Fuel Cycle Safety Research—Role and Development in Future

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1. Introduction

Nuclear facilities have been the potential to harm a number of people and environment if a serious accident occurs. Therefore, It is necessary to establish design criteria, safety assessment standards and operation regulations to ensure an adequate margin for safety on the design and the operation of such facilities. The facility design and its operation continue to be improved with new technology and knowledge, while the standards, operation regulation are improved to reflect the lessons learned from incidents and accidents. The accident at Three Mile Island and Chernobyl nuclear power plant made it clear that the reliability of the people performing the operation and maintenance, as well as other human factors, is important. As a result of these accidents, there was a greater recognition of the importance of probabilistic risk assessment.

While, in the chemical process industries, accident of the pesticide manufacturing facility in Bhopal, India also served as a wake up call unlike any other. It was of great importance to undertake the development of prescriptive risk management and regulatory action to mitigate its side effects. Risk informed methodology plays an important role on chemical process safety issues. Risk informed in-service inspection was used in risk quantification in formulating an in-service inspection plan. This methodology has been successfully adopted by the oil and gas industries and chemical plants. These sectors have been able to establish effective structural integrity management programs that reduce plant down time and industrial and regulatory burdens, whilst continuing to maintain plant safety.

Nuclear Safety Commission reported the policy for introducing regulation that utilizes risk information last year. The report expects that the risk informed regulation will be developed to complement and advance the current regulation, maintaining the concept of defense-in-depth. (prevention of occurrence of abnormality, prevention its escalate into accidents, mitigation of consequence). The application of risk information into the quantitative assessment and confirmation of safety assurance will help to improve the rationality, consistency and transparency of safety regulation.

Today, there continues to progress on the understanding and analysis methods for the process behaviors of nuclear facilities. It has become possible to investigate frameworks for effective, comprehensive safety assurance and safety regulation using the risk information. Nuclear fuel cycle facilities, especially reprocessing facility are now shifting from design of reprocessing plant to the construction and operation phases, and its operational safety improvement must be achieved by using the risk information obtained through the operation experiences including problems such as troubles.

2. Lessons learned from Bhopal

Twenty years have been passed since the world's worst industrial disaster — Bhopal accident— released forty metric tons of methyl isocyanate from the pesticide manufacturing facility of Union Carbide Corporation in Bhopal, India. No one really knows how many people died after inhaling the chemicals that were released from cylindrical storage vessel on the night of December 2, 1984. A

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report released by the Indian government last may notes a conservative estimate of 2,500 immediate human fatalities. In 1997, Indian officials tabulated a death toll of 15,000 people, most of whom died of chemical gas—related aftereffects, such as tuberculosis and respiratory problems. Moreover, hundreds of thousands of people may have been injured.

The specter of Bhopal catalyzed many voluntary programs and legislation aimed at prevention, training, preparedness and response, which are now integral parts of the process safety landscape. The American Institute of Chemical Engineers established its Center for Chemical Process Safety which plays the role of an information and training clearinghouse for process safety. In 1985, American Chemistry Council mandated its members to adopt a program called Community Awareness and Emergency Response which required companies to develop emergency response plans in cooperation with local emergency responders. In 1987, Canadian Chemical Industry launched Responsible Care which endorses the ethic of continual improvement in health and safety practices. The Responsible Care was adopted by the American Chemistry Council in1988 and the program is now embraced by 47 countries.

U.S government followed industry's lead by creating or amending legislation to better protect people and environment. In 1986, Congress passed the Emergency Planning and Community Right to Know Act. The act mandated the responsibilities of industry to inform neighboring communities of chemical hazards, as well as to coordinate and plan emergency response procedures both on and off site. It also required certain facilities to annually report the release of certain toxic chemicals. The first such compilation in 1988 indicated that some 4 billion lb of toxic chemicals were being released into the air each year. That finding triggered amendments to the Clean Air Act in 1990, such as the Process Safety Management standard which was promulgated by the Occupational Safety and Health Administration in 1992, and the Accidental Release Prevention, Risk Management Program, which was promulgated by the Environmental Protection Agency in 1999. The Clean Air Act amendments also authorized the creation of the U.S. Chemical Safety and Hazard Investigation Board, an independent federal agency that investigates major chemical incidents to determine their root cause.

Educational institute are also placing more emphasis on process safety. Many universities now include a process safety course in the core curriculum of their chemical engineering programs. Engineering undergraduates at some schools can specialize in safety by option for elective courses in related areas, such as design safety or fire protection. Graduate students are conducting research on safety—related topics, such as runaway reaction or fires and explosions.

This mounting awareness appears to be paying off. Responsible Care companies in the U.S. succeeded in halving their rate of occupational injury and illnesses since 1990, while effecting a 35 % decrease in the number of reportable process safety incidents since 1995. According to Occupational Safety and Health Administration, the number of fatal or catastrophic incidents requiring agency inspections also appears to be trending down. Only one fatality has been recorded so far in 2004.

3. Abnormal Situation Management

Many process plants in chemical industries have proven procedures for dealing with emergencies. However, between normal operation and real emergencies is a gray area that few facilities effectively address. Most companies are aware of the risk of operator overload during such abnormal situations. Often, the only real response has been to improve control system alarm with alarm management so that operator don't face numerous, confusing alarms. However, this is not enough, according to in-depth surveys conducted on a number of plants.

Abnormal situation management is a safety issue, and safety long has been a top priority for companies in chemical process industries. The Occupational Safety and Health Administration (OSHA) 29 CFR 190.119 Process Safety Management Standards will further reinforce this. To investigate and identify root cause of abnormal operations and to pinpoint best practices for preventing these situations or at least handling them most effectively, the survey works were carried out around world, including in the U.S.A., Canada, the U.K., Europe, and Japan. On those surveys, eight key issues were identified. One of them was the absence of procedures for dealing with abnormal operations (as opposed to emergencies).

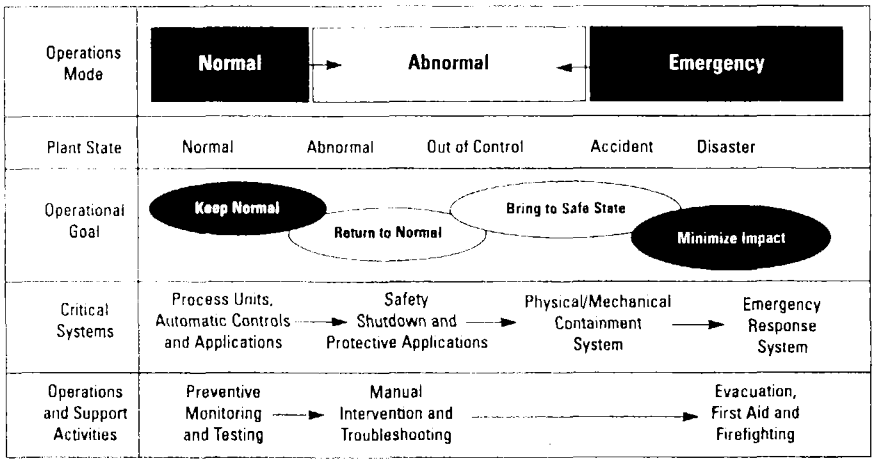

Fig.1 Anatomy of a disaster form an operation perspective.

Operator work within a simple framework that has three main areas : normal, abnormal, and emergency operation shown in Figure 1. The diagram shows that the operator is driven by management goals that start with " Keep Normal ". The operator's task is to prevent and react to deviations. This is done by monitoring, testing, and responding to process and equipment alarm. The goals include safety, environmental, quality, economic, and productivity target. As an event occurs, the operator's goal are modified dynamically and automatically to " Return to Normal ". However, success depends on response time and the actions taken. On some occasion, 0perators may have to manually intervene. If the incident escalates, the operator may sacrifice lower priorities to achieve " Bring to Safe State ". The operator often is supplemented by automatic shutdown system and other safety devices. Many processes still required a considerable amount of manual intervention during this phase. The operator frequently is faced with weighing unit shutdown against plant shutdown. The consequences are balanced against goals, risks, and operator/supervisor judgment. In worst scenarios, the containment systems may not be adequate, and the operator's goal again change to " Minimize Impact ". This involves implementing emergency response procedures, which may include first aid, fire fighting, and evacuation.

The surveys have revealed that plants typically have well defined normal operating procedures, that is, very basic abnormal operating procedures such as for shutdown, and very good emergency planning and response procedures. However, it has been seen very little in the way of procedures for " Return to Normal " and operating under abnormal conditions. It also have been found that little or no technology exists for coping when between normal and out-of-control operation, that is, diagnosis and recovery can be difficult because of process dynamics and the need for speedy response. Many operators have stated that controls and procedures are inadequate during this difficult operation. Therefore, we can contemplate addressing the missing technology area that lies between " Return to Normal Operation " , and " Bring to a Safe State ". The Surveys can deliver significant benefits as we contemplate changing the culture from a reactive control system designed for normal and emergency situations to a predictive and preventive one that invests significant design time to abnormal situations. Dynamic simulation technique will play an important role on doing so in the future.

4. Learning from Accident

When a new process has run for a while, unanticipated phenomena, related to trace components that may not even have been identified during process development or on process change, often become key issues in the everyday functioning of the process. One such effect is entrapment of trace components as bulges in distillation columns. Such bulges have figured in many process problems in the chemical process industries. An example of such kinds of unanticipated phenomena is shown here.

A violent explosion accident occurred at the rectification tower for methanol/water solution at a newly surfactant plant developed in Japan in 1991. This explosion was characterized as a detonation. The pressure at the center of the explosion was estimated as more than 160 kgf/cm . The explosion was caused by trace amounts of organic peroxide as an impurity of bleaching stage of the surfactant which unexpectedly concentrated to more than 40 % in the rectification tower as shown in Figure 2.

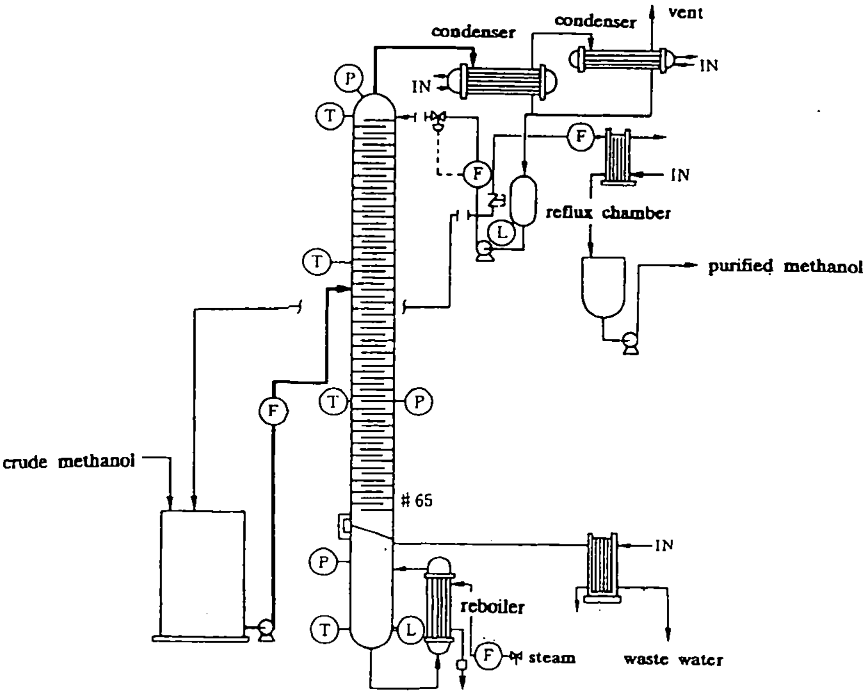

Fig.2 Rectification Process of Crude Methanol/Water Solution.

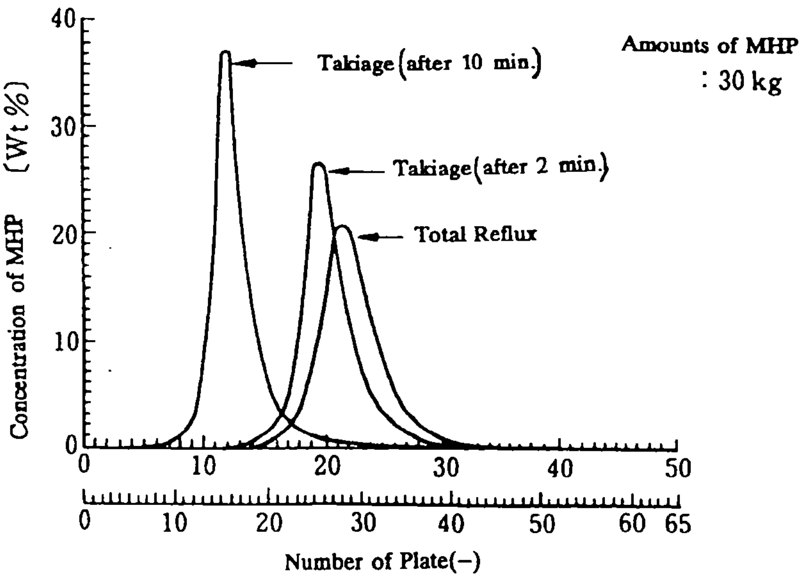

Fig.3 Computer Simulation for Concentration of MHP in the Rectification Tower (Takiage;Flux by Stream).

The explosive substance was identified as methyl hydroperoxide (MHP) in post-accident investigations. The feed with a MHP concentration of only 0.1 % was not explosive itself. However, the boiling point of MHP is between that of methanol and water. MHP was accumulated in the rectification tower. According to computer simulation, the maximum concentration of MHP in the rectification tower was 40 to 50 % at the shutdown stage as shown in Figure 3.

Trace amount of MHP contained in the feed of methanol/water solution was concentrated at shutdown stage of the rectification tower. The imbalance of thermal equilibrium of the rectification tower introduced self-accelerated thermal decomposition of MHP, which resulted in a violent explosion. Although the chemical identity of trapped trace component may not be known in advance, the trapping itself increases concentration to the point where sampling can furnish analytical identification. Such phenomenon is also abnormal situation on the operation of chemical process. Dynamic simulation can help to analyze the transition from normal to abnormal state. Such problems can be anticipated, or at least readily diagnosed.

5. Dynamic Simulation

The use of models in chemical industries is well established, but the use of dynamic models, as opposed to the more traditional use of steady-state models for chemical plant analysis, is much more recent. This is reflected in the development of a powerful commercial software packages for dynamic simulation, which has arisen owing to the increasing pressure for design validation, process integrity and operation studies for which a dynamic simulator is an essential tool. Indeed, it is possible to envisage dynamic simulation becoming a mandatory condition in the safety assessment of plant, with consideration of such items as start up, shutdown, abnormal operation, and relief situations assuming an increasing importance. Dynamic simulation can thus be seen to be an essential part of any hazard or operability study, both is assessing the consequences of plant failure and in the mitigation of possible effects. Dynamic simulation is of equal importance in large scale continuous process operation, as in other inherently dynamic operation such as batch, semi-batch and cyclic manufacturing processes. Dynamic simulation also aids in a very positive sense in enabling a better understanding of process performance and is powerful tool for plant optimization, both at the operational and at the design. Furthermore,

Steady-state operation is then seen in its rightful place as the end result of a dynamic process for which rates of change have become eventually zero.

The characteristics or principles of mathematical modeling can be summarized as follows:

1) The mathematical model can only be an approximation of real-life processes, which are often extremely complex and often only partially understood.

2) Modeling is a process of continuous development, which it is generally advisable to start off with the simplest conceptual representation of the process and to build in more and more complexities, as the model develops.

3) Modeling is an art but also a very important learning process. In addition to a mastery of relevant theory, considerable insight into the actual functioning of the process is required. One of the most important factors in modeling is to understand the basic cause and effect sequence of individual processes.

4) Models must be both realistic and robust. A model predicting effects, which are quite contrary to common sense or to normal experience, is unlikely to be met with confidence.

One of the more important features of modeling is the frequent need to reassess both the basic theory (physical model), and the mathematical equations, representing the physical model (mathematical model), in order to achieve agreement between the model and actual process behavior (process data). As shown in Figure 4 the following stages in the modeling procedure can be identified.

1) The first involves the proper definition of the problem and hence the goals and objectives of the study.

2) All the available knowledge concerning the understanding of the problem must be assessed in combination with any practical experience, and perhaps alternative physical model may need to be

developed and examined.

3) The problem description must then be formulated in mathematical terms and mathematical model can be solved by computer simulation.

4) The validity of the computer prediction must be checked. After agreeing sufficiently well with available knowledge, the strategy for taking the process data must be designed to further check its validity and to estimate parameter values. Steps (1) to (4) will often need to be revised at frequent intervals.

5) The model may now be used at the defined depth of development for design, control, operation procedure, and for other purposes

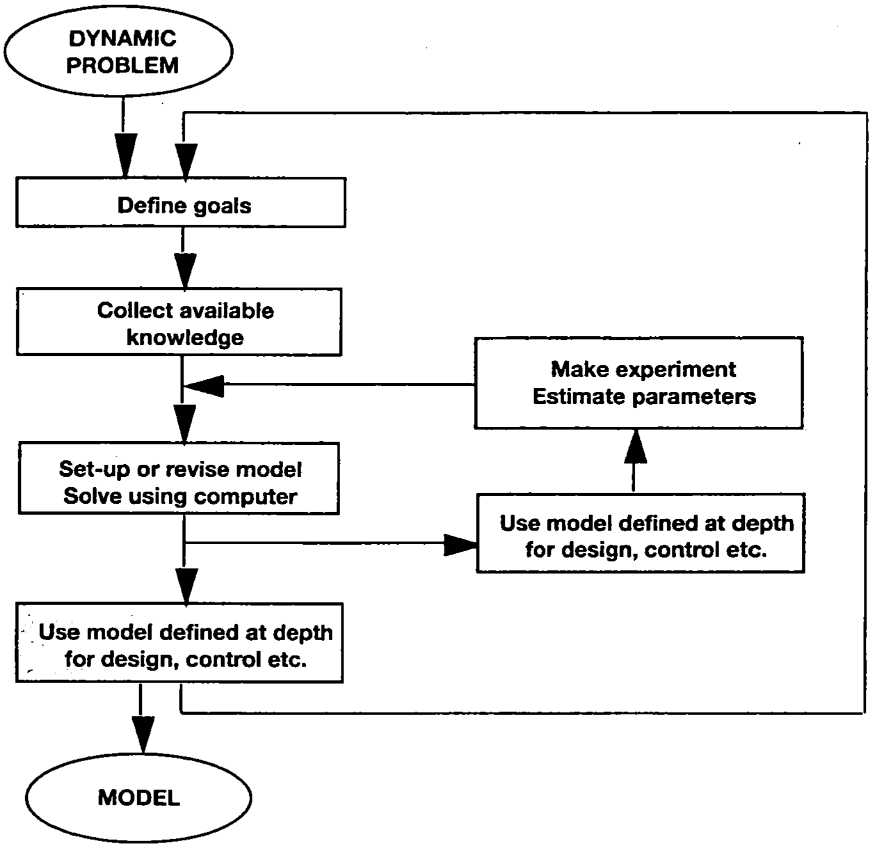

Fig.4 Steps in model building.

6. Conclusion

Abnormal situation management is a safety issue. Little attention has been given to understanding the issues regarding performance during normal versus abnormal situation. The first step is in abnormal situation management is to define what really is abnormal. The second step is to ensure that everyone understands the difference between normal and abnormal, and the root causes of abnormal events. The third step is to be aware of current practices that support abnormal situation management, and the procedures, practices, and techniques used to respond to abnormal conditions. Dynamic simulation will become to an useful technique for abnormal situation management as well as probabilistic safety assessment for process facilities including nuclear fuel cycle.

3. Keynote Address

Accomplishment of 10-year Research in NUCEF and Future Development

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