WHITE PAPER

Incident Investigation (Part 1): A Key Element in Effective Process Safety

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Incident investigation is a powerful prevention tool in the process safety portfolio. It has been plagued, however, by misinterpretations of Heinrich's pyramid, which misconstrue the relationship between minor incidents and full-blown catastrophes. A corrective view of this misunderstanding lays bare the value of investigating incidents and near misses, and demonstrates how the results of these investigations can be used as drivers for process safety risk reduction.

Recurring incidents masquerading as "unforeseeable"

In the early hours of Saturday, April 26, 1986, reactor number 4 at the Chernobyl nuclear power station, in what was then the Ukrainian Soviet Socialist Republic and is now Ukraine, was undergoing a test. The sequence of operations during the previous day, combined with several design flaws and an alleged violation of procedures by the operators, had put the reactor in a highly unstable state. At about 1:24 am, the attempt to shut down the reactor pushed the core into an unstoppable runaway reaction in the form of severe reactivity and a critical power excursion. It is estimated that the runaway reaction lasted for about 20 seconds. During this lapse, the power generated rose from about 0.2 GW to an estimated 300 GW. As a consequence, both the core and the enclosing building were damaged, exposing the unshielded heavily radioactive core and starting a fire in the 1850 t graphite moderator block, further facilitating the dispersion of radionuclides in the atmosphere.

Out of the reported 237 people who suffered from acute radiation sickness, 31 died within three months of exposure. The long-term effects of increased exposure to ionizing radiation are more difficult to assess, but they may range in the thousands if not tens of thousands of fatalities. Even today, a 30 km circle around the site is considered hazardous for human habitation and is only populated by a few people who refused to relocate. The reactor building has been enclosed in a series of protective "sarcophagi" most likely encompassing one of the deadliest areas on Earth.

When a disaster like this occurs, we immediately hear the "un-advocates"— people who claim that such an event is un-precedented and therefore un-foreseeable. Facts nearly always disprove them. In the case of the Chernobyl disaster, for example, very similar runaway incidents, obviously with much less serious consequences, had occurred in Unit 1 of the Leningrad nuclear power plant on November 28, 1975 and in Unit 1 of the very same Chernobyl plant on September 9, 1982.

Process safety events and the trouble with a "predictive" approach

Nearly a century ago, Herbert William Heinrich, an assistant superintendent at an insurance company, analyzed thousands of incident reports to formulate an early scientific theory of incidents. He summarized his findings in a seminal book[1] and in what is nowadays commonly known as the Heinrich triangle (or pyramid). Figure 1 shows the pyramid, as enhanced later by Frank E. Bird.

Heinrich's main thesis was fairly simple: there is a constant numeric ratio between the different incident severity categories, i.e. for every 600 near misses there will be, on average, one fatal incident. The corollary seemed to be that if you take action to reduce the number of near misses, the number of fatalities will be proportionately reduced. Heinrich's pyramid has been in use since its inception and has proved useful as a descriptive vehicle.

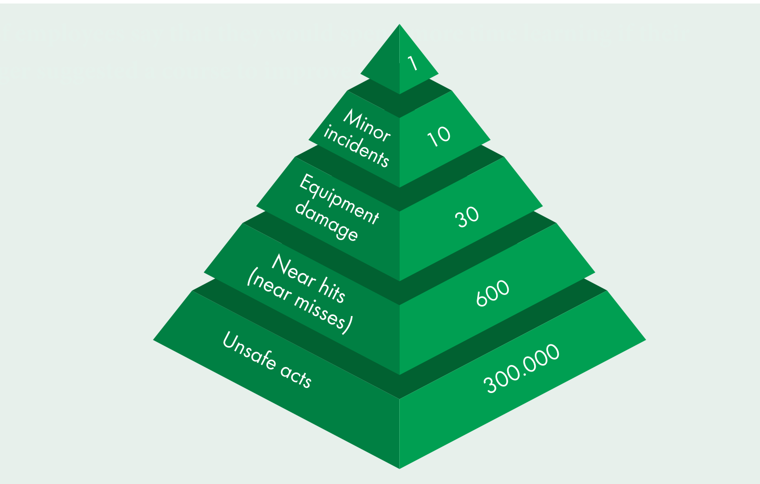

Figure 1. Heinrich's pyramid (Frank E. Bird version)

At DEKRA, we analyzed a series of major industrial accidents, and found a similar correlation.[2] We discovered that the potential distribution function provides a model for the number of fatalities (or the remediation costs), as shown in Figure 2: for every 10 accidents with 10 fatalities there is one accident with 100 fatalities; for every 10 accidents with 100 fatalities there is one with 1,000 fatalities, and so on.

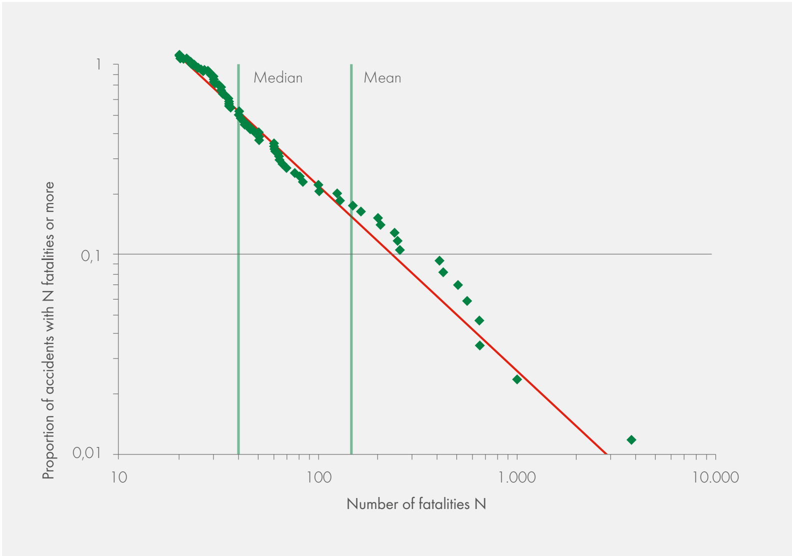

Figure 2. Probability distribution function of major industrial accidents

One would be tempted to conclude, along with Heinrich, that reducing the number of near misses (or minor incidents) would automatically mean a reduction in fatalities and, even, in catastrophic events. Unfortunately, experience has taught us otherwise. For example, it is widely known that the operator of the Deepwater Horizon rig received a safety award on the very same morning of the day it blew out (April 20, 2010), causing 11 fatalities and the largest oil spill in history. Similarly, and more pointedly, the investigating committee[3] of the infamous Texas City incident (March 23, 2005) concluded that *"BP mistakenly interpreted improving personal injury rates as an indication of acceptable process safety performance at its U.S. refineries. BP's reliance on this data, combined with an inadequate process safety understanding, created a false sense of confidence that BP was properly addressing process safety risks."*

1 Heinrich HW (1931). Industrial Accident Prevention: a scientific approach. McGraw-Hill

2 A. Trujillo (2016). Industrial Accidents: are more Serious Events than Bhopal Possible?. Chemical Engineering Transactions. Vol. 48.

3 The report of the BP U.S. refineries independent safety review panel "Baker panel".

The problem here is one well known to statisticians and logicians: **one cannot infer causation from correlation**. The fallacy is so old and common, it even has an elegant Latin name: *cum hoc ergo propter hoc* ("with this, therefore because of this"). In other words, and contrary to Heinrich's thesis, we cannot expect that by reducing the number of minor incidents we will achieve a commensurate reduction in fatalities.

DEKRA explored the fallacy more deeply in a groundbreaking white paper that made explicit the assumptions underlying Heinrich's conclusions. Among them, two are especially relevant for our purposes:

> All injuries of low severity have the same potential for serious injury.
> Injuries of differing severity have the same underlying causes.

It is clear that neither of these assumptions was true for Deepwater Horizon, BP Texas City, Chernobyl or any other of the countless process safety incidents that have occurred. Poor process safety knowledge and culture may be root causes in many of these examples, but certainly not the only cause. And, clearly, fooling around without a hard hat does not have the same potential for serious consequences as an inadequate nuclear reactor design. Both are unsafe (at the bottom of the pyramid), but the magnitude of the consequences differs significantly.

The most we can glean from Heinrich's pyramid is the knowledge that under given circumstances, the number of minor events is correlated with the number of major events. However, this relationship is completely useless in preventing major incidents, which is, after all, the goal of process safety.

Disaster prevention through incident investigation

Preventing major incidents is what process safety is all about. Back in the 1980s, a series of catastrophic incidents (including the infamous Bhopal and San Juan Ixhuatepec disasters) led the American Institute of Chemical Engineers (AIChE) to establish the Center for Chemical Process Safety (CCPS) and to task it with developing the newly defined discipline of process safety, that is, with developing the tools required to comprehensively identify, assess and manage risk. The result was Process Safety Management (PSM). We can think of it as what one needs to do to optimize safety performance and minimize the probability of major accidents.

Table 1 shows the twenty elements identified by the CCPS as pillars for world-class process safety performance. DEKRA has developed its own process safety management solution: Organizational Process Safety (OPS) , based on the CCPS model. OPS groups the twenty elements into seven workstreams, also shown in table 1.

Among the twenty OPS elements, there is one that seems to contradict our criticism of Heinrich's thesis: incident investigation. Clearly, we investigate incidents in order to prevent them from recurring. However, what about major events? Unfortunately, they do occur and have to be investigated from time to time, but by then, it's too late. Instead we investigate minor incidents, as well as what we call near misses. Why? Because these are the incidents that have

> the potential to escalate into a major incident, or
> common causes with major incidents.

In the field of process safety, these would be the incidents or near misses with the potential to escalate into a process safety event and cause SIF (Serious Injuries or Fatalities).

In this context, incident investigation of minor events provides a fantastic opportunity to learn major incident prevention lessons "for free" — that is, it provides the results without the harm. We can reasonably ask, for example, whether the Chernobyl disaster could have been prevented had previous near misses at the plant been properly investigated and their lessons adequately assimilated.
To obtain the maximum preventative power out of incident investigations one must:

Workstream	CCPS Elements
1. Capability	> Compliance with Standards > Process Knowledge Management > Process Safety Competency > Training and Performance Assurance
2. Incident Response	> Stakeholder Outreach > Emergency Management > Incident Investigation
3. Risk Management	> Hazard Identification and Risk Analysis
4. Asset Integrity	> Asset Integrity and Reliability > Management of Change
5. Accountability	> Measurement and Metrics > Auditing > Management Review and Continuous Improvement
6. Operations	> Operating Procedures > Safe Work Practices > Operational Readiness > Contractor Management > Conduct of Operations – Operational Discipline
7. Culture and Organization	> Process Safety Culture > Workforce Involvement

Table 1. Workstreams and CCPS elements

- Clearly identify which incidents or near misses to investigate, e.g. those with potential to escalate into a process safety event.
- Proceed rigorously throughout the investigation.
- Analyze not only immediate, but also root causes, including culture and leadership in the organization.
- Make public and apply the lessons learned.

Every one of these key principles must be carried out in close accordance with the PSM system implemented in the facility or organization.

Investigating incidents with an eye to reducing risk

Heinrich's pyramid has been very popular for a century as a tool to describe the numerical relationship between incidents with varying degrees of severity. The correlation can even be extrapolated into process safety, considering major incidents. The numerical correlation between the different severity levels is useful to describe reality, but cannot be used as a driver to change it.

A sound organizational process safety system is key in reducing the risk of a catastrophic event to tolerable levels. Among the twenty elements identified by CCPS as essential for process safety performance, incident investigation is crucial in that it provides an opportunity for organizations to learn valuable lessons from minor incidents that then help prevent major disasters. Choosing the right methodology for incident investigation facilitates the process and must be tailored to the purpose and available resources in order to be effective.

PIETER DE KORT

Pieter de Kort has accumulated 25+ years of experience in the process industry gained through various positions in process safety for large chemical companies. His experience has given him a broad know-how for tackling process safety issues. His main areas of expertise are process safety management, incident investigation, due diligence studies, chemical reaction hazards, HSE auditing / process safety auditing, process hazard analysis (PHR, HAZOP, What-If) facilitation and he is an experienced facilitator and trainer.

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DEKRA Process Safety and Chemical Safety

The breadth and depth of expertise in process safety makes us globally recognised specialists and trusted advisors. We help our clients to understand and evaluate their risks, and work together to develop pragmatic solutions. Our value-adding and practical approach integrates specialist process safety management, engineering and testing. We seek to educate and grow client competence to provide sustainable performance improvement. Partnering with our clients we combine technical expertise with a passion for life preservation, harm reduction and asset protection. As a part of the world's leading expert organisation DEKRA, we are the global partner for a safe world.

Process Safety Management (PSM) Programmes

> Design and creation of relevant PSM Programmes
> Support the implementation, monitoring, and sustainability of PSM Programmes
> Audit existing PSM Programmes, comparing with best practices around the world
> Correct and improve deficient Programmes

Process Safety Information/Data (Laboratory Testing)

> Flammability/combustibility properties of dusts, gases, vapours, mists, and hybrid atmospheres
> Chemical reaction hazards and chemical process optimisation (reaction and adiabatic calorimetry RC1, ARC, VSP, Dewar)
> Thermal instability (DSC, DTA, and powder specific tests)
> Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
> Regulatory testing: REACH, UN, CLP, ADR, OSHA, DOT
> Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

Specialist Consulting (Technical/Engineering)

> Dust, gas, and vapour flash fire and explosion hazards
> Electrostatic hazards, problems, and applications
> Reactive chemical, self-heating, and thermal instability hazards
> Hazardous area classification
> Mechanical equipment ignition risk assessment
> Transport & classification of dangerous goods

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