can be found in 'Nurturing Science Talent' at http://www.iiserpune.ac.in/~mohanan/educ/nurture-talent.pdf. A web course that I designed to nurture the capacity for academic inquiry among undergraduate students across a wide range of subjects (Academic Knowledge and Inquiry at http://wiki.nus.edu.sg/display/aki), may give the reader a sense of how (c) and (e)–(i) can be developed among students.

1. Srinivasaraju, S., *Outook India*, April 2007; http://www.outlookindia.com/article.aspx?234521
2. Gupta, V., *Infocell*, 2000, **3**(4); http://www.iitk.ac.in/infocell/Archive/dirjuly3/cover_story.html
3. Mahadevan, G., *The Hindu*, 27 July 2010; http://www.hindu.com/edu/2010/07/27/stories/2010072750040100.htm

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Safety of systems for industry and environment: relevance and challenges

G. S. Mukherjee

3rd December 2009 marked the 25th anniversary of the Bhopal gas tragedy. On 3 December 1984, water tank was contaminated with methyl isocyanate at a pesticide plant in Bhopal, the capital of Madhya Pradesh, initiating a series of events that led to a catastrophic toxic release. The 40 tonnes of methyl isocyanate released from the plant killed more than 3000 people and permanently injured more than 50,000 (refs 1, 2). Ironically, in the same month December 2009, there was an accident in a prestigious chemical laboratory in Mumbai, where two young PhD students were killed as a result of explosion[3]. In December 2009, there were also newspaper reports on the contamination of water by the radioactive isotope of hydrogen, tritium which caused a high level of radiation effect to more than 50 workers of a power plant in Karnataka. This calls for revisiting the safety issues more earnestly than ever before[4].

The use of radioactive materials cannot be avoided because of their useful applications[5–7]. Radioactive ^{60}Co has many applications, for example, for sterilization of medical equipment, radiation source for medical radiotherapy, industrial radiography, and for improvement of shelf life of edible items. The recent casualty resulting from the radiation hazard due to cobalt-60 in Delhi is an eye opener[8] and calls for the necessity to take extra care on the issues of safety management particularly while handling radioactive inventories. It is shocking that the educational institution was negligent in disposing radioactive items in an auction, without following proper safety procedure which left common people to face the risk of being exposed to radiation. In spite of strict guidelines by the Atomic Energy Regulatory Board (AERB) that all radioactive materials should be disposed of in controlled conditions, there was apathy towards following the process of safety.

In addition to the accidents in the factories or laboratories, there are many miscellaneous fires reported from different parts of the country, especially in summer, either due to electrical short circuit or negligence or mishandling of fire. More recently, in July 2010, there was a report on leakage of chlorine gas from the stack of abandoned cylinders disposed off in Mumbai which caused illness to a number of people. This is a result of lack of knowledge on the effect of disposal of condemned cylinders before disposing of the abandoned cylinder. The disposal approach is so casual that the authority paid little or no attention to the remnant of chlorine gas in the cylinder. All such events were the outcome of either lapse of duty and/or lack of scientific safety culture.

The most deplorable fact about Bhopal havoc is that the events of the tragedy could have been avoided, even if a few safety precautions had been properly implemented, as believed by many experts. It is now understood that the Bhopal accident was associated with many technological and managerial shortcomings that caused initiation and escalation of the toxic release[1,2].

In India probably as yet there has not been any proper assessment of negligence and status of safety vis-à-vis corresponding loss due to disaster. However, response to hazards, its consequence and the probability of accident can provide a qualitative measure of the risk associated with a process operation[6]. The fire disaster not only creates immediate havoc but in larger perspective it remains mostly unnoticed that the root cause of such fire hazards finally contributes carbon footprint[10] to the atmosphere. It is therefore necessary that the carbon footprint, i.e. the total set of emitted green house gases (GHG) caused by a fire accident should be estimated to make an appropriate strategy for implementation of safety measure. The heat energy generated from any fire hazard is a waste since it cannot be used for obvious reason that there is no mechanism to utilize it from an accidental fire. On an average 1 kg of rice husk yields about 0.5–1 kWh of electricity[11]; this figure gives a rough estimate of energy released due to fire.

In the past, forest fires were more frequently noticed in Indonesia and Australia and the effect of such forest fire was so intense that even the neighbouring countries such as Singapore, Malaysia

and Vietnam were covered with smoke and ash to different degrees. More recently, the forest fire near Moscow was also unusual. Another smoke problem which remains more or less unnoticed is the result of coal fire in the mines. Burning of coal fire is an environmental catastrophe worldwide[12–14]. Some of the largest coal fires in the world have occurred in China, USA and India. It is worthwhile to mention here the incidence of continuous coal burning in the coal mines of Jharia situated in Jharkhand, India that started since about a century ago. The first fire in the mines of Jharia was detected in 1916. And more than 70 fresh fires of mines of Jharia were reported in this region in 1972 (refs 13, 14).

It is important to note that even though before 1972 man made history by making his footprints on the moon in 1969, he failed to contain fire of Jharia mine and other coal mines of different countries. Even though science and engineering has progressed, it is not significantly applied to solve many of the problems such as Jharia fire hazard. Since 1916 fire of Jharia is not only causing colossal loss of coal without any value addition but it is continuously increasing the carbon footprints. The origin of mine fire is presumably either due to negligence towards safety process or ignorance about the methodology to mitigate a mine-fire at the time of its initiation and subsequent propagation. It is also creating problems in the local earth structure and gradually generating voids underneath, thus threatening the local population. More than 400,000 people who reside in Jharia are in danger of subsidence due to such fires; and the Jharia township is on the brink of an ecological and human disaster. This hazard is the result of a perceived lackadaisical attitude towards the safety process. Heavy fumes emitted by the fires lead to severe health problems such as breathing disorders and skin diseases among the local population[12–14].

Safety measure can be a supplement to the green technology approach to reduce the risk of carbon footprints. Of late occurrence of fire hazards is not infrequent and it all contributes to the micro form of damage to the environment due to sheer safety lapse. Green technology has a big role to play in restricting global warming. Logically, integration of various micro safety processes in our daily life can help strengthen the effort of Green Peace movement.

Safety issues do not get attention but their importance is realized when some mishap occurs[15–17]. The safety process remains latent because hazard does not happen on a daily basis but once mishap occurs, the loss is immediate and sometimes non-recoverable, e.g. loss of life, heritage items, valuable documents, archival articles, etc.

Industrial safety and environmental problems are often due to economic competition and the urge of exigency to deliver. In this situation, the organizations remain under relentless pressure and that tempt them to cut down costs[17–19] without proper regard to quality and safety. And in the process they adopt many unrealistic methods in increasing productivity, implementing too many new initiatives, and/or installing new technologies too frequently to cope with the market challenges.

In this context, it may be germane to mention the incidence of fire in the marcopolo low-floor buses in Delhi[20,21] because they failed to maintain quality fire safety while carrying passengers. Similar failures of small cars[20–23] during vehicular movement have been reported. All these imply that there was probably overemphasis on reducing the cost without regard to quality control which ultimately dislocate reliable safety mechanism meant for the prevention of fire in the dynamic situation. Such failure may be the result of deficiency of quality control wing to properly review, analyse and assess various latent aspects of micro-safety issues for automobile system in Indian condition. Thus, compromise in quality control adversely impact the safety of public and private transport system.

In recent times the Indian Railways has announced that there is marginal or no increase in the cost of passenger's tickets; but ironically there were many railway accidents. It is anybody's guess that such accidents may be the manifestation of compromised safety issues[24].

In the cut-throat competition of global economy, sometimes the companies have to increase production target, efficiency and quality but often at the cost of safety and/or environmental records. All these are accomplished without employing more people, equipment or capital investment. To cope with the threat of competition the authority has to stretch organization[17,18,24] by reducing manpower, equipment and/or investment to accomplish increased production and improved efficiency. But if the organization is stretched far enough, a major system failure is likely to occur concomitantly. Such failure due to organization stretch is like the phenomenon of rubber band snapping after being stretched beyond its breaking point[17,18,25,26].

Attempting to achieve increased production in a framework which is in disproportion with its actual capacity and infrastructural support system causes overall loss due to safety lapse. The losses and associated other cost negate many times over the accrued benefits prior to the accident.

Production creep occurs when production goals are gradually increased without a corresponding increase in resources (equipment or personnel)[9,18,26]. In a given condition if a facility makes normally 100 tonnes of products per week; but in that situation if the organization wants to increase the production to 110 tonnes per week without using any extra resources, then production creep occurs due to this extra 10 tonnes. In the initial phases this marginal production creep could not be sensed and that is dangerous because it breeds further greed. Such successes in the initial phase lure the organization to accommodate more such production creeps. If this production creep continues to increase, then it ultimately reaches to a breaking point. And in this way eventually, this stretching leads to a major failure. In this context, recent failure in fire safety for marcopolo bus is understandable[19–23]. With even a single failure, all the incremental gain that has been generated by stretching the cost parameter is cancelled out by the loss of goodwill and reliability.

Slackening of safety also occurs from the extra initiatives. It is common when operating and maintenance personnel are to simultaneously implement a range of performance-improvement initiatives in the form of, say ISO 14001, six sigma[27], and equipment upgradation and the like. If all these initiatives are applied with proper introspection then these are a good investment of time and resources, and may even be a regulatory requirement. But there is a caveat that if too many initiatives are attempted simultaneously, then the system becomes overloaded to effect catastrophic failure. Therefore, it is always essential that the new targets and goals should be reviewed from time to time to ensure that production creep

and other stretch goals do not lead to unsafe conditions.

Another cause of slackening of safety measure occurs from the excessive emphasis on the concept of outsourcing[19,29]. A common way to reduce staff while keeping the organization functioning is to outsource or subcontract some activities. If the work is truly one-off, such as the engineering and installation of new piece of equipment, then the use of an outside company will be a good function, but the use of outsiders can create difficulties because of the behavioural differences and indifference between the master and hired workforce.

The contribution of all employees is crucial to the success of a safety programme. The hollowing out of an organization that occurs with excessive outsourcing is likely to materially reduce such whole-hearted participation and accountability.

Mergers, acquisitions and divestitures[26–30] are also adopted to run the business more effectively but the new companies created by such merging process invite some problems on safety issues because the inherent safety process systems of different organizations may be profoundly different from one another. Process safety approaches that were good for one of the former organizations may no longer apply to the newly-emerged establishment, and an accident may occur because people from different backgrounds did not fully understand each other or clarify new lines of responsibility.

The incidences of Bhopal or Flixborough[31] of UK will always remind us that economic, business factors or institutional objectives will always exert pressure on planners, managers, scientists and engineers alike; but such factors must not be allowed to interfere with the organization's coherent and proactive safety culture. Scientists, engineers and their employers must remain vigilant for behaviours, and short-sighted modi-operandi that can undermine responsible safety practice. Where the safety and well-being of people, the environment, and the assets are at stake, the consequences of misplaced priorities, benign neglect or complacency are neither sustainable nor culturally sound[29–32]. It is necessary to nurture safety culture by introducing subjects as a part of curriculum in the undergraduate engineering courses and departmental continuing education programme. And professors and professionals should teach students how to design plants that are operational, cost effective, and safe. On the other hand, students should be receptive to studying past incidents and learning about the importance of considering process safety in every phase of the plant lifecycle – from design to operation, maintenance and shutdown.

The very saying 'prevention is better than cure' in the doctors' domain may be recalled. And that evokes me to add a corollary comment before the engineers' echelon that 'safety is better than recovery and restoration'. Therefore, the culture of safety and precaution must diffuse to every aspect of any industrial base and its infrastructure.

1. Bryce, A., Bhopal disaster spurs US industry, Legislative Action, US Chemical Safety and Hazard Investigation Board Library of Investigations, 1999.
2. Incidents that define process safety, Centre for Chemical Process Safety (CCPS), New York and John Wiley & Sons, Inc., Hoboken, 2008.
3. *The Times of India*, 30 December 2009.
4. *The Hindu*, 3 December 2009.
5. Ghosh, S., *Indian Sci. Cruiser*, 2010, **24**(1), 65–66.
6. Pramanik, N. K., Haldar, R. S., Bharadwaj, Y. K., Sabharwal, S., Niyogi, U. K. and Khandal, R. K., *Radiat. Phys. Chem.*, 2009, **78**, 199–205.
7. Vijalatha, K. R., Srividhya, S., Senthamizh Selvi, B. and Kannan, M., *Everyman's Sci.*, 2010, **XLIV**(5), 295.
8. Mukherjee, G. S., *The Statesman*, 8 May 2010, p. 8.
9. Guidelines for developing quantitative safety risk criteria, Centre for Chemical Process Safety, New York, John Wiley, August 2009, p. 248.
10. Stuart Sim, *The Carbon Footprint Wars: What Might Happen if we Retreat from Globalization*? Edinburgh Univ. Press, 2010; *The Statesman*, New Delhi, 10 June and 25 August 2010.
11. Balasankari, P. K. and Mathias Arul Joe, *Renewable Energy World*, July–August 2009, pp. 1–87.
12. Stracher G. B., *Int. J. Coal Geol.*, 2004, **59**(1–2), 1–151.
13. Anonymous, *The Times of India*, 31 August 2008.
14. Michalski, S. R., *Int. J. Coal Geol.*, 2004, **59**(1–2), 83–90.
15. Incidents that define process safety, Centre for Chemical Process Safety (CCPS), New York, and John Wiley & Sons, Inc., Hoboken, 2008.
16. Hopkins, A., Lessons from Longford: The Esso Gas Plant Explosion, CCH Australia, North Ryde, NSW, 2000.
17. Kletz, T., Lessons from disaster: how organizations have no memory and accidents recur, Institute of Chemical Engineers, Rugby, UK, 1993.
18. Brander, R., The *Titanic* disaster: An enduring example of money making management versus risk management, 1995.
19. Morgan, K. C., A report of the panel of the National Academy of Public Administration for the US Congress and Bureau of Economic Analysis, January 2006.
20. *The Hindu*, New Delhi, 4 December 2009; Daily Indian Newspapers March–April 2010.
21. *The Hindustan Times*, India, 27 April 2010.
22. *The Statesman*, 2 September 2010.
23. *Current News India*, 25 March 2010, DWS Auto India, 29 October 2009.
24. Mukherjee, G. S., *The Statesman*, New Delhi, 10 December 2008, p. 6.
25. Centre for Chemical Process Safety, Guidelines for risk based process safety, American Institute of Chemical Engineers, New York, 2007.
26. Sutton, I., *Process Risk and Reliability Management*, Elsevier, Maryland Heights, MO, 2010.
27. Tennant, G., *Six Sigma and TQM in Manufacturing and Services*, Gower Publishing, 2001.
28. Chakma, J., Calcagno, J. L., Behbahari, A. and Mojtahedian, S., *Nature Biotechnol.*, 2009, **27**, 886–888.
29. Einolf, D. and Menghini, L., Acquisition of the PSM-Subject Facility: Considerations in due diligence, American Society of Safety Engineers' Professional Development Conference, Orlando, 2008.
30. American Chemical Council, Process safety incidents for responsible care companies, 2008.
31. Health and Safety Executive, The Flixborough Disaster : Report of the Court of Inquiry, HMSO, ISBN 0113610750, 1975.
32. 6 Global Congress on Process Safety, 21–25 March 2010, San Antonio, TX, USA.

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