WHITE PAPER

Who Moved My Cheese? How Climate Change Can Have Unforeseen Process Safety Impacts

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We are observing a gradual increase in process safety incidents triggered by natural causes. Traditional prevention measures, such as good engineering practices and the sound design of plants and processes, seem to be failing. In this paper, we analyse the causes and recommend a course of action to reestablish acceptable safety levels.

A Growing Menace: Natural Hazard Triggered Technological Incidents (Natechs)

The atmosphere is a layer of gas surrounding planet Earth. It does not have a defined boundary: its density decreases with height until it fades away in inter-planetary space, but only the 10 lowermost kilometers are breathable. To get an idea of the extreme thinness of this layer, if we envision Earth as a football (or soccer ball, as the case may be), the breathable atmosphere would be thinner than the paint coating its surface, yet, it weighs about 5.5 quadrillion (5.5×10^{15}) tons. This means that increasing its average temperature by one degree centigrade requires 5.5×10^{21} Joules, or the yield of 100 million nuclear weapons like the one detonated over Hiroshima in 1945. This energy then becomes available to fuel phenomena such as gusty winds, hurricanes and tornadoes. The situation is even worse in the oceans, whose temperature is closely linked to that of the atmosphere, and whose mass is several orders of magnitude larger. And steadily increasing the temperature of the atmosphere and the oceans is precisely what humankind has been doing over the last few decades.

As a consequence, we are observing more and more of what planetary scientists call "extreme weather": droughts, but also flooding; scorching heat, but also extreme cold; wildfires, thunderstorms, hurricanes and more. The 2017 Atlantic storm season, for instance, was one of the most intense ever recorded, giving rise to hurricane Harvey, which flooded extensive areas of Texas; the wildfire seasons of 2018, 2019 and 2020 severely affected Europe; in February 2021 an Arctic outbreak caused temperatures to fall below -10ºC in most of Texas, reportedly leading to more than 20 fatalities and severe utility disruptions.

At the same time, we have observed process safety incidents increasing in number and severity and which can be directly linked to abnormal weather conditions. For example:

> Hurricane Harvey flooded an Arkema plant in Crosby (Texas), where organic peroxides were stored at low temperatures to prevent exothermal decomposition. Since most of the safeguards failed as a result of the flooding, there were several runaway reactions. There were no fatalities, but the plant and its surroundings had to be evacuated[1].

> Heavy rainfall flooded an ironworks plant in Saga prefecture (Japan) in late August 2019. Water entered several lubricating oil tanks, releasing their contents into the environment[2].

> The French Bureau for Analysis of Industrial Risks and Pollution (BARPI) reported recently that the number of accidents caused in French industrial facilities as a direct consequence of extreme natural events has more than doubled in the period 2010-2019[3].

As early as 1994, the term "Natech"— natural hazard triggered technological accidents —was coined to describe such phenomena. Incidentally, Natechs include events unrelated to the climate emergency such as the Fukushima Dai-ichi nuclear power plant disaster, which occurred in the wake of the Great East Japan Earthquake and Tsunami (GEJET) on March 11th, 2011.

How Well Are We Protected From Natechs?

The Swiss cheese model (Figure 1) illustrates (deliciously!) the relationships among hazards, consequences (loss) and safeguards. It was first introduced in 1990 by Dante Orlandella and James T. Reason of the University of Manchester[4], and has since gained widespread acceptance. The image represents safeguards as slices of Swiss cheese standing between hazard and loss. Whenever we can draw a straight line through the holes in all the slices, loss will occur. When the line is intercepted by a safeguard/slice, then loss has been effectively prevented. Every slice has holes, just as any safeguard has the potential to fail (e.g. a safety valve could become stuck closed, the alarm might not be heard by the plant operator, and so on).

As the figure illustrates, we can group our safeguards/slices into three major categories, depending on who or what is responsible for preventing loss:

> Technology: this slice represents all devices that help keep the plant safe, such as safety relief valves, rupture discs, interlocks, control systems, etc.

> Process: this slice stands for the features of the process itself that make it intrinsically safe: the chemicals and reactions involved, engineering practices, etc.

> People: finally, this slice includes all the safeguards that require action by human beings: response to alarms, emergency preparedness, etc.

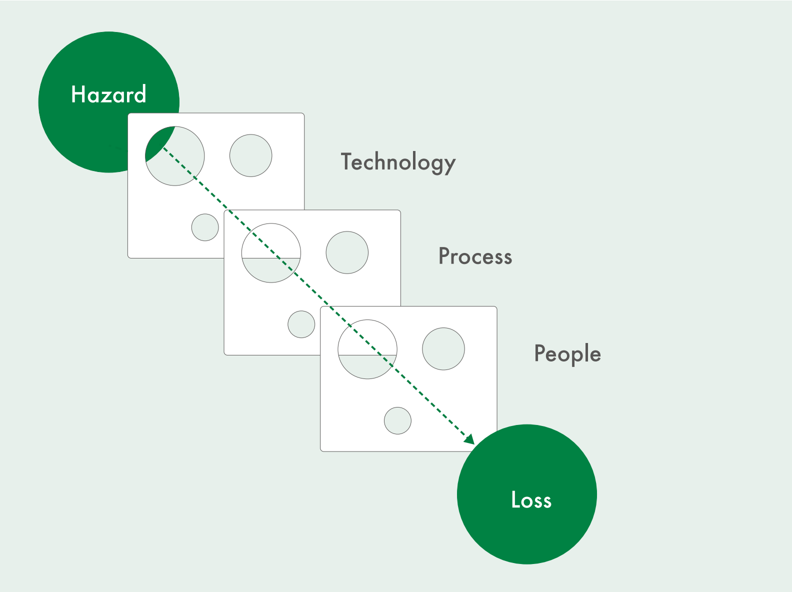

Figure 1 The Swiss cheese model

Expert designers of industrial plants have relied on good engineering practices[5] to establish a compact "process" slice. One of the most important decisions these designers are tasked with has always been the definition of the Basis of Design (BoD), or the collection of principles, assumptions, rationale, criteria, and considerations used for the calculations and decisions made during the design process. A consistent feature in the BoD is extreme weather and other environmental conditions that must be considered during the planning stages.

1 Carson, Ph. and R. Abhari. "Rain starts fire." Loss Prevention Bulletin 277, 29-32.

2 Misuri, A., A.M. Cruz and V. Cozzani. "Understanding the risk posed by complex industrial accidents brought by natural hazards – a milestone to develop effective climate change adaptation strategies." Loss Prevention Bulletin 277, 15-18.

3 Vaysse, G. "The impact of climate events on French industrial facilities between 2010 and 2019." Loss Prevention Bulletin 277, 19-22.

4 Reason, James (1990-04-12). "The Contribution of Latent Human Failures to the Breakdown of Complex Systems". Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 327 (1241): 475–484.

5 More formally, Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).

Conventional wisdom expects us, therefore, to define maximum and minimum temperatures, humidity, wind speed, precipitation and maybe a couple of additional parameters for the site in question and then declare mission accomplished. The problem is, conventional wisdom may fail in several ways.

First of all, our weather database might not be able to support with sufficient precision our estimates of the parameters we need. Consider flooding, for instance. Is it enough to consider a 100-year return period? 500 years? 1000 years? As almost always in process safety, the answer depends on the severity of the consequences: if we predict some loss of production and maybe minor environmental damage, then we can settle for the 100 year return period. If, on the other hand, the consequences of exceeding our Basis of Design are catastrophic (consider Fukushima, for instance), then we may need to factor in longer return periods whose estimates may harbor huge uncertainties. Take, for instance, the recent incident at the Arkema plant in Crosby. The plant was built in the 1960s, before flood mapping of the area and, therefore, before the magnitude of the flooding caused by Harvey could be anticipated[6].

In addition, the planet's climate is changing and, as a consequence, local conditions may also change. Thus, what 40 years ago was considered the maximum absolute temperature ever registered may be exceeded today, and the same can be said of other parameters such as wind speed, rainfall, and so on.

Managing Natech Risk in Times of Climate Change

Nowadays, the Swiss cheese model looks a little different, like someone has moved the "process slice" or eaten some parts of it: its holes are now larger than they used to be. Immediately, of course, the motivational business fable "Who Moved My Cheese"[7] comes to mind. Whose role are we going to take, Sniff and Scurry's who start looking for new cheese, or Hem and Haw's, who get angry at the unfairness of the situation and, essentially, do nothing to correct it?

Good process safety management provides both an answer to this question and guidelines for its implementation. The answer is, undoubtably, that we need to search for new cheese or, in other words, we need to restore our "process" slice to its former, more robust, condition. To understand how, let's return to the example of the Arkema plant. When new information about flooding danger became available, was this not a change? It was, albeit of a type very rarely captured by current Management of Change (MOC) practices. Indeed, the Center for Chemical Process Safety says that "*an MOC system should address all of the types of changes that can be reasonably be foreseen. Anticipated change types can be identified by (1) searching historical records, such as maintenance work order files, incident reports, hazard/risk studies, audits and design reviews…*"[8] In the Arkema plant case, flood planning and insurers' audits were potential sources for identifying change and should have been consulted as such—but, of course, everything is clearer in hindsight.

In light of this and other examples, operators of hazardous plants should revise their MOC procedures so that new and emerging information regarding extreme weather and other environmental conditions that affect their sites is included in the definition of change.

6 However, insurers reported in 2007 and 2016 that the plant was built on a flood plain, which was mostly unknown to the staff. See CSB, May, 2018, 'Organic Peroxide Decomposition, Release, and Fire at Arkema Crosby Following Hurricane Harvey Flooding Crosby, Texas', https://www.csb.gov/assets/1/20/final_arkema_draft_report_2018-05-23.pdf?16272

7 Johnson, S. Who Moved My Cheese: An Amazing Way to Deal With Change in Your Work and in Your Life. Putnam, 1998.

8 Center for Chemical Process Safety. Guidelines for Risk Based Process Safety. Wiley, 2007.

Conclusion: Mitigation and Prevention

With the rise of Natechs, or industrial accidents with natural causes, specifically those resulting from climate change, we are witnessing a fundamental weakness in the traditional preventive framework. Very strictly speaking, this should be addressed under standard Management of Change (MOC) procedures and practices, but unfortunately, this is seldom the case. Two practical steps operators of industrial plants can take to remedy the situation are to revise their MOC procedures to include changes in the Basis of Design (BoD), and to update their BoD as soon as possible.

It is also important to take a step back and consider the big picture. Incident investigation and the ability to learn lessons from errors and near hits are key principles of process safety. In particular, investigating not only the immediate causes of an incident, but also the root causes helps prevent future incidents of a similar sort as well as many others stemming from the same root cause. Moreover, acting on root causes tends to be more preventive, so that incidents and their accompanying losses are avoided entirely, whereas acting on immediate causes tends to be more mitigative, meaning the consequences are somewhat less harsh, but nonetheless there are consequences (losses). When we face the challenges posed by Natechs head on, it is clear that revising the Basis of Design of existing plants looks more like a mitigative than a preventive action. Is it not more advisable to act on root causes and work to revert climate change? By doing so we would not only preserve our environment, but also save lives, both directly (those otherwise doomed to be lost to catastrophic meteorological events) and indirectly (those potentially lost to process safety events resulting from shortcomings in current Basis of Design).

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