
Great Lakes Science Advisory Board. Technological Committee

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Spills: The Human-Machine Interface

Proceedings of the Workshops on Human Machine Interface
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This report to the Science Advisory Board was carried out as part of the activities of the Technological Committee. Although the Board supported this work, the specific conclusions and/or recommendations do not necessarily represent the views of the International Joint Commission, the Science Advisory Board or its other committees.
# Table of Contents

1. **EXECUTIVE SUMMARY**  
2. **INTRODUCTION**  
   
   *Definition of Human–Machine Interface.*  
   *Placing the Definition in a Great Lakes Context.*  
3. **DESCRIPTION OF THE WORKSHOPS**  
   3.1 The First Workshop: Laying the Foundation  
   *The selection of invitees and a review of their findings*  
   3.2 The Second Workshop: Focus on Great Lakes Spills  
   *Narrowing the focus; selection of a focal topic (spills) and of participants; determination of a structure; the definition of four subject areas (people, technology, scope and program); a review of the workgroups and the workshop.*  
4. **FINDINGS AND RECOMMENDATIONS OF THE WORKGROUPS**  
   4.1 People  
   4.2 Technology  
   4.3 Scope  
   4.4 Program  
   4.5 Other  
5. **THE PEOPLE FACTOR: LESSONS LEARNED FROM AVIATION,** *by Guice Tinsley, U.S. Department of Transportation, Washington, DC*  
8. **PROGRAM: WORKING PAPER,** *by Wayne Bissett, Chemical Industries, Conservation and Protection Service, Environment Canada and Leo Weaver, Environmental Engineering Consultant, Cincinnati, Ohio*  

**APPENDIX:**  
Human–Machine Workshops – List of Participants
EXECUTIVE SUMMARY

INTRODUCTION

1. Definition of Problem and Scope of Investigation
   
2. Objective of Project
   
3. The Project's Activity Centers
   
4. Description of the Workshops

5. The Project's Activities

6. The Project's Interests

7. The Project's Interactions

PHYSICS AND MECHANICS OF THE WORKSHOP

THE PROBLEM OF Electromagnetic Induction in Ferroelectric

TECHNOLOGY AND THE RATIONALE OF ELECTRIC ENERGY

A FEASIBILITY EXAMINATION OF THE EFFECT OF

EXTRAORDINARY POLICY-MAKING MEASURES ON THE CHINESE ECONOMY

PROGRAM WORKSHOP

REFERENCES

APPENDIX

INDEX
1.0 EXECUTIVE SUMMARY

Manufacturing and related urban growth processes in the Great Lakes basin have resulted in an estimated 3,000 significant spills of toxic contaminants annually. Many of these spills contribute significantly to the toxic burden in the Great Lakes basin and there exists the potential for a catastrophic accident that might do permanent damage to one of the lakes. Spills are often caused by a breakdown in the complex relationships between humans and machines.

Two workshops were attended by experts in a diversity of related fields to assess concerns at the human—machine interface. The workshop members discussed sources and circumstances of accidental releases, jurisdictional responses, technological and human considerations.

The workshop participants recommended improvements in data reporting, analysis, programs and legislation and determined that special attention should be given to communications, training, education and nuclear facilities. They recommended a code of practice for prevention of spills and a specific research program.

THE WORKSHOPS

The first Human—Machine Workshop attracted participants from a wide variety of occupations: the design and operation of nuclear power plants, associated nuclear control agencies, government agencies concerned with labour and the environment, air traffic safety, the petrochemical industry and the academic community. Nearly all were knowledgeable about or expert in the human factors field.

The first workshop forwarded a number of preliminary findings to the Science Advisory Board, including identification of the following needs:

- Inclusion of human design factors in the earliest stages of facility planning.
- Better education and training of those charged with operating the facilities.
- More comprehensive reporting and data collection from incidents involving failure at the human—machine interface.
- The need for regulatory agencies to encourage more effective self-regulation, with appropriate safeguards and penalties.

The second workshop built on the preliminary findings of the first and augmented a core of participants from the first workshop with further expertise from the nuclear utilities sector, sewage treatment plant operations, labour and academic community.

In preparation for the second workshop, four working papers were commissioned. The first of these, entitled SCOPE, attempted to estimate the impacts of spills or accidental releases of contaminants in the Great Lakes basin from various sources. The second, PROGRAM, reviewed the current and possible jurisdictional responses to such releases. The third and fourth, TECHNOLOGY and PEOPLE, tried to determine how elements of these two areas influence the occurrence of accidental releases.
FINDINGS

- Spills can have a much greater impact than point source discharges.

There is a common misconception that the impact of spills, although a nuisance, does not compare over the long-term with ongoing point source discharges. The Canadian National Analysis of Trends in Emergencies System (NATES) database reveals a unique example involving styrene spills into the St. Clair River; two spills were found to be equivalent to the pollution loadings of 1,428 and 58 years of the respective point source discharges. The comparison indicates that accidental releases may significantly exceed the impact of regulated point source discharges.

- Data bases on spills are inadequate.

Existing databases on spills from basin jurisdictions are incomplete and inconsistent with respect to the data reported. Furthermore, they demonstrate a lack of liaison among jurisdictions. Currently there is no precisely defined spill inventory for the Great Lakes basin. In addition, information related to human factors, if present at all in existing records, is usually not sufficiently definitive for an analysis to identify preventive actions.

Several of the U.S. databases, particularly those maintained by the National Response Center (NRC) and the Hazardous Material Information System, are inflexible and not amenable to the access and integration of data nor for the transfer of information to the public. The Canadian federal system is of a more sound design; however, a need to enter current spill data from the Province of Ontario into the federal database was identified.

- Programs designed to prevent spills are inadequate or nonexistent.

Any comprehensive effort designed to prevent accidental releases, particularly of toxic substances, will require: inventories of hazardous and toxic substances and their movements; research to analyze a range of questions from total systems approaches to human factors; education and training for a wide range of responsibilities in the field as well as technological fixes; and, legislation requiring prevention, reporting, program coordination and right-to-know. There is a modicum of such program elements among the jurisdictions in the Great Lakes basin but what exists is inadequate for the task and lacks effective coordination.

The significance of spills remains difficult to determine because the term has not been clearly defined. A common definition and a common approach are needed within the Great Lakes basin.

- Accidents or incidents arising from human errors are not adequately addressed.

Human errors frequently arise from faulty human-machine interface design: instructions can be difficult to read, machinery can be difficult to use, controls can be inappropriate, workers can become inattentive, there can be inadequate supervision or training, automation or high technology can be inappropriately used or the allocations of functions between humans and machines can be inappropriate.

- Social values play an important role.

As explained by a United State Congressional leader in 1985, the public perceives a serious problem if there are 150 fatalities per year for air carriers, but exhibits little concern if there are 50,000 fatalities per year on highways. This attitude reflects a
difference in values. Although data on spills are sketchy, there appears to be approximately 3,000 significant accidental releases of hazardous substances per year in the Great Lakes basin provinces and states. More attention must be given to the ways in which a society, through its institutions and values influences attitudes and conceptualizes science, technology and human life. The values that are held by people and governments regarding spills will significantly affect the degree of success achieved in addressing the deleterious impact of such releases.

RECOMMENDATIONS

All participants in the Human–Machine Workshops recommend that the International Joint Commission:

1. Data Reporting and Analysis
   - Urge the adoption of a uniform reporting format by all jurisdictions and offer to coordinate efforts to achieve such a format.
   - Work with all appropriate jurisdictions to develop and use a uniform definition of a spill for reporting purposes.
   - Monitor and report on the quantities, trends and causes of spills in greater detail in reports on water quality, including advocating adequate reporting of human factors data.
   - Promote the compilation of an inventory of all hazardous materials, including hazardous wastes, in the basin. Such an inventory should include the production, use and disposal of radioactive material and the associated transportation activities.

2. Program and Legislative Initiatives
   - Encourage a consideration of the question of responsibility and liability in the event of disasters involving hazardous substances.
   - Encourage national and international emergency prevention plans that would obligate Great Lakes jurisdictions to provide resources and guidance to local communities. This would allow appropriate authorities to take the lead in planning and executing emergency responses and in developing plans that: a) prevent or minimize the risk of spills; b) are proactive as well as reactive; and, c) collect, using established or common procedures, comparable data with respect to spills, hazard identification and response protocols.

3. Fostering of Legislation
   - Define or at least outline the essential elements of acceptable right-to-know legislation and advocate that all Great Lakes states and provinces enact comparable legislation. Such legislation should include, as a minimum, hazardous substance identification, quantities, locations and chemical forms and modes of human health impact.
   - Encourage the development of legislation to allow the worker or operator to refuse to execute nonroutine tasks that could result in the discharge of a deleterious substance into the environment.
Encourage the appropriate jurisdictions to impose a statutory duty to report all spills meeting an agreed basinwide definition (in some jurisdictions legislation such as is proposed above has already been enacted or is under consideration).

4. **Special Attention Directed to Nuclear Facilities**

   - Given the prevalence of nuclear power generating facilities and related activities in the basin, consider reestablishing the Committee on Radioactivity to monitor developments in this sector.

5. **Training, Education and Communication**

   - Ensure that various concepts of risk and methods of risk assessment be debated publicly. The Commission, by advocating a public component to risk assessment, could ensure that all risk discussions consider societal as well as individual risks. The combined risk of human and animal exposure by means of air, skin, food and drinking water sources would thus be considered.

   - Promote the development of a uniform basinwide or North American pollution hazard information system for use on warnings, labels, placards, displays and material safety data sheets. For easy and effective recognition, such warnings should be nonverbal.

   - Advocate a total systems approach, including special attention to human factors engineering, in the education of professionals both early in the design of new systems or equipment and in the retrofit of older systems or equipment.

   - Promote development of a formal communication system directed at all potential polluters to assure that guidance information on human error, prevention, human factors design criteria and technology transfer would be considered on a timely basis.

   - Encourage the jurisdictions to engage in public education programs related to the reporting and prevention of accidental releases. The public should be further educated on the impact on the environment of inappropriate personal waste disposal habits. Simultaneously, viable options for the disposal of hazardous goods or household products should be presented.

   - Urge that there be a provision for confidentiality where appropriate, particularly in the investigation of a narrowly averted spill or near accident. The focus should be on prevention rather than remediation.

6. **Code of Practice for Prevention of Spills**

   - Promote a Code of Practice for the prevention of spills in basin facilities containing the following elements:

     - Senior management or its equivalent must set standards for the organization and must repeatedly reflect a commitment to those standards. The evolution of a corporate ethic is crucial to an
effective pollution control and prevention program. Knowledge crucial to pollution prevention and control should be shared freely within the organization.

- Every attempt should be made to include the operators in the design of equipment and facilities.

- Training should encompass not only how a machine works from an operator's perspective, but also how people interact with the machine. The importance of the operator should be recognized and acknowledged through job enrichment and a diversity of challenges. Training should be enhanced to communicate broader pollution concerns, including the legal restrictions and their rationale, and the collective consequences of individual actions.

7. Research Initiatives

- Encourage the use of a total systems approach, including human factors and socio-technical considerations, with respect to Great Lakes pollution problems.

- Sponsor or advocate research on selected pollution incidents, using specialists in human factors and socio-technical systems to determine causal factors in pollution discharges.

- Study human factors data gleaned from upgraded databases and initiate research on preventive measures and the development of specific human factors design criteria. These criteria can be applied to pollution alarms, pollution monitoring systems annunciators and other instrumentation to ensure that releases of pollution are controlled at the source.

- Sponsor or recommend studies to ensure that new technology is implemented only after a deliberate and effective allocation of functions to both humans and machines. Appropriate information about the system and cognitive support, in a form intelligible to the user, should be included in the design.

- Recommend and support research to determine the relative contribution of accidental releases to the total pollution of the Great Lakes basin.

On the basis of the findings and conclusions formulated in connection with the Human–Machine Workshops and considering both long-term cumulative effects and the potential disasters, the workshop participants and the Science Advisory Board concluded that spills may, in some cases, have a greater impact on the Great Lakes than the cumulation of all point source discharges. It concludes further that data on spills and programs designed to prevent spills are inadequate or nonexistent. Also, the contribution of human error to spill incidents is not adequately addressed and that the lack of social perception of the importance of the problem is reflected in the inadequacy of current preventive and remedial efforts.

In summary, the workshop participants and the Science Advisory Board recommend that:
The Commission urges the Parties to adopt a uniform and comprehensive reporting system for the spills of hazardous substances and hazardous wastes, and should offer to coordinate the attainment of such a system.

The Water Quality Board monitor and report in greater detail on the quantities, trends and causes of spills.

A methodology to evaluate the ecosystemic effects of spills be developed by the Science Advisory Board's Ecological Committee.

The Commission investigates the issues of responsibility and liability in the event of a disaster resulting from a major spill in the Great Lakes Basin Ecosystem, in accordance with Annex 9 of the Water Quality Agreement. The Commission should ensure that there is a unified international emergency prevention plan that encourages Great Lakes jurisdictions to establish a clear delineation of responsibility and provides resources and guidance to local communities, thus minimizing the risk and impacts of spills.

The Commission encourages the adoption of right-to-know and right-of-refusal legislation in jurisdictions throughout the basin. The Commission also encourages research and the reporting and prevention of spills and research, communication and training in systems and human factors engineering, risk analysis, pollution hazard information systems and the appropriate uses of automation.

The Commission promotes the development of a corporate ethic with respect to the ecosystem and associated codes of practice for persons involved in the design of technical systems, operator training, human motivation and interaction in work situations.
2.0 INTRODUCTION

The Great Lakes are an enormous and fragile resource. Together, the Great Lakes and the St. Lawrence River form the largest surface expanse of fresh water in the world. With its 9,400 miles of coastline, the basin is home to 45–million Americans and Canadians; 24–million draw their drinking water from the lakes. The volume and associated retention time of the lakes ensure that persistent contaminants can linger in individual lakes for periods from seven to 500 years. Hundreds of millions of tonnes of materials, whose release would have a deterrent impact on the environment, are stored and transported by various means in the basin.

The infrastructure of the Great Lakes basin contains a diversity of old and new technology in manufacturing, the generation of power, transportation and waste management.

For the past several years, led by Walter Lyon, board member and former Water Pollution Control Administrator of Pennsylvania, the Science Advisory Board has been considering the impact of errors at the human–machine interface on the contamination of the Great Lakes. Among the studies that piqued interest in this topic was an EPA review of the operation of newly constructed sewage treatment plants. The review indicated that poor staff training and by implication, design, had resulted in performance of these plants being significantly below that which should have been achieved. It was clear that, for those plants studied, the expenditure of many millions of dollars had not reduced contamination of the waterways to the extent it should have; full value for the public dollar had not been achieved.

A superficial review of this phenomenon might suggest that the source of the difficulty was the frontline plant operators and recommend a wholesale review of their performance and dismissal as appropriate. However, setting aside the infeasibility of such a solution in many of the affected facilities, a more careful consideration of the problem could indicate that the responsibility for failure to achieve the defined goals falls on a much wider population. Was the design of the plant as clear, concise and comprehensible as possible, given the task? Was the background, knowledge, aptitude and attitude of those who would work with this equipment considered from the first stages of design? Were any representatives of the work force involved in the design? Were procedures and manuals designed with the work force in mind? Was training in the principles of sewage treatment offered to the staff? Were provisions made to keep the operators continually interacting with the system, rather than responding only to aberrant behavior or emergencies?

As those questions should illustrate, a breakdown at the human–machine interface that has a deleterious impact on the environment should very rarely be viewed as the failure of one individual at the lower or lowest echelon of the chain of responsibility. Rather, in these workshops, failure at this interface will be considered as a systemic breakdown whose roots may have been laid in the earliest stages of system design and may thread up to the highest levels of the responsible organization. The human–machine interface, far from being considered as the interaction of one person and one device with one impact (one man, one valve, one pollution incident) is more frequently concerned with the interaction between the entire technical process and the entire responsible human hierarchy.

These two workshops drew together experts in the area of human factors and socio–technical interfaces with individuals from the nuclear regulatory, occupational health and environmental quality agencies, labour unions, public interest groups, sewage treatment plant operations, and representatives of the Science Advisory Board.
The first one-day workshop, held on April 14, 1986, defined the general areas of interest, including design considerations, operations and training considerations and the role of the regulatory agency and arrived at a number of generic findings.

Building on the output of the first workshop, the second workshop focused on a particular aspect of pollution of the Great Lakes that traditionally has been largely associated with human error; the extraordinary discharge or accidental release of pollutants within the basin. In preparation for this second workshop, four working papers addressing four aspects of the human—machine issue, People, Technology, Scope and Programs, were drafted by selected participants in this second event. This workshop, held over one and one-half days on March 17 and 18 of 1987, gave rise to a number of specific recommendations regarding spill accounting and management practices in the basin.
3.0 DESCRIPTION OF THE WORKSHOPS

3.1 THE FIRST WORKSHOP: LAYING THE FOUNDATION

The first workshop was held over one day (April 14, 1985) at the offices of the International Joint Commission (IJC) in Windsor, Ontario. It attracted academic and corporate experts in the area of human behavior/human factors, with a particular emphasis on the nuclear power generation field, as well as administrators from the petrochemical industry and the environmental and occupational health agencies. A complete listing of participants and their affiliated organizations is attached to this report.

After an introduction to the workings of the IJC in the Great Lakes basin, the participants highlighted what they considered to be the relevant and essential items they had learned in their experience with the human factor. The ensuing discussion can be summarized under the following topics.

a. Design Considerations

There was common agreement that, in the construction of many facilities, human factor design, if considered at all, is often treated as an afterthought or an appended item. A dramatic example was cited to illustrate this: a maintenance worker routinely cleaned and reassembled a valve every few days on an oil-drilling platform in the North Sea. One day, after cleaning, he replaced the valve in a reversed position. The resulting petroleum leak was ignited and damage amounting to several million dollars resulted. In the final analysis, the fault was determined not to be with the maintenance worker who had performed the task well, numerous times, but with the design engineer who had failed to create a design that would make such a reversal impossible.

In considering the deployment of human factors personnel, their placement in a number of groups working directly on the design was considered superior to their isolation in a human factors group serving as consultants to other units. In the former situation, human factor considerations would be incorporated into a number of areas from the outset and both the human factor and other personnel would be encouraged to continually consider it in the construction and operation of the unit. The use of human-reliability data was considered appropriate as long as it would be treated as indicative and inexact.

b. Operations and Training Considerations

There was a consensus of the need for better training, education, monitoring and data collection. All too often, organizations succumb to the belief that anyone can learn to do anything, frequently by allowing training on the job. Although such training methods frequently offer insights into how the task is actually performed, they can unnecessarily elevate the level of risk of procedural failure. A proper amount of training with the assistance of a clear and concise manual, prepared in cooperation with its users and the input of experienced personnel who have demonstrated teaching skills, was advocated as much more effective.

It was recognized that formal educational requirements should match the demands of a given position. If a high level of education and intelligence were to be prerequisites for a given position, there would be a responsibility
to continually involve the individual in that position in the broader aspects of his work. A need for the inclusion of human factors as part of the scientific and engineering education at the university level was also identified.

Incident reporting and data collection were considered essential for the development of a database for the accurate assessment of risk and the adequacy of safeguards. Feedback should occur in a positive environment and operators should be offered anonymity to encourage responses. Data should be collected on both the accidents and incidents that could have had significant repercussions. It was considered important to review the data collection methodology to ensure that, while remaining comprehensible to the individuals being questioned, the information collected would be relevant for as many applications as practical. These applications include procedural corrections, design modifications, identification of significant (and insignificant) factors. The need for adequate inventory and loss record keeping was also noted.

Feedback should be accompanied by appropriate task analysis. Such task analysis, while reducing the risk associated with an operation, also frequently may yield significant reductions in cost.

In discussing the encouragement of feedback, the need to implant a proper attitude within an organization was emphasized. The success of the Smokey the Bear campaign in affecting such an attitude shift was noted as was the relative failure of campaigns associated with the voluntary use of seatbelts. A need to recognize cultural differences, even within states and provinces, was also noted. It was considered crucial that the message and the priority shift among the public for control programs be endorsed and disseminated from the upper echelon or pinnacle of an organization. The link among lax operations, poor maintenance, poor public relations, elevated risks and increased incidents has been demonstrated again and again.

c. The Role of the Regulatory Agency

The workshop attendees were of the opinion that jurisdictions should foster an environment where the regulated can respond positively. The objective should be to encourage self-regulation, with the threat of significant financial loss in case of failure. Public involvement would be an important part of any regulatory activity. The regulatory method should be clearly explained to the public so that they have some grasp of the goals and techniques being used by the agencies to control facilities of concern.

Regulatory bodies should also consider when it is appropriate to do research, when to regulate and when to take no further action. In establishing regulations, often it would be best to leave the selection of precise control methods to those regulated. However, the regulatory body should set tolerance levels and allowable frequencies of excursion from control. The goals of any regulation should be clarified among the regulated community to the extent possible before enactment.

The current development of a decision framework for toxic chemical management for the Quebec government was also reviewed. In Canada, it was noted that there are 70 agencies with an interest in toxic chemicals. Thus it would be necessary to identify all the significant factors and participants as well as postulate their responses to any particular initiative. It is important as well to distinguish between those with a technical interest in the regulatory development and those with a nontechnical interest.
d. Preliminary Findings

In the course of one day, the participants had only an opportunity to define a common approach to the topic of interest, advance some general findings that could have a bearing on the control of Great Lakes contamination and further narrow the focus of any future activities. Further development of the topic, accompanied by additional interaction with the industrial and municipal sectors of the Great Lakes community to ensure that findings of any future workshops could be considered for implementation, was recommended. However, the following generic recommendations were extracted from the summary of the workshop.

i. The need for further training and sensitization of those who have the potential to accidently contaminate the Great Lakes should be reviewed. Training is used in a comprehensive sense to mean a thorough grounding in the specifics of a particular activity, as well as a communication of the broader impacts of such activity. Individuals with experience in human factors' studies should be involved in such training to ensure that it is effective and adapted to the actual execution of the task.

ii. Incident prevention is most effective when it is endorsed actively by the highest level in an organization. There often is a need for task analysis and technology transfer in the area of human factors in organizations that have the potential to pollute the lakes.

iii. There is a need to develop an enhanced database of information on pollution incidents including both those having a significant impact and those that had the potential for significant impact in the basin. Such a database would assist in the setting of priorities for future preventative efforts.

The methodologies for collecting this information should be reviewed to ensure that the responses are of use to the widest range of persons within the organization – human factor specialists, design engineers, environmental control personnel, production supervisors, senior management, etc. A no-fault system of reporting often engenders the best response. Hazard audits prior to incidents may distinguish between minor and major hazards and can be an effective part of such a database development. Enhanced data on the amount of material losses associated with process and storage should be a part of this effort.

iv. Those organizations with effective internal communications, maintenance and planning mechanisms and a conducive work environment also frequently have an excellent safety record. It is likely that the same relationship could be demonstrated with regard to good environmental stewardship.

v. Regulators should devote more effort to human factors in engineering design and reviewing the appropriateness of regulations that mandate and thus restrict the application of technology.

3.2 THE SECOND WORKSHOP: FOCUS ON GREAT LAKES SPILLS

Following a review of the discussion of the first workshop, the Science Advisory Board agreed to sponsor a second Human-Machine Workshop, which would
place issues raised at the first workshop in a Great Lakes context and develop specific recommendations for the consideration of the Board.

a. The Goal

The goal of the IJC Human–Machine Interface effort remained the assessment and recommendation of steps to the jurisdictions to document and overcome difficulties or breakdowns at the human–machine interface, difficulties that could result in serious or catastrophic adverse effects on the Great Lakes ecosystem. It was determined that this goal could be best achieved through consideration of a particular concern and the impact of extraordinary discharges, including spills, was selected for this purpose.

b. Objectives

The objectives of the second workshop were to develop and rank topics in need of further attention in the Great Lakes basin, using the following categories and the example of extraordinary discharges as a framework. The categories were developed based on discussions at the first workshop and the preparation of working papers for the second workshop was assigned to selected participants. These papers were circulated to the participants in advance of the Workshop to allow them an opportunity to prepare their thoughts prior to the event and thus enhance the level of the discussion. The authors were provided with the following guidance in the preparation of their papers.

i. People

° Screening. The selection of appropriate personnel for positions associated with technology using criteria such as education, prior training, experience and written or oral testing or both. The use of human factors expertise in the selection process.

° Training. How are new employees trained; what tools and methods are conducive to effective training, including the design of manuals and interaction with experienced personnel; how can effective incentives for improved skills, abilities and vigilance be put in place; how can high-seniority employees be best retrained to work with new technology; and what can be done if the aptitude of the senior employee does not match well with the technology? Where government licensing is a requirement, how effective are the licensing programs; and do the licensing authorities have adequate mechanisms in place to regulate continuing practices of the licensee, such as the length of working shifts for truck drivers and commercial pilots?

° Management. How are signs of stress, instability, drug dependence (including alcohol) best detected and managed; how are effective lines of communication established; how is job performance best assessed; how is the boredom and inattention often associated with routine tasks combatted; and how is a sense of responsibility and stewardship best communicated?

ii. Technology

The essential question to be examined is how can technology be designed to effectively anticipate and prevent a breakdown at the human–machine interface and ensure the continuing proper functioning
of the technology. Points to be considered include: human interaction with technology; display of data (e.g. the limits to the amount of visually-presented data that can be absorbed by humans); type of control (incorporation of manual control or feel); accommodation of the differences in computer-based decision-making and human-thought processes; the extent to which the controller should understand the functioning of the technology; the need to involve the human in the routine control/execution cycle; use of appropriate alarm systems; and checks and balances, particularly with other humans.

iii. Scope

A first attempt at preparing a list of priorities to guide jurisdictions, industries and universities in further deliberations was required in this area.

The relative impacts of the various sources of pollution incidents such as trucks, vessels and other forms of transportation; fixed installations such as sewage treatment plants, chemical plants and generating stations would be considered.

Through research, correspondence and telephone interviews with state, provincial and federal agencies having jurisdiction in the Great Lakes basin, as well as other sources of information and opinion about the prevalence of discrete pollution incidents, the relative severity of discrete pollution incidents and suggested priorities for further consideration were determined.

iv. Program

To advocate for government, industry, the academic community and the public a more substantial effort in the prevention of human-machine interface failures that could have a serious or catastrophic impact on the Great Lakes ecosystem, the dimensions of the current situation must be examined.

Under this area, the management of data relating to environmental catastrophes, such as spills, fish kills and other adverse events, and the extent to which these data are available or need to be collected, analyzed and reported, was reviewed.

Based on this review and associated evidence, consideration was given to the kind of priorities and techniques that have been or should be established in terms of programs designed to prevent catastrophic environmental events.

This activity should attempt to estimate, at least in part, the potential impact of extraordinary pollution incidents (such as spills) from the following sectors or activities:

- The transport of hazardous goods by means of air, water, road and rail in the basin and the accident record and severity of the associated impact (local and lake-wide) of activities in this sector as a source of toxic pollutants to the system over the last decade.
- The industries discharging in the basin, including the type of toxic materials discharged and their compliance records with regard to
the occurrence and prevention of pollution incidents. A preliminary estimation of what enhanced training and communication might contribute toward the reduction of the environmental insult from these incidents should also be attempted.

- Pollution incidents from municipal treatment works, bypasses, overflows and emergency shutdowns in the Great Lakes basin.

- Pollution incidents from other users of Great Lakes waters — especially from the generation of electrical power (nuclear and nonnuclear). The importance of pollution incidents involving toxic substances from this source segment should also be estimated.

Through a review of the above assembled information, a list of priority sectors or categories for the consideration of the workshop participants was developed.

c. **Structure**

All participants received all four working papers prior to the conference for their review. The workshop was held over one and one-half days on March 17 and 18, 1987 at the Great Lakes Regional office of the International Joint Commission in Windsor, Ontario. The first morning was dedicated to a discussion of the four working papers, associated questions and the establishment of four workgroups to consider and review the papers in further detail. These workgroups met privately in the afternoon of the first day to develop findings and recommendations for the consideration of the entire workshop.

The following morning, facilitators for the individual workgroups presented their notes on common and specific findings to all the participants. Recommendations and findings to be forwarded to the Science Advisory Board were agreed upon. A list of participants (for both workshops) is given in the Appendix.

d. **Proceedings**

After a brief review of the history of the International Joint Commission and the development of the Science Advisory Board, the findings of the first Human–Machine Workshop and the preparations for the second were summarized. The decision to develop a more precise focus on the human–machine topic by emphasizing, where appropriate, the impact of extraordinary discharges to the Great Lakes basin was noted. It was hoped that, at the end of the day–and–a–half workshop, a consensus on findings and recommendations from the four topic areas could be developed for the consideration of the Science Advisory Board.

In response to a call for other comments, Dr. Vanderburg emphasized that in considering the possibility of the most catastrophic events, such as accidents at nuclear power facilities, his perspective extended beyond the traditional human factors considerations. In his view, some of these systems were so complex and beyond total and absolute rational control that a certain number of system or normal accidents in such facilities was inevitable.

Mr. Rubin noted his concern regarding the exemption of the Canadian nuclear power generation industry from total liability for the consequences of a
nuclear accident. Mr. Rubin's organization, Energy Probe, is challenging this exemption in the Canadian courts. The utilities maintain there is no demonstrable correlation between the extent of liability and the duty of the nuclear industry to operate safely.

i. People

Following these comments, Mr. Tinsley of the Federal Aviation Administration (FAA), U.S. Department of Transportation, gave a précis of his working paper, People. The complete text of his paper can be found in Chapter 5.

In his remarks, Mr. Tinsley focused on the many factors which could contribute to human error, which is given as the cause of a great majority of the aviation accidents in the United States. Although he acknowledged that the term has no set and common definition, he defined human factors engineering as the study of the physical, physiological, psychological, psychosocial and pathological variables that affect human performance.

Mr. Tinsley was of the opinion that the concepts of human factors engineering have not yet achieved an impact in the management of the FAA that they deserve, given the prevalence of human error in the accident data collected to date. The Administration has conducted workshops in human factors engineering, but in his opinion, to be effective, the concept must penetrate more thoroughly to the working level.

On the subject of employee screening, he noted that many of the commercial pilots have come from the military and have been subjected to extensive screening and that controllers must pass through a screening test for aptitude and motivation; however, civilian pilots frequently are not subjected to the same level of scrutiny. He noted that the FAA is now screening for drug use, with the focus being on the hard drugs rather than alcohol and marijuana.

The use of flight simulators for reexamining commercial pilots has changed recently to include, on occasion, the entire flight crew. Inclusion allows assessment of the crew's interaction under emergency situations. He observed that although the lessons of experience can be passed on, the transfer of judgement is often difficult.

The FAA has been endeavoring over the years to establish a methodology for measuring workload. Although physical workload is easily characterized, mental workloads and associated stresses are not. Automation of the cockpit has lowered the physical workload and forced crews and regulators to continually combat boredom.

In considering the applicability of the FAA experience to the area of pollution control, he noted that one of the factors that works in favor of the Administration is the explicit public concern with safety in flight. Standards are the most rigorous of any in the transportation field and deviations and errors can receive a good deal of public scrutiny. Further education and public stimulation to a similar extent in the area of pollution control and prevention could have the same positive effect.
Dr. Christensen, Universal Energy Systems, asked how responsible personnel can be continually motivated, particularly in the traditionally less prestigious jobs such as aircraft maintenance. Mr. Tinsley felt that leadership by managers was essential to this task, noting that management is appropriate for inventories but people must be led. Those who set the corporate goals and objectives must extend them to include safety and a responsibility for the environment and must identify and recognize those individuals at whatever level in the organization whose performance is crucial to the achievement of these goals.

In commenting on the presentation, Walter Lyon, University of Pennsylvania, noted the many valuable lessons that can be learned from the aviation experience, where the level of training and associated monitoring are generally high. He asked that the workgroup assigned this topic address other areas in the Great Lakes basin that are not subjected to the same level of scrutiny, such as the transport of hazardous substances by road, rail and sea, the operation of industrial and municipal wastewater treatment plants and the generation of electricity.

ii. Technology

Mr. Harold Price of the Essex Corporation next summarized the salient points from his working paper on Technology. The complete paper can be found in Chapter 6. He noted that, in general, regulation usually stimulates management, at least initially, as clients (including the public) come to recognize the resulting enhancements.

As a member of the Human Factors Society, Mr. Price was concerned with the socio-environmental aspects of the workplace, including training, education, screening and communications. His experience indicated that human error is often a complex phenomenon best addressed through a combination of factors such as system design, organization, procedural modification and leadership.

His work has focused on the effective integration of technology into human endeavors. He noted that the wholesale application of technology to such endeavors is not always positive, particularly when the technology is not well suited to human capabilities for recognition, reasoning and retention. Human error he defines as a situation where a human does something that is inappropriate or fails to do something that is required. Instances of human error, both those with catastrophic and ongoing insidious impacts, are seldom the result of individual clumsiness and stupidity. Much of this error is design induced and could be reduced or avoided altogether.

Studies have demonstrated that the application of human factors considerations have a positive impact on the operations of an organization, including profits. These considerations can enhance skill levels and reduce training costs while increasing user acceptance of new technology. Sabotage, misuse and abuse can be minimized or avoided and retrofit requirements can be reduced.

Technology can be viewed as an attempt to replace humans (automation) or to enhance and extend human activity, or both. Its deployment must not be driven by the availability of the technology but
rather by the needs of the user. Automation without consideration of some of these factors can be a major disappointment, particularly when the great part of the responsibility of the humans is to observe the machine. People are generally proactive and thus are more open to adaptive control systems that allow for some ongoing interaction with the operator.

The term computer error is an illustration of a superficial and mistaken assignment of responsibility. In a great majority of cases, what is referred to as a computer error is ultimately a human error in hardware or software assembly or definition of task. As more complex tasks are assigned to these machines through multi-authored, multi-layered programs, the likelihood of bugs in the software evading detection during the verification process becomes significant. The computer also is a dedicated program executive; unless interrupted, it will continue with the task beyond the point where a human operator could well perceive something wrong.

The comments following this presentation emphasized the need to ensure that technology is the servant of humans and not vice versa. There was some discussion of significance of attitude at the workplace and it was agreed that, with the exception of attempts to create a positive attitude through the appropriate use of technology, variation in attitude was a difficult factor to incorporate into a design. Dr. Jones, U.S. Nuclear Regulatory Commission, emphasized the differences in the performances of humans, noting that error variances are a function of differences in individuals. Mr. Rubin commented on the need to engender an appropriate corporate culture and voiced his opinion that vigilance in the nuclear power generating industry may be subconsciously dulled by that industry’s repeated reassurances to the public of the safety of their operations.

iii. Scope

Mr. Wisdom of Wisdom Research Associates reviewed the contents of his working paper, Scope. Of all the working papers, this one examined data generated largely in the Great Lakes basin and thus developed very specific findings and recommendations. The complete text of the paper is in Chapter 7.

In focusing on the impact of spills and other extraordinary discharges in the Great Lakes basin, the definition of discharge used was the one found in Annex 8 of the 1978 Great Lakes Water Quality Agreement:

"... means the introduction of polluting substances into receiving waters and includes, but not limited to, any spilling, leaking, pumping, pouring, emitting or dumping; it does not include continuous effluent discharges from municipal or industrial treatment facilities."

Thus, for example, the bypassing of wastewater by sewage treatment plants due to chronic undercapacity or severe atmospheric precipitation events was considered as an extraordinary discharge.

The 1978 Agreement further emphasizes control of oil and its various forms, including but not limited to petroleum, fuel oil, oil sludge, oil refuse and oil mixed with wastes, as well as specific hazardous polluting
substances — chemicals that are toxic, lethal to animal life and pose a real risk of discharge into the Great Lakes. A list of specific chemicals under this category can be found on page 91 of the Scope paper in Chapter 7.

The collection of data for consideration under this topic proved to be complicated. Reasons included the inflexibility and incompatibility of most of the systems logging data on extraordinary discharges and the lack of data collection systems confined to a part or all of the Great Lakes basin exclusively. Only discharges from the State of Michigan could be considered as entirely within the basin; the balance of jurisdictions had boundaries that were in part outside the basin. The ongoing surveillance performed by the Water Quality Board of the International Joint Commission, which relied largely on a joint U.S. and Canadian Coast Guard report, did not adequately convey the impact of oil and hazardous substance discharges on the basin.

The Scope paper provided an indication of the magnitude of extraordinary discharges through a review of a number of databases that provided coverage of either the entire Canadian or U.S. portion of the basin. Emphasis was placed on four distinct sectors: transportation, industrial, municipal waste water treatment and energy generation.

Current efforts by the U.S. EPA to incorporate spill data from the National Response Center and regional EPA operations into a single database (called Emergency Response Notification System (ERNS)) were noted, but concerns regarding system flexibility and comprehensiveness remained. For the purposes of this examination two databases were reviewed: the Hazardous Materials Information System (HMIS), maintained by the U.S. Department of Transportation and the database associated with the National Response Centre (NRC) and maintained by the U.S. Coast Guard. A search of the NRC database for all spills to water in the eight Great Lakes states for 1984 listed almost 2,000 spills. All spills in the states (including those to water) for 1984 totaled 18,000 for the same time period.

An examination of spills related to transportation accidents for the state of Michigan from the HMIS database indicated 203 spills, of which 27 were in excess of 25 gallons. The total volume of these larger spills was approximately 9,000 gallons. A review of this database by the Office of Technology Assessment of the U.S. Congress has found that not all significant transportation accidents are noted in this database.

The Canadian National Data Base, maintained by Environment Canada under the National Analysis of Trends in Emergency Systems (NATES), was determined to be more flexible than comparable U.S. systems. There were concerns regarding the entry of the most recent data from the Province of Ontario, which would include data from the Great Lakes basin. However, significant quantities of oil and hazardous materials, including sodium hydroxide, sulfuric acid and oil contaminated with PCBs, ranging from several tonnes to several thousand tonnes, were identified as spilled in the Great Lakes basin for the year 1984.

With the evolution of the Ontario Spill Action Centres and a related computerized spill reporting system (using an entry protocol tailored to the provinces' needs rather than that of NATES), simple transfer of
data between the provincial and the federal system was no longer possible. A new arrangement for entry of the Ontario data in the national database is now under development by the two levels of government.

A separate search of the Ontario database for spills to water was performed and information on approximately 1,500 spills was retrieved. However, 518 of these reports did not contain any information on quantity. The largest entries were associated with overflows from sewage treatment plants.

A very limited and selective comparison was made for quantities of specific chemicals spilled into the waterways versus quantities of the same chemical continuously discharged in industrial effluent. The selected chemical was styrene; in one case the amount spilled by an industry in one incident was equivalent to that contained in one-and-a-half years of continuous effluent. In the second case, the amount was equivalent to almost 1,500 years of continuous discharge. Although far from conclusive, this limited examination suggested that the impact of spills could deserve the same level of examination as is given to contaminant point sources in the basin.

Mr. Wisdom also examined extraordinary discharges from combined sewer overflows of municipal sewer systems. He noted that such overflows were a very significant contributor (in excess of 800 tonnes) to phosphorus loadings in the Great Lakes. These combined sewer overflows were also sources of toxic contaminants such as PCBs and other organic and metallic compounds. Again, there were indications that the record of such overflows and treatment plant bypasses was incomplete.

In reviewing selected data on the power generation industry, Mr. Wisdom found that this industry was the source of significant spills of organic contaminants to the basin. With regard to the nuclear power industry, he noted that the IJC has reviewed data on the release of radioactivity since 1975. The U.S. emission data does not specify how radioactive releases compare to allowable limits, whereas the Canadian reports do. For 1981 and 1982, the amounts of radioactivity released from Canadian facilities totalled less than 1% of the allowable limit.

The IJC also monitored incidents at nuclear power generating and related facilities that resulted in unplanned releases of radioactivity. Over the 1981–82 period, one incident was reported for the 13 U.S. reactors in the basin and nine incidents reported for the nine reactors at three generating stations in Canada. Six incidents were reported for fuel processors and users. The IJC committee overseeing these unplanned releases ceased to function with the completion of its 1983 report; a report is now under preparation by IJC staff using data supplied by the jurisdictions. It should be noted that there is no common definition between the two federal jurisdictions of what constitutes an unplanned release; thus, the information offered on releases should not be considered as indicative of the comparative state of operational control within the nuclear energy sectors of the two countries.

The working paper also reviewed the incident reports from the U.S. nuclear safety information database and presented information on the
number of License Event Reports at U.S. nuclear power facilities in the Great Lakes basin. Specific events that increased the probability of damage to the reactor core were also presented. The report concluded that the IJC should become more active in their overview of these facilities.

iv. Program

Mr. Bissett of Environment Canada and Mr. Weaver, an environmental engineering consultant from Cincinnati, Ohio, presented a synopsis of their findings on jurisdictional efforts to prevent catastrophic environmental events and reduce extraordinary discharges. The full text of their working paper can be found in Chapter 8.

Mr. Bissett noted that the working paper was concerned with mechanisms for the identification of hazards and the assessment of risk. It also reviewed the adequacy of available record keeping and information systems for dealing with unplanned or extraordinary releases of hazardous materials into the environment. He noted that major catastrophic or potentially catastrophic events such as those at Love Canal, Bhopal, Seveso, Mississauga and the Rhine River have largely motivated various regulatory programs, such as the Superfund Program, the Ontario Spills Bill and recent action by the World Bank, to include hazard analysis as part of their funding decision process.

Reference was also made to the Toxics Catastrophe Prevention Act, passed by the State of New Jersey in 1986. This act requires notification or registration of facilities involved in any way with an extremely hazardous substance. A state agency will review risk assessments and management plans of those firms dealing with such substances. The Transport of Dangerous Goods Act of Canada was also referred to in this discussion.

In reviewing initiatives of nongovernmental groups, the efforts of the U.S. Chemical Manufacturers Association in their 1,500 Community Awareness – Emergency Response (CAER) programs were noted. These community outreach programs are sponsored by individual companies to ensure that the community recognizes the potential hazards and understands what is being done to reduce the risk and to provide adequate emergency response plans and capabilities.

A parallel development in Canada is the Canadian Chemical Manufacturing Association's Responsible Care program, which involves senior plant management in development of a Code of Good Practice for their operations, including transport and community response.

With regard to the question of spills response and inventories, the working paper indicated that a number of organizations are active in the collection of spill data. However, in addition to the difficulties in retrieval and manipulation determined by Mr. Wisdom, there were indications that a significant number of spill events may not have been stored in appropriate database systems. Repeated reference was made to the study done by the Office of Technology Assessment, U.S. Congress, on the transportation of hazardous materials. This study found that truck transport is the sector with the least complete database, although it accounts for 86% of the incidents of accidental discharge.
Mr. Weaver also noted that several states, including Illinois, Pennsylvania, New York, California and New Jersey, are developing inventories of hazardous materials, at least partly in response to demands for a community right-to-know. There was a consensus that legislation responding to this right-to-know issue would undoubtedly become more common in various jurisdictions in North America, including those in the Great Lakes basin.

In response to a query regarding the extent to which spills go unreported, it was noted that the Office of Technology Assessment study compared data maintained by the State of Washington to that contained in the HMIS database and found that only 20% of the spills in HMIS had been reported to the state. Only 18% of the spills reported to the state were included in HMIS. Similarly, the 1986 Ontario data on spills show a very substantial increase over that available from the 1985 NATES record and a good portion of this increase is undoubtedly due to the greater awareness of a reporting requirement on the part of the responsible parties.

Discussion ensued regarding the use of human factors in the labelling of hazardous materials and it was determined that there was a need to apply the knowledge gained in this area to the development of such labels.

It was also noted that the fragmentation of jurisdiction has an impact on the quantity and quality of data collected. For example, the Nuclear Regulatory Commission in the U.S. has control over the shipment of most radioactive material, but does not regulate the less radioactive isotopes, such as radium.
4.0 FINDINGS AND RECOMMENDATIONS OF THE WORKGROUPS

4.1 People Workgroup Members: Dr. J. Christensen, Guice Tinsley, Stuart Sullivan, Dave Stephenson and John McDonald.

In his presentation of the findings of the People workgroup, Dr. Christensen noted there was evidence that the selection and certification process had broken down in the transportation sector, elevating the risk of accidental releases of hazardous materials to the environment. He cited the current licensing practices for transport drivers in several of the United States and noted concern with the chain of responsibility and the extent of awareness of possible consequences associated with the transportation of hazardous goods.

The group identified a need for appropriate selection and training methods, including both initial and ongoing training to establish new skills and maintain proficiency. Training procedures must recognize and allow for the fact that there is no one best way of performing any task, but rather the individual will, to some extent, tailor task execution to his aptitudes and personality. There must also be a recognition of the capabilities of the audience addressed by training devices such as manuals. For example, the average work force reads at approximately the seventh grade level and some alteration in the content of any training manual or a workplace remedial reading program may be appropriate. Positions requiring ongoing vigilance and skill maintenance often benefit from the inclusion of simulation exercises as part of the regular work program. For effective training, the organization must become sensitive to the work force and their requirements.

Modern selection methods are now frequently adequate to predict the success of a given applicant in a given task, providing the requirements of the task are accurately defined. Consideration should be given to the more widespread use of such selection methods. In summary, the workgroup offered the following recommendations:

a. Every attempt should be made to include the ultimate operators in the design of equipment and facilities.

b. Training should encompass not only how the machine works, as described from an operator's perspective, but also how people work; that is, a consideration of interpersonal interaction. Training should be performed by people with a demonstrated aptitude for teaching. The importance of the operator should be recognized and acknowledged through job enrichment and a diversity of challenges. Knowledge should be shared within the organization, not hoarded.

c. Senior management or their equivalent must set standards for a given organization and repeatedly reflect a commitment to those standards. The evolution of a corporate ethic is crucial to an effective pollution control program.

d. Although good lines of communication among all levels of an effective organization is an obvious necessity, there should be provision for confidentiality where appropriate, particularly in the investigation of a narrowly adverted spill or near accident. The focus should be kept on prevention rather than on correction.

e. The IJC should encourage the development of legislation to protect the worker or operator from reprisals for refusing to execute nonroutine tasks that would pollute the environment.
4.2 Technology Workgroup Members: Harold Price, Drs. William Vanderburg, Geoff Wright and George Peters.

The recommendations of the workgroup were summarized as follows:

a. Investigations and analyses of selected pollution incidents using specialists in human factors and socio-technical systems should be conducted to determine the related causal factors in pollution discharges.

b. The use of a total system approach, including human factors and socio-technical considerations, to all Great Lakes pollution problems should be encouraged.

c. Consideration of human factors engineering should be included early in the design of new systems or equipment or in the retrofit of older systems or equipment.

d. A uniform or standard pollution hazard information system should be developed for use on warnings, labels, placards, displays and material safety data sheets. Warnings should emphasize nonverbal or nonlanguage information. In addition, human factors data, techniques and tests should be used to assure the effectiveness of these pollution prevention messages.

e. The IJC should sponsor research into the development of specific human factors design criteria, as applied to pollution alarms, pollution monitoring systems, annunciators and other instrumentation, to ensure that releases of pollution are controlled at the source.

f. The IJC should perform studies to ensure that automation is only implemented after a deliberate and effective allocation of functions between humans and machines. Appropriate information about the system and cognitive support to the user must be included in the design.

g. The IJC should develop a formal communication system directed at all potential polluters to assure that guidance information on human error, prevention, human factors design criteria and technology transfer will occur on a timely basis.

h. A shift in regulatory emphasis away from precise prescriptions of required actions and toward defining goals for management, with some flexibility in the methods used to attain them, could be more productive in protecting the environment.

4.3 Scope Workgroup Members: Mr. Ken Reeves, Dr. Harold Quinn, Prof. Ted Manzig, Dr. Jack Vallentyne, Mr. Jerry Wisdom.

In an assessment of the problem of satisfactory delineation of the human factors associated with spills to the environment, the major deficiency identified has been
the inadequacy of the available databases. The existing databases from different jurisdictions are both incomplete and inconsistent with respect to the data reported. Furthermore, any information related to the human factor, if present at all, is usually not sufficiently definitive to allow analysis for the purpose of identifying preventive action.

Findings:

a. There is no precisely defined spill inventory for the Great Lakes basin. Currently available inventories follow jurisdictional boundaries and in the majority of cases of computerized record storage and maintenance, the supporting software is not designed to provide basin specific searches.

b. There is evidence of incomplete reporting of spills in the Great Lakes basin and a lack of liaison among those charged with maintaining spills databases.

c. Several of the U.S. databases, particularly those maintained at the National Response Centre and the Hazardous Material Information System, are inflexible and not amenable to efficient and effective data retrieval. The federal Canadian system is a more sound design; however, a delay in the storage of current spill data from the Province of Ontario was evident.

d. With the U.S. Environmental Protection Agency moving to centralize spill data in a database called Emergency Response Notification System (ERNS), the IJC should attempt to bring the Parties and jurisdictions together to design flexible, efficient spills databases for the basin.

Recommendations:

a. To enable the IJC to effectively use the databases, it is recommended that the Commission work with all appropriate jurisdictions to develop and implement use of a uniform definition of a spill for reporting purposes.

b. The IJC should encourage the appropriate jurisdictions to impose a statutory duty to report all spills meeting the agreed upon definition.

c. The IJC should recommend the adoption of a uniform reporting format by all jurisdictions involved and offer to coordinate efforts to achieve such a format.

d. The above reporting format should include requirements for adequate reporting of human factors data. The Nuclear Precursor Study undertaken by the U.S. Nuclear Regulatory Commission could provide guidance in achieving such reporting.

e. The IJC should study the human factors data gleaned from any upgraded databases and initiate research on preventive measures.

f. Complementary to these activities, it is recommended that the IJC encourage jurisdictions to engage in public education programs related to the reporting and prevention of spills.

4.4 Program Workgroup Members: Mr. Ed Piché, Mr. Leo Weaver, Mr. Wayne Bissett and Mr. Norm Rubin.

To recommend and prioritize programs and initiatives that are designed to minimize or prevent the occurrence of catastrophic environmental events, five areas of activity are identified:
a. Encourage national and international emergency prevention plans by focusing on and encouraging local leadership.

The Commission should encourage Great Lakes jurisdictions to provide resources and guidance to the local communities so that they can take the lead responsibility in planning and executing emergency response by advocating:

- prevention and minimization of risk;
- proactive as well as reactive planning initiatives; and
- compatibility of data and procedures with respect to spill, hazard identification and response protocols.

Effective local leadership would involve integrating the response of police, firemen, environmental officers, health officials, politicians, industry representatives, citizen groups, media and emergency planners. This integration should be given a high priority, as this level may be tested first and most strenuously in any given emergency.

b. Foster right-to-know legislation

The IJC should advocate that all Great Lakes states and provinces pass right-to-know legislation. The Commission should define, or at least outline, the essential elements of acceptable right-to-know legislation. Such legislation should be consistent among jurisdictions to as great an extent as possible and should include, as a minimum, hazardous substance identification, quantities, location, chemical form and mode of impact, including physiological implications.

c. The IJC should advocate the compilation of an inventory of all hazardous materials, including hazardous wastes, in the basin. This inventory should include both chemical manufacturers and users and nuclear power plants and transportation activities linked to both. The IJC should encourage consideration of the question of responsibility and liability in the event of a disaster involving hazardous substances.

d. The IJC should continue to ensure that various concepts of risk and methods of risk assessment are debated publicly.

The Commission should advocate a public component to risk assessment and ensure that all risk discussions consider societal as well as individual risks. The IJC should not confine these discussions of risk to the water medium but rather consider the combined risk of human and animal exposure by means of inhalation, dermal, food and drinking water pathways.

e. The Commission should continue and enhance current communication initiatives.

The IJC should continue to foster communication and consultation on all relevant issues at all levels by: providing appropriate fora for professional contacts; publishing annual reports; and providing library and information distribution services. The Commission should ensure that objectivity is maintained throughout such activities.
4.5 Other

The workshop also recognized that modern technology is inextricably linked to human beings, groups and organizations in the many socio-technical systems characteristic of any industrially advanced society. It is recommended that those who design, build, operate and maintain these systems be trained not only to achieve excellence in their area of specialization, but also to appreciate how their specialization contributes to the socio-technical performance of the whole system.
5.0 THE PEOPLE FACTOR: LESSONS LEARNED FROM AVIATION

Mr. Guice Tinsley
U.S. Department of Transportation, Washington, D.C.

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>30</td>
</tr>
<tr>
<td>5.1 AVIATION HUMAN FACTORS</td>
<td>30</td>
</tr>
<tr>
<td>5.2 ROLE OF THE HUMAN IN THE FUTURE AVIATION SYSTEM</td>
<td>31</td>
</tr>
<tr>
<td>a. Selection and Training Procedures for Controllers</td>
<td>31</td>
</tr>
<tr>
<td>b. Proficiency Measurement Requirements</td>
<td>31</td>
</tr>
<tr>
<td>c. Pilot's Judgement Training</td>
<td>31</td>
</tr>
<tr>
<td>d. Information Transfer</td>
<td>32</td>
</tr>
<tr>
<td>e. Work Load Measurement and Control</td>
<td>32</td>
</tr>
<tr>
<td>f. The Effects of Fatigue and Desynchronosis</td>
<td>32</td>
</tr>
<tr>
<td>g. Alcohol and Drugs</td>
<td>32</td>
</tr>
<tr>
<td>h. Human Relations</td>
<td>32</td>
</tr>
<tr>
<td>5.3 REGULATORY CLIMATE</td>
<td>32</td>
</tr>
<tr>
<td>5.4 PERSONNEL PRACTICES</td>
<td>34</td>
</tr>
<tr>
<td>5.5 PLANNING</td>
<td>36</td>
</tr>
</tbody>
</table>
INTRODUCTION

This background paper is prepared for the second Human—Machine Interface Workshop Planning Committee of the International Joint Commission. I will attempt to address, in a limited way, the following five areas:

- aviation human factors;
- role of the human in future aviation systems;
- regulatory climate;
- personnel practices; and,
- recommendations on planning.

5.1 AVIATION HUMAN FACTORS

Federal Aviation Administration (FAA) reports and other literature contain the comment that human factors are the last unexplored frontier in aviation safety. Whether it's the last frontier remains to be seen, but what is clear at this time, is that too much of the field of human factors and its influence on safety have eluded past study attempts, adequate documentation of study results or both. To make matters worse, there are also indications that even the term human factors has no set definition. For the purposes of this discussion, by human factors, I mean the study of the physical, physiological, psychological, psychosocial and pathological variables that affect human performance. The term human factors engineering is the application of the knowledge of human factors to the design of devices, systems and environments to optimize the safety, efficiency and the general well-being of the persons who interact with them.

Certainly, consideration for human factors in aviation safety is not new. Its influence in systems design and operational procedures can readily be seen in all elements of aviation. What is new, however, is the need to evaluate the effects of rapidly changing roles of human operators interfacing with new technology systems and changing operating procedures.

This need is vividly expressed in National Transportation Safety Board (NTSB) accident data. For the period 1972–76, in 84% of all accidents, the pilot was the causal factor. For this same period, the pilot was the causal factor for 88% of all fatal accidents. In air carrier operations for the 10–year period 1968–77, the pilot was the causal factor in 62.6% of all fatal accidents. In contrast, powerplant failure accounted for 4.7% of all fatal accidents for the ten–year period 1968–77 in air carrier operations. This dramatic improvement in engine reliability resulted from the adoption of new technology systems. A similar effort has not been made to reduce human error or to analyze fully the human factors/safety relationship.

The earliest safety–related human factors data and criteria were empirically derived from operational experience. Besides being very inefficient, this technique has serious accuracy and documentation limitation. Establishment of acceptable workload levels and specifications with this technique is difficult at best.

Although recent approaches to human factor studies have identified new techniques to improve the quality of crew work load assessment, it appears that there is no single technique by which total work load can be determined. Work load measurement techniques are even more elusive.
This is a concern to the Agency for new aircraft certification, where determinations must be made regarding the combination of work load measurement techniques needed in the certification process. Additional complications arise when considering factors associated with new technology aircraft systems.

The limitations and validity of available work load measurement techniques must be understood and expressed so that we and the aircraft manufacturers clearly understand the tools available. No documentation exists to provide this information.

Furthermore, the traditional concepts of work load influence on safety have associated high work loads with lower safety levels and low work loads with higher safety levels. Strict adherence to these concepts is being challenged. Data suggesting that work load that is too low or too high can be both detrimental to safety is beginning to emerge.

In response to this challenge, the FAA must develop an understanding of the work load/safety relationships. In assessing the work load safety relationship, there is a need to develop new human factors criteria. The development of human factors criteria will support the adoption of advanced technology such as innovative aircraft systems, electronic displays and new flight operational concepts. These developments are expected to generate new pilot functions and operational considerations. The development of computer and computer graphic displays and applications now outstrip our understanding of how controllers and pilots can use this technology to achieve optimum performance.

5.2 ROLE OF THE HUMAN IN THE FUTURE AVIATION SYSTEM

To properly deal with this subject would require an iterative process that would allow adjustments to the human role to occur as the new system evolves. However, there are several important areas to consider. In defining the role of the human in the future system, we need to evaluate:

a. Selection and Training Procedures for Controllers. The FAA has continued to revise written tests and training techniques for control specialists. These instruments and procedures have resulted in reduced attrition during training and assisted in the orderly replacement of those controllers who were on strike. For example, a recent before and after comparison of Academy pass rate using new tests versus old tests indicates that the success rate improved from 43% to 71%.

b. Proficiency Measurement Requirements. With large numbers of newly trained controllers entering the work force, there is an increasing need to develop reliable, valid and objective methods to certify their performance. These measurement techniques will, of course, have to be revised when the new, more automated, equipment is installed.

c. Pilot's Judgement Training. This topic appears to offer great promise in lowering the numbers of pilot error accidents. The FAA, in conjunction with the Canadian government and the General Aviation Manufacturer's Association, has developed and is evaluating training manuals and procedures for student and instructor pilots. We are also monitoring recent related developments by NASA and some airlines in the flight deck resource management area.
d. Information Transfer. A review of the accident statistics and Aviation Safety Reporting System suggests that communication and information transfer between flight crew members and controller is a major problem. The application of new technology should be of value here.

e. Work Load Measurement and Control. The aircraft and the ATC equipment designers continue to refine methods of measuring and controlling operator work load. The FAA had to administratively restrict the National Airspace System temporarily after the controller strike by reducing the total number of flights and introducing flow control to avoid peak period overloads. This resulted in, among other things, a reduction of the controller workweek from a maximum of 50–plus hours immediately after the strike to less than 44 hours at present.

e. The Effects of Fatigue and Desynchronosis. The economic necessity of operating aircraft across time zones and control systems around the clock produces concomitant problems for the operators. While the FAA, NASA and others have not yet been able to establish with great accuracy the degree that the phenomenon degrades human performance, the topic will continue to be of great interest to all concerned.

f. Alcohol and Drugs. Although alcohol and drug abuse continues to be a factor in about 7% and 5%, respectively, of general aviation fatal accidents, there is little evidence that substance abuse is a growing problem in the aviation community. We must, however, continue to develop and monitor drug and alcohol use because of widespread acceptance of nonprescription drugs and the relatively high incidence of substance abuse by the general public.

g. Human Relations. As a result of the controllers' strike, the FAA work environment for all employees was examined by a group of outside labour management experts. The FAA has undertaken a number of programs to improve the work environment, particularly in areas of internal communication training.

5.3 REGULATORY CLIMATE

I think you will be interested in a brief overview of the regulatory environment we are creating in the federal sector to accommodate and respond to the challenges of the future.

For the past several years, there has been concern over the growing pervasiveness of the federal establishment. This concern came to focus on rules that intruded directly into people's lives at nearly every level — our families, their education, our homes, our businesses and more. Forces that favored a stronger federal role were countered by forces that sought to rein in pervasive government — the latter largely through indirect restraint on federal rulemakers. Through the '70s, lawmakers and chief executives put more and more discipline into the rulemaking process. Congress passed various pieces of legislation designed to remove or relieve regulatory burdens on the aviation industry and the public. The Airline Deregulation Act, the Regulatory Flexibility Act and the Paperwork Reduction Act are examples of such legislation.

President Reagan's Executive Order 12291, issued February 17, 1981, reflects the clearly stated objectives of the current federal administration:

* to reduce the burdens of existing and future regulations;
• to increase agency accountability for rulemaking actions;
• to provide for presidential oversight of the regulatory process;
• to minimize duplication and conflict of regulations; and
  (most importantly)
• to ensure well-reasoned regulations.

The Executive Order sets out five specific requirements rulemakers such as the FAA must meet in proposing or adopting new rules or reviewing existing rules:

• Administrative decisions shall be based on adequate information concerning the need for and consequences of proposed government action.

• Regulatory action shall not be undertaken unless the potential benefits to society from the regulation outweigh the potential cost to society.

• Among alternative approaches to any given regulatory objectives, the alternative involving the least net cost to society shall be chosen.

• Agencies shall set regulatory priorities with the aim of maximizing the aggregate net benefits to society, taking into account the conditions of the particular industry affected by the regulations, the condition of the national economy and other regulatory actions contemplated for the future.

• The regulation must be clearly within the authority delegated by law and consistent with congressional intent.

• The factual conclusion upon which the rule is based has substantial support in the agency record viewed as a whole, with full attention to public comments in general and the comments of persons directly affected by the rule in particular.

I have spent some time on what the federal government has done to reduce the burden of regulation. Now, I want to share some of the guidance we have received from the FAA Administrator. The purpose of the FAA is to provide for the regulation and promotion of civil aviation.

How do we do this? Again, the Administrator's words:

• "We should control, but not constrain";
• "We should regulate, but not interfere with free enterprise or competitive purposes"; and
• "We should recognize that most air travelers do so by means of scheduled air carriers. We have a responsibility to consider their priority, but not to the extent that excludes the single individual from enjoying man's greatest achievement — solo flight."

I want to briefly touch on several aspects of the FAA's program to improve their response to the safety regulatory aspects of the Federal Aviation Act and to concurrently reduce the regulatory burden on the industry and the public, while simultaneously providing a regulatory environment that fully complements our system planning.
The FAA is considering a significant change in its method of establishing air transportation safety regulations. Under a new concept entitled Regulation by Objectives (RBO), the FAA would substitute broadly stated safety objectives for many of its detailed regulations.

Regulation by objective has two major goals:

- to continue the high level of safety that has made the United States Aviation Regulatory Standards a model for almost every aviation regulatory body in the world; and,

- to provide regulatory flexibility so that the aviation industry will not be impeded in developing innovative methods for achieving the level of safety thus far maintained under federally established safety objectives. The "what" portion of these regulatory parts has been separated out and cited as safety objectives that have been incorporated into a proposed new air transportation regulation. The old regulatory provisions have been left as regulatory guidelines. The proposed rule is intended to provide much needed flexibility for the aviation community through specifically tailored rules as desired by individual operators.

The FAA has long taken pride in our nonadversarial relationship with the aviation industry. However, with the increased emphasis on reducing or eliminating the federal regulatory burden, combined with a requirement to do more with less staff, we are looking for greater emphasis on direct participation by industry's special interest groups in the rulemaking and enforcing programs.

In addition to the major overhaul of our regulatory structure, we now have a comprehensive plan for modernization and improving air traffic control and airway facilities services from now to the year 2000. It was published in December 1981 and is updated yearly.

The plan addresses the compelling problems of how best to accommodate the spiraling demand for aviation service, constrain costs, recast the technical framework and deal with aging facilities.

The plan also delineates specific improvements to facilities and equipment and supporting research and development associated with the National Airspace System. Particular emphasis is given to terminal and en route air traffic control, flight service stations and weather services, ground-to-air services, inter-facility communications and auxiliary services such as airway facilities maintenance and flight inspection of navigational aids. The recurrent theme throughout the plan is that safety, capacity, productivity and economy will be chiefly realized through higher levels of automation, consolidation of major facilities and the application of rapidly changing and lower cost technologies in telecommunications.

5.4 PERSONNEL PRACTICES

Regulatory agencies have three avenues of dealing with the regulated population. These processes include selection, training and compliance with the regulatory documents. Historically, in aviation, the selection process requires that specific criteria be met for licensing. Recently, some form of screening has been additionally required.
The government is expanding the substance abuse control program. The FAA has initiated a drug testing program that requires all employees who normally take an annual physical to submit to urine testing. Random tests are also conducted when there appears to be just cause or in the event of accidents/incidents.

Prior studies in the Department of Transportation indicate that substance abuse in the aviation industry is not much different from that in the general population. Approximately 15% of the population involved in transportation may be considered drug dependent. Of these 15%, alcohol encompasses 90% of the users, with marijuana usage at 8%. Other drugs that get a lot of notoriety (cocaine, PCP) are only used by one or 2% of aviation personnel. The preferred drugs are not randomly distributed but are age-related, which also puts users into occupation categories. Pilots and mechanics are generally older than other airline employees and alcohol is their major problem, while flight attendants are more likely to abuse marijuana or cocaine. Some drugs are used on the job to improve performance and alertness, while others are used recreationally.

Many companies conduct drug screening. In some skills, because of the shortage and difficulty of obtaining new employees, some drug usage is allowed. Urinalysis is the most common type of testing and does show evidence of drug usage but not the amounts involved.

A successful screening program should consider the following:

a. The government/company should formulate a policy about drug abuse that spells out why it is unacceptable and how it will be addressed;

b. It should communicate that policy to employees;

c. It should encourage and support supervisors in the active identification and referral of problem workers and allow for self-referral, by peers and by management.

d. It should locate treatment and rehabilitation resources for its employees;

e. It should institute follow-up procedures to ensure that the employee's condition is being treated and that, insofar as possible, the workplace supports the recovery process; and,

f. It should define enforceable and appropriate alternatives (reassignment, early retirement, termination, disability) for those employees who are unwilling or unable to successfully return to full function.

Training requirements can be very detailed and specific or in some cases can be defined as a desired outcome. The FAA is now frequently legislating the latter by imposing the phrase, "Train to a demonstrated performance level." The use of flight simulators and the resulting training flexibility permitted with these devices allows a realistic evaluation of pilot performance.

Attaining the desired level of regulatory compliance is the most difficult act to accomplish. Many times good regulations are misunderstood or intentionally misinterpreted. Frequently, rules are violated because they create operational inefficiencies that the operators elect to avoid. To create an atmosphere of a high level of compliance, regulations must be valid, realistic, understood and a control/injection mechanism is needed to measure the lack of compliance and impose appropriate penalties.
5.5 PLANNING

In planning for improved safety and to enhance the environment in and around the Great Lakes, I suggest a two part effort. The first phase would be a short term effort (one to two years) to establish programs and efforts to resolve these problems that are widely acknowledged and fall under some agency or government jurisdiction for control. Also, establish a media campaign that highlights this very important effort to avoid conditions that may adversely affect the Great Lakes ecosystem. In the short term, relationships must be established with the people or organizations who exercise control over sectors creating the problems. Human behavior can only be changed by changing the pressures on the individual. In the second or long term phase, a detailed plan should establish the approach to determine the issues to be resolved, the process for resolution resource requirements, schedule and follow-up action to assure that overall objectives are being met.

Human performance enhancement deserves an elevated priority. Increased understanding and better application of present knowledge in human factors areas will result in gains in safety. More time should be allocated to determine the root causes of operator errors. If we can find out why the individual errs, we can ensure future avoidance of operator errors by changing methods, practices or the application of complex systems and hardware.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTRODUCTION</strong></td>
<td></td>
</tr>
<tr>
<td>° Background and Premises</td>
<td>38</td>
</tr>
<tr>
<td>° The Problem</td>
<td>38</td>
</tr>
<tr>
<td>° Approach</td>
<td>39</td>
</tr>
<tr>
<td><strong>6.1 HUMAN ERROR AND THE HUMAN–MACHINE INTERFACE BREAKDOWN</strong></td>
<td></td>
</tr>
<tr>
<td>a. Human Error and System Malfunctions</td>
<td>42</td>
</tr>
<tr>
<td>b. Human Error: Fact and Fallacy</td>
<td>43</td>
</tr>
<tr>
<td>c. Prevention of Errors</td>
<td>44</td>
</tr>
<tr>
<td><strong>6.2 THE HUMAN SIDE OF TECHNOLOGY</strong></td>
<td></td>
</tr>
<tr>
<td>a. The Changing Role of Man</td>
<td>45</td>
</tr>
<tr>
<td>b. High Tech/High Touch</td>
<td>46</td>
</tr>
<tr>
<td>c. Technology Driven or User Driven Designs</td>
<td>47</td>
</tr>
<tr>
<td><strong>6.3 AUTOMATION AND HUMAN FACTORS ISSUES</strong></td>
<td></td>
</tr>
<tr>
<td>a. Area: General Automation Considerations</td>
<td>49</td>
</tr>
<tr>
<td>b. Area: Allocation of Functions</td>
<td>51</td>
</tr>
<tr>
<td>c. Area: Man as a Monitor: Cognitive Support</td>
<td>52</td>
</tr>
<tr>
<td>d. Area: Work Load: More or Less</td>
<td>53</td>
</tr>
<tr>
<td>e. Area: Adaptive Control Systems</td>
<td>55</td>
</tr>
<tr>
<td>f. Area: User Acceptance: Affective Support</td>
<td>56</td>
</tr>
<tr>
<td><strong>6.4 TECHNOLOGY AND HUMAN FACTORS ISSUES</strong></td>
<td></td>
</tr>
<tr>
<td>a. Area: General Technology Considerations</td>
<td>58</td>
</tr>
<tr>
<td>b. Area: Computer–Driven Displays</td>
<td>60</td>
</tr>
<tr>
<td>c. Area: Computer–Driven Displays</td>
<td>62</td>
</tr>
<tr>
<td>d. Area: CRT Color Displays</td>
<td>63</td>
</tr>
<tr>
<td>e. Area: Data Input Techniques</td>
<td>64</td>
</tr>
<tr>
<td>f. Area: Voice Input/Output</td>
<td>65</td>
</tr>
<tr>
<td>g. Area: Artificial Intelligence/Expert Systems</td>
<td>66</td>
</tr>
<tr>
<td>h. Area: Robotics</td>
<td>67</td>
</tr>
<tr>
<td>i. Area: Technology and Organizational Effectiveness</td>
<td>71</td>
</tr>
<tr>
<td>j. Area: Technology and Organizational Effectiveness</td>
<td>72</td>
</tr>
<tr>
<td><strong>6.5 COMPUTER ERROR: DEDICATION CAN BE DANGEROUS</strong></td>
<td></td>
</tr>
<tr>
<td>a. Area: Dedicated Program Execution</td>
<td>76</td>
</tr>
<tr>
<td>b. Area: Software Bugs</td>
<td>77</td>
</tr>
<tr>
<td>c. Area: Truth In Computers</td>
<td>79</td>
</tr>
<tr>
<td><strong>6.5 CONCLUSIONS</strong></td>
<td></td>
</tr>
<tr>
<td><strong>6.6 REFERENCES</strong></td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

Recent disasters such as Three Mile Island (TMI-2), Bhopal, the Rhine River pollution and Chernobyl have all resulted in accidental releases of hazardous materials and have all involved human error. These and similar events have led to a growing need to focus attention on current and potential contamination of the Great Lakes basin as a result of breakdowns at the Human–Machine Interface (HMI). As a result of this concern, the International Joint Commission (IJC) formed by the governments of the United States and Canada to reverse contamination of the Great Lakes basin, established a Human–Machine Interface Workshop to assess and recommend steps to overcome HMI problems that may result in serious or catastrophic effects on the Great Lakes ecosystem.

The next Workshop meeting is scheduled for March 17 and 18, 1987. This working paper helps focus awareness of the HMI problem for the Workshop participants and establishes priorities for further work. It deals with technology and addresses the following question:

How can technology be integrated into system design to prevent a breakdown at the human–machine interface that could result in adverse effects on the Great Lakes ecosystem?

For those unsure of the boundaries of the Great Lakes basin, the following definition is provided by Great Lakes United of Buffalo, New York:

The Great Lakes–St. Lawrence River basin contains the watersheds of Lake Superior, Lake Michigan, Lake Huron, Lake Erie, Lake Ontario and the St. Lawrence River.

- Together the Great Lakes–St. Lawrence River form the largest surface expanse of fresh water in the world and 95% of the fresh water in the United States.
- The basin is home to 45 million Americans and Canadians.
- The sports fishery has a regional economic benefit of 1.16 billion dollars annually.
- Twenty-four million people get their drinking water from the Great Lakes.
- There are 9,400 miles of coastline in the basin.
- Cargo shipped by vessel on the Great Lakes exceeds 100 million tonnes per year.

a. Background and Premise

The first meeting of the IJC HMI Workshop was held April 14, 1986. The premise of the Workshop follows.

Incidents such as Three Mile Island, the recent Canadian train crash in Alberta and on a less acute level, the identification by the IJC and others of the need to improve the performance of wastewater treatment plants, all involve the interaction of humans and machines. Human failure is often inadequately identified as the cause of the above and related incidents.
What are the design and operating elements that could be improved to enhance routine operations and avoid the catastrophic?

A summary of the proceedings from the first workshop was prepared and a decision to conduct a second meeting of the workshop participants was made. In addition, a decision was made to prepare four working papers, of which this is one.

The purposes of this paper are to first and foremost heighten the awareness of the workshop participants and other readers about the importance of the HMI and how it relates to controlling accidental releases of hazardous materials into the Great Lakes basin. This paper will also attempt to provide background information for the topic of technology and HMI effectiveness; technology and human factors issues will be identified to help prioritize future work in the HMI area. Although this paper concentrates on new designs, latent HMI problems (or human error) in existing systems should not be overlooked. The fundamental issues are the same.

b. The Problem

No attempt will be made to define the scope of the pollution problem in the Great Lakes basin, as this is the topic of another working paper. However, on the assumption that some people may read this paper without the benefit of the other working papers or the Charter of the IJC, some general comments of the magnitude of accidental releases of hazardous materials1 will be presented.

After the tragic accident in Bhopal on December 3, 1984, the United States Environmental Protection Agency (U.S. EPA) decided to establish an Acute Hazardous Events (AHE) database. The database is to be used to characterize the kinds of events releasing acutely toxic substances in the U.S., the substances involved and the causative factors leading to their release (see EPA Interim Report 560-5-85-029). The Interim Report, released in December 1985, describes the database that contains 3,121 records which, through sampling, represent 6,928 separate events, mostly occurring in 1983 and 1984. The database is not considered statistically valid and the summary statistics do not represent the totality of potentially hazardous materials released. Nevertheless, the summary statistics do give a feel for the magnitude of the problem. The following is excerpted directly from the Executive Summary of the Interim Report (EPA 1985):

Events with Injuries or Deaths

Human casualties occurred in fewer than 7% of the recorded events. These events — a total of 468 — led to 138 deaths and 4,717 injuries, ranging in severity from temporary respiratory problems treated on-site to critical injuries and extended hospitalizations. Information on causation was scanty in many records.

Four high-volume industrial inorganic chemicals (chlorine, ammonia, hydrochloric acid and sulfuric acid) together were reported to have been released in over 25% of the events recording human casualties. Over 200 additional identifiable substances were recorded as released during events associated with deaths or injuries.

Neither great quantity nor high inherent toxicity alone produce the conditions for human casualties. When the characteristics of the released substances are examined, toxicity appears to be the cause of

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1 Hazardous materials are defined herein as those that pose exceptional risks to human health.
most of the injuries recorded, while flammability and explosivity are the mechanisms associated with most of the fatalities in the database.

Transportation releases account for 25% of all events in the database and a somewhat higher percentage of death or injury events (33%). Trucks are the predominant mode of transport in the death and injury events. Among events with human casualties at fixed facilities, storage vessels play a much larger role as release points than they do among events not leading to deaths or injuries.

When viewed from an industry perspective, the chemicals and allied products and the petroleum refining industries together account for 34% of the reported injuries and more than half of the reported deaths. The transportation industries account for 36% of reported injuries and about one-fourth of the reported deaths. Industries that use chemical or fuel products account for about 25% of the deaths and injuries.

Substances and Quantities Released

For events reporting quantity released, the quantities approximate a log normal distribution. Amount released exceeds 1,000 pounds for over 38% of the recorded events. Releases over 100,000 pounds occur in less than 3% of the events, but these events account for 93% of the total quantity of materials released. Over 80% of the events in the database reported that at least one of the substances released was a liquid; 16% of the events involved the release of a gas.

Causative Factors

Among events occurring at fixed facilities, spills are the predominant end effect, followed by vapor releases, fires and explosions. Storage vessels, process vessels and valves, or piping are responsible for nearly equal shares of in-plant events, but storage vessels typically release much larger quantities. Equipment failure is the cause most frequently reported for in-plant events, followed by operator error. Causation is difficult to assess for many of the events in the database, however.

Over half of the in-transit events involve trucks, another 36% involve rail cars. Over 38% of the in-transit releases stem from a leak and another 20% from collisions. Although few events were reported for pipelines, those spills dwarf other in-transit releases in terms of total quantity released.

While causation is difficult to assess, operator error was coded as the cause in approximately 11.4% of the in-plant events. Equipment failures were coded as the cause for 43.3% of the events, but as we shall see, many of these failures are due to human errors.

In the Great Lakes basin, the two major system-wide environmental quality problems of the lakes are eutrophication and toxic chemicals. These problems are described in the Second Biennial Report of the IJC (1984) as follows:

Eutrophication

At the time the 1972 Great Lakes Water Quality Agreement was being negotiated, the major water quality problem of the Great Lakes was considered to be man-induced or cultural eutrophication. The causes
included phosphorus in household detergents, municipal sewage and agricultural fertilizers. Advanced eutrophication is characterized by an abundance of nuisance algae and other aquatic plants, turbidity and oxygen depletion in bottom waters. These impacts can lead to clogged water intakes and filters, taste and odour problems and changes in the distribution and abundance of fish populations and other organisms.

**Toxics**

Unlike the efforts to control phosphorus, there has been limited success in coming to grips with the overall problem of toxics in the Great Lakes basin.

Specific regulatory measures have had an impact on controlling levels of some targeted substances such as mercury and DDT. However, there are many thousands of chemicals in use in the Great Lakes basin and new chemicals are being introduced continually. Even if only a few are known to be harmful, it is becoming increasingly apparent that their individual, combined and long-term effects do present serious environmental problems.

Most quantitative data about the extent of the problem is unavailable to the author at this time. However, some feeling for the magnitude of the problem can be drawn from the simple fact that the municipal phosphorus load in Lake Erie in 1983 (which accounts for about 50% of the load for the total basin) was about 2,500 tons (2,268 tonnes) per year. While this load is still a considerable problem, it should be compared with the load of over 14,000 tons (12,700 tonnes) in 1972.

Given that there is a problem of pollution in the Great Lakes basin, the question presented earlier, "How can technology be integrated into system design to prevent a breakdown at the human–machine interface that could result in adverse effects on the Great Lakes ecosystem," returns us to the object of this paper. An attempt will be made to answer the question using the following approach.

c. **Approach**

The primary emphasis for the approach taken here, to reiterate what was stated earlier, is to heighten the awareness of the workshop participants and other readers about the importance of the human–machine interface in controlling accidental releases of hazardous materials into the Great Lakes basin. The first step will be to review the relationship between human error and the human–machine interface breakdown. This is addressed in the second section of this paper and should establish the fact that most human error is design–induced and can be kept to an absolute minimum through good human factors design.

The third section of the paper makes the case that technology has a human side that must be considered in any application to design of the HMI.

The next step is to identify specific HMI or human factors design issues related to various technology areas. This will be done in the fourth, fifth and sixth sections of this paper that deal with automation, technology and computer error, respectively. Automation is considered to be a subset of technology, but because of its impact on human factors and the human–machine interface, it is treated separately from the other areas of technology. Computer error is treated separately because of the unique technical and cultural issues it raises.
Finally, some conclusions are drawn with respect to the importance of the various technology areas and issues identified to prevent a breakdown of the human–machine interface. Conclusions will also be offered for related human factors consideration. However, since this is a working paper for the HMI workshop participants, the ultimate conclusions and recommendations will be left to them.

6.1 HUMAN ERROR AND THE HUMAN–MACHINE INTERFACE BREAKDOWN

The problem of human error, its causes and its contributions to system malfunction and accidents, became widely recognized with the Three Mile Island–2 nuclear power plant accident. The United States Nuclear Regulatory Commission (USNRC) and several independent commissions conducted detailed analyses of that accident, which revealed that human error was one of the principal causes. More importantly, these analyses showed that, had basic human factors principles been applied to the design of the HMI, training and operating procedures, the accident could have been avoided.

Human error, as used in this paper, means that a human did something he or she shouldn't have done, or failed to do something that was required. In this sense, human error is a breakdown of the human–machine interface if that interface is broadly interpreted as the interface between humans and control panels, procedures or communication with other humans.

While the incidence of human error has been well documented in recent years, it has also been recognized that the reason for human error may well have been due to what another human did or failed to do. As stated by Parsons (1985a):

That another human may have been a designer of software, hardware or some environmental condition that, had it been better designed, would not have induced the human error. The human might instead have been the trainer who failed to bring skills to levels where there would not have been a human error or a manuals writer whose product, if more intelligible, would have provided the guidance needed to avoid the error. Or the original human error might have resided in a management that arranged motivational variables — incentives and deterrents — in a way that made the ultimate human error more probable. This view of human error is, to be sure, a crude kind of fault tree analysis from a systems viewpoint.

a. Human Error and System Malfunction

Since the Three–Mile Island accident, numerous studies have shown that human error causes or is a major factor in perhaps 50% of system malfunctions in nuclear power plants. For example, Dr. Howard L. Parris of the Electric Power Research Institute stated during his opening address as Chairman of the IEEE (Institute of Electrical and Electronic Engineers) Third Conference on Human Factors and Nuclear Safety in 1985:

As evidence of the further improvements that are required, the Office of AEOD (Analysis and Evaluation of Operational Data, NRC) and the Institute of Nuclear Power Operations (INPO) have independently conducted studies within the last year which concluded that human error rates are still at an unacceptable level. For example, INPO found, in an analysis of significant
event reports issued in 1983, that human error was the root cause in approximately 44% of them. The AEOD figures were about 6% lower. While the precise number may be debated, the figures do represent a challenge to the industry ...

Similarly, in December of 1985, a NRC report stated:

_During 1981 to June 1984, 65% of the loss of safety systems' functional events were the result of human factors contributions; for example, personnel errors._

Estimates for human error in other industries run as high as 80%. More recently, human–computer interface errors have become a problem. For example, Shneiderman (1983) cited one study where novice users of a 15-command subset of a text editor made mistakes in 19% of their commands; experienced users had 10% in error. In another study, experienced professional users of text editors and operating systems were committing errors in 31% of the tasks assigned them; another investigator found that professional workers made mistakes in 7 – 46% of their transactions in a challenging decision–making job. Since errors have occurred in use of command names, choices within menus and other software features, research efforts have been directed at preventing or reducing these errors by creating effective error recovery procedures and on–line and off–line training.

Hyman Rickover, father of the nuclear navy, once said all errors are human: human errors in design, construction or operation. While this may be true, it does not follow that they are inevitable or correctable.

b. **Human Error: Fact and Fallacy**

Hardly a day goes by that one does not read newspaper headlines about some accident that has been attributed to human error. Accident statistics compiled by insurance companies on home, street, railway and industrial accidents are full of causes such as carelessness, faulty attitude and inattention. Although these causes appear to tell us something, they really don't. Everyone is inattentive at some time or another and to say that an accident was caused by inattentiveness gives no clue whatsoever about how it could have been prevented. Yet, in examining these accident statistics, it is easy to conclude that the human is a highly unreliable component. In fact, the notion of human unreliability has long been part of popular wisdom, possibly from the notion that "To err is human," as coined by the poet, Alexander Pope.

The facts are that human errors are not random phenomena, nor are they usually caused by the perversity of the individual involved. Rather, in the majority of cases, the errors are attributable to factors external to the individual, factors that can be identified and controlled. Human error is induced by such factors as poor human–machine interface design (e.g. difficult to read or use, inappropriate controls and displays, poor workstation layout and, more recently, inappropriate use of automation and high technology) and inadequate personnel support system (e.g. poor procedures, supervision, communication, tools, job aids and training) or by environmental factors (e.g. excessive noise, glare and poor illumination, excessive heat or cold).
As stated earlier, the high frequency of human errors in all systems is well documented and varies from about 85% in automobiles/highway systems to 20% in the much simpler consumer product area. There are many root causes of human error, ranging from inadequate aptitude on the part of an individual to inadequate training or job performance aids. However, as stated earlier, the majority of human errors may be attributed to deficient equipment/system design or a lack of human factors considerations. These design-induced errors can have results that range from a situation where human performance is not possible (infrequent occurrence) to the situation where a greater potential for human error exists than is necessary (frequent occurrence). What we must recognize and deal with is that the causes of human error in most systems can be controlled, although some factors (e.g. work environment, equipment design and procedures) are more controllable than others (personal health or well being, spontaneous random error).

Accidents in systems can usually be accounted for by one of two variables. The first variable is the unpredictable manner in which the quality of human performance can change or human error can occur. The second variable is the unpredictable manner in which system demands change. If system demands on an operator are high at the very time when the level of quality of human performance happens to be low, the probability of an accident increases significantly. However, another factor that influences the occurrence of an accident is the lag time between the occurrence of the error and the evident consequences of that error. For example, a steering error when driving a car will typically result in a consequence in a very short period of time. However, a steering error when piloting a large ship will usually have a much larger lag time before the consequences occur. Thus, in some cases the lag between a human error and the response of a system to it can result in a delay period within which the operator can detect and correct his error. Therefore, when dealing with human error we must be concerned not only with the likelihood that an error will occur, but also with the probability that the error will be detected, the probability that if the error is detected recovery can occur and, if recovery occurs, an accident can be prevented or minimized.

Finally, many designers will develop a model to analytically test the hypothesis of the design. This technique builds confidence that the design will not fail. However, if the design includes explicit operations to be performed by a human, then most designers assume (frequently unknowingly) that the reliability of the human is absolute. In fact, they assume that the human will use the design, say a human–machine interface, exactly as the designer intended and will perform correctly every time. This is fallacious, as there are no perfect humans just as there are no perfect machines. Thus, the human error problem cannot be eliminated by just assuming it away, but it can be minimized by knowing the capabilities and limitations of humans and accounting for them in the design.

HMI design can do something about reducing the likelihood of making an error in the first place and can facilitate the detection of an error once it has been made. Human engineers must work closely with systems engineering people to develop design features that permit the system to recover from an error and to reduce the vulnerability of a system to the consequences of an error that has been made but not detected and not recovered.

c. Prevention of Errors

The fact that most human errors can be avoided, or at least their consequences reduced, suggests that design of the HMI is not only a
technology concern, but a human concern as well. This is the domain of human factors, and while it is beyond the scope of this paper to expound on the value of human factors methods (such as task analysis, the application of behavioral principles to control and display design and ergonomics), these factors are well-established techniques for reducing human error. The remainder of this paper will address human factors issues in technology concerned with the human–machine interface design. However, it should be noted that good human–machine interface design will not only hold human error to a minimum but will also:

- decrease training costs;
- possibly reduce the skill requirements of operators and maintenance personnel;
- increase users’ acceptance of that system and of the job they are required to do as part of it;
- reduce the life cycle cost of a system (because it reduces the need for costly retrofit);
- increase system safety and availability; and
- increase the productivity of personnel.

To conclude the discussion of human error, I would like to simply reiterate that prevention and treatment exist for the human error illness and the earlier applied, the better.

We will now examine the interaction of technology and the human factor.

6.2 THE HUMAN SIDE OF TECHNOLOGY

During a recent two-day meeting with many of my colleagues in human factors engineering at the Essex Corporation, the question of technology and its impact on the profession of human factors and the human–machine interface came up many times. There seemed to be a general consensus on two points. First, we must learn to use the technology we now have and will have in the future to support man and the human–machine interface in systems. Second, we must ensure that designs are driven by user needs and not by technological possibility. Both the advances of technology and the associated risks of its uses are potentially awesome. We have already discovered that just letting technology proliferate does not work (Bowser 1985). Left unconstrained, technology will force its way into every HMI that affects our larger ecosystem and we may end up being the victims rather than the beneficiaries of technology. Technology does have a human side that must be considered when designing the human–machine interface. Before looking at specific issues of technology and the HMI, we will briefly examine the human side of technology.

a. The Changing Role of Man

The earliest systems devised by mankind as an aid to survival made use of the full range of human capabilities. People developed and implemented plans, initiated and stopped action, provided muscle power, manually controlled processes, monitored results and solved problems. These simple systems merely augmented or extended human capabilities.
most of the injuries recorded, while flammability and explosivity are the mechanisms associated with most of the fatalities in the database.

Transportation releases account for 25% of all events in the database and a somewhat higher percentage of death or injury events (33%). Trucks are the predominant mode of transport in the death and injury events. Among events with human casualties at fixed facilities, storage vessels play a much larger role as release points than they do among events not leading to deaths or injuries.

When viewed from an industry perspective, the chemicals and allied products and the petroleum refining industries together account for 34% of the reported injuries and more than half of the reported deaths. The transportation industries account for 36% of reported injuries and about one-fourth of the reported deaths. Industries that use chemical or fuel products account for about 25% of the deaths and injuries.

Substances and Quantities Released

For events reporting quantity released, the quantities approximate a log normal distribution. Amount released exceeds 1,000 pounds for over 38% of the recorded events. Releases over 100,000 pounds occur in less than 3% of the events, but these events account for 93% of the total quantity of materials released. Over 80% of the events in the database reported that at least one of the substances released was a liquid; 16% of the events involved the release of a gas.

Causative Factors

Among events occurring at fixed facilities, spills are the predominant end effect, followed by vapor releases, fires and explosions. Storage vessels, process vessels and valves, or piping are responsible for nearly equal shares of in-plant events, but storage vessels typically release much larger quantities. Equipment failure is the cause most frequently reported for in-plant events, followed by operator error. Causation is difficult to assess for many of the events in the database, however.

Over half of the in-transit events involve trucks, another 36% involve rail cars. Over 38% of the in-transit releases stem from a leak and another 20% from collisions. Although few events were reported for pipelines, those spills dwarf other in-transit releases in terms of total quantity released.

While causation is difficult to assess, operator error was coded as the cause in approximately 11.4% of the in-plant events. Equipment failures were coded as the cause for 43.3% of the events, but as we shall see, many of these failures are due to human errors.

In the Great Lakes basin, the two major system-wide environmental quality problems of the lakes are eutrophication and toxic chemicals. These problems are described in the Second Biennial Report of the IJC (1984) as follows:

Eutrophication

At the time the 1972 Great Lakes Water Quality Agreement was being negotiated, the major water quality problem of the Great Lakes was considered to be man-induced or cultural eutrophication. The causes
The introduction of the high technology of word processors into our offices has led to a revival of handwritten notes and letters.

Whenever institutions introduce new technology to customers or employees, they should build a high-touch component; if they don't, people will try to create their own or reject the new technology. That may account for the public's resistance to automation and electronic accounting.

High tech/high touch. The more technology we introduce into society, the more people will aggregate, will want to be with other people: movies, rock concerts, shopping. Shopping malls, for example, are now the third most frequented space in our lives, following home and workplace.

High-tech robots and high-touch quality circles are moving into our factories at the same time — and the more robots, the more circles.

When we fall into the trap of believing or, more accurately, hoping that technology will solve all our problems, we are actually abdicating the high touch of personal responsibility. Our technological fantasies illustrate the point. We are always awaiting the new magical pill that will enable us to eat all the fattening food we want and not gain weight; burn all the gasoline we want and not pollute the air; live as immoderately as we choose and not contract either cancer or heart disease.

In our minds, at least, technology is always on the verge of liberating us from personal discipline and responsibility. Only it never does and it never will.

The more high technology around us, the more need for human touch.

I have quoted so liberally from Mr. Naisbitt because he makes the point so well about the need for human factors considerations in the utilization of high technology. As we shall see, however, Naisbitt isn't the only one who recognizes the symbiosis between technology and people.

c. Technology Driven or User-Driven Designs

Unfortunately, we are beginning to see more and more examples of complex human-machine interface designs that are technology driven rather than driven by the needs of users. There is a growing temptation to incorporate some new technological pizzazz in a design just because it can be done rather than because it is necessary. For example, during a recent conversation with a design engineer who worked for a major corporation, he proudly told me he was able to put 128 colors on the CRT (Cathode Ray Tube) display. I could only respond, "What are you going to do with the extra 120? One person can deal effectively with about eight colors." Because of the importance of the technology versus user issue in preventing a breakdown at the human-machine interface in future systems, the experience of a few others is included below.
Thus, the real progress in human–machine design does not, at this time, depend on breakthroughs in hardware technology. Rather, it depends on a better understanding of how to use what we have in a manner compatible with the nature of the human in the system.

Finally, technology may also affect the organizational structure. Perrow (1983) states:

Rather than technology determining organizational structure, it would appear that machines and equipment are designed so that they reinforce existing structures and reproduce these structures in new settings. Organizational structures as well as human–machine interfaces may contribute to accidents, a matter of concern where catastrophic potential exists, as in so many of the military and industrial systems.

In other words, organizational structures should not be driven by technology, but rather be based on the safety, productivity and social needs of the individuals and groups (or crews) in the work environment.

The next two sections will examine HMI issues related to various areas of automation and technology.

6.3 AUTOMATION AND HUMAN FACTORS ISSUES

In 1985, a special issue of Human Factors (the Journal of the Human Factors Society on Automation, Parson 1985a) was published. The editor of this issue, H. McIlvaine Parsons, wrote about human factors and automation in the preface as follows:

Our field concerns the interactions between modern technology's processes or products and the individuals who use them and automation constitutes a subset of that technology — indeed, the largest. By automation is meant not the state of automaticity, but rather any technological development in which a device of one kind or another replaces some human activity. Because automation in this sense has been going on for a long time and will continue perhaps even longer, it would seem to merit some explicit attention.

I, too, believe automation is a subset of technology that deserves separate consideration from those areas of technology that are intended to enhance human performance rather than replace it.

I shall borrow liberally from the articles in the special issue of Human Factors on Automation (including one I authored) to present arguments to support the proposition that automation is not just a design engineering issue, but is also a critical human factors issue. Returning to the preface written by Parsons, he states:

The person in the street, interpreting the term either way, might view automation as consigning human factors scientists and practitioners into the ranks of the unemployed along with the operators whose activities some hardware or software replaces. What need for human factors without humans? We know better. There still will be humans there, doing less perhaps or doing new things. When the epitome of automaticity came along, replacing the horse–and–wagon, the saddled
horse and walking, humans had to operate and maintain it with new and more complex skills. With the accelerating progression of human performances in the technological world from motor to perceptual–motor to verbal–imagery (cognitive) emphasis, the need for human factors involvements has grown, not lessened.

Following are some of the automation issues that will impact the performance of humans in systems:

- general considerations;
- allocation of functions;
- man as a monitor: cognitive support;
- work load: more or less;
- adaptive control systems; and
- user acceptance: affective support.

Within each of the above areas, HMI issues are identified and presented according to the following format:

- issue;
- argument;
- related considerations; and
- conclusions.

The argument, in most cases, is an example or an opinion found in the literature. The issue, related considerations and conclusions are my own. Each issue starts on a separate page.
a. AREA: GENERAL AUTOMATION CONSIDERATIONS

ISSUE: AUTOMATION DOES NOT REPLACE HUMANS IN SYSTEMS; RATHER, IT PLACES THE HUMAN IN A DIFFERENT, MORE DEMANDING, ROLE.

ARGUMENT: It is natural for system designers to exploit automation to the limits of affordable technology. The question of what should be automated is seldom asked. Design decisions are made on engineering grounds alone and are soon firmly cast into hardware and software, after which they permanently limit the flexibility of the human role. Consider the three supporting arguments below.

A case in point is aircraft cockpit automation, discussed by Wiener (1985):

Designers responded to pilot error and the increasing cockpit work load by attempting to remove the error at its source, that is, to replace human functioning with device functioning; in their view; to automate human error out of the system. But there were two flaws in this reasoning: (1) the devices themselves had to be operated and monitored by the very humans whose caprice they were designed to avoid; human error was not eliminated, but relocated; and (2) the devices themselves had the potential for generating errors that could result in accidents. Overall, the movement toward cockpit automation has undoubtedly enhanced safety, but new problems have been created that are only now being appreciated.

Bainbridge (1982) offered a similar opinion about designers who attempt to automate operators out of the system.

The designer's view of the human operator may be that he is unreliable and inefficient, so should be eliminated from the system. There are two ironies of this attitude. One is that designer errors can be a major source of operating problems. The second irony is that the person who tries to eliminate the operator still leaves him to do the tasks which he cannot think how to automate. It is this approach which causes the problems to be discussed here, as it means that the operator can be left with an arbitrary collection of tasks and little thought may have been given to providing support for them.

And Perrow (1984) talked about the interactions in more complex systems:

Linear systems also have interactions that are not visible, of course, but they occur within well-defined and segregated segments of the production of maintenance sequence. Controls, such as dials, warning lights, audible alarms and switches read the presence of these interactions and inform the operators and allow them to intervene.

In systems with a fair degree of complex interactions, however, well-defined and segregated segments do not necessarily exist. Indeed, jiggling Unit D may well affect not only the next Unit, E, but A and H also. This increases the number of controls that must be installed and monitored. The control panel of a nuclear plant is considerably denser and larger than that of an oil or coal plant, in part because so many components are linked in branching paths and feedback loops.

Attempts are continually made to reduce the number of controls by automating the subsidiary interactions and leaving only the main parameters for the operators to worry about. But this decreases the system's flexibility; the operator loses the ability to correct a minor failure in a part and must shut down a whole unit or subsystem. The operator cannot exit from the high-level, summary controls to the low-level, specific one required to deal with a single part.

CONCLUSION: Automation creates a whole new set of needs for human factors considerations in system design, especially since there are fewer established design principles.
b. AREA: ALLOCATION OF FUNCTIONS

ISSUE: THE ALLOCATION OF FUNCTIONS (TO MAN AND MACHINE) SHOULD BE A SPECIFIC ACTIVITY IN THE SYSTEM DESIGN PROCESS.

ARGUMENT: To optimize performance and avoid animosity of users toward automation, tasks and decisions should be allocated properly, according to Price and Pulliam (1982):

The startling advance of microprocessor and display system technology could be the most significant technological fact of this decade and its pace is clearly accelerating. It creates a vacuum of technological opportunity which we hurry to fill. The military services, for example, are rushing to automate their command, control and intelligence activities. In spite of some disappointments they continue to hope that, using the computer, they may be able to succeed in managing the speed and complexity of modern warfare. Similarly, we who serve the nuclear power industry believe that automation may provide the best hope for mastering the complexity of Nuclear Power Plant (NPP) control and may permit the design of control systems which are at the same time safer, more efficient and better suited to the characteristics of man.

The rush to automation has not always fulfilled these optimistic hopes. In fact, it is almost a rule that automated systems are in some ways not as satisfactory as the manual systems they replace. Nearly every new system creates some new work load as it alleviates others. Nearly every new system generates new causes of error. Automated systems are often considered less friendly by operators and we constantly see instances in which the users resist automation, seek to override the new system or continue to do by hand what the system was designed to do. In a large proportion of these cases the problem can be traced to an improper allocation of functions between man and machines. Almost always this is due in part to the fact that there has been no deliberate consideration of which tasks and decisions are best performed by man and which by machine.

Additionally, in a 1985 article by Price:

In most modern workplaces there is a close sharing of tasks between people and machines. How these tasks are apportioned is determined by the design of the system—the physical system and the human organization. That apportionment is usually called the allocation of functions between humans and machines. Allocation of functions is the most basic of system design decisions. Most often it is a decision that the designers make unconsciously rather than by deliberation and it is a decision that establishes the framework within which job or task analysis and the requirements for personnel selection, training, procedures development and design of the human-machine interface are developed.

CONCLUSION: Allocation of function decisions should begin early in system design; if not made correctly, they can be very expensive to correct, especially after elements of the system have been built as hardware.
c. AREA: MAN AS A MONITOR: COGNITIVE SUPPORT

ISSUE: IF MAN IS TO BE AN EFFECTIVE MONITOR IN A SYSTEM, THEN HE MUST BE PROVIDED WITH UNIQUE COGNITIVE SUPPORT INFORMATION.

ARGUMENT: Man's effectiveness as a supervisory controller depends both on design considerations to enhance monitoring performance and on specific information to satisfy his mental needs to be ready for intervention. Many researchers and designers have acknowledged the possibility that automatic systems may not provide the necessary information for the operator or supervisor to remain in the loop mentally. As Wiener (1985) stated:

*In my research on the MD-80 with a major airline, pilots have remarked about being along for the ride. The problem is not one of insufficient work load, although boredom and complacency are often mentioned, but a strong sense of being out of the loop.*

Price (1985) defines cognitive support as follows:

*Cognitive support refers to the human need for information to be ready for actions or decisions that may be required. Could displays or other sources of information be provided to furnish all the information needed? Can a work sequence be established so that the human will maintain an adequate mental model of the system and its conditions by being actively involved in controlling or approving the key system changes? Could the human operator be given sufficient activity to ensure alertness?*

Bainbridge (1982) discusses some general solution concepts, as follows:

*In any situation where a low probability event must be noticed quickly then the operator must be given artificial assistance, if necessary, even alarms on alarms. In a process with a large number of loops, there is no way in which the human operator can get quickly to the correct part of the plant without alarms, preferably also some form of alarm analysis. Unfortunately, a proliferation of flashing red lights will confuse rather than help. There are major problems and ironies in the design of large alarm systems for the human operator.*

*Displays can help the operator to monitor automatic control performance, by showing the target values. This is simple for single tolerance bands, but becomes more complex if tolerances change throughout batch processing. One possible solution is to show the currently appropriate tolerances on a VDU by software generation.*

*This does not actually get around the problems, but only raises the same ones in a different form. The operator will not watch the VDU if there is a very low probability of the computer control failing. If the computer can generate the required values, then it should also be able to do the monitoring and alarms. And how does the operator monitor that the computer is working correctly or take over if it obviously is not? Major problems may be raised for an operator who is highly practiced at using computer generated displays if these are no longer available in an emergency. One ironic but sensible suggestion is that direct-wired displays should be used for the main process information and software displays for quantitative detail.*

*Catastrophic breaks to failure are relatively easy to identify. Unfortunately, automatic control can camouflage system failure by controlling against the variable changes, so that trends do not become apparent until they are beyond control. This implies that the automatics should also monitor unusual variable movement ... automatic systems should fail obviously.*

*If the human operator must monitor the details of computer decision-making then, ironically, it is necessary for the computer to make these decisions in a way, using criteria and at a rate which the operator can follow, even when this may not be the most efficient method technically. If this is not done, then when the operator does not believe or agree with the computer, he will be unable to trace back through the system's decision sequence to see how far he does agree.*

One unique aspect of cognitive support often not recognized by system designers is information that is relative to the intentions of the human and the computer. Bainbridge (1982) refers to the important point made by other researchers:

*...that the human being must know which tasks the computer is dealing with and how. Otherwise the same problems arise as in human teams in which there is no clear allocation of responsibility.*

Another way of looking at the above is that the operator must have confidence in the computer, for we discovered some time ago (Sinaiko 1972) that:
"... when loads were light, the man appeared willing to let the computer carry most of the assignment responsibility; when loads were heavy, the men much more often stepped in (and) over-rove the computer." Evidently, quite apart from technical considerations, the design of computer aiding is a multi-dimensional problem.

Sharit (1985) provides another perspective about human supervisory control of manufacturing systems, as expressed in the excerpts below.

Although precise delineations of the human supervisory role in future batch manufacturing facilities depend on the evolution of computing power and software, one fact is clear: the impact of the development and implementation of Computer Assisted Manufacturing (CAM) on the human worker has been largely ignored... More specifically, we need to have a clearer understanding both of the cognitive demands associated with supervisory control that are imposed by the automated batch manufacturing environment and of the supervisory capabilities of the human with respect to those demands.

Although the potential exists for an active supervisory role, the job design philosophy assumed by most manufacturers regarding supervisory control ...implicitly negates human decision-making functions. Most of the human's actions result by default — that is, when something goes wrong. This makes the human's involvement more passive and in the process, violates various human factors principles of job design. A coherent role would demand a significant portion of the human's attention and abilities by requiring the properties of display information to be studied instead of being only scanned for problems. By not being actively involved in system control, the human is less likely to be efficient in reacting to critical system events. The presence of such events could, in fact, go entirely unnoticed. The human's supervisory role essentially reduces to monitoring, a task humans may perform poorly over prolonged periods of time.

Sharit goes on to state that an interactive design strategy that acknowledges the best use of the human and the computer is necessary.

RELATED CONSIDERATIONS: Bainbridge (1982), Price et al. (1980) and Price (1985) also remind us of the related considerations of maintaining skill proficiency in systems where the operator is primarily a monitor. It has been well established for many years that manual-control skills need to be practiced to be effective. This results in an ironic situation, as stated by Bainbridge:

> When manual take-over is needed there is likely to be something wrong with the process, so that unusual actions will be needed to control it and one can argue that the operator needs to be more rather than less skilled and less rather than more loaded than average.

Cognitive skills likewise deteriorate without use and feedback. Additionally, the operator's knowledge of the current state of the process may be limited or at least incomplete. As Bainbridge states:

> The implication of this for manual take-over from automatically controlled plants is that the operator who has to do something quickly can only do so on the basis of minimum information; he will not be able to make decisions based on wise knowledge of the plant state until he has had time to check and think about it.

Finally, user acceptance is a related area and as Price (1985) has stated:

> If a system design is unacceptable to the user — regardless of engineering performance and reliability — he will under-use it, misuse it or even sabotage it.

Acceptance is highly dependent on the information available to the user or operator.

CONCLUSIONS: Perhaps this issue can best be concluded by restating what I recently wrote (Price 1985) about tools of cognitive analysis that must be developed. Specifically, designers must:

> ... ensure that operator (or maintainer) and computer each know what the other is doing. The human must understand the objectives of automatic control and the allocation of responsibility to human operation and machine logic. In the same way, the automatic logic must be informed about the actions and objectives of the operator. Otherwise, the human and hardware/software systems may work at cross-purposes.

It is also important that the operator have the opportunity to practice manual intervention.
ISSUE: AUTOMATION TYPICALLY REDUCES MANUAL WORK LOAD BUT INCREASES MENTAL WORK LOAD.

ARGUMENT: Much has been studied and written about cockpit automation. One of the foremost authorities in this area is Earl Wiener, who recently wrote (1985):

A principal rationale for cockpit automation has been the assumption that work load is reduced, thus achieving the following three objectives: (1) Pilots prefer to be relieved of much of the routine manual controlling and mental computation in order to have time to supervise the flight more effectively and to perform optimally in an emergency; (2) at lower altitudes, especially in terminal areas, it is essential that pilots spend less time with their heads in the cockpit and more time doing what no presently certified airborne device can do, that is, scan for other aircraft; and (3) airlines have demanded and are now receiving wide-body aircraft that are flown by two-pilot crews. For two pilots to perform a task previously performed by three, work load must be reduced. To achieve this, designers look to automation.

The mental work load dimension further compounds this issue. Pilots complain of more programming, planning, sequencing and alternative selection and more thinking; in short, more cognitive processing. Field studies by the author on the MD-80 indicate that pilots perceive some reduction in the total work load, but probably less than that claimed by the manufacturers during the certification process. Designers emphasize reducing manual work load, not accounting adequately for mental work load. As for more time to look for other traffic, pilots generally are unimpressed with the claims for automation. Their attitude is that the automatic devices demand constant attention, scanning as they call it and although crews may be relieved of such head-in-the-cockpit duties as maintaining airspeed (which an autothrottle does quite competently), each device creates its own scanning demand ... A B-767 captain told me, "It is more complicated to direct an automatic system than to do the job manually ..."

Following the same theme, Perrow (1984) discusses pilot work load.

All of these automatic systems make the craft more efficient in terms of commercial or military criteria. Indeed, in the newest jets, such as the Boeing 767, the flight crew has been reduced to two and a large number of knobs, switches and dials have been replaced by CRTs and buttons linked to computers controlling computers. But with each bit of automation, more difficult performance in worse weather or traffic conditions is demanded. It appears, indeed, that work load has become more bunched, with long periods of inactivity and short bursts of intense activity. Both of these are error-inducing modes of operation.

Finally, Ephrath and Young (1981) have reported a study in which system performance was worse with computer aiding, because the operator made the decision anyway and checking the computer added to his work load (also reported in Bainbridge 1982).

CONCLUSION: Automation has not resulted in a net work load reduction and may, in fact, cause periods of too little demand with occasional bursts of intense demand. Also, cognitive workload may increase due to human needs to understand and follow what is going on in highly automated systems.
ISSUE: WE NOW HAVE TECHNOLOGICALLY FEASIBLE ADAPTIVE CONTROL SYSTEMS THAT CAN BE MODIFIED (MANUALLY OR AUTOMATICALLY) TO REDISTRIBUTE THE ALLOCATION OF RESPONSIBILITIES TO MAN AND MACHINE. HOWEVER, THIS DESIGN DECISION IS DEFINITELY AS MUCH A HUMAN FACTORS CONSIDERATION AS IT IS AN AUTOMATION CONSIDERATION.

ARGUMENT: It would appear that adaptive control systems can solve many of the human factors issues raised about automation. Indeed, there is unique potential here for both success and failure. This area is an excellent example of where art and science must be considered together. If the design outcome is not acceptable to the user, then a costly or dangerous mistake is possible. Discussions from three human factors professionals are offered.

Price et al. (1982) described the potential for adaptive allocation of function while investigating the context of nuclear power plants:

>An entirely different type of functions allocation may be evolving with the advent of computers which now have the ability to make certain types of decisions in a manner closely resembling that of a human operator. This is the concept of adaptive computer aiding or adaptive allocation of functions. In a system of this type, allocations between the human operator and machine components (computers, in this case) are all or none assignments. Both the operator providing direction and control at one time and for one event and the computer providing direction and control at another time for another event, represent a departure from past systems in which man was hard-wired into a system with a rigid and fixed set of allocated functions. With adaptive computer-aiding, a form of sharing has become possible that capitalizes on the strengths of both man and computer but which introduces an altogether new perspective on functions allocation.

Research on systems of this type is still in its infancy. Crooks et al. (1974) report on a long-term research project designed to explore this type of system. Sinaiko (1972) gives an account of an experiment on naval antiaircraft systems which included one condition closely resembling an adaptive system. One point that all authors make when discussing this type of system is the conviction that it is essential that the final decision-making responsibility rest with the human operator. Therefore, the human operator should have, as part of his role, the option to over-ride the computer when the operator determines that the situation warrants such an action. The goal, then, if not to replace the human operator or to imply that the computer can take over all the functions of the human operator, but rather to enhance system performance using the best available resources.

Bainbridge (1982) provides a collaborative account relative to general complex systems:

>There will always be a substantial human involvement with automated systems, because criteria other than efficiency are involved, e.g. when the cost of automating some modes of operation is not justified by the value of the product or because the public will not accept high-risk systems with no human component. This suggests that methods of human-computer collaboration need to be more fully developed...

Using the computer to give instructions is inappropriate if the operator is simply acting as a transducer, as the computer could equally well act as a more reliable one... When following advice, the operator's reactions will be slower and less integrated than if he can generate the sequence of activity himself; and he is getting no practice in being intelligent. There are also problems with the efficient display of procedural information.

A few practical points can be suggested. There should be at least one source of information permanently available for each type of information which cannot be mapped simply onto others, e.g. about layout of plant in space as opposed to its functional topology. Operators should not have to page between displays to obtain information about abnormal states in parts of the process other than the one they are currently thinking about, nor between displays giving information needed within one decision process. Research on sophisticated displays should concentrate on the problems of ensuring compatibility between them, rather than finding which independent display is best for one particular function without considering its relation to information for other functions. To end on a more optimistic note, software displays offer some interesting possibilities for enriching the operator's task by allowing him to design his own interface.
Wiener (1985) once again provides some excellent insight in the context of cockpit automation.

It should be clear by now that to discuss automation we must examine the rapidly changing nature of the flying task, which has resulted from two developments: (1) the increasing complexity of the environment in which pilots fly—an environment congested with aircraft, demands, regulations and procedures; and (2) a vast number of computer-based devices at the pilots' fingertips, replacing the demand for manual control and mental arithmetic. Also, modern aircraft contain an array of warning and alerting systems (the machine monitoring the pilot), which are a subject of considerable controversy. These devices remind pilots to take action (e.g. altitude alerters), warn them of deviations (e.g. the excessive airspeed clacker), suggest (or demand) action (e.g. the pull-up message of the ground proximity warning system), warn them of unacceptable configurations (e.g. flap over-speed on the MD-80) and even take action on their own, such as autoslats and stick pushers, which are designed to break stalls if pilot intervention has not relieved the problem.

Machines Take Action

Not surprisingly, pilots are concerned. The last example is a good one, for it exemplifies what pilots fear in the automation movement, that decisions will actually be implemented without their consent.

Pilots and observers have been alarmed at the tendency of crews to attempt to program their way out of trouble with the automatic devices, rather than shut them off and fly by traditional means of guidance. Not only are the pilots worried about a possible erosion of skills due to overuse of automation, but they are also more concerned about their perceived loss of control—that the machines are taking over and making decisions on their own, as in the case of the stick pusher. On the other hand, it could be argued that there is nothing more serious than a stall and that the stick pusher is designed to save the aircraft when all else has failed—the human crew has not responded to the stall warnings and indications. The device takes over by default. It is the ultimate backup.

Pilot fears may be justified, as we shall see in the section of this paper that deals with Computer Errors.

Wiener (1985) also talks about the flexibility of soft displays that suggest the potential for adaptive control:

Equally important, soft displays permit the pilots to configure their instrument panels and displays as they see fit. With soft displays pilots can select or deselect features according to their own style of flying and their desire for information... My former colleague Renwick Curry and I have advocated allowing the pilot more freedom to fly the plane and use the automation in the manner he or she wishes, but surrounded by a multidimensional warning and alerting system that informs the crew if they are approaching some limit. As long as the plane stays well within the limits, the pilot has great freedom to conduct the flight according to his or her individual style. We called the concept an electronic cocoon or flight management by exception.

RELATED CONSIDERATIONS: The area of adaptive control systems is closely intertwined with the areas of allocation of functions and user acceptance, as well as computer error.

CONCLUSION: Adaptive control system design is more of a human factors problem than a technological one.
ISSUE: "IF A SYSTEM DESIGN IS UNACCEPTABLE TO THE USER — REGARDLESS OF ENGINEERING PERFORMANCE AND RELIABILITY — HE WILL UNDER-USE IT, MISUSE IT, OR EVEN SABOTAGE IT." (PRICE 1985)

ARGUMENTS: I have been aware of the effects of user acceptance on system performance for more than 20 years. In the 1960s, I conducted a study for the National Aeronautics and Space Administration (NASA) of pilot acceptance factors in the design of all-weather landing systems (Price et al. 1964). NASA was looking into several approaches for automating all or a portion of the tasks required to land an aircraft during conditions when visual contact with the runway would be virtually impossible. Such a system could be feasibly solved from the engineering standpoint but posed a severe acceptance problem on the part of the pilot. Table 1 shows several generalized principles of acceptance and automation that resulted from that study and are still valid.

More recently (Price 1985), I referred to the issue of user acceptance as the need for affective support in system design.

Affective support refers to the emotional requirements of humans, such as their need to know their work is recognized for its value, to feel personally secure and to feel that they are in control. Although such judgments are difficult to make, they can be estimated from experience with similar systems, from self-report data or from design factors such as extent of feedback.

With the advent of more advanced forms of automation, others have recognized the necessity of considering user acceptance of affective support in the design of automated systems. Excerpts from appropriate authors follow.

Perrow, the author of Normal Accidents (1984), states:

Operators tend to resist the introduction of more general, high-level controls such as CRTs, which produce a television screen display of the state of a number of units or subsystems, because they feel they cannot make selective interventions as easily. Only these high-level controls can be manipulated; the selective ones are more difficult to get because it is assumed they will not be needed. They may be out of the way or accessible only by a complicated series of steps that inactivate the more general controls. On the other hand, operators also complain about the arrangement of less automated systems that allow selective intervention, because they are confronted with 15-foot banks of identically designed switches with tiny numbers above them. These are not even grouped in any way that reflects operation, but only in the way that reflects ease of installation. One of the most common operator errors in nuclear plants is, understandably, operating the wrong switch. Surely the choice need not be reduced discretion versus endless, identical displays.

Bainbridge (1982) writes about the importance of operator attitudes.

The writer knows of one automated plant where the management had to be present during the night shift, or the operators switched the process to manual. This raises general issues about the importance of skill to the individual. One is that the operator knows that he can take over adequately if required. Otherwise the job is one of the worst types, it is very boring but very responsible, yet there is no opportunity to acquire or maintain the qualities required to handle the responsibility. The level of skill that a worker has is also a major aspect of his status, both within and outside the working community. If the job is deskilled by being reduced to monitoring, this is difficult for the individuals involved to come to terms with. It also leads to the ironies of incongruous pay differentials, when the deskilled workers insist on a high pay level as the remaining symbol of a status which is no longer justified by the job content.

Wiener (1985) reports on flight crew acceptance issues:

... modern aircraft contain an array of warning and alerting systems (the machine monitoring the pilot), which are a subject of considerable controversy. These devices remind pilots to take action (e.g. altitude alerters), warn them of deviations (e.g. the excessive airspeed clacker), suggest (or demand) action (e.g. the pull up message of the ground proximity warning system), warn them of unacceptable configurations (e.g. flap over-speed on the MD-80) and even take action on their own, such as autoslats and stick pushers, which are designed to break stalls if pilot intervention has not relieved the problem.

Not surprisingly, pilots are concerned. The last example is a good one, for it exemplifies what pilots fear in the automation movement, that decisions will actually be implemented without their consent.
In my research on the MD-80 with a major airline, pilots have remarked about being along for the ride. The problem is not one of insufficient workload, although boredom and complacency are often mentioned, but a strong sense of being out of the loop. Pilots and observers have been alarmed at the tendency of crews to attempt to program their way out of trouble with the automatic devices, rather than shut them off and fly by traditional means of guidance. Not only are the pilots worried about a possible erosion of skills due to overuse of automation, but they are also more concerned about their perceived loss of control — that the machines are taking over and making decisions on their own ... An airline check captain made an unforgettable statement to me about the DC-9-80: "I am willing to fly it as long as it has the yellow button (autopilot disengage). I can always turn it back into a DC-9."

Beltracchi and Lapinsky (1985) observe:

In summary, it is our belief that a useful display is one that the operator can trust. This goal can only be achieved by designing a system that's reliable and provides valid information. In addition, the system credibility must be maintained and protected through routine maintenance and configuration control, administrative controls and security measures if necessary. The industry is making gains in the realm of automation of operator tasks—we must strive to assure that we do not lose ground in doing so by destroying the operator's faith in the system.

If users do lose faith in the system, we run the risk of the ultimate design rejection — sabotage, as reported in Time, September 20, 1982:

Robot Sabotage

As the Industrial Revolution gathered strength in the 19th century, English workmen attempted to destroy new textile machines because they seemed to be taking away their jobs. Nearly two centuries later, some employees are using similar tactics against the new robots that are beginning to appear in more and more plants.

Management Training Center in The Netherlands, has just concluded a study of the acceptance of the automatons in his country, where 70 firms currently use robots. He found that the most common form of sabotage was to slow down the machines by feeding them parts in the wrong order, with the hope that management would be disappointed in robot performance. In other cases, employees repaired the machines incorrectly, mislaid essential spare parts or put sand into the robots' lubricating oil. In one metal construction plant, production was reduced for more than six months because of worker resistance. Other companies are certain to face similar troubles, says Nijland, unless management encourages honest discussion with workers about the effect robots will have on the jobs.

CONCLUSION: A number of attitudes, needs and concerns can affect acceptance of a system design with which the user must interface. Acceptance can be negative even where the design engineering is excellent. It has been shown clearly that user acceptance and affective support must be integrated into system design along with good engineering practices.
6.4 TECHNOLOGY AND HUMAN FACTORS ISSUES

The course of technology for the remainder of this century is fairly well known — particularly those areas of technology that will impact the effectiveness of the human-machine interface. However, what has not been established is how technology will be integrated into design of the HMI in effective ways to support rather than overwhelm man. The one thing we cannot do is ignore the proliferation of technology; it touches the lives of everyone. As stated by Van Cott (1985):

*Technology helps bring us into the world, gives us jobs, shapes the way we think, electrifies our homes, feeds us, entertains us and埋了 us. When a major system malfunctions, nations are helpless. We have become utterly dependent upon technology.*

*But we have only begun to experience the future. In the next decade millions of jobs in factories, offices, hospitals, railroads, schools and stores — and in other workstations from submarines to space shuttle — will be reshaped or replaced by high technology. None of us will be immune from the effect of high technology on human life.*

*With good planning and appropriate design, this high technology revolution could be of great benefit to society. People could spend less time in the arduous acts of survival that have characterized most of human history and more in pursuing their lives' goals. But without adequate planning and design we could be headed for a time of anguish and frustration.*

Left unconstrained, technology will force its way into every HMI that affects the larger ecosystem and may increase rather than decrease the risks of system breakdown. The following are some of the technology issues that will impact the integrity of the HMI in system design. The material is organized into the areas listed below:

- General Technology Considerations;  
- Artificial Intelligence/Expert Systems;  
- Computer-Driven Display;  
- Robotics; and  
- CRT Color Displays;  
- Technology and Organizational Effectiveness.  
- Data Input Techniques;  
- Voice Input/Output;

Within each of the above areas HMI issues are identified and presented according to the following format:

- Issue;  
- Argument;  
- Related Considerations; and  
- Conclusions.

The argument in most cases is an example or an opinion found in the literature. The issue, related considerations and conclusions are my own. Each issue starts on a separate page.
ISSUE: HIGH TECHNOLOGY MAY INDUCE GREATER RISK-TAKING BEHAVIOR ON THE PART OF THE USER.

ARGUMENT: Technological interfaces may induce risk-taking behavior as well as human error. Perrow (1984) discusses the widespread use of radar and other electronic navigator devices on ships and how they have failed to reduce the number of marine accidents. This failure is alluded to in an account provided by a ship's captain to Perrow:

*Instruments for course keeping, position finding, depth recording, have all improved very considerably over the last several years and the twin radar sets now commonly fitted in tankers mean that there is data readily available on the position of all other vessels in contact, regardless of visibility; yet ships continue to collide, to strand and occasionally to founder. It appears that one must conclude that improved instrumentation is being used to enable navigators to prosecute their voyage with greater economical efficiency and certainly with greater ease, but the risk per ship would seem to remain about constant.*

Petroski (1985) introduces the idea that high speed computations by computers may also increase the risk that designers are willing to take:

*Because the computer can make so many calculations so quickly, there is a tendency now to use it to design structures in which every part is of minimum weight and strength, thereby producing the most economical structure. This degree of optimization was not practical to expect when hand calculations were the norm and designers generally settled for an admittedly over-designed and thus somewhat extravagant, if probably extra-safe, structure. However, by making every part as light and as highly stressed as possible, within applicable building code and factor of safety requirements, there is little room for error—in the computer's calculations, in the parts manufacturers' products or in the construction workers' execution of the design. Thus computer optimized structures may be marginally or least-safe designs, as the Hartford Civic Center roof proved to be.*

CONCLUSION: The question of whether automated systems and computers provide a false sense of security or validity arises over and over again in the literature.
ISSUE: THE EXTREME FLEXIBILITY OF SOFT DISPLAYS (SOFTWARE-GENERATED) INVITES TECHNOLOGY-DRIVEN RATHER THAN USER-DRIVEN DESIGN.

ARGUMENT: Soft displays permit the designer to use symbols, colors, text, three-dimensional graphics, perspective views, enhanced images, overlays and other techniques to provide information in formats never used before. However, in modern aircraft cockpits, this technology is not proving as successful as expected. Wiener (1985) emphasizes this point in his article on cockpit automation:

But with flexibility comes problems. We have seen a tendency for proposed soft displays to become a jungle of clutter, of ill-considered symbols and text and a dazzling presentation of colors. Little wonder that pilots are now referring to the modern instrument panels as Pac Man and Atari. The attitude of too many computer experts is, "We can do it, so let's throw it up on the display. It can't hurt anything." Thus it will fall to human factors practitioners to persuade designers to go back to the fundamental question: What information does the operator need and in what form (or forms) should it be displayed?

Finally, we might take note of the striking similarity between the conceptualized cockpit and the office of the future ... The cockpit is starting to resemble an office and the office a cockpit. This is an example of what biologists call convergent evolution, whereby disparate systems begin to resemble each other over time. Why does convergent evolution occur? Because the separate systems are attempting to solve the same problem using roughly the same resources. What is the common problem here? Essentially it consists of information management, communication, decision-making and supervisory control.

RELATED CONSIDERATIONS: The flexibility of soft displays not only gives the designer a great deal more freedom in dealing with information, but provides control flexibility as well. This can result in an economy of cockpit space or panel space in many work situations where panel space is valuable. Multifunction controls and touch panel displays are impressive. Nevertheless, as with information, the design of computer-driven controls will demand careful attention from human factors engineers to maintain the user's viewpoint.

Another potential advantage of computer-driven displays and controls is that they permit the operator (a pilot, for example) to configure the instrument panels and displays as he sees fit. As Wiener (1985) states, "With soft panel displays pilots can select or deselect features according to their own style of flying and their desire for information ... " Desires and needs for automation will vary with operators and with time, for any one operator.

CONCLUSION: The flexibility provided with automation and computer-driven controls/displays is indeed a technological marvel. It is also an invitation for zealous designers to build in too much information and control function without relating them to user tasks or needs, or human capabilities and limitations.
ISSUE: COMPUTER-BASED DISPLAY SYSTEMS MUST BE PROTECTED TO AVOID INADVERTENT CHANGES TO THE DATA BASE.

ARGUMENT: Beltracchi and Lapinsky (1985) report an example of this protection problem found in a nuclear power plant.

... in order to maintain credibility, a display system must be reliable and produce valid information; after achieving that, credibility can only be maintained by protecting displays and controlling access to them and the database that feeds them.

The Nuclear Regulatory Commission staff has seen several systems in which this was not adequately done. For example, one of the early prototypes was a system that had CRT terminals in the control room, the Technical Support Center (TSC) and the Emergency Operations Facility (EOF). The control room CRT was partially slaved to the TSC terminal; that is, the control room operators could call up displays on the control room terminal, but the TSC had overriding control of the control room CRT. This potential pre-emption of control room displays by TSC personnel was unacceptable. The situation was further complicated by the fact that the TSC was used as a training facility and the Safety Parameter Display System (SPDS) was often used as a part-task simulator. With this configuration it became possible to change the control room displays from the TSC and present simulated data in the control room without the knowledge or consent of control room operators. The licensee involved has taken action to correct this situation.

RELATED CONSIDERATIONS: Data base or display integrity should be protected from unwarranted intrusion by disgruntled employees or others bent on deliberately distorting the display information.

CONCLUSION: Software protection is a necessary design feature; particularly in situations where there are multiple slaved (at least in part) displays.
ARGUMENT: Beltracchi and Lapinsky (1985) describe a classic example of this issue, as follows:

The trends of critical process variables during anticipated operational occurrences and accidents contain important information about the status of the plant's process. Displays of trends for critical process variables must be easily accessed, read and comprehended if they are to be rapidly and reliably used by operators.

A common use of cathode-ray tubes within control rooms is to display the time history and current trend of a process variable. In general, the recent data for the process variable is located in the right hand portion of the display screen with a time continuous trace of older data extending to the left portion of the display screen. Thus, the scale for time is from right to left, with current time on the right. This form of time scale is directly related to the one used in the strip chart recorder.

However, the scale for the process variable is generally located in the left portion of the display screen, where the oldest data for the process variable is displayed. With this location for the scale, it is not possible to view the scale together with the current real-time trend of the process variable as each is located at opposite ends of the display screen. An operator's task to determine margin to a setpoint from the current value and trend of the process variable displayed is now more complex with the display screen than for the chart recorder. In simulator tests of these trend display formats, operators have detected and noted these differences.

CONCLUSION: Display designers should not overlook the good features of conventional displays and operator expectations built up from using these conventional displays.
e. AREA: CRT COLOR DISPLAYS

ISSUE: COLOR HAS GENERALLY NOT BEEN SHOWN TO IMPROVE PERFORMANCE, BUT THE USE OF TOO MUCH OR POOR QUALITY COLOR CAN NEGATIVELY AFFECT USER PERFORMANCE.

ARGUMENT: A controversial issue concerns the efficient application of color to the information retrieval process. CRT colors on a black background tend to be esthetically pleasing and thus provide their own reason for being; therefore, a user may tend to color-code as many categories of information as there are colors available (usually seven or eight). This approach to coding probably will not improve the user's performance beyond that of a monochromatic CRT. For instance: (1) Different subsystems of a larger system are often assigned different colors even though the different systems seldom, if ever, appear on the same screen together, so coding by labeling is sufficient; (2) Since there are often fewer colors than functions to be coded, colors tend to be used to code more than one function. Such practice greatly reduces, if not eliminates, the effectiveness of a code and raises the possibility of misidentification; and (3) The presence of several color-coded functions on a screen, no matter how carefully planned, runs the risk of color clutter, a condition in which there is so much stimulation in the picture that the intended information is obscured. In these conditions, color is working against, not for, the user.

An additional constraint is placed on the use of the color red for coding when process control data for electrical utilities are displayed on CRTs. In most control rooms, red has two basic meanings or functions. First, when color is used for prioritization, red signals a high-priority warning or potential problem by means of the annunciator system. Second, red signals that equipment is actuated or energized (i.e. water is flowing through a pump or valve or a breaker is closed). When a color is used to code two meanings, there is a likelihood that its coding effectiveness will be decreased and the desired or intended response will be weakened because of a competition between the meanings. This problem may be alleviated somewhat in the control room because the warning function and equipment actuation function are usually separated spatially. The annunciators are on a high panel and the equipment indications are below the annunciators.

However, when both functions of red are displayed on a CRT, the spatial separation context is no longer present; the two applications of red can appear not only on the same CRT but even in the same location. For instance, a running pump may be represented as red on the CRT screen, but nearby is a bar chart or numerical value, also shown in red to represent a value that is out of tolerance or beyond a limiting condition. Such multiple meanings of a stimulus often require time to double-check the meaning and under severe time constraints, the color may be misinterpreted. One effective way to resolve the issue is to use red for only one meaning (e.g. alarms). However, once a convention has been developed and in place, it is often difficult to change.

CONCLUSION: The use of color in display designs should be made by a qualified human factors engineer in conjunction with the display designer and representative users.
ISSUE: MOST COMPUTER DATA INPUT TECHNIQUES (OR DATA ENTRY DEVICES) HAVE HAD LITTLE OR NO HUMAN ENGINEERING IN THEIR DESIGN.

ARGUMENT: Since very little human factors research has been done on data input techniques, there is very little literature to call upon. An article by Cary Lu (1984) described data input techniques and discussed some of the problems. This article is the basis for the argument presented here, together with some specific concerns about touch screen displays, prepared by Essex Corporation staff members. Lu identified the following types of data input techniques:

- Cursor keys;
- Cursor discs and joy disks;
- Track balls;
- Joy sticks;
- Light pens;
- Touch pads;
- Digitizer tablets;
- Mice; and
- Touch screens;

Some brief human factors engineering concerns will be identified with respect to some of these input techniques.

Cursor keys. This data input technique is found on nearly all computer keyboards and works well for moving a few characters at a time; in addition, your hands need not leave the keyboard. But keys are awkward if you want to move in a diagonal direction or over a long distance. For example, cursor keys are rarely satisfactory for moving about graphics.

Light pens. These devices allow fairly natural movement (although the screen angle is usually awkward). Light pens have rarely had any anthropometric design considerations and come in all shapes and sizes. Frequent use of the pen on the screen can result in some arm fatigue problems. Finally, light pens require a storage location and extra steps to pick up and put down the pen.

Touch pads. Present finger-operated touch pads are a little too erratic for professional use. Future touch pad designs might adopt features for professional applications. They should sense relative motion rather than absolute position and use a zoom feature for pixel-by-pixel motion when your finger moves slowly; larger motions when your finger moves quickly. Touch pads, of course, also require extra desk space.

Digitizer tablets. This data input technique is used extensively for computer-aided design. Using a stylus or crosshairs, a point on the surface can be accurately identified. However, tablets also require desk space. Recently, ultrasonic tablets have become available with which you can digitize discrete locations on three-dimensional objects.

Mice. This technique has actually been around since the 1960's. The two principal types are mechanically driven balls and optically sensed grids. Optical mice offer quiet, reliable operation, but require a special pad. Mechanical ball mice are cheaper but sometimes noisier. In either case, some amount of desk space is required to use a mouse. Most mice have had no anthropometric design considerations. If you need to move a mouse while holding down a button, the movement can be rather uncomfortable. Additionally, the number and locations of buttons seem to be arbitrary. All in all, mice have many attractive features and could benefit from some ergonomic considerations.

Touch screen display. The touch-sensitive screen allows the user to retrieve and control the information displayed on the screen. This device has the general advantage of being more direct and easier to learn than controls that require more remote manipulation. The touch-sensitive screen integrates the control and the display. Thus it is not necessary to learn how to operate a qualitatively different type of control system with its own movement dynamics (Gaertner and Holzhausen, 1980).

There are several disadvantages, the significance of which may depend on the particular application.

1. Hand movements to actuate touch screen controls may temporarily obscure parts of the display. If frequent control actions are necessary, it is possible that important information may be missed. If that information is urgently needed, as sometimes occurs in air traffic control situations, the problem is even worse.

2. Continual and frequent use of the touch screen could easily result in discomfort or arm fatigue if, for instance, the screen is oriented vertically to optimize the visual angle of the viewer.

3. If, on the other hand, the CRT screen is oriented to optimize arm comfort, it will tend to be facing upward and reflect more glare than usual. Placing a nonreflective cover over the screen could help, but then the light transmission would be reduced.
4. If the user is close enough to the screen to allow adequate comfort for his arm, the eye may be too close to the CRT. As one gets nearer the CRT, it becomes easier to see the graininess of the image on the screen.

5. Research indicates a relatively high error rate for touch-sensitive screens relative to CRT screens (Stammers and Bird, 1980). One contributing factor to this high error rate is parallax, in which the user tends to miss the point aimed at and hits a nearby point. A second contributing factor is the inadvertent touching of an adjacent area when the finger is removed from the screen. This can be corrected, in part, by enlarging the size of the control area, although the appropriate size will probably be larger than an equivalent hardwired button (Gaertner and Holzhausen, 1980; Pfauth and Priest, 1981; Usher 1983).

Speech recognition systems are also becoming more popular. This technique is covered as a separate issue.

RELATED CONSIDERATIONS: There are numerous external factors that affect data input techniques, depending on the work environment. Among these factors are illumination, noise, temperature, vibration, workspace and work station design.

CONCLUSION: Human engineering of input devices would improve data input time and accuracy, as well as alleviate physical discomfort and health problems. Thus, overall HMI performance would improve.
ISSUE: AUTOMATED SPEECH RECOGNITION AND SPEECH GENERATION BY MACHINE OFFER THE POSSIBILITY OF
NATURAL LANGUAGE HUMAN TRANSACTIONS AND REduced VISual-Manual WORK LOAD IN SOME
WORK ENVironMENTS.

ARGUMENT: Applied interest in speech recognition and generation as an input/output technique for control systems
apparently started with concern about the military fighter pilot work load. Speech input/output techniques provide an
alternative to the normally overloaded visual-manual channel. Like the use of color, this technology can become overworked
without human factors considerations. Simpson et al. (1985) provide an excellent review of the status and considerations
necessary in system design for speech recognition and generation. The material that follows is largely adapted from that
article. Human factors considerations are organized by: (1) speech recognition; (2) speech generation; and (3) system
integration.

Speech Recognition

One compelling reason to incorporate speech recognition into complex systems is the potential for reducing the visual-manual
work load. However, the decision to use speech for a particular task should be made only after a careful analysis of the
advantages and constraints of the manual mode versus the speech mode in the context of the task to be performed. Research
comparing the speed and accuracy of voice with the speed and accuracy of manual keyboard input has produced conflicting
results. Speech input is likely to improve system performance only for complex tasks that require a high degree of cognitive,
visual and manual loading. Once the decision is made to use speech for a particular task, a matching of speech mode features
with task characteristics is imperative. Characteristics of the speech recognition design must include the following:

- **Speech recognition algorithms.** Currently, speaker-dependent (recognizes only the original speaker) word
  systems can perform in the laboratory with vocabularies of up to 100 words with an error rate of less than
  1%. However, high recognition performance in the laboratory often degrades dramatically under the effects
  of noise, user stress and operational demands.

- **User characteristics.** Research has indicated that a few people have distinct problems in speech recognition.

- **Enrollment.** This is the process of providing voice templates to the recognition system for the different
  vocabulary items and is critical in speaker-dependent speech recognition systems. For example, recognition
  performance is enhanced when enrollment occurs in an acoustic or motion environment similar to that of
  operational conditions.

- **Adaptive recognition algorithms.** This is one method for dealing with speech variability over time for a
  given speaker in speaker-dependent systems.

- **System feedback.** Feedback by the system to the user may enhance performance either by altering the user's
  speech or by user error correction.

- **Error correction.** Speech recognition system performance can be improved with two types of error
  correction. The system can be designed to detect illegal sequences automatically and correct them to the most
  likely legal sequence or provision can be made for error correction by the user. Three documented types of
  user errors include failure to remember the vocabulary set, failure to follow the speech cadence restrictions
  and conversing with coworkers over an active microphone.

- **Environmental factors.** Physical, physiological, emotional and work load factors can be expected to
  partially determine the success or failure of a particular speech system design. The major environmental
  factor, of course, is the effect of background noise on recognition accuracy.

Speech Generation

Properly designed voice displays can reduce a user's visual work load when he is performing visually demanding tasks.
Examples of such tasks are reading technical maintenance or operations manuals while operating or repairing a system,
checking multiple visual readouts from a process control station panel and simultaneously controlling a robotic arm and
multiple cameras. In these situations, not only is the user engaged in visually demanding tasks, but efficiency of task
performance also depends on the user being able to maintain visual contact with the task. A good deal of research has been
done to determine where auditory (speech or nonspeech) rather than visual displays are most effective. Applications include
the following functions:
Warnings. This is a particularly effective application, since the auditory senses are omnidirectional. However, the selection of particular words or phrases and the voice type can have a definite effect on perception and response time.

Prompts. If the system prompts the user for a reasonable next data entry or control input, the user will assume the previous input was correctly received.

Feedback. Feedback is another form of prompting. Additionally, feedback provides responses to user queries.

Advisories. The utility of using speech to provide advisories depends on other functions for which speech is being used. Just like visual overload, voice overload can occur and if too much information is presented by voice; it may become annoying to the user. When something becomes annoying, there is a tendency to ignore it.

Commands. Caution must be used with voice commands since the user may sometimes be reluctant to follow a command without knowing the reason for it.

Simulation of human communications. Another important speech display application is the simulation of human speech communications; for instance, eliminate the need for human speakers to play a role in a training situation.

Speech generation characteristics such as synthesized speech versus pre-recorded human speech, sex, speaking rate, accent and many other variables will affect intelligibility and comprehension.

System Integration

The third human factors consideration for a speech input/output technique is system integration. The critical human factors issues are task design and human-system dialog design.

Task design. Speech is a discrete, single-channel, omnidirectional, familiar method for transmitting information. It commands the user's attention and should not be allowed to deliver false information. Used for the control of systems, speech can, if properly implemented, reduce the need for the user to learn computer programming languages and can provide an alternative to manual control inputs. Speech requires time to be spoken and comprehended and may be misunderstood by human or machine listeners in the presence of other competing voice messages, oral signals or noise. Speech is also a single-channel mode in two senses: neither humans nor current machines can talk and listen accurately at the same time and both have great difficulty in processing more than one speech message at a time. Speech messages have a transitory existence unless they are recorded for later playback. Finally, current speech recognition technology requires a vocabulary that consists of acoustically distinct words and constrained syntax.

Human-system dialogue design. Careful design of all of the interchanges between the human and the system, not just the speech interchanges, will have major effects on the overall system performance. The dialogue between the user and the speech system and the dialog between the user and all of the control display systems must be considered in a mission-oriented, task-analytic manner.

CONCLUSION: Speech generation technology seems to be more advanced than speech recognition technology, but human factors guidelines and standards for the application of speech technology have not been well established for either. The application of this technology requires human factors engineers to: (1) identify appropriate applications of speech technology; (2) select appropriate speech recognition or generation algorithms and systems characteristics; and (3) integrate speech subsystems within the context of the users' work environment or tasks.
ISSUE: HUMAN FACTORS ENGINEERING AS WELL AS COMPUTER SCIENCE IS REQUIRED IN THE SUCCESSFUL DESIGN OF ARTIFICIAL INTELLIGENCE/EXPERT SYSTEMS.

ARGUMENT: Artificial intelligence (AI) is a term whose definition computer scientists and human factors professionals cannot agree upon. In fact, one scientist has said that a definition in the usual sense seems impossible, because intelligence appears to be an amalgam of so many information representation and processing talents. Hillman (1985) states, "There are many different activities that collectively comprise AI. The one common thread is that all the activities involve complicated, mostly ill-defined, multivariable problems that normally require human experience, expertise and sometimes intuition for their solution." Most researchers do agree, however, that expert systems (or, more accurately, knowledge-based expert systems) are one aspect of AI. As Hopkin (1984) states, "Expert systems are a development from artificial intelligence, in which attempts are made to codify expert knowledge into a form compatible with other information in a database so that it can be made available for use by experts and others." In simpler terms, an expert system will capture the knowledge of experts and organize it for presentation to a user at a later time. Expert systems have been under development by computer scientists since the mid-1960s. Recently, as these systems have come into limited use, the need for human factors engineering in expert systems has been recognized. This need exists in two areas; the knowledge acquisition process and the user interaction process.

Knowledge Acquisition Process

Hillman (1985) reports that several researchers agree that the process of extracting knowledge from experts and codifying it for user interaction does indeed require human factors considerations. The human factors considerations of the knowledge acquisition process have been summarized by Hamill (1984), based on the work of the Committee on Human Factors of the National Research Council, as follows:

... (1) ensuring a common frame of reference to ensure that the knowledge engineer and the expert are talking about the same thing; (2) matching questions to mental structures to ensure compatibility between the way in which knowledge is organized and the way in which that knowledge is elicited; (3) clarifying and assessing information quality, since people usually have only partial, incomplete appreciation of the extent of their knowledge, a condition that expresses itself in overconfidence that is impervious to most debiasing efforts except intensive training; (4) ascertaining the fidelity of representation produced by extant elicitation systems and the conceptual systems they are intended to model, as by determining whether formally equivalent ways of eliciting the same information produce the same or different responses or by assessing an expert’s ability to judge the completeness of a representation; (5) detecting reporting biases reflecting unintentional or deliberate misreports or wrong answers; and (6) detecting distortions in the reporting of past events, since hindsight can produce exaggerations of what could have been or was known in foresight at the time of an event and since experts may have over-emphasized particular events, leading to misinterpretations of the importance and generality of causal forces involved.

Each of these issues has a potential impact on knowledge acquisition and must therefore be considered in developing techniques and protocols for practical applications as well as for guiding analytical and empirical research efforts.

For knowledge to be used in a system, it must be represented in some fashion in the systems knowledge base. Hamill (1985) says that this representation is essential psychologically, in that it requires the investigator to produce an explicit analytical model of the process being used by the decision-maker in response to sets of situation requirements. Human factors professionals insist on keeping the user needs in mind (through task analysis or some other technique) when designing human-machine interfaces. Knowledge acquisition and representation must also be done with the end users of the expert system in mind.

User Interaction Process

Hillman (1985) also reports that investigators agree on the need for human factors considerations in the user interaction process. In general, this means that the interaction between the system and the user must be such that the user can easily understand both what the system is doing and why. This interaction process is described by Hamill (1984) in the following excerpt:

Knowledge utilization. Once knowledge has been acquired from experts and represented appropriately in the system’s knowledge base, it must be accessed and utilized in making decisions and solving problems. The manner in which the system is to perform these functions influences the design of the control structure that drives its
operations, searching through the knowledge base, making use of necessary facts, applying rules and keeping track of the course the system follows in arriving at satisfactory evaluations, predictions, decisions and solutions to problems (see Barr, Cohen and Feigenbaum, 1981-82; Hayes-Roth, Waterman and Lenat, 1983; Rich 1983; Winston 1977, 1984). Knowledge utilization research is a necessary complement to research in knowledge acquisition and representation, since it provides insight into the processes by which knowledge elicited from experts and stored in a knowledge base may be employed in attaining acceptable system performance and in meeting research and operational goals.

RELATED CONSIDERATIONS: The use of an expert system will be affected by all the other design considerations associated with computer systems — data input/output techniques, display characteristics and the work environment.

CONCLUSION: Successful expert system development depends upon human factors professionals who can deal effectively with issues related both to the acquisition and representation of human knowledge and a user-friendly interface.
ISSUE: IF ROBOTS ARE TO BE USED EFFECTIVELY BY TECHNICIANS AND CRAFTSMEN RATHER THAN COMPUTER
SCIENTISTS AND ENGINEERS, HUMAN FACTORS ENGINEERING WILL BE REQUIRED TO HELP DESIGN THE
INTERFACES AND OPERATIONAL/MAINTENANCE PROCEDURES.

ARGUMENT: Human factors practitioners have not been engaged very much in the design of industrial robots. However,
as robots become more flexible and adaptable to different work situations, the control of the robot will become more of an
operator function than a designer function. This change in function assumes that three modes of operation will be possible:
(1) a fully automated mode in which the operator intervenes only when a discrepancy or mishap occurs; (2) an on-line
programming or training mode; and (3) a tele-robotic mode. The design of a user-friendly robot will require human factors
considerations in at least the following areas:

- Human sensing/perception and displays;
- Control panel design;
- Training arm grip design;
- Software interface design; and
- Safety.

The human factors considerations in each of the design areas will be briefly discussed.

Human Sensing/Perception and Displays

In each operating mode the operator must be able to get visual information about the manipulator arm, the end effector and
the target object. In some situations, this information may be made available by direct visual access. In other situations,
indirect access through a closed circuit TV camera on the arm and a CRT display may be necessary. Parsons (1985b) addresses
the human factors considerations as follows:

From a human factors engineering standpoint, a number of design parameters are significant for the CRT
display from the camera on the manipulator arm (and from the camera on the tines). One is the display’s
location in the workstation and its orientation with regard to key elements in the work envelope. Direct
(through a window) and indirect (CRT) images should not differ in ways to create confusion, such as
differences between the televised display’s orientation and a direct view of the arm. Similarly, orientation
should be consistent between the CRT displays from the arm camera and from the end effector camera (if this
has a CRT). The location and orientation of the workstation itself will be significant. In manually controlled,
heavy construction equipment, the operator station (including the seat) rotates with the arm, so the operator’s
gaze is continuously aligned with the work envelope, such as the ground where a pallet was dropped and must
be recovered. Other issues include signal-to-noise ratios in camera-display transmission, monochrome
versus color, monocular versus stereo (and if the latter, type of stereo system and its implementation), direct
CRT viewing versus projections, display (monitor) size, pixel density for visual acuity, camera zoom
capability and iris control, frame rate, directional illumination for nighttime operation and backlighting at
platform, flatbed trailer and conveyor (or color differentiations) to heighten contrast for human discrimi-
nations, especially in case of fog, snow and smoke or sandstorm. These last considerations might also benefit
the machine vision in the RCS system.

The workstation will have robot status indicators and an alphanumeric CRT for information coming from the
robot control equipment and displaying keyboard inputs to it. Such displays reflect software design as well
as hardware aspects in human-computer interactions. They resemble those for factory robots and must be
optimized — though such has not been done systematically in industry.

Control Panel Design

The description above inferred the need for a control panel of some sort to contain displays (other than CRTs) and controls (other
than the training or tele-operator grips). The design of the control panel should follow traditional human factors control/display
design considerations and be based on a task analysis of user needs. If one operator will be responsible for controlling multiple
robots, consideration must be given to the delineation of robotic activity as well as visibility. Since this design activity requires
rather traditional human factors engineering, no further discussion will be provided here.
Training Arm Grip Design

The teaching mode or tele-operations mode can benefit from the great amount of human factors tele-operation research and development done by NASA; these methods will not be elaborated here. Suffice it to say that known guidelines and standards with respect to anthropometrics and perceptual-motor task design must be applied if adequate transfer of training to the robot is to be accomplished or if the robot is to successfully operate in a tele-robotic mode.

Software Interface Design

While design of the control panel and the training arm grip are straightforward human engineering problems, a unique set of human engineering considerations must be applied when designing the flat panel display that will represent the operator’s interaction with the system software. Some of these issues are discussed by Shulman and Olek (1985). In general, these considerations will include the use of text, graphics and color to provide a dialog with the operator; hierarchical display design; data input techniques; and other external factors affecting performance, such as illumination, noise and vibration.

Safety

Accidents may occur with robots that will damage the target object or surrounding equipment, the robot itself or personnel. Parsons (1985b) indicates that accidents occurring in the tele-robotic mode may be called operator errors, but more cogently are designer errors that permitted the accident to happen. Parsons also notes numerous human factors considerations that relate to safety, including: maintenance precautions; training of operators and others; operator workstation precautions and operator intervention precautions; material/equipment protection precautions; on-line (teaching) programming precautions; and intrusion detection devices.

RELATED CONSIDERATIONS: Effective utilization of robotics will also require maintenance, skill requirements and training and organizational/operational design considerations.

CONCLUSION: As the design of robots becomes more flexible, the need for operator interface with the robot will become more demanding. System performance and safety will depend to a large extent on the adequacy of human factors considerations during design.
ARGUMENT: In 1949, Norbert Wiener, the father of cybernetics, wrote in his book The Human Use of Human Beings:

In my opinion, any utilization of a human being is degradation and waste if it asks for less and expects from him less than his full capacities. It is a degradation to chain man to a thwart and use him as a source of energy; but it is almost as great a degradation to set him in a factory to a perpetually reiterating task which claims less than a millionth of the capabilities of his brain.

More recently, Margulies and Zemanek (1982) said that where material needs to some degree and to some period of time have been overcome in the work force, mental need as expressed in the lack of challenge and content of work is all the more present. They further state: "Thus technological needs and human aspiration meet in the search for new patterns of work organization and for new relationships between man and machine." Their article, entitled Man's Role in Human-Machine Systems, addresses many of the social and humanistic aspects of technology rather well. The material that follows was excerpted from that article:

... opinions are expressed in a great number of publications by social scientists, trade unions, governments and enterprise managements. They all strike the note that Humanization of Work and Productivity or Economic Viability of alternative work organizations need not be contradictory or mutually exclusive. And in fact over the last fifteen years we have witnessed an increasing number of experiments and research concerning alternative work organizations.

In fact, every man/machine system links two extremely contradictory structures. Take, for example, the computer. It is an artificially created, formalized system with stable features. Once having been designed and built, it can fail, but it can never change. Man, on the other hand, is a natural, nonformalized system. He is never stable, he changes as long as he lives — even if he does not fail.

If information processing as a technology and profession has already so many and important human aspects, its impact on society must correspondingly have many and important peculiarities. There is no nontrivial engineering innovation without an impact on society.

The worker should not continue to be considered the object of decisions taken by other people like designers, organizers, technologists, he should rather become the subject of work organization, participating in the design and in all decisions to be taken. The options provided by modern technology allow for more autonomy of the individual worker or of small groups of workers, they allow for work structures supporting the development of one's personality, they allow for identification with one's work.

RELATED CONSIDERATIONS: User acceptance, which is discussed as an area of Automation in Control Systems, is another psycho-social consideration in system design.

CONCLUSION: Social and humanistic considerations, in addition to human-machine interface considerations, will affect the total system effectiveness, particularly over the long run.
6.5 COMPUTER ERROR: DEDICATION CAN BE DANGEROUS

The notion of human error is firmly ingrained in our everyday lives. However, a new and more insidious blunder — the computer error — may be infiltrating our newest and most sophisticated systems. Moreover, a concomitant myth has been built up that the computer can do no wrong and the mesmerism may be creating a monster — a blind faith in computers.

Computer errors can be categorized as:

1. **Dedicated Program Execution**: These are errors in the sense that computers equivocally pursue their instructions, even though the system that they control may be heading for a catastrophe (economic or safety-related).

2. **Software Bugs**: These are programming errors that don't usually show up until some unique situation is presented to the computer.

3. **Truth in Computers**: These are errors of perception in that we are often willing to accept the results if it is done by a computer.

These computer errors, as I have called them, are, of course, human errors, because the source of the error (in most, but not all cases) is a designer or programmer error. As with other kinds of system errors, computer errors do not always show up until the system is in operation and a specific set of circumstances prevails. In any event, there seems to be more and more computer errors showing up in highly automated systems that have been touted as technological marvels. Consider the examples that follow.
a. AREA: DEDICATED PROGRAM EXECUTION

ISSUE: COMPUTERS, ONCE INSTALLED IN SYSTEMS, EXECUTE THEIR PROGRAMMED INSTRUCTION WITH UNFLAGGING COMMITMENT — WHETHER IT BE RIGHT OR WRONG AT THE TIME.

ARGUMENT: The dedication with which computers pursue their programmed instructions is at once both awesome and scary. Could they be programmed incorrectly or could data entry errors lead to some insidious result? Many incidents, such as those cited here, prompt us to say yes.

Perrow (1984') has many examples of computer error in his book, Normal Accidents. The excerpts below describe but a few of those he has documented.

For an unknown reason a short circuit occurred in some of the controls in the control room. The utility said it could have been due to a bent connecting pin in the control panel, so sensitive are these devices, or the malfunction may have been caused by some maintenance work being done on an adjacent panel. The short circuit distorted some of the readings in the control system, in particular the important and very sensitive one of coolant temperature. The computer perceived the coolant was growing too cold, so it speeded up the reaction in the core. (The Babcock and Wilcox reactor operates within a very efficient, but quite narrow, temperature band.) The reactor overheated, the pressure in the core went up to the danger level and then the reactor automatically shut down. The computer was apparently now puzzled and correctly ordered the pressure relief valve (PORV) to open, but incorrectly ordered it to remain open until things settled down. This was an error on its part, because pressure dropped so quickly that it automatically caused high pressure injection to come on and stay on, flooding the primary coolant loop — including the core, steam tubes and pressurizer. A valve stuck and 43,000 gallons of radioactive water were dumped on the floor of the reactor building. Fortunately it was not worse; after several minutes an operator noticed the computer’s error in keeping the relief valve open and closed the valves manually. Had the frequent injection been followed that the computer knows best and that the (dumb) operators should keep their hands off the system until its routines are carried out, the sump would have overflowed and we would indeed have had a wet reactor.

Perrow also cites a maritime incident:

Of course, the automation makes the ships vulnerable to small errors. An incident is described in Mostert’s book in which the engine room was on automatic control and everyone was asleep. Alarms then went off; the main boiler had tripped and the engines had automatically tripped in turn — a safety device, just as in a nuclear power plant. Emergency electrical power was produced by the residual heat — twenty minutes of it and then blackout. The crew couldn’t find the problem, so they started the boilers up anyway in order to have power to search further.

It took six hours to find that a half-inch wide rubber diaphragm had split on a reducing valve. The valve used high-pressure air to hold up a flap on a forced draft fan. The diaphragm failure caused the flap to close, but only momentarily, which told the computer that the fans had stopped, although they hadn’t. Thinking the fans were stopped, the computer immediately put the boiler fires out, which stopped the engines and the ship. Fortunately, the ship was not in busy waters or close to the coast, or in a storm. As Mostert aptly puts it, “automation is marvelous; it has a pretty, animated face.” But automation depends upon a ship’s undependable power system, itself automated.

Wiener (1985) reminds us that unanticipated computer errors are appearing in the new automated aircraft.

In the last two years, several accidents and incidents, rightly or not, were laid to automation. A DC-9-80 (MD-80) lost both engines due to fuel starvation because the center-tank pumps were not turned on after takeoff (Aviation Week and Space Technology (AW&ST), 1983). Digital fuel gauges were blamed ... Soon after, another 767 during descent, had to have both engines shut down and restarted to bring them out of idle power. An over-efficient computer was seen as the villain (Beck 1983; Miami Herald 1983).

One airline captain warns of the danger of stick pushers. His fears may be justified by recent events. A Fairchild Metro crashed in a steep nose-down attitude shortly after takeoff from Terre Haute. The Metro has a stall warning system that gives an aural alert upon recognizing an impending stall, then activates a stick pusher with a 60-pound force to lower the nose to avoid the stall. Two other incidents of pilots having to overpower or deactivate stick pushers have recently been examined by the National Transportation Safety Board (NTSB) (AW&ST 1984).
b. AREA: SOFTWARE BUGS

ISSUE: AS COMPUTER PROGRAMS GET MORE MASSIVE AND COMPLICATED, SOFTWARE BUGS WILL BECOME ALMOST IMPOSSIBLE TO FULLY DETECT DURING PROGRAM TESTING AND VALIDATION, AND THESE DEFECTS WILL SURELY SHOW UP AFTER OPERATIONS HAVE BEGUN.

ARGUMENT: A Wall Street Journal article in January 1987 vividly described some of the incidents from software bugs, as the excerpts below describe (Davis 1987):

Verdon Kidd, an East Texas bus driver, was making progress against his skin cancer last spring when his computerized radiation-therapy machine went haywire and killed him.

Federal and state regulators say a defect in the machine’s software caused the machine to burn Mr. Kidd with radiation 80 times more potent than the prescribed dose. Atomic Energy of Canada Ltd., the manufacturer, acknowledges that its equipment may have been partly to blame but says that it cannot possibly catch every bug.

The tiniest software bug can fell the mightiest machine—often with disastrous consequences. During the past five years, software defects have killed sailors, maimed patients, wounded corporations and threatened to cause the government-securities market to collapse. Such problems are likely to grow as industry and the military increasingly rely on software to run systems of phenomenal complexity, including President Reagan’s proposed Star Wars anti-missile defense system.

“We have to be very careful what we trust to computers,” cautions Peter Neumann, a computer scientist at SRI International, Inc., a Menlo Park, California, Think Tank. “The vast majority of systems are deeply flawed from the viewpoint of reliability, safety, security and privacy.” Adds Edward Lieblein, formerly the Pentagon’s top software expert: “Software problems have reached crisis proportions.”

Software bugs breed as quickly as cockroaches and are as difficult to stamp out. A computerized banking system, for instance, may consist of millions of lines of code, written by hundreds of people who each work on small segments of the program. Software experts say they can’t ever know with certainty whether all the segments will work in harmony; an error as tiny as a misplaced semicolon can cause a system to malfunction.

Sometimes fixing a small bug can lead to greater problems. Two years before the first launch of the space shuttle, a programmer changed the timing on some shuttle software by one-thirtieth of a second. Unknown to the National Aeronautics and Space Administration, that miniscule change introduced a 1-in-67 chance that the shuttle’s five on-board computers wouldn’t work in sync. Twenty minutes before launch in April 1981, the bug appeared, the computers couldn’t communicate and NASA scrubbed the flight.

NASA says that thousands of hours of testing hadn’t uncovered the bug. “It’s as hard to predict software failure as it is to predict what your poker hand will be in the next deal,” says John Garman, a leading NASA software expert.

Bank of New York discovered how high the stakes can be in late 1985. A computer error blocked the bank from delivering huge amounts of government securities to customers and accepting payment. As a result, the bank was forced to borrow $23.6 billion overnight from the Federal Reserve Bank in New York to cover the shortfall and pay $5 million interest on the loan.

Though the bank resolved its software problem within two days, E. Gerald Corrigan, the president of the New York Fed, says that the government-securities market showed signs of unraveling even in that short period of time. There was “a backup in the willingness and ability of some other market participants to transfer securities among themselves,” he told Congress.

Petroski (1985) also provides an incident that makes one wonder about the sanctity of computer programs:

Unfortunately, nuclear plants and other complex structures cannot be designed without the aid of computers and the complex programs that work the problems assigned them. This leads to not a little confusion when an error is discovered, usually by serendipity, in a program that had long since been used to establish the safety of a plant operating at full power. The analysis of the many piping systems in nuclear plants seems to be especially prone to gremlins and one computer program used for calculating the stresses in pipes was
reportedly using the wrong value for π, the ratio of circumference to the diameter of a circle that even a high school geometry student like my daughter will proudly recite to more decimal places than the computer stores. Another incident with a pipeline program occurred several years ago when an incorrect sign was discovered in one of the instructions to the computer. Stresses that should have been added were subtracted by the computer, thus leading it to report values that were lower than they would have been during an earthquake. Since the computer results had been employed to declare several nuclear plants earthquake-proof, all those plants had to be rechecked with the corrected computer program. This took months to do and several of the plants were threatened with being shut down by the Nuclear Regulatory Commission if they could not demonstrate their safety within a reasonable amount of time.

CONCLUSION: Computer-based HMIs must be carefully scrutinized for symptoms of bugs. Human users should be knowledgeable about the systems they operate and maintain to sense the presence of computer errors.
ISSUES: COMPUTERS USED AS DESIGN AIDS MAY INDUCE A KIND OF OVER-CONFIDENCE OR LACK OF HANDS-ON EXPERIENCE THAT CAN LEAD TO ACCEPTING QUESTIONABLE OR EVEN WRONG RESULTS AT FACE VALUE.

ARGUMENT: Petroski (1985), in his book To Engineer is Human, discusses this phenomena as he describes the transition from slide rules to computers:

The trend is clear that eventually no engineer will own or use a traditional slide rule, but that practicing engineers of all generations will use — and misuse — computers ... Now, a decade after the calculator displaced the slide rule, we are beginning to ask these questions, but we are asking them not about the calculator but about the personal computer. And the reason these questions are being asked is that the assimilation of the calculator and the computer is virtually complete with the newer generations of engineers now leaving school and the bad effects are beginning to surface. Some structural failures have been attributed to the use and misuse of the computer and not only by recent graduates and there is a real concern that its growing power and use will lead to other failures.

Now, the computer not only can perform millions of simple, repetitive calculations automatically in reasonable amounts of time but also can be used to analyze structures that engineers of the slide rule era found too complex. The computer can be used to analyze these structures through special software packages, claimed to be quite versatile by their developers and the computer can be instructed to calculate the sizes of the various components of the structure so that it has minimum weight since the maximum stresses are acting in every part of it. That is called optimization. But should there be an oversimplification or an outright error in translating the designer's structural concept to the numerical model that will be analyzed through the automatic and unthinking calculations of the computer, then the results of the computer analysis might have very little relation to reality. And since the engineer himself presumably has no feel for the structure he is designing, he is not likely to notice anything suspicious about any numbers the computer produces for the design.

The computer does not work with ideas but with numbers and it can only solve a single problem at a time. The pipe it looks at must have a specified diameter, a specified crack, a specified strength and a specified load applied to it. Furthermore, the computer model of the cracked pipe must have a specified idea as to how a crack grows as the postulated accident progresses.

All these specifications are made by human beings and thus the results of the computer are only as conclusive about the safety of the system as the questions asked are the critical ones. Thus, while the computer can be an almost indispensable partner in the design process, it can also be a source of overconfidence on the part of its human bosses. When used to crunch numbers for large but not especially innovative designs, the computer is not likely to mislead the experienced designer because he knows, from his and others' experience with similar structures, what questions to ask. If such structures have failed he will be particularly alert to the possibility of similar modes of failure in his structure. However, when the computer is relied upon for the design of innovative structures for which there is little experience of success, let alone failure, then it is as likely, perhaps more likely, for the computer to be mistaken as it was for a human engineer in the days of the slide rule. And as more complex structures are designed because it is believed that the computer can do what man cannot, then there is indeed an increased likelihood that structures will fail, for the further we stray from experience the less likely we are to think of all the right questions.

CONCLUSION: Computer models and simulators can be excellent design aids, but the results from these analyses should always be questioned and perhaps calculated or approximated some other way before being relied upon. Just because it was done on a computer does not make it right or righteous.
6.5 CONCLUSIONS

- HUMAN ERROR OR BREAKDOWNS AT THE HUMAN–MACHINE INTERFACE CAN HAVE A DIRECT EFFECT ON SYSTEM PERFORMANCE AND THE POTENTIAL FOR ACCIDENTAL RELEASE OF CONTAMINANTS.

- MOST HUMAN ERROR CAN BE AVOIDED OR REDUCED. The fact is, very few human errors are a random phenomenon caused by inattentive, careless human beings. Most human error is design–induced or process–induced and can therefore be controlled.

- HIGH TECHNOLOGY REQUIRES HIGH TOUCH. Innovative technological advancements that interfere with human users present new human factors issues as well as many of the standard design concerns. HMI designs must be user–driven rather than technology–driven to be most effective.

- AUTOMATION DOES NOT REPLACE HUMANS IN SYSTEMS. Rather, it places the humans in a different, more demanding role. Poor application of automation technology will result in:
  - increased rather than decreased work load, particularly mental work load; and
  - inadequate cognitive support for man to function effectively as a monitor or supervisory controller. Humans are poor monitors and need to be in the loop if they are expected to intervene in crisis or accident situations. Perhaps the real question is not how much man can do, but how little.

- THE ALLOCATION OF FUNCTIONS MUST BE A DELIBERATE DESIGN ACTIVITY TO OPTIMIZE WHAT HUMANS DO, WHAT MACHINES DO, AND WHAT THEY DO BEST TOGETHER. Humans and machines are not competitors, they are complements. We must not automate those things that are feasible to automate and leave the rest to the human components. The design team must use a method that will bring humans and machines together systematically to do those things that each can do best and those that they can accomplish jointly to improve system performance. This should include consideration of adaptive control systems.

- USER ACCEPTANCE HAS A DIRECT EFFECT ON SYSTEM EFFECTIVENESS. System designs that are unacceptable to the user, regardless of engineering performance and reliability, may induce the user to either under–use, misuse or even sabotage systems. People have emotional and motivational needs that must be considered along with their visual, manual and physical capabilities and limitations.

- IF TECHNOLOGY IS NOT PROPERLY INTEGRATED INTO THE HUMAN–MACHINE INTERFACE DESIGN, THE EFFECTIVENESS OF THE HMI WILL BE DEGRADED. It is imperative that we learn to use technology to support rather than overwhelm the user. This consideration will be particularly important for those technology areas that effect performance at the HMI, such as:
  - computer–driven displays;
  - CRT color displays;
  - data input techniques; and
  - voice input/output.
ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS CANNOT BE EXPECTED TO BE A MAJOR APPLICATION IN CONTROL SYSTEM DESIGN FOR QUITE A WHILE. Their successful implementation will require close harmony between systems engineers, computer scientists, human engineers and of course, experts.

ROBOTICS MUST BE CAREFULLY DESIGNED TO MEET USER NEEDS AND EXPECTATIONS IN ORDER TO MAXIMIZE EFFECTIVENESS AND SAFETY. In many cases, robotics are really a form of remote control and the HMI is still a critical element in performance.

SOCIAL AND HUMANISTIC CONSIDERATIONS WILL BE AFFECTED BY THE APPLICATION OF TECHNOLOGY AND IN TURN WILL EFFECT THE ULTIMATE PERFORMANCE OF SYSTEMS.

APPLIED HUMAN FACTORS IS EFFECTIVE. It has been well established that applied human factors will reduce human error, decrease training costs, reduce skill requirements and increase user acceptance. These types of impacts improve human-machine performance and thus system performance.

COMPUTER ERROR IS A NEW CAUSE FOR CONCERN. The digital computer is another black box between the operator and the process. The computer also represents a source of error from stored instructions or faulty elements (e.g. microchips). Computers do make errors in the sense that they unequivocally pursue their instructions, even though the system they control may be heading for a catastrophic event. There are also perennial bugs in software and the real danger is believing computer results without question.

Finally, I want to close with the conclusion that HUMAN FACTORS IS NOT COMMON SENSE. Many of the horror stories in this paper and those that appear almost daily in the news, are due to well-intentioned common sense. In complex systems and facilities today, a common sense approach has produced marginally acceptable systems (from a human factors viewpoint) based on the fact that the hardware and the technology associated with that hardware have been around for some time. Experience with technology has produced a level of knowledge that one might term lessons learned — which may really be what is referred to as common sense.

In periods involving such quantum leaps in technology, hardware and software sophistication, and the changing role of man as we have been experiencing recently, this common sense approach breaks down — primarily because of the absence of lessons learned that come with experience with a technology or method. Therefore, the integration of technology into the interface of systems that will affect the larger ecosystem must be done with the fullest utilization of the principles and philosophy of human factors to avoid breakdowns at the human-machine interface that could be catastrophic.

6.7 REFERENCES


7.0 SCOPE: PRELIMINARY EXAMINATION OF THE IMPACT OF EXTRAORDINARY POLLUTION INCIDENTS IN THE GREAT LAKES BASIN

Mr. Jerry Wisdom
Wisdom Research Associates, Windsor, Ontario

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>88</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>89</td>
</tr>
<tr>
<td>7.1 LEGAL FRAMEWORK</td>
<td>89</td>
</tr>
<tr>
<td>7.2 METHOD</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>92</td>
</tr>
<tr>
<td>7.3 EXAMINATION: TRANSPORTATION AND INDUSTRY</td>
<td>92</td>
</tr>
<tr>
<td>a. United States – Database Review</td>
<td>92</td>
</tr>
<tr>
<td>b. United States – Retrievals</td>
<td>93</td>
</tr>
<tr>
<td>c. Canada – Database Review</td>
<td>94</td>
</tr>
<tr>
<td>d. Canada – Retrievals</td>
<td>95</td>
</tr>
<tr>
<td>e. Canada – Impact of Discharges versus Continuous Effluent</td>
<td>95</td>
</tr>
<tr>
<td>f. Canada – Municipal</td>
<td>96</td>
</tr>
<tr>
<td>7.4 ENERGY GENERATION</td>
<td>98</td>
</tr>
<tr>
<td>a. Conventional Pollutants</td>
<td>98</td>
</tr>
<tr>
<td>b. Radiation</td>
<td>98</td>
</tr>
<tr>
<td>c. Specific Incidents</td>
<td>98</td>
</tr>
<tr>
<td>d. Current IJC Monitoring</td>
<td>101</td>
</tr>
<tr>
<td>7.5 FINDINGS</td>
<td>101</td>
</tr>
<tr>
<td>7.6 RECOMMENDATIONS</td>
<td>102</td>
</tr>
<tr>
<td>7.7 REFERENCES</td>
<td>102</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hazardous polluting substances</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>Comparison of the spills to water for Michigan and Ontario</td>
<td>94</td>
</tr>
<tr>
<td>3</td>
<td>Volume of individual and cumulative spills in Michigan, 1984</td>
<td>94</td>
</tr>
<tr>
<td>4</td>
<td>Selected spills in Canadian segment of Great Lakes basin in 1984</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>Comparison of approximate number and quantity of spills from broad sources in Ontario in 1984</td>
<td>95</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of selected accidental releases and point source discharges</td>
<td>96</td>
</tr>
<tr>
<td>7</td>
<td>Estimated annual discharges from combined sewer overflows (CSOs) in the U.S. segment of the Great Lakes basin</td>
<td>97</td>
</tr>
<tr>
<td>8</td>
<td>Selected data on incidents of three releases from the power generation facilities in Ontario</td>
<td>98</td>
</tr>
<tr>
<td>9</td>
<td>Discharges from nuclear generating stations</td>
<td>99</td>
</tr>
<tr>
<td>10</td>
<td>Incidents reportable in LERS in operating U.S. nuclear reactors in the Great Lakes basin in January 1985 to November 1986</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>Precursors to potential severe core damage accidents in the Great Lakes basin, 1985, listed by probability</td>
<td>100</td>
</tr>
</tbody>
</table>
INTRODUCTION

Recent accidents at Chernobyl and Bhopal and the sudden appearance of a blob in the St. Clair River have heightened public concern about the impact of extraordinary pollution incidents. Such concern is of particular relevance to the Great Lakes basin, with its concentration of industry, chemical manufacturers, nuclear-power generating plants and well-developed transportation infrastructure.

Massive catastrophic accidents are rare and because of their low probability, are often dismissed as not being of real concern. However, the findings of the investigations prompted by the perchloroethylene blob near Sarnia focused attention on repeated, lower-level incidents that warrant further examination by the jurisdictions of the Great Lakes basin.

A review of available records over the past ten years reveals a spate of regular minor accidents, each releasing between ten and 4,000 tonnes of contaminants into the St. Clair River, in close proximity to the drinking-water intakes for several metropolitan areas. These contaminants are complex, man-made chemicals and many of them are designated as hazardous.

Although efforts have been directed towards the prevention and cleanup of spills and accidents, their significance as a source of pollution to the Great Lakes has not been determined with any precision. The purpose of this paper is to develop a first indicative estimate of the impact of these extraordinary pollution incidents on the basin.

7.1 LEGAL FRAMEWORK

One reason why spills have been overlooked as a pathway of pollution is simple confusion. Is the chemical spill from a truck tanker flushed down the sewer and into the river the equivalent of the leaking pipe at the refinery, the spill from the oil tanker or the occasional illegal dumping of oil into the sewers by the local gas station or the individual citizen? Although some commonality of treatment of spills is now being achieved, even now one incident may be reported to the fire department, the next to the environmental agency, the next to the coast guard and yet another, possibly not reported at all. Often each organization receiving these reports will maintain discrete records, with the result being that no single annual quantification of chemicals spilled is available that would allow us to determine their relative significance.

As agencies improve their focus on spills and increase their cooperation and communication, there are some signs this confusion of what constitutes a spill is lifting. However, the International Joint Commission (IJC) could, and should, be playing a more active role in dispelling this confusion.

The IJC Great Lakes office has a primary oversight role in the implementation of the 1978 Great Lakes Water Quality Agreement. This Agreement between Canada and the United States considers spill incidents as discharges. In Annex 8 to the Agreement, discharge is defined as:

... the introduction of polluting substances into receiving waters and includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting or dumping; it does not include continuous effluent discharges from municipal or industrial treatment facilities; and discharges are defined broadly to include everything that is not a continuous effluent discharge.
The Annex also defines where those incidents can originate in the broadest possible terms. Facilities include:

... motor vehicles, rolling stock, pipelines and any other facility that is used or capable of being used for the purpose of processing, producing, storing, disposing, transferring or transporting oil or hazardous polluting substances but excluding vessels.

This includes almost any type of mode of transport, factory or storage facility. Vessels are covered in their own annex with requirements that are more specific to shipping.

Under Article VI, section (h), the Agreement requires the parties to enact measures:

... for the abatement and control of pollution from onshore and offshore facilities, including programs and compatible regulations for the prevention of discharges of harmful quantities of oil and other hazardous polluting substances, in accordance with Annex 8.

The Agreement also requires the governments to review the operation of facilities for their adequacy to prevent discharges and also very explicitly defines chemical discharges of concern, specifying oil or hazardous polluting substances. Oil is defined as:

... oil of any kind or in any form, including but not limited to petroleum, fuel oil, oil sludge, oil refuse and oil mixed with wastes, but does not include constituents of dredged spoil.

The Agreement has a separate Annex 10 to define Hazardous Polluting Substances. For inclusion in this list, a chemical must be toxic, lethal to animal life and pose a real risk of being discharged into the Great Lakes. Table 1 is a listing of such chemicals as they appear in the 1978 Agreement. It should be noted that these chemicals are distinct from the more high profile chemicals known as persistent toxic substances, defined elsewhere in the Agreement.

7.2 METHOD

To arrive at a first estimate of the extent of discharges into the Great Lakes basin, relevant International Joint Commission reports, selected government reports and scientific literature were reviewed. Officials in the Environmental Protection Agency, Environment Canada, the U.S. Department of Transport, the U.S National Response Center, Michigan Department of Natural Resources and the Ontario Ministry of the Environment were contacted; in addition, a survey of several of the most relevant government databases was undertaken.

Although there are individual state databases, due to time constraints it was decided to concentrate only on those databases that provided coverage of the entire U.S. or Canadian basin. Thus, some data will be omitted from consideration in this report; these omissions would be corrected in any full-scale review of this issue.

Discharges from four distinct sources were examined:

- the transportation sector;
- industries;
- municipal sewage plants and sewer systems; and
- energy generators.
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**TABLE I. Hazardous polluting substances.**

- 91 -
a. Database Overview

Article VI, Section (h) and Annex 8 of the Great Lakes Water Quality Agreement specifically require governments to prohibit discharges of harmful quantities of oil and hazardous polluting substances and requires the IJC to monitor the progress of these efforts.

Under Annex 4 of the Agreement, the Coast Guards of the United States and Canada provide to the IJC each year a review of discharges from vessels. The latest report lists 94 pollution incidents in the Great Lakes reported to the Canadian Coast Guard for 1985 and 478 reported to the U.S. Coast Guard for the same year. However, it appears that there is no corresponding report for Annex 8 discharges. No comprehensive or current review of data on discharges or on efforts to arrest this type of pollution from all types of facilities was available through the IJC library. The need for further scrutiny of this issue was acknowledged in contacts with several IJC officials.

Government reports quantifying discharges in particular segments of the basin for limited time spans were located; however, there are no unified studies of the whole basin on either side of the border for immediate comparison. For that reason efforts were concentrated on establishing what data are available in the categories outlined above, in what form, how these data could be accessed and if the data were available, what was the significance of the information.

7.3 EXAMINATION: TRANSPORTATION AND INDUSTRY

a. United States – Database Review

In the United States, the Environmental Protection Agency (U.S. EPA) is the federal agency with primary responsibility for all spills. However, at this time it does not have an operational database covering spills on a multi-state basis. The Agency is in the process of creating a database called ERNS (Emergency Response Notification System). It is intended that this will become the main national spills database in the United States. Initially, it will receive reports from the EPA and from the National Response Center's 24-hour national spill hot line\(^1\), described below.

Outside the EPA, there are numerous national databases containing information on spills and accidents, including those in the Great Lakes basin. A report from the U.S. Congress Office of Technology Assessment\(^2\) lists 12 U.S. spill databases. Some have been replaced by new versions and many are too specialized to yield appropriate data for an initial overview.

The National Response Center (NRC) is staffed by the U.S. Coast Guard and funded by a large number of U.S. agencies. Its role is to serve as a central facility for reception of reports of emergency spills occurring anywhere in the United States. It maintains a spill-information database; discussions were held with numerous National Response Center officials involved with that database to attempt to extract Great Lakes basin information. Unfortunately, the database proved somewhat inflexible, necessitating numerous redefinitions and restrictions on search activities. Further, inadequate control had been exercised on the data input and complete, comprehensive retrievals were impossible. For example, a number of names, with a variety of spellings. This could be used to describe locations and
materials spilled. This thwarted any effort for complete retrieval based on name parameters other than painstaking manual review of the printed data.

Eventually, as noted above, this National Response Center database will be combined with the regional databases of the EPA to form the ERNS system. At a later date the database will be modified to allow the adding of reports on spill remedial action. This should allow the input of improved estimates of quantities of materials spilled.

Many officials believe that this enhanced database will provide the best coverage of spills in the United States when it is operational. However, adequate inclusion of state data, which in many cases may be more extensive than either that of the National Response Center or the EPA, remains a concern. EPA officials noted that, at the time of this review, the details of state cooperation had not been defined and agreed upon. Should these matters go unresolved, the effectiveness of the database could be severely hampered. The implementation of the ERNS database is now moving ahead and the IJC will have to move expeditiously to influence its final form.

A second database, maintained by the U.S. Department of Transportation, was determined worthy of further consideration in this preliminary examination. U.S. federal laws require that many transport related spills be reported directly to the U.S. Department of Transportation. Such information is maintained in a database called the Hazardous Materials Information System (HMIS). HMIS lists information on spills from the level of a quart of paint up to major tanker accidents. However, retrievals were subject to the same level of difficulty detected in the National Response Center database.

b. United States – Retrievals

A search of the National Response Center base retrieved all spills to water for the eight states surrounding the Great Lakes for 1984. The search listed almost 2,000 spills for the period; however, this database and the one by the Department of Transportation can only be searched by state. Since the Great Lakes basin as a geographic area does not trace state boundaries, only data from Michigan were of immediate use in a basin compilation. The balance required manual sorting of the printed retrieval, a laborious and time consuming task.

This task would be even more strenuous if, rather than only those occurring on water, all spill entries for the eight states for one year were retrieved for review. The output would have been in excess of 18,000 references for the eight states for 1984.

Although Canadian data will be examined in more detail later, a comparison of the number of incidents reported in a year for Ontario and the number reported to the National Response Center for Michigan suggest that the National Response Center database may be lacking a significant amount of data that may be available from state files. It is mandatory to report spills in Ontario; in the United States, law requires the reporting of spills to the National Response Center. Yet Table 2 suggests far fewer spills are reported to the National Response Center than to the Ontario spills centre. Since Ontario and Michigan are similar jurisdictions, they could be expected that they would experience a similar number of spills. This points out a possibly significant under-reporting to the National Response Center.
TABLE 2. Comparison of the spills to water for Michigan and Ontario.

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<tr>
<th>Jurisdiction</th>
<th>Year</th>
<th>Number of Spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>1984</td>
<td>98</td>
</tr>
<tr>
<td>Ontario</td>
<td>1986</td>
<td>1,500</td>
</tr>
</tbody>
</table>

A preliminary retrieval from the HMIS of the Department of Transport was also attempted. Again, no method of limiting the search to areas in the Great Lakes basin was available. It was necessary to search for the eight border states and then manually eliminate those locations that did not rest in the basin. Needless to say, this method is highly inefficient and an eight state scan was beyond the scope of this report. However, data extracted (Table 3) for Michigan, a state entirely in the Great Lakes basin, are indicative of the magnitude of such events recorded in this database.


<table>
<thead>
<tr>
<th>State</th>
<th>Spills</th>
<th>Spills over 25 U.S. gallons</th>
<th>Total volume of over 25-gallon spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>203</td>
<td>27</td>
<td>8,953 gallons</td>
</tr>
</tbody>
</table>

While this database nominally covers transportation accidents, the Office of Technology Assessment cautions that they have found significant traffic accidents that did not appear in this record.

c. Canada – Database Review

Environment Canada has maintained a spills database for over a decade. Called NATES (National Analysis of Trends in Emergency Systems) it has been revised several times and now has 43 fields with many subcategories within those fields. It has a precisely defined information format (see attached) that allows easy and extensive searches. Among the information the database listed: location; date; material; weight in tonnes; amount recovered; transportation or industry; cause of spill; and cost and injuries. It will allow searches by river basin; however, time constraints did not permit this. If this function were available in the U.S. databases, the IJC could begin the efficient compilation of data for the entire basin.

The data for the NATES database came primarily from Ontario, where it was used to prepare periodic reports on spills in the province. Ontario has recently passed a law, commonly called the Spills Bill. The Bill requires reporting of spills, with sanctions for those that don’t. It imposes a duty to clean up and restore the environment on those that own the material. Since passage of this legislation, the province has begun to keep its own computerized records and has changed its reporting requirements somewhat from the NATES format. As a result of this, Ontario data can no longer be transferred directly to NATES and entry of Ontario data into the national record is being significantly delayed. This is a significant blow to record-keeping in Canada as NATES is capable of providing the best overview of spills so far identified in the basin.
d. Canada – Retrievals

A very crude first estimate from the NATES database of spills from various sectors in Ontario yields the following (Table 4). Note that the numbers associated with the municipal sector include overflows of raw sewage. This does suggest that on the basis of quantity, transportation may not be as large a source as the various fixed sources, although this finding bears further investigation. Further, more sophisticated data manipulation was not possible due to time constraints.

**TABLE 4.** Selected spills in Canadian segment of Great Lakes basin in 1984.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Number</th>
<th>Amount</th>
<th>Chemical</th>
<th>Number</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>40</td>
<td>1,302</td>
<td>Sulfuric Acid</td>
<td>5</td>
<td>227.6</td>
</tr>
<tr>
<td>Sewage</td>
<td>7</td>
<td>32,948</td>
<td>Phosphoric Acid</td>
<td>1</td>
<td>13.18</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>3</td>
<td>99.4</td>
<td>Oil-PCB</td>
<td>2</td>
<td>5.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Uranium Slurry</td>
<td>2</td>
<td>5.05</td>
</tr>
</tbody>
</table>

**TABLE 5.** Comparison of approximate number and quantity of spills from broad sources in Ontario in 1984.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of Spills</th>
<th>Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>30</td>
<td>310</td>
</tr>
<tr>
<td>Industry</td>
<td>62</td>
<td>2,000</td>
</tr>
<tr>
<td>Municipal*</td>
<td>8</td>
<td>132,000*</td>
</tr>
<tr>
<td>Energy</td>
<td>5</td>
<td>95</td>
</tr>
</tbody>
</table>

*largely raw sewage overflows.

The Ontario government has begun keeping its own computer database in 1986 to correspond with the implementation of the Spills Bill. It contains approximately 6,000 entries for the year, indicating that reporting has increased with the introduction of the new more stringent legislation.

The Ontario system allows some searches and a retrieval for spills to water was performed. Of the approximately 1,500 spills reported in the retrieval, 518, or 34%, had no quantity attached to them. It is not known whether this is a function of the search or the new reporting requirements. The NATES data from Ontario previously had a great deal of information on quantity.

e. Canada – Impact of Discharges versus Continuous Effluent

There is a common perception that spills, while being nuisances, do not compare over the long-term with ongoing effluent discharges. It is here that the NATES database is particularly valuable. It provides records of the amount spilled in kilograms and the amount recovered so that the amount released into the environment can be determined.

It is difficult to find continuous effluent discharge figures that can be used for comparison; they have often been measured in a very imprecise manner. In Ontario, the permitted releases of industries are not well-defined for toxic substances, particularly specific organic chemicals. Rather, these substances
are often lumped together under categories such as Total Organic Carbon. In other circumstances, while concentrations in tested effluents have been determined to the level of micrograms per litre, total flow volume has not been readily available to allow calculation of total loadings. This situation has been alleviated to a degree in recent sampling along the St. Clair River. Because of concern about pollution from the chemical industries there and new concerns about the blobs, current loading measurements have been made available. With this information it is possible to compare loadings of selected chemicals from on-going discharges with those from spills.

The following table was prepared using measurements from a 1985 Environment Canada study by King and Sherbin on point sources of toxic chemicals in the upper St. Clair River. As one of the compounds listed in the Agreement as a Hazardous Polluting Substance and a substance for which spill and effluent discharge data were available, styrene was chosen as the basis for comparison. To estimate an annual release, the daily discharge has been extrapolated over 350 days. This may overestimate the release, but the method does allow some rough comparison with the amount of this chemical spilled into the St. Clair River, as shown in the following table (Table 6).

<table>
<thead>
<tr>
<th>Company</th>
<th>Chemical</th>
<th>Daily Effluent</th>
<th>350 days</th>
<th>Weight of Spill (kg)</th>
<th>Equivalent Years*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dow</td>
<td>Styrene</td>
<td>5.0 kg</td>
<td>1,750 kg</td>
<td>2,700</td>
<td>1.5</td>
</tr>
<tr>
<td>Polysar</td>
<td>Styrene</td>
<td>0.16 kg</td>
<td>46 kg</td>
<td>80,000</td>
<td>1,328</td>
</tr>
</tbody>
</table>

*as compared to point source discharge, 350-day basis.

For one incident, the spill was roughly equivalent to over 1400 years of continuous effluent discharge and for the other, it equalled a continuous discharge of 1.5 years.

These results suggest that the loading from spills may significantly exceed the amounts released into the environment through regulated pathways. This is not only true for major spills but may also be true of relatively minor spills of under 0.5 tonne. An unpublished study of the St. Clair River indicates many industries have reduced their permitted releases to less than 1 kg/day per chemical. Compared to this level, a spill of 0.5 tonne would be significant.

f. Canada – Municipal

Sewage and Phosphorus

The primary extraordinary discharge in volume from municipal sewer systems is that from combined sewer and storm water overflows. Data collected for U.S. discharges by GCA Corporation for the Environmental Protection Agency gives the following loadings for phosphorus from combined sewer overflows (Table 7).

As with all data of spills, data on municipal spills is only good if all spills are reported. On April 14, 1987, The Toronto Globe and Mail reported that "thirty to forty times a year, after heavy rain storms, Fort Erie town workers pump overflowing storm water contaminated by sewage into a creek flowing into Lake Erie."
TABLE 7. Estimated annual discharges from combined sewer overflows (CSOs) in the U.S. segment of the Great Lakes basin.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Amount of discharge (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Michigan</td>
<td>207</td>
</tr>
<tr>
<td>Lake Huron</td>
<td>33.8</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>457.8</td>
</tr>
<tr>
<td>Lake Ontario</td>
<td>106.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>805.2</td>
</tr>
</tbody>
</table>

A review of all spills to water in Ontario for 1986 revealed no reports of these spills to the provincial government. It is not clear what this means for the quality of reporting of municipal discharges.

**Chemical Pollution**

Sewage is not the only discharge from the sewer systems. Considerable amounts of contaminants from urban runoff enter the sewer systems during storms and are released into the Great Lakes basin. These contaminants include oil, antifreeze and tire particles from automotive sources and other chemicals used in urban areas.

Chemicals have always entered the sewer system from urban users, both by design and by accident. Efforts have been made to reduce authorized and unauthorized release of chemicals into sewers and these efforts have met with some success. But research has demonstrated that small scale and unauthorized contamination is occurring and it is having a significant effect.

A study of a selected section of sewers in downtown Ann Arbor, Michigan, by Schmidt and Spencer showed a considerable discharge of hazardous chemicals. A detailed survey found a wide variety of improper and illegal discharges.

This type of urban user pollution can have a significant effect on the Great Lakes basin. A study in 1985 by Oliver and Bourbonniere pointed out that the western basin of Lake Erie had a high level of contamination from PCBs. Recent unpublished data indicate discharges of PCBs from the Detroit sewage treatment plant of between 0.4 and 1.1 kg/day and a large-scale survey of the Detroit sewer system by Giffels/Black/Veetch Inc. in 1981 found that the treatment plant was a major contributor of chemical contamination to the Detroit River, particularly during storms. Much of this contamination was released through the storm and overflow bypass systems.

Further investigations into sediments in the Detroit sewer system by the Michigan Department of Natural Resources (DNR) verified that "PCB contaminated sediments were moving from the Carter industrial site into the 18th Street sewer and eventually into the Detroit River through a combined sewer overflow (Kengga, 1986)." Concentrations of PCBs in these sewer sediments were as high as 1.6 g/kg PCB in July of 1986. These levels had declined to .48 g/kg in January 1987, due both to clean up efforts at the site and the flushing of the sewer sediment into the river during and after heavy rainfall events.
Further monitoring by the CNR revealed another source of contamination from an area referred to as the Frederick Avenue PCB site. PCB contamination in the sewer system near the site averaged .025 g/kg and was accessible to the river through the Concord Street sewer. The DNR has now recommended that other CSOs should be sampled in the Detroit sewer system to identify further sources of PCB contamination.

7.4 ENERGY GENERATION

a. **Conventional Pollutants**

The energy sector is also a contributor of chemical discharges to the lakes. The range of chemicals is more limited than other industries but in some circumstances, quantities can be very significant (Table 8).

b. **Radiation**

Since 1975, the IJC has reviewed data on the emission of radioactivity from nuclear power stations, mines and mills, fuel fabrication and conversion facilities, waste management sites and other facilities in the Great Lakes basin.

<table>
<thead>
<tr>
<th>Location</th>
<th>Chemical</th>
<th>Amount (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trent River</td>
<td>transformer oil</td>
<td>2.48</td>
</tr>
<tr>
<td>Lake Ontario (10 ppm)</td>
<td>hydrazine</td>
<td>91.00</td>
</tr>
<tr>
<td>Trent River</td>
<td>transformer oil</td>
<td>2.45</td>
</tr>
</tbody>
</table>

In the United States, operators of nuclear power plants are required to report to the Nuclear Regulatory Commission when releases, both planned and unplanned, exceed what are considered conservative limits. These figures (Table 9) have been published by the IJC in the Appendix on Radioactivity to the 1983 Report on Great Lakes Water Quality. Data for 1981 and 1982 are included in this Appendix. The data from the Nuclear Power Regulatory Commission does not differentiate between planned and unplanned releases. As well, the Commission does not specify how the releases compare to allowable limits.

Canadian figures for the release of radiation are also given in the Appendix. In addition, the Atomic Energy Control Board in Canada provides a calculation that relates the emissions to allowable limits. In all cases, for 1981 and 1982 the releases were less than 1% of the annual allowable limit. As in the United States, the amount of radioactivity released from planned and unplanned releases is not distinguished.

c. **Specific Incidents**

In addition to reporting on the release of radioactivity, the IJC report has also noted incidents that led to an unplanned release of radioactivity. In both countries, the IJC relies on information provided by the regulatory agencies.

For the 1981–82 period, one incident was reported for the 13 operating reactors in the United States and nine incidents were reported for the nine reactors at three generating stations in Canada. Six incidents were reported for fuel processors and users.
### TABLE 9. Discharges from nuclear generating stations.

<table>
<thead>
<tr>
<th>STATION</th>
<th>PARTICULATES</th>
<th>$^{131}$I</th>
<th>NOBLE GASES</th>
<th>$^3$H</th>
<th>FISSION AND ACTIVATION PRODUCTS</th>
<th>$^3$H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ANNUAL RELEASE IN CURIES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GASEOUS</td>
<td>AQUEOUS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1981</td>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big Rock Point</td>
<td>0.004</td>
<td>0.002</td>
<td>17,900</td>
<td>10.22</td>
<td>0.39</td>
<td>3.1</td>
</tr>
<tr>
<td>Bruce A</td>
<td>0.0025</td>
<td>0.0028</td>
<td>16,000</td>
<td>92,000</td>
<td>2.2</td>
<td>20,000</td>
</tr>
<tr>
<td>Cook 1 &amp; 2</td>
<td>0.278</td>
<td>0.037</td>
<td>5,421</td>
<td>5.47</td>
<td>1.87</td>
<td>916</td>
</tr>
<tr>
<td>Davis-Besse 1</td>
<td>0.004</td>
<td>0.054</td>
<td>1,012</td>
<td>8.65</td>
<td>0.79</td>
<td>157</td>
</tr>
<tr>
<td>Douglas Point</td>
<td>0.00098</td>
<td>0.12</td>
<td>32,000</td>
<td>11,000</td>
<td>0.2</td>
<td>2,200</td>
</tr>
<tr>
<td>Fitzpatrick</td>
<td>0.165</td>
<td>0.115</td>
<td>119,500</td>
<td>6.65</td>
<td>2.51</td>
<td>4.1</td>
</tr>
<tr>
<td>Ginna</td>
<td>0.00001</td>
<td>0.001</td>
<td>546</td>
<td>70.1</td>
<td>0.04</td>
<td>240</td>
</tr>
<tr>
<td>Kewaunee</td>
<td>0.00003</td>
<td>0.00009</td>
<td>118</td>
<td>4.01</td>
<td>0.82</td>
<td>251</td>
</tr>
<tr>
<td>Nine-Mile Point</td>
<td>0.080</td>
<td>0.006</td>
<td>611</td>
<td>63.4</td>
<td>5.35</td>
<td>5.1</td>
</tr>
<tr>
<td>Palisades</td>
<td>0.001</td>
<td>0.040</td>
<td>3,002</td>
<td>6.42</td>
<td>0.03</td>
<td>278</td>
</tr>
<tr>
<td>Pickering</td>
<td>0.0046</td>
<td>0.0017</td>
<td>6,800</td>
<td>16,000</td>
<td>0.21</td>
<td>7,500</td>
</tr>
<tr>
<td>Point Beach 1 &amp; 2</td>
<td>0.0004</td>
<td>0.004</td>
<td>611</td>
<td>480</td>
<td>1.09</td>
<td>652</td>
</tr>
<tr>
<td>Zion 1 &amp; 2</td>
<td>0.008</td>
<td>0.005</td>
<td>6,910</td>
<td>a</td>
<td>2.65</td>
<td>870</td>
</tr>
</tbody>
</table>

|                 | ANNUAL RELEASE IN CURIES |          |             |      |                                 |      |
|                 | GASEOUS       | AQUEOUS   |             |      |                                 |      |
|                 | 1981          | 1982      |             |      |                                 |      |
| Big Rock Point  | 0.002         | 0.003     | 12,930      | 6.26 | 0.26                            | 2.98 |
| Bruce A0.0024   | 0.024         | 0.032     | 14,000      | 41,000| 2.1                            | 26,000|
| Cook 1 & 2      | 0.024         | 0.104     | 3,883       | 5.11 | 1.90                            | 1,295|
| Davis-Besse 1   | 0.00003       | 0.005     | 535         | 35.5 | 0.22                            | 57   |
| Douglas Point   | 0.00045       | 0.092     | 62,000      | 8,600| 0.50                            | 3,300|
| Fitzpatrick     | 0.337         | 0.434     | 211,000     | 5.26 | 0.65                            | 0.65 |
| Ginna           | 0.0002        | 0.0008    | 1,955       | 96.6 | 0.62                            | 308  |
| Kewaunee        | 0.00003       | 0.00003   | 166         | 8.07 | 1.52                            | 318  |
| Nine-Mile Point | 0.071         | 0.020     | 51.1        | 53.5 | 0.003                           | 5.82 |
| Palisades       | 0.004         | 0.023     | 7,382       | 4.49 | 0.127                           | 179  |
| Pickering       | 0.0027        | 0.0019    | 6,600       | 18,000| 0.49                           | 10,000|
| Point Beach 1 & 2 | 0.0002       | 0.008     | 993         | 1,017| 2.95                            | 503  |
| Zion 1 & 2      | 0.082         | 0.007     | 16,090      | a    | 5.25                            | 90,753|

a. Not available
b. Information from References (1) and (2)

Incidents that lead to a release of radioactivity are not necessarily the only important incidents. Other incidents may point to a weak spot where an accident may occur. Given the potential severity of a major release of radioactivity, these incidents can provide an important preventative role.

Although some nuclear-power incidents can appear trivial, they can have significant consequences. The Presidential commission investigating the accident at Three Mile Island said, "The same problem of water leaking into the polisher's valve control system had occurred at least twice before at TM 1–2. Had Met Ed corrected the earlier polisher problem, the March 18 sequence of events may never have begun." The key note these incidents can play is to reveal a pattern so that a problem can be spotted and corrected before an accident occurs.

In the course of preparing this report, a number of conversations were held with the Nuclear Safety Information Center at Oak Ridge National Laboratory. They maintain the U.S. nuclear safety information database. This database contains incident information extracted from reports the nuclear power
generating facilities are required to file with the Nuclear Regulatory Commission. Data for these facilities in the basin have been secured.

The data are based on the U.S. Nuclear Regulatory Commission's (National Response Center) Licensed Event Reports (LERs). These reports essentially describe any circumstance when a plant does not meet a standard demanded of it. Incidents vary in their severity, from reports of instruments slightly out of calibration to those concerned with major accident sequences.

For the 13 operating reactors in the Great Lakes basin there were 652 LERs for the period January 1986 to November 1986.

Each report is coded by the National Response Center by reason for filing. Categories range from a violation of a technical specification to an activation of an emergency feature. Often one incident may have several codes if several violations were involved. The following table (Table 10) shows the number of LERs at the 13 operating reactors in the basin for the noted time period.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Number of LERs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis-Besse 1</td>
<td>75</td>
</tr>
<tr>
<td>Fitzpatrick</td>
<td>46</td>
</tr>
<tr>
<td>Cook 1</td>
<td>94</td>
</tr>
<tr>
<td>Cook 2</td>
<td>73</td>
</tr>
<tr>
<td>Kawanee</td>
<td>36</td>
</tr>
<tr>
<td>Zion 1</td>
<td>88</td>
</tr>
<tr>
<td>Zion 2</td>
<td>51</td>
</tr>
<tr>
<td>Point Beach 2</td>
<td>28</td>
</tr>
<tr>
<td>Palisades</td>
<td>69</td>
</tr>
<tr>
<td>Ginna</td>
<td>29</td>
</tr>
<tr>
<td>Nine-Mile Point</td>
<td>54</td>
</tr>
<tr>
<td>Big Rock</td>
<td>15</td>
</tr>
</tbody>
</table>

As well as the National Response Center codes, the Nuclear Safety Information Center codes the data as they are filed. The most significant code is Possible Significant Event. There were eight incidents in this category for this time period in the basin.

The Nuclear Safety Information Center also periodically releases a report called Potential Precursors to Severe Core Damage Accidents. This report extracts incidents that, based on an engineering analysis, could have led to core damage or damage to the nuclear fuel. The latest report is for 1985; of the 53 noted incidents for the entire United States, four were at reactors in the basin (Table 11). This includes the worst accident of the period, which occurred at Davis-Besse 1 in June 1985.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Plant</th>
<th>Date</th>
<th>Failure</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Davis-Besse 1</td>
<td>Jun. 9/85</td>
<td>Loss of feedwater and auxiliary feedwater</td>
<td>$10^{-2}$ to $10^{-1}$</td>
</tr>
<tr>
<td>6</td>
<td>Davis-Besse 1</td>
<td>Jun. 15/85</td>
<td>Loss of feedwater auxiliary feedwater failure</td>
<td>$10^{-4}$ to $10^{-3}$</td>
</tr>
<tr>
<td>40</td>
<td>Fitzpatrick</td>
<td>Jan. 19/85</td>
<td>Coolant system failures</td>
<td>$10^{-6}$ to $10^{-5}$</td>
</tr>
<tr>
<td>51</td>
<td>Fitzpatrick</td>
<td>Feb. 2/86</td>
<td>Emergency power system</td>
<td>$&lt;10^{-6}$</td>
</tr>
</tbody>
</table>

TABLE 11. Precursors to potential severe core damage accidents in the Great Lakes basin 1985, listed by probability$^{12}$. 
The previous report for 1980–81 cited seven incidents in the basin for the period, including the fourth and fifth worst incidents of 1980 (again at Davis-Besse).

The current report also notes a trend to accidents involving major feed water systems that take heat out of the reactor. It notes that although these systems are rigorously tested the failures are not showing up in tests but only during full-power operation.

The Atomic Energy Control Board of Canada (AECB) also keeps nuclear incident records and analyses significant events. The significant event reports are available from Ontario Hydro; a monthly publication entitled Event Analysis and Statistics is available from the AECB. This last publication includes accidents trends identified by the AECB.

d. Current IJC Monitoring

The last report on Radioactivity prepared for the IJC was released in 1983. A new report is being prepared and will be included as part of the Water Quality Board's 1987 Appendix B. In the past, staff at the IJC have been aided in the preparation of this report by a committee on radioactivity, but this committee has been disbanded.

The IJC also depends on the agencies to select the information to review. There is currently more than ample material for the IJC to receive, review and make its own determination as to what is significant.

Since a major release of radioactivity from an accident at a nuclear power plant would have a calamitous impact that could dwarf all previous incidents and since the IJC is the only independent international body with an overview of the regulatory agencies in this area, the reduction of IJC activity should be reconsidered.

7.5 FINDINGS

It appears that while there is an annual review of Annex 4 discharges there is no corresponding annual review of discharges under Annex 8. Such a review would require the examination of at least two national U.S. databases and all eight border states data as well as at least two Canadian databases.

From my preliminary review of discharges into the lake, there is enough evidence to conclude that extraordinary discharges into the lake from industry, transportation and municipal sewer systems are a significant contributor to the pollution load of the Great Lakes basin. Efforts to place these discharges into context with the contaminant burden associated with continuous effluent discharges should continue. Although all the data are not yet readily available, enough of a start has been made by the various agencies that it should be possible to evaluate the question of contaminant burden more completely.

The framework for understanding and pursuing this concern is readily available under the current Great Lakes Water Quality Agreement.

In addition, since most databases are now on computer, it may be possible to download data on to a disk and manipulate it at the IJC.
7.6 RECOMMENDATIONS

1. The IJC should monitor in more detail the quantity and trends of extraordinary discharges in their reports on water quality.

2. The IJC should recommend research to determine the relative contribution of such discharges to pollution of the Great Lakes basin.

3. The IJC should monitor the progress of the EPA to set up its new ERNS database and should make use of the information when it is available.

4. The IJC should encourage efforts to make data on discharges in all jurisdictions compatible and easily retrievable.

5. Environment Canada and the Ontario Ministry of the Environment should work to ensure that the valuable federal NATES database is continually updated with information from Ontario.

6. The IJC should consider re-establishment of its committee on radioactivity to monitor developments in the generation of nuclear power in the basin.

7.7 REFERENCES


5. Personal communication with Dr. Harold Quinn, Corporate Director, Health and Environmental Section, Dow Chemical Canada Inc., Sarnia, Ontario.


9. Unpublished data on effluent testing at the Detroit Sewage Treatment Plant.


8.0 PROGRAM: WORKING PAPER

Mr. Wayne Bissett  
Chemical Industries, Conservation and Protection Service  
Environment Canada

and

Leo Weaver  
Environmental Engineering Consultant, Cincinnati, Ohio

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>106</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>106</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>107</td>
</tr>
<tr>
<td>8.1 EXISTENCE AND MANAGEMENT OF DATABASES</td>
<td>107</td>
</tr>
<tr>
<td>a. Canadian Databases</td>
<td>107</td>
</tr>
<tr>
<td>b. United States Databases</td>
<td>107</td>
</tr>
<tr>
<td>c. Discussion Points</td>
<td>109</td>
</tr>
<tr>
<td>8.2 PROGRAMS TO PREVENT CATASTROPHIC ENVIRONMENTAL EVENTS</td>
<td>110</td>
</tr>
<tr>
<td>a. Two Approaches to Prevention Priorities</td>
<td>110</td>
</tr>
<tr>
<td>b. Regulatory Programs</td>
<td>112</td>
</tr>
<tr>
<td>c. Non-Regulatory Programs</td>
<td>115</td>
</tr>
<tr>
<td>8.3 OBSERVATIONS AND CONCLUSIONS</td>
<td>117</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

1. United States incident and accident databases


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LIST OF FIGURES

1. Number of chemical spill events by source in Canada (1974–1985)

2. Number of chemical spill events by cause in Canada (1974–1985)


4. "NATES" chemicals related to spill or supply volume
INTRODUCTION

This working paper aims to stimulate discussion on the kinds of programs that have been or should be designed to prevent catastrophic environmental events and suggests priorities where possible. Reference is made to those regulatory and non-regulatory programs that are proliferating due to recent world-scale incidents such as Bhopal and the Rhine River spill. Guidance provided by the chair of the workshop suggests that the Program area should focus on examination of the management of databases. From this documentation, directions for improved collection, analysis and reporting of incidents can be recommended and priorities for prevention programs established.

8.1 EXISTENCE AND MANAGEMENT OF DATABASES

A detailed review of existing databases relevant to the Great Lakes ecosystem was outside the scope of this particular Working Paper. Nevertheless it is necessary to at least briefly refer to specific examples of database management in both Canada and United States in order to draw on the current situation so that we might learn for the future.

a. Canadian Databases

In Canada, at the Federal level, no formal mechanism requiring industry to share information on accidental releases exists. As such, learning from experience the causes of certain incidents is left to informal discussions between technical experts. Companies are reluctant to share information formally due to perceived liabilities should certain information be made public.

With the implementation of the Spills Bill in Ontario, all incidents must now be reported to the Ministry of the Environment. While no formal analysis of reported data has yet been made public, there has been an increase in the number of incidents reported since 1985. This increase is probably the result of unfamiliarity with regulations including, the Transportation of Dangerous Goods Regulations which became effective July 1, 1985 (reporting of spills of inconsequential amounts of relatively innocuous substances).

The National Environmental Emergency Centre (NEEC), operated by Environment Canada, has been compiling data on significant spills since 1974. Spills are listed as significant according to, among other things, the type and quantity of material released, the implications for public safety or environmental concern and media attention. Figure 1 shows that in the twelve-year period from 1974 through 1985, on a national basis, some 4,942 spills of chemicals were listed, averaging out to more than one significant spill per day.

Transport Canada also collects data on spill incidents as part of its Transport Emergency Centre (CANUTEC) operation, providing 24 hr/day emergency response information. However, as is the case with Environment Canada, not all incidents are reported directly to Transport Canada's database.

b. United States Databases

Federal, state and local governments collect data to help set regulations, plan for emergency response and accident reduction and guide enforcement. Data and information systems are maintained by a number of federal
Two notable examples of resource systems in the U.S. for information pertaining to control and amelioration of spills and accidental discharges are: 1) the Chemical Hazard Response Information System (CHRIS), a database of information on toxic and hazardous substances; and 2) CHEMTREC, sponsored by the Chemical Manufacturers Association to dispense advice from manufacturers on toxic substances. CHRIS is sponsored by the National Response Center (U.S. Coast Guard). CHEMTREC and CHRIS both have toll free 24-hr. telephone numbers.

The databases listed in Table 1 cover four major freight modes – truck, rail, marine and air. These databases are maintained by federal agencies, state and local governments, trade associations, carriers, shippers and consulting firms.

Separate, relatively complete databases are available for rail and marine transport. Rail databases result from sample waybill data collected by the Interstate Commerce Commission (ICC) and are adequate to determine rail flows. The Train II data is the property of the American Association of Railroads (AAR). It contains complete chemical data on at least 80% of the rail shipments.

The U.S. EPA's requirements for hazardous waste shipments provide fairly complete data on such material even though there are significant differences in record maintenance between EPA Regions. Data on radioactive shipments, as maintained by the U.S. Department of Energy (DOE), are also relatively complete.

The Office of Technology Assessment found that the truck transport is the sector with the least complete database, yet it represents the most widespread public risk.

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<td>Rail</td>
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<td>Other</td>
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Source: U.S. Office of Technology Assessment (OTA)

c. Discussion Points

There are some obvious similarities in both United States and Canada data management systems. Some of these are:

- the lack of integration of government databases;
- the need for improved reporting procedures by companies, i.e. causes;
- lack of access to databases from outside government and transfer of information to public;
- lack of fora where learning from experience could take place; and
- lack of mechanisms whereby industry/government/public can agree on priorities for prevention activities based on these databases.
8.2 PROGRAMS TO PREVENT CATASTROPHIC ENVIRONMENTAL EVENTS

a. Two Approaches to Prevention Priorities

There are at a minimum two approaches to setting priorities for prevention activities. One is to perform an analysis of incidents from an historical perspective, i.e. examining various incidents over a period of time to determine causes, types and quantities of chemical involved and location. The second approach is a more proactive approach using hazard identification and assessment, followed by a determination of risk, to set priorities.

i. Historical Spill Perspective

Data compiled by the NEEC in Canada has been analyzed in various ways to set priorities for activities. In Figure 2, the distribution of chemical spills by cause is shown, while Figure 3 shows the quantity of chemicals spilled by source.

![Pie Chart]

**Figure 2.** Number of chemical spill events by cause in Canada (1974–1985).

In reviewing the data mentioned above, one might draw the conclusion that there is a need to direct resources towards reducing the number of overflows at industrial plant sites before addressing container leaks from ships. However, the potential impact may still be higher in the case of a shipping accident than a more readily containable on-site spill.

Environment Canada has also examined the data from another perspective to determine what chemicals are spilled most frequently. The data shown in Figure 4 indicate that ten chemicals account for 75% of all materials spilled, whereas 150 chemicals account for 97% of all spills. Having this list of chemicals allowed Environment Canada to develop its ENVIROTIPS series of emergency planning manuals for particular chemical substances in a prioritized way.

FIGURE 4. "NATES" chemicals related to spill or supply volume.
Although these examples are from a government perspective, there are many examples from the industrial side as well. Historical information is analyzed to direct resources to those areas or activity sectors most in need of fixing. However, it should also be stated that where incidents involve hazardous chemicals or dangerous situations, the fix is usually made before any historical trend is allowed to develop.

ii. Hazard Identification and Risk Assessment

The whole area of risk assessment and decision-making is currently growing so quickly that it is difficult for those not specifically involved in the field to understand just how one can use these techniques to set an agenda for action.

However, since Bhopal, there has been much literature of a general nature, as opposed to detailed mathematical treatises, made available to company and community officials to set priorities for action in their areas. This working paper will not try to summarize this work but a listing of pertinent literature will be provided at the Workshop.

In trying to identify the potential for accidents in Canada as part of the Bhopal Aftermath Review Project, the Working Group established under Environment Canada noted that there was a basic requirement to classify the hazardous nature of chemicals. Fortunately the Canadian Transport of Dangerous Goods Act identifies such criteria as toxicity and flammability in its regulations. Knowing the quantities of chemicals manufactured, transported or used in various locations, those areas that present the highest risk potential can be identified. It follows that priorities can then be set for a number of activities, including risk reduction through inventory management, contingency planning, community awareness and emergency response; all of these activities can be accomplished through a mix of regulatory and non-regulatory initiatives.

b. Regulatory Programs

Regulatory programs are almost always initiated in response to public demand based on real or perceived considerations. The field of public safety and protection is no exception. We have seen the regulatory responses in Europe, as a result of Seveso, Italy in 1976, in Canada, with the Transport of Dangerous Goods Act as a result of the train derailment in Mississauga and in the United States, with Institute, West Virginia and other incidents at the state and local level. In Ontario, the Spills Bill, while on the books for some years, is now being implemented and events such as the St. Clair blob encourage and drive this legislation as well as create other new programs to deal with continuous releases of toxic chemicals.

Specific programs in certain areas will provide examples of increased regulatory actions.

i. Identification of Locations Using Hazardous Chemicals

As a result of the Seveso accident and a subsequent directive within countries of the European Economic Community, all countries have developed legislation that requires companies to identify locations of hazardous chemicals.
Recent legislative changes in the United States, under the Superfund Amendment and Reauthorization Act of 1986 (SARA), require facilities that have certain quantities or storage capacity for chemicals on-site, to report the presence of an extremely hazardous material to the local community. Further, each state must now establish local planning districts to deal with contingency planning and emergency response. Local planning committees consisting of industry, government, public and environmental interest groups will assess the ways in which extremely hazardous substances are handled and the safeguards which are put in place to protect the community. In addition to reporting to the local committees, companies using hazardous chemicals must also provide Material Safety Data Sheets (MSDS).

In Canada, the federal government will soon propose legislation entitled: the Hazardous Products Act. This legislation will implement the Workplace Hazardous Materials Information System (WHMIS), developed jointly by a government/industry/labour task force, to establish a uniform system of product labelling that includes the use of MSDS. The province of Ontario has introduced legislation that goes further in saying that the hazardous materials information must be made available to public officials.

The mandatory notification of sites using hazardous materials is an area where further legislative efforts will no doubt occur. However, programs that allow community officials to fully utilize this information are, at best, only in their infancy.

ii. Hazard Analysis

The most recent legislative step in this area is the Toxic Catastrophe Prevention Act, passed in 1986 by the State of New Jersey. Briefly stated, the Act requires notification or registration of facilities involved in any way with an Extremely Hazardous Substance (EHS). In addition, the Act requires the submission of a Risk Management Program to the N.J. Department of Environmental Protection on the development of a Risk Reduction Work Plan that includes a Risk Assessment for those facilities that do not have a Risk Management Program already in place.

As a new approach, this initiative is being watched closely by the other agencies. One concern is the heavy resource implication for the agency, i.e. highly trained specialists are necessary to review the hazard analysis programs of many companies in any technical detail. Another issue involves the liability (moral or legal) of an agency that approves a particular activity and subsequently, after some accident, is found to have erred in its approval.

iii. Environmental Impact Assessment

All jurisdictions in the basin require some form of environmental impact assessment for new plants manufacturing, handling, transporting or using dangerous chemicals.

These assessments, should and often do, include hazard analysis and involve issues such as siting, contingency plans, community awareness and protection and emergency response.
Areas of concern in impact assessment include minimum acceptable buffer zones, public warning and transportation routes. Risk quantitation methods remain a subject of debate by those skilled in this field.

iv. Other Associated Areas

Following most major accidents, media attention often focuses on the need for more frequent safety inspections of industrial facilities. The difficulty here is that safety inspections, as they are normally conducted, are aimed at detecting hazards to health and safety of employees from chronic exposure to chemicals or unsafe working conditions pertaining to the equipment or buildings. Very seldom does a safety inspector conduct a detailed review of a process design and operation; these are processes often far too complex for the inspector to fully understand based on his knowledge and day-to-day routine experiences.

In the United States, OSHA (Occupational Safety and Health Administration) and EPA have combined their resources to carry out in-depth safety reviews at plant sites. Although these audits are extremely expensive from a resource point of view, they do work well in identifying areas for improvement. Unfortunately, the number of plants that can be reviewed in this detailed manner has to be very limited.

The insurance industry performs a quasi-regulatory role in safety reviews through their independent safety audit programs. This has been particularly true in the past few years as insurance rates have risen significantly.

v. Considerations

In developing positions on the need for and focus of regulatory activities in the prevention of accidents, the workshop participants may wish to consider the following issues:

- Chemical process industries are complex, making it difficult to maintain highly trained government inspectors, i.e. the problem is resources plus knowledge.

- Does acceptance of a company hazard analysis put the responsibility for accidents partly on the government's side?

- Should governments require companies to participate in community awareness programs?

- What motivating events will trigger further regulatory initiatives in the Great Lakes basin and can we prevent those events from happening?

- Are government inspection programs adequate to ensure that spill containment/mitigation measures are in place?
c. Non-Regulatory Programs

It is a law of human nature to respond to a given stimulus. Major industrial accidents have always involved some form of response, usually corrective action to ensure that a similar problem does not repeat itself.

One could logically suggest that the Bhopal accident has generated a response in the chemical industry, at least in North America, unlike any before. Industrial associations, through their influential corporate members, have been increasing the attention paid to the issues of accident prevention, emergency response and information sharing. In turn, these programs are being picked up by related industrial sectors and adopted for their use as appropriate.

Specific results of the increased number of safety audits carried out by individual companies include:

° process changes; for example, Methyl Isocyanate (MIC) is no longer transported in large quantities in the United States;

° reductions of inventories of hazardous chemicals; and

° improved detection and alerting in case of spills.

The Chemical Manufacturers' Association (CMA) and its sister organization in Canada, the Canadian Chemical Producers' Association (CCPA), have embarked on some ambitious programs for their member companies. Many of these programs have similar aims, but there are some structural differences between the two groups:

i. CCPA has an overall program entitled: Responsible Care — A Total Commitment

° This is a set of guiding principles to which each member company must agree through its Chief Executive Officer.

° The principles are implemented in practice through specific programs that members adopt as self-regulatory Codes of Practice.

° A particular program unique to Canada is the Safety Assessment whereby an annual review, conducted according to a detailed questionnaire format and signed by the CEO for each plant site, provides an on-going analysis of progress being made in safety management.

ii. Community Awareness – Emergency Response (CAER)

Both CMA and CCPA have instituted CAER programs across the United States and Canada. CAER is "a community outreach program on the part of a company to ensure that the community recognizes: the potential hazards; what is being done to reduce the risk; and that adequate emergency response plans and capability are being put in place."

This program should motivate municipal and industry officials to interact more positively to each other's and the community's benefit.
In the United States, there are nearly 1,000 CAER programs underway and in Canada all member companies of CCPA have now appointed CAER coordinators.

Other industrial associations are adopting CAER programs for their members.

Acceptance of this kind of voluntary program will no doubt be helpful to those communities that are not able, for whatever reason, to institute legislative means for ensuring industry/government cooperation.

iii. Chemical Referral Centre

CMA has developed the National Chemical Response and Information Centre (NCRIC) to provide the public and emergency response organizations with information about chemicals and advice or assistance during emergencies. Part of this program is CHEMTREC, mentioned earlier.

In Canada, chemical emergency information is provided nationally by Transport Canada through CANUTEC. Recently the CCPA has set up a Chemical Referral Centre to work jointly with CANUTEC, i.e. sharing resources in the same room to provide information on chemicals to companies and the public.

The establishment of these centres will readily allow community officials and citizens access to information that will help the dialogue between industry and the community.

One might debate how this directly affects prevention priorities. However, a more informed public should be in better position to judge the initiatives taken by the chemical industry to prevent accidents.

iv. Safety and Accident Prevention Programs

Although all of the above programs are associated with CMA and CCPA (representing the chemical industry), there are other highly-recognized non-regulatory programs that individual companies can adopt. Perhaps the most visible of these is the 5-Star International Rating System of the Loss Control Institute in Atlanta, Georgia. Plant sites are ranked against a series of detailed questions for some 20 elements ranging from Management Training through Planned Inspections to Program Evaluation and Off-the-Job Safety. In Ontario, the 5-star program is made available through the Industrial Accident Prevention Association. There are some 24 chemical and petroleum companies using this system in Ontario.

v. Considerations

To aid the workshop discussion, participants may wish to consider the following issues:

- Is the process of hazard identification and analysis adequately understood and utilized by companies in the Great Lakes basin?
Is self-regulation adequate both to prevent accidents and to satisfy public concern in this area?

Are company safety/operator training programs generally adequate?

8.3 OBSERVATIONS AND CONCLUSIONS

Without prejudicing the outcome of the workshop, there are several observations or conclusions, or both, one might make based solely on events that have transpired as a result of industrial accidents. Some of these follow:

1. There exist a number of data management systems in both countries that are designed to serve the needs of individual agencies but these systems are not compatible and do not appear able to be interlinked.

2. There have been a number of serious spills in the Great Lakes basin that have the potential to impact drinking water and public health directly.

3. Techniques such as hazard analysis are being used to identify problem areas and develop solutions.

4. There is a mixture of regulatory and non-regulatory tools available to increase prevention-oriented activities.

5. Emphasis will shift from non-regulatory (self-regulation) to a stronger regulatory regime as the number and seriousness of catastrophic events demands.

The authors hope that this Working Paper will assist all participants in their discussions during the Workshop.
APPENDIX

Human-Machine Workshops

List of Participants

- 119 -
HUMAN—MACHINE WORKSHOPS

LIST OF PARTICIPANTS

Mr. David Beattie1,2
Design Engineer Specialist
Ontario Hydro
700 University Avenue, 8th Floor
Toronto, Ontario M7A 1T7

Mr. D. Wayne Bissett2
Chemical Industries Division
Industrial Programs Branch
Conservation and Protection Service
Environment Canada
Ottawa, Ontario K1A 1C8

Mr. Peter Boyer2
International Joint Commission
100 Ouellette Avenue, 8th Floor
Windsor, Ontario N9A 6T3

Dr. Julien Christensen1,2
Universal Energy Systems
4401 Dayton—Zenia Road
Dayton, Ohio 45432

Mr. Keith Dinnie1
Nuclear Studies and Safety
Ontario Hydro
700 University Avenue
Toronto, Ontario

Dr. Baruch Fischhoff1
Carnegie—Mellon University
Department of Social
and Decision Sciences
College of Humanities
and Social Sciences
Pittsburg, Pennsylvania 15213–3890

Dr. Daniel Jones1,2
U.S. Nuclear Regulatory Commission
HF Safety Division
Washington, D.C. 20555

Mr. Walter A. Lyon1,2
Engineering Consultant and
Adjunct Professor of Civil Engineering
University of Pennsylvania
20 Clifton Road
Camphill, Pennsylvania 17011

Professor Ted Manzig2
University of Windsor
Faculty of Law
401 Sunset Avenue
Windsor, Ontario N9B 3P4

Mr. John F. McDonald1,2
International Joint Commission
100 Ouellette Avenue, 8th Floor
Windsor, Ontario N9A 6T3

Dr. Neville Moray1
University of Toronto
Department of Industrial Engineering
Toronto, Ontario M5S 1A1

Dr. George A. Peters1,2
Peters and Peters
1460 Fourth Street
Santa Monica, California 90401

Mr. Walter A. Lyon1,2
Engineering Consultant and
Adjunct Professor of Civil Engineering
University of Pennsylvania
20 Clifton Road
Camphill, Pennsylvania 17011

Mr. Harold E. Price2
Essex Corporation
333 N. Fairfax Street
Alexandria, Virginia 22313

Dr. Harold Quinn1,2
Health and Environmental Section
Dow Chemical Canada Inc.
1086 Modeland Road
Sarnia, Ontario N7T 7K7

Mr. Ken Reeves2
Emergency Planning
Office of the Solicitor—General
Government of Ontario
25 Grosvenor Street
Toronto, Ontario M4Y 1A9

1 Participant Workshop I
2 Participant Workshop II
Mr. Norm Rubin  
Energy Probe  
100 College Street  
Toronto, Ontario  MSG 1L5

Dr. Jean–Louis Sasseville  
Université du Québec  
2700 rue Einstein, C.P. 7500  
Ste. Foy, Québec  JIV 4C7

Mr. Dave Stephenson  
Professional Wastewater Operations Division  
Water Pollution Control Federation  
c/o City of Chatham  
28 McKinnon Drive  
Chatham, Ontario  N7M 1B4

Mr. Stuart Sullivan  
Energy and Chemical Workers Union  
603 Angus Road  
Oakville, Ontario  K6J 6G6

Mr. Guice Tinsley  
Human Factors Specialist  
8415 Thornberry Drive East  
Upper Marboro, Maryland  20772

Dr. Jack Vallentyne  
Fisheries and Marine Service  
Canada Centre for Inland Waters  
P.O. Box 5050, 867 Lakeshore Road  
Burlington, Ontario  L7R 4A6

Dr. Willem H. Vanderburg  
Department of Industrial Engineering  
University of Toronto  
Toronto, Ontario  MSS 1A1

Mr. Leo Weaver  
Environmental Engineering Consultant  
6978 Presido Court  
Cincinnati, Ohio  45144

Ms. Madelyn F. Webb  
The Centre for the Great Lakes  
39 Spadina Road  
Toronto, ON  M5R 2S9

Mr. Jerry Wisdom  
Wisdom Research Associates  
237 Sunset Avenue  
Windsor, Ontario  N9B 3A6

Dr. Geoff Wright  
Special Studies and Service Branch  
Ministry of Labour  
400 University Avenue, 8th Floor  
Toronto, Ontario  M7A 1T7

1 Participant Workshop I  
2 Participant Workshop II