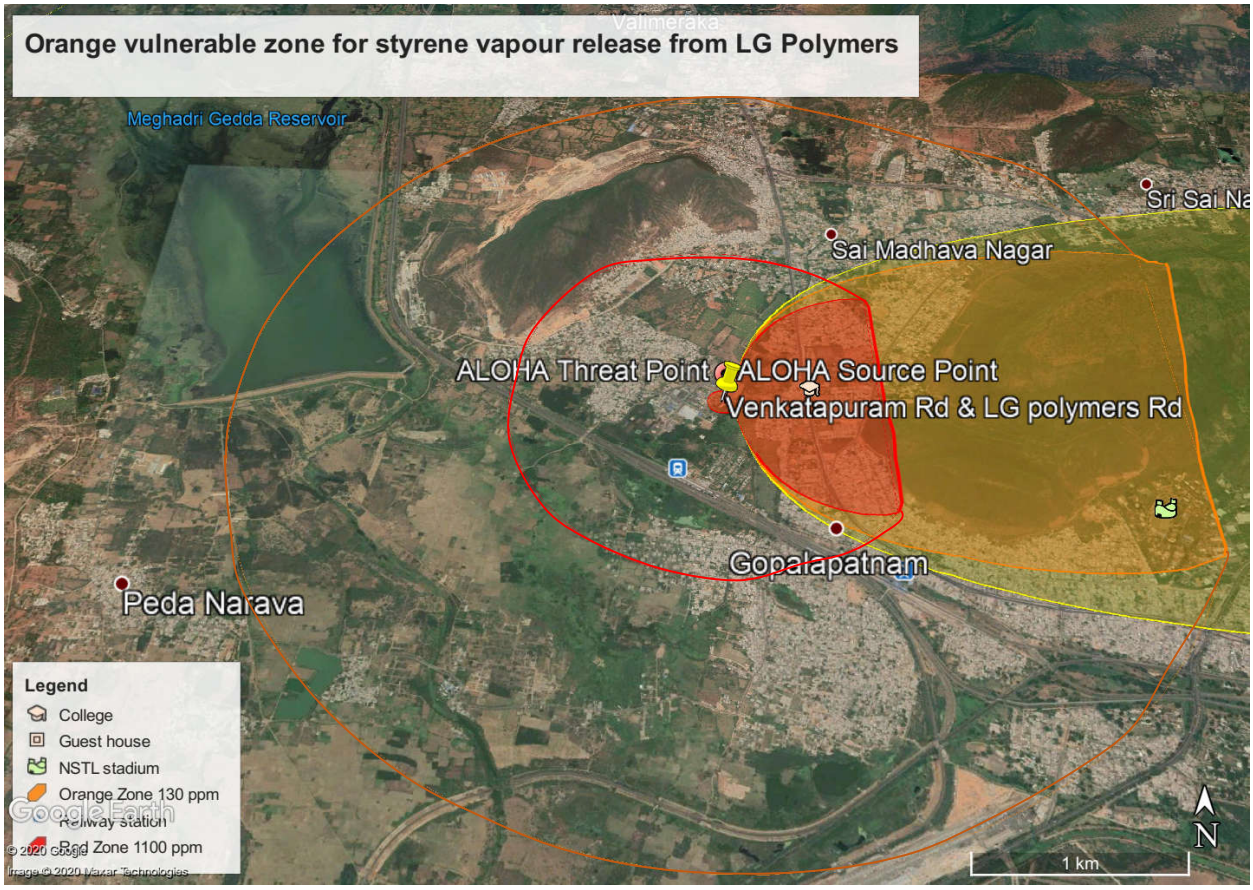
[3] AEGLs estimate the concentrations at which most people—including sensitive individuals such as old, sick, or very young people—will begin to experience health effects if they are exposed to a hazardous chemical for a specific length of time (duration).
[4] Acute exposures are single, non-repetitive exposures that do not exceed 8 hours.



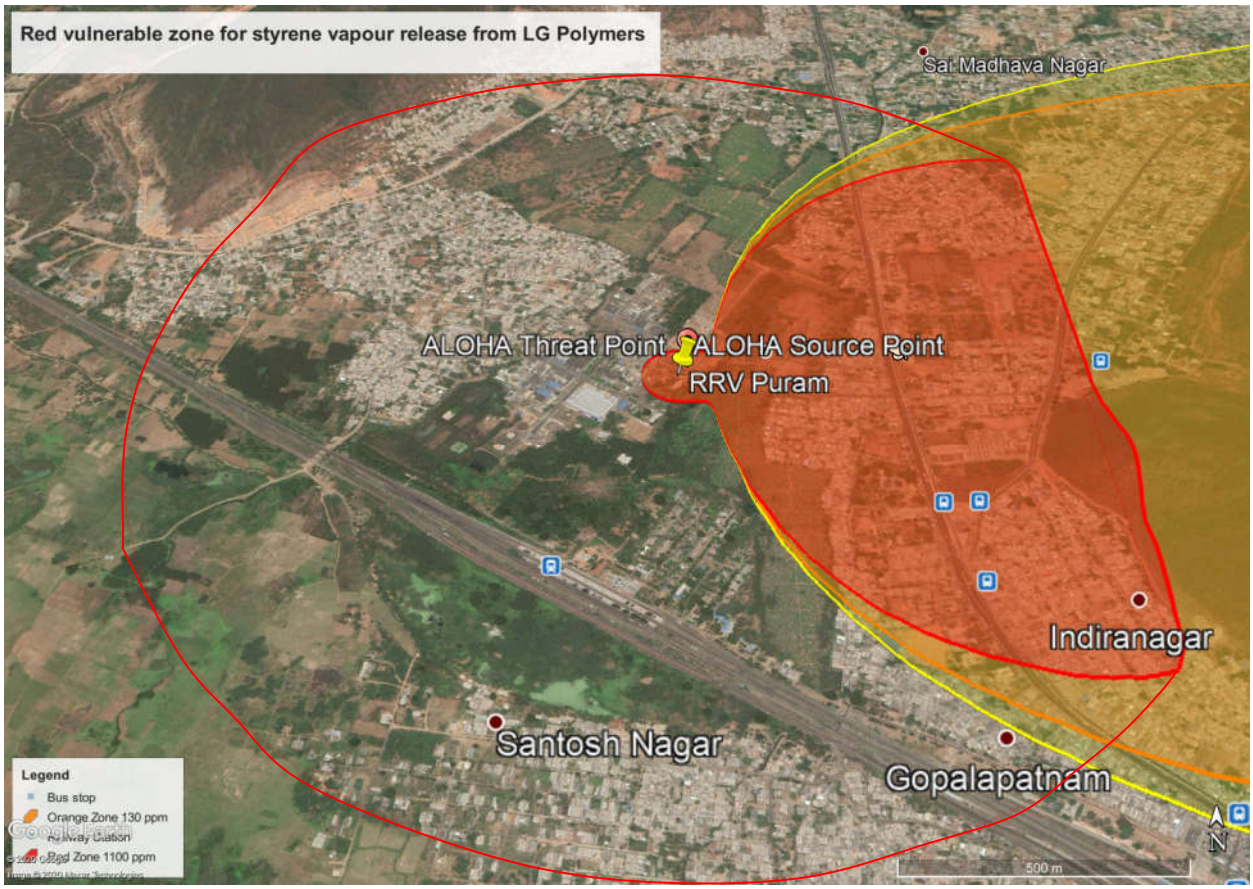
Vulnerable zones computed by model



Yellow, orange, and red vulnerable zones shown on Visakhapatnam map



Orange, and red vulnerable zones shown on Visakhapatnam map



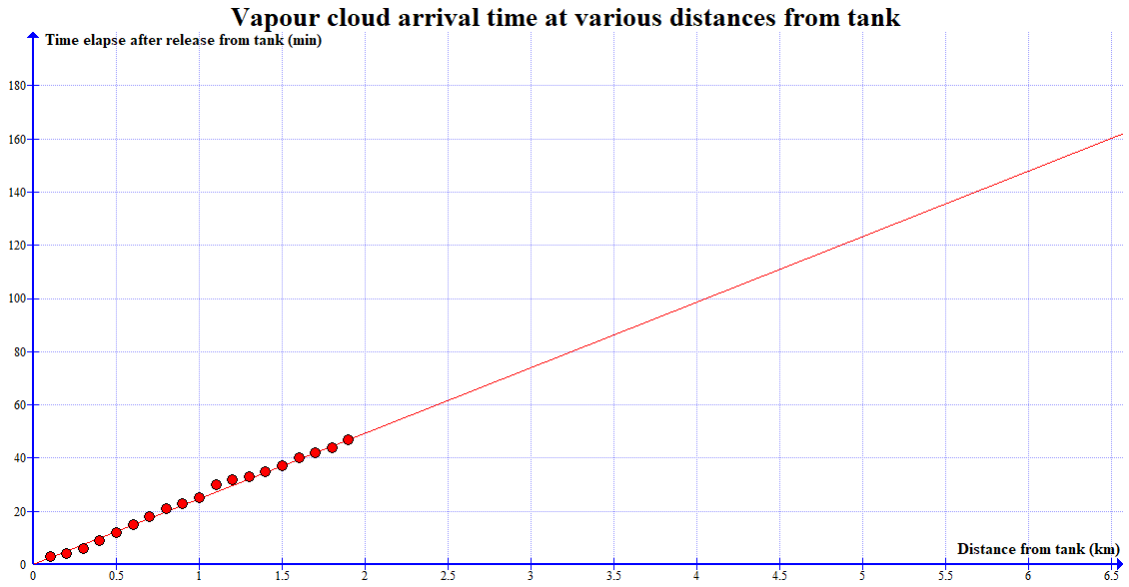
Red vulnerable zone shown on Visakhapatnam map

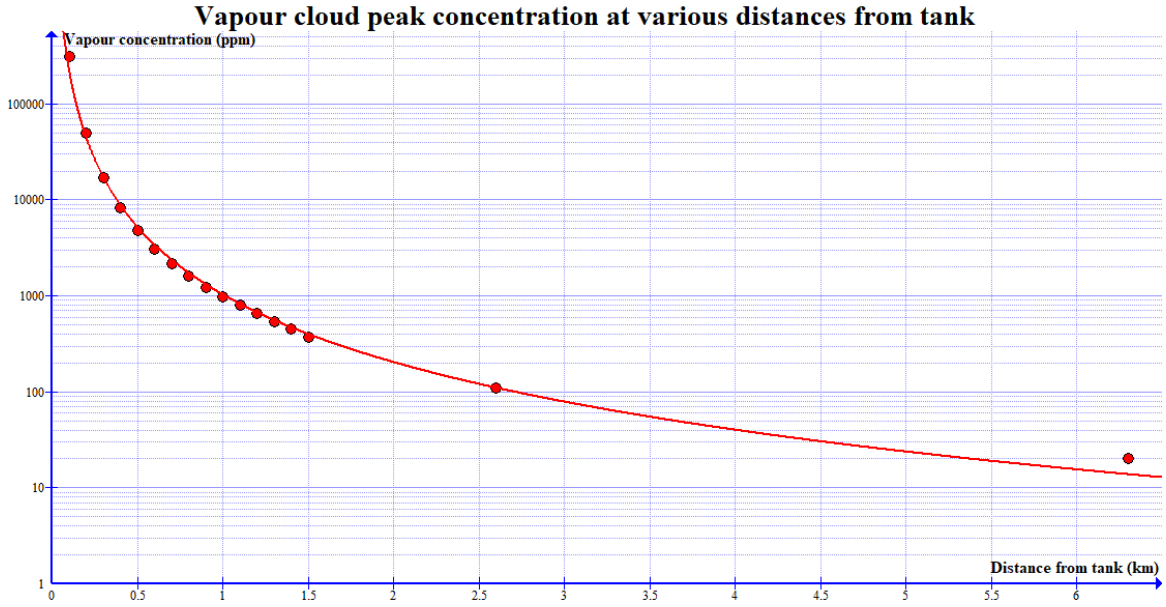
The modelled results of the time the vapour cloud took to reach various distances in the red and orange zones, the peak vapor concentration at these points, and the time it took to build up to peak concentrations at various distances in the red and orange zones (see table below).

Modelled results of vapour cloud arrival time, peak concentrations, and build up time for peak concentrations in red and orange zones

Downwind distance	Vulnerable zone	Time for vapours to reach downwind distance	Peak vapour concentration at downwind distance	Time for vapours to reach peak vapour concentration
(km)		(minutes)	(ppm)	(minutes)
0.1	Red	3	312,000	5
0.2		4	49,700	10
0.3		6	17,100	16
0.4		9	8.250	20
0.5		12	4,770	25
0.6		15	3,080	26
0.7		18	2,160	30
0.8		21	1,600	35
0.9		23	1,230	40
1.0		25	975	45
1.1	Orange	30	792	50
1.2		32	653	55
1.3		33	542	60
1.4		35	450	>60
1.5		37	368	>60
1.6		40	294	>60
1.7		42	227	>60
1.8		44	167	>60
1.9		47	151	>60
2.0		52	137	>60
2.5		61	114	>60

Based on the above modelled results, best fit curves were drawn for these parameters (see graphs below), an extrapolation was done to obtain the time the vapour cloud took to reach various distances in the yellow zone, and the peak vapor concentration at these distances (see table). The vapour concentration of 20 ppm at a a distance of 6.3 km from the tank is a modelled result and not an extrapolated value.





Extrapolated vapour cloud arrival time and peak concentrations in yellow zone

Downwind distance	Vulnerable zone	Time for vapours to reach downwind distance	Peak vapour concentration at downwind distance
(km)		(minutes)	(ppm)
2.6	Yellow	65	110
3.0		74	81
3.5		84	55
4.0		102	45
4.5		109	37
5.0		125	29
5.5		134	26
6.0		147	23
6.3		154	20

OBSERVATIONS

1. **Important locations in vulnerable zones:** There are several hospitals, educational institutes, places of worship, railway stations and the airport within the vulnerable zone.

2. **No UVCE**: Styrene is an explosive substance with a lower explosive limit (LEL) of 0.9% v/v in air, and an upper explosive limit (UEL) of 6.8% v/v. It was fortuitous that the release happened during the night and therefore the vapour cloud did not meet a flame and explode in an unconfined vapour cloud explosion (UVCE). Had a UVCE occurred, the number of casualties would have been higher.

3. **Higher casualties if release had happened during daytime:** Had the release occurred during the day, when more people may have been on the streets despite the COVID-19 lockdown, casualties may have been higher.

4. **Time between process upset and vapour cloud reaching red, orange and yellow zone outer boundaries:** According to Plastics Europe's *"Styrene Monomer: Safe Handling Guide,"* if the temperature of styrene monomer exceeds 65°C there is a 20-minute window of opportunity before a runaway reaction sets in.

   After the vapour cloud was released from the tank, it would have taken 15 minutes to reach the outer limit of the red zone, i.e., 1 km from the tank. If the siren had been sounded 5 minutes after the tank temperature had risen to 65°C, persons at that distance from the tank would have had 40 minutes to

evacuate their homes. Evacuation times for all three vulnerable zones were computed similarly and shown in the table below.

Evacuation time available in various zones if siren was sounded 5 minutes after tank temperature reached 65°C

Zone	Distance from tank	Time available if siren had been sounded 5 minutes after temperature in the tank rose to 65°C	Time available before vapour cloud reaches zone	Evacuation time available in each zone
	(km)	(min)	(min)	(min)
Red	0-0.5	15	3-12	18-27
	0.6-1.0	15	15-25	30-40
Orange	1.0-2.5	15	30-61	45-76
Yellow	2.6-6.3	15	65-154	80-169

5. **Violation of legal provisions:** Per Section 15 (1)[5] of the *Manufacture, Storage, and Import of Hazardous Chemicals Rules, 1989,* bystander populations should have been informed of the risk they were at, and trained in evacuation procedures in the event of an accident. From anecdotal information, this apparently was not done.

6. **Violation/non-enforcement of APPCB orders:** The Andhra Pradesh Pollution Control Board's (APPCB) Consent for Operations (CFE) Committee had passed an order in the period 1999-2000 stating that all facilities handling hazardous chemicals must put a board with a figure of the maximum vulnerable zone in the event of a catastrophic accident at their main gate and that is visible to public. Since this order was passed when Andhra Pradesh was a single state, the APPCB order unless rescinded, is still applicable to Andhra Pradesh and Telangana. Several plants, e.g., Indian Oil Corporation LPG Bottling Plant, Kondapalli, put up such boards at their main gates (see pictures below).

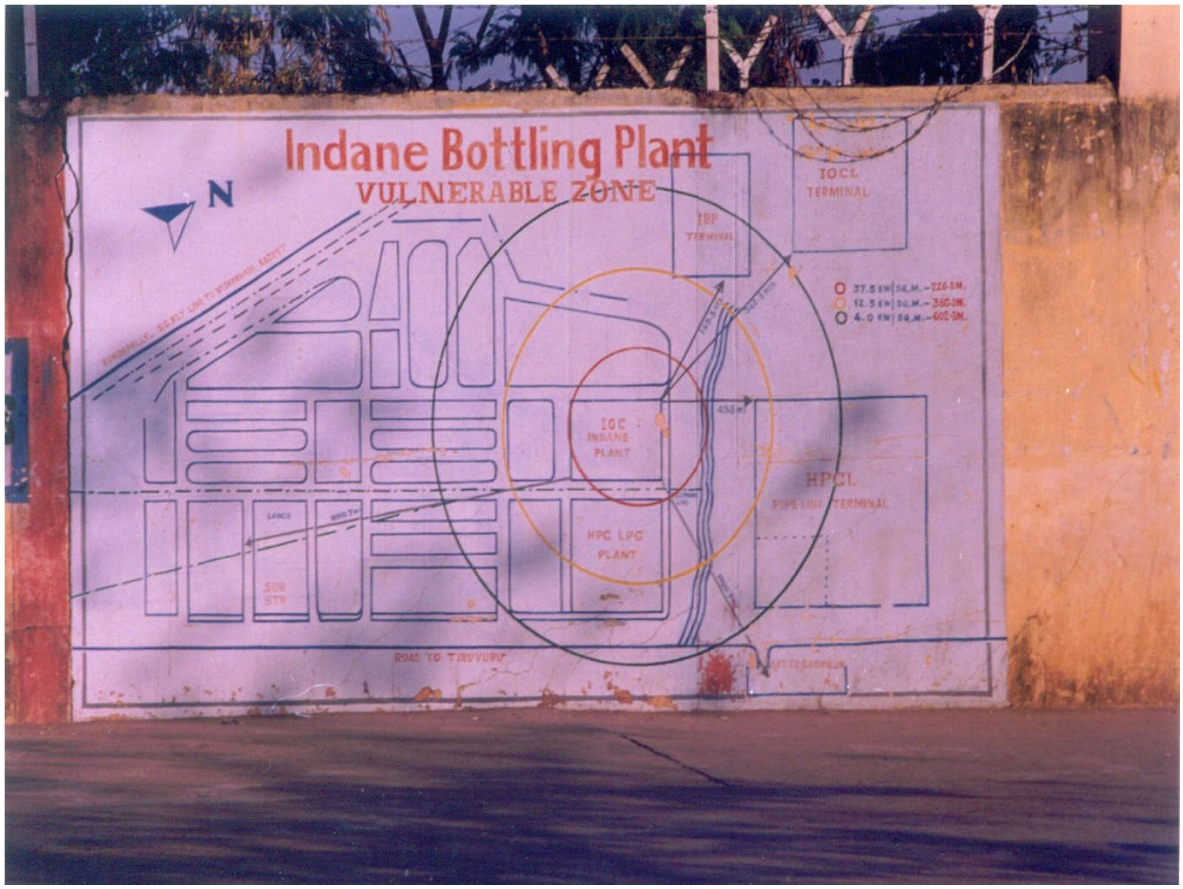
   There has been no public information that this order was rescinded by APPCB and is therefore still applicable to Andhra Pradesh. From anecdotal information, such a board carrying the maximum vulnerable zone in the event of a catastrophic accident was not put up by LG Polymers. It appears that APPCB did not enforce its own orders.

CONCLUSION

If the siren had been sounded 5 minutes after the temperature had risen to 65°C, persons staying in the orange and yellow zones had 45-70 minutes and 80-170 minutes, respectively, to evacuate their homes (see table above). Persons in the red zone between 0.5-1 km distance from the tank had between 30-40 minutes to evacuate. These were ample for an evacuation in the yellow, orange and the outer half of the red zones. Yet, evacuation was not done until later. This increased the number of deaths and injuries. It is only persons in the red zone who lived within 0.5 km from the tank, who would have had 18-27 minutes to evacuate.

Per the Hazardous Chemicals Rules provisions and the APPCB CFO order, had a) information regarding the risk that LG Polymers plant posed to bystander population been told to them, b) had the bystander population been trained in emergency evacuation procedures, and c) had the siren been sounded soon after the tank temperature had risen to 65°C, deaths may have been avoided and injury to public minimized.

[5] 15. **Information to be given to persons liable to be affected by a major accident.** (1) The occupier shall take appropriate steps to inform persons outside the site either directly or through District Emergency Authority who are likely to be in an area which may be affected by a major accident about-(a) the nature of the major accident hazard; and (b) the safety measures and the "Do's and Don'ts" which should be adopted in the event of a major accident



Maximum vulnerable zone area map at Indian Oil Corporation Ltd, Kodapalli LPG Bottling Plant