SAFETY SCIENCE Monitor
Issue 2 2009
Article 6
VOL 13

SAFETY ASSESSMENT IN DRINKING WATER CHLORINATION STATIONS

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ABSTRACT

Chlorine is widely used as a disinfectant in drinking water in many parts of the world. It is produced relatively easily, cheap and is more effective in low consumptions. Chlorination of water by liquid chlorine is a common practice in water treatment plants, while by chlorine gas is made just before reaching the consumer's premises at special stations. Tehran's drinking water system has 24 chlorination stations, each of which has 2 rooms named as cylinder and chlorinator rooms. The main accident occurring in stations is chlorine gas being released into the atmosphere. For assessing the safety of stations FTA was used. By visiting all stations and interviewing employees, all data regarding stations, chlorination processes, work procedures etc. were collected. Then FT for chlorine gas release was constructed. There were 1224 Basic Events (BEs), which were in fact 16 different events, each of which were repeated at many different times across the tree. All BEs were categorized into 4 groups; Human Error (HE), Management Oversight (MO), Design Fault (DF), and Hardware Failure (HF). Distribution of 16 different BEs in these groups showed that the highest percent of BEs were in the HE group (43.5%) and the lowest in the HF group (0.8 %). Doing Work in Wrong Way was the most repeated BE in the constructed FT (250 times), and the Crane Technical Fault was the least (10 times). In total 2083 minimal cut sets were identified- 370 of which were only in unsuitable stations. Due to some differences, stations were grouped as suitable & unsuitable. Probabilities of the top event occurring in the chlorinator room (12.5 /y) was 1.43 times higher than in the cylinder room (8.73 /y). Also the probability of the top event in suitable stations (103.62×10^{-1} /y) was less than half of that in unsuitable stations (212.25×10^{-1} /y). Lack of adequate training for employees leading to multiple errors being made was the second most repeated basic event.

1. INTRODUCTION

Chlorine is widely used as a disinfectant in drinking water in many parts of the world. According to WHO standards, for a man of 60 Kg who drinks 2 liters of water a day, the total amount of chlorine intake should not be more than 4 ppm (Sadeghpoor, 1999). Iranian health authorities have standardized a range of 0.4 to 0.8 ppm for chlorine residue in drinking water. This means that in 2 liters drinking water the maximum amount of chlorine to enter the body would be 1.6 ppm. Chlorine is produced relatively easily, cheap and is more effective in relatively low consumptions. Chlorination of water by liquid chlorine is a common practice in water treatment plants, while by chlorine gas is made just before reaching the consumer's premises at special stations.

This study was carried out in Tehran's drinking water chlorination stations, the number of which was a total of 24. As previously stated, chlorination stations have 2 rooms - the cylinder and chlorinator rooms. In the first room there are 3 cylinders each with a one ton capacity, and a jib crane for handling the cylinders. Figure 1 shows the cylinder room where 3 cylinders have laid horizontally on the ground. They are connected to each other by copper tubes and a piece of steel pipe as a collector, through which chlorine gas is sent to the chlorinator room. With 3 valves in chlorine gas line, the arrangement of cylinders is such that the first one was in service, the second was spare, and the third used as a trap cylinder. At the dead end of the chlorine gas line there is a vent which directs the gas residue in the pipes (during maintenance jobs when 3 cylinders have been disconnected) via a monometer and valve into the atmosphere on the roof of the room. In the second room a chlorinator connects to a water pipe via an injector. In the chlorine gas line there was also a precipitator, two monometers, a regulator, and a solenoid valve (Fig. 2). Since the situations as well as the sizes of chlorination stations were all different in 24 stations, the number of employees varied from 2 - 5 persons. The size of both cylinder and chlorinator rooms were different from station to station. Some of them had windows and some did not (due to the situation and location). Most stations had a venting fan and a fixed electric heater, however not all of them.

The main accident occurring in chlorination stations is large amount of chlorine gas being released into atmosphere. Considering the fact that all chlorination stations were in different locations of the city, some were just 3 to 4 meters distance from residential areas, and also the high dense population of the city (10000 persons in every Km^2 (Tehran Municipality site)), accidental release of chlorine gas can be catastrophic.. An example of chlorine gas being released as an accident is in Astara, a small city (north of Iran) where a 5 ton capacity tank ruptured and chlorine gas was released into the atmosphere. It resulted in 3 dead and 200 injured (Nezamoddini, 2006). In 16 states of the USA, the number of accidents caused by the release of chlorine gas from 1993 to 2000 declined but the number of effected people in comparison to other chemical accidents increased (Horton et all, 2000). In 2002 the same authors of another study showed that from a total of 44164 chemical accidents, 952 were caused by chlorine gas release. In 275 cases of these accidents 1071 individuals had been injured (Horton, 2002).

Understanding the reasons for these accidents occurring was important for the authorities. Therefore assessing the safety of chlorination stations was the main objective, and also selecting a method from those which have been developed to achieve this goal.

To ensure safety of critical systems, well-known safety analysis methods have been formalized (Ortmeier, 2007). In this study we used Fault Tree Analysis (FTA), which is one of the most wide spread safety analysis methods. FTA is a deductive technique and is widely used as a strong technique in assessing safety and reliability of systems (Crosetti, 1971). It is a systematic, deductive and probabilistic risk assessment tool that elucidates the causal relations leading to a given undesired event. Quantitative fault tree (failure) analysis requires a fault tree and failure data of basic events. Development of a fault tree and subsequent analysis require a great deal of expertise, which may not be available all the time. The methodology includes fault tree development, minimal cut-set determination, cut-set optimization and probability analysis (Ferdous, 2007). In Iran FTA has been used in many different systems for assessing safety. For example, the probability of chlorine gas being released from a flexible hose during unloading liquid chlorine from a road tanker into a fixed tank was estimated by the aid of FTA (Adl, 2000). Evaluation of explosion hazards in ethylene oxide storage tanks in a petrochemical company was also done by FTA (Parsamanesh, 1999). In this study the top event for constructing the Fault Tree (FT) was the release of chlorine gas in chlorination stations. This led us not only to the probability of chlorine gas being released in the station with all reasons behind it, which was the main objective of this work, but also to the data about both cylinder and chlorination rooms which could help us identify the most dangerous room (sub objective of present work).

2. MATERIALS & METHODS

Initially a check was done to see if there were any differences in the chlorination systems of 24 stations.

For Top Event (TE) as well as for Intermediate Events (EVs), the probability of occurrence was calculated in both cylinder and chlorinator rooms, and as a whole in chlorination stations by quantitative analysis of constructed FT. Careful examination of chlorination processes revealed that the best temperature for chlorine injection was between 15 to 20 ºC. However, one has to keep in mind that some of the stations had no heating / cooling systems. In this situation, temperature problems were solved by opening windows and doors (if any) in summer time, and using portable electric heaters in colder seasons. By considering this difference between stations and also the difference in the area of both cylinders and chlorinator rooms, we could divide all stations in 2 groups and name them as suitable and unsuitable stations. The first group having cooling and heating systems and also having enough space for doing normal tasks like changing empty cylinders with full ones by aid of a jib crane. The unsuitable stations were without heating / cooling systems, having limited areas in comparison to the first group.

3. RESULTS

The constructed FT (main result of this study) was a big and wide tree with coverage of 54 pages of A4 size. There were 1224 Basic Events (BEs) in the constructed FT. These BEs were actually 16 different events which were repeated many different times across the tree. Table one shows all these 16 BEs with their frequency of repetition. According to their nature all BEs were categorized in 4 groups; Human Error (HE), Management Oversight (MO), Design Fault and Deficiencies (DF), and Hardware Failures (HF). The number of BEs in every group is shown in table 2. Qualitative analysis on the fault tree yielded a total of 2083 Minimal Cut Sets (MCS).

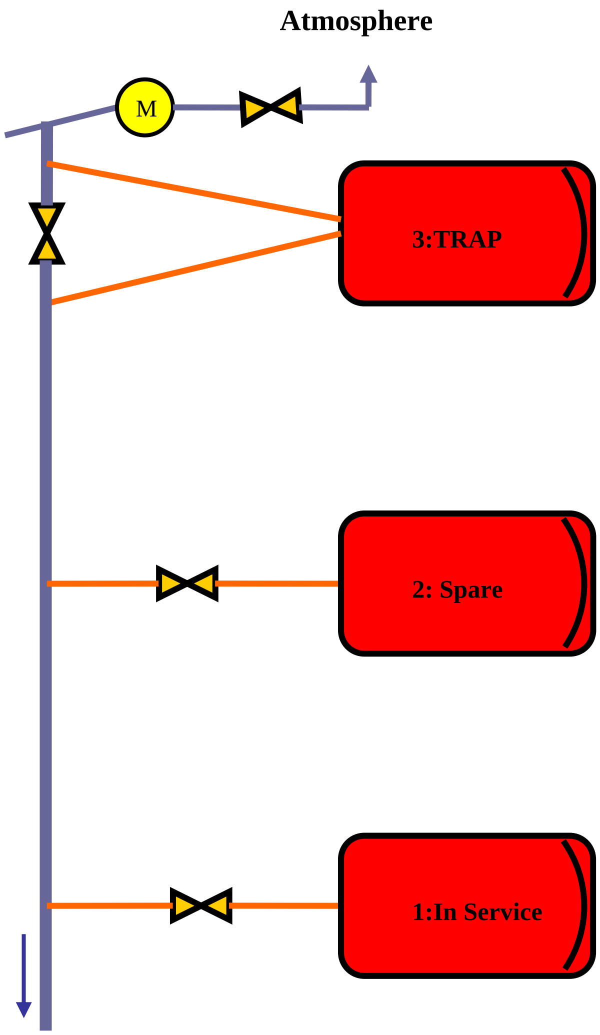

Figure 1: CYLINDER ROOM

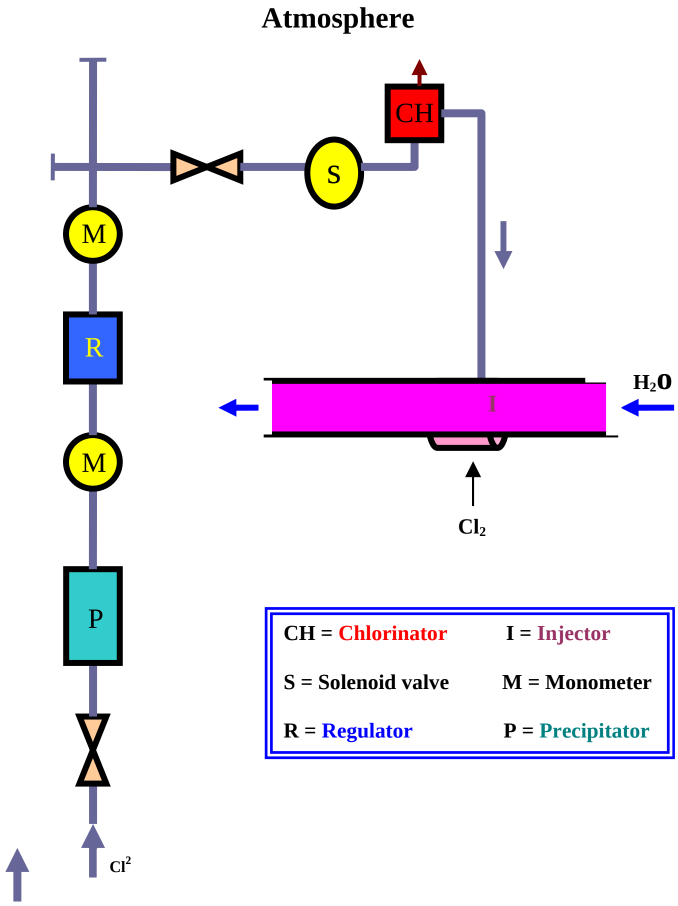

Figure 2: CHLORINATOR ROOM

The number of MCS in suitable stations was 1713 and in unsuitable stations it was 2083. This means that 370 of these MCS specially belonged to unsuitable stations. One of these MCS is shown in figure 3 as an example. By aid of Kirwan (1996) data bank, the probability of occurrence of all BEs which were categorized in the HE group, were determined. This probability for other BEs, which belonged to 2 groups of MO, and DF, was obtained from the results of observations, interviews, and measurements, which were carried out in the stations. For determination of failure rates of those BEs which were in the group HF, the existing record keeping system during last 5 years was used. By aid of these probabilities and constructed FT the probability of occurrence for IEs and TE were determined. Table 3 shows all these probabilities for both suitable and unsuitable stations.

Table 1: Sixteen basic events and their repetition number in FT

No. of BE	Basic Event	No. of Repetition
1	LAT	239
2	DWiWW	250
3	ECaI	149
4	EFaI	99

5	SID	83
6	DWIdtLT	53
7	LBA	52
8	HWL	43
9	LPHS	38
10	LPCS	36
11	ILfH	36
12	LFH	36
13	LE	34
14	IDE	33
15	DTBnC	33
16	CTF	10
Total		1224

LAT = Lack of Adequate Training
DWiWW = Doing Work in Wrong Way
ECaI = Employee's Carelessness and Irresponsibility
EFaI = Employee's Forgetfulness and Inattention
SID = Station's Improper Design
DWIdtLT = Doing Work In hurry due to Lack of Time
LBA = Lack of Budget Allocation
HWL = High Work Load
LPHS = Lack of Proper Heating System
LCS = Lack of Proper Cooling System
ILfH = Improper Location for Heater
LFH = Lack of Fixed Heater
LE = Less Experience
IDE = Improper Design of Equipment
DTBnC = Date of Test Being not Clear
CTF = Crane Technical Fault

Table 2: Number of basic events in 4 groups

Group	Name	Frequency	%
1	HE	532	43.46
2	MO	387	31.61
3	DF	295	24.1
4	HF	10	0.816

Table 3: Probabilities of Intermediate events and top event of Constructed FT

HAZARD	**PROBABILITY / YEAR**	
	Unsuitable Stations	**Suitable Stations**
Cylinder Rupture	6.38×10^{-1}	1.4×10^{-6}
Leak From Cylinder	32.5×10^{-1}	20.4×10^{-1}
Leak From Pipes & Fittings in Cylinder Room	39.32×10^{-1}	18.96×10^{-1}
Leak From Auxiliary Equipments in Cylinder Room	9.13×10^{-1}	4.32×10^{-1}
Chlorine Gas Release in Cylinder Room	$\mathbf{87.3 \times 10^{-1}}$	$\mathbf{43.68 \times 10^{-1}}$
Leak From Main Equipments in Chlorinator Room	0.4×10^{-1}	0.2×10^{-1}
Leak From Auxiliary Equipments in Chlorinator Room	21.25×10^{-1}	10.04×10^{-1}

Leak From Pipes & Fittings in Chlorinator Room	63.7 ×10 $^{-1}$	29.9 ×10 $^{-1}$
Chlorine Gas Release in Chlorinator Room	**124.95 ×10 $^{-1}$**	**59.94 ×10 $^{-1}$**
Chlorine Gas Release in Station	**212.25 ×10 $^{-1}$**	**103.62 ×10^{-1}**

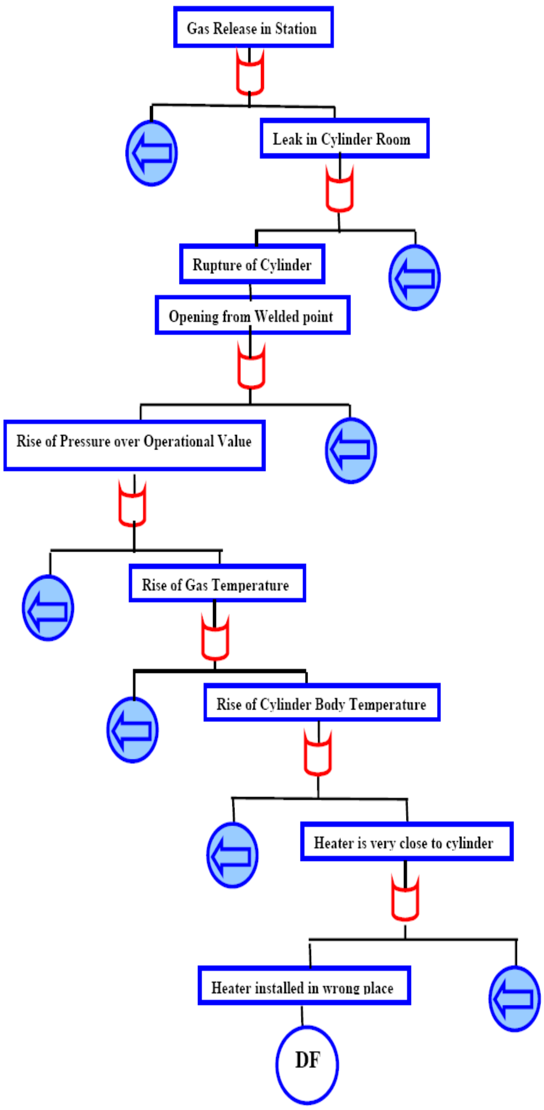

Figure 3: One of the minimal cut sets

4. DISCUSSION

It has been mentioned that the *FT handbook* has become the de facto standard for FTA, defining the notation and mathematical foundation of this widely used safety analysis technique. The *handbook* recognises that classical combinatorial fault trees employing only Boolean gates cannot capture the potentially critical significance of the temporal ordering of failure events in a system (Walker, Nov.2008). Our constructed FT could not capture the significance of the temporal order of events, but clearly as Walker (June 2008) stated, it determined the effects of combinations of failure events.

“Doing Work in Wrong Way" (DWiWW) more than any other BEs has been repeated in the FT while "Crane Technical Fault" (CTF) was repeated less than the rest (table1). DWiWW is a human error and table 2 shows that the majority of BEs (43.46 %) belong to the HE group. This is some how in agreement with what has been shown in many research works. For example, the following conclusions have been quoted from different publications (Adl, 2006): studies on industrial accidents have shown that human errors play the main and most important role in their occurrence (Santamaria, 1998); 60 to 90 percent of accidents have been directly caused by human errors (Kletz, 2002); Investigation of catastrophic accidents like Flixborough (1976), Three mile island (1979), Bhopal (1984), and Chernobyl (1986) have shown that in spite of very large and considerable progress in technology, and use of automation in all industries and chemical processes, still human's occupational tasks are very sensitive and critical. Very simple errors like opening or closing a valve at the wrong time can turn the situations into an unfortunate and unpleasant accident (Mostia, 2002).

In table 1 one can also see that In table 1 one can also see that lack of Proper training (LPT) as a BE has been repeated 239 times across the FT (the second most repeated BE). It looks very apparent and shows the importance of training even in comparison with different works of maintenance and processes (LFH with 36 times and IDE with 33 times repetition - table 1).

As mentioned in ‘section materials & methods’, the differences between suitable and unsuitable stations were the: area size of station and the availability to electric heaters. Although these differences do not seem considerable, 370 MCS to be set aside for unsuitable stations in addition to what has been identified in suitable stations, shows that these differences are very important. They should not be ignored in the future when improving programs of existing stations as well as designing and constructing new stations.

Table 3 shows that the probabilities of occurrence of IEs such as chlorine gas release in cylinder and in chlorinator rooms, as well as the probability of TE in unsuitable stations are twice more than that in suitable stations. The actual probability of chlorine gas release in suitable stations is more than 10 times per year and in unsuitable stations is 21/Y. This again shows the importance of those aforementioned differences between suitable and unsuitable stations.

The rate of 10 times per year for chlorine gas to be released in chlorination stations, which are randomly distributed in populated urban areas is really very high and should be taken seriously by all city and drinking water organization authorities. During interviews and in the process of visiting stations, we discovered that there was not any awareness for people that live in adjacent areas of the station, about chlorine accidental release and what one should do in case of an occurrence. Therefore the criticality of the situation in unsuitable stations where the probability of chlorine gas release is 21 times per year is undeniable.

Inspection of table 3 observes that the probability of chlorine gas being released in a cylinder room is considerably less than that in a chlorinator room. The former is around 70 % of the latter (in chlorinator room is 1.43 times higher than in the cylinder room). This means that the chlorinator room is more dangerous than the cylinder room. Although the probable reason can be the high number of fittings in chlorinator room but giving more consideration to design and maintenance of this room, it is the most important proposal for the authorities.

REFERENCES

Adl J. (Fall 2000) The Methodology of Safety Role in cost Control; *A Case Study of Chlorine Unloading Operation., J. of Env. Sc. Tech., No. 10.*

Crosetti P.A. (1971) Fault Tree Analysis with Probability Evaluation, *IEEE Transaction Nuclear Science NA- 18. 465-471*

Ferdous R., Khan F. I., Veitch B., and Amyotte P.R. (2007) Methodology for Computer-Aided Fault Tree Analysis, *Process Safety and Environmental Protection, Vol. 85, issue 1, 70-80*

Horton DK., Berkowitz Z., Kaye WE. (2000 Oct.) The Public Health Consequences from Acute Chlorine Releases, J. Occup. *Environment Med., 44* (10), 906-913.

Horton DK., Berkowitz Z., Kaye WE. (2002) Adverse Public Health Consequences from Acute Chlorine Releases, J. Occup. *Environment Med., Nov.* 11

Kirwan B., Scannali S., Robinson L. (1996). A Case Study of a Human Reliability Assessment for An Existing Nuclear Power Plant. *Appl. Ergon. Oct* 7:289-302 15677070 (P,S,E,B)

Kletz T. (2001). An Engineer's View of Human Error, 3rd edition, *Institution of Chemical Engineers, Rugby, UK*

Mostia B. (2002). You can reduce human error in chemical processing plant instrumentation and operation by understanding the types and sources of error, Part one. Available at: http://www.chemicalprocessing.com/ articles/2003/6.html

Nezamoddini Z., Adl J., Assessment of Chlorine Gas Release in Tehran's Chlorination Stations by Fault Tree Analysis Technique and Proposing Preventing Measures. *Thesis for the degree of MSPH, Tehran University of Medical Sciences, 2006.* .

Ortmeier F. (July 2007) Schellhonr G., Formal Fault Tree Analysis - Practical Experiences, *Electronic notes in theoretical Computer science, volume 185, 139-151.*
Park A., Seung Ju Lee (2009) Fault tree analysis on handwashing for hygiene management, *Food Control, Vol. 20, Issue 3, 223-229*

Parsamanesh H., Adl J., Evaluation of Explosion Hazard in Ethylene Oxide Storage Tanks, *Thesis for the degree of MSPH, Tehran University of Medical Sciences, 1999*

Sadeghpoor H., Farrahi M., Nikravesh Sh., "Guidelines for sewage treatment plant operation, *Rastan publication institute, 1999.*

Santamaria Ramino J. M., & Brana Asia P. A. (1998). Risk Analysis and Reduction in Chemical Process Industry, Blacking Academic & Professional

Tehran Coordinates according to 2006 statistics, 2009. Available at: http://en.tehran.ir/Default.aspx?tabid=2213

Walker M., and Papadopoulos Y.(2008 Nov.) Qualitative temporal analysis:Towards a full implementation of the Fault Tree Handbook, Control Engineering Practice, In Press, available online.

Walker M., and Papadopoulos Y. (2008 June) Synthesis and analysis of temporal fault trees with PANDORA: The time of Priority AND gates, Hybrid Systems, Vol.2, Issue