hazardex
the journal for hazardous area environments
hazardexonthenet.net
July 2020

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On June 3, Russian President Vladimir Putin declared a state of emergency after 20,000 tonnes of diesel fuel leaked from a power plant belonging to a subsidiary of Norilsk Nickel (page 9). The leak occurred after a fuel tank became depressurised due to the subsidence of its support pillars.

In a televised government meeting, President Putin criticised the local government for its response to the incident after it emerged that officials first heard about the leak on social media, two days after it had happened. During the meeting, Putin asked: "What, are we to learn about emergency situations from social networks? Are you alright healthwise over there?"

The question could also have been asked of Norilsk Nickel when the company explained how the impacted fuel tank's support pillars had held it in place for 30 years without difficulty. This explanation is a prime example of how complacency can lead to process safety incidents. As has been discussed countless times in Hazardex, including within this issue, risk assessments and asset maintenance are vital to ensuring potential incidents are identified and dealt with before accidents can occur.

Just because a process is working without issue does not mean all is well. Corrosion is one such example where a false sense of security can lead to incidents. A pipeline may seem to be in perfect working order, but undetected corrosion could be occurring due to poor asset maintenance or simply because it hasn't even been looked for.

The issue of complacency has been amplified by the coronavirus pandemic as companies change their methods and operations to account for lockdown restrictions and social distancing measures. These changes have meant many maintenance tasks were postponed or cancelled during the pandemic, or some tasks would have been prioritised over others. However, as mentioned this could lead to a complacent attitude regarding products, systems and equipment which have been operating without issue. These assets may have been deemed low priority, exacerbating any undetected problems. It could therefore be argued that maintenance is now more important than ever and should play a key role in the ramping up of post-pandemic operations – regardless of an asset's past performance.

As can be seen by the incident in Russia, where the clean-up could cost up to 100bn roubles (£1.2bn; $1.5bn) and take up to ten years, if companies simply rely on the past as evidence for a safe and reliable asset, then the results can be catastrophic.

...Alistair Hookway, Editor, Hazardex
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in this issue

The issue with deferred maintenance is that it only grows in scope – and cost – the longer it is prolonged

This alternative design uses multiple well-established explosion protection techniques to produce a viable alternative for a flameproof Ex d instrument

Risk assessment software applications combine technology advantages with organisational experience and best practices to create improved safety solutions

This article aims to review different explosion scenarios and describe one representative model within each category of methodology and explosion scenario.

Hazardex is a controlled circulation journal published monthly. Completed print or online registration forms will be considered for free supply of printed issues, web site access and online services. Annual subscription for non-qualifying readers is: UK £147; EU £215.25; Airmail £315 and single copy price is £23.10 plus P&P.

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ISSN 1476-7376


Image: Shutterstock

Global oil & gas decommissioning to total **$42 billion through 2024, dominated by UK North Sea**

Independent energy research company Rystad Energy has estimated that the total global value of decommissioning projects that will accumulate through 2024 could reach $42 billion. The prediction is a result of energy companies looking to increase spending in decommissioning work due to a shortage in profitable investment alternatives caused by the coronavirus pandemic.

Rystad says that with an average asset age of 25 years, the Northwest European decommissioning market could grow 20% in annual commitments through 2022 if the current low oil prices don't show signs of substantial recovery soon. In addition to a rapidly maturing asset base and low oil prices that erode commercial viability and potential life extensions, the North Sea decommissioning market will also be helped by favourable service contract prices.

Only about 15% of North Sea assets have been decommissioned to date, but in the coming five years Rystad expects an average of 23 assets to cease production annually. The UK is poised to lead the way with nearly 80% of total estimated expenditure on Northwest European decommissioning in the next five years, followed by Norway with 14% and Denmark with 4%. The pool of removal projects in the region for that period is estimated at about $17 billion. By comparison, decommissioning costs in the US for the same period are estimated at $5.7 billion.

"A protracted low price environment can potentially motivate operators to leverage low contract prices and commit to their asset retirement obligations, thus spurring decommissioning activity in the Northwest Europe region. This will also provide welcome opportunities for contractors in an otherwise gloomy oilfield services market," says Sumit Yadev, energy service analyst at Rystad Energy.

The high market share of the UK can be largely attributed to its rapidly maturing production levels, as almost 80% of the country's oil and gas assets have produced more than 75% of their available resources. Additionally, lacklustre exploration results, growing regulatory stringency and a prolonged low oil price environment may lead operators to fulfil their asset retirement obligations in the absence of any lucrative competing investments.

Some of the leading assets that will drive the decommissioning market in the region include the Brent, Ninian and Thistle fields in the UK and Gyda in Norway. Shell's Brent project would emerge as the single largest asset ever decommissioned globally, representing an outlay of nearly $3 billion alone over the coming decade. Ninian and Gyda would collectively present contracting opportunities worth nearly $2 billion.

The increased spending on decommissioning may limit the room for operators to invest in other segments such as exploration, development and enhanced oil recovery projects. Leading players such as Shell, Total, Repsol and Premier Oil are expected to assign 10% or more of their North Sea spending in the next five years to decommissioning activities.

Plugging and abandonment (P&A) of wells is expected to make up about 45% of decommissioning costs for the period, followed by platform removals, which account for nearly 20% of the total costs. Platform wells are set to be the dominant segment for well P&A activity, making up about 65% of the total wells to be abandoned, while the rest are subsea wells. However, in terms of costs, subsea wells will take the lead as they cost on average $11 million each to abandon, compared with $5 million for an average platform well.

The low oil prices could play a pivotal role in boosting decommissioning spending in the UK if they persist beyond the end of this year. Nearly 10% of all UK offshore assets have lifting costs above $25 per barrel, which will hamper their life extension prospects and make decommissioning a better financial option if low prices persist.

Operators implemented strong cost optimisation measures after the oil price crash of 2014 and therefore have little room for further cost and efficiency gains now, which may also expedite decommissioning spending.

Overall, more than 2,500 oil and gas wells are expected to be decommissioned across the North Sea in the coming decade, of which 1,500 are in the UK. The UKCS will also witness the removal of nearly 300,000 tonnes of topsides in the next five years, with nearly 50 topsides set to be decommissioned, representing an average topside removal cost of $5,300 per tonne. Additionally, almost 100,000 tonnes of substructures are expected to be removed in UK waters. In line with the broader North Sea trends, platform wells are expected to account for the bulk of the well P&A activity with nearly 70%. ■

UK approves plans for country's largest solar park

The UK approved plans for the proposed £450 million ($554 million) Cleve Hill Solar Park Project on May 28 which could include one of the largest energy storage systems in the world. A 25-acre battery facility will be part of a 900-acre site near Faversham, southeast England which will include 880,000 solar panels generating 350 megawatts of power.

Secretary of State for Business, Energy and Industrial Strategy Alok Sharma approved the plans which were first announced in 2017 but were met with opposition from locals who say the project will damage the environment, ruin the countryside and cause the loss of farmland.

Announcing the government's decision, the Planning Inspectorate's Chief Executive Sarah Richards said: "The Planning Inspectorate is committed to giving local communities the opportunity of being involved in the examination of projects that may affect them. Local people, the local authority and other interested parties were able to participate in a 6-month long examination. The Examining Authority listened and gave full consideration to local views before making their recommendation."

The project is a joint venture between Hive Energy and Wirsol Energy. Local website KentOnline reports that due to the large size of the project, planning powers were taken away from local authorities as it is considered a Nationally Significant Infrastructure Project (NSIP). Construction of the site is expected to start next year with the facility becoming operational in 2022.

Campaigners who have been fighting against the project say that the large battery facility would be a significant safety hazard capable of devastating the local area should an explosion occur.

The Cleve Hill Solar Park will generate up to 350MW of renewable electricity to power around 91,000 homes. According to Hive Energy, the project will reduce the UK's dependence on fossil fuels and lower CO2 emissions by 68,000 tonnes a year. The project won't require any Government subsidies and aims to be one of the lowest cost generators of electricity in the UK.

Giles Redpath, CEO of Hive Energy said: "Since 2017, we have worked alongside stakeholders and the community to listen to their feedback and to design a solar park that benefits the local environment whilst delivering a significant amount of renewable, affordable and secure energy generation. We are proud to lead the way, together with our partners at Wirsol, to deliver the UK's largest solar park. Due to be operational by 2022, the Cleve Hill Solar Park offers a real solution to our urgent climate needs and showcases the potential for the UK to lead the green recovery." ■

EDF submits planning application for Sizewell C nuclear power plant

EDF announced on May 27 that it had submitted a development consent order (DCO) for Sizewell C to the UK's Planning Inspectorate after the process was delayed by the coronavirus pandemic in March. If plans are approved, Sizewell C will power around 6 million homes and create around 25,000 jobs during construction.

EDF had intended to submit a DCO in March, however the decision was taken to defer it by two months due to the uncertainty created by coronavirus, the energy company said in a statement. The application for a DCO follows four rounds of public consultation which began in 2012.

More than 10,000 locals and organisations have so far contributed views and helped shape the proposals, however some residents raised concerns after EDF submitted the DCO while lockdown measures were in place, preventing any public gatherings for locals to discuss the plans. EDF said extra measures

An artist's impression of Sizewell C – Image: EDF

will be introduced to make it easier for the final proposals to be scrutinised.

Located on the coast of Suffolk in the east of England, Sizewell C will employ 900 people once fully operational. Up to 70% of the construction value will be spent with firms across the UK. To lower costs, Sizewell C will re-use the designs for Hinkley Point C in Somerset, south west England. Using the same design means Sizewell C will benefit from significantly reduced construction costs and lower risk.

Humphrey Cadoux-Hudson CBE, Managing Director, Sizewell C said: "Sizewell C is a net zero infrastructure project ready to kick-start the economy following the Coronavirus crisis. It will offer thousands of high-quality job opportunities and long-term employment for people living in Suffolk and it will strengthen the nuclear supply chain across the country. On top of the economic benefits, Sizewell C will avoid 9 million tonnes of CO2 being pumped into the atmosphere each year. The project will play a key role in lowering emissions while helping the UK keep control of its low carbon future."

EDF plans to fund the Sizewell C project through a method that would see the company paid during construction of the plant. The method would see costs of construction added to energy bills as the project went along, possibly decreasing development risk and lowering the final cost for consumers. However, critics believe that if the project was to be delayed or over-run, as the Hinckley Point C project has, then the taxpayer would be left with paying the extra cost.

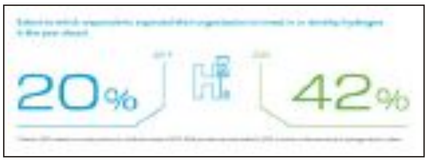
EDF hopes to complete the Development Consent Order process for the 3.2GW project within the next 18 months. ■

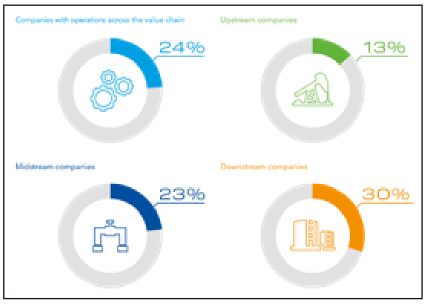
Image: DNV GL

Study shows hydrogen is central to oil & gas industry decarbonisation as **market growth expectations surge**

A new report reveals that hydrogen has surged up the priority list of many oil and gas organisations, taking a primary position in the sector's decarbonisation efforts.

A fifth (21%) of senior oil and gas industry professionals say their organisation is already actively entering the hydrogen market, according to a new report published by DNV GL. The proportion intending to invest in the hydrogen economy doubled from 20% to 42% in the year leading up to the Coronavirus-induced oil price crash.





The 'Heading for Hydrogen' report draws on a survey of more than 1,000 senior oil and gas professionals and in-depth interviews with industry executives. The report suggests that recent shifts in the industry's investment priorities are unlikely to affect the sector's long-term efforts to reduce carbon emissions.

DNV GL found a significant rise in those reporting that their organisation is actively adapting to a less carbon-intensive energy mix – up from 44% for 2018 to 60% for 2020. Carbon-free hydrogen production, transmission and distribution is now widely recognised as a central component to the oil and gas industry's decarbonisation efforts.

"Hydrogen is in the spotlight as the energy transition moves at pace – and rightly so. But to realise its potential, both governments and industry will need to make bold decisions," said Liv A. Hovem, CEO, DNV GL – Oil & Gas. "The challenge now is not in the ambition, but in changing the timeline: from hydrogen on the horizon, to hydrogen in our homes, businesses, and transport systems."

More than half of respondents to DNV GL's research in Asia-Pacific (56%), the Middle East & North Africa (54%) and Europe (53%) agree that hydrogen will be a significant part of the energy mix within 10 years. North America (40%) and Latin America (37%) are only a little behind.

The success of a hydrogen energy economy is closely aligned with the future of natural gas, renewable energy, and carbon capture and storage (CCS) technology, according to Heading for Hydrogen.

While hydrogen gas produced from renewable energy (green hydrogen) is the industry's ultimate destination, analysis shows that the sector can only realistically scale up to large volumes and infrastructure with carbon-free hydrogen produced from fossil fuels combined with CCS technology (blue hydrogen).

DNV GL's 2019 Energy Transition Outlook, a forecast of world energy demand and supply, predicts that natural gas will become the world's largest energy source in the mid-2020s, accounting for nearly 30% of the global energy supply in 2050. Natural gas and hydrogen can play similar roles within the global energy system, and the synergies between them – in application and infrastructure – will drive the hydrogen economy.

However, Heading for Hydrogen points to political, economic, and technical complexity in scaling the hydrogen economy. "To progress to the stage where societies and industry can enjoy the benefits of hydrogen at scale, all stakeholders will need immediate focus on proving safety, enabling infrastructure, scaling carbon capture and storage technology and incentivising value chains through policy," said Hovem.

Download Heading for Hydrogen at: dnvgl.com/headingforhydrogen ■

Fife Energy Park – Image: Flickr / Sludge G

World's first 100% green hydrogen project set for east coast of Scotland

Fife on the east coast of Scotland has been chosen as the location for the world's first 100% green hydrogen project if approved by UK energy regulator Ofgem. Gas distribution company SGN has asked Ofgem to approve its plans for the H100 Fife project which will see the production of green hydrogen to replace natural gas for an initial 300 homes.

In a statement, SGN said that H100 Fife would provide critical evidence for a potential zero carbon energy source, helping to inform the UK's long-term policy decisions for decarbonisation. SGN will bid for £2.8 million of funding from Ofgem this summer after passing an initial screening submission process for Ofgem's annual Network Innovation Competition. If successful, a 100% zero-carbon hydrogen network will be built later this year at the Fife Energy Park in Methil, around 17 miles (28km) north of Edinburgh across the Firth of Forth estuary.

The plans would see hydrogen produced via an electrolysis plant powered by the Offshore Renewable Energy Catapult's nearby offshore wind turbine. The proposed hydrogen production and storage system and heating network will run alongside the current natural gas system, demonstrating every aspect of an end-to-end hydrogen-to-homes system to support plans for large scale roll-out in the future.

The system will be designed and built to ensure at least the same safety and reliability standards expected from the current gas system. An on-site storage unit will hold enough hydrogen to ensure supply won't be disrupted during even the coldest weather conditions.

H100 Fife is part of the national Gas Goes Green initiative, a collaborative series of projects to prove the viability of hydrogen for heat. They share an objective to demonstrate how the UK's world class gas network, comprising of over 280,000 km of pipes connected to 23 million homes and businesses, can provide a clear and cost-effective pathway to decarbonise heat through hydrogen at low cost, at pace and at scale. Decarbonisation of the gas networks is necessary in order to achieve the Scottish Government and UK Government carbon net-zero targets by 2045 and 2050 respectively.

The project aims to provide critical insight into hydrogen demand and supply management, security of supply and 'real world' asset operation. As well as testing technical and engineering capabilities, the project will provide insights into customer appetite and interest for hydrogen. Customers can participate on an opt-in basis, meaning they will have the choice to switch to hydrogen, or remain with their existing natural gas supply. A demonstration facility within the project is proposed to allow customers to interact with hydrogen appliances in a home-like setting prior to opting-in. ■

Image: CSB - Still image taken from CSB safety video

Two US chemical companies fined $1 million each for 2016 leak

Two companies were fined $1 million each on May 27 after they pleaded guilty to violating clean air laws in relation to a 2016 chlorine gas leak in Atchison, Kansas. Harcros Chemicals and MGP Ingredients violated the Clean Air Act after they caused the gas leak which resulted in a large toxic cloud covering the city.

Both companies pleaded guilty and paid their respective fine following sentencing in Topeka on May 27. The incident in October 2016 occurred when a delivery truck, owned and operated by Harcros Chemicals, carrying 4,000 gallons of sulphuric acid was mistakenly connected to a tank containing 5,800 gallons of sodium hypochlorite at MGP's plant in Atchison, around 50 miles (80 kilometres) northwest of Kansas City.

The chemical reaction formed a chlorine gas cloud which spread across the city for around 45 minutes. Local authorities ordered local communities to shelter-in-place while some residents were forced to evacuate the area. In all, around 140 people required medical attention, including residents and employees of both companies.

According to its website, MGP is a supplier of premium distilled spirits, and specialty wheat proteins and starches. The US Chemical Safety and Hazard Investigation Board (CSB) released its final report on the incident in March 2018, details of which can be found here: ***https://www.csb.gov/mgpi-processing-inc-toxic-chemical-release-/*** ■

US chemical manufacturer cited for 2019 explosion and fire which injured three

The US Department of Labor's Occupational Safety and Health Administration (OSHA) has cited TPC Group LLC for exposing employees to workplace safety and health hazards after a fire and explosion at the Port Neches plant in November 2019. The company is facing fines totalling $514,692 for the blast which injured three workers at the plant in east Texas.

Homes and businesses were evacuated, and a shelter-in-place order was issued after the large early morning explosion. The blast blew out the windows of homes in neighbourhoods miles away and sent a chemical plume over the area.

OSHA opened an investigation after vapour which formed at the base of a butadiene finishing tower ignited and caused several explosions and fires. OSHA cited TPC for three wilful violations for failing to develop and implement procedures for emergency shutdown and failing to inspect and test process vessel and piping components.

"Employers are required to conduct regular inspections and address potential hazardous conditions associated with chemical processes to prevent catastrophic events from occurring," said Principal Deputy Assistant Secretary of Labor for Occupational Safety and Health Loren Sweatt. "OSHA has extensive resources available to help employers and workers understand requirements for process safety management."

The company has 15 business days from receipt of the citation and penalties to comply, request an informal conference with OSHA's area director, or contest the findings before the independent Occupational Safety and Health Review Commission ■

Port Neches explosion - Image: Shutterstock

President Putin holds meeting about spill response - Image: Kremlin

Russia declares state of emergency after 20,000 tonne oil spill

Russian President Vladimir Putin declared a state of emergency on June 3 after 20,000 tonnes of diesel fuel leaked from a power plant near the Siberian city of Norilsk on May 29. A "considerable amount" of the spilled petrochemicals seeped into the Ambarnaya River, the Kremlin said.

The spill originated from a power plant belonging to a subsidiary of Norilsk Nickel, the world's leading nickel and palladium producer. The leak occurred after a fuel tank became depressurised due to the subsidence of its support pillars. The spill consisted of fuel and lubricants and much of it flowed into the nearby Daldykan and Ambarnaya rivers.

In a televised government meeting, President Putin criticised the local government for its response to the incident after it emerged that officials first heard about the leak on social media, two days after it had happened.

Rosprirodnadzor, Russia's state environment watchdog, says that around 15,000 tonnes of oil products leaked into river systems while around 6,000 tonnes seeped into the subsoil.

The spill is thought to have contaminated around 135 square miles (350 sq. km) and turned large parts of the Ambarnaya river a crimson red. The state of emergency was decalred to enable extra resources and manpower to be sent to the area to help clean-up efforts.

In the conference call with President Putin, Minister for Civil Defence, Emergencies and Natural Disaster Relief Yevgeny Zinichev said that measures are being taken to localise the spread of the spill, oil booms have been installed, and work is underway to collect oil products, contaminated water and soil. Specialists from Moscow were flown to the area to help section off parts of the river.

An investigation into the incident is ongoing while three employees at the plant have been detained for breaching environmental protection rules.

Norilsk, located around 190 miles (300km) inside the Arctic Circle, has a population of around 175,000 and is built around the Norilsk Nickel plant. The nickel and palladium producer released a statement saying it was doing all it could to clear up the spill and that the incident was reported in a timely and proper way.

On June 5, Russia's Prosecutor General's office ordered a review of all hazardous objects built on permafrost in the country. President Putin held a second online meeting with officials where he asked them to amend Russian law to help prevent similar incidents from occurring in the future. Putin was also critical of Norilsk Nickel's President, Vladimir Potanin, for not replacing the impacted fuel tank sooner.

Officials said that on June 9, the leak had reached Lake Pyasino. The lake is around 70km long and feeds into the Pyasina River which eventually leads to the Arctic Ocean.

The BBC quotes a former deputy head of Rosprirodnadzor who said the clean-up could cost up to 100bn roubles (£1.2bn; $1.5bn) and take up to ten years.

Norilsk Nickel has been accountable for an oil leak before, notably in 2016 when it admitted responsibility for a spill which turned parts of a nearby river crimson red. ■

Representative image: Shutterstock

Indian chemical plant explosion **kills eight, injures 50**

An explosion on June 3 killed eight workers and injured 50 others at a chemical plant in the state of Gujarat on the western coast of India. The cause of the blast is unknown, with some local media reporting that it was a boiler explosion, while others suggested it occurred in a storage tank housing chemicals.

Around 200 workers were on the site when the incident happened at the plant belonging to chemical manufacturer Yashashvi Rasayan. A preliminary report by local authorities said the explosion happened in a chemical storage tank and caused a fire that spread across the plant. The report added that some workers who were near the storage tank at the time were killed instantly after being covered in highly concentrated chemicals.

The injured workers were taken to local hospitals while around 5,000 local villagers were evacuated as a precaution. Footage posted on social media following the blast shows a large plume of smoke rising from the factory as workers run from the factory.

The fire was brought under control after a few hours, allowing a search and rescue operation to begin. Six bodies were found on the site while two workers died in hospital. According to a local official, methanol and xylene were stored in tanks close to where the blast occurred.

On June 8, a tribunal ordered Yashashvi Rasayan to make an interim deposit of around Rs 25 crore (around £2.6 million) while an investigation into the incident continues. The National Green Tribunal, a body set up in 2010 to handle environmental disputes and issues, said it held Yashashvi Rasayan liable for the damage caused to both human lives and the environment. The six-person panel comprising retired judges and former officials is expected to publish an investigative report within a month.

The Rs 25 crore is in addition to the compensation which Yashashvi Rasayan has already been ordered to pay, including Rs 15 lakh (£15,694) to the families of those killed, Rs 5 lakh (£5,232) to those seriously injured, Rs 2.5 lakh (£2,616) to anyone injured, and Rs 25,000 (£261) each to anyone displaced from their home as a result of incident. ■

Every two months, SGS Baseefa Technical Manager Ron Sinclair MBE gives his perspective on the latest developments in the world of standards.

Coronavirus: the end, or a new beginning?

I am writing this on June 1, the day that the UK government set for the start of easing lockdown restrictions. Except that we are now not a totally United Kingdom, with England, Wales, Scotland and Northern Ireland making their own slightly different rules on how to progress. So, even at the UK level we are seeing fragmentation, but it becomes more obvious the bigger the group you consider. How is this going to affect the standardisation process and certification worldwide?

Electronic meetings are now becoming the normal way of working. But internationally, this brings problems of timing. IECEx has decided on a 12:00 UTC (13:00 BST) start. This suits Europe and the east coast of America, but anyone in California has to get up very early, and anyone in Australia gets to bed very late. We are yet to have any participants from New Zealand!

The IECEx meetings in May ran very smoothly, in part because most participants had met each other at previous meetings and could recognise voices. The secretariat imposed good "mute" discipline on microphones and, apart from the secretary who was sharing his screen showing the documents, cameras were off, in order to minimise bandwidth problems. We were unaware of latency issues in the sound and, because video was off, we were not put off by lip-sync issues or other glitches in the video stream.

The quality of some of the links for the recent UK Downing Street press conferences demonstrated that, even for those prepared to pay a premium for their service, latency and lip-sync can still be a major problem.

So, will remote working replace our international face-to-face meetings after we have emerged from the current situation? There are clearly advantages in being able to hold short meetings for the discussion and resolution of particular matters, but I am concerned that we will miss out on many of the advantages of being in the same room. And it is not just being able to judge reactions in the actual meetings, it is the side meetings, during the coffee breaks, that can be just as important. Many a discussion point, where two people seem to hold opposing views during the meeting, can be resolved in a group of two or three in the break-out area. An interchange of emails, after the remote meeting has finished, is not really effective in the same way.

IECEx held the May meetings remotely and will do the same for those previously scheduled for Niagara in late September. This will certainly be a new innovation for me, as I have not yet sat through meetings with over 150 remote participants. These are the formal annual meetings for the organisation, also attracting many observers into the various national delegations. The rule book provides for just three delegates per country, with only the lead delegate allowed to vote. This is normally done by the lead delegate holding up the country identification card from the table. It will be interesting to see how we manage this process online. Provisionally, it has been decided that any observers beyond the official three delegates will have their microphones and cameras muted by the secretary of the meeting, so they will truly be just that, observers.

One of the major decisions, taken at the May meetings, was to finalise a version of the new Operational Document OD 060, which was drafted in response to the coronavirus pandemic and deals with how the schemes can continue to operate during the crisis, but in a way that still provides adequate confidence in the system.

The current interim version of the document is available to view on the IECEx website and the final version should get formal approval in September. This includes the protocols for when surveillance visits can be delayed and how they can be conducted remotely. This is not just for the certification bodies and their manufacturing clients, but also for the IECEx System's supervision of certification bodies.

In contrast to IECEx, IEC TC31 postponed its March standards meetings until the end of October, in the hope that two weeks of meetings will still be able to take place. Over 100 people would normally gather in a series of separate one-, two- or three-day meetings, spread across the fortnight. A maximum of four meetings will be held simultaneously. There can be conflicts, with a few people trying to be in more than one meeting at a time, but as the meeting rooms are all co-located this usually works. That would be more difficult with remote meetings, unless they are spread out across a much longer period, with only one meeting being held at any one time. However, this then removes the ability to have short "corridor" meetings for those that are based in different meeting rooms.

Not all work is being postponed until October, with some of the smaller Maintenance Teams being able to work electronically, so although some revised standards will be delayed, others are keeping on target. ■

About the author

SGS Baseefa's Technical Manager Ron Sinclair MBE is a vice-chair of the European Notified Bodies Group for ATEX (ExNBG), as well as Chair of the IECEx Service Facility Certification Committee and a member of the IECEx Executive. He is chair of both the UK and European Standards Bodies operating in this area.

Caribbean Petroleum Corporation Disaster – Image: CSB

Potential effects of the economic climate on asset integrity

During the current economic climate, when it comes to budgets, practically every facility owner and manager has the same dilemma: doing more with less. When faced with shrinking budgets, it's tempting to delay general maintenance, repairs, inspections and other operating costs to a future point where the budget available may be more favourable – or even postponing the tasks indefinitely.

Similarities can be drawn between the current economic climate with the economic crisis of 2008/2009 which saw budgetary constraints across the energy industry. The COVID-19 pandemic has doubtlessly challenged operating budgets, but it has also had a direct impact on human resources. There have been reports of worker's shifts being extended due to the pandemic, which in some cases have been extended to as long as 12 hours a day for two weeks, allowing employees to work up to 86 hours a week compared to the 72 hours currently permitted.

In addition to allowing changes to shift patterns, the US Nuclear Regulatory Commission also allowed US nuclear plants to delay some inspections. Hence, when there is a challenge to an operating budget, maintenance and integrity related tasks are often reviewed as an option for cost cutting.

The major hazards for energy facilities are ever present – fire, explosion and the release of hazardous materials. All these hazards have the potential to cause a major process safety incident. The energy industry is a dynamic and rapidly changing industry but one with ageing infrastructure and increasing cost pressures as the available revenue from oil and gas sales declines. There is a risk that the dedication of resources towards asset integrity will be allowed to decline as a result of the changing economic factors currently present in the industry.

Shortfalls in maintenance and asset integrity related activities are often highlighted in investigation reports as a leading cause of process safety incidents. Some contemporary examples are:

- On 23 October 2009, a large explosion at the Caribbean Petroleum Refinery in Puerto Rico caused extensive damage to numerous petroleum storage tanks as well as damage beyond the refinery's boundary. The incident occurred during the offloading of gasoline from a tanker ship to the tank farm. The tank being filled overflowed, resulting in a vapor cloud release and subsequent explosion. One maintenance-related cause was identified in the investigation report – a malfunctioning tank fuel gauge. The faulty equipment prevented workers from noticing that one of the tanks was overflowing before the fuel vapours ignited. It was reported at the time that the level transmitters were often out of service, awaiting maintenance tasks.

- Pipe rupture on the Crude Unit of the Chevron Refinery in Richmond, California on 6 August 2012, resulted in a vapour release and explosion. Around 15,000 people from the surrounding area were treated for breathing problems and 20 people were admitted to hospital. The pipe was found to have been damaged by sulphidation corrosion. The key activity designed to combat this kind of failure is the implementation of routine inspections as part of a preventative maintenance strategy. In this case, recommendations for improvements were not followed-up.

Within the energy industry, there has been sizeable investment within asset integrity. This has resulted in improvements to physical integrity, progress in effective asset integrity management, awareness and performance. Many operators have found that by applying best practices in maintenance and reliability they can optimise asset integrity and reduce total maintenance cost.

The key to effective decision making when revising maintenance plans is to review the criticality of the systems. The definition of critical equipment may vary from organisation to organisation and if it is not formalised, there may be several interpretations of equipment criticality within a single organisation. If the assumptions used to assess what equipment is critical are not technically based, then different individuals will identify different pieces of equipment as being critical as the selections will be based on individual opinions and lacking consensus. As a result, the potential for equipment failure having significant safety, environmental or economic consequences may be overlooked.

The greater issue with deferred maintenance is that it only grows in scope – and cost – the longer it is prolonged. When repairs are delayed they can quickly become replacements. The longer that maintenance is deferred, the more components that are affected and the more costly that maintenance becomes. Run-to-failure is only a viable tactic in situations when there is little economic and no safety or environmental impact. The bigger the deferred maintenance number becomes, the potentially harder it may become to maintain the facility at an acceptable level of safety management. However, facilities that have implemented comprehensive preventive maintenance programmes have found that the operation of their systems is more reliable, and those systems also last longer.

Deferral of maintenance tasks for energy facilities is not a new concept and there are often situations where tasks become postponed due to operating constraints. These factors could be because of the equipment not being made available for maintenance due to plant configurations or a turnaround being postponed for a year or more due to commercial drivers or increased confidence in the equipment. The key to safe management of postponing these tasks is for the use of risk-based tools for work prioritisation which has a defined clear responsibility for tracking overdue tasks to completion. An effective risk assessment may also provide the required evaluation of the effects of prolonging shutdowns and the effects on safety critical devices (such as pressure safety valve calibrations) must be considered.

Across the industry, there is a current trend of challenges to provide the skills, training and competencies required to deliver the high standards of asset integrity necessary in major hazard industries. The economic cycles in the global oil and gas industry have significant influence on recruitment and preservation of necessary competence. This needs to be recognised and effectively managed to ensure that the necessary skills base is always retained within an organisation, particularly during an economic crisis.

When the costs of process safety related incidents in the energy industry can be in the hundreds of millions, or even in the billions of dollars, it ought to be relatively simple to make the case that prevention is a far more cost-effective option. Decisions based within short term budgetary challenges should consider this fact. ■

About the author

Dr Jason Shirley is an experienced risk engineering manager within the high hazard process industries. He has had the privilege to view the operating practices across multiple energy installations throughout the Middle East and globally. Jason has 10 years of operations management experience within the energy industry. He has a strong background in sharing knowledge and best practice within the industry.

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An alternative approach to Zone 1 display instrumentation

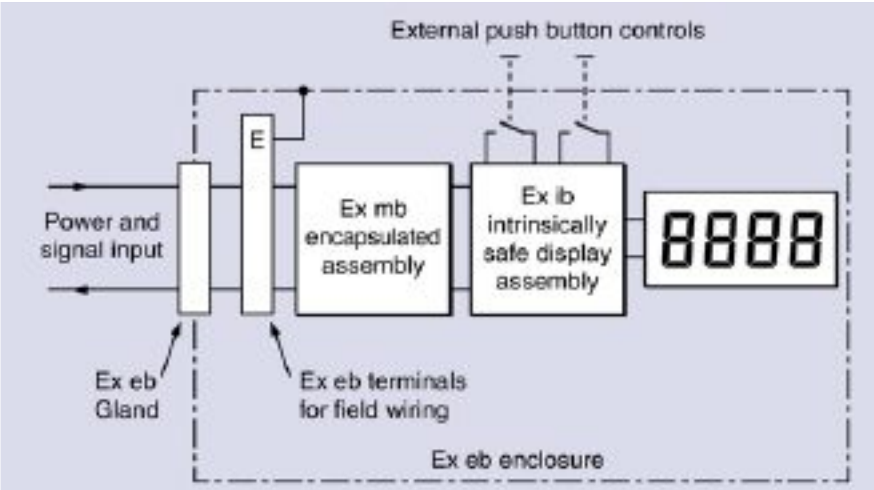

Figure 1 – Alternative Zone 1 instrument design

Flameproof instruments are fairly simple to understand and apply, do not require Zener barriers or galvanic isolators and they do not involve users with the perceived complexity of entity and cable parameters. Worldwide, flameproof Ex d explosion protection probably remains the predominant means of preventing Zone 1 and 2 field mounting instrumentation igniting a flammable gas atmosphere.

However, for hazardous area instruments incorporating a display such as indicating transmitters and loop displays, small flameproof enclosures do not lend themselves to accommodating large windows through which displays can be easily seen. A new alternative design based on increased safety Ex e protection overcomes this limitation, allows tactile push buttons to be used and reduces the instrument cost. The resulting instrument may be installed in a Zone 1 or 2 hazardous area and used in the same way as an Ex d explosion proof instrument.

Increased safety Ex e

Increased safety Ex e is an explosion protection technique which when applied to electrical equipment, provides increased security against the possibility of excessive temperatures and against the occurrence of arcs and sparks. It has traditionally been used for protecting Zone 1 and 2 electrical machines, luminaires, trace heating and is widely used for protecting terminal enclosures. Until recently, Ex e has rarely been used for protecting low power instrumentation.

The latest edition of the IEC increased safety standard IEC 60079-7:2015 introduced two levels of increased safety Ex e protection:

Ex ec (Equipment Protection Level EPL 'Gc')
For applications in Zone 2
Intended as replacement for Ex nA protection.
Electronic components such as semiconductors and capacitors may be used.

Ex eb (Equipment Protection Level EPL 'Gb')
For applications in Zone 1 and 2
Excludes the use of electronic components such as semiconductors and capacitors.

Ex e increased safety relies heavily on the integrity of the equipment enclosure to protect the electrical equipment within the enclosure, although the explosive atmosphere is not excluded from the enclosure. Unlike most flameproof enclosures which are manufactured from aluminium or steel, an increased safety Ex eb enclosure can be compression moulded in glass reinforced plastic (GRP) with provision for a large toughened glass window. If required, an elastomeric keypad to activate internal switches for the control and calibration of the instrument while it is in the hazardous area can be incorporated.

To ensure that safety is maintained in an industrial environment during the lifetime of the product, the IEC increased safety standard IEC 60079-7:2015 requires non-metallic Ex eb and Ex ec enclosures to be subjected to both lengthy thermal endurance at high temperature and high humidity and to a period at a very low temperature. This is followed by subjecting the enclosure to 7J impacts at above the maximum and below the minimum operating temperature before measuring the water and dust ingress protection provided by the enclosure. Although the standard only requires a modest IP54, most certified GRP Ex eb enclosures satisfy IP66 requirements and provide similar impact protection as a metal flameproof enclosure.

Alternative Zone 1 design

This alternative Zone 1 instrument design, which is housed in an Ex eb enclosure, is shown in Figure 1. To allow installation in Zone 1, the electronic assembly within the Ex eb enclosure requires protecting by an additional method of explosion protection. Although any protection technique suitable for use in Zone 1 could be used, the low voltage and power consumption of modern electronics make intrinsic safety Ex ib and encapsulation Ex mb particularly attractive. To provide maximum flexibility, this new alternative instrument design employs both Ex mb and Ex ib explosion protection techniques.

Energy limiting components are mounted within an encapsulated Ex mb assembly with an intrinsically safe Ex ib output. The encapsulation prevents a potentially flammable gas atmosphere accessing the energy limiting components and the intrinsically safe output is nonincendive allowing a wide range of electronic components including a display

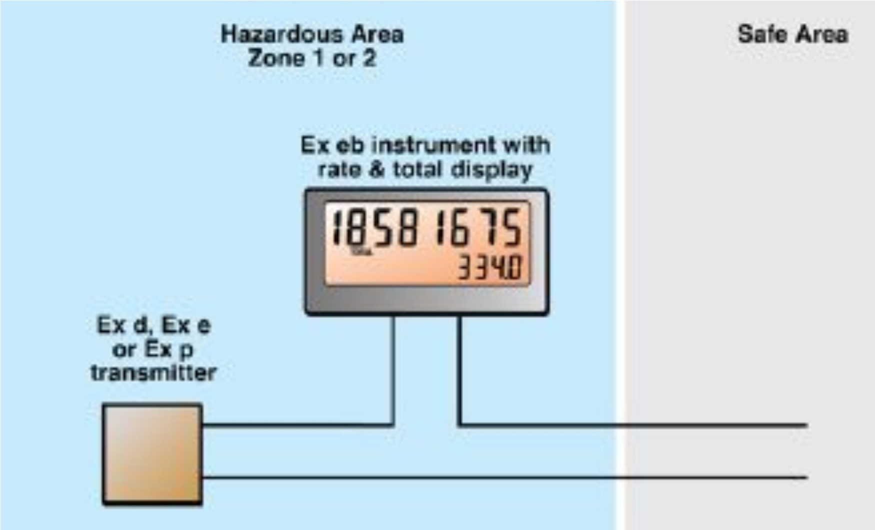

Figure 2 – Ex eb instrument can be safely connected to instruments with other types of explosion protection.

to be connected to it. The capacitance and inductance of the instrument display, associated electronics and the push button switches comply with hydrogen IIC intrinsic safety limits, and power is limited to prevent excessive surface temperatures, ensuring that the circuits remain safe even under fault conditions.

Advantages of the alternative design

This alternative instrument design uses multiple well-established explosion protection techniques to produce a lower cost, drop-in alternative for a flameproof Ex d instrument. Providing a much larger display and tactile push buttons the technique is suitable for many types of hazardous area instruments including fieldbus indicators, indicating transmitters and loop powered indicators. The new design has the additional advantage that only Ex eb field wiring glands or conduit fittings are required, eliminating the need for Ex d glands. Like the explosion proof Ex d instrument they replace, instruments employing the new alternative design do not require protection by a Zener barrier or galvanic isolator. They may be installed in Zones 1 or 2 and may be connected to almost any other certified instruments having flameproof Ex d, increased safety Ex e or pressurised Ex p protection, but they cannot be used with intrinsically safe instruments or systems.

Figure 3 – BA304SG Ex eb loop powered indicator.

First new models

The new design technique has led to the production of two IECEx and ATEX certified Ex eb loop powered 4-20mA indicators which are a lower cost alternative for flameproof Ex d indicators. The new models are housed in a robust IP66 GRP enclosure, have a large easy to read display, tactile push buttons and do not require flameproof cable glands.

These new Ex eb models may also be used in place of Ex nA indicators for Zone 2 applications in anticipation of Ex nA non-sparking protection being replaced by Ex ec increased safety protection. This will happen when BS EN IEC 60079-15:2015, which defines Ex nA non-sparking explosion protection, is de-harmonised in April 2022. ■

About the author

Olivier Lebreton CEng, MIET, is the newly appointed Managing Director of BEKA associates. Olivier joined BEKA in 2013 and became Technical Director in 2018 before becoming MD in June 2020. As Managing Director, Olivier will be responsible for all company operations, but will initially retain his Technical Director responsibilities. He is a chartered engineer and has 20 years' experience managing design projects for many different applications including, oceanographic equipment, safety critical products and hazardous area instrumentation in France, Canada and the UK.

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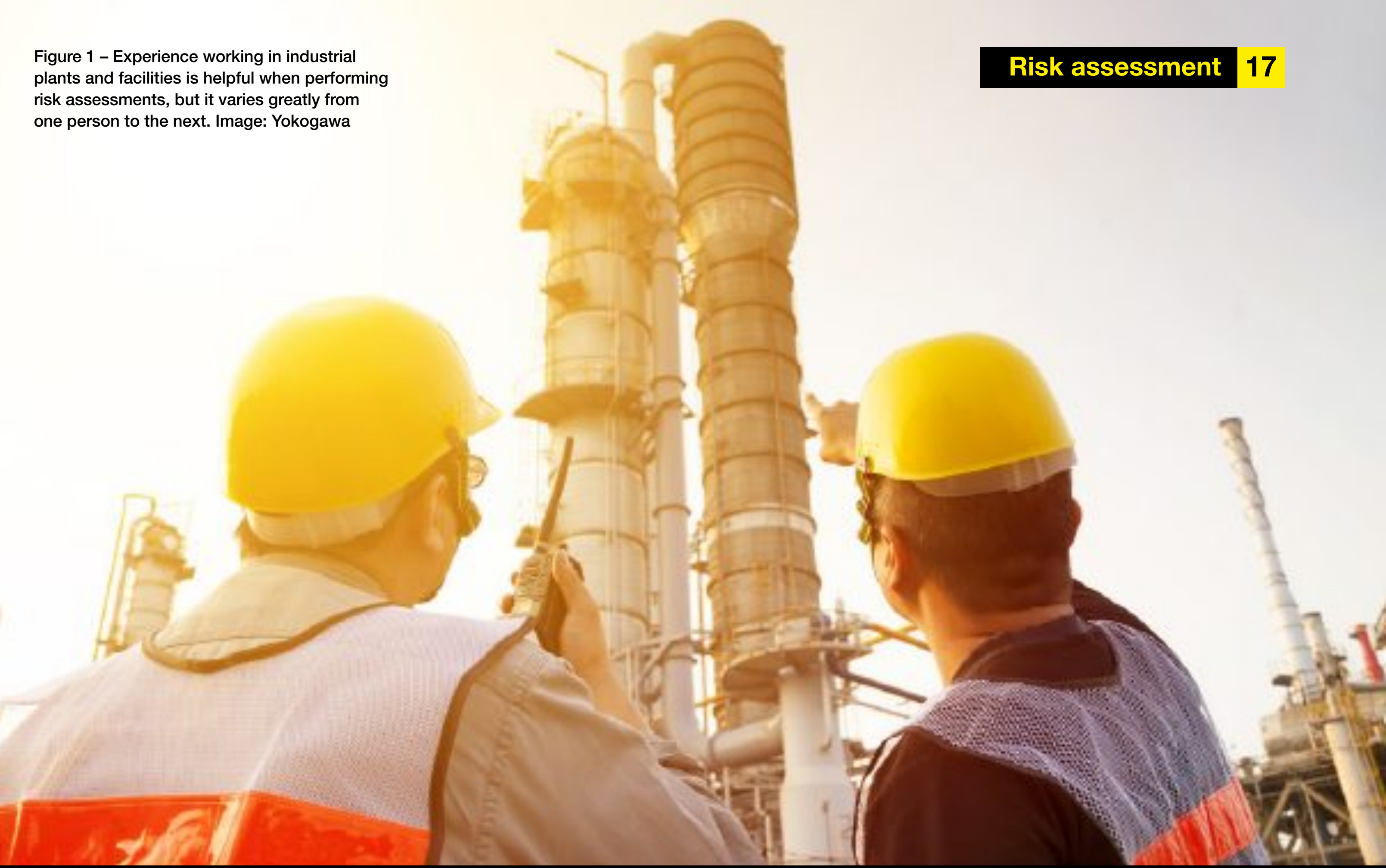

Figure 1 – Experience working in industrial plants and facilities is helpful when performing risk assessments, but it varies greatly from one person to the next. Image: Yokogawa

Risk assessment for plant maintenance in the digital age

Risk assessment software applications help industrial plants and facilities combine technology advantages with organisational experience and best practices to create improved safety solutions.

We live in an era where many of our day-to-day activities are carried out digitally – and many industrial plants and facilities also commonly perform tasks digitally – such as real-time machine and process control, work planning, and performance optimisation. Is it therefore a reasonable assumption that the same can be true for risk assessment? Can we say that the electrons required in any digital evaluation of risk can replace the neurons required for the thought processes we currently use to perform these tasks?

Like many questions in life, the answer is a bit yes and some no. Few individuals would fully entrust their own well-being or the safety of personnel they supervise to an algorithm, and not many companies would stake their reputation as a responsible employer completely in the hands of a software program, however well designed. On the other hand, there is plenty we can do digitally to help ensure the safety of personnel working in industrial plants and facilities.

Issues with risk assessment

Let's start by looking at the current methodology of risk assessment, where one evaluates the likelihood and potential of something going wrong before and after the selection of mitigating factors. These types of assessments rely on several sources for information.

Experience leads the way for many, with years of work in industrial settings (Figure 1) informing many decisions. Standards, legislation, best practices and good old common sense play a part also – but plant personnel possess different levels of experience and yes, common sense. These types of variations often result in unacceptable levels of consistency or accuracy.

It is difficult to imagine a completely digital solution where a risk assessment software program trawls safety and other operating records and spits out a comprehensive solution. The risk assessment software would undoubtedly find instances of things going wrong, and it could possibly identify some learnings from these incidents. However, what most people consider experience is also made up of things that don't go wrong, as when long periods with no incidents are used as evidence of safe work practices.

Times when things don't go wrong probably by definition would not make it into any

Figure 2 – Risk assessment software guides users through the steps required to identify and mitigate risks. Image: Yokogawa

recordkeeping system, and these would therefore not be found by any digital system. So, are digital solutions therefore of no use for risk assessment? And apart from digital solutions, how does one reconcile differences among plant personnel to create consistent results?

Fortunately, it is possible to address these and other issues by combining digital systems with human experience to produce better risk assessments.

Risk management software solves problems

Analysing every single maintenance task that could ever happen in a plant to identify not only past incidents, but all possible future risks, is not practical. The solution is to instead break down the maintenance workplace into all its discrete elements using risk assessment software. These elements include all work conditions, activities and tools – and all materials a worker might come into contact within the course of their prescribed duties.

Each of these elements includes a description of the source of risk and how it might be mitigated. Combining all these elements completely characterises the risks inherent in the workplace and presents a means for dealing with each, creating a digital knowledge base of risks and mitigation factors. Risk assessment software solutions are now available to assist with creating these knowledge bases, guiding users through the required procedures step by step.

Users first select the icon elements for each task in the risk assessment software (Figure 2). The information contained within each element then expands to inform of the necessary controls and authorisations required, in this manner dictating the necessary workflow.

Selections within the risk assessment software are then used to identify any exacerbating factors within the job, with the appropriate controls identified. This is carried out by selecting a series of ‘Considerations’ associated with the work element. These considerations lead the user into identifying any additional potential hazards, and ultimately to identifying suitable controls.

For instance, when working on a roof, the consideration might prompt the user to consider if there may be skylights present. If there are, the user will investigate further to establish what the consequences might be of working in the vicinity of these potential hazards. In this case, falling through a skylight would be a reasonable, if not desirable, outcome.

Figure 3 – Work in potentially dangerous areas can be classified as such using risk assessment software. Image: Yokogawa

If the user then selects this consideration, they will be presented with a variety of controls they could put in place to prevent the fall from happening. These controls could range from the erection of barriers, perhaps different types, to creating exclusion zones, or just a simple warning to keep clear. This element of the knowledge base is where the bulk of site and company experience is located.

The risk assessment software also ensures the risks identified aren't too prescriptive, and all importantly, encourages the users to think and add helpful input. There is a free text area where users can add elements not present in the knowledge base, each of which can then be reviewed and added back to the knowledge base, thus strengthening and expanding it.

In addition, when accidents and incidents do occur, learning from these can be quickly and easily added to the knowledge base for all to share going forward. The same is true for changes in legislation and identification of best practices.

With the proper risk assessment software, these knowledge bases can be translated into different languages. This means that every worker can follow the same standards and consistency, wherever they may be located worldwide. It also means best practices identified at one site in one language can be quickly assimilated at other sites, so a plant need not experience an incident to capture learnings from others.

This specific functionality has been used to great effect by one multinational energy company. They have been able to set standards and adopt learning across all of their 20+ locations across the globe. What's more, each site can now view what anyone is doing with the risk assessment software at any other site, translated to their own local language. This affords each site the opportunity to reinforce best practices and gain early warning of any sub-standard ways of working, before things go wrong.

Risk reduction results

Risk assessment software helps deliver consistency. Manual use of standard risk assessment techniques typically produces very different results among different people. People's skills and attributes differ, including perception of risk, so two people assessing the same job often come up with different findings. Although companies can provide guidelines to improve consistency, it can often be difficult for an individual to choose between outcomes, for example the possibility of causing mild or serious injury.

To address this issue, risk assessment software can prescribe a risk level to each element contained within a task, thus guiding users to help them reach a consistent and accurate conclusion. The risk levels of these elements can be adjusted at any point to reflect continuous learning from actual workplace experience.

Another benefit concerns the competency of the individual carrying out the assessment. Most sites will have a recognised group of people who can perform risk assessments, and they will have the systems and methodologies in place to both train and support them. However, these people can become overloaded at times – especially during turnarounds and capital projects. In these situations, it is difficult to allow other people to share the workload as each of them should first undergo full training and have the necessary experience.

But if the knowledge base software is organised in terms of discrete job elements, plants can make use of the allocated risk levels to allow certain people to carry out some assessments but not others. For instance, a less experienced worker can be used to assess a simple cleaning operation in a non-hazardous area, but not repair work in a potentially dangerous environment (Figure 3).

By dividing tasks in this manner, more personnel with wider levels of experience can work on a project, thereby taking some of the load away from the typically limited supply of more experienced personnel.

This technique was used to great effect by one operator. They had analysed the inherent risks associated with their up-and-coming turnaround and identified the majority of tasks as relatively low risk, helped by the fact that during a turnaround there is likely to be a battery limit isolation in place to keep certain areas certified as gas free. Therefore, the plant trained a larger number of low-risk assessors, freeing up time for higher-risk assessors to concentrate on their tasks. This proved to be very successful, delivering their safest turnaround ever for this particular plant.

Conclusion

In the foreseeable future, industrial plants and facilities will probably not reach a stage where risk assessment can be completely carried out using only digital methods, but one can certainly anticipate how risk assessment software can be used to augment experience, incorporate learnings, and provide consistency and accuracy when assessing risk. The knowledge bases contained within these types of software applications will naturally grow and improve through use, eventually transforming to add wisdom by representing the desired safety culture of the organisation.

For after all, is not wisdom the best use of knowledge? ■

About the author

Mark Carter has had a varied career. As well as 12 years as a plant engineer with BP, he has also spent years sailing the Great Lakes and developing onboard ship devices, and he spent lots of time carrying out research into alternative energies and managing laboratory/quality facilities. For the 25 years following these endeavours, Mark has been the Managing Director of RAP International, the risk assessment company that he founded and sold to Yokogawa in September 2019. Latterly, he has been working as a Consulting Business Development Director for Yokogawa.

Explosion prediction metho

1. Introduction

Explosion risk assessment usually involves high explosives or large gases/vapour cloud explosion, which represents a considerable hazard for various infrastructures such as buildings, stations, petrochemical plants, mines, gas utilities, etc. Predicting the possible consequences of these explosions has involved efforts through experiments, theoretical models and computational simulations.

This article aims to review different explosion scenarios and describe one representative model within each category of methodology and explosion scenario, with a focus on empirical models.

In most engineering applications, simple empirical models are sufficient for the project purpose as long as the engineer knows what they are doing and the applicability range of the model. Therefore, applying the correct theoretical model is the key to the success of the project. Computationally expensive CFD methods are getting more popular but are deemed only necessary in this article when detailed analysis is required. There are also limitations of computational simulations for many industry applications due to the actual cost to run the simulations (numerous inputs that are both error prone and sensitivity prone, sophisticated usage, long simulation time, etc.).

Representative image: Shutterstock

odologies overview

2. Unconfined explosion

2.1. High explosive explosion

The wide variety of explosives has led to the adoption of a universal quantity, which is used for all necessary computations of blast parameters. TNT (Trinitrotoluene) was chosen as its blast characteristics resemble those of most solid type explosives. An equivalent TNT weight is computed according to following equation that links the weight of the chosen design explosive to the equivalent weight of TNT by using the ratio of the heat produced during detonation:

$$W = W_{exp} \frac{H_{exp}^{d}}{H_{TNT}^{d}} \qquad [1]$$

where W is the weight of the explosive in terms of TNT equivalence [kg], W_{exp} is the weight of the actual explosive [kg], H_{exp}^{d} is the heat of detonation of the actual explosive [MJ/kg], and H_{TNT}^{d} is the heat of detonation of the TNT [MJ/kg].

Table 1 gives some examples of the produced heat of detonation of some common explosives. It's worth mentioning that approximately one third of the total chemical energy of the explosive is released by detonation. The rest is released at a slower rate as heat of combustion through burning of the explosive products mix with the surrounding air.

Table 1 – Explosive heat of detonation (Ref. [1])

Name of explosive	Heat of detonation [MJ/kg]
TNT	4.10-4.55
C4	5.86
RDX	5.13-6.19
PETN	6.69
PENTOLITE 50/50	5.86
NITROGLYCERIN	6.30
NITROMETHANE	6.40
NITROCELLULOSE	10.60
AMON./NIT.(AN)	1.59

The impact of explosive munitions can be broken down into the principal damage mechanisms and their primary effects, and the secondary and tertiary effects induced by these (Ref. [2]). Primary effects of explosive weapons are defined as those caused directly by the destructive effects that radiate from a point of initiation and include blast overpressure, fragmentation, heat and light. The term 'blast' refers to a high-pressure blast wave moving at supersonic speed, referred to as the shockwave, which is followed by blast winds. An ideal blast wave's pressure time history is provided in Figure 1. The value of the peak overpressure P_{so} and the velocity of propagation of the shock wave decrease with increasing distance from the detonation centre.

When characterising the blast loading on structures, there are three explosion types that need to be distinguished:

1) Free-air bursts: the explosive charge is detonated in the air, the blast waves propagate spherically outwards and impinge directly onto the structure without prior interaction with other obstacles or the ground;
2) Air bursts: the explosive charge is detonated in the air, the blast waves propagate spherically outwards and impinge onto the structure after having interacted first with the ground; a Mach wave front is created;
3) Surface bursts: the explosive charge is detonated almost at ground surface, the

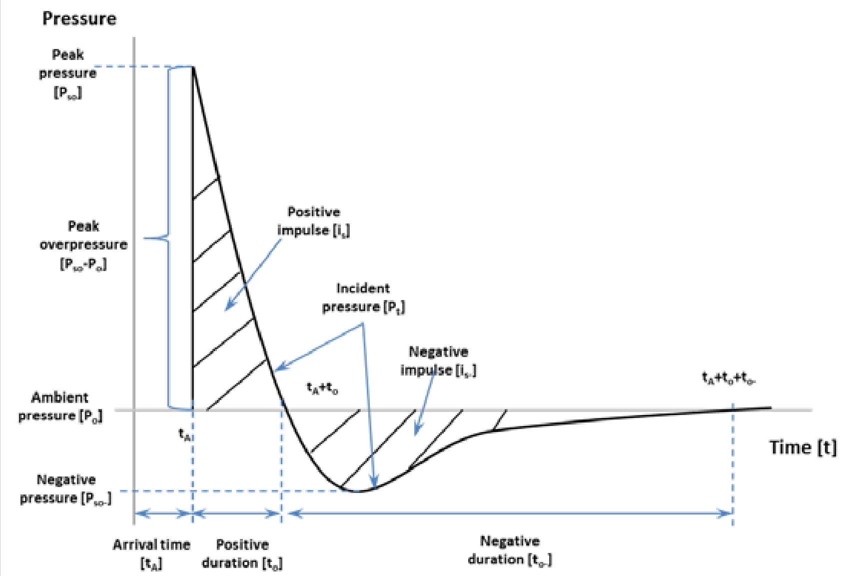

Figure 1 – Ideal blast wave's pressure time history

blast waves immediately interact locally with the ground and they next propagate hemi-spherically outwards and impinge onto the surface.

Figure 2 illustrates the three types of burst. A blast assessment will firstly need to determine the location of the charge, then blast loading is decided based on the burst type. For outputs of blast prediction, P_{so} and the positive impulse are the most often required output from such blast prediction. The Kingery-Bulmash curve in section 4.1 provides a direct look up for the outputs. On the free-air burst, the free-field blast load can also simply be decided using many empirical formulas. The Kinney equation is one of the formulas (see Eq.[2]) which agrees well with the widely accepted Kingery-Bulmash curve.

$$P_{so} = P_o \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\left\{\left[1+\left(\frac{Z}{0.048}\right)^2\right]\left[1+\left(\frac{Z}{0.32}\right)^2\right]\left[1+\left(\frac{Z}{1.35}\right)^2\right]\right\}^{0.5}} \quad [2]$$

where Z is scaled distance and is defined as:

$$Z = \frac{R}{\sqrt[3]{W}} \quad [3]$$

where R is the distance from the detonation source to the point of interest [m], and W is the weight of the explosive in terms of TNT equivalence [kg].

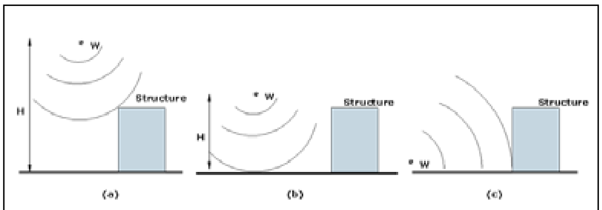

Figure 2 – Three types of unconfined blast - a) free-air burst; b) air burst; c) surface burst

2.2. Vapour cloud explosion

Vapour cloud explosion features a different loading pattern from the HE explosion, as demonstrated in Figure 3. Different vapour cloud explosion prediction methodologies exist, varying from simple empirical models to more sophisticated models. The more sophisticated methods are usually very complex, since these methods try to solve the governing equations for the intrinsic physical phenomena. These include phenomenological models (SCOPE, CLICHÉ, etc) and CFD models (CFX, AutoReaGas, EXISM and FLACS, etc). One of the major drawbacks of the sophisticated models is the large amount of inputs and running time for one calculation case.

There are several simplified models such as the TNT-equivalent method, TNO multi-energy method, Baker-Strehlow-Tang model (BST) and Congestion Assessment Method (CAM), etc. All require the determination of amount of flammable material released, cloud size and energy release upon ignition. These models feature simplified physics and are useful for quick calculations and screening purposes for later detailed analysis with complex models.

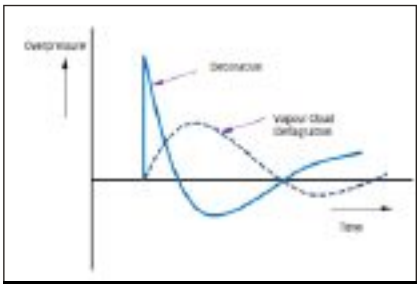

Figure 3 – Difference on Pressure Curve Characteristics: VCE vs. HE Detonation

2.2.1. TNT equivalency model

In a TNT model, the energy of the material released is converted into TNT equivalency (as per section 2.1), based on which the local explosion overpressure is determined based on TNT blast charts. It is self-evident that the blast waves produced by a TNT explosion and gas explosion are quite different: TNT blast is characterised by a shock wave of higher overpressure and shorter duration, while a gas explosion blast features lower overpressure and longer duration. Therefore, using a TNT method to model gas explosion is not strictly valid and is usually not recommended to be used for vapour cloud explosion scenarios.

2.2.2. TNO Multi-Energy Method

TNO Multi-Energy Method (MEM)[5-7] is based on the premise that a vapour cloud explosion can occur only within that portion of a flammable vapour that is partially confined, i.e. recognising that turbulence is the major cause of explosive, blast generating combustion. Thus, the amount of energy released during a VCE is limited by the volume of the partially confined portion of the flammable vapour cloud. The MEM is a blast curve-based method. The blast curves are pressure-distance and duration-distance plots divided into 10 curves, with each curve being called a severity level ranging from 1 to 10.

TNO has further published formulating Guidance for the Application of the Multi-Energy method (GAME).[8,9] The GAME project aimed to improve the Multi-Energy method, on reducing conservativeness when determining the charge strength and charge size. Through designed experiment, formulas were developed to relate the explosion overpressure to explosion parameters. For an open 3D configuration (low ignition energy and no confinement):

$$P_0 = 0.84 \cdot \left(VBR \cdot \frac{L_p}{D}\right)^{2.75} \cdot S_L^{2.7} \cdot D^{0.7}$$
[4]

For a 2D configuration (low ignition energy and confinement between parallel plates):

$$P_0 = 3.38 \cdot \left(VBR \cdot \frac{L_p}{D}\right)^{2.25} \cdot S_L^{2.7} \cdot D^{0.7}$$
[5]

P_0 is Maximum Explosion Overpressure (bar), *VBR* is Volume Blockage Ratio (-), L_p is Length of Flame Path (m), *D* is Average Obstacle Diameter (m), S_L is Laminar Burning Velocity of Flammable Mixture (m/s).

2.2.3. CFD method

Computational fluid dynamics (CFD) is a branch of fluid mechanics that solves fluid flow problems by numerical methods and algorithms. FLACS is a widely used CFD solver for gaseous and vapour cloud explosion.[10] Other solvers include AutoReaGas, EXSIM, OpenFOAM, etc., each having its own features and limitations.

With CFD methods, factors controlling explosion effects can be thoroughly taken into account, such as fuel type, configuration, containment vessel nature, size, volume, level of congestion and obstacles within vessel, ignition source location and magnitude, venting, etc. The CFD approach should allow a higher accuracy for the explosion analysis; however, this advantage is also often complicated by the numerical cost and other cost such as the efforts of tuning the model, model and parameter selection, grid sensitivities, etc., which can offset the advantages gained in some cases.

2.3. Pressure Vessel Burst explosion

Unlike the high explosive or vapour cloud explosion, which is a chemical explosion, the Pressure Vessel Burst (PVB) explosion is a mechanical explosion from purely physical reaction. It is usually discussed together with Boiling Liquid Expanding Vapour Explosion (BLEVE), although the different terminology can point to similar phenomena from different perspective, more details can be found in CCPS 2010 [11]. Here we see it as a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapour and flashing liquid. Overpressure and fragments are the usual consequence of such explosions, although if the vessel contains flammable material, a fireball is another usually discussed consequence.

Blast parameters of PVB explosion or BLEVEs can be calculated using the CCPS guideline[11], while efforts on modelling BLEVE using CFD has also demonstrated feasibility.[12] Other work includes Geng's directional blast effects study from PVB explosion.[13] PVB from cylindrical vessels needs to be treated carefully. In the near field, the overpressure along the axis of symmetry (0 degrees) remains higher for the cylindrical PVB than for the spherical case. As distance increases, however, overpressure from the cylindrical PVB drops to a value that is less than the sphere. Along the 45-degree direction, overpressure is similar to that for the sphere, in particular in the far field ($\bar{R}$>1).

3. Confined explosion

3.1. Fully confined explosion

When an explosion occurs within a cubicle or containment-type structure, the peak pressures as well as the impulse associated with the shock front will be extremely high and will be amplified by the confining structure. The pressures reflected and reinforced within the structure are termed interior 'shock pressure'. In addition, the effects of the high temperatures and accumulation of gaseous products produced by the chemical process involved in the explosion will exert an additional 'gas' pressure. For the design of most fully vented cubicle type structures, the effects of gas pressure may be neglected.

For confined gas explosion, the simplest method to calculate the pressure rise is via the energy conservation in an adiabatic system.[15]

3.2. Vented explosion

Various formulas exist to predict the peak overpressure in vented explosions.[16,17] A widely accepted document on vapour explosion enclosure design is NFPA 68.[18] The following equation determines the minimum venting area required for a low-strength enclosure (NFPA 68 Eq. 7.2.2).

$$A_v = \frac{C \cdot A_s}{P_{red}^{1/2}} \qquad [6]$$

where A_v is the vent area (m²), C is venting parameter (barg$^{1/2}$), A_s is internal surface area of enclosure (m²), P_{red} is the maximum venting pressure (barg). The equation can reversely be used to determine P_{red} given a certain venting condition.

The venting parameter *C* is determined by the following equation for a fundamental burning velocity, S_u, less than 60 cm/s (NFPA 68 Eq. 7.2.2.1a).

$$C = 1.57 \times 10^{-5} \cdot (S_u)^2 + 1.57 \times 10^{-4} \cdot (S_u) + 0.0109 \qquad [7]$$

3.3. Dust explosion

Dust explosions and gas cloud explosions share many characteristics when it comes to ignition and combustion properties, and this section could have been placed in Section 2 'unconfined explosion'. However, as most often the dust explosion hazard is related to dust accumulated indoor, it is usually discussed together with vented explosion.

Dust may occur from agricultural products, carbonaceous materials, chemicals, dyes, pigments, metals, plastic, wood, etc. Apart from NFPA 68[18] for dust explosion enclosure design guidance, another widely used document in Europe is EN 14491.[19] The following equation determines the minimum venting area required for dust in a low-strength enclosure (NFPA 68 Eq. 8.2.2). The equation can reversely be used to determine P_{red} given a certain venting condition.

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot P_{stat}^{4/3}\right) \cdot K_{st} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1} \qquad [8]$$

where P_{stat} is the nominal static burst pressure of the vent (bar), V is enclosure volume (m³), K_{st} is the deflagration index (bar-m/sec), P_{max} is maximum pressure of the deflagration (bar), P_{red} is the maximum venting pressure (bar).

A few phenomenological models of vented dust explosions, such as ISOVEX from FM Global and EFFEX from INERIS, to solve a set of coupled time dependent differential equations to obtain the deflagration pressure as a function of time. Gexcon has also developed a CFD code called DESC (Dust

Explosion Simulation Code) to simulate dust explosions including explosions in complex industrial facilities. The code has also been bundled with FLACS as FLACS-DustEx.[10]

4. Blast-structure interaction

4.1. Empirical method

Empirical formulas and charts are normally adopted when designing protective structures to resist the effects of accidental explosion.[3] Figure 4 illustrates a graph known as 'Kingery-Bulmash curve', usually used to determine pressure and impulse loading on structures based on the scaled distance. The reflected pressure is usually a lot higher than incident pressure, which is a key question in the blast structural design. The reflected pressure can also be described in Eq. [9]. Reflected pressure corresponds to when blast pressure front hits object and compression occurs. On the other hand, when one region is compressed, there are other regions which are decompressed. This region features negative pressure and is known as rarefaction wave, which can be another concern to some structures depending on the mitigation objective.

$$P_r = 2P_{so}\frac{4P_{so}+7P_o}{P_{so}+7P_o} \qquad [9]$$

where P_0 is the ambient pressure, P_{so} is the incident pressure, and P_r is the reflected pressure.

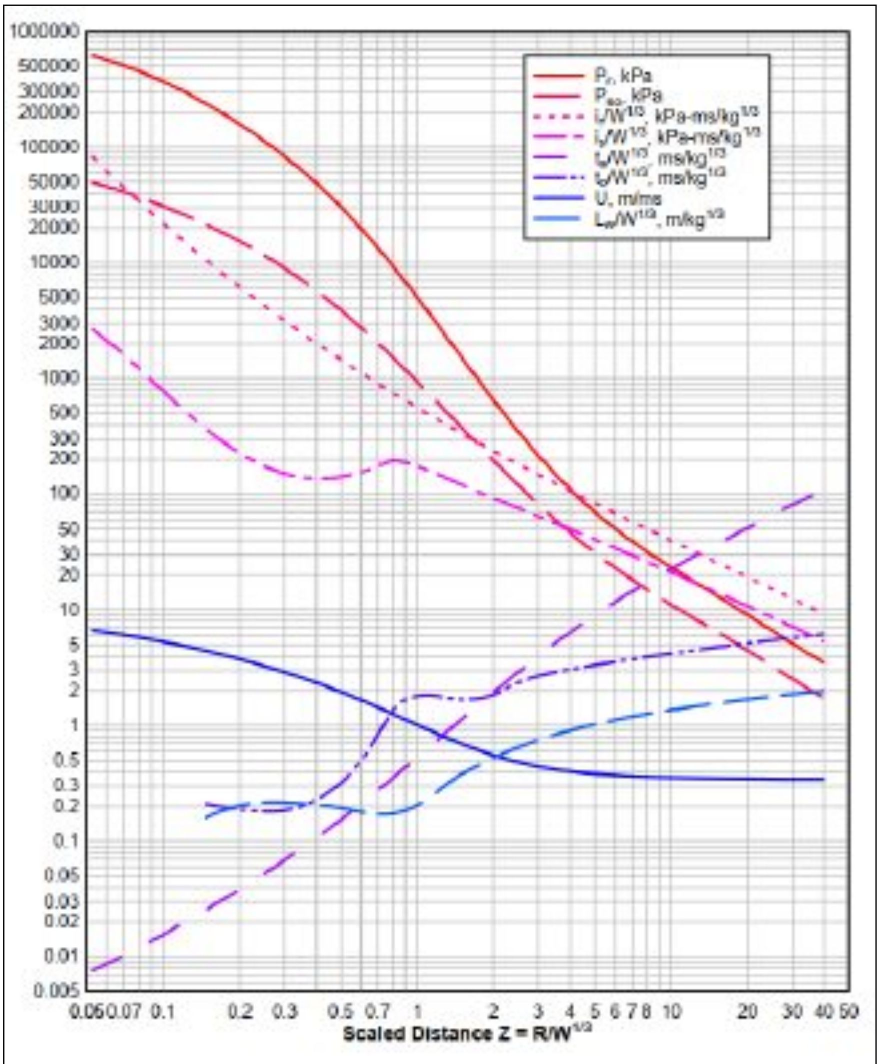

Figure 4 – Parameters of positive phase of shock spherical wave of TNT charges from free-air bursts [3]

4.2. CFD method

CFD modelling is often also used to assist blast structural design and weapon effects mitigation. There are a variety of CFD tools for HE blast simulations, among them there are ProSAir[20, 21] from Cranfield University, BWTI[22] from BakerRisk, EAGLE[23] from QinetiQ, BlastFOAM[24] from Synthetik Technologies, etc.

The equations governing the HE blast CFD solvers take a different form from those governing the VCE CFD solvers, in that shockwaves are a consequence of the hyperbolicity of the systems of Euler equations governing inviscid flows, hence the HE blast solvers adopt Euler numerical scheme typically for high explosive purpose. The Euler numerical scheme for the hyperbolicity equations has been proven to be more efficient than solving traditional CFD governing equation, as mixing process

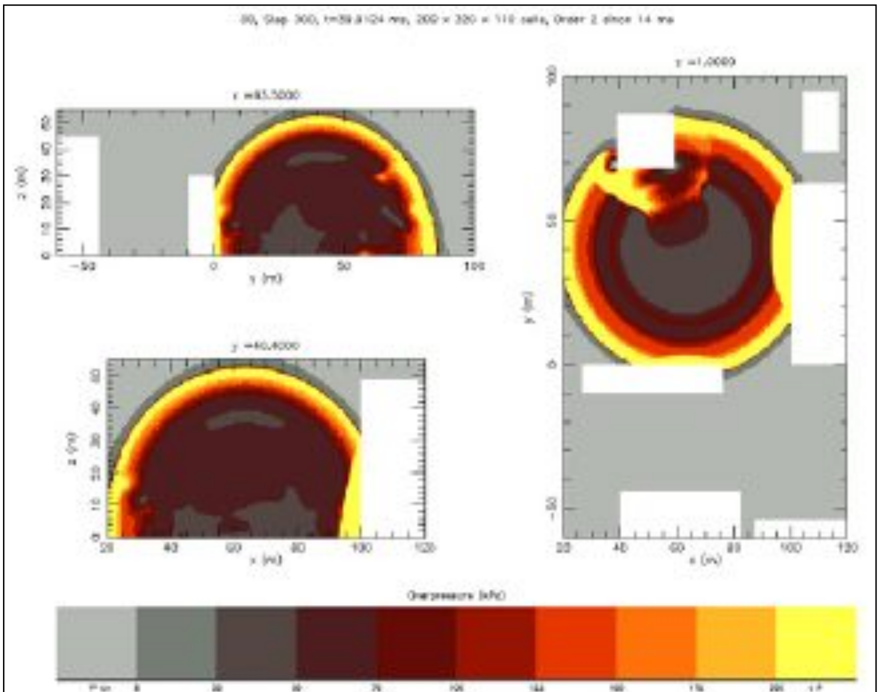

Figure 5 – CFD modelling of blast wave propagating against buildings (ProSAir[8,9])

is not considered important for this type of explosion and therefore diffusion process is not required to be modelled. For a tailored package such as ProSAir, an additional feature is the 1D and 2D phase modelling results can be mapped to 3D configuration before the blast wave hit relevant obstacles, so to greatly enhance the efficiency of modelling process.

5. Conclusion

A review of existing models for predicting different explosion scenarios has been performed. The aim is to provide guidance and point to at least one representative model for usage at different types of explosion scenario. In most engineering applications, a simple empirical model is sufficient for the purpose as long as the engineer knows what they are doing and the applicability range of the model, therefore applying the correct theoretical model is the key to the success of the project. In some cases, detailed analysis may be required, which is when computationally expensive CFD methods are applied. In this case, more expertise knowledge is usually required. ■

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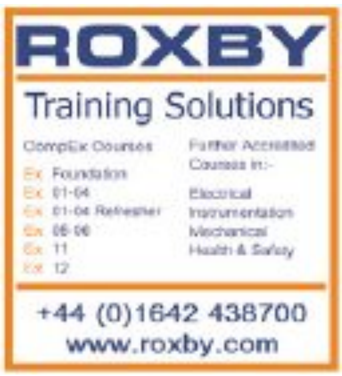

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