How China is establishing a new COMAH system

Pat Swords BE CEng PPSE, FIChemE, Principal Process and EHS Consultant, PM Group, Killakee House, Tallaght, Dublin 24, Ireland.
Robert Liang, Senior Process and EHS Engineer, PM Group, Unit 416, ShingTak Business Complex, No 402 Guilin Road, Xuhui District, Shanghai, 200233, China

While China has an unfortunate recent history with respect to major industrial accidents, 2019 was a very significant year with respect to the measures adopted there to introduce a Control of Major Accident Hazards (COMAH) system. Three national standards were introduced, which effectively have equivalence there to technical regulations, and (i) require the identification of major accident facilities; (ii) establish acceptable risk criteria for individual and societal risk and; (iii) provide a robust template as to how the applicable quantified risk assessment should be completed. The implications for land use planning in a densely populated region are of course significant. Strong direction has also come from the top of the Chinese administration that the safety and environmental performance of the highly hazardous chemical sector has to improve. As a result major reforms of this sector are underway, in one province alone in 2019 nine chemical parks and five hundred and seventy nine chemical companies were closed, a position which is being replicated throughout China. This not only has significant impacts on the industrial landscape of China, but supply chain disruptions are now also being experienced in the West.

1.0 Background

For those who have not spent significant time in China, it is extremely difficult to comprehend both the pace of change and the scale of the country. However, to help illustrate these concepts the World Bank makes available on the internet an extremely comprehensive data catalogue. Globally poverty is assessed by reference to four income classes, the lowest being $1.90 a day in 2011 Purchasing Power Parity (PPP), which equates to extreme poverty. In 1990 in China 66.2% of the population fell within this classification, but by 2015 this percentage had dramatically reduced to 0.7%. Equally one could point out that in the same twenty five year period, the Gross National Income per capita went from $330 to $7,910. In the Western world in the same period, while change occurred, it was in comparison very subtle and slow moving.

Naturally when one talks of scale with respect to China, its population of circa 1.44 billion springs to mind. However, its chemical industry is also extremely large, which was reported in 2019 (McKinsey, 2019) to be the largest in the world by revenue since 2011, with around $1.5 trillion of sales in 2017, amounting to nearly 40 percent of global chemical-industry revenue. It is also common knowledge that this industry sector in China has been characterised by a significant number of major industrial accidents. Indeed, the European Commission's Joint Research Centre's 'report of chemical accidents as reported by the global media in 2017' was demonstrating 443 fatalities for the Asia region and 29 for Europe (Chen, 2019).

The ISO/IEC Guide 51 (ISO, 2014) defines:

- *Safety: Freedom from risk which is not tolerable*
- *Tolerable risk: Level of risk that is accepted in a given context based on the current values of society*

Risk is inherently connected with reward and where rapid economic growth is being prioritised, a society is more likely to accept a higher level of risk. However, as a society develops its values change and hence its acceptability of risk. This situation can now be clearly seen in China, where effective measures are now being taken, to establish a COMAH system. Indeed, as is explained later, even in the period in which this article was originally submitted as an abstract in September 2019 and its finalisation in early 2020, significant developments occurred in this area.

2.0 The Tianjin Accident

While nobody wants major industrial accidents to occur, their occurrence is followed by a window of opportunity to implement change, such as the Enschede fireworks disaster or the Sandoz warehouse fire in Basel, which led to subsequent amendments to the EU's COMAH (Seveso) Directive. Similarly in a Chinese context, the hazardous goods warehouse explosion at Tianjin Port, which occurred on the 12th August 2015, was so devastating in its consequences that change had to occur. A detailed analysis of this accident and the circumstances, which led to it, is provided in a paper (Chen, 2019) produced jointly by Chinese chemical engineering academics and Maureen Wood of the European Commission's Major Accident Hazard Bureau (MAHB). It is not proposed to replicate here the detailed analysis of the Tianjin accident contained in that paper, but suffice to say that an initial fire broke out in the delivery zone of the hazardous goods warehouse. Numerous firefighters arrived on site and were subsequently exposed to two explosions in rapid succession, the first estimated at 15 tonnes of TNT and the second at approximately 430 tonnes of TNT. The initiating event was the spontaneous combustion of nitrocellulose in the elevated summer temperature, a material which was improperly stored. This burning material subsequently spilt out and the fire engulfed hazardous material stored nearby, which included ammonium nitrate that subsequently reached its explosion temperature.

The consequences were devastating, 173 deaths, 798 injuries, 304 destroyed buildings, 12,428 destroyed cars with a total cost estimated at approximately 0.93 billion Euros. However, accidents don't happen by accident, there was a systematic series of failures by both the operator and the authorities to control the risks associated with the storage of hazardous goods in this port. The nitrocellulose was improperly stored such that it ignited; inadequate segregation and separation of hazardous goods occurred; excessive amounts of hazardous goods were stored in breach of permit conditions; planning conditions were violated with respect to distances between warehousing and other buildings; firefighting access was blocked by containers;

firefighters did not have knowledge of the quantities and nature of hazardous materials present and subsequently failed to protect themselves, etc.

The accident was a complete systems failure, as the paper (Chen, 2019) describes, the approval of the hazardous goods operations at the port was issued illegally, there was no proper supervision and coordination with the fire services, the municipal planning requirements were violated, supervision and inspection did not occur, etc. In summary, while regulations did exist for the permitting of such facilities and for the regional planning in the area, they were in practice just not followed at Tianjin.

3.0 The Chinese Regulatory Structure

The EU's legislative structure is composed of mandatory technical regulations, which establish overarching principles, while leaving the supporting information to guidance documents and standards, which are of a voluntary nature. For example, the overarching requirement of the COMAH (Seveso III) Directive 2012/18/EU is "*to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment*", this then has to be interpreted in each individual case.

The Chinese approach is quite different, in that overarching technical regulations are quite limited. For example the principal safety act, the "Law of the People's Republic of China on Work Safety" requires in Article 16 that: *"Production and business units shall have the conditions for work safety as specified by the provisions in this Law and relevant laws, administrative regulations and national standards or industrial specifications."* These legislative acts are then supported by a very wide-ranging set of standards. For example, at a national level GB Standards apply (GB stands for Guobiao, or "National Standard"), where mandatory standards are prefixed "GB", recommended standards are prefixed "GB/T" and "GB/Z" are a national standardization technical guide. It is generally estimated that approximately 15% are mandatory standards and equate to technical regulations in other jurisdictions. However, it is also clarified that those classified as GB/T are not voluntary and should largely be treated as mandatory. In addition to the GB standards, the various ministries can issue standards, such as "AQ", "AQ/T", which relate to the State Administration of Work Safety. While at provincial level, provincial standards titled as DBxx or DBxx/T are drafted by local government, in which the numbering xx corresponds to the number assigned to one of the thirty one provinces and autonomous regions in China. These DB standards are generally more stringent than the National GB standards or contain additional content to the GB standards. Finally enterprise standards, which are never mandatory, are developed by industries for their own use.

The Ministry of Emergency Management (MEM) for the People's Republic of China is the relevant competent authority for COMAH introduction at the National level. This is a new Ministry officially established in April 2018 as part of the Institutional Reform Plan of the State Council, which was adopted at the National People's Congress in March 2018. The MEM provides guidance for emergency management at provincial, city and county levels. Naturally it is to be expected that the MEM will play an increasingly prominent role in the future regulation of industry in China. However, it is also worth pointing out that the Law of Work Safety, which has been effective since November 2002 and which was amended in 2014, is extremely comprehensive and gives the authorities wide powers, such as in relation to investigating and fining enterprises for breaches of recognised conditions for worker safety.

4.0 Recent Developments in GB Codes related to COMAH Implementation

The following GB codes were recently adopted in China and form the backbone of what those of us familiar with the EU's COMAH legislation would recognise as the core elements of such a COMAH system.

- GB 18218-2018 "Identification of major hazard installations for hazardous chemicals"
- GB 36894-2018 "Risk criteria for hazardous chemicals production units and storage installations"
- GB/T 37243-2019 "Determination method of external safety distance for hazardous chemicals production units and storage installations"

However, while the successful EU model provides a useful template, which has already been utilised with some modification by the United Nations Economic Commission for Europe (UNECE) in Geneva with its 'Convention on Transboundary Effects of Industrial Accidents', the Chinese approach is adapted to its regulatory structure and does contain many unique features. GB 18218, based on defined thresholds of dangerous substances, establishes four tiers of hazard facilities. GB 36894 defines individual and societal based risk acceptance criteria referencing similar EU land use planning guidance. GB/T 37243-2019 is an extremely comprehensive document for calculating the risk profile of hazardous chemical storage and production facilities, e.g. appendices include "Typical equipment (facilities) leakage scenario frequency values" and "Combustible material release event tree and ignition probabilities". These are discussed in more detail in the following sections.

5.0 GB 18218-2018 "Identification of major hazard installations for hazardous chemicals"

GB 18218-2018, which came into effect in March 2019, is a revised version of GB 18218-2009 and is a standard proposed and under the jurisdiction of the MEM, which is applicable to installations, which produce, store, use and operate with hazardous chemicals. Where hazardous chemicals are those, which are toxic, corrosive, explosive, combustible, combustion supporting, etc., based on the GB 30000 series of standards, which implement in China the UN's Global Harmonized System (GHS) for classification and labelling of chemicals. The threshold quantity is defined as the minimum amount required for a hazardous chemical or classes to constitute a major hazard. In a similar manner to the approach utilised in the EU's Seveso III Directive 2012/18/EU two tables are provided. Table 1 contains some 85 named substances with for each a critical mass defined in tonnes. The second table is based on categories of hazardous chemicals and their critical amounts not listed in Table 1, utilising the generic GHS classifications. Furthermore, in a similar manner to the Seveso Directive an additive approach is taken to assessing the threshold quantity if there are multiple chemicals with similar properties.

Section 4.3 of GB 18218-2018 is entitled "Grading of major hazard sources". It provides a calculation method for assessing the 'Major Hazard Classification Index R', which is based on a number of parameters: (i) α is a correction factor for the number of people who may be exposed outside the plant; (ii) β a correction factor for each chemical, for example phosgene has a value of 20 and for flammable liquids the value is essentially 1; (iii) q is the actual storage quantity (tonnes); (iv) Q is the threshold quantity for each chemical (tonnes). Table 6 of GB 18218-2018 is entitled "Grade of major hazard classification" and specifies four grades based on the calculated R value. The most serious grade, based on $R \geq 100$ is Grade 1, while Grade 4 equates to $R < 10$.

6.0 GB 36894-2018 "Risk criteria for hazardous chemicals production units and storage installations"

GB 36894-2018 was also proposed and is managed by MEM, entering into force in March 2019. It specifies the acceptable risk baseline values for both individual risk and societal risk associated with production units and storage installations for hazardous chemicals. There is a graded scale of protection targets, which are divided into high-sensitivity protection targets, important protection targets, and general protection targets. Examples of high-sensitivity protection target, which are characterised by groups with relatively low self-protection ability in an accident scenario, are:

- "*Medical and health places including medical, health, sanitation, epidemic prevention, rehabilitation and first-aid places; excluding: Residential quarters and below-level health service facilities".*

Examples of important protection targets, which are characterised by inconvenient evacuation in the event of an accident, are:

- "*Public book exhibition facilities including public libraries, museums, archives, science and technology museums, memorials, art galleries, exhibition halls, convention centres and other facilities*".

General protection targets are further classified into first-class protection targets, second-class protection targets, and third-class protection targets according to their size, for example as documented below:

Table 1: Translated example from Table 1 of GB 36984-2018 "Classification of General Protection Targets":

Protection Target Type	*First-class Protection Target*	*Second-class Protection Target*	*Third-class Protection Target*
Housing and related services *Dwellings including: Rural settlements, low-rise settlements, mid-rise and high-rise residential buildings.* *Corresponding service facilities include: Residential and below-level child care, cultural, sports, commercial, health services, elderly care and disability facilities, excluding primary and secondary schools*	*30 or more households or 100 or more residents*	*Number of households 10 to 30 or between 30 to 100 residents*	*Number of households less than 10 or number of residents less than 30*

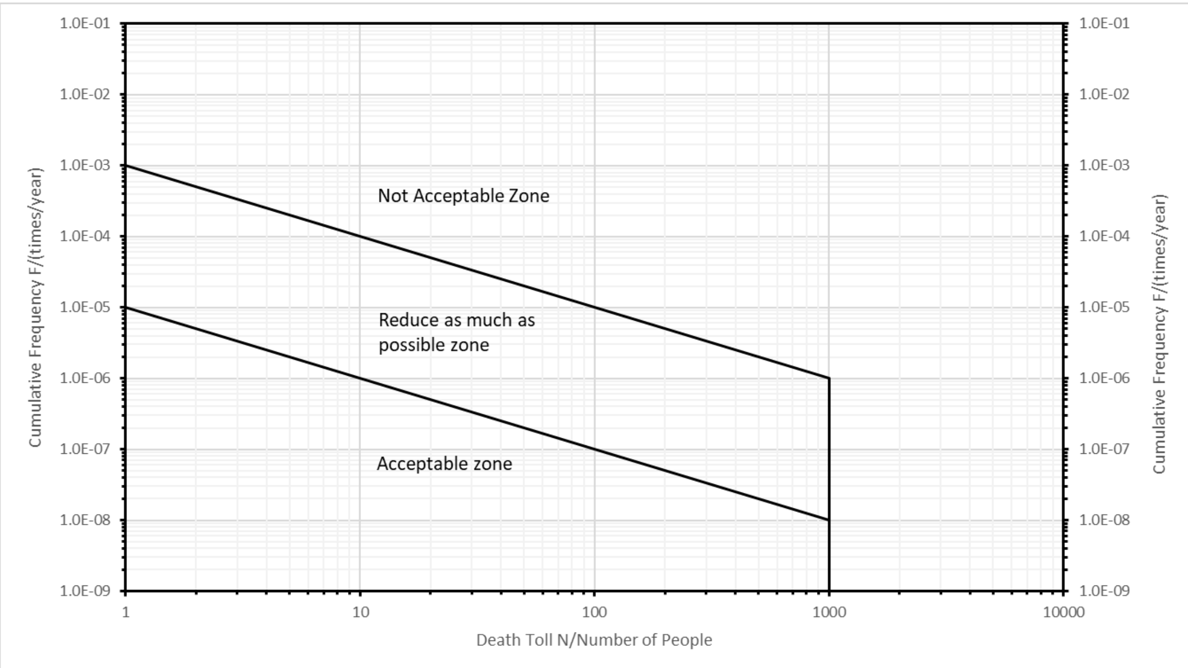
The individual risk benchmarks are then given by the following table:

Table 2: Translated example of Table 2 of GB 36984-2018.

Protection Target	*Individual Risk Benchmark / (time / year) ≤*	
	New, rebuilt, and expanded production facilities and storage facilities for hazardous chemicals	*Production facilities and storage facilities for hazardous chemicals in service*
High-Sensitivity Protection Target *Important Protection Target* *First-class Protection Target in general protection target category*	3×10^{-7}	3×10^{-6}
Second Class Protection Target in general protection target category	3×10^{-6}	1×10^{-5}
Third Class Protection Target in general protection target category	1×10^{-5}	3×10^{-5}

The societal risk is then based on the following graph:

Figure 1: GB 36984-2018 Fig 1 "Societal Risk Benchmark" (F/N curve)



The quantified risk assessment for the installation evaluates the annual probability of a fatality occurring, which is shown on the Y-Axis above. The X-Axis relates to the number of people in the area, who would be affected i.e. N the number of persons who would suffer a fatality. The societal risk is divided into three areas (from top to bottom) in Figure 1 above through two risk boundaries; (i) unacceptable area; (ii) as low as possible and; (iii) acceptable area.

- (i) If the societal risk curve calculated for the installation enters the unacceptable area, immediate safety improvement measures should be taken to reduce this societal risk.
- (ii) If the societal risk curve enters the area where it is as low as possible, safety improvement measures should be taken to reduce this societal risk as far as practicable.
- (iii) If the societal risk curve falls entirely within the acceptable area, the risk is acceptable.

These risk benchmarks are clearly of great significance for improving the safety management of Chinese hazardous chemical production and storage facilities. GB 36984-2018 it is not a revision of a standard, but a newly introduced standard, although it is related to the "Interim Provisions on the Supervision and Management of Major Hazardous Sources of Dangerous Chemicals" Order No. 40 of the State Administration of Work Safety of August 2011. This interim provision established the broad objectives related to: (a) Identification and Evaluation, (b) Safety Management, (c) Supervision and Inspection. It required that the safety assessment report of major hazard sources should include the individual risk and societal risk values based on the use of quantitative risk assessment methodologies, although this interim provision did not actually define how this should be done.

In drafting GB 36984-2018 recognition was given to the risk acceptance criteria in other countries, with the standard specifically referencing the COMAH land use planning guidance used in Ireland (HSA, 2010) and a guidance document prepared for the Danish Ministry of Environment on acceptance criteria in Denmark and the EU (Duijm, 2009).

7.0 GB/T 37243-2019 "Determination method of external safety distance for hazardous chemicals production units and storage installations"

As any experienced process safety professional will confirm, actually calculating the risk contours for a given major accident scenario is a complex task. GB/T 37243-2019 was proposed and managed by MEM and entered into force in June 2019. It is a new standard and provides detailed guidance on how to complete quantified risk assessment for a range of major accident scenarios. The external safety distance is based on the context that in order to prevent and mitigate the impact of potential accidents (fire, explosion, toxic release, etc.) from hazardous chemical production facilities and storage facilities on off-site protection targets, distances or risk control contours shall be established between the facilities and the protection targets. GB/T 37243-2019 specifies that this form of quantified risk assessment is applicable to production equipment and storage facilities handling explosives and those facilities falling within the scope of GB 18218-2108.

For explosive scenarios, the worst case accident scenario is based on an assessment of the maximum number of explosives, which can explode simultaneously. The shock wave overpressure value is evaluated using a formula provided and compared to tabulated threshold values for the various protection targets. The starting point of the outer safety protection distance is the outer edge of the outermost equipment of the facility or the outermost axis of the building, and the finishing point is the outer wall of the building at the protection target.

The quantified risk assessment procedure for other scenarios is based on the following steps:

a) Collecting data;

b) Identifying units to be evaluated;

c) Identification of hazards and leakage scenarios;

d) Analysis of accident probability;

e) Analysis of the consequences of the accident;

f) Quantitative risk calculations and;

g) Determination of the external safety protection distance.

GB/T 37243-2019 is a very detailed guidance document on how to complete quantified risk assessment, in the same manner as the Dutch purple book (RIVM, 1999). For example, there is a detailed section and supporting appendix on how to calculate leakage quantities and frequencies. Additional appendices provide supporting information on such as calculation of the source term and gas cloud diffusion, event trees and ignition probabilities and relevant toxicity values, e.g. Emergency Response Planning Guidelines (ERPGs). Tabulated values presented in GB/T 37243-2019, such as for the impacts of various blast overpressures or thermal radiation impacts, would be familiar to process safety professionals worldwide.

In the final task of determining the external safety protection distance, the risk contours are drawn around the production unit and storage facilities for hazardous chemicals based on the criteria in GB 36894-2018 for different types of protection targets. The societal risk benchmark is based on the determination of the individual risk benchmark combined with the population distribution for the surrounding areas. To draw the societal risk F-N curve for the facility, the societal risk benchmark in GB 36894-2018 is used to determine whether the societal risk level of the facility is acceptable.

8.0 Other Relevant GB Standards

With the three standards, GB 18218-2018, GB 36984-2018 and GB/T 37243-2019, China has established a robust system for identifying high hazard facilities, quantifying the risk associated with those facilities and integrating the control of that risk into its land use planning decision-making. However, China has also developed other GB standards, which complement those above in implementing a COMAH system.

GB 18265-2019 "Basic requirements for safety technology of hazardous chemicals business" was also proposed and managed by MEM in 2019 and is a revision of a previous version of the same standard dating to 2000. It specifies in general terms applicable design and operational requirements, such as for fire resistant construction requirements and requirements for segregated storage for particularly hazardous chemicals, e.g. peroxides. Furthermore, for warehouses that involve toxic or flammable gases and constitute a major hazard, it is necessary to use the quantified risk assessment methodology in GB/T 37243 to calculate the external safety protection distances.

The pace at which China adopts and revises GB standards is quite rapid and many of these are actually adoptions or close adoptions of relevant international ISO and IEC standards. For example, GB/T 35320-2017 "Hazard and operability studies (HAZOP studies) - Application guide" is equivalent to IEC 61882: 2001 "Hazard and operability studies (HAZOP studies) - Application guide", although at IEC level this 2001 edition has subsequently been replaced by the later IEC 61882:2016.

9.0 The manner in which GB Codes are adopted

If we consider as an example GB 36894-2018 “Risk criteria for hazardous chemicals production units and storage installations”, then the implementation of the requirements in this standard is bound to have very significant repercussions in the densely populated regions, which are so characteristic of many parts of China. It is therefore worth looking briefly at how this standard actually evolved. As the standard itself makes clear in its introduction, it was drafted by the Chinese Academy of Safety Science, the China Chemical Safety Association and the Nanjing University of Technology.

In March 2011, Order No. 591 of the State Council of the People's Republic of China on "Regulations on the Safety Management of Hazardous Chemicals" was issued. It established the general legislative framework for the design, operation, permitting, inspection, etc. of facilities for manufacturing and storing hazardous chemicals. It included in its Article 19 that for such facilities sufficient separation distances should be maintained from sensitive locations (protection targets), based on relevant state regulations. GB 36884-2018 was developed in order to implement these requirements. Already by 2010, the research phase had begun, in which the State Administration had organised the Chinese Academy of Sciences and three other units to conduct a special study on "External Safety Protection Distance for Production and Storage of Dangerous Chemicals".

In May 2014, Announcement No. 13 of the State Administration of Work Safety on individual risk and societal risk of hazardous chemical production and storage facilities (draft) was made. In December 2014 the National Standardization Commission issued a development plan for a new standard. During the research and drafting process of the standard, opinions from a number of academics in China, relevant persons in charge of the Hong Kong Environmental Protection Agency, and drafters of related policies in Singapore were sought. In July 2017 the website of the General Administration of Chemical Industry and the Chemical Association's website were used to publicly solicit comments on the "risk benchmark for hazardous chemical production equipment and storage facilities (draft for comments)". In October 2017 the draft standard passed the Chemical Safety Sub-Committee and went to the final review meeting before being issued in finalised form in November 2018.

The individual risk was based the lowest average age mortality rate in China multiplied by a risk control coefficient corresponding to the different protection targets. To explain, children in their infancy are somewhat vulnerable to a fatality, while the mortality rate then decreases with age to reach a lowest average rate of 3.6×10^{-4} at about ten years of age. As one continues to age, the mortality rate now starts to increase, such that by the time one is approaching a hundred years of age, the mortality rate is approaching 0.3×10^{-1}. The proposed risk criteria for China were also benchmarked against those used in other countries. For example, it was considered that China's societal risk standards were lower than those of the Netherlands, but higher than those of the United Kingdom. However, the aim of the standard was to solve the problem of ‘acceptable risks caused by hazardous chemical installations to the surrounding society’. It is therefore based on the risk acceptance coefficient determined by the requirements of the general public and it is not intended that it should be used as a basis for judging the risks caused by hazardous chemical enterprises within chemical parks or for the design of the layout of such facilities.

10.0 Practical Implementation

MEM has issued additional ‘guidelines for the investigation and management of safety risks in chemical industry parks’ (draft) and ‘guidelines for the investigation and management of safety risks in hazardous chemical enterprises’. If we consider the latter, then this is a comprehensive document which in its appendix provides a detailed tabulated checklist, the first column of which lists the applicable requirements, while the adjoining column provides the justifying clause, such as by reference to a legislative act or a GB standard. There are nine different themes to this checklist based on:

1. Risk management safety checklist; clarification of the required safety management structures, such as the number of trained personnel, their competencies and responsibilities, etc.
2. Design and master plan safety checklist; this relates to the calculation of the external safety distances, etc.
3. Checklist of safety risks in trial production management; relates to design , construction and operation of trial / test facilities
4. Checklist for safe operation of facilities; relates to such factors as operational procedures, availability of chemical information, etc.
5. Checklist for equipment safety; includes specification, maintenance, inspection, spare parts, etc.
6. Checklist for automation and control; addresses such aspects as interlocks and their design, approval, permits to remove or bypass, etc.
7. Checklist for electrical safety; addresses issue such as reliability of power supplies (dual power sources, emergency supply, etc.).
8. Emergency and fire safety checklist; establishment of emergency plans, etc.
9. Checklist for special hazardous chemicals under special control; additional requirements for such as liquefied Natural Gas (LNG) facilities, liquid chlorine facilities, etc.

One can certainly conclude that while process safety in the chemical and related sectors is a complex task, there is now in China no ambiguity on the part of the authorities, as to how it should be properly implemented. Yet difficult decisions have to be made about 'sins of the past' in relation to the many installations, which fall well short of what, is now documented as best practice. Jiangsu is the coastal province north of Shanghai, which includes the cities of Nanjing and Suzhou. It is the most densely populated of the Chinese provinces and it is also reported as being the province with the highest GDP. In September 2019 the Jiangsu province administration, with their "Safety and Environmental Protection Improvement Plan for the Chemical Industry", gave the go ahead for a huge wave of modernisation in the chemical and petrochemical sector. This included the goal of closing in 2019 a total of 579 chemical companies and nine chemical parks. Additional enterprises are included in regional plans, which require rectification or relocation and reconstruction to modernise to the required safety and environmental protection standards, their future operational status depending on the successful implementation of these measures.

The previously mentioned Article 19 of the March 2011 Order No. 591 of the State Council of the People's Republic of China on "Regulations on the Safety Management of Hazardous Chemicals" provides the legislative basis, which allows for these measures to be implemented. Namely, where existing hazardous chemical production facilities or hazardous chemical storage facilities whose storage quantities constitute a major hazard source and do not comply with the necessary external safety distances, the local competent authority shall implement a rectification plan within a prescribed time limit. This can require as appropriate, changes to production, the ceasing of production, relocation or closure.

A driver for these measures was the chemical plant explosion of March 25, 2019 at the Jiangsu Tianjiayi Chemical Co., Ltd. (JTC) in Xiangshui County, Jiangsu Province. The explosion claimed 78 lives, severely injured 76 people and destroyed much of the adjoining industrial park. The cause was attributed by the State Council investigation to the spontaneous ignition of nitrified waste, which was illegally stored for protracted periods. The investigation not only pointed out negligence by the company itself, but also misconduct in the emergency management, environmental protection, industry supervision, planning and other departments in Jiangsu Province (State Council, Nov 2019).

The location of this JTC facility was in one of the above mentioned chemical parks, which are now to close. Jiangsu province is China's largest chemical industry province with more than 6,000 chemical companies and 53 chemical parks. Many of these parks are built in southern areas of the province along the densely populated Yangtze River, which is prone to flooding or in its northern region, which is prone to uneven seasonal distribution of water resources. In April 2019 in its consultation paper on its plan for the chemical industry, Jiangsu Province proposed that by the end of 2020, the number of chemical production enterprises in the province may be reduced to 2,000. While by 2022, the number of chemical production enterprises in the province would not exceed 1,000 with the number of chemical parks reduced to 20.

Shandong province is the coastal province to the north of Jiangsu province, with a number of high technology and export zones. In 2018 and 2019, 65 chemical parks and 7 specialised chemical parks were assessed there, in total 6,094 companies participating in the evaluations with more than 1,500 companies being shut down. Similar measures have occurred in Henan province, Jiangxi province and other provinces to significantly rectify the existing situation with the chemical industry and reduce the number of chemical parks.

The State Council is the chief administrative authority of the People's Republic of China, which also announced in November 2019 that it will scale up measures to phase out safety hazards in the production, storage, transportation and waste disposal procedures of dangerous chemicals. These will include a nationwide inspection on the safety of hazardous chemicals. MEM launching on November 23rd 2019 a three-month, nationwide work safety campaign, targeting problems in major industries, such as the production of dangerous chemicals. According to the State Council in November 2019, a previous national survey of the China Petroleum and Chemical Industry Federation, as of the end of 2018, documented that there were 676 national key chemical parks or industrial parks dominated by petroleum and chemical industries, 351 provincial-level chemical parks and 268 prefecture-level chemical parks. The State Council is not shy when it states that China's chemical industry is undergoing a revolutionary "shock." While the willpower and direction to see this through is clearly coming from the very top of the Chinese administration. The fittest will survive and will be consolidated into fewer and more modern chemical parks, which will be located in areas, which are not surrounded by population centres or other sensitive infrastructure. (State Council, Nov 2019)

A National Registration Centre for Chemicals (NRCC) under the Ministry of Emergency Management (MEM) has been established and currently companies operating Grade 1 and 2 major hazard installations are required to register information concerning their installations. In the future all companies operating major hazard installations will be subject to the same requirements. There is no doubt that MEM carries great clout within the Chinese administration and is using this to push through the necessary reforms, although at the same time it is not all bad news, the State Council reporting in December 2019 fewer production-related accidents in first eleven months of 2019 (State Council, Dec 2019).

- *From January to November, the total number of major accidents in China, which refers to those caused 3-10 deaths, dropped 10.4 percent year-on-year.*
- *Meanwhile, the number of extraordinarily serious accidents, causing 30 deaths or more, declined 16.7 percent from the same period of last year.*

As two extraordinarily serious accidents and more major accidents occurred in November 2019, one cannot be complacent, but at the same time, the above is part of a noticeable and welcome trend in China since 2003, in that a steady reduction is occurring in the number of accidents and fatalities in the hazardous chemical industry sector.

Yet equally, there is a significant short and medium term economic cost, until such time as the industry base is restructured. As a minimum companies are burdened with increased regulatory compliance and inspection requirements, while they also have to struggle with interruptions in their supply chains, as these inspections and closures have also resulted in cancelled and unfulfilled orders. For example, the Jiangsu chemical sector is characterised by many companies supplying pharmaceutical and pesticide intermediates, i.e. fine chemicals. Indeed, chemical plant closures in China have affected mainly small- and medium-sized enterprises, which were often in this fine chemical sector, while the petrochemical sector is characterised by larger firms, which generally have more resources to adapt to the changing political and regulatory landscape.

11.0 Supply Chain and Economic Impacts

Supply chain disruptions are not just limited to China, as many Western companies were relying on low cost manufacturing there for the supply of active pharmaceutical ingredients, intermediates, dyestuffs, etc. Those days have now come to an end, as China transitions to a quality manufacturing base with associated higher cost. This impact is now being actively reported, for example in the contract pharmaceutical sector in the West, where it is reported that; "*the number of plants that have closed in China over the last twelve months is mind boggling -there have been thousands, accounting for about 20% of all Chinese chemical enterprises"* (Contractpharma, Nov 2019). However, at the same time Chinese chemical output is reported to only have reduced by 5%, which reflects the fact that the closures are predominately occurring in the small- and medium-sized enterprises. Yet these are the very companies that many Western firms had come to rely on for their intermediates and end molecules, such as Active Pharmaceutical Ingredients (APIs). It is therefore no surprise that it is now also being reported that the wave of closures observed in China is creating havoc with the global supply chain for several products. For example:

- *"Supply of sartan anti-hypertensive API has been threatened by the draconian restrictions imposed by the Jiangsu authorities following the aftermath of the Yancheng explosion, disrupting the operation of ammoxidation capacity producing key intermediates".*

12.0 Practical Barriers to Implementation – Closure of Companies

The first named author spent a considerable period of his working career between 1999 and 2016 on EU technical assistance projects, helping to implement the EU's industrial pollution control and COMAH legislation into the accession and candidate countries of Central and Eastern Europe (Swords, 2009). The difficulties faced by regulators in such developing countries are not to be underestimated; lack of resources, lack of the necessary technical training, industry in poor economic circumstances, etc. Forcing change is not easy, particularly when it can involve shutting down industries in areas, where they are a significant employer and economic contributor.

Indeed, if we take the chemical park where the 2019 Jiangsu explosion occurred, this had suffered a number of previous chemical accidents, an explosion in 2007 for example resulting in eight fatalities. Furthermore, the JTC facility where the explosion happened in March 2019 had already been fined six times between 2016 and 2018 amounting to RMB 1 billion (€128 million) for violation of waste-handling and atmospheric pollution regulations. Following an explosion in 2018 in another nearby chemical plant, the JTC facility had been inspected and thirteen significant issues had been identified, yet the facility remained in operation and did not implement the relevant regulations (Zhang et al, 2019).

Any regulator will tell you, shutting down industrial plants is the last resort, while in the West such prohibition orders can often take quite some considerable time, often involving multiple judicial proceedings. The pace of change in implementing a COMAH system in the West can therefore be quite measured, while still being based on the principle that individual operators cannot be allowed to make financial gain by not implementing the required changes, which their competitors have already done. Difficult decisions can therefore be left with the individual regulator or a group of regulators at local level, who have to implement these measures on a day to day basis.

However, the current direction in 2019 in China, right from the top of the administration, is that these changes to restructure their chemical industry will go ahead. While the economic cost of this change will be carried by the sector as a whole, in which the fittest and most adaptable will survive. In many respects the responsibility for the decision making, such as the closure of non-compliant firms, has passed from the local inspection authorities, to society at large. In doing so one of the major barriers to rapid change, i.e. having to make individual judgements in a local context, has been removed.

13.0 Practical Barriers to Implementation – Skilled Resources

The other major barrier to implementation of a COMAH system is the availability of skilled resources. Process safety is complex, there are many judgement calls to be made about the acceptability of risk and the proportionality of measures used to reduce it. While techniques such as 'quantified risk assessment' exist, they are not a precision tool. Neither can all aspects of risk can be quantified in this manner, not least as accurate data related to failure frequencies is often limited. From the first author's experience in Central and Eastern Europe, many regulators were comfortable with the implementation of industrial pollution control legislation, where the various objectives were often numerically defined or described in considerable detail with respect to 'best available techniques'. However, COMAH compliance to take "*all necessary measures*" required considerable interpretation and quite an intimate knowledge of the process sector, while those with that necessary skill set were often employed by the operating companies, at higher wages than the regulatory agencies could offer.

For example, Romania has a tradition in petrochemicals dating back to the 19th Century and its own indigenous petroleum sector. The first author helped with the initial implementation of the EU's COMAH legislation there in 2001. There was a strong tradition of process engineering and civil defence and available resources with that experience, such that by 2009 Romanian experts were participating in the training of other Candidate Member States on the implementation of this COMAH legislation. However, in other countries, which did not have such a tradition of process engineering, the implementation was much slower, not least due to the limited availability of competent personnel for the required site inspections and evaluations. The point being made here is that human resources ultimately drive successful process safety.

This is a point, which the Chinese authorities have specifically recognised. The State Council in its press release on 'Guideline to reduce industrial accidents' (State Council, Nov 2019), documented how: "*The Ministry of Emergency Management said all workers in high-risk industries will need to have vocational certificates by the end of 2021 because low-skilled workers are one of the main causes of industrial accidents"*. As it went on to explain:

- *"The ministry said migrant workers, usually poorly educated, account for the majority of employees in high-risk industries.*
- *Of the 18 million employees in such industries, about 34 percent have a junior high school education or below, and only around 20 percent have received formal vocational skills training.*
- *In small workshops, most frontline operators are migrant workers, and accidents in such enterprises account for more than 80 percent of those in high-risk industries".*

A senior official with the ministry was then quoted as saying; *"safety training is globally considered one of the four pillars of safety supervision, along with legislation, enforcement and insurance".* Indeed, if we refer back to the MEM's 'guidelines for the investigation and management of safety risks in hazardous chemical enterprises', which in its appendix has a checklist with nine detailed sections. This requires in its Section 1 in relation to safety management structures, that the full-time safety production management personnel should be not less than 2% of the total number of employees in the enterprise (at least one person is required for enterprises with less than 50 employees). These personnel must have a technical secondary school education or a degree in chemical or safety management and have engaged in chemical production related work for 2 years. An enterprise with more than 300 employees shall be equipped with registered safety engineers at a rate of not less than 15% of production safety management personnel; if the production safety management personnel are less than 7 personnel, at least one registered safety engineer shall be employed.

The importance of the availability of such trained personnel has been recognised in other ways, the China Chemical Safety Association, which participated in the development of GB 36894-2018, has been promoting the HAZOP technique for a number of years. Indeed, it was reported back in 2012 that: *"With the support from State Administration of Work Safety, the association has edited and publicized HAZOP analysis application guidance book series and started training for enterprise engineering personnel. It plans to use 3 years to train 20 thousand HAZOP technical personnel to provide guarantee for promoting HAZOP technology in our country's chemical industry"* (SECCO, 2012). By the end of 2019, the China Chemical Safety Association was holding its 9th HAZOP chairman training class in Beijing from December 10th to 15th and its 36th HAZOP professional training course in Jiangxi Province from November 6th to November 9th, each course having some 50 participants. The association also provides additional training in functional safety, implementation of the new Chinese guidelines and checklist, etc.

14.0 Some Conclusions

Officials from MEM have publically stated that "ensuring work safety is not a short-term task", but at the same time China has moved a considerable distance in a short period, to not just establishing an effective COMAH system, but in doing so also restructuring its hazardous chemical sector. There is no doubt that by the end of 2019, the momentum for establishing this progress is established and will, like much of the change Chinese society has experienced in recent decades, proceed at a pace, which to a large extent would be inconceivable in a Western society. It also has to be acknowledged, that due to its previous low cost manufacturing advantages, a considerable amount of chemical production, particularly in fine chemicals, was previously transferred from the West to Chinese manufacturers.

No doubt, this pendulum will swing back. China will continue to be a major supply hub, but will no longer be able to leverage low cost production based on access to cheap labour, low cost of capital and low environmental and safety standards. Instead, the surviving companies, which will be fitter and more efficient, will be able to leverage more sustainable advantages, such as based on scale and technology.

Many chemical engineers in the West would consider that too many once strong chemical companies there have become accountancy driven and neglected many essential technology drivers. Indeed, some of these companies entered into important supply arrangements with Chinese suppliers, which while they functioned up until now, may well turn out to be ventures with doomed or soon to be doomed companies. A period of readjustment has started, which has already gained considerable momentum, which will not only have an impact on the landscape of China, but will also have an impact on the industrial landscape and business practices in the West.

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