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A FRAMEWORK FOR RISK MANAGEMENT OF PETROCHEMICAL PLANTS IN DEVELOPING COUNTRIES

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I. INTRODUCTION

A common characteristic of petrochemical plants, such as chemical processing plants and refineries, is that large amounts of potentially hazardous materials are concentrated in single sites under the centralized control of a few operators. Accidents at these facilities could not only have serious and long-lasting health and environmental consequences for those within the plant, but also for the neighboring public, and even the whole region, state and country. For example, the 1984 Bhopal chemical accident, which resulted in the death of more than 3,500 and permanent injuries to more than 200,000 residents. To date, on the average, two of the 200,000 people who were injured at the onset of this disaster die every day. Moreover, those who initially survived the gas "are continuing to suffer not only deterioration of their lungs, eyes and skin but also additional disorders that include ulcers, colitis, hysteria, neurosis and memory loss" (*Los Angeles Times*, March 13, 1989, p. 1). The chemical exposure has even affected the second generation: "Mortality and abnormalities among children conceived and born long after the disaster to exposed mothers and fathers continue to be higher than among a selected control group of unexposed parents" (Ibid).

An increasing number of developing countries are developing their petrochemical industries. This has a double advantage: it would supply their domestic need for their ever-increasing demand of petrochemical commodity products, and by exporting the surplus production they can acquire hard currency which is a relief to their worrisome balance of payment and foreign debt burden. According to a study by the United Nations Industrial Development Organization (UNIDO), due to the richness of hydrocarbons resources, and the availability of other raw materials necessary for petrochemical production, many developing countries rapidly develop their petrochemical industries (UNIDO, 1985). According to this study, "the availability of the necessary raw materials, an inexpensive labor force, and an increased demand products is expected to lead to the development of petrochemical production capabilities within developing countries" (p. 105). Moreover, based on a comprehensive analysis of the global petrochemical industry by the U.S. Office of Technology Assessment (OTA), among the four major geographic entities that are likely to become more important sources of petrochemical products -- Canada, Mexico, the Middle East, and South East Asia-- three are associated with developing countries (*Technology Transfer to the Middle East*, 1984). It is also anticipated that the Middle East's ethylene capacity increase nearly "six fold" from 1985 to 1990; and to take advantage of economies of scale, "Middle Eastern petrochemical plants are planned to be very large" (Ibid). According to an OECD (1985) study of the world's petrochemical industry , the Middle East/North Africa's ethylene production capacity by 1990, would total 3.4 million tons (1.1 of which could be for export), [to bring home the scale of the figure, this compares with the 1.3 million tons ethylene-equivalent exported by the United States in 1981 and the 9.6 million tones consumed in Europe the same year (OECD, 1985, p. 93). According to a 1986 study entitled *Petrochemicals in the Middle East* (conducted by Tandy, 1986; and cited in *The Working Papers of the MIT Commission on Industrial Productivity* (1989), Vol. 1, p. 62), the petrochemical capacity of the Arab nations of the Persian Gulf is estimated to supply about 15.8% or world demand for urea, 13.3% for ethylene glycol, 10% for industrial ethanol, 9.5% for methanol, 5.1% for ammonia, 4.4% of low density polyethylene (LDPE), 3.2% for ethylene, 2.6% for ethylene dichloride (EDC), and 2.2% for high density polyethylene (HDPE)] For instance, Iran, a developing country, in the next five years, will invest up to $6 billion in her petrochemical industries for expanding the existing or constructing new plants (*Iran Times*, April 20, 1990). It is also expected that through these plans, at the end of the five year period, Iran's total production level petrochemicals reaches the 5 million tons per year; three times higher than the present level (*Iran Times*, February 16, 1990).

In comparison with developed counties of the West, developing countries also suffered from and have had their own share of losses at petrochemical plants. Using Marsh & McLennan's (1988) thirty-year review of 100 large property damage losses in the hydrocarbon-chemical industries, these figures have been calculated by the author: (a)- out of the 100 large losses (with the total of $3,966,100 million and average of $39,700,000), 43 were at refineries, 5 of which were located in developing countries (two in Venezuela, India, Kuwait, and Brazil). The total dollar value of these 5 losses was $151,396,000 and the average was $30,273,000; (b)- 8 out of the 100 large losses were at natural gas plants throughout the world, where 6 of which were located in developing countries (four in Saudi Arabia, Indonesia, and Qatar). The total dollar value of these 6 losses was $414,577,000 and the average $69,0970,000. [All dollar values were trended by Marsh & McLennan (1988). Using a petroleum equipment related index allowed the comparison of events on a constant-dollar over 30 years.]

The inherent risk of petrochemical plants and the seriousness of their calamities' aftermath mandate development of proactive risk management strategies. It is not only required for the purpose of accident prevention, but also for the protection of citizens, inside and outside of the these hazardous technological systems. Also, to avoid the adverse effects on public health and environmental quality of the foregoing increased petrochemical production, according to UNIDO (1985), adequate pollution control regulations must be promulgated.

In fact, risk, safety, and danger are analogous to the terms temperature, cold, and hot; temperature being a measure of how cold or how hot. Just so, risk is a measure of how safe or how dangerous; and the concept of risk deals with the danger of loss from accidents (U.S. Department of Energy, 1982). Loss in this context can be anything that increases cost of operation or reduces productivity. It also includes liabilities, political, social, and environmental costs. Risk management, therefore, is loss control exercised by sound management principles, done through the process of allocation of resources for analysis of potential sources or causes of failures and a plan to prevent, control, and/or mitigate them. Risk management, in other words, involves the understanding of potential adverse effects and the systematic application of controls to optimize productivity by minimizing loss.

The purpose of this project, therefore, is to identify a systematic, *holistic* framework for risk management of petrochemical plants in developing countries, that considers all the stakeholders and integrates human, organizational, and technological factors. The need for such holistic approaches to environmental protection and industrial safety is reiterated in the recommendations of an international workshop, consisting of 12 countries, on the "Issues Relevant to Management of Hazardous Waste." As a part of the "Recommendations for Effective Reduction and Control of Hazardous Waste," according to Maltesou (1989, p. 7), the workshop coordinator:

> *A key to environmental protection and industrial safety is the knowledge and attitude of all levels of people working toward such goal. These include the policy makers, the managers of industrial plants, the technical community, the labor force, as well as the affected public.*

Finally, it should be noted that this study and its presented framework, using the Operations Research language, try only to Formulate the problem, identify variables of the Objective Function, and define the Solution (or) Feasible Region for risk management of petrochemical plants in developing countries. This work, however, should neither be considered as an Algorithm for finding Optimal Solutions (to the risk management problem), nor be construed as an attempt to develop *guidelines* for such techniques. The present body of knowledge and state-of-the-art of risk management (as a scientific and technical field) is far from adequate and is also not theoretically capable of supporting such bold steps; because as concluded by Rasmussen and Batstone (1989), "the *total* system involved in the safe operation of large-scale systems should be considered in the design of guidelines... and guidelines for various (involved) parties should be interrelated and coordinated" (p. 35). Moreover, as also suggested by Rasmussen and Batstone (1990, p. 16), before developing specific guidelines for risk management of large-scale technological systems, in order

to prepare and finalize the "guidance for guidelines," further research in four different areas is necessary. [These areas are: risk analysis in system design and in operation; operations management; influence of cultural factors; and organization and planning of emergency management.]

II. RISK AND ACCIDENT POTENTIALS OF PETROCHEMICAL PLANTS IN DEVELOPED AND DEVELOPING COUNTRIES

II.1 Major Causes of Accidents in Developed Countries

According to a recent study of the accidental chemical releases in the United States, by the Environmental Protection Agency (EPA, 1989), operator error was a primary or contributing cause in 31 percent of cases, only second to the equipment failure which was responsible for 56 percent of the accidents. Approximately 25 percent of the accidental releases occurred during loading, unloading, and maintenance.

Based on Occupational Safety and Health Administration's (OSHA) investigation of 30 accidents in the petrochemical industry in the United States for the fiscal year 1989, 77% of the accidents involved the performance of regular job functions, whereas only 23% of the accidents involved unique or infrequently performed tasks. About 46% of all the accidents involved employees who had not received any safety training, and 56% involved the use of improper tools, materials, and equipment (OSHA, 1990).

According to the American Insurance Association Report (1979) on the analysis of 465 major fires and explosions that occurred at the chemical and allied industries, between 1960 and 1977 in the U.S., which resulted in 279 fatalities and 1,727 nonfatal injures, the following were found to be the principal causes of or factors contributing to the accidents studied: (1) Approximately 26.6% of the incidents resulted from operational failures, which generally involved one or more of the following: (a) absence of detailed descriptions and recommended procedures in operating the various sections of the plant, (b) inadequate start-up and shutdown procedures, lack of emergency control plans and drills, and (c) poor training programs. (2) Approximately 20.1% of the incidents resulted from inadequate materials, education, and chemical process problems. These inadequacies and problems included (a) insufficient evaluation of fire, health, and stability characteristics of all materials involved; (b) lack of required information on process temperature or pressure violations; and (c) failure to observe requirements for extreme process conditions. (3) Approximately 26.6%

of the incidents resulted from equipment failures due to such factors as (a) processes that exceeded design limitations, (b) poor maintenance programs, (c) inadequate repair and replacement programs, and (d) lack of "fail-safe" instrumentations.

The Marsh and Mclennan (1989) report on Large Property Damage Losses in the Hydrocarbon-Chemical Industries, reviewed 150 industry accidents that had the largest dollar losses from 1959 through 1989. These accidents represented more than $5 billion in property damage, debris removal, and cleanup costs based on 1988 prices (the cost of business interruption, employee injuries, or liability claims were excluded). Refineries has had the largest share of the losses, 40%, and petrochemical plants were second with 17% of the losses. [Actually, the largest of the 150 losses, reported by this study, occurred on May 5, 1988 in the fluid catalytic cracking unit of the Shell Oil Company Refinery in Norco, Louisiana. The property damage was estimated to be $309,000,000.] According to this study, Mechanical Failure of equipment was the cause of loss in 41% of the incidents. The second most frequent cause of loss was Operational Error, accounting for 19% of the losses. The other causes of losses included: Process Upsets 10%, Natural Hazards 5%, Design Error 4%, and Sabotage/Arson 4%. It is noteworthy to mention that the author(s) stated: "We recognize that, except for natural disaster, human error is ultimately responsible for all losses. The category 'operational error' includes those human errors make on-site that led directly to the loss" [emphasis by the original author(s)] (Marsh and Mclennan, 1989, p. 4)].

In an analysis of 110 losses over $250,000 each, in chemical plants during the years 1974, 1975, and 1976; the "accident-contributing factors to loss of dollars", in descending order, were: Equipment Design 41%, Operator Error 31%, Maintenance 12%, Chemical Process Design 10%, and Material Hazard 6% [*Loss Prevention and Protection for Chemical and Petrochemical Plants*; cited in Hammer (1985), p. 11].

In a study of incidents at the chemical and petroleum industries (SIC codes 28 and 29) from 1982 to mid-1988, by Charles Rivers Associates prepared for OSHA, the causes of the incidents are classified in four broad categories: human error, equipment failure, other, and unknown. While the percentage of incidents due to each cause varies within the petrochemical SICs, this report estimates that human error and equipment failure each account for 25% of the accidents within industry as a whole. Approximately 33% of the incidents are of unknown origin, with the remaining attributable to other causes (OSHA, 1990). According to this study, which corroborate the aforementioned Marsh and Mclennan's finding, petroleum refining is a high hazard industry compared to other industrial sectors in petrochemical industry. The largest number of incidents and injuries and the second largest number of deaths within the industry were reported for the petroleum refining. The petroleum refining industry in the U.S. is estimated to have a fatality rate of 8.6 deaths per 100,000 workers.

The largest accident of all the petrochemical plants, so far, has been what is called America's biggest postwar industrial accident: the explosion at the Phillips 66 Company's Houston Chemical Complex, at Pasadena, Texas, on October 23, 1989. This explosion, with the force of 2.4 tons of TNT, sent shock waves measured between 3.5 to 4.0 on the Richter Scale to Houston, killing 23 and injuring more than 130 workers. Moreover, according to insurance sources, this tragic accident produced perhaps the largest single U.S. business insurance loss in history: up to $750 million dollars. According to an extensive investigation by OSHA (1990), this explosion was avoidable had recognized safety procedures been followed. Finally, it was concluded that "the primary causes of the accident were failures in the management of safety systems at the (Phillips) Houston Chemical Complex" (p. 70).

Moreover, according to the above study (OSHA, 1990), the major causes of accidents in any industry sector may be found in the insufficient recognition of hazards, aging and poorly maintained equipment, unsafe conditions or procedures, poor planning, improper risk management, unsafe engineering practices, inadequately trained personnel, or disproportionate attention to production. "Each of these factors reflects a failure in management responsibility to maintain a safe workplace. Collectively, they represent a breakdown of the management systems essential for controlling risk and preventing disaster. Accidents that have occurred in the petrochemical industry all reflect insufficient attention to these elements" (p. 71).

Analyses of major technological and chemical accidents indicate that "80-90 percent of the failures are in the hierarchy of the management and organizational system and only 10-20 percent can be attributed to the (true) operator and equipment failures, that are so often the focus of the blame" (Batstone, 1987, p. 5.129). Also, "the sophisticated risk analysis techniques developed to-date by the engineering, human factors, and scientific disciplines only address 10-20 percent of the problem, since they have not focussed on the management and organizational aspects of the system failures" (Rasmussen and Batstone, 1989, p. 5).

II.2 Major Causes of the Accidents in Developing Countries

The situation in developing countries is even worse. This is according to the conclusion of a recent UNIDO-sponsored survey of industrial risk management in India, "about 70 percent of the accidents can be attributed to human failures. This state of affairs indicates ignorance amongst management, supervisors and workers of the available information on risk management and its use" (Dave, 1989, p. 7).

A thorough analysis of the current problems of risk management in Brazil conducted by Barreto Vianna (1988a), reported of a longitudinal study of major accidents for the past ten years (1978-1987) by the State of Sao Paulo's Environmental Agency (CETESB). According this study, almost 90% of the 415 accidents were caused by unsafe acts due to operational and mechanical failures.

Finally, it is highly critical to realize that the Bhopal accident should not necessarily be considered as an isolated event which is unique to, and could only happen in developing countries. For instance, according to Williams (1985), "the factors which led to the MIC release in Bhopal were not unique to Union Carbide, India, or developing countries" (p. 48). The findings of an extensive comparative analysis, presented at a recent UNIDO-organized international conference on Industrial Risk Management and Clean Technologies, also demonstrated that with the *present* safety precautions, the Bhopal accident <u>could</u> happen at any comparable plant in any developed country, e.g., the Federal Republic of Germany (Uth, 1988). It could also happen, as easily in the United States. In fact, according to an expert with the Environmental Policy Institute, there have been "17 accidents in the U.S., where each of which released the Bhopal equivalent toxic gases.... Only because the wind was blowing in the right direction, Bhopal did not happen here" (*USA Today*, August 2, 1989).

II.3 Human Error and Technological Systems' Accidents

As demonstrated by aforementioned statistics, traditionally, many (technological) systems' failures implicated in serious accidents have been attributed to operators and their errors (e.g., Three Mile Island and Bhopal). However, this is a great over-simplification. Perrow (1984) has reckoned that while 60-80 percent of all accidents are officially attributed to operators, the real figure might be closer to only 30-40 percent. Implications of the so-called *stop-rule* for accident investigation is the key to understanding this significant difference. Based on Rasmussen's (1989) excellent study (of human error and the problem of causality in analysis of accidents, in a causal explanation of accidents), the level of decomposition of an accident depends entirely on the intuitive background of the intended audience. That is, identification of accident causes is controlled by pragmatic, subjective stop-rules. These rules depend on the aim of the analysis (or analyst), i.e., whether the aim is to explain the course of events, to allocate responsibility and blame, or to identify possible system improvements in order to avoid future accidents.

It is said that human performance factors are the 'guts of every accident,' or, according to Cherns (1962), an accident is "an error with sad consequences" (p. 162). By declaring that operators must have failed, it always helps to avoid a lot of "undesirable" problems. As suggested by Perrow

(1986a), "finding that faulty designs were responsible would entail enormous shutdown and retrofitting costs, finding that management was responsible would threaten those in charge; but finding that operators were responsible preserves the system, with some soporific injunctions about better training" (p. 146). Thus, implicating the front-line operators in systems accidents is an oversimplification that results in blaming the victims.

Nowadays, it is known that performance, as well as the inherent accident potential, of large-scale technological systems is a function of the interactions of their *engineered* and *human* (i.e., personnel and organizational) subsystems. On many occasions,human error is caused by the inadequate responses of operators to unfamiliar events. These responses depend very much on the conditioning taking place during the normal work. The behavior of operators is conditioned by the conscious decisions made by work planners or managers. Therefore, the error and the resulting accidents are, to a large extent, both the *attribute* and *effect* of such factors as complicated operational processes, ineffective training, non-responsive managerial systems, non-adaptive organizational designs, haphazard response systems, and sudden environmental disturbances, rather than being their *cause* (Meshkati, 1988a; 1989b). Traditionally, the solution to the problem of technological systems safety has been defined as an engineering one (Perrow, 1986). Nowadays, however, through many rigorous scientific and multidisciplinary investigations, it is known that system accidents are caused by the way the (system) parts -- *engineered* and *human* -- fit together and interact.

Operators' errors should be seen as the result of human variability which is an integral element in human learning and adaptation (Rasmussen, 1986). This approach considers the human-task or human-machine mismatches, instead of solely tasks or machines, as a basis for analysis and classification of human errors (Rasmussen, Duncan, and Leplat, 1987). Thus, human error occurrences are defined by the behavior of the total human-task system (Rasmussen, 1987). Frequently, the human-system mismatch will not be due to spontaneous, inherent human variability, but to events in the environment which act as precursors. Furthermore, in many instances, the working environment can also aggravate the situation. Rasmussen (1986) has characterized this phenomenon as the "unkind work environment." Once the error is committed, it is not possible for the person to correct the effects of inappropriate variations in performance before they lead to unacceptable consequences, because the effects of the 'errors' are neither observable nor reversible. Finally, according to many case studies, a good portion of errors in complex human-machine systems, the so called *system-* or *design-induced errors*, are forced upon the human operators.

According to Perrow (1984, p. 351), "the dangerous accidents lie in the system, not in the components," and the inherent system accident potential can *increase* in a poorly-designed and managed organization. Moreover, operational settings in developing countries, impose extra stress and aggravate the safety and performance of these already fragile and unprepared systems. As the 'system's environment,' developing countries' *different* contexts and their operator populations' physical and psychological characteristics, and educational, cultural and religious orientations are major factors that significantly affect the functioning and interaction of the -- 'as is' transferred -- engineered and human subsystems in complex ways. Thus, these different operational milieus may exacerbate the vulnerability of such interactive subsystems, and if not proactively dealt with, could activate a chain reaction resulting in low system performance and efficiency, unsafe operations, higher accident potential, and even disasters. The Bhopal tragedy, for instance, was a typical example of such a vicious circle causing total system failure -- an inherently faulty and unprepared human-technological system aggravated by a developing country's (India's) contextual factors (Meshkati, 1989a & c; Shrivastava, 1987).

III. CRITICAL ELEMENTS AND PRACTICES IN PROCESS SAFETY OF PETROCHEMICAL PLANTS

III.1 Management's Role in Safety of Petrochemical Plants

The EPA, recently, conducted a review of emergency systems for monitoring, detecting, and preventing releases of hazardous substances at representative domestic facilities that produce, use, or store these substances (EPA, 1988). Among the findings in EPA's June 1988 final report was that "prevention of accidental releases requires a holistic approach that integrates technologies, procedures, and management practices" (EPA, 1988, p. 3). Moreover, the report stated:

> "The commitment of management to accident prevention, mitigation, and preparedness is essential. Without such commitment, installation of the most advanced technologies will be an expensive, but ineffectual safeguard for preventing serious injury, death, of environmental damage."
>
> "While accidents can occur in well-managed facilities, the lack of management commitment can lead to disaster... The ultimate responsibility for safe design, operation, and maintenance of a facility rests with management."

The aforementioned OSHA's (1990) investigation of the Phillips 66 Company's Houston Chemical Complex explosion and fire also corroborates, in principle, the above findings and recommends that "it is important that companies in the petrochemical industry implement comprehensive chemical process safety management plans to manage risks" (p. 71).

As mentioned before, there is a much higher burden on the management of petrochemical plants in developing countries for safety promotion, than developed countries. This is primarily due to (a) the transferred nature of most of the needed technologies for petrochemical plants in developing countries; (b) the lack of reliable safety-related data which could be used by system designers and operators in accident prevention; and (c) the relatively short track record of these industries in developing countries. [Most of the petrochemical industries of Eastern Europe were established in late 1960s (Spitz, 1988), and the Middle East's one started in early to mid-1970s; the first ammonia plant in the Persian Gulf was opened in Kuwait in 1966, and by 1980 the Middle East as whole already accounted for about 5% of world ammonia capacity. Also, the first ethane cracker in the Persian Gulf, with a capacity of 280,000 tones and located in Qatar, started up only in 1981 (OECD, 1985, p. 91).] The latter, inevitably, results in lack of experiential knowledge, which according to Rochlin (1989), is highly critical for the operational "success" and safety of complex human-technological systems]. Thus, a practical guide to define good management plans and practices for the construction and design of facilities, and for production, processing, use, and storage of hazardous substance in developing countries is imperative. The following is an outline of such practical guide (adopted form EPA, 1988):

1. Capital project review and design process review should be conducted to analyze all designs for safety problems before they are approved; this can include preliminary hazard assessments as well as pre-start-up safety inspections. Human factors, such as the ease of operating equipment, should be considered in the design of the system.

2. Management must recognize that compliance with standards and codes of industry, associations, and laws of governments is a minimum, and the intent of these standards must be applied on a case-by-case basis. Compliance with standards alone does not secure a safe operation.

3. Process safety information should be documented to provide identification of the hazards, a description of key design data, and technical specification of each step of the path to procedures for a safe operation.

4. Accountability of personnel involved in the operation of the facility should be defined.

5. Risk management should include identification and evaluation of potential hazards using valid hazards evaluation techniques. These must be regularly scheduled hazard evaluations involving key personnel, not weekly or monthly inspections.

6. All process and facility changes should be evaluated for their impact on safety; each process or facility change should be subjected to the same rigorous review as would be applied to a new process. Authorization for change should include new operating procedures, training, and maintenance schedules.

7. Process and equipment integrity should be checked by periodic testing and inspection; this includes quality assurance.

8. Prompt investigation of all serious and potentially serious incidents should determine the cause(s) of the incident. The investigators should make recommendations for corrective actions.

9. Training, including testing and refresher courses, should be provided to all workers.

10. Audits of key elements should be conducted by technically qualified personnel; with deficiencies and corrective actions documented.

11. The facility should have methods to enhance its knowledge of process safety; that is, the facility should have a method to increase knowledge about the processes and equipment.

12. Emergency procedures should be in place to respond to a release and to contact the local community. The facility should also have ongoing programs for communications with the community.

III.2 Process Hazards and Process Safety Management

As concluded by the EPA's (1988) survey, "There is no single method or technology that works best in every situation... The determination of what constitutes a 'state-of-the-art' technology for a particular facility depends on the individual circumstances of the facility -- its location and layout, its process, the chemicals handled, and the hazards associated with the specific chemicals and processes." Notwithstanding, a holistic and *functional* (though, admittedly, as mentioned in the Introduction, may not have the desired thoroughness), risk management framework of an existing petrochemical plant should cover all the operational, procedural, political and organizational practices which are designed to prevent accidents and releases of toxic material. As of today, several attempts have been made by industry and professional groups, international organizations, and organized labor to develop such a functional safety and risk management system. They include:

- *Management of Process Hazard.* Developed by the Production and Refining Departments of the American Petroleum Institute (API, 1990). These guidelines are intended to assist in preventing the occurrence or minimizing the consequences of catastrophic releases of toxic or flammable materials. They are applicable to refineries, petrochemical operations, and major processing facilities. These guidelines address the management of process hazard in design, construction, start-up, operation, inspection, maintenance, and modification of facilities. In order to accomplish its objective, the Management of Process Hazards addresses these eleven areas (or sub-systems): Process Safety Information; Process Hazard Analysis; Management of Change; Operating Procedures; Safe Work Practices; Training; Assurance of the Quality and Mechanical Integrity of Critical Equipment; Pre-Start-Up Safety Review; Emergency Response and Control; Investigation of Process-related Incidents; and Audit of Process Hazard Management Systems (API, 1990, p.1).

- *Process Safety Management (Control of Acute Hazards).* Developed by the Chemical Manufactures Association (CMA, 1985). The purpose of this report was to review and evaluate the systematic approaches to process safety analysis, and to inform the (CMA) membership of the systematic approaches to process safety analysis. It has reviewed and documented, through its survey, industry practices in four areas: management policies toward safety, hazard identification methods, hazard assessment methods, hazards control methods (CMA, 1985, p. 7).

- *Recommendations for Process Hazard Management of Substances with Catastrophic Potential.* Developed by Organizational Resources Counselors, Inc. (ORC, 1988). Its "purpose is to "protect employees by preventing the occurrence, or minimizing the consequences, of catastrophic releases of dangerous substances" (ORC, 1988, p. 1). Its "recommendations comprise a systematic approach to chemical process hazard management which ensures that the means for preventing catastrophic releases, fire, and explosion are understood" (ORC, 1988, p. v). Its developers contend that an adequate and effective process hazard management system must provide for: (a) proactive management of systems that minimize the likelihood of chemical, mechanical, and human failures; (b) construction of multiple lines of defense, or barriers, that are designed to prevent an initiating, or low-level failure from progressing to an uncontrolled, catastrophic event; and (c) means to ensure that the lines of defense, or barriers, which have been constructed, are maintained in a state of readiness.

- *Guidelines for Technical Management of Chemical Process Safety.* Developed by the Center for Chemical Process Safety of the American Institute of Chemical Engineers (1989). It links the safety management systems to process safety engineering and describes how to use management approaches in process safety. According to this document, management systems for chemical process safety are comprehensive sets of policies, procedures, and practices designed to ensure that barriers to major incidents are in place, in use, and effective. The management systems serve to integrate process safety concepts into the ongoing activities of everyone involved in operations -- from the chemical process operator to the chief executive officer. The Chemical Process Safety Management consists of twelve elements: Accountability, Objective and Goals; Process Knowledge and Documentation; Capital Project Review and Design Procedures (for new or existing plants, expansions, and acquisitions); Process Risk Management; Management of Change; Process and Equipment Integrity; Incident Investigation; Training and Performance; Human Factors; Standards, Codes, and Laws; Audits and Corrective Actions; and Enhancement of Process Safety Knowledge. The primary objective of the Technical Management of Chemical Process Safety is "to describe each element of process safety management, explain why is important, and provide information on alternative approaches to the implementation of each element and its components" (p. 6).

- *Major Hazard Control: A Practical Manual.* Developed by the International Labour Office (ILO, 1988). It is a thorough compendium with useful forms, data tables and checklists primarily designed to address the safety aspects of sitting, planning, design, construction and operation of plants. It explains how to identify major hazard installations and describes all the components of a major hazard control system. As its title says, it's a *practical* manual, and as such, for instance, the rather abstract concepts human and organizational errors (p. 15) are treated parochially.

- *Techniques for Assessing Industrial Hazard (A Manual).* Developed by Technica, Ltd. for the World Bank (Second printing, February 1990). This manual and its' Appendix B (*World Bank Guidelines for Identifying, Analyzing and Controlling Major Hazard Installations in Developing Countries*) is developed for use in assessing World Bank and International Finance Corporation (IFC) development proposals, provides guidelines for the identification of the potential hazards of new or existing plants or processes in the chemical and energy installations, and assesses the consequences of the release of toxic, flammable or explosive materials to the atmosphere. The presented guidelines, which are largely based on the European Economic Community Directive of 1982 (EEC, 1982), provide criteria for identifying acutely toxic, flammable, and explosive and reactive hazards, as well as a list of these hazardous chemicals. Threshold quantities are specified that require the developer to undertake a major hazard assessment and to implement measures to control the major hazards, identified in such assessment. As mentioned before, these guidelines were designed primarily "to provide a framework in which a developer can supply evidence and justification for the safe operation of the proposed industrial activity. It is <u>not</u> the objective of these guidelines to provide details of specific methods of analysis, safe, operation procedures, etc." (p. 127) (emphasis by the author). This document places heavy emphasis on reducing or eliminating major hazards and has not adopted hazard and risk analysis techniques. A possible reason and justification for this is offered by Batstone (1985, p. 144), "regardless of the special safety precautions taken in the design of a major hazard plant, the continued safety of the system will depend on human factors such as training, maintenance, supervision accessibility, responses to emergency conditions, etc. They may vary quite substantially from company to company and from country to country." All things considered, this document, despite its robust analytical methods, and because of its main objective and focus -- to cater to the needs of World Bank/IFC (investment), projects evaluations -- has limited practical and field application.

- *Blueprint for Prevention: A Guide to Preventing Chemical Releases*. Developed by the Center for Emergency Response Planning, The Workplace Health Fund (November, 1989). This document is developed to help workers of the (petrochemical plants) gather the needed information and to assist them in their prevention effort. It is a short, well-written document and an effective blueprint which sensitizes and enables the workers to identify major parts and components which could affect occupational health and safety at their plants. This document could very well be integrated into a process safety system which is based on the total systems paradigm and utilizes participative approach to hazard identification and risk management.

IV. MAJOR COMPONENTS OF A RISK MANAGEMENT FRAMEWORK

After a thorough examination of all the foregoing documents by the author, despite their apparent similarities, it was decided that the *Guidelines Technical Management of Chemical Process Safety*, because of its systemic *and* integrative orientation toward all the necessary elements of process safety, is relatively a more appropriate approach for adoption for a preliminary risk management of petrochemical plants in developing countries. It should, however, be noted that neither this document, in its entirety, nor any part of it can be used "as is" (without proper adjustment and fine-tuning) in the context of developing countries (see section VI for further discussion). Thus, the following adoption should only be considered as a provisional risk management framework; until the lingering, important research questions raised by Rasmussen and Batstone (1990) being fully addressed and resolved.

IV.1 Process Risk Management

Process risk management involves the systematic identification, evaluation, and control of potential losses that may arise in existing operating facilities from future events such as fires, explosions, toxic releases, runaway reactions, or natural disasters. The practice of process risk management anticipates the possibility of process safety-related losses and evaluates their potential impacts so they can be managed effectively. Process risk management requires recognition of possible risks, evaluation of the likelihood of hazardous events, the magnitude of their consequences, and determination of appropriate measures for reduction of these risks. Thus, process risk management is a practical instrument that can assist in business decision-making in the face of uncertainty, as well as running the plant.

The core or major components of a process risk management include: (1)- Hazard Identification; (2)- Risk analysis of operations; (3)- Reduction of risk; (4)- Residual risk management; and (5)- Process management during emergencies.

IV.1.1 Hazard Identification. Hazard identification is the process of determining what hazards are associated with a given operation or design, as it is operating. In existing operations, hazard identification is performed periodically to determine the implications of changes to process knowledge, and to recognize changes to processes, procedures, equipment, and materials. The role of hazard identification, in process risk management at existing plants, is to establish the foundation upon which many of the other process safety management components build. Some of the common approaches to hazard identification include (cf., *Guidelines for Hazard Evaluation Procedures*, 1985):

- Checklists -- comparisons against codes, standards, and typical hazards previously identified for well-understood operations;

- "What-if" -- an approach in which a multidisciplinary team generates and addresses a series of "what-if" type questions;

- Hazard and Operability (HazOp) study -- a structured, systematic review conducted to identify all deviations from the design intent that could potentially yield to hazards and/or operability problems. A HazOp study systematically identifies hazards or operability problems for an entire process or facility. The consequences of possible deviations are assessed and potential means for detection and correction are examined;

- Failure mode and effect analysis -- a systematic review of the implications of specific component failures.

VI.1.2 Risk Analysis of Operations. After performing hazard identification in existing operations, the next component in process risk management program is evaluation and interpretation of the hazards. This activity usually entails an evaluation of both the potential consequences of a hazard and its likelihood of occurrence. The goals of such evaluations are to determine the significance of a given hazard, to prioritize the hazard for the most cost-effective application or risk mitigation measures, to help develop risk reduction measures, and to help identify residual risks requiring extra management attention. Risk analysis are sit-specific and should consider and reflect local meteorological conditions and surrounding populations. If they are qualitative, the output of such studies is usually a prioritized, or grouped, listing of hazard scenarios. If they are quantitative, they can be used to produce overall measures of risk, such as risk profiles, risk contours, and/or individual risk levels (cf., *Guidelines for Chemical Process Quantitative Risk Analysis*, 1989).

IV.1.3 Reduction of Risk. Once process risks in ongoing operations have been both identified and evaluated, the acceptability of the risks and the need for risk-reducing must be considered. Some examples of potential risk-reducing measures include increasing operator training, substituting less hazardous materials, reducing inventories, modifying equipment (e.g., to handle temperature or pressure excursions or runaway reactions), upgrading protective systems (such as deluge system), installing additional or improved process control, increasing separation distances, improving and testing, and changing materials of construction.

IV.1.4 Residual Risk Management. The purpose of this component is to manage the risks that remain (i.e., residual risk) after implementation of risk controls. There are always residual risks that need to be dealt with, because risk analysis (either qualitative or quantitative) is based upon a series of assumptions and uncertainties. For example, risk analysis is likely to assume a given plant layout and design as well as certain operating procedures and certain neighboring facilities (and distance from vulnerable locations). The analysis may be based on a current understanding of chemical hazards (e.g., toxicity, reactivity) and hazard modelling methodologies, both of which are evolving.

IV.1.5 Process Management During Emergencies. The purpose of this component is to control all relevant processes, such that consequences are minimized. There are two parts to this component: (1) management of the particular process that had experienced the emergency incident; and (2) management of other processes that interact with, or are near to, that particular process. Implementation of emergency process management programs require more that just staff preparedness. Early detection and on-line assessment of an impending emergency can contribute to successful control and mitigation. Process control systems should be designed to provide rapid feedback of key information on the cause of each emergency, and operators should be knowledgeable and trained in emergency response procedures. Appropriate shutdown switches or kill buttons should be provided. In automated and computer-controlled processes, emergency shutdown sequences should be programmed-in; notwithstanding, operators should also know and be allowed to by-pass the computer and take-over the control the system, should the computer fail or whenever deemed needed.

IV.2 Risk Management and Prevention Program (RMPP)

Another useful guide for risk management of petrochemical plants is the RMPP. An RMPP is the sum total of programs for minimizing acutely hazardous material (AHM) incident risks. This can include, but it is not limited to [adopted from the *Risk Management and Prevention Program (RMPP) Guide*, 1989]:

1- Systems' safety review of design for new and existing equipment;

2- Safety evaluation of standard operating procedures;

3- System review for reliability;

4- Preventive maintenance procedures;

5- Risk assessment for failure of specific pieces of equipment or operating alternatives;

6- Emergency response planning;

7- Analyses of organizational structure, feedback system, training, supervisory styles, etc.; and

8- Internal or external auditing procedures to that ensure safety programs and safety engineering controls are being executed as planned.

IV.3 A Sample of the Questions Which Should be Addressed by the Risk Management Framework

The following are the types of questions that should be addressed by the holistic risk management framework in a petrochemical plant (adopted from the *Blueprint for Prevention: A Guide to Preventing Chemical Releases*, 1989):

- Is there a system in place at the plant that ensures an open line of communication between management and workers on safety concerns?

- What are the built-in and active risk reduction systems in place at the plant? How do workers find out about them?

- Are all risk reduction systems completely operational? How do workers know about them?

- Are risk reduction procedures reviewed and updated periodically? Are they written? Are they possible to execute? Are these procedures bypassed when production schedules are tight?

- Is there a mechanism to study previous near misses or incidents in the plant or other similarly designed, so that similar occurrences may be avoided?

- Has the plant done hazard identification and risk assessment survey?

- What are the worse-case scenarios at the plant? What are the prevention strategies? What are mitigation policies?

Thus, for the existing petrochemical plants, the risk management framework should highlight the need for a total change of the complacent philosophy and attitude of 'business as usual,' that only avoids and, if lucky, defers confronting the problems. Also, it should emphasize the replacement the dangerous axiom of *if it ain't broke yet, then don't fix it* with *if it ain't broke yet, (it may), don't wait -- fix it*.

For the future and to-be-designed petrochemical plants, a holistic risk management framework should be based on a *total* system design approach. From the beginning and the inception of the plan, there should be ***equal*** and ***adequate*** consideration given to all of the petrochemical system's components (i.e., human, organizational, and technological). In doing so, the need for a proactive and totally integrated approach to the design, construction, staffing, and operation of these systems should be highlighted. Also, this approach should facilitate and enforce the interaction and inter-disciplinary dialogue among all the decision-makers -- investors, engineers, managers. This is particularly important for developing countries where, according to Otway (1988, p. 13), "industrial risk is more intimately linked to standards of living that it is in industrialized countries," and legislation on risk communication are not fully developed or enforced, yet.

V. A CAUTIONARY NOTE ON RISK ASSESSMENT

A key component and a major building block of any risk management program, as mentioned above, is risk assessment. As such, it deserves special attention.

The typical accident in a complex, large-scale installation such as petrochemical plants is often not caused by only one simple equipment fault or human error. On the contrary, major events will depend on a complex chain of events including equipment failure, latent risky conditions from repair and modifications as well as human mistakes and decision errors. Analytical risk assessment depends upon the assumption that these individual events occur frequently enough to allow empirical fault rates to be collected. At present, however, the collection of human error data suffers from some methodological problems, empirical data are scarce and analysis has to be based on estimates and special assumptions (Rasmussen, 1981). The availability and reliability of human error data for developing countries' operator populations is even more methodologically problematic. Attesting is Barreto Vinna's (1988a) evaluation of availability of such data in Brazil -- "very scarce" (p.3).

Moreover, the result of a Probabilistic Risk Analysis (PRA) is a calculated risk figure which, if accepted, covers the 'accepted risk'. If not accepted, the design of the plant has to be modified until acceptance has been achieved. Owing to incompleteness and errors during the PRA, however, an 'additional risk' may exist, which is not included in the acceptance risk. Contribution to, or a plausible cause for this additional risk can also arise from the fact that the real plant and its operation may depart from the PRA preconditions because of many factors including, but not limited to: (a) components used do not belong to the populations providing the PRA failure data;

(b) the real plant does not correspond with the models of the plant used for the PRA; (c) the real plant is not operated and maintained according to the assumptions made in PRA (Rasmussen, 1984). After the calculated risk is accepted, the PRA assumptions, methods and data should be used as requirements an references for construction, modification and operation during the lifetime of the plant, i.e., as references for the risk management functions. Risk management, in turn, should employ effective measures to make sure that the plant is kept in agreement with these references. A sample of these control mechanisms include: quality control, functional test and inspections, training of operators, operational procedures, etc. However, due to the inherent limitations of the present PRA methods (Freeman, 1989; Pate-Cornell and Boykin, 1987), and consequently the lack of its full adoption by risk management programs (Brown and Reeves, 1988) the foregoing role and functions have not yet being fully developed.

VI. NEEDS FOR FURTHER RESEARCH

As mentioned in the Introduction, because of certain inherent limitations of the existing, present field of risk management, basic research is highly needed (cf., Rasmussen and Batsone, 1990). Moreover, a holistic risk management of petrochemical plants in developing countries, in addition to the aforementioned considerations, should take into account the specific characteristics and needs of these countries. These include developing countries' operator populations' needs, capabilities and limitations. It should also cover, for instance, physical and psychological characteristics, and cultural and religious norms (cf., Meshkati, 1989c & d). It is proposed that the following (additional) factors, which need further research, also be incorporated in the risk management framework:

1- Considering local user population's attributes -- e.g., anthropometric and perceptual characteristics, psychomotor skills, and mental models which affect task performance, error, and determination of efficient human workstation interaction. This ought to include close examination of human operators' physical and psychological needs, capabilities and limitations in the contexts of the plant's normal and emergency operation. It should also be coupled with thorough analyses of critical workstations and their design features; job demands (during normal as well as emergency situations);

2- Considering physical environmental conditions affecting operators' safety and performance -- e.g., adjusting ventilation requirements based on the installation site's down-draft wind, heat exchange characteristics, and climatical conditions;

3- Considering the effects of cultural and religious variables -- e.g., adopting separate production schedules and adjusting shift duration for the holy month of Ramadan due to dawn to dusk fasting, for the production facilities operating in Islamic countries (see also Rasmussen, 1989b; Barreto Vianna, 1988a &b).

4- Considering appropriated organizational structures; employing more adaptive managerial and organizational factors -- e.g., deciding the rigidity and flatness of the organizational structure; and

5- Considering the optimum span of control; designing feedback mechanisms; and determining the proper supervisory style based upon the identification of local operators' background, understanding, expectations, and tolerance for uncertainty.

Additionally, the are certain issues which also affect risk and safety of petrochemical plants in developing countries. Some of the following issues deal directly with safety and risk associated with petrochemical plants in developing countries, with spill-over effect on the ecological environment in these countries; and some deal directly with environmental impact of these plants:

6- People's perceptions of technologies and risk, according to Otway and von Winterfeldt (1982), depend on: the information to which people have been exposed, the information they have chosen to believe, the values they hold (including the religious and ideological beliefs), the social experiences to which they have had access, the dynamics of stakeholder groups, the vagaries of their political process, and the historical context in which all of the aforementioned have taken place. The perception of the risk of a given technology is also (positively) influenced by, among other things, whether the technology: increases the standard of living, creates new jobs, enhances national prestige, and/or creates greater independence from foreign suppliers.

A common source of people's erroneous decisions or judgments is the *Availability* Heuristic (or bias) (Kahneman, Slovic and Tversky, 1982). Availability occurs when people judge the likelihood of something happening by how easily they can call other examples of the same thing to mind. By employing this concept, Spettel and Liebert (1986) studied operators' judgment in complex person-machine systems. They suggested that the Availability Heuristic "may lead operators to begin the task of interpreting abnormal readings by considering the most obvious or vivid possibilities, whereas less salient interpretations may not even be considered... Thus, the manner and sequence in which possible interpretations of the causes of deviant readings are generated and evaluated may lead both to incorrect diagnoses and to inaccurate assessment of risk" (p. 546).

As mentioned before, the intuition level of operators influences their attribution of causes of error and risk perception. Needless to say, people with fatalistic orientations have a different Availability Heuristic and intuition level. It is critical to understand people's orientation toward errors, their Availability Heuristic, intuition level, and risk perception. All these become even more critical in the context of developing countries, where advanced technology, in general and petrochemical plants in particular, have illustrious and glamorous images. By virtue of simply being an 'advanced' technology, there comes the conviction of and an over-reliance on its (imaginary) 'flawless' performance. In some Third World countries, when the system is functioning normally, its operators may become less vigilant, more complacent, and over-confident of the system's 'defense-in-depth' mechanisms, than their counterparts in developed countries. Once there occurs an incident of system abnormally, the operators may shift to a state of fatalistic passivity, panic or total withdrawal.

7- Developing countries are also subject to natural hazards, such as earthquakes and hurricanes, likewise developed countries. However, their level of preparedness and mitigation plans are not quite as advanced as developed countries. Thus, natural hazards in developing countries exacerbate the vulnerability of their petrochemical plants, and if not mitigated, activates a chain reaction which could result in a man-made hazard. [e.g., chemical release, or, "toxic spill" according to the *Network of Earthquake-Related Events* model (Petak and Atkisson, 1982)]. After all, earthquakes not only stem from "the restless earth," but according to Perrow (1984, p. 233) (their damages) stem from "restless humans who think on a small scale in an ecology that is large scale."

8- As suggested by UNIDO (1985) and referred to in the Introduction section, to avoid adverse effects on public health and the environment, in developing countries, due to petrochemical plants, adequate pollution control regulations must be promulgated. Such regulations should require the evaluation of possible environmental impacts and public health effects of the construction and operations of petrochemical plants, and require measures to mitigate adverse effects. Moreover, to assess possible environmental impacts, "a survey must be conducted of existing environmental conditions at the proposed plant site. A survey of the wastes generated at a plant should also be conducted. These surveys should include a characterization of the volume of waste generated, the rate of flow of the wastes, and the physical, chemical, and biological properties of the generated waste" (UNIDO, 1985, p. 105).

VII. CONCLUDING REMARKS AND IMMEDIATE PLAN OF ACTION

The longer we wait for the petrochemical industries in developing countries to realize the importance of risk management and take action, or for the scholarly community to come to a consensus and establish scientific certainty as to how to handle and what to do with the safety of these plants, the greater the risk of disasters these countries will have to face. Any delay, due to the lack of enough scientific breakthroughs, would only compound the complexity of this problem and exacerbate an already long over-due process. As noted by the renowned scientist, Dr. Stephen Schneider (1988) of the U.S. National Center for Atmospheric Research, in the context of an equally disastrous situation, the Greenhouse Effect, "platitudes about scientific uncertainty have for too long been used as an excuse to avoid action" (p. 30). Thus, in order to avoid risky inaction, it is suggested that, until a comprehensive risk management plan be fully developed and for the time being, an optimal mix or combination of the aforementioned methods, covered in the section III.2 (Process Hazards and Process Safety Management) be developed and used; even only as a strawman, *per se*. This approach would take advantage of the synergistic effect of these already researched and implemented works. Should such a product be developed, of course, it must be fine-tuned and adjusted to the specific needs of developing countries.

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