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Risk Analysis of a Gas-Processing Complex in India

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ONGC's Hazira Gas-Processing Complex (HGPC) consists of facilities for receiving natural gas along with associated condensate from an off-shore field at a rate of 20 MMN M^3 per day. After separating the condensate, which is processed in condensate fractionation units, the gas is processed through various steps to recover LPG and to reduce its dew point to less than 5°C in order to make it suitable for transportation over long distances. The acid gas recovered during the gas-sweetening step is processed to obtain sulphur. The major products manufactured at HGPC therefore are lean sweet gas, LPG, NGL, and sulphur. The Oil and Natural Gas Commission awarded the assignment on Hazard Study and Risk Analysis of their Hazira Gas-Processing Complex (HGPC) to the Council of Scientific and Industrial Research (CSIR) in association with the Netherlands Organisation for Applied Scientific Research (TNO). The scope of this assignment covered a number of closely related and fully defined activities normally encountered in this type of work. Identification of hazards through the most appropriate methods, assigning frequency of occurrence of major unwanted incidents, quantification and assessment of probable damage to plant equipment, environment, human and animal life due to an unexpected event, and evaluation of various methods for reducing risk, together constituted the methodology for this assignment. Detailed recommendations aimed at reducing risk and enhancing reliability of plant and machinery were made. This article gives an overview of the assignment.

KEY WORDS: Hazard identification; HAZOP; FTA; risk quantification.

1. INTRODUCTION

The processing of natural gas involves a number of unit operations, some of which are carried out at high pressures and temperatures. Depending on the process requirements, pipelines and vessels are constructed in special alloy steels and other suitable materials. Complex process control equipment is deployed to ensure that the operations are conducted strictly under specific conditions for which the plant and equipment is designed. Adequate safety measures are planned in the form of gas detectors, relief systems, etc., in order to check effects of any deviations in operating parameters. These precautions do significantly reduce the frequency of, and the damage caused by, undesirable events. Nevertheless, a systematic assessment facilitates efficient and effective management of risk associated with the operations.

The Oil and Natural Gas Commission of India assigned the task of risk analysis of their Gas-Processing Complex, located at Hazira, to the Council of Scientific and Industrial Research of India (CSIR) in association with the Netherlands Organization of Applied Scientific Research (TNO). The assignment covered facilities to receive the sour natural gas and associated condensate, processing units, storage, loading and unloading stations of all products, and raw materials as well as other offsites.

The scope of the assignment was adequately defined to include hazard identification through MCA studies, hazard analysis through checklists and HAZOP, failure

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frequency for process equipment/instrumentation, risk analysis through risk contours, emergency preparedness plans, recommendations for safety of plant and personnel, special measures for storage and handling of LPG, NGL, and other inflammables, and hazards due to toxic gases. While TNO nominated their Department of Industrial Safety, CSIR participated through the following institutes: Indian Institute of Chemical Technology, Hyderabad (Co-ordinating Institute), Central Leather Research Institute, Madras, Regional Research Laboratory, Jorhat, Industrial Toxicology Research Centre, Lucknow, and National Environmental Engineering Research Institute, Nagpur.

2. THE COMPLEX

The Hazira Gas-Processing Complex (HGPC) is built to process 20 MM NM^3/day of gas and associated platform as well as pipeline condensate from the South Bassein Gas. The gas and the condensate are received at Hazira through an off-shore pipeline up to the landfall point at Umrat and an onshore pipeline from Umrat to Hazira.

Since the gas/condensate contains H_2S and water, facilities for gas/condensate sweetening—along with gas dehydration, dew-point depression, and sulphur recovery—are available at HGPC.

The integrated utilities and off-site facilities are provided for the various plants. These include power, steam, condensate and soft water, raw water, product storage and transfer system, chemical storage and transfer system, flare system, caustic wash unit for LPG/NGL, and effluent treatment system.

Products from HGPC facilities are:

Sweet Gas: 15 MM NM^3/day
Lean sweet gas (HP): 4 MM NM^3/day
(LP): 0.64 MM NM^3/day
LPG: 4,26,000 TPA
NGL: 10,70,000 TPA
Sulphur: 17,800 TPA

Once fully implemented, HGPC is expected to meet the feed stock requirements of 8 fertilizer plants producing 5.9 million tonnes per annum of urea. The LPG produced from the complex is expected to provide additional 2.8 million LPG connections in the country. NGL from the complex can be substituted for Naphtha.

Figure 1 gives an overall block diagram of the gas-processing facilities.

3. OVERALL METHODOLOGY

Hazard studies and risk assessment are customized combinations of standard procedures[1] which help to create a model/representation of a complex system[2] through which potential hazards are identified,[3,4] categorized,[5,6] and quantified. The overall risk management is then based upon an effective deployment of decision-making tools commensurate with this assessment.[7]

In the present case, identification of potential hazards through the following techniques was attempted:

- Scrutiny of process conditions and process control strategy
- Maximum credible accident analysis by calculation of physical effects and consequences
- HAZOP

In addition, processing areas were also classified according to *Dow's Fire & Explosion Index* to provide data for a formal safety audit. Scenarios short-listed as a result of the above exercises were subjected to further investigation to arrive at the frequency of the occurrence through Fault Tree Analysis. Quantitative risk assessment in terms of levels to which individuals or groups are exposed was performed by forming "clusters" of undesirable events. Meteorological and demographic data as well as the probability of occurrence were important parameters for the latter. Specific risk-reducing measures were considered and recommended where the probability and the consequences of incidents were found unacceptable as per the predetermined criteria.

4. INVENTORIES

A large number of chemicals and hydrocarbons are handled at the complex (Table I). An area-wise inventory of materials was prepared where essential information with respect to conditions of containment were listed. Consequence evaluation procedures deploy mathematical models to describe the pattern of dispersion of toxic and hazardous materials. For this purpose, a comprehensive database of relevant physicochemical and thermodynamic properties had to be generated corresponding to the chemical composition of various process streams. Each inventory is evaluated based on its hazardous nature, temperature, and pressure in relation to the flash point, auto-ignition characteristics, and its location in the complex.

In the case of pipeline flow, the flow rates and the total material handled are also considered since these

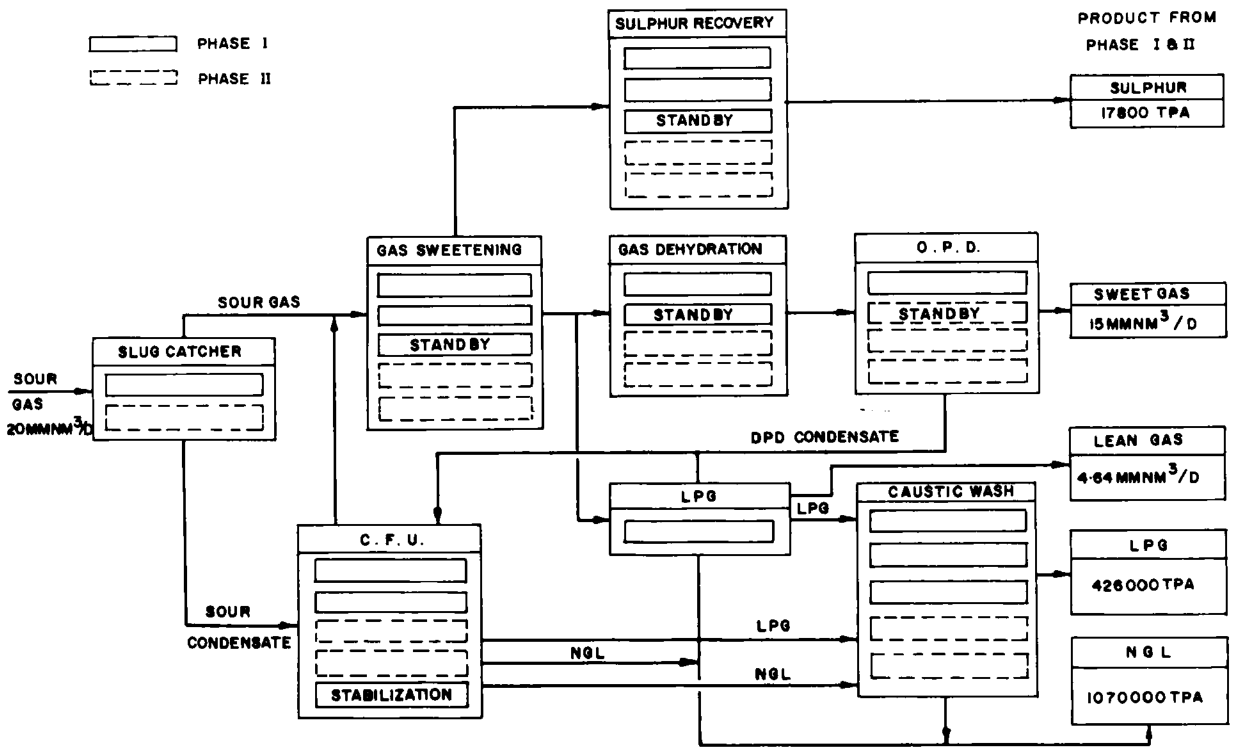

Fig. 1. Overall flow scheme of Hazira Gas Processing Complex

Table I. Chemicals Handled

Sour gas	LPG
Acid gas	Condensate
Sweet gas	NGL
MDEA	Ethyl mercaptan
Methanol	Chlorine
Fuel gas	Sulphuric acid
TEG	Sodium and potassium hydroxide
Propane	Hydrazine

Table II. List of Vulnerable Process Steps

1. Sulphur recovery unit
   - Lo-cat reactor
   - Molten sulphur storage
2. Gas sweetening unit
   - Absorber
   - Stripper
3. Dew point depression unit
   - Propane accumulator
4. LPG recovery unit
   - Dryer regeneration
   - LEF column
   - KO drum
5. Condensate fractionation unit
   - Stripper
   - LPG column
6. Utilities and off-sites
   - LPG storage
   - LPG loading
   - Propane storage
   - Propane unloading

"dynamic" inventories may or may not be isolated effectively during an incident.

5. VULNERABLE OPERATIONS

Process steps which were considered "vulnerable" and required further investigation were listed (Table II) along with the reasons for their identification.

A study of process know-how documents of the plant reveals the extent of variation allowable in process parameters for safe operation. Deviations of these parameters beyond the allowable limits may lead to process instability and hazardous situation. While deciding the vulnerability of a process step, these limiting conditions were considered by a group of process design, process control, and instrumentation engineers.

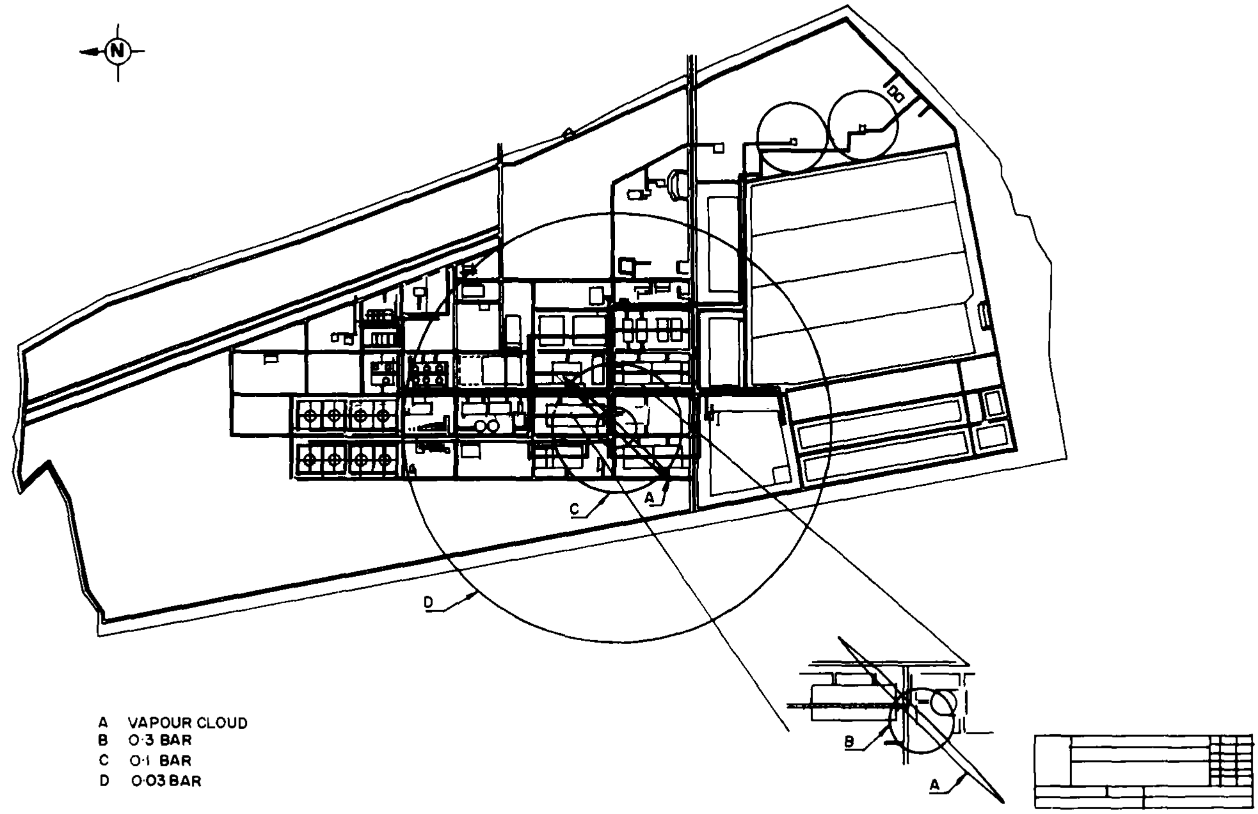

Fig. 2. Damage distances for Scenario No. 16

Table III. Hazop Cases

1. Sulphur recovery unit
Lo-cat reactor
Molten sulphur storage
2. Dew point depression unit
Propane accumulator
3. LPG recovery unit
Dryer regeneration unit
LEF column
KO drum
4. Condensate fractionation unit
Stripper
LPG column
5. Utilities and off-sites
LPG storage
LPG loading
Propane storage
Propane unloading

Since probability of human failure has, in some cases, been rated higher compared to mechanical failure, manual operations obviously find a place in the list of vulnerable operations. Operations involving mechanical equipment operating at severe conditions of temperature and pressure are also considered vulnerable.

6. MCA ANALYSIS

Maximum credible accident analysis formed a major part of the initial phase of the assignment. For this rapid evaluation of events resulting from a series of simultaneous and independent errors or failures were considered whose probabilities are well-established from the literature or from the past accident data.[9,10] The strategy adopted was designed to arrive at a list of scenarios which could be termed serious or most undesirable because of the possible damages/consequences. Release cases originating from vulnerable operations along with others were examined[8] by performing outflow calculations, behavior of the materials immediately after release, the dispersions in the surroundings, fires explosion, and toxic effect. It was thus possible to rank the scenarios with respect to their potential impact. A typical

Table IV. Hazop Work Sheet

Process Parameter: Flow — Process Unit: LPG storage — Node: Inlet line to sphere

Guide Word A	Deviation B	Instrument tag no. C	Causes D	Direct consequences of B E	Any other consequences F	Available safety provisions G	Clarification required H	Remarks I
Less	Less flow	ROV TSV-A TSV-B	Less flow from LPG and CF units	Loading takes more time		LSH LAH-A LAH-B		Potential hazard associated with overfilling
			Improper isolation of sphere	LPG level build up in other tanks				
			LPG going to other suction lines	Quality of LPG in other tanks may get affected				
			Other ROVs partially open	LPG in other tanks may get contaminated				
			Leakages	Iceing may occur during less flow which may weaken the pipelines				
			Obstruction in caustic wash unit	Extended operation time				
			TSV failure in loading line	Quality control problems in loading section				

Table V. List of Fault Trees

Release of acid gas to atmosphere from reactor
Release of SO_2 gas from sulphur storage
Overfilling and leakage of LPG Horton sphere
Bleve due to leakage from LPG Horton Sphere
Overfilling of LPG road tanker
Bleve due to overfilling of LPD road tanker
Overfilling of LPG rail tanker
Bleve due to overfilling of rail tanker
Overfilling of NGL road tanker
Propane release from propane accumulator
Hydrocarbon release from dryer regeneration unit
Hydrocarbon release from LEF column
Hydrocarbon release from KO drum
Hydrocarbon release from stripper of condensate fractionation unit
Hydrocarbon release from LPG column of condensate fractionation unit

example of the results plotted on the plot plan is illustrated in Fig. 2.

7. HAZOP STUDIES

This technique of identifying potential hazards originated from the need for a multidisciplinary approach to the problem of detecting an unsafe situation. It provides a clear understanding of the intentions of the designer through a systematic analysis of plant sections with respect to deviations from design intent.[11]

Since each of the process parameters gets examined for deviations at several "nodes," the exercise is time-consuming. Therefore, in the present assignment, a list of 12 cases (Table III) were subjected to HAZOP after considering the results of MCA analysis. Table IV is part of a HAZOP worksheet for LPG storage unit for the inlet line to the sphere. In this instance, the low flow to one sphere could be due to unintentional filling of another one leading to possible overfilling of the latter. Similar indications of potential hazard, involving specific process units were observed and recorded for further investigation or for formulating the final recommendations.

8. RISK QUANTIFICATION

The ultimate objective of assigning a numerical value to any specific release scenario is to assess its impact and devise means of mitigating its consequences. *A priori* knowledge or estimation of frequency of occurrence therefore is a prerequisite for any quantification efforts.

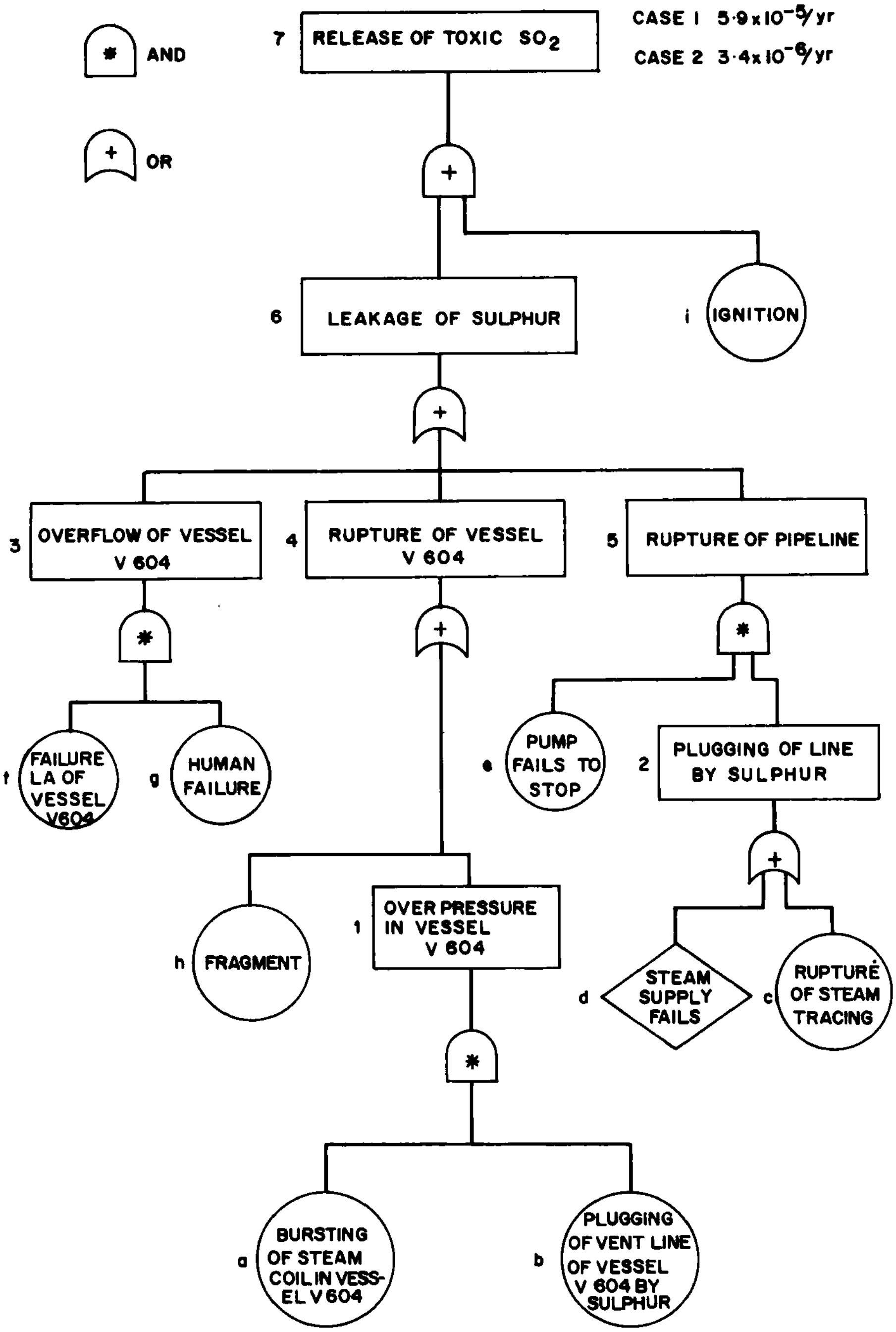

Fig. 3. Fault Tree for V-604

Frequency data is an essential component of other characteristics of the scenarios, such as its location, quantum and period of release of toxic/inflammable materials, relevant demographic and meteorological data, etc. These characteristics together determine the risk to which individuals or groups are exposed.

8.1. Fault Tree Analysis

Probability of the release scenario in terms of its occurrence, physical effects, and damages is an important aspect of quantification of risk. Exhaustive databases are available which provide probabilities of incidents commonly encountered in the chemical industry (e.g., probability of failure of pipelines, vessels, heat exchangers, control instrument, etc.). However, for those incidents where interaction between control instruments and operator is involved, under normal circumstances, such information can be derived from the construction of fault trees for specific undesirable event. A number of such events were identified (Table V). In each case, it was possible not only to calculate the frequency of occurrence but the primary events which contribute substantially to the increase in frequency could also be identified. Recommendations based on such analyses were made, giving due consideration to the total cost of implementation, to reduce the chances of occurrence of a "top event." A typical fault tree is illustrated in Fig. 3.

8.2. Risk Analysis

The damage criteria with respect to overpressures, heat radiation, and toxic effects of chemicals are presented in Table VI.

A frequency of less than 10^{-6} per year for hazardous events (of the type considered for fault tree analysis) was regarded as acceptable. Similarly, individuals or groups in areas with probability of fatality falling in the range of 10^{-5} to 10^{-4} per year were considered vulnerable, and accordingly suitable protective measures were suggested in those cases.

Failure rate data available in the literature were used for instruments, pipelines, vessels, etc. Whenever required, results of fault tree analyses were also utilized.

Locations of the undesirable events were decided by clustering of various scenarios. In this way, seven "clusters" were formed. Respective characteristics of the scenarios were used for the preparation of risk curves. The risk curves were presented in the following forms.

- Group risk curves for plant personnel and people living in the surroundings.

Table VI. Damage Criteria

	Lethality		
	100%	50%	1%
Heat radiation	Within the fire ball or cloud	—	—
Over pressure	—	—	—
Toxicity (mg/M^3/H_2S)	—	621	361

- Individual risk curves for the seven locations identified in the clusters.
- Individual risk contours on the plant and the surroundings.

The group risk curve or F–N curve (Fig. 4) is the graphical representation of probability and extent of damage. A point on the curve indicates the probability F that N or more fatalities would occur as a result of an accident at the plant. These group risk curves are obtained using the program RISK CURVES, available with TNO. The analysis of these group risk curves indicates the effect of the scenarios, source locations, and weather types. It also indicates the dominating scenarios, among others on the location, with respect to the risk involved.

An individual risk curve or F–X curve (Fig. 5) is the graphical representation of probability and the extent

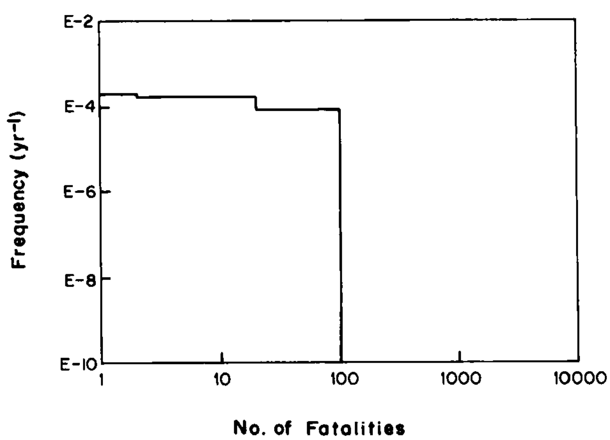

Fig. 4. F-N curve for location 5

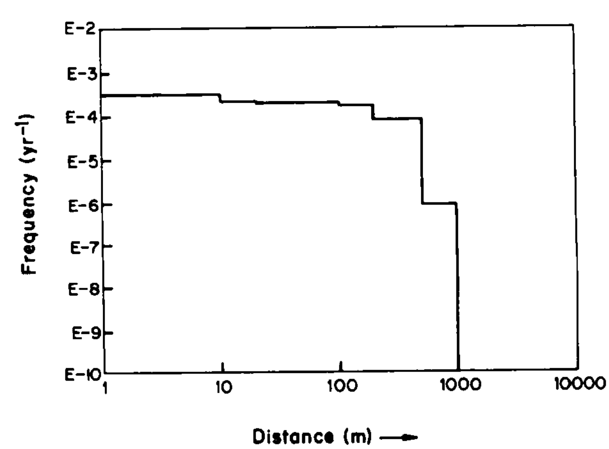

Fig. 5. F-X curve for storage area

of effects. A point on this curve represents the probability, F, that an individual at a distance, X, from the location of accident will be fatally injured.

An individual risk curve is only a representation of the risk in one direction; therefore, the individual risk contour is obtained as a two-dimensional plot in order to assess/visualize the areas of damages (Fig. 6).

9. RISK-REDUCING MEASURES

Several recommendations were made to achieve acceptable levels of risk for individuals and groups. Attention was focused on LPG storage and loading areas, LPG and sulphur recovery units, and the NGL storage area. A few examples of the suggestions made to reduce the risk associated with some operations are as follows:

- It was found that the existing level control instruments could be adopted to significantly lower the probability of overfilling of Horton spheres.[12]
- Automatic introduction of snuffing steam on to the heating coils of the regeneration gas heater was suggested to avoid the delay in activating the quenching system.
- Additional protection to the electrical substation could be provided (from heat radiation), in case of fire in the NGL storage area, by constructing a barrier.
- Confinement of liquid sulphur in case of pool fire, by installation of a bund, was suggested.

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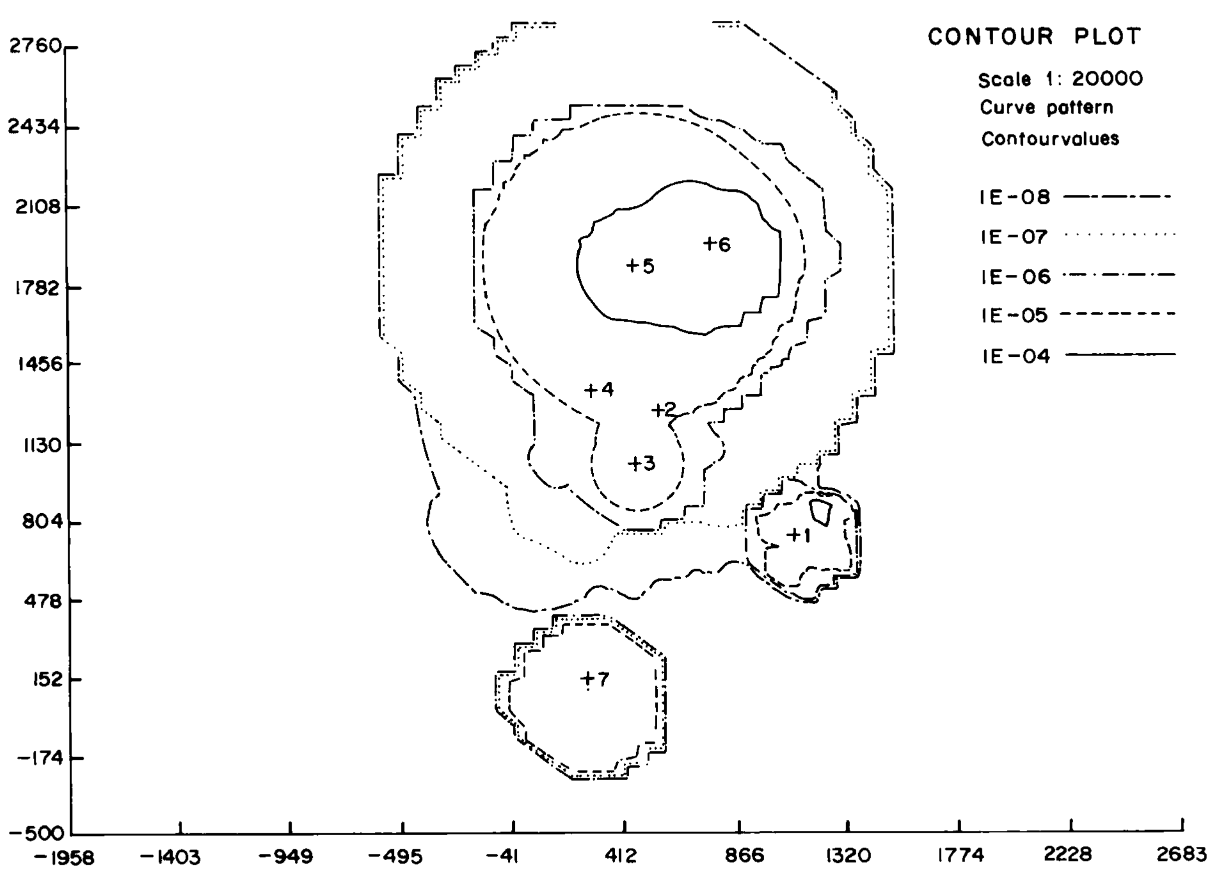

Fig. 6. Risk Contour Plot for all locations

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