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QRA IN THE COMMERCIAL EXPLOSIVES INDUSTRY

William B. Evans, A-P-T Research, Inc.

OUTLINE

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    - Evolutionary Trends
    - Identified Need
- Hazards Management
- Evolution to Risk Management
    - Risk Matrices
    - Advent of IMESAFR
- IMESAFR as a Risk Management Tool
- Role of Industry Associations
- Summary/Conclusions

BACKGROUND

- The first revolution in commercial explosives technology was in the 1860s, with the ‘taming’ of nitroglycerin (NG) in dynamites, using other nitrates to improve performance and the development of commercial detonators and blasting caps
    - Thank you, Alfred Nobel
- These products may have undergone a slow evolutionary improvement but would have been recognizable a century later
- The same was also true, to a lesser extent, of the process technology used to manufacture both the basic materials, intermediates, and final products
    - Production rates got higher, processes safer (not safe) and manning levels declined but there were no revolutions in process technology
    - Someone from Nobel’s Explosives in 1870 would recognize a dynamite or detonator plant today, with the exception of electronic detonator plants where the electronics are primary and the explosives secondary

BACKGROUND

- In many ways, this was the golden age for commercial explosives companies
  - Barriers to entry were very high (capital cost and technical expertise)
  - Profitability was very good
  - Explosives companies were large, at least comparative to today, and technically sophisticated, at least for the day
  - They also tended to be part of very large and very technically competent chemical or petrochemical companies
- All of this was balanced by the inherent hazards of manufacturing, e.g., NG, styphantes, fulminates, azides, etc., and then manufacturing the final products using such sensitive primary or molecular explosives
  - Managing this was the first generation of Risk Management

HAZARDS MANAGEMENT

- Explosives companies recognized that their products and processes were inherently hazardous and this needed to be managed.
- By the 1950s, there was almost a century of experience with these products and processes.
  - Companies had a good understanding of how accidental explosions happened
  - Companies had a good understanding of how often these events could happen
  - Companies had a good understanding of preventative/mitigative factors
  - They also knew that the materials being processed were so sensitive that intrinsic safety was not achievable
- Risk Management requires the understanding of three factors:
  - Event frequency
  - Consequences
  - Acceptable level of risk

HAZARDS MANAGEMENT

- Companies had a good understanding of both baseline event frequency and the effectiveness of various preventative measures
- Companies did not have a good understanding of consequences
  - Beyond “bad thing happens,” i.e., explosion and fatalities
  - Consequences were managed by minimizing quantities, minimizing operator levels, and separation distances (QD) to other inventories and populations
    - Fatalities did occur outside QD and, more frequently, there were survivors inside QD
    - Managing consequences by QD is expensive (dynamite plants had very large footprints, fine when they were built in the 1800s, less fine by 1950)
- There was no real effort to determine acceptable risk criteria and certainly no system available to estimate risk or manage it
- This was hazards management, where companies used expertise and experience to minimize event frequency and consequences were minimized as discussed above

EVOLUTION OF THE CUSTOMER BASE

- World War II, the rebuild, and economic (and baby) booms thereafter generated an unprecedented demand for minerals and fuels
  - Mining had been dominated by underground (u/g) mines with relatively high-grade ores/coal seams
  - New u/g mines were relatively slow and expensive to develop and had limited capabilities for very high outputs
  - The mining trend became to mine lower-grade ore bodies, which were close to the surface, using open pit mines
    - Because of the relatively low grade of ores being mined in open pits, very large amounts of overburden and waste had to be removed to be economical
    - This required large boreholes and very large quantities of explosives
    - Even surface coal mines, which were more economical than u/g, still required large boreholes and very large quantities of explosives to optimize efficiency
  - Dynamites could not be made in the required sizes at the required rates at the required cost/price to meet this demand

EVOLUTION OF THE EXPLOSIVES INDUSTRY

- Note that the rest of this presentation omits advances on the initiating products (I/P) side of the business
  - A 2018 detonator would be recognized by someone in 1870 or 1950 for what it is
  - A 2018 cast pentolite booster would be very similar to one from 1960
  - Bulk ANEs are not obviously explosives, let alone recognizable as such for someone from the dynamite era
  - There has been a huge evolution in detonator technology in the past 60 years – but hazard and risk management has evolved little
    - The use of primary and molecular explosives still drives the hazards and, because of the relatively small quantities in the process, hazards management still works
- The explosives side of the business needed to evolve rapidly to meet this new demand and by 1960 had new technologies (ANFO and watergels) available in the required quantities and loading efficiencies (bulk trucks)

THE EVOLUTION OF HAZARDS MANAGEMENT

- The explosives industry was very pleased with itself, a view that would prove to be wrong on almost every level
- One of the things that was gotten wrong was that the new products were seen to be much safer to manufacture/transport/store/use than dynamites
  - This was obviously true in the sense that the new products were much less sensitive to, e.g., friction and impact (or static, to a much smaller degree) than dynamites
  - But the known sensitiveness of dynamites had created manufacturing systems where
    - Material of construction were soft (wood and brass were commonly used)
    - Tip speeds of moving process parts were as low as possible; mixers were open
    - In-process inventories were minimized
    - Number of operators present was minimized
    - Inventories were separated by full QD, e.g., mixing and packing were done in different buildings

THE EVOLUTION OF HAZARDS MANAGEMENT

- A standard packaged watergel or emulsion plant would be very different, e.g., the Orica PE plant in Brazil (when first purchased)
  - All process equipment was stainless steel
  - Some process equipment ran at thousands of rpms with correspondingly high tip speeds; much of the process was closed (high confinement)
  - In-process inventory was thousands of kg
  - There were 27 operators for the process
  - Mixing and packaging was done in the same building, bringing the total inventory to greater than 10,000 kg
  - There was not full QD to/from other process buildings, magazines, and offices
- The higher tip speeds, in-process inventories, etc., were necessitated by the need for much higher production rates
  - If one made the new products with the old processes, there would not have been a process explosion since their development
  - But the margin of safety was compromised by the new processes

THE EVOLUTION OF HAZARDS MANAGEMENT

- This erosion of safety margin was demonstrated conclusively by several major process explosions globally in the first 15 years of the new technologies
  - Dynamite plants also had several major accidents in this period but no one was surprised by that
- The old hazards management approach clearly did not translate to the new technologies
  - There was not nearly the same expertise and experience levels available
  - There was very limited historical event frequency data available (a few plants for a decade vs. hundreds of plants for a century)
  - New initiation modes had ‘become available’; thermal events are N/A for dynamites (but not for nitrations clearly) and not for emulsions or watergels either
- It became clear to the industry that a more formal and comprehensive approach to hazards management was needed.

THE EVOLUTION OF HAZARDS MANAGEMENT

- The remainder of this section will focus on the approach taken by ICI but much of it will be generically valid for the industry
- It was recognized that major explosion hazards could occur at three levels
  - An event, e.g., friction or impact, in a piece of process equipment
  - An event, e.g., no flow pumping in a process
  - An event, e.g., fire engulfment, in the plant
- Therefore a system was developed to ‘cover’ all three levels
- This was the six Hazard Study (plus specialist studies) system
  - HS1: a project overview including siting, environment impact, health and safety, material compatibility, possibility of inherent safety
  - HS2: Major process explosion hazards, guideword driven with specialist studies where needed (e.g., HERC and HIRAC (a risk management study))

THE EVOLUTION OF HAZARDS MANAGEMENT

- Hazard Study system continued
    - HS3: the HAZOP (Hazard and Operability) study which ICI made public domain after development (by Mond Division) and remains in broad use in the chemical and petrochemical industries; guideword driven, looks for process issues (not just hazards, but operability, quality, etc.)
    - HS4 and HS5: pre-commissioning and post-commissioning respectively, is the plant built to design, will it work as designed, potential process/ equipment issues (HS4), potential operator safety/injury issues (HS5)
    - HS6: 6 – 12 after the end of commissioning; essentially a project review – what was gotten right and what needs to be improved. A report card so that next time is better
- There was one additional leg to this already six-legged stool and that was as critical as any of the studies
    - A robust change management system was developed and put in place

THE EVOLUTION OF HAZARDS MANAGEMENT

- The specialist studies
  - Hazard Evaluation and Risk Control (HERC)
    - Developed by CIL (ICI in Canada) and Hercules Inc.
    - Requires a great deal of specialist hazards data (many man years of data generation)
    - Looks at many factors, e.g., product sensitivity vs. initiation mode, degree of confinement vs. Minimum Burning Pressure (MBP), product critical diameter vs. process diameter, etc.
    - It uses either historical data or some methodology, e.g., Fault Tree Analysis, to generate an event frequency
    - It then calculates the explosion frequency for a specific product/process condition scenario (generally the ‘worst case’, i.e., most sensitive product at most extreme process conditions)
  - This is almost true risk analysis/management as opposed to Hazards management, as there was a fully quantified event frequency and ICI did have a numerical risk criterion (1 explosion per 100 million operating hours) – but consequences were still ‘bad thing happens’
  - CHAZOP: HS3 for PLC controlled processes, looks for programming issues

THE EVOLUTION TO RISK MANAGEMENT

- The emphasis in Hazards Management was almost totally on a reduction in event frequency
  - Consequence management was generally on “easy” mitigation steps
  - Many of the easy mitigation steps in dynamite manufacturing were lost in the transition to the new technologies
- It was recognized that while accident frequency could be ‘minimized’, the real minimum appeared to remain uncomfortably high
- It was also recognized that fatalities were not the only consequence that needed to be managed
- This meant that the industry needed to evolve towards real risk management and needed additional tools to do so
- ICI’s first step on the path was to add Hazard Identification Risk Assessment and Controls (HIRACs), which required both frequency and consequences be estimated and the acceptability of that risk be assessed on the Orica Risk Matrix
  - This is a Semi-Quantitative Risk Assessment (SQRA) system

ORICA RISK MATRIX

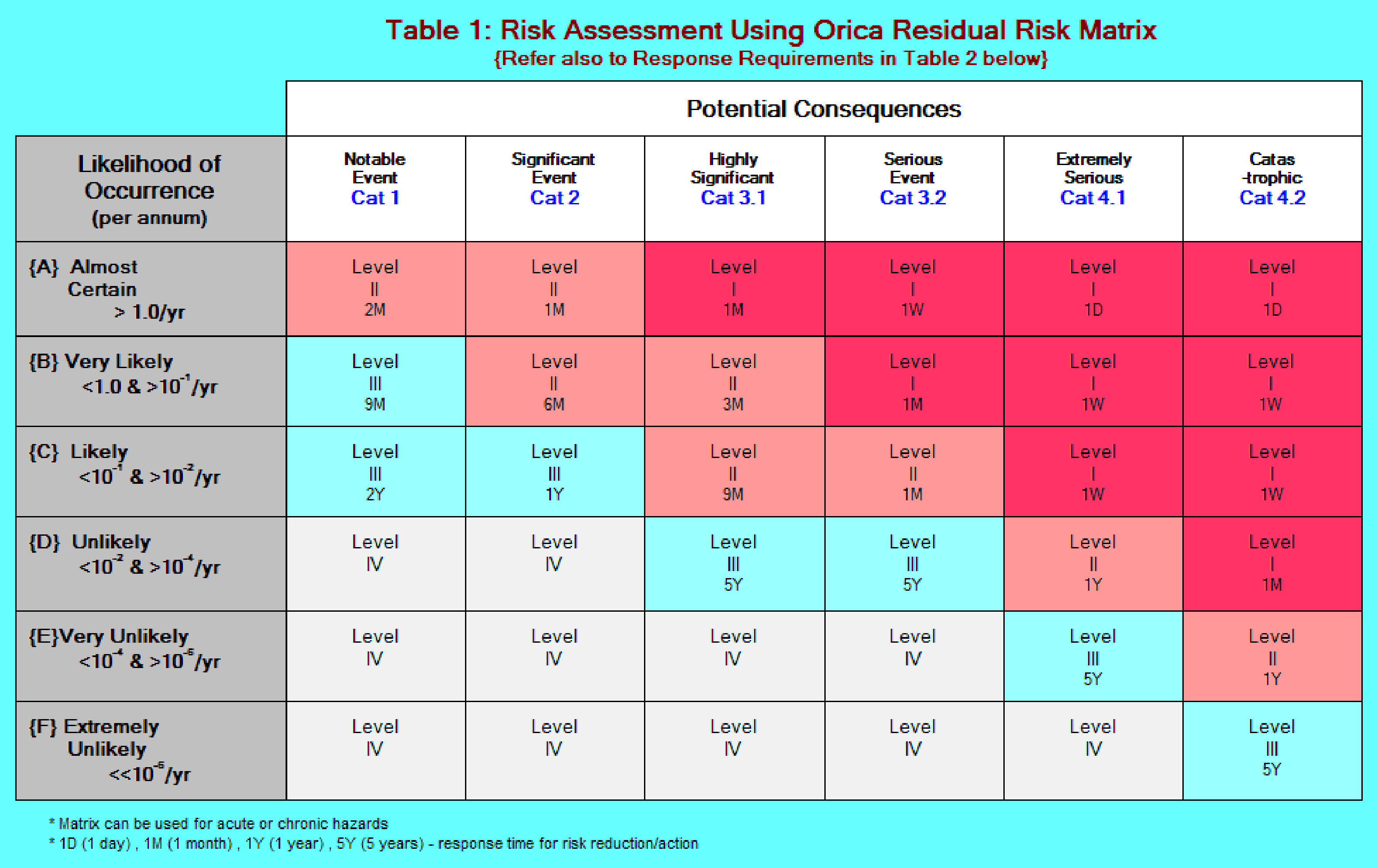

Table 1: Risk Assessment Using Orica Residual Risk Matrix

{Refer also to Response Requirements in Table 2 below}

	Potential Consequences					
Likelihood of Occurrence (per annum)	Notable Event Cat 1	Significant Event Cat 2	Highly Significant Cat 3.1	Serious Event Cat 3.2	Extremely Serious Cat 4.1	Catas -trophic Cat 4.2
{A} Almost Certain > 1.0/yr	Level II 2M	Level II 1M	Level I 1M	Level I 1W	Level I 1D	Level I 1D
{B} Very Likely <1.0 & $>10^{-1}$/yr	Level III 9M	Level II 6M	Level II 3M	Level I 1M	Level I 1W	Level I 1W
{C} Likely $<10^{-1}$ & $>10^{-2}$/yr	Level III 2Y	Level III 1Y	Level II 9M	Level II 1M	Level I 1W	Level I 1W
{D} Unlikely $<10^{-2}$ & $>10^{-4}$/yr	Level IV	Level IV	Level III 5Y	Level III 5Y	Level II 1Y	Level I 1M
{E}Very Unlikely $<10^{-4}$ & $>10^{-5}$/yr	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level II 1Y
{F} Extremely Unlikely $<<10^{-5}$/yr	Level IV	Level IV	Level IV	Level IV	Level IV	Level III 5Y

* Matrix can be used for acute or chronic hazards
* 1D (1 day) , 1M (1 month) , 1Y (1 year) , 5Y (5 years) - response time for risk reduction/action

ORICA RISK MATRIX

- Each row on the Y axis represents a range of event frequencies
- Each column along the X axis represents a range of consequences
- The HIRAC Team would determine the “correct” frequency and consequence ranges, and therefore the risk/risk acceptability, using the Risk Matrix
  - In the case of an unacceptable or barely acceptable risk, the Team could recommend additional preventative and/or mitigative safeguards to reduce the event frequency and/or consequences and thereby the risk
- Orica used five risk areas (e.g., Safety and Health, Environmental Impact) with defined ranges for all the consequence levels (columns)
- Frequency ranges did not vary with risk area
- HIRACs were not limited to process/plant explosions but to any scenario where there was significant risk (e.g., ammonia sphere rupture, loss of containment in a cyanide plant storage area)

RISK MANAGEMENT

- The addition of the HIRAC tool allowed true risk management
  - But the use of ranges left an uncomfortable level of "fuzziness"
  - The consequence number continued to be less well defined than the frequency values in general
  - For explosion scenarios in particular, a more quantitative tool was needed
- The development of IMESAFR, based on the Department of Defense Explosives Safety Board (DDESB) SAFER program, for the commercial explosives industry provided this tool.

NDIA Paper No. 20720, "IMESAFR Overview,"
Technical Track – C, Tuesday, 3:10-4:50

- IMESAFR provides an "exact" risk value, i.e., both the frequency and consequences are fully quantified
  - IMESAFR does not provide default risk criteria but the IME does provide recommendations
    - These values are similar to guidance from DDESB, many regulators globally, and what most companies have as internal standards
  - IMESAFR based QRAs have become a standard tool with the explosives industry and have growing acceptance within the regulatory community

IMESAFR AS A RISK MANAGEMENT TOOL

- IMESAFR provides fully quantified risk values (Individual and Group), which is extremely valuable to both the industry and regulators; but it is far more valuable than just that, e.g.:
  - Does the scenario fail Individual or Group risk criteria?
  - What is the dominant fatality mechanism, e.g., horizontal debris or glass?
- The answer to this type of question allows one to focus risk management (reduction) efforts on the factor that’s most effective
- For existing sites, options may be more limited, but for a new PES, one can look at a number of easy ways to potentially reduce risk
  - With 2.0, directionality, i.e., the cruciform pattern for horizontal debris was introduced and the right orientation can reduce the risk at a given ES by orders of magnitude at the same distance

IMESAFR AS A RISK MANAGEMENT TOOL

- IMESAFR 2.1 provides even more simple options to reduce risk
  - Bin G will automatically reduce risk calculated in 2.1 compared to 2.0, by a large amount in some scenarios (e.g., concrete structure) where debris is a dominant fatality mechanism
  - One can now reduce the effect of horizontal debris by increasing barrier height, as barriers can now remove side impact as well as fly through horizontal debris
  - Frangible roofs and walls, while still treated very conservatively, will reduce debris in at least one direction
- IMESAFR not only allows one to measure and therefore manage existing risks from explosives inventories, but also allows one to find the most cost-effective method to add a new building to an existing site or to a new site while meeting both internal and, where they exist, regulatory risk standards.

MANAGEMENT OF RISK IN THE INDUSTRY

- The Explosives industry includes companies with thousands of employees in dozens of countries to companies with less than 10 employees operating locally
- The level of risk management capabilities covers the same range
  - Big companies have always recognized that a serious accident in the industry generates the same regulatory response to the entire industry
  - Methods of passing on safety and hazards information from the big companies to smaller players has always been seen as enlightened self-interest
  - This has been done through national, regional, and global associations
    - The initial focus was on safety and has evolved through hazards management to risk management, as the industry has
    - That said, ‘safety’ will always be an integral role for these associations
  - This is generally done formally through publications, e.g., IME SLPs and SAFEX GPGs

SUMMARY/CONCLUSIONS

- As the explosives industry made the transition from dynamites to blasting agents and water-based products, there had to be a corresponding transition in managing the hazards and risk from explosives operations and inventories
- This evolution has moved from, at best, data-based expert opinion to fully quantified risk assessments
- The advent of IMESAFR was the required tool that allowed the transition to full QRA
- IMESAFR has already proved to be an invaluable and uniquely capable tool for QRA, both internally for companies and for requests to regulators for exemptions from, e.g., QD in a specific scenario
- IMESAFR will allow companies to do more and/or new things at a lower cost and a lower risk level to employees and the public