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DISASTER RISK MANAGEMENT IN ENGINEERING AND TECHNOLOGY WITH FOCUS ON CHEMICAL ENGINEERING

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EXECUTIVE SUMMARY

This paper seeks to provide a general overview of Disaster Risk Management (DRM) in engineering and technology with special emphasis on Disaster Risk Management as it borders on the Chemical Engineering discipline. Terms such as disaster, risk, risk management and disaster risk management as it concerns the fields of engineering and technology are defined to provide a fine background and refresher for the subject matter under consideration. Hazards identification is established as the basis for risk analysis, assessment and consequently management. A general overview of the disaster risk management process comprising of strategic steps such as planned reviews, hazards identification, risks analysis, assessment and reduction where applicable is described. The peculiarities of the Chemical engineering discipline in the area of disaster risk management are discussed. Causes of chemical process accidents, areas of focus in study and analysis for setting up an effective Disaster Risk Management system as well as recommendations for improved disaster risk management systems in chemical process plants are presented.

Key Terms: Chemical Engineering, Disaster, Risk analysis, Risk Management.

1.0 INTRODUCTION

Risks and risk management are an integral part of everyday life. As long as one breathes, one is faced with diverse kinds of risks arising from the existence of diverse conditions with the potential to cause harm and/or disaster. The simple act of choosing to cross an expressway with fast moving cars, alongside the attendant measures and precautions taken In order to avoid loss of any kind is an elementary but practical example of a risk management activity in everyday life. It should not therefore sound strange if it is said that every field of endeavour entails some form of risk and risk management even as there are diverse kinds of risks and risk management activities.

The fields of Engineering and Technology are however somewhat distinguished in this discuss of disaster risk management in the sense that the potentials, scope and severity of catastrophic harm that may arise from engineering and technological practices are much more vast when compared to other disciplines. The failure of an engineer or an engineering team to perform effective and efficient disaster risk management activity can result in the loss of much lives and property with attendant consequences for even the generations yet unborn. The Chernobyl and Fukushima Daiichi nuclear disasters of 1986 and 2011 respectively, the collapse of the Mississippi River Bridge in 2007, The Japan Airlines flight 123 crash of 1985 leading to the loss of 520 lives as a result of poor mechanical and technical maintenance etc. are a few historical examples that stand in attestation to the above stated viewpoint. Furthermore, the process of Disaster risk management in Engineering and Technology is not usually as simplistic as that involved in crossing an expressway for example, it is essentially more complex compared to other fields of endeavours. It usually entails detailed and complex engagements by a team of competent professionals including engineers, technologists, economists, legal practitioners etc. employing a wide variety of data collation, analytical and simulation tools. The subject of disaster risk management in engineering and technological practices is thus a crucial matter that requires intensive attention.

This paper seeks to provide a general overview of Disaster Risk Management (DRM) in engineering and technology and then go on to zero in on Disaster Risk Management as it borders on the Chemical Engineering discipline. The peculiarities of the Chemical process industry as regards Disaster risk management are highlighted. Causes of chemical process incidents are discussed, areas of focus, techniques and approaches for disaster risk management in the chemical process industries are mentioned. Recommendations for improved Disaster Risk Management in the Chemical engineering discipline are presented. Indeed, the subject of risks and risk management is so vast that no single document can sufficiently address it in its entirety. However, an addition to the wealth of materials already available on the subject matter is presented herein.

2.0 What is Disaster Risk Management in engineering and technology?

In order to have a good grasp of the term ‘Disaster Risk Management’ as it borders on engineering and technology, functional definitions of terms such as disaster, risk, risk management are presented herein in the engineering and technology context.

2.1 Disaster

Disaster is defined as a crisis situation causing wide spread damage which far exceeds our ability to recover. It is described as a serious disruption , occurring over a relatively short time, of the functioning of a community or a society involving widespread human, material, economic or environmental loss and impacts which exceeds the ability of the affected community or society to cope using its own resources. This situation is such that it arises from poorly or inappropriately managed risks. From the definitions, we see that for an occurrence to be regarded as a disaster, it must be such that the ability of the affected body, community or organization to completely recover from the losses incurred are exceeded. A typical example of such a scenario is when there is loss of human life, another example is when there is so much release of toxic or nuclear emissions into the environment that it becomes unsafe to continue to reside in such environment.

Disasters are of two broad types namely; Natural disasters and Man-made disasters. As the names implies, natural disasters are orchestrated by the forces of nature and include phenomena such as earthquakes, hurricanes, floods etc. (Reid 2013; UNESCO 2010).

Man-made disasters on the other hand are borne out of human activity and/or inactivity and include occurrences such as pipeline explosions, chemical leaks, environmental pollution etc. Whereas natural disasters on the one hand cannot be completely averted or prevented and their impacts can only be reduced via intensive forecasts, analysis of trends and prompt information dissemination to prone areas, Man-made disasters on the other hand can actually be prevented from happening via effective, efficient and consistent risk management and safety practices. This paper focuses on Man-made disasters such as those mentioned above arising from poor disaster risk management and safety practices and which can thus be prevented in the engineering and technological fields via a proactive and pragmatic Disaster Risk Management approach.

2.2 RISK

A risk is the possibility or chance of loss, harm or injury to persons, the environment, assets and/or production arising from exposure to hazardous conditions. Risks and hazards are often used interchangeably to mean the same thing, they are however technically different. Whereas a risk is as defined above, a hazard entails a physical, chemical or environmental condition which has the potential of causing harm to people, the environment, assets and/or production.

We thus see from the above, that risks arise from hazards and hence a major starting step towards disaster risk management is to identify hazards that could result in disaster. It is only when these hazards are identified that the risks associated with them can be analysed, assessed and managed. In talking about risks and hazards, we also have to make mention of the concept of vulnerability. Vulnerability is the degree to which people, the environment, assets and/or production are susceptible to the impacts of hazards. It is held that the measure of a risk is a product of the hazard resulting to the risk and the vulnerability to the hazard (FIG, 2006).

$$RISK = HAZARD \times VULNERABILITY$$

As seen in the above definitions, there are four major areas of loss from an engineering perspective which are; People, The environment, Assets (equipment, buildings, financial losses etc.) and production (such as a shutdown of operation due to industrial accident). There are two broad aspects of risks which are the probability of occurrence and the severity of the consequences should the risk eventually result in actual disaster. It is imperative to mention here that there are various types of risks ranging from financial risks, to risks of physical injury to risks of litigation to health risks etc. Though these risks are somewhat interconnected and usually go together, there are marked differences between them. For the purpose of this paper, the type of risks in focus are risks arising from plants, equipment, structural and process designs and operations that could result in a disaster if not well managed. Such risks are termed Disaster risks in engineering and technology.

2.3 RISK MANAGEMENT

A functional definition of risk management is given by (Wilson & McCutcheon, 2003) thus;

The complete process of understanding risk, risk assessment, and decision making to ensure effective risk controls are in place and implemented. Risk management begins with actively identifying possible hazards leading to the ongoing management of those risks deemed to be acceptable. Risk management is taken to mean the process of analysing exposure to loss and taking appropriate steps to eliminate the risk or reduce it to acceptable levels.

Captured in the above definitions is the cycle of risk analysis (bordering on possibility of risk and severity of risk), which enables risk assessment (To check whether the risk is acceptable or not), which in turn enables risk management (Bird & Germain, 1996)

Risk management in engineering and technology thus entails a well-organized approach of identifying physical, chemical, nuclear and environmental hazards, outlaying and analysing the risks associated with these hazards, assessing the risks and taking proactive steps to manage these risks if it is agreed upon that the risks can be viably managed.

2.4 DISASTER RISK MANAGEMENT

Disaster risk management in engineering and technology can thus be defined as a set of strategic, organized activities geared towards hazards identification, risk analysis and assessment coupled with the decision to completely avoid the risk or to continue with the process and put measures in place to significantly lower the possibility and severity of the risks so as to prevent man-made disasters in the engineering and technological practice.

2.5 THE NECESSITY OF DISASTER RISK MANAGEMENT IN ENGINEERING AND TECHNOLOGY

It seems superfluous to talk about the necessity of Disaster Risk Management in engineering and technology. However, a brief outline on the necessity of Disaster Risk management in Engineering and Technology for all well-meaning engineers is provided herein

There are several grounds on which the necessity of Disaster Risk Management in engineering and technology can be established. Some of them are;

a) **Moral/Ethical Considerations:** Disaster risk management is both right and professional for all engineers. Any engineer must know how to evaluate his/her activities on the basis of how it affects people, the environment, assets and production operations and seek ways to mitigate any adverse effect that may arise as a result of these activities. As engineers, our projects, products and designs must have in their core part, a concern for the well-being of the public that we hope to serve with our expertise and this cannot be achieved without a good grasp and practice of Disaster Risk Management.

b) **Legal Requirements:** Every nation that cares about the well-being of her citizens would usually have in place statutory laws and regulations to help protect lives, property and the environment from the adverse effects of industrial accidents. A great deal of legal litigation with its attendant consequences can arise due to a plant, product or design failure if it is established that the engineer has been negligent in carrying out adequate risk analysis, assessment and management. Ignorance would not serve as a tenable excuse in the law court.

c) **Financial Concerns:** The first duty of business is to survive, and the guiding principle of business economics is not the maximization of profit – it is the avoidance of loss. – Peter Drucker, as quoted on the front cover of Wilson (1998). The above quote furnishes an emphasis on the financial implications of a lack of sound understanding and application of Disaster risk management. A great deal of financial loss of a magnitude that will wipe out all accrued profits and plunge the company into a state of bankruptcy is very possible if proactive and competent steps are not taken in the direction of Disaster Risk Management. The Westray coal mine explosion illustrates this (Richard, 1997)

The above and many other considerations not stated here clearly shows the non-negotiability of a sound grasp and practice of Disaster Risk Management for all engineers and technologists irrespective of specific disciplines.

3.0 THE DISASTER RISK MANAGEMENT PROCESS IN ENGINEERING AND TECHNOLOGY

Disaster risk management has been defined as entailing a set of strategic, organized activities. A general collection of these activities in the engineering and technology disciplines are given below;

a) Planned reviews
b) Identification of hazards
c) Risk analysis
d) Risk assessment (Is the risk acceptable as it is or not)
e) Managing the residual risk (If the risk is acceptable as it is)
f) Reducing the risk (If the risk is not acceptable as it is) and Rechecking for hazards and acceptability of the risks involved
g) Discontinuing the process or practice (If the risk is not acceptable and not sufficiently reducible)

A flow chart is presented below to give a graphic view of the general engineering practice of disaster risk management.

3.1 Planned Reviews: This is a management activity that entails planned routine collation and analysis of data such as incident reports, near-miss reports, working condition reports, insurance company reviews and reports, regulatory activities (equipment, plant and product testing data, environmental reporting, follow-up on changes to laws, codes and standards etc.) as well as reports on regular business and general maintenance checks. The essence of these planned reviews is to provide the industry with a rich database for effective hazards identification and assessment which will in turn result in thorough risk analysis and assessment. Also. These planned reviews provides the organization with the needed data for an appraisal and upgrade of its disaster risk management approach.

3.2 Identification of Hazards: The next stage after the planned reviews is to utilize the data collected for identification of workplace and environmental hazards (or 'concerns'). There are variety of tools for hazard identification and analysis for a variety of engineering disciplines. Some of these tools include Hazard and Operability study, checklist, what-if-analysis, fault tree etc. (Paul and Douglas, 2006)

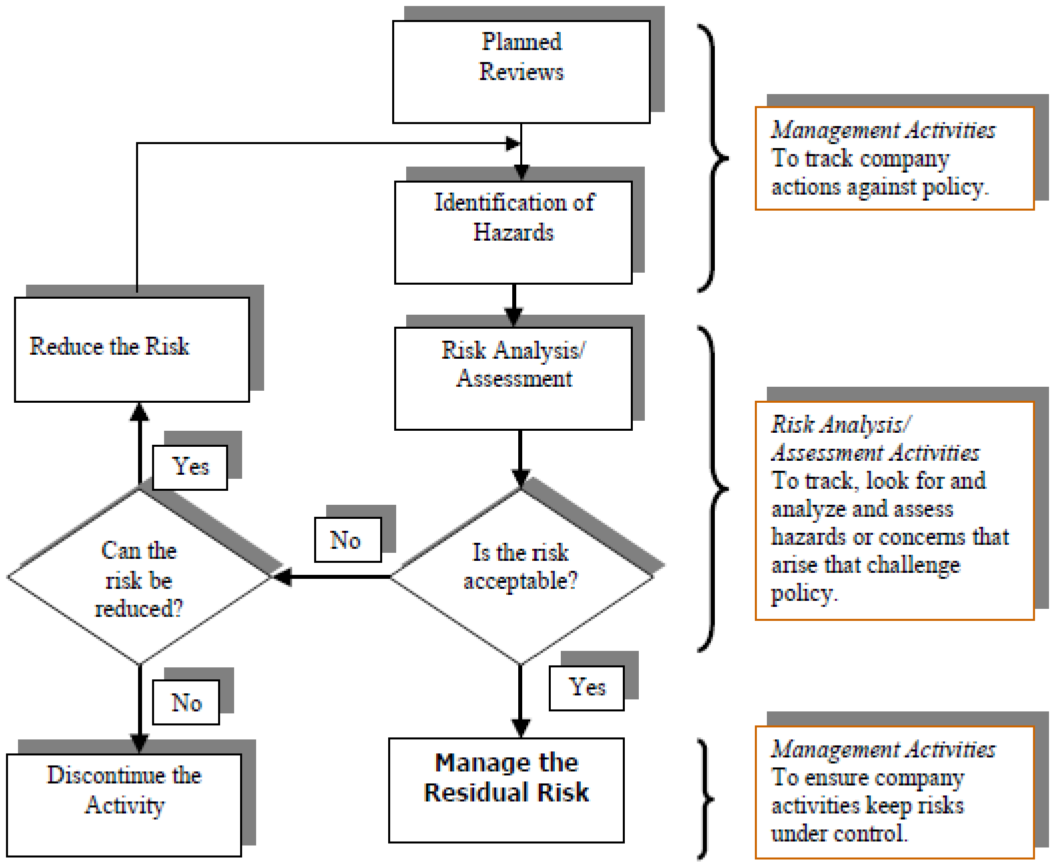

Figure 3.1: The Risk Management Process (Paul and Douglas, 2006)

3.3 Risk Analysis: The next step in the Disaster risk management process is to analyse the risks associated with the hazard. There are two major risk components that must be taken into account at this stage which are the probability of the risk and the severity of the risk.

The probability of any risk is a measure of the chance or likelihood of such an event occurring. There are tools which are able to employ data obtained from the planned reviews and hazard analysis to quantify the probability of a risk. Same applies to the severity or consequence of the risk. Usually, some form of quantification in terms of likely range of casualties and asset damage that may arise from risk mismanagement is possible using data analysis and simulation tools.

3.4 Risk Assessment: Once the probability and consequence(s) of a risk is ascertained, the next step will be to decide on if the risk is acceptable and if the process or operation which involves the risk in question can be continued without any modification or special measures put in place to reduce the risk. If the risk is not acceptable due to a high probability of occurrence and/or disastrous consequences should there be an occurrence of the event that the risk point to, then decision would have to be made on measures for risk reduction or a total jettisoning of the process or operation to which the risk is attached.

3.5 Managing the residual risk:

If the risk is judged to be acceptable, then the identified risk(s) must be kept in check via routine monitoring and observation of relevant safety guidelines. Regular appraisal should be conducted to assess the risk level in terms of probability and severity just in case there are changes to these parameters with time.

3.6 Reducing the risk and rechecking for hazards and acceptability of the risks involved:

If the risk is judged to be unacceptable in terms of the probability of occurrence and the severity of occurrence, measures can be initiated to reduce the risk factors. Examples of such measures in industry include replacing a toxic or carcinogenic substance in a production process with a less toxic or non-carcinogenic substitute, replacement of ordinary steel pipes with special alloy steels for transport of certain fluid substances so as to mitigate against corrosion risks etc. A change or modification of the production process or of the plant orientation may be done. Once any of these changes is implemented in order to reduce an identified risk, there must be a re-evaluation of hazards and a re-analysis of risks so as to ensure that other and probably greater risks have not been incurred in a bid to reduce a particular risk. These processes are basically repeated until all risks associated with the process or operation have been reduced to acceptable levels.

3.7 Discontinue the Process or Practice: There are certain risks that cannot be viably reduced. It will require a great deal of financial burden to reduce such risks in addition to the possibility of other risks springing up as measures are taken to reduce the risk in question. Under such circumstances, the engineering team may be forced to consider other process routes which will involve less risks and require less overall financial commitment. Management must be keen enough to know when a particular risk is not feasibly manageable and thus the process or operation associated with the risk must be jettisoned altogether. This singular ability can save management, the engineering and technical teams in charge of risk management a whole lot of losses and aid development of safer operations and industrial practices.

4.0 DISASTER RISK MANAGEMENT IN CHEMICAL ENGINEERING.

The Chemical engineering discipline is a very vast and sophisticated field of engineering that cuts across several disciplines. Although, the issue of disaster risk management is and must be the concern of all engineering disciplines as well as engineering and technical professionals, Chemical engineering bears the greatest weight in this subject matter of disaster risk management. Records shows that a great percentage of the most tragic engineering accidents in history are associated with chemical and nuclear process plants.

Furthermore, majority of present research on engineering Disaster risk management is focused on the chemical process industry and systems. This further buttresses the point of the greater weight which is borne by the chemical engineering discipline as regards disaster risk management. In fact, discussions and researches on engineering and technological disaster risk management as it concerns man-made disasters are incomplete without an apt mention of risk management and safety in chemical process plants. Some of the most detailed, complex and challenging disaster risk management systems and safety measures are found in chemical process plants. Although, the procedure is generally as discussed already in a previous section, the actual execution of the steps involve much more intricate activities and usually involve the use of all kinds of data interpretation and analytic tools as well as simulation software when dealing with chemical process plants.

4.1 Peculiarities of the Chemical Process Industry as regards Disaster Risk Management

Process plants and facilities often involve several operating conditions and variables. The potential for disaster is ever-present and is relatively often greater than that in purely electrical, mechanical or structural installations for example. Hazards abound from the properties and conditions of substances used in process operation, to the design and reliability of process equipment, to the design and operation of the process itself, systems control and optimization etc. (Crowl & Louvar, 2002)

In a Process plant, putting on protective wears, being careful while operating equipment and conducting once in a while checks and maintenances are not enough to ensure safety and mitigate against risks. There has to be an elaborate disaster risk management system in place. Process variables such as temperature, pressure, liquid level, flow rates etc. must be closely monitored. In fact, in an ideal process plant, there is usually a central control room with automated computer control systems in place and a team of sound process engineers to monitor the automated systems so as to ensure the process variables do not go above or below desired limits. The consequences of process variables going uncontrollably out of order can be disastrous, the Fukushima Daiichi nuclear disaster of 2011 was as a result of the failure of process cooling systems which resulted in excessive uncontrolled temperature increases in the nuclear plant which in turn resulted in a nuclear breakdown and multiple nuclear explosions. The effects of that disaster on the environment surrounding the nuclear plant and people that were exposed to the excessive radiation discharge still lingers.

The substances and chemicals used in process plants constitute another set of potential hazards. These chemicals may be toxic, carcinogenic, highly inflammable, corrosive etc. and special risk management measures must be put in place for the safe handling, transportation and use of these substances. There may even be need to replace certain chemical substances with less hazardous alternatives for the sake of enhanced process safety. All these hazards and risks peculiar to Process plants abound in addition to hazards arising from possible electrical, mechanical and structural failures as well as possible failure or malfunctioning of automated control systems. It is therefore not out of place to state that a great measure of the hazards found in other engineering disciplines are present in an ideal process plant in addition to the peculiar conditions and hazards obtainable in process plants as discussed above.

4.2 Some Major Chemical Disasters in recent history

These are provided to further drive home the salient point of the gravity and weight of Disaster Risk Management in Process plants.

In 2005, a disaster at a major petroleum refinery in Texas City, United States, was considered
US' worst industrial disaster in 15 years. Several explosions took place when a hydrocarbon isomerization unit was restarted and hydrocarbons flooded a distillation tower. 15 were killed and 180 were injured.

In September 2001, an explosion occurred in a shed containing about 300 tonnes of downgraded ammonium nitrate at a chemical plant in Toulouse, France. The incident resulted in the death of 31 people and injured more than 4,500 people, 27,000 buildings were also destroyed in the area.

In February 2000, a toxic chemical spill took place in the Romanian city of Baia Mare and destroyed wildlife and fish stocks and endangered the water supplies of 2.5 million People all over Central and Eastern Europe. Approximately 100,000m^3 of cyanide, used in the
Gold extraction process at a local mine was released into the River Somes when a reservoir wall at the mine collapsed. The event has been described as Europe's worst disaster since the Chernobyl nuclear disaster.

In 1984, at a pesticide plant in the state of Madhya Pradesh in central India. A combination of factors ranging from hazardous handling of dangerous chemical substances to the use of obsolete and malfunctioning industrial equipment resulted in the exposure of over 500,000 people to poisonous gases and by-products, nearly 3,800 human deaths were confirmed.

In June 1974, near the village of Flixborough in the United Kingdom, an event occurred which led to a significant tightening of the UK government's regulations covering hazardous industrial processes. A locally owned chemical plant, while repairing one of its chemical

reactors, produced in less than one minute, a discharge of 40 tons of cyclohexane, which formed a vapour cloud. The cloud exploded and completely destroyed the plant, about 1,800
buildings were damaged on a more than 1.5 km radius. (Gupta et al., 2009; Gupta and Shreeja, 2009; Gupta and Shreeja, 2012)

These examples are only a tip of chemical plant disasters that have happened and that can still happen if appropriate attention and efforts are not invested in Disaster Risk Management in Process plants.

4.3 Categories of Causes of Process Plants Incidents

There are a variety of cause of process plant incidents. However, the cause of process plant incidents are categorized into four (4) broad categories which are:

a) Technological failures
b) Human Failures
c) Management system failures
d) External Circumstances and natural phenomena.

There has over the years been so much focus on preventing plant accidents by minimizing technological failures and human failures. However, in the mid – 1980s, due to an unprecedented increase in chemical process accidents, the need for the establishment of management systems that are risks and safety oriented became imperative. Companies developed policies, standards were published, and governmental regulations and decrees were instituted, all these were done to fast - track the adoption of a management systems approach to process safety. Thus, the initial, somewhat fragmented, hazard analysis and equipment integrity efforts became harmonised into management systems and the attendant benefits were soon evident as chemical process plants accidents were consequently reduced.(CCPS, 2014)

As regards the influence of external circumstances and natural phenomena in causing accidents in Process plants, not so much can be done as to completely avert them. There are however technologies in place aimed at forecasting and predicting the occurrence of these natural phenomena so measures can be taken to reduce the impact of these natural phenomena on people, environment, assets and operations. It is however instructive to note here that the vast majority of accidents in process plants in history arose as a result of the first three causes highlighted above. So, if the first three causes are sufficiently addressed, the chances of accidents in process plants would be greatly reduced.

4.4 Areas of Focus for Disaster Risk Management in the Process Plants

Key areas of study, research and analysis for the purpose of Disaster Risk Management in Process plants are highlighted below:

a) **Hazardous Properties of Substances**: Knowledge about the specific hazardous properties of each and every chemical substance used in process plants must be acquired, analysed and measures for mitigating against the risks associated with these hazardous properties designed and implemented. Data about the properties of substances over a wide range of process conditions should be investigated with keen observation for changes in hazardous properties and tendencies with changes in process variables. The effects of these substances in their hazardous state on people, environment, assets and operation should be given apt attention

b) System Safety: System safety has to do with the safety analysis of the system and closeness of approach of a system to designed system models. The operation of the system components as well as the overall controllability of the system are vital points for investigation if we are truly interested in establishing a reliable Disaster Risk Management system. Elements of system safety analysis includes Operability, Controllability, Reliability and maintenance of systems, uncertainty analysis etc.

c) Process safety: This has to do with investigations bordering on the safe design and operation of physical and chemical processes. Processes should be designed with some measure of inherent safety. Issues such as process technology and stability, chemical reaction engineering, heat and mass transfer considerations, process control, adherence to safety culture and practices by people in the plant environment, incident analysis and simulation etc. are considered under the area of process safety. (AGS, 2009)

4.5 RECOMMENDATIONS FOR IMPROVED DISASTER RISK MANAGEMENT

The following recommendations aimed at fostering improved Disaster risk Management in the Chemical engineering discipline and indeed the broader fields of engineering and technology are given thus:

- **A concerted and continued academia focus on safety and Disaster risk management:** There is need for more concerted academia research into the areas of focus mentioned above needed to establish Disaster Risk Management systems. The academia in Nigeria should do more to engage in real, industry applicable and practicable research in the areas of investigation of hazardous materials used in the process industry and also in the areas of system and process safety. Furthermore, professional courses on safety such as the Health and Safety Executive (HSE) should be introduced into the engineering curricula of universities, such that every engineering graduate from our universities would be safety certified.

- **Industry – Academia partnership in research activities bordering on safety and Disaster risk management should be encouraged:** Industry – academia research partnership in the area of plant and process safety and disaster risk management would yield great benefits to both the industry and academia. There would be a better grasp of safety and disaster risk management by the academia and the industry would be able to operate safer plants resulting in increased profitability in the long run.

- **Laws for the protection of lives, properties and the environment should be promulgated and enforced to the letter:** The activities of certain petroleum and chemical companies in polluting the environment and endangering the lives of people in their host communities attests to the fact that the safety and environmental laws in the Nigerian state are somewhat too loose. These laws should be enforced to the very last dot on the 'I' so as to minimize environmental pollution and degradation and loss of lives and properties due to accidents such as oil leaks, pipeline explosions, toxic release of chemicals into water bodies etc.

- **Standards and regulations should be put in place to ensure management of companies employ best practices in Disaster Risk Management:** There are currently a wide array of modern tools such as SCOPE-FP, SCOPE-OHS etc. for effective and efficient risk analysis, assessment and management activities. The process of Disaster risk management should be standardized and unified for the various industries involved in the use of engineering and technology for production processes with due allowance given for the peculiarities of the various process and manufacturing industries.

- **The 'Drift factor' should be avoided:** After companies have experienced a remarkable success in risk management and safe plant and process operations, there is a tendency for these companies to want to cut down costs and increase profits by relaxing safety and risk management measures put in place. It is quite true that safety and disaster risk management activity can be expensive but the records have shown us time and again that it pays. For companies who succumb to the drift factor, a single accident in the plant would more than erode all the profits that the company sought to make by cutting corners.

5.0 CONCLUSION

Disaster Risk Management is a field of study that concerns all well-meaning engineers and technologists and must be accorded due attention for safer process operations and less industrial accidents. This is even more so for the chemical process industries overseen by the chemical engineer due to the peculiarities associated with process plants. We can have smooth engineering and technological operations if we take proactive actions to mitigate and manage industrial risks. We may not have absolute control of all the factors that may result in an engineering or technological disaster, but if only we would take a competent grasp of those factors that are within our control, a lot can be achieved in the area of Disaster risk management in engineering and technology.

REFERENCES

Bird, F. E. & Germain, G.L. (1996). *Practical Loss Control Leadership*. Loganville, GA: Det Norske Veritas.

Centre for Chemical Process Safety (CCPS), (2014). Guidelines for Risk Based Process Safety

Crowl, D.A. & Louvar, J.F. (2002). *Chemical Process Safety – Fundamentals with Applications*. Second Edition, Upper Saddle River, NJ: Prentice Hall PTR.

Gupta A. K., Sreeja S. N. and Shard (2009) Chemical Disaster Management. Proceeding volume
Of the National Workshop held on 30 September – 01 October 2008, New Delhi. National Institute of Disaster Management, India.

Gupta A. K., and Sreeja S. N. (2009). Management of Chemical Disasters: Background note Of the National Workshop (30 Sept.-1 Oct. 2009). Ministry of Environment & Forests, Govt. of India and National Institute of Disaster Management, New Delhi, P-42.

Gupta A. K. and Sreeja S. N. (2012). Training Module – Chemical (Industrial) Disaster Management. National Institute of Disaster Management, India.

Hazardous Substances Council of the Netherlands (AGS), (2009). Strategic Approach for Safe Chemical and Energy Industries.

Hopkins, A. (2005). *Safety, Culture and Risk*. Sydney: CCH Australia Limited.

International Federation of Surveyors (FIG), (2006). The Contribution of the Surveying Profession to Disaster Risk Management. A publication of FIG Working Group 8.4

Paul, R. A. and Douglas J. M. (2006). Risk Management – An Area of Knowledge for All Engineers. A Discussion Paper prepared for The Research Committee of the Canadian Council of Professional Engineer

Richard, Justice K.P. (1997). *The Westray Story – A Predictable Path to Disaster*. Report of the

Westray Mine Public Inquiry, Halifax, NS: Province of Nova Scotia.

Reid B. (2013). Science and Technology for Disaster Risk Reduction: A review of application And coordination needs.

UNESCO Report (2010). Engineering: Issues, Challenges and Opportunities for Development. UNESCO publishing, pages 272-273

Wilson, L. (1998). *Basic Learnings in Industrial Safety and Loss Management*. Edmonton, AB: Association of Professional Engineers, Geologists and Geophysicists of Alberta

Wilson, L. & McCutcheon, D. (2003). *Industrial Safety and Risk Management*. Edmonton, AB: University of Alberta Press.

11 Epic Technology Disasters – Network computing. Accessed from https://www.networkcomputing.com/government/11-epic-technology-disasters/305027696 accessed on 06/08/2017

Chernobyl disaster – Wikipedia. Accessed from https://en.m.wikipedia.org/wiki/Disaster accessed on 06/08/2017

Disaster – Wikipedia. Accessed from https://en.m.wikipedia.org/wiki/Disaster accessed on 06/08/2017

Disaster Risk Management and Questions. Accessed from www.cyen.org/innovaeditor/assets accessed on 06 /08 /2017

Types of disasters – IFRC. Accessed from http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/ accessed on 06/08/2017

www.process-worldwide.com/a-look-at-disaster-management-strategies-for-chemical-process-industries-a-316211/ accessed on 06/08/2017