UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

CHAIRMAN

June 21, 1990

Mr. Philip R. Clark, President
GPU Nuclear Corporation
One Upper Pond Road
Parsippany, New Jersey 07054

Dear Mr. Clark:

Thank you for your letter dated May 23, 1990, enclosing the final report of the Three Mile Island Unit 2 (TMI-2) Safety Advisory Board (SAB). The Commission recognizes the important contribution the members of the Board have made to GPU's efforts to clean up the TMI-2 reactor.

The SAB's recommendations as a result of the TMI-2 accident and cleanup described in Appendix A to its report will be reviewed by the NRC staff for future Commission program consideration.

Sincerely,

Kenneth M. Carr

Kenneth M. Carr

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Nuclear

P.R. Clark
President

GPU Nuclear Corporati
One Upper Pond Road
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May 23, 1990

Kenneth M. Carr, Chairman
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Chairman Carr:

During our briefing to the Commission on the status of TMI-2 Cleanup activities on April 20, 1989, I advised Chairman Zech that the final report of the TMI-2 Safety Advisory Board (SAB) would be made available to the Commission.

With more than 99 percent of the damaged reactor fuel removed from the TMI-2 site, the SAB has no further activity planned and has completed their Final Report, a copy of which is provided herewith.

Appendix A to the report is a set of recommendations from the SAB on possible research opportunities. During our briefings to the Commission over the years, the SAB was encouraged to identify any such opportunities they saw from their unique position overseeing the TMI-2 Cleanup. From our own perspective of the TMI-2 accident and its aftermath, we believe these recommendations deserve careful consideration as the NRC looks forward to the future.

Sincerely,

P R Clark

P. R. Clark

/amm

Enclosure

cc: w/Enclosure
Commissioner James R. Curtiss
Commissioner Thomas M. Roberts
Commissioner Kenneth C. Rogers
Commissioner Forrest Remick

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FINAL REPORT

THREE MILE ISLAND - UNIT 2
SAFETY ADVISORY BOARD

March 1981 - December 1989

MARCH 1990

FINAL REPORT

THREE MILE ISLAND - UNIT 2 SAFETY ADVISORY BOARD

March 1981 - December 1989

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EXECUTIVE SUMMARY

This Final Report of the SAB constitutes a summary of the activities of the SAB from its establishment in 1961 through its final meeting in December, 1969 when the Board entered containment for a final inspection of the plant. Beyond providing a chronicle of specific activities, the report inevitably raises important policy issues. For instance, regulations for decommissioning operating plants are only now being developed. GPU Nuclear has had to cope with the even more difficult task of long term monitoring of the severely damaged TMI-2 plant.

Thus the Board has reviewed, since 1966, the GPU Nuclear plan to place the TMI-2 plant, at completion of the cleanup, into a monitored storage condition. The Board has stated repeatedly that when the end point objectives are achieved for removal of the damaged reactor core and dispersible radioactive contamination, the TMI-2 plant will pose no hazard to the public health and safety. Furthermore, because GPU Nuclear has stated publicly that it has no plans to return TMI-2 to service, the most responsible plan after safe and secure end points are reached is to slow down the final stages of the cleanup operations to be more effective in protecting the health and safety of the workers.

On December 16, shortly after the last meeting of the Board, an important goal was achieved - the completion of the bulk removal of fuel from the reactor vessel. It is against the background of this and other successes that the SAB recounts problems that had to be overcome and quite frankly errors, which in our opinion, were made.

It is now a decade since the nuclear accident at Three Mile Island Unit-2 on March 26, 1979 and the TMI-2 Safety Advisory Board (SAB) is concluding its 8-1/2 year oversight responsibilities to ensure execution of a safe and reliable cleanup and recovery program for the TMI-2 plant. The most important question to be addressed is whether any health effects occurred as a result of the accident. The Board believes that far and away the most extensive, indeed the only detectable health effects, have been the mental stress in certain groups in the general population and in a few of the plant workers. Additional matters such as the improved techniques developed during the cleanup to protect the health and safety of the workers and the public and the lessons learned from the cleanup applicable to nuclear and Industrial type accidents are addressed in this Final Report of the SAB.

The Board was established on March 16, 1981 to provide GPU Nuclear with a qualified, independent appraisal of the recovery program with particular emphasis on the assurance of public and worker health and safety. In its 8-1/2 years of existence, the SAB has reviewed many aspects of recovery activities, including regulations, nuclear criticality, safety, risk assessment, project organization, project financing, project procedures, technical planning and public communications. These reviews have resulted in frank, critical appraisals which have always received full consideration by GPU Nuclear executive management. Additionally, the Board has expressed its views regularly to the Nuclear Regulatory Commission and to the Board of Directors of General Public Utilities, the parent company of GPU Nuclear. From time to time, the Board has participated in public hearings, especially those of the NRC Citizens' Advisory Panel on the Cleanup of TMI-2, either through its chairman or through testimony and observations by individual Board members.

The primary objective of the SAB has been to ensure the continued safety of the surrounding community and of the on-site work force. This involves minimizing total risk, as well as ensuring that those at risk fully understand that their interests are of concern. Ensuring continued safety also requires that the cleanup proceed on a sufficiently expeditious schedule to avoid the development of unsafe situations, either on or off the site due to the passage of time.

Since an accident of the magnitude experienced at TMI-2 has potential for serious consequences on the health and safety of the workers and the general population if not brought under immediate control, it was paramount, at the outset, that the reactor plant be placed in a stable, controllable condition. Hence a major share of the Board's early effort was focused on the preclusion of inadvertent nuclear criticality and an assessment of the potential for radiation induced health effects on the general population and the workers involved in the cleanup. The scientific, engineering, administrative and technical skills of the Board members were focussed on:

1. assuring that the cleanup was performed in a safe, efficient and timely manner;

2. minimizing the radiation exposures of the workers and the general public;

3. providing oversight that the planning was adequate to ensure that the necessary personnel, equipment and engineering could be provided to complete the cleanup within the constraints of the available funding; and

4. taking part in appropriate communications to the public, a large segment of whom were skeptical.

For a number of years after the accident, there was only a limited understanding of the extent of damage to the plant, to its internal components and to the nuclear fuel assemblies. Furthermore, the radioactive contamination to the internal structures of the containment and the sources and characteristics of airborne radioactivity in it were poorly understood and lacked adequate measurement. However, the Board was soon unanimous in its opinion that TMI-2 was in a stable condition and did not pose any measurable risk to public or worker health and safety.

GPU Nuclear early recognized that a strong and well qualified health physics organization was imperative if safe working conditions were to be established and protection of the public maintained. An outstanding group of health physics/radiation protection personnel were assembled and effectively utilized. The Board strongly supported this GPU Nuclear initiative as a result of which there has been, during the cleanup, no measurable radiation dose to members of the public and the plant workers have received less radiation exposure than in a normal nuclear power plant--an outstanding accomplishment.

The Board began its oversight function at the end of the second year following the accident. By that time the initial national trauma had subsided, the Presidential Investigation committee (the Kemeny Commission) had made its report, the GPU Nuclear/Bechtel recovery organization had been formed, the NRC regulatory structure was in place and the financial and legal arrangements to support the effort were well advanced.It was soon evident that the learning curve would be steep and difficult to climb, that putting into place an efficient and hard driving management team would require several painful iterations and that building competent operating and technical support staffs would be time consuming. Further, the NRC was painfully slow in developing new regulatory approaches for TMI-2. The problems and achievements of these earlier years are discussed in more detail in the following sections of this report.

The TMI-2 Safety Advisory Board in its oversight of the TMI-2 cleanup has witnessed remarkable and innovative engineering achievements at each stage of the cleanup program to meet the diverse and complex technological challenges. Planning, engineering, training and operations have been successfully developed to decontaminate the auxiliary and fuel handling building to levels that allow entry to many areas without protective clothing. The reactor building, with the exception of the basement, has been decontaminated to ambient exposure rates that permit access with minimal protection. Concurrent activities required to disassemble the reactor, and to remove, store and ship reactor fuel debris have been carried out with no radiation hazard to the general public and minimal occupational hazards to the workers. The successful effort devoted to managing radioactive wastes resulting from the accident and cleanup have involved the processing, packaging and disposal of these wastes in a safe and reliable manner. Subsequent to initial technical difficulties, the defueling water cleanup system has filtered and processed many millions of gallons of reactor coolant system water in support of decontamination and defueling.

Decontamination and dose reduction activities have been highly effective, permitting worker entries into most areas, and frequently attaining ambient radiation levels that are below safety standards established for operating nuclear power plants. Most significantly, this has been accomplished with individual worker exposure levels below those recorded at operating nuclear power facilities. The collective dose equivalent for the workers performing the cleanup has been approximately 60 person sieverts (6000 person-rem), or about 13% of the conservative estimate made in the 1984 addendum to the Programmatic Environmental Impact Statement (PEIS). No radiation injury to any worker has occurred and no worker has been exposed to levels of whole-body or internal radiation that exceed the regulatory standards set by the USNRC.

A compelling need to assess the quantitative risk to humans living within the range of the radioactivity released during the accident (almost entirely noble gases) resulted in estimates derived from limited data and yielded numerical values that were tentative at best.

The President's Commission on the Accident at Three Mile Island concluded that, based on the state-of-the-science available and in spite of the serious damage to the nuclear plant, almost all of the radiation was contained, and the actual release of radioactivity was so low that it would have a negligible effect on the physical health of individuals living within the vicinity of TMI-2.

The Board believes that the cleanup of the TMI-2 plant has far-reaching implications for the nuclear industry in the United States and abroad and that the public reaction to the accident and its aftermath should alert the entire industry to the need for open discourse between the operators of nuclear power plants and the residents of adjacent communities. Despite the uncertainty during the early hours and days following the accident, it soon became clear that real danger no longer existed. However, the public was unable to accept this fact fully and thus was subjected to undue mental stress. There is no single approach to communication with the public which will alleviate all fears of health and safety risks. However, maximization of information improves the knowledge base within the community and serves to build confidence in the professional management and technical staff of the utility.

Section 1

INTRODUCTION

This eighth and final report of the Safety Advisory Board brings to an end the unique experience of a group of scientists and engineers who remained strongly committed to the successful cleanup and recovery process and of societal and industry needs throughout the entire duration of a difficult project, particularly during a decade when the public attention was diverted from the need of a strong coherent energy program in the United States, and at a time when a negative societal attitude compromised the role of nuclear energy as an electrical power source. The political climate for nuclear power was passive and at times hostile, and thus the task of cleanup and recovery required full disclosure and community support. These were not easy times for all participants in the process, and the roles of each interested party--political, societal, economic, community and industrial--had to be accommodated and respected. Throughout this period, the Board remained intact and responsive.

The SAB was only one of many players in the successful clean-up of TMI-2. While it's mission was highly focussed on public and worker safety, the Board had the advantage of intermittent review rather than a day-by-day operational responsibility. Thus, the Board's commitment to candor may sound to some as undue criticism or suggestive of wisdom better shared more broadly.

The Board worked closely over the years with GPU Nuclear and with Bechtel. It is noted in the report that the Board considered the integrated management/worker team as one of the best in the United States for the work being carried out. On a more personal basis, the SAB treasures the opportunity to have worked with a large number of highly talented and dedicated people from these two organizations.

The cleanup would not have been possible without the commitment of $965 million from: the GPU Nuclear Corporation, insurance, the nuclear power utilities, the United States Department of Energy, the Commonwealth of Pennsylvania, the state of New Jersey and the Japanese Federation of Electric Power Companies (FEPC).

Additionally, the Board recognizes the difficult problems faced by regulatory agencies at all levels as they monitor this very important nuclear industry.

The accident at the TMI-2 nuclear power plant in 1979, although contained within the plant structures, created a situation that was technically unique and potentially hazardous for cleanup workers and a potential threat to the general population living in the surrounding community. Recognizing this, the president of GPU Nuclear Corporation at that time, Mr. Robert. C. Arnold, established an independent review group of scientists and engineers that would take a broad view and provide guidance for all aspects of the cleanup of the damaged plant that related to public and worker health and safety.

The TMI-2 Safety Advisory Board (SAB) was formed In March 1981 and was composed of nationally and internationally recognized specialists in the fields of nuclear science, engineering, physics, economics, government and medicine. Members were drawn principally from university faculties and government research laboratories. The first chairman, Dr. James. C. Fletcher, was former Administrator of NASA and returned to that position in 1986 at the request of President Reagan. Dr. Robert. Q. Marston, who succeeded him, was former Director of the National Institutes of Health and former President of the University of Florida. Members of the Board are listed below; all served the entire 8-1/2 years of the Board's tenure, unless otherwise noted.

Dr. James C. Fletcher, Chairman (1981-86)
Dr. Robert Q. Marston, Chairman (1986-89)
Dr. John A. Auxier
Prof. Merril Eisenbud
Dr. Jacob I. Fabrikant (1982-89)
Dr. Robert S. Friedman
Dr. Clark Goodman (1981-83)
Dr. Bruce T. Lundin
Prof. Howard Raiffa
Prof. Norman C. Rasmussen
Mr. Lombard Squires (1983-89)
Dr. William R. Stratton
Dr. Arthur C. Upton (1981-82)

In addition, Mr. Ronald. H. Fillnow served as Executive Secretary. Brief biographical information about the members is provided in Appendix B.

To attract an expert advisory board of the highest quality and to ensure an independent review process free of bias and conflict, complete autonomy was a basic philosophy that required constant vigilance. GPU Nuclear supplied administrative assistance as required, but the Corporation's role was to provide information, data, reports as necessary and access to the plant so that the Board could examine all issues of concern.

The Board reviewed a broad spectrum of relevant and interrelated issues: the organization, funding and administration of the project; the plans for and the performance of decontamination and fuel removal operations; radiological protection practices; working conditions and safety and educational programs; and the radioactive waste handling and shipping programs. Furthermore, the Board was charged to examine issues related to community interactions, both to ensure that public and worker health and safety issues were properly addressed and to assure the public that its interests were being considered and protected.

To help develop communications between GPU Nuclear and interested involved groups outside of the utility, the Board discussed issues with selected local citizens; workers and union representatives from the International Brotherhood of Electrical Workers and other worker representatives and with the Board of Directors of General Public Utilities, the parent company of GPU Nuclear. The Board also followed the activities of the NRC Citizens' Advisory Committee on the Cleanup of TMI-2. The Chairman of the SAB reported to the NRC Commissioners each year regarding the Board's perception of safety issues associated with the cleanup and the progress achieved.

The full Board customarily met four times each year, either in Gaithersburg, MD or at the TMI-2 site in Middletown, PA. A continuing review of safety matters was also conducted by membership panels of the SAB established to examine and provide more detailed analyses. Four panels were created in 1981: Community Linkage, Radiation Hazards, Systems Safety and Waste Storage and Disposal. The Board reorganized these panels the next year to respond to evolving plans and programs for the cleanup and to focus the reviews more efficiently:

Core Removal Panel - Dr. Lundin, Chairman; Prof. Rasmussen; Dr. Stratton; Prof. Eisenbud (1982-83); Mr. Squires (1985-89) and Dr. Auxier. This panel focussed on all actions associated with core removal and shipment (including those previously covered by the Systems Safety Panel).

External Affairs Panel - Dr. Friedman, Chairman; Prof. Raiffa; Dr. Fabrikant (1982-1989); Dr. Fletcher (1982-86) and Dr. Marston (1986-89). Formerly the Community Linkage Panel, this panel focused on providing advice to GPU Nuclear concerning public interrelationships and communications concerning issues related to the health and safety of the general public and the workers.

Source Identification and Radioactive Waste Panel - Dr. Goodman, Chairman (1982-83); Mr. Squires, Chairman (1983-89); Dr. Auxier and Dr. Stratton. Initially called the Source Identification Panel, this panel focussed on identification of all radioactive materials generated by the accident. Its responsibilities were expanded in 1984 to include radioactive waste disposal, with emphasis on identifying radioactive waste sources on the site and maintaining an inventory of radionuclides.

Radiation Hazards Panel - Prof. Eisenbud, Chairman (1981-85); Dr. Fabrikant, Chairman (1985-89), Dr. Auxier and Dr. Stratton (1986-1989). This panel examined personnel radiation exposure and its relationship to industrial hygiene, health and safety, radiological protection in relation to decontamination and dose reduction activities in worker populations and the potential of general population exposures during the cleanup.

Mr. Fillnow served as a member of each panel to ensure coordination of activities.

The four panels issued reports to the Board at each Board meeting, and additionally as required, based on their reviews. These, combined with the full Board's review of presentations by GPU Nuclear and others, provided the bases for the Board's scope of investigations and deliberations, advice and recommendations. The Board's written recommendations were submitted directly to the executive management of GPU Nuclear (1981-84, to Mr. Robert. C. Arnold, President, 1984-89 to Mr. Edwin. E. Kintner, Executive Vice President). GPU Nuclear replied formally to each recommendation at the succeeding SAB meeting.

The Board issued seven annual reports covering the April to March periods from 1981 to 1988. A Chairman's Appraisal in each report summarized the Board's work in that annual period and provided additional review and appraisal of the Board's positions on a number of issues. Rather than publish an eighth annual report, the Board has chosen to integrate the issues discussed during the past year into this Final Report, which records the Board's overall assessment of the safety of the cleanup program and some of the lessons learned during the course of the Board's 8-1/2 year review of the cleanup and recovery program, bringing the Board's advisory responsibilities to a close by December 1989.

GPU Nuclear executive management continued to be responsive to SAB recommendations and suggestions throughout the Board's existence. It was evident that the Corporation appreciated the depth and broad range of advice and assistance that the Board could provide, not only on technical and scientific matters but also on matters involving medicine and public health, social, political and economic issues and those of organization and management. In certain areas requiring expert scientific and engineering advice, although not within the purview of the Board's direct responsibilities, GPU Nuclear was free to direct the requests to a specific individual(s) on the Board, and this relationship proved to be a valuable and mutually beneficial arrangement.

Relations between the TMI-2 site management and the Board, while always respectful and open, were not always optimal and in certain matters were sometimes strained at an individual level. This did not hamper the work of the Board, nor constrain the openness of the relationship. The staff at the site was busy, often stressed and under public and media pressure and understandably some of them felt that the time required to prepare briefings, reports or plant tours for the Board and other organizations were an unnecessary imposition. This situation gradually improved with time and eventually the staff began to recognize the advantage of the professional exchange with Board members and the benefits to be gained from preparing a detailed briefing and associated reports.

Shortly after the Safety Advisory Board was formed, a second advisory group was created--the TMI-2 Technical Assistance and Advisory Group (TAAG). To avoid overlapping functions between the two groups, the Chairman of the TAAG, Mr. William. H. Hamilton, attended all SAB meetings, at which time he explained the TAAG's actions and positions on various technical Issues. Similarly, the SAB Core Removal Panel Chairman attended the TAAG meetings, at the conclusion of which he sent a letter report to Board members describing activities and his reactions to them. In this manner, the Board and the TAAG were able to coordinate their efforts. In general, the two were In agreement and GPU Nuclear probably benefited from the combined advice of the two different organizations. The TAAG was discontinued in 1988.

This report records, with sorrow, the death of one of its most energetic members, Dr. Clark Goodman, whose insights and demands for excellence set the standards the Board achieved throughout its 8-1/2 year odyssey.

This report comprises six sections that deal with those areas that have been considered and addressed by the Board as the most cogent in the cleanup program: scheduling and funding, organization and administration, community interactions that impacted the program, worker health and safety, planning and operations for recovery of the plant and removal of the core and the management of radioactive waste. A closing summary is also provided.

Section 2

SCHEDULING AND FUNDING

The research and development nature of the TMI-2 cleanup program was such that unexpected problems were inevitably identified with each stage and with successive core or plant examinations--examples were the loss of visibility in the reactor vessel caused by microorganisms growing in the radioactive coolant water, the difficulty of removing large solidified masses of fuel debris from the reactor vessel and the difficulty of cutting apart the lower core support assembly under 40 feet of water. The Board strongly supported an approach to scheduling that was flexible, provided for contingencies, allowed for the reallocation of resources when necessary and could be used as a management tool rather than as a strict measure of success. To regard a schedule otherwise risked the undermining of safety and technical issues with unrealistic expectations.

The Board frequently pressed its position that timely and expeditious completion of the cleanup was essential to long-term public and worker health and safety. However, given the uncertainties about the extent of damage to the plant, particularly the core and the reactor vessel, and the unprecedented tasks involved, a reliable schedule was not developed during the early cleanup period. Additionally, funding uncertainties, coupled with management that had not previously encountered the undertaking of a program of such complexity in scope and size, necessarily affected the course, direction and pace of the cleanup process from the beginning. At this stage it was necessary for GPU Nuclear to bring into the recovery program the resources, experience and management of Bechtel Corporation to assist in coordinating, carrying out and completing the overall recovery program (see Section 3).

The Initial concerns of the Board revolved around the pace of the cleanup and the worker safety of the various operations. The Board believed that proposed schedules were unduly optimistic and that the cleanup would extend considerably beyond the early estimates of

5 years. Extended schedules had major financial implications and could exacerbate operational difficulties by increasing the potential for deterioration of mechanical, structural or electrical components. While it was unlikely that this would increase the risk to the public, it would add further to the complexity and cost of the cleanup. The Board was concerned that as individual tasks were prolonged, the total radiation exposure to the workers would also increase and reach or exceed regulatory limits, thereby requiring additional trained workers with an attendant increase in cost and further schedule delays. The Board was concerned that with an extended period for recovery, worker morale would suffer, the risk of accidents would increase and as a possible worst case, a shortage of funds could result in the lay-off of the experienced and competent workforce.

Concern with the pace of the cleanup was most acute in 1982-83, when funding was limited and the schedule was delayed for approximately eight months by the investigation of allegations, to be proven unfounded, regarding the safety of cleanup operations. The allegations were primarily related to the refurbishment of the reactor building polar crane which was essential to the lifting of the reactor vessel head and gaining access to the damaged core. The principal concern of the Board was the lengthy delay with potential for a reduced level of safety. Because the Board had reviewed the actions involved and was satisfied that safety had not been impaired, the Board urged GPU Nuclear and the NRC to find some accommodation to permit work to continue while these or any future allegations were being resolved through legal processes. (The implications of this are discussed in terms of project management in Section 3.)

The sources, amounts and availability of funds to complete the cleanup were finally in place in 1984. With the funding in place and the allegations concerning the polar crane resolved, the pace of the cleanup increased in 1984-85 as access was gained to the damaged core and the removal of the fuel debris began. Removal of the fuel from the reactor vessel and shipment off site were the essential steps to be accomplished in order to establish a safe and secure plant condition. Nonetheless, the Board continued to raise concern about the unrealistic work schedules developed by GPU Nuclear/Bechtel, Inc.--these were designed to be optimistic and provided little or no contingency for unexpected delays. Progress against the schedule was almost impossible to monitor because of the lack of a fully integrated, iterable cost and schedule control program that recognized both financial and personnel resources.

Although the funding issue was not a major concern in the later years of the cleanup, the Board continued to maintain an overview of any financial developments that could result in unforeseen delays or dislocation of established priorities. Finally, in the last several years of the cleanup, GPU Nuclear created a discretionary management reserve of funds in anticipation of possible delays. This policy of balancing funding plans against potential delays was an effective means of providing management with the flexibility needed to perform a research and development type task.

In 1985, GPU Nuclear/Bechtel began presenting the initial plans for the post-cleanup phase to the Safety Advisory Board. The Board's own criteria for this phase were that they should be technically sound and easily understood by the public, and that the final plan should specifically address those aspects that pertained to public and worker health and safety. To closely scrutinize GPU Nuclear/Bechtel's plans for placing the plant in a safe and monitored condition when defueling was complete, that is, a Post-Defueling Monitored Storage (PDMS) condition, a special committee of Board members was established to review the proposed end-point conditions and recommend Board action.

The prerequisites for entering PDMS are: 1) substantially all fuel has been removed and packaged and all potential recriticality configurations have been eliminated; 2) all packaged fuel debris has been shipped from the site; 3) any potential for more than a trivial release of radioactivity with no associated health hazard has been eliminated; 4) to the extent practical, plant systems have been drained of radioactive coolant and other liquid reservoirs; 5) all radioactive waste from major cleanup activities has been shipped from the site or packaged and staged for shipment and 6) radiation within the plant has been reduced, consistent with as-low-as-reasonably achievable (ALARA) principles, to levels that allow all necessary plant monitoring activities consistent with the long-term goals, required maintenance and any necessary Inspections.

Following considerable review and recommendations for revision, the Board concluded that PDMS was an acceptable plant configuration for marking the completion of the TMI-2 cleanup. Furthermore, the natural decay of radioactivity over time would decrease the exposure rates to workers while posing no threat to the public. In addition to the overriding assurance of protection of public and worker health and safety, certain societal and economic benefits would accrue over time thereby further supporting the fourth stage of the recovery; i.e., PDMS.

As plans for PDMS were developed, the Board recommended that GPU Nuclear/Bechtel develop contingency approaches and alternatives to avoid being impacted by delays in NRC and political approval of the PDMS condition. The Board urged and supported Technical Specification Change Request 53 (TSCR #53), which permitted the plant to be operated in a mode that invokes most of the PDMS conditions prior to the latter concept being formally approved by the NRC. While the Board was pleased that the NRC finally approved TSCR #53 in May, 1988 it regretted that this approval could not have been effected earlier. The cost of the cleanup was probably greatly increased by the need to continue management and technical practices designed for an operating nuclear power plant during the cleanup program since 1979, but without in any way adding to public or worker health and safety.

Section 3

ORGANIZATION AND ADMINISTRATION

The manner in which the TMI-2 cleanup project was organized and managed played an important function in the efficiency and safety with which work was conducted. Thus the Board devoted considerable time to examination of the organizational structure of the management team and the procedures and methods employed to accomplish the work.

During the latter half of the cleanup program, the Board was pleased to observe that the entire GPU Nuclear/Bechtel project team had developed into a highly professional and experienced R&D engineering organization. The integrated management/worker team was probably one of the best in the United States for the work being carried out and, in that sense, a national resource for dealing with another challenge such as the TMI-2 accident. Although the Board recognized the inevitable breaking-up of the highly effective team, it had the satisfaction of knowing that the team members and their parent organizations would carry with them the benefits and valuable experiences of 10 years spent cleaning up the TMI-2 nuclear power plant following the accident.

However, in the immediate aftermath of the accident, the organizational response was *ad hoc* and unorganized, but reasonably effective. Within weeks, 2000 workers, engineers and scientists from over 150 different companies and organizations were at the site. When the damaged plant had been stabilized and secured, GPU chose to employ Bechtel Corporation, one of the largest architect/engineering companies in the world, as the primary contractor for the cleanup and recovery. The Board considered this action by GPU to be a wise decision because the utility had limited skills and experience in the necessary technical areas and was not prepared to carry through a cleanup task of this magnitude and complexity. The resulting GPU/Bechtel management organization was the subject of much of the Board's review, deliberation and recommendations during this stage of the cleanup program.

During the first few years of review, the Board considered the planning and management of the cleanup program to be inadequate for the tasks being faced. The situation could be traced directly to the lack of experience of both GPU Nuclear and Bechtel in the management of a complex research and development (R&D) engineering program. The management team continued to view the cleanup of the plant as a production operation, not dissimilar to operating a plant or conducting a major construction project, with limited appreciation for the health and safety implications, public and political pressures and federal regulatory control and constraints. Compounding these difficulties were overlapping and conflicting contracts with two different Bechtel organizations involving different work experience and resources, further emphasizing the lack of an integrated and coordinated working team.

As a result, most of the recommendations made by the Board in those earlier years of the program were directed to improving the overall integration of the management system required for the development of an integrated operating plan, development of an adequate system for cost and schedule control and the formation of a dedicated risk assessment program, as examples. GPU Nuclear's formal merger with Bechtel management and workers into one functional, operational and organizational entity focussed on the cleanup program in 1982 was in keeping with the Board's recommendations.

Developing this integrated team illustrated the difficulties to be expected in establishing an organization of management and worker personnel from more than one company--with different experience, organizational background and career focus--and molding it into a single integrated organization with specifically defined responsibilities and authorities to carry out a complex engineering program of such size and scope.

The 1983 experience of worker allegations related to the potentially unsafe refurbishment and operation of the polar crane was a symptom of the difficulties that required this organizational restructuring. The allegations not only had significant impact in delaying the cleanup schedule, but reflected and exacerbated problems of worker morale. Three employees (two GPU Nuclear and one Bechtel) raised several serious allegations, some related to potential safety violations. The allegations and their proponents were given extensive attention by GPU Nuclear management, the

NRC, the media and the public. Because of the Board's concern for potential safety hazards and delays in the cleanup, the Chairman of the Core Removal Panel examined the allegations of the most senior of the three individuals and concluded that the allegations were unfounded. A thorough investigation by the NRC Office of Investigation similarly concluded that the allegations were without substance.

Early concerns about the administration of the cleanup project were often related to the cumbersome and expensive support system for accomplishing potentially hazardous work. This was reflected in a 1982 report that estimated 100 hours were spent in preparation for each one hour actually spent working in the reactor building. As the frequency of entries each month increased and experience was acquired, the preparation time dropped substantially, indicating the improving efficiency with which work was conducted.

One of the lessons learned during the cleanup was that many of the administrative inefficiencies were related to the constraints of the TMI-2 Technical Specifications. The Technical Specifications did not realistically portray plant conditions or potential hazards to the public, workers or the environment. As a result, TMI-2 was constantly subjected to controls and restraints more applicable to an operating nuclear power plant. The Board urged GPU Nuclear to pursue aggressively license modifications recognizing that TMI-2 was not an operating plant. Over time, GPU Nuclear was able to modify the Technical Specifications to remove some of the unnecessarily restrictive technical requirements. The cleanup did require special considerations, but the excessive constraints placed upon the plant and the cleanup operations implied a greater risk to public and worker health and safety than actually existed.

After the delay caused by resolution of the polar crane allegations, there was a marked increase in management efficiency and worker morale. The increased efficiency of the project team was demonstrated repeatedly as unexpected technical challenges were encountered. In 1986, the team responded to the loss of visibility due to microorganism growth in the reactor vessel by concentrating many of its resources on the problem, including the forming of task groups composed of experts in biology, filtration mechanics and chemistry. GPU Nuclear's successful resolution of the microbial growth and filtration problems was a major management achievement.

Development of the specialized tools for defueling the reactor demonstrated the project team's ability to concentrate personnel and resources to solve difficult problems. During the early phases of defueling, the Board had been concerned with the inordinate amount of time required to develop improved defueling tools. When GPU Nuclear consolidated its engineering efforts in 1987 into a single organization responsible for the design and development of remote tools for defueling, there was a marked improvement in moving tool development rapidly through design, construction, testing and operation.

Despite failure early-on to recognize the R&D nature of the job, the need to go through a number of organizational arrangements and the necessity of working under overly restrictive NRC regulations, the GPU Nuclear/Bechtel management team soon developed into a highly productive group which has brought the cleanup close to a reasonable conclusion at this time.

Section 4

COMMUNITY INTERACTIONS

Non-technical community-based factors worked to impact the cleanup program in many ways, some of which delayed progress and Increased the cost and complexity of work, and, correspondingly may have increased the potential or real hazards to workers. For example, the 1980 out-of-court agreement with the City of Lancaster prohibited river discharge of over 2 million gallons of water and public concern coupled with legal challenges delayed the necessary venting of krypton-85 from the reactor building prior to worker entry taking place. These are examples of major, costly delays over issues that involved negligible public exposure to radiation with no concomitant hazard to public health.. The SAB recognized that it was important to minimize the potential for these kinds of delays which result from a lack of public knowledge and awareness by maintaining a high level of public communication and public understanding of the cleanup.

The SAB was charged with the responsibility "to support and evaluate communications between GPU Nuclear and interested groups outside of GPU Nuclear in carrying out this program to protect public and worker health and safety." The SAB regarded this as an important responsibility. Therefore, an SAB panel was established to undertake the tasks associated with this function of the Board. The group identified four tasks: (1) to develop a community interface including the establishment of a leadership contact group to monitor community attitudes; (2) to develop a relationship with the NRC Citizens' Advisory Committee on the Cleanup of TMI-2; (3) to evaluate GPU Nuclear public opinion surveys and their linkage to GPU Nuclear community programs; and (4) to nitiate resolution of conflicts through introduction of a mediation effort, including (a) develop information about other such efforts, (b) Initiate contact with conflict resolution specialists, and (c) experiment to determine desirability of arrangements to enhance mutually agreed upon programs for GPU Nuclear's future In Central Pennsylvania.

The panel, chaired by Dr. Robert S. Friedman, initially devoted most of its attention to the first three tasks. However, because the Board was concerned with worker and public health and safety, the group incorporated worker perception of occupational health and safety during the cleanup into its assignment.

A list of twenty-five community leaders in the Harrisburg, York, Lancaster and Carlisle areas were identified to provide community-based periodic evaluation of attitudes about GPU Nuclear management, the TMI-2 cleanup program and its progress. Among the leaders were public officials, leaders of civic groups, trade associations and labor unions, academic administrators and business and industrial leaders. Four rounds of interviews with these individuals were conducted between April 1982 and July 1984. This program was discontinued after July 1984 because it had lost some of its effectiveness and because other, more available, sources of information about community opinion had become available.

In the twenty-seven month period during which the community-based interviews were conducted, it was noted that reactions of the community leader group changed noticeably. During the first two rounds of interviews in 1982 and early 1983, respondents were still preoccupied with the events of the accident rather than the events of the cleanup. Reference was often made to what individuals were doing at the time of the accident. Accident "war stories" often prefaced answers to questions or comments on what was happening with the cleanup of Unit 2. There was considerable uncertainty about cleanup progress and concern about adequacy of funding, particularly since funding arrangements had not been completed at the time. Moreover, the sense of confusion and crisis management that surrounded media coverage at the time of the nuclear accident itself had not fully dissipated.

By the time of the fourth and last round of interviews, in the summer of 1984, there was evidence of a shift in focus and response among the leaders being interviewed. Responses were directed to activities concerning the cleanup, i.e., core examination, headlift, etc. that had had considerable public exposure. Discussion turned to steps to achieve the end of the cleanup process. The announcement of a long-term full-scale spending program for cleanup brought responses of optimism about cleanup progress from the leader group. Sentiment toward media reporting and public relations communications from GPU Nuclear also shifted. In contrast to earlier comments of confusion and inaccuracy in reporting, the late 1983 and 1984 leader responses characterized the information flow as accurate, complete and informative. Many respondents expressed the opinion that GPU Nuclear was now open and forthcoming with respect to the ongoing cleanup issues surrounding the complex engineering problems such as core examination, headlift, etc.

By the summer of 1984, except for some concerns about management competence at TMI-2, respondents were primarily interested in discussing the issues surrounding restart of TMI-1, which was down for refueling at the time of the accident and had not been operated since that time. Much of this concern was undoubtedly the result of wide media coverage on the restart issue, the heightening legal environment in which the issues were escalated by community-action groups and its current significance in the decision-making processes at the NRC. Nevertheless, in the minds of the community leader group, by this time, the cleanup program had become a routine matter, funding was in place and its attention had shifted to other matters.

Meetings were held on four occasions in 1983 and 1984 with union leaders and rank-and-file workers to ascertain their views about health and safety issues and GPU Nuclear/Bechtel reactions to their concerns. Additionally, meetings were held with union leaders and building trade workers employed by Catalytic Construction Co. on March 29, 1983 and with GPU Nuclear-employed union leaders from the International Brotherhood of Electrical Workers (IBEW) on three occasions during 1983 and 1984. The individuals interviewed represented the largest contractor and subcontractor work force and trades group in the cleanup program.

The concerns and issues raised by the Catalytic building trade workers involved health and safety, training and communications. For example the requirements for respiratory protection against internal radioactivity resulted in greater fear among workers than external radiation exposure or industrial accidents. Furthermore, there was concern about rule changes involving respiratory protection that were introduced without advance notice and/or without explanations to them for the changes when these involved the use of respirators and rules involving regulatory guidance with which they might not agree. It appeared that workers had an important psychological need for respirators and wanted more training and information so as to appreciate changes in need for respirators. Complaints centered also on the training program which was considered to be too hurried and should be spread out over time for better assimilation. They sought improved communication between workers, managers and engineers to increase efficiency and reduce wasteful entries and thus reduce unnecessary exposure into contaminated areas. Finally, workers expressed feelings of esprit de corps, pride in their work and desire to get on with cleanup tasks without outside interference.

On the other hand, the meetings with IBEW officials representing GPU Nuclear workers at TMI-2 produced few fears of safety hazards. The primary concerns raised by GPU Nuclear workers were job security when the cleanup was completed and a number of management practices unrelated to safety. As a result, there was no evidence that workers believed they were exposed to unwarranted or unnecessary occupational health or safety risks. The union representatives expressed confidence in the radiation protection provided by the GPU Nuclear Radiological Controls personnel.

SAB members regularly attended meetings of the NRC Citizens' Advisory Committee on the Cleanup of TMI-2 and kept the SAB informed of the deliberations of that group. On occasion, SAB members made presentations to that Committee. In addition, the SAB chairmen with selected members of the SAB met on a number of occasions with the NRC Commissioners and staff to provide SAB perspectives on the cleanup progress.

Board members regularly offered advice and consultation to the GPU Nuclear Communications Division on its educational and communications programs. In 1985 it made an evaluative progress report on its appraisal of the GPU Nuclear communication program to the director of the program.

The monitoring of community opinion on nuclear power and the TMI-2 recovery process was an important activity for the External Affairs Panel. Community leader interviews (discussed above), public participation at the NRC Advisory Committee meetings, newspaper and other media information and opinion surveys provided a variety of sources to chronicle changes in opinion. Overall, there was evidence of a decline after late 1979 of public fear of health risks associated with the accident and its aftermath and increasing assurance that public health and safety had been safeguarded. Nevertheless, the experience at TMI-2 in the aftermath of the accident has been instructive about difference existing between the perceptions within the scientific community and the public regarding health risks of nuclear power. There remains continued fear among some individuals and vulnerable groups in the Three Mile Island area regarding potential health risks in spite of assurances by most experts that radiation exposure from the accident and cleanup has been negligible.

At the time of the accident in March 1979 GPU/Metropolitan Edison Corporation had only a small communications staff and was unprepared for the demands placed on them. Subsequent to the formation of the GPU Nuclear Corporation in 1982, the communications staff has increased substantially in size, in experience and professionalism. In addition to its role of informing the public of events regarding cleanup plans and activities, it has conducted and maintained educational programs, a speakers bureau and plant tours to enable the public to understand better the nature of the accident, its cleanup progress and the safe operation of the undamaged nuclear reactor, TMI-1. Evidence suggests that this has resulted in increasing public knowledge about the the accident, a growing satisfaction regarding the success of the cleanup and perhaps increased confidence in the utility. It is not possible to separate the degree to which this change is the result of the cleanup progress, the communications program or the passage of time. Nevertheless, the Board has recognized that the work of GPU Nuclear's professional communications division has been helpful in effecting a positive change in community perceptions about conditions at TMI-2.

An electricity generating power plant is operated in full public view and its success is based in large measure on the efficient production of electricity and a "good neighbor" policy. This is especially true for a plant powered by nuclear energy. However, because of negative public attitudes toward nuclear energy and fear of accidents it is essential that such public utilities pay close attention to their neighbors and the public they serve. This has been especially true with respect to the TMI-2 accident and the successful restart and performance of the TMI-1 nuclear power plant.

The NRC Advisory Committee on the Cleanup of TMI-2 gave GPU Nuclear the opportunity to explain its activities during the cleanup and plans for TMI-2 in a public forum available to open debate and scrutiny. As the cleanup comes to an end, GPU Nuclear would benefit from continuing these discussions with the community. Decline in newsworthiness and public attention concerning the cleanup a decade after the accident makes the NRC Advisory Committee forum a less effective method and tends to link GPU Nuclear with the events of the accident.. However, GPU Nuclear should consider establishing its own mechanisms for regular cooperative interactions with citizen groups including those that have been highly critical of its activities. It should also continue to maintain a multidimensional communications program.

The Board believes that the public reaction to the 1979 accident and its aftermath should alert the entire electric power industry to the need for open discourse between the operators of nuclear power plants and the residents of adjacent communities. There is no single approach which will alleviate all fears of risks to health and safety. However, availability of information should improve the knowledge base within the community and serve to build confidence in the management and staff of the utility.

Section 5

WORKER HEALTH AND SAFETY

Highly restrictive industrial hygiene and radiological protection standards were used during the cleanup to protect the health and safety of the workers. The worker exposures were remarkably low, representing a collective dose equivalent of approximately 60 person-sieverts (6000 person-rem) or approximately 13 percent of the conservative estimate made in the 1984 addendum to the Programmatic Environmental Impact Statement prepared by the NRC. No radiation injury to any worker occurred, and no worker was exposed to levels of whole-body or internal radiation that exceeded the regulatory limits of the NRC.

The radiation protection program instituted by GPU Nuclear and carried out by the GPU Nuclear/Bechtel team was, in large measure, responsible for this excellent record. The program was not in place at the time of the accident and took several years to evolve. It started with a separate health physics section within the TMI-2 organization--the Radiological Controls Division--established in 1980 and reporting to the President, GPU Nuclear. This reporting level ensured appropriate attention, authority and independence for the program. The Board closely advised and monitored the radiation protection program and made numerous recommendations regarding its role and practices in the performance of the cleanup. In 1982, the Board regarded the radiation protection program as adequate but in need of a broader perspective that balanced all potential radiological and industrial health hazards involved in the complex occupational environment of the TMI-2 cleanup.

A balanced perspective was the consistent theme of positions taken by the Board throughout the cleanup. The Board recommended an approach to minimizing potential risks to workers by identifying and reducing hazards, instituting appropriate administrative controls, taking a reasonable and practical approach to interpreting regulations and maintaining a balanced view of worker safety in order to reduce all potential occupational hazards. This proved to be an effective practice carried through the entire period of the cleanup program.

Of major concern were the excessive regulatory controls and selective corporate restraints exerted on cleanup operations, particularly in the control of skin contamination and the sometimes unnecessary use of respiratory protection. While caution in interpreting regulations in a novel situation such as TMI-2 was understandable, the Board was very concerned that this lengthened the cleanup process, increased costs and could have increased some risks to the workforce. The responsibility for this undue conservatism was shared by both NRC and GPU Nuclear.

A partial origin of the excessive conservatism was the PEIS issued by the NRC in March, 1981. The PEIS was interpreted in a manner that led to its use as a set of bounding values rather than in its normal role of providing guidance. The collective dose equivalent limits set forth in the PEIS were unrealistically low when compared to the experience of other nuclear plants under normal operating conditions. The maximum permissible dose to individual workers is limited by 10 CFR Part 20, and is appropriately the same for all radiation workers. However, it would seem reasonable to allow higher levels of collective dose equivalent when larger numbers of highly trained workers are recruited for recovery operations or permit higher individual exposures, but still within NRC limits, to reduce the number of workers to be trained and thus reduce costs and improve efficiency.

The Board was satisfied with the realistic evaluation of projected personnel exposures set forth in the supplement to the PEIS in 1984. The original level of personnel exposures expected during the cleanup had previously been constrained to a range of 20-80 person-SV (2000-8000 person-rem) collective dose equivalent and may have been, in part, responsible for some of the excessively conservative approaches taken to limit radiation exposures of the workers. The supplement issued by the NRC raised the estimate to a range of 130-460 person-SV (13,000-46,000 person-rem) collective dose equivalent. By the end of the cleanup, the original estimate proved to be the more accurate, although the scope of work actually conducted was considerably less than projected in the first PEIS estimate.

Radiological conditions, decontamination activities and use of protective clothing and equipment within the TMI-2 plant were followed closely by the Board. Improved radiation source identification was recommended to allow effective dose reduction and/or decontamination. The question of airborne contamination in the reactor building was one of considerable and extended concern by the Board since it was felt that GPU Nuclear did not address the issue with sufficient urgency nor consider it a matter of high priority.

The Board recommended a greater effort to reduce surface and airborne contamination levels in order to lessen the need to use respirators and cumbersome protective clothing in containment. In the opinion of the Board, this unnecessary equipment caused some reduction in productivity, increased the level of radiation exposure due to the lowered efficiency and increased the probability of industrial safety risks resulting from heat stress or restricted movement. The tradeoffs between protection from radioactive contamination and industrial hazards had to be continually evaluated.

For many years, the Board argued in favor of the reduced use of respirators when radiological conditions permitted. This was to be accompanied by increased training and education of workers about all potential health risks, including those of internal vs external radioactive contamination. To support the reduced use of protective equipment, Board members made entries into the reactor building without wearing respirators when the ambient air quality levels warranted..

For several years, beginning in 1985, radiological conditions in the reactor building had improved sufficiently to permit an increasing number of entries to be made without respirators (35 percent of the entries in September 1985 were without respiratory protection). The Board was encouraged by this trend but was disappointed when, in 1987, GPU Nuclear chose to require use of respirators for all work on the defueling platform. The management decision was made primarily because sporadic, high-radiation levels were detected on breathing zone apparatus (BZA) equipment worn by the defueling operators on the platform. The Board regarded the decision as unnecessarily conservative because the BZA filter head design allowed no airborne contamination to contact the filter surface, thus implying the existence of higher-than-actual airborne activity levels. An improved head design for the filter could have improved the accuracy of determining airborne levels and, perhaps, altered the decision to use respirators. However, since the workers were comfortable in the respirator protection equipment and preferred this arrangement, the Board did not pursue the use of a new BZA filter design nor press for reduced use of respirators. The Board recognized that although the respirators were not required for the radiation protection of the workers, there were other reasons that could justify their use in the hostile environment of the reactor vessel defueling platform.

In general operational terms, the Board observed that detailed planning for operations and extensive training--especially the use of mockups--were essential to ensuring worker health and safety. The Board strongly endorsed the constant training of workers in the use of defueling tools and in general safe working practices. Contingency plans and readiness review meetings before all major operations proved to be a vital component to effective and successful completion of each difficult task.

Remotely-controlled equipment was used in the reactor vessel, reactor building, and auxiliary and fuel handling building to help keep personnel radiation exposures low. Consideration of the use of a fully robotic defueling system was supported by the Board, but rejected by GPU Nuclear as too untested, time consuming and expensive. The use of some robotic equipment was effective in supporting defueling operations; e.g., the remotely-operated plasma arc torch used to cut up the lower core support assembly. Remotely-operated mobile devices were developed to characterize, decontaminate and defuel some otherwise inaccessible or extremely hazardous regions of the plant. The Board strongly endorsed the development and use of this equipment.

Decontamination by robotic means represented only a small portion of the total decontamination effort. Most decontamination procedures were conducted by workers using traditional methods such as water flushing, hand wiping, scabbling and high pressure washing with water. One of the more difficult aspects of developing suitable decontamination methods was the working in the hostile environment of a high beta radiation field in addition to that of a high gamma field. Extensive use of mockups was again an important part of preparation for the successful execution and completion of the radioactive decontamination tasks. In addition, close support was provided by Radiological Controls personnel to ensure maximum protection from both beta and gamma radiation.

Section 6

PLANNING AND OPERATIONS

The most important and central operation of the TMI-2 cleanup was the safe removal and shipment of the damaged reactor fuel. Therefore, the planning, preparation, and conduct of fuel removal operations represented the largest part of the Board's attention and deliberations. This ranged from concern about potential recriticality, the need to understand the conditions within the reactor vessel and to the approaches and equipment required to remove the internal components and fuel debris in a safe and reliable manner.

From the outset, the review by the Board, and especially through the Core Removal Panel oversight, set forth certain principles which were based on the realization that the work ahead would require substantial research and development and was not a straight forward operational or construction task. The following principles were embodied in this philosophy:

1. Data acquisition designed to provide information about the physical conditions to be encountered at each step in the cleanup process was central to the process and would prove to be the fastest and least troublesome way to proceed. Such data would provide the bases for procedure analyses, design of tools, execution of appropriate operational procedures and thorough training of operators and workers to carry through the task to satisfactory completion.

2. Workers and operators would receive intensive training on realistic mockups or simulators before engaging in actual operations, particularly for tasks within the hazardous environment of the reactor building.

3. All critical equipment such as the polar crane or canister transfer system should be tested under realistic conditions before operational use.

4. All equipment failures or operational errors would be treated as potentially serious events requiring failure analysis and corrective action to preclude recurrence.

5. Schedules in a complex research and development project do not represent a commitment to carry out a task at a particular time but rather a system of management control to keep a dynamic and complex process working in concert to achieve specific engineering goals. Modifying a schedule and establishing contingency plans when required are responsible approaches of management. Poor performance or failure to complete the task is considered to result from inadequate management.

The first major event in the defueling of the damaged plant was the removal of the reactor vessel head using the polar crane. GPU Nuclear/Bechtel was pursuing the process of head removal in the spring of 1983 when the Board examined the preparations critically and concluded that the project organization was not prepared to proceed with the work. The crane was unavailable, planning was incomplete, procedures were not fully available, much needed equipment was not at hand and operator training was inadequate. The reactor head removal was delayed, however, because of investigation of allegations concerning the safety of the polar crane. This was discussed in section 3 of this report.

In the following year, the project was able to complete plans, develop procedures and train operators for the lifting of the reactor vessel head. The performance of the operation proved unsatisfactory. Three crane failures occurred and two surveillance cameras failed, one of which was an essential camera with no backup. There were several problems with cable management, an incorrect disruption of electrical power, communications problems, leaking shield containers, an overcrowded command center and inappropriate shift turnovers. In all, 52 hours were required to accomplish a planned 12-hour task. While the time elements of the head lift may have been unduly optimistic, it was the series of procedural failures that proved to be the signature of poor operational planning and management decision making.

Most of the failures should not have occurred. The successful removal of the reactor head can only be attributed to the performance of the emergency response team and the fact that the equipment failures happened at times that permitted ad hoc on-site corrective actions. Because similar failures in the future could have serious consequences, the Board strengthened its recommendations for more thorough training, better procedure planning, a crane reliability program, improved interface communications and control and the establishment of a safety-oversight or failure-avoidance group.

The reviews conducted by both GPU Nuclear/Bechtel and the Safety Advisory Board resulted in increasing the understanding that the scope of the cleanup project was more of a research and development task than had been anticipated and should be approached accordingly. This resulted in improved performance when the plenum was removed from within the reactor vessel in May 1985, which was a more difficult task than head removal. The operation was performed without incident and completed with great skill, indicating that GPU Nuclear/Bechtel had made significant progress in preparing an operational plan and in developing the procedures required for the complex task.

By the end of 1984, it was clear that removing the damaged fuel and other structural debris from the reactor vessel would be a very complex procedure unrelated to established methods for defueling a plant. A large void involving approximately the upper third of the core region had been identified; under it lay a bed of broken fuel rods, stub remains of assemblies and smaller fines and pellets, all residing on a solid crust. A large amount of fuel had melted during the accident and had formed large masses of resolidified material in the lower portion of the lower core region, primarily in the lower core support assembly (LCSA) and in the bottom head of the reactor vessel.

Throughout 1985, two fundamentally different methods of approaching the problem of removal of 300,000 pounds of core debris were discussed. One method would have employed a robotic system to load debris into a shredder to be cut and ground into small pieces, converted to a slurry and placed into fuel canisters. An alternative method was the use of long-handled tools in a pick-and-place procedure that represented a more conventional approach to fuel removal. Several different tools (or end effectors) would be required by operators to place material into fuel canisters, and to chisel or dig, saw and cut, or lift and pry fuel and structural material apart. To reach the bottom of the reactor vessel from a work platform above the vessel, the tools would have to have a variety of design features for special task requirements and would have to be approximately 40 feet long.

The Board recommended, after examination of the two alternatives, that consideration be given to the use of remotely operated defueling equipment because of its potential for reduced worker exposure, greater and more effective throughput of debris collection and improved canister loading. The Board also urged that the use of a shredder be given appropriate consideration. GPU Nuclear, however, decided to pursue the use of long-handled tools because of its concern that an untried shredder procedure and unproven robotic equipment and methods would present major development obstacles. The Board accepted the decision but continued to press for the development of alternative techniques and procedures in case the manual method was judged to be unsatisfactory.

In retrospect, the GPU Nuclear decision to use long-handled tools cannot be properly assessed because alternative techniques would probably also have incurred delays due to the unanticipated research and development effort. However, the nuclear industry should plan ahead for other needs of this kind that may arise in the future and should initiate development of the required equipment with consideration of the use of robotic equipment and procedures where appropriate.

As expected, the defueling operation was a slow, costly, tedious and often frustrating task with numerous interruptions to overcome unanticipated obstacles, and took approximately two years longer than originally estimated. Defueling was able to proceed as a result of the innovative designs of the tool engineers and the training, dedication, skill and perseverance of the workers on the defueling platform.

When defueling work began in October 1985, the focus of the Board's oversight moved from planning to the conduct of defueling operations. The start of defueling was a significant achievement in a technically complex situation and was associated with improved morale and professional pride. The Board believed that the accelerated schedule that had achieved this milestone was noteworthy; it also believed that, given the unknown challenges ahead, further acceleration would have to be tempered by consideration of the unique nature of the project. The Board reiterated that the expectations of GPU Nuclear/Bechtel and the public regarding the rate of fuel removal should not be unrealistic nor allow the priority of safe working practices to be diminished.

The loss of water clarity in the reactor vessel in early 1986 and the attendant year-long slowing of defueling progress were of great concern. Visibility was reduced to inches by the virulent growth of microorganisms, apparently introduced in the river water into the containment cooling system during the accident. Growth was nurtured by heat, light and organic hydraulic fluid leaking from the defueling tools. However, the clarity did not improve when the microorganisms were killed because the presence of degraded organic material and inorganic colloids continued to clog the defueling water cleanup system filters and obscured visibility. The Board was pleased with the effective research programs that were put into place to solve the problem and proceed with the defueling operations.

With visibility restored, the defueling operators were able to complete defueling the core region using long-handled tools. While visibility had been lost, operations had been conducted with little or no capability for direct observation of the operation resulting in the prolonging of fuel debris removal operations. A modified oil drilling rig was used to drill out samples of the debris and to break up a large mass of resolidified material in the central core region.

The final steps to defuel the reactor vessel were the most difficult in what proved to be an extremely difficult series of tasks. Starting in 1988, it was necessary to cut apart five plates in the lower core support assembly (LCSA), remove the debris from the LCSA and lower head and remove the fuel debris from behind the core former baffle plates. The drilling machine was used to cut out some of the stainless steel structures of the LCSA, but the primary disassembly tool was a plasma arc torch, which was used in untried underwater depths and under difficult chemistry conditions. The Board evaluated and observed the progress of this operation closely because of concern that the arc might contact an alloy of fuel and stainless steel and release a fuel-bearing aerosol to the surface of the water. The time-consuming and careful work performed by GPU Nuclear/Bechtel assured the Board that its concerns had been addressed.

Of special concern was the potential for damage to the incore Instrument nozzle welds to the lower head of the reactor vessel with subsequent loss of water and fuel debris. Special procedures were required to guard against any drop of heavy loads onto the welds. The integrity of the reactor vessel lower head had been a long-standing concern of the Board. The data about the vessel's integrity and the possibility of fuel debris being present in the cavity below the reactor vessel were extensively reviewed. The Board concluded that because the reactor vessel had withstood pressures up to 2300 psi during and shortly after the accident, this provided compelling evidence that the lower head had not been breached. Calculations by the Board indicated that there was little basis for assuming the presence of fuel in the cavity. The excessive personnel exposures that would have accompanied an examination of the cavity dissuaded the Board from recommending such an action.

An ongoing concern of the Board was the potential for a recriticality, particularly during the defueling operation. This received much of the Board's attention during the first three years of its operation. Criticality scenarios for the damaged core were examined in detail and the Board concluded that the controls instituted by GPU Nuclear/Bechtel were adequate in any situation provided that unborated water was excluded from the reactor system and the specified level of 3500 ppm boron was maintained in the coolant water. As a further conservative step, the boron concentration was subsequently raised to 5000 ppm during fuel removal operations. The Board reexamined the potential for recriticality during the defueling operations. Based on the analysis of one of the SAB members, including a review of previous studies by others, the Board concluded that there was no potential for recriticality during core alterations.

One of the most important lessons to come from the cleanup was the importance of accurate data about conditions. GPU Nuclear/Bechtel recognized this need and created an engineering organization responsible for data acquisition and analysis. The Board was pleased with this action and believed it played an important role in the final success of the cleanup. However, the Board concluded that GPU Nuclear did not always assign adequate time or resources to the acquisition of accurate data and this hindered many cleanup plans and subsequent operations.

One impact of a lack of adequate knowledge about core conditions was the difficulty in planning for adequate tooling. Because data were often insufficient or not timely, there was a poor definition of tooling requirements. Defueling safety was not compromised by tooling difficulties, but the project schedule was probably delayed to some extent.

It was necessary to obtain information about the quantities of fuel debris that were carried from the reactor vessel to other parts of the primary system during the accident. The work of GPU Nuclear/Bechtel was satisfactory and revealed that only minimal amounts of fuel (0.13%) were to be found in the major components of the reactor coolant system. Therefore, the potential for recriticality was not an issue in the final cleanup.

Section 7

RADIOACTIVE WASTE MANAGEMENT

The Board focussed on identifying all radioactive materials originally in place and generated by the accident, the steps taken to remove them from the site and the monitoring of the inventories of residual materials and those removed for disposal. The Board was interested in identifying all unusual problems or potentially hazardous situations that resulted from waste processing, staging on site, handling, shipment and disposal.

The principal emphasis during the first years of review was to identify radioactive waste sources and to maintain a continuing inventory of the radionuclides. By 1984, a source identification program was well established and, with defueling preparations underway, concern turned to the safety and efficiency of water processing systems and the safe disposal of radioactive waste.

The Source Identification Program (SI) was initiated soon after the TMI-2 accident as part of the activities sponsored under the GEND agreement (among GPU Nuclear, Electric Power Research Institute, NRC and Department of Energy). These organizations were interested in both the recovery of the power plant and the acquisition of information about the accident to benefit the nuclear power industry. The SI Program had two parts: 1) by use of the appropriate computer codes, to establish the amount and distribution of radioactive isotopes in the reactor core just prior to the accident and to follow the decay of these isotopes; and 2) to develop a radionuclide mass balance and a radioactive waste inventory. The radionuclide mass balance would identify the redistribution of the types and quantities of radionuclides throughout the plant following the accident while the waste inventory would classify, quantify and monitor the status of radioactive wastes being shipped off site.

Both parts of the SI Program were underway by 1982. The Board reviewed the Program, which used the ORIGEN-2 code to calculate the initial radionuclide inventory and its subsequent decay, and felt that It was possible to improve and systematize the mass balance and waste Inventory aspects.

One of the first recommendations of the Board to GPU Nuclear/Bechtel was to develop a summary of the various radioactive wastes and their subsequent depletion by decay or by shipment. The thrust of this approach was vigorously reiterated by the Board, which desired considerably more information on radioactive waste sources, the amounts of waste in place and removed, the transport of various waste into and out of the environment, and other basic information that would be required by the Board to develop an inventory on the wastes generated by the accident. In time, the GPU Nuclear/Bechtel staff responded well to these recommendations, producing an outstanding set of analytical procedures and technical reports that permitted effective surveillance and control of radioactive wastes produced by the cleanup.

The accident and subsequent cleanup resulted in the accumulation of almost 2 million gallons of radioactive liquid in a number of locations, including the basement of the reactor building, the reactor coolant system and various tanks and sumps in the auxiliary and fuel handling building. The radionuclides of most concern In these liquid wastes were cesium-137 and strontium-90, both of which could be removed by adsorption on suitable ion exchange media. Three liquid waste processing systems of increasing efficiency and capacity were built as the cleanup progressed: EPICOR II for lower activity water; the submerged demineralizer system (SDS) for higher activity waste; and the defueling water cleanup system (DWCS) for water used during defueling operations. Having removed all but trace amounts of cesium-137 and strontium-90 and other fission and activation products, less than 1000 curies of tritium remain in the water used for cleanup purposes and was not removed in the treatment process. Ultimately the tritium would decay and be removed by evaporation of the accident-generated water stored on-site.

From a health and safety perspective, the disposal of over 2 million gallons of accident-generated water at the end of the cleanup was not of concern. GPU Nuclear's proposed method of evaporation of the water was safe and effective, although the Board considered the controlled release of the water to the Susquehanna River to be the preferred method of disposal. The quantities of radionuclides that would have been discharged were less than those discharged by nuclear plants in the course of normal operation and were well within the limits imposed in the TMI-2 operating license. However, public concern about this issue formulated GPU Nuclear's decision and the Board accepted their decision on this matter.

The Board monitored the operations of these systems and procedures to ensure that the concentration levels of radioactive cesium and strontium in the water were maintained sufficiently low to ensure no more than minimal levels of worker exposure. The Board also monitored the safety of these operations.

Defueling of the reactor vessel began in the summer of 1985 with the successful removal of the reactor head and plenum and with the installation of the defueling work platform on the top of the open reactor vessel. During this same period, serious increases in turbidity were encountered in both the reactor coolant and in the water of the defueling canal. These turbidity spikes could be reduced by SDS processing and filtration through a swimming pool filter. Early in 1986, the appearance of gelatinous deposits were noted on reactor vessel components and tests revealed the presence of bacteria and fungi thriving vigorously in the coolant water.

During the first three months of 1986, the clarity of the reactor coolant decreased steadily and became essentially zero by early April. The defueling crews were able to improvise "pick-and-place" defueling procedures while operating without the benefit of direct observation. However, the lack of reactor coolant clarity and direct observation threatened to seriously undermine the schedule for the entire defueling program.

An intensive research and development effort found that hydrogen peroxide in the presence of boron was an effective biocide for the microorganisms in the coolant and established tests and dosages to keep the growth under control. Further tests determined the nature of the colloidal material responsible for the turbidity and loss of filter capacity. Suitable treatments with coagulating agents and filteraids were worked out so that the turbidity could be removed by the defueling water cleanup system filters at acceptable rates. By the end of 1986, both microorganism growth and turbidity were under control and the DWCS was routinely maintaining complete clarity of the reactor coolant water to permit the defueling program to move forward rapidly.

Another concern of the Board related to the disposal of the damaged TMI-2 reactor core. Approximately 300,000 lb of fuel debris and core stiuctural components were shipped to the Idaho National Engineering Laboratory under the terms of an agreement signed by the Department of Energy and the Nuclear Regulatory Commission. The Department of Energy had agreed to accept the radioactive waste material at its facility for research and storage until the national high-level radioactive waste disposal issue was resolved. The Board observed all aspects of the process, from the criticality-safe design of the defueling canisters and fuel shipping cask to the packaging and transportation procedures. The Board found that adequate safety measures were taken to protect the health and safety of both the public and the workforce.

Section 8

SUMMARY

The overview by the Safety Advisory Board of the cleanup of the TMI-2 reactor plant following the accident of March 28, 1979 was broad in its scope and reviewed many facets of the cleanup and recovery program. The principal focus of the Board's review and deliberations during its 8-1/2 year tenure were on core removal, worker and public health and safety, radioactive waste management and external affairs. The Board noted that, understandably, the cleanup and recovery program began with an inexperienced and untrained team, inadequately prepared to achieve poorly-defined goals. In rapid succession, the GPU Nuclear/Bechtel management program developed well trained, effective and productive workforces that resulted in a coordinated research and development engineering program that successfully removed the damaged fuel with minimal hazard to the worker teams and with no hazard to the public health and safety.

In spite of numerous constraints, obstacles and regulations that hampered the recovery program, the GPU Nuclear/Bechtel combined management organization achieved noteworthy successes, albeit with a much extended schedule and at a large financial cost. The damaged plant will be stored in a monitored condition and will pose no hazard to the health of the public or the workers nor to the safety of the community.

Appendix A

POSSIBLE RESEARCH OPPORTUNITIES AS A RESULT OF THE TMI-2 ACCIDENT AND CLEANUP

1. More Realistic Source Term Assumptions

Despite considerable effort by the ANS, IDCOR, and others for the last 6-8 years, there is limited evidence of a move away from overly conservative source term assumptions and adoption of a more realistic approach to severe accident source terms. During the TMI-2 accident, fission products did not behave as would have be predicted. In fact, utilization of codes of that era with early available fission product data would indicate the severity of reactor core damage was considerably less than reality.

During the TMI-2 accident approximately 50% of the core was in a molten state but there is evidence that only about 55% of the highly volatile fission products and noble gases were released from the reactor vessel with the majority of them being retained in the reactor building. There is also evidence that less than 5% of the medium volatile and low volatile fission products were released from the reactor vessel.

It is now accepted that the chemical conditions in the reactor vessel were "reducing" in nature as opposed to "oxidizing" in nature. For an example the iodine was driven to or converted to the iodide ion which very readily combines with available metallic ions. The water soluble character of these chemical forms prevented a major release of iodine to the atmosphere of the containment or auxiliary buildings and only a few curies where released to the environment. Throughout the TMI-2 accident sequence the chemical state was such as to preserve this water soluble character. With the large number of PRA studies completed, it should be possible to identify which accident sequences are similar in chemical conditions to TMI-2. Such a listing should then provide a guide as to which accidents might be regarded as hazardous and which are non-hazardous relative to the possible escape of iodine.

Such a classification could assist in design of safety devices and the writing of rules and regulations.

A great deal of work has been performed to understand what happened during and after the TMI-2 accident and considerable laboratory-scale research has been performed. More experiments could be devised that would create oxidizing or reducing conditions with the presence/absence of water and hydrogen. A much better understanding of the technical factors surrounding "Source Term" issues has been obtained. It is now known that some of the assumptions which are being used for source term considerations are seriously wrong in both timing and process. Plants can be designed, operated and regulated more safely if we restate the source term based on present scientific knowledge, and then apply adequate conservatisms. The ALWR program is also trying to get recognition of these needs. A more correct assessment of source term would also be provided to the public regulators.

As we all believe, there will be a re-birth of nuclear construction and therefore, it is an almost absolute necessity that the source term issues be revisited.

2. Establish Licensing Requirements for Non-Operating Facilities

The general lack of guidance concerning the applicability of 10CFR Part 50 to non-operating/inoperable reactors have been very prominent during the recovery of the TMI-2 facility. We have learned much from the experiences at TMI-2 while defueling the facility and preparing it for the post defueling monitored storage phase. Regulations in 10CFR Part 50 were propagated primarily for the design, construction, and operation of nuclear facilities and do not provide appropriate guidance for facilities in a post accident condition such as TMI-2. It is not necessary to provide complete and specific regulatory guidance for post accident facilities such as TMI-2, but it is reasonably expected that some guidance would be provided for non-operating and defueled facilities such as a facility entering a storage phase prior to decommissioning.

The NRC should review the conditions, issues and circumstances surrounding non-operating facilities and prepare a rule or set of guidelines as to what should be done in the case of future accidents. If these guidelines are not issued now while TMI-2 is still in the spotlight, they may not be made until after another accident has occurred.

The necessity to perform a review of Part 50 for TMI-2 has highlighted the fact that there is very little clear regulatory guidance for facilities in non-operating and defueled conditions. A number of studies have been conducted addressing decommissioning activities and their results have been published in various NUREGs, they address primarily the technology, safety and cost associated with dismantling and decommissioning facilities and do not describe any regulatory structure for non-operating and defueled facilities entering a storage period prior to actual decommissioning activities.

With little regulatory guidance existing for non-operating and defueled facility plus the fact that other facilities will soon be entering a non-operating and defueled storage phase as part of the early decommissioning process (SAFSTOR) illustrates an area in which new and clear regulatory guidance would be beneficial to the nuclear industry.

3. Improve Design Requirements for Nuclear Facilities

The lessons learned at TMI-2 need to be incorporated into the design of any new reactor facilities. TMI-2 has shown the need to simplify the design, construction and operation of nuclear facilities. As a result of the TMI-2 accident it has also become apparent that other design modifications need to be considered if a new facility is to be constructed.

One of the considerations would be the recovery from a severe accident should it occur. This would include such items as prohibiting the use of cinder blocks inside the reactor building which absorb so much contamination and become a radiological hazard or designing the facility to be "robot friendly." TMI has also demonstrated the need for the utilization of higher range radiation instrumentation in order to monitor the environment inside the reactor building during a severe reactor accident. Based on design criteria and clear evidence that the TMI-2 containment building was not challenged, a reduction in criteria might be prudent based upon actual accident conditions. The NRC had reviewed in some detail the capability of reactor containment structures to withstand accident environments including significant pressure increases and a review of this studies might be helpful and may lead to a reduction in design criteria. A similar effort for reactor vessels has not been undertaken and should be undertaken considering the condition of the lower head of the TMI-2 reactor vessel with the severity of the accident.

TMI-2 has also demonstrated the need to provide access to the underside of a reactor vessel for remote inspections to determine the extent of possible damage in the aftermath of a severe reactor accident. The 52 instrument penetrations in the lower head of the TMI-2 reactor vessel have been a concern since the discovery of once molten material on the lower head of the reactor vessel and thus lower head integrity has been a major concern during the TMI-2 recovery efforts. For future reactor vessels it would be recommended that incore instrumentation penetrate the reactor vessel by the head instead of the bottom of the reactor vessel. It is recommended that the NRC undertake an effort to evaluate the lessons learned at TMI to incorporate into the design of any future reactor facilities.

4. Improve Criticality Calculations

Re-criticality has been a major concern to the TMI-2 program since the day of the accident. Criticality studies to support the TMI-2 recovery efforts have consumed many hours and dollars during the past ten years. The NRC needs to establish some guidelines dealing with criticality in the aftermath of a severe reactor accident. These guidelines need to take into account the abnormal geometries and possible core conditions as a result of a severe reactor accident. It is even more important today as some of the new core designs use uranium enriched much higher than TMI-2.

In the technical community interested in both criticality and reactor physics, doubts still exist as to whether the TMI-2 core became critical or was very close to critical during the accident in 1979. The question can be resolved with little real dollar cost.

The accident scenario that has been developed by GPU and the EG&G Idaho team is sufficiently detailed that a series of geometric configurations could be created for criticality calculations that should clarify the problem. Variables include the presence of water, oxidation of cladding, melting and movement of fuel, melting of poison rods and movement of poison. Most of these variables can be estimated reasonably well and the resulting plus and minus values of keep should not be unreasonably large.

5. More Realistic Severe Reactor Accident Scenario

The TMI-2 accident was a severe accident in which approximately 50% of the core was in a molten state at some point during the accident, and 25% of the core relocated into the core support structure. Approximately twenty tons of the once molten debris poured onto the lower head of the TMI-2 reactor vessel. Most codes would have predicted a failure of the lower head under these conditions. In-vessel core melt progressions for severe reactor accidents need to be studied further to understand the mechanisms of in-vessel core melt progression, so that this information could be incorporated into the codes and standards. The severity of the TMI-2 accident has shown that a reactor vessel is more difficult to breach than originally anticipated.

The capability to predict the course of events during a fuel-melting accident is a serious matter for the preparation of a probability risk assessment study. Any code or study must show the ability to reproduce the TMI-2 accident (with reasonable accuracy) before it can be accepted as a predictive tool. This testing of codes has been started (e.g. CSNI study groups) but the successful completion and publishing of results is less clear. These studies or testing of codes should be completed and results published.

6. Improve Decontamination Regulations

The NRC is issuing guidelines on decontamination and the experiences of TMI could be very useful for these guidelines. There are a number of decontamination techniques used throughout the industry which are very applicable to small decontamination activities, but are not very applicable to large scale decontamination activities. The experience gained at TMI could be utilized in preparing guidelines for decontamination and decommissioning of large facilities. DOE has published a large amount of information on decontamination and with the TMI-2 experiences the NRC could prepare some guidelines on decontamination.

7. Improve Decommissioning Regulations

The NRC should perform the necessary studies to determine what regulations would be required to support decommissioning a commercial nuclear facility. There are concerns as to the requirements in regard to disposal of highly contaminated components. Unless such studies are done the first large scale commercial facility to undertake decommissioning will encounter significant hardship trying to get answers to many needed questions in order to decommission their facility. Such a study could examine any added or different regulatory or institutional issues involved.

CHARTER FOR THE SAFETY ADVISORY BOARD THREE MILE ISLAND UNIT 2 PROGRAM

INTRODUCTION

The unique importance of the TMI-2 Program to General Public Utilities and to the utility industry in general requires the highest quality technical performance possible. The Program should reflect the best scientific and engineering judgment. Provision of an independent "Safety Advisory Board" of highly qualified people to provide a broad appraisal of the TMI-2 Program will further this purpose.

ESTABLISHMENT AND PURPOSE

The Safety Advisory Board is established by the President of GPU Nuclear Corporation and serves in an advisory capacity to him.

The primary purpose of the Board will be to provide to GPU Management a high level appraisal of the technical aspects of the TMI-2 Program as to how it fulfills the responsibility to protect public and worker health and safety. (A secondary purpose is to support and evaluate communications between GPU and interested groups outside of GPU in carrying out this program).

SCOPE

The TMI-2 Program encompasses cleanup, waste disposal, and decommissioning or recovery.

The Board shall review the technical plans for Program operations and the technical basis for these plans and shall report to the President of the GPU Nuclear Corporation on the safety and operational adequacy of these plans. It may also perform other related duties as mutually agreed between the Board and President of GPU Nuclear Corporation.

BOARD SIZE AND COMPOSITION

The size of the Board should be the minimum consistent with providing a broad overview capability with the required variety of skills and backgrounds.

BOARD OPERATION

1. The Board will meet approximately once every three months.

2. The Board meetings will be scheduled so as to permit review of planning for major activities before they are implemented.

3. The proposed agenda for each Board meeting, will be agreed upon between the Chairman and GPU Nuclear, prior to each scheduled meeting.

4. The agenda and relevant written material will be distributed to the Board members two weeks before each scheduled meeting.

5. A nonvoting secretary, supported by appropriate staff, will be made available to the Board by GPU Nuclear to assist in the development of the agenda, arranging meetings, and the drafting of the required reports.

6. GPU Nuclear, its contractors, or other interested parties, as agreed, will provide briefings to the Board on agenda topics. The Board shall be provided full access to all relevant information.

7. A formal report of each meeting will be submitted by the Board Chairman to the President, GPU Nuclear Corporation, within one week following each meeting. Meetings will be scheduled to provide time for preparation of a draft report before adjournment. In addition, the Board Chairman will present a report annually to the President, GPU Nuclear Corporation, which summarizes the Board's overall assessment of the adequacy of all aspects of TMI-2 activities as they relate to public and employee health and safety.

8. The Board is expected to reach a consensus on all important issues. If this is not the situation in a particular instance, the Chairman's report should include identification of significant minority views.

9. The President of GPU Nuclear Corporation will respond formally to all recommendations made by the Board stating what action resulted or explaining why particular recommendations were not adopted.

10. Correspondence between the Board and any of its members and the President, GPU Nuclear Corporation, involving recommendations and conclusions will be made available to interested groups and members of the public.

Approved: R C Arnold 4/21/81
President, GPU Nuclear Corp.

Appendix C

SAFETY ADVISORY BOARD MEMBERS BIOGRAPHICAL INFORMATION

CURRENT MEMBERS

Dr. Robert Q. Marston (Chairman 1986-1989)
Dr. Marston is President Emeritus and Professor of Medicine at the University of Florida. He has an MD degree from the Medical College of Virginia and a BS degree from Oxford University. Formerly, Dr. Marston was Director of the National Institutes of Health, President of the University of Florida, and Vice Chancellor and Dean of Medicine at the University of Mississippi, Jackson. He is a member of the Institute of Medicine of the National Academy of Sciences. Dr. Marston provides the SAB with a broad background in medicine and health physics, and experience in managing large and complex organizations.

Dr. John A. Auxier
Dr. Auxier is the President of the Applied Science Laboratory, Inc., in Oak Ridge, Tennessee. He has a PhD degree in Nuclear Engineering from the Georgia Institute of Technology. Formerly, he was Director of the Division of Health Physics and Safety at the Oak Ridge National Laboratory and president of the Health Physics Society. He is a member of the National Council on Radiation Protection. He brings to the SAB extensive experience in nuclear health physics and radiological protection.

Professor Merril Eisenbud
Professor Eisenbud is Professor Emeritus of Environmental Medicine and former Director of the Laboratory for Environmental Studies at the Institute of Environmental Medicine, New York University Medical Center. He is a member of the National Academy of Engineering and has served for many years on the National Academy of Sciences Board on Radioactive Waste Management. He is an Honorary Life Member of the NCRP and is currently Scholar in Residence at the Duke University Medical Center and Adjunct Professor of Environmental Science and Engineering at the University of North Carolina. He brings to the SAB extensive

experience and expertise in the fields of environmental and industrial health and hygiene, with special emphasis on environmental radioactivity and radiological protection.

Dr. Jacob I. Fabrikant

Dr. Fabrikant is Professor of Radiology, University of California School of Medicine, San Francisco, and Professor, Biophysics and Medical Physics, University of California, Berkeley. He has an MD degree from McGill University and a PhD degree in Biophysics from the University of London. He is a member of the National Academy of Sciences' Committee on the Biological Effects of Ionizing Radiations and Board of Radiation Effects Research of the National Council on Radiation Protection and Measurements and of the International Commission of Radiological Protection. He is a Fellow of the American College of Radiology, and is certified in diagnostic, therapeutic and nuclear radiology. He brings to the SAB expertise in the radiological sciences, radiological protection and the health effects of ionizing radiation exposure.

Dr. Robert S. Friedman

Dr. Friedman is Program Director for the Center for Science Policy, Institute of Policy Research and Evaluation, and Professor of Political Science, Pennsylvania State University. He has a PhD degree from the University of Illinois. He brings to the SAB extensive experience in the politics of developing public policy in response to scientific and technical issues.

Dr. Bruce T. Lundin

Dr. Lundin is currently a private consultant. He was formerly Director, National Aeronautics and Space Administration, Lewis Research Center. He is a member of the National Academy of Engineering. Dr. Lundin has a degree in Mechanical Engineering from the University of California and an honorary Doctorate of Engineering degree. He brings to the SAB extensive experience in the organization and management of large, advanced technology programs.

Professor Howard Raiffa

Professor Raiffa is the Frank P. Ramsey Professor of Management Economics, Harvard University Graduate School of Business Administration and the Kennedy School of Government. He has a PhD degree in Mathematics from the University of Michigan. He brings to the SAB extensive experience in the application of risk analysis techniques and decision-making processes to advanced technology activities.

Professor Norman Rasmussen
Professor Rasmussen is the McAfee Professor of Engineering at the Massachusetts Institute of Technology. He is a member of the National Academy of Engineering, the National Academy of Sciences and the National Council on Radiation Protection and Measurements. He was the chairman and principal author of the WASH-1400 Report, a major contribution in the area of nuclear power plant safety analysis. He brings to the SAB extensive experience in nuclear engineering, nuclear safety, and technical risk assessment and risk management.

Mr. Lombard Squires
Mr. Squires is currently a private consultant. He was formerly a faculty member in Chemical Engineering at the Massachusetts Institute of Technology, Technical Director and later Manager of Du Pont's Atomic Energy Division, and Assistant General Manager of Du Pont's Explosives Department. He was a member of the United States Atomic Energy Commission's General Advisory Committee and its Advisory Committee on Reactor Safeguards. He is a member of the National Academy of Engineering. He brings to the SAB extensive experience in nuclear chemistry and in the management of large, advanced technology programs.

Dr. William R. Stratton
Dr. Stratton is currently a consultant to the Los Alamos National Laboratory and serves as Chairman of the New Production Reactor Safety Board. He has a PhD in Physics from the University of Minnesota and was formerly Chairman of the Advisory Committee on Reactor Safeguards of the Nuclear Regulatory Commission. He brings to the SAB extensive experience in nuclear reactor safety and criticality safety.

PREVIOUS MEMBERS

Dr. James C. Fletcher (Chairman 1981-1986)

Dr. Fletcher was formerly Whiteford Professor of Technology and Energy Resources, University of Pittsburgh, a director of several companies and during two administrations was Administrator of the National Aeronautics and Space Administration. He resigned his chair of the SAB at the time of his second appointment as NASA Administrator in 1986. He has a PhD degree in Physics from the California Institute of Technology. He is former President of the University of Utah. He is a member of the National Academy of Engineering. He brought to the SAB his extensive experience in directing large and complex technical engineering projects.

Dr. Clark Goodman

Dr. Goodman was formerly Assistant Director of Reactor Development for the United States Atomic Energy Commission, consultant, Joint Congressional Committee on Atomic Energy, member, USAEC Atomic Licensing and Regulations Panel Board and chairman, the National Academy of Sciences Committee on Radioactive Waste Management. He had a PhD degree from the Massachusetts Institute of Technology. He was Emeritus Professor of Physics, University of Houston. He died in June, 1983. During his tenure on the SAB, he brought to the SAB an extensive background in nuclear physics, nuclear engineering and radioactive waste management.

Dr. Arthur Upton

Dr. Upton has an MD degree from the University of Michigan. He is Professor and Chairman, Department of Environmental Medicine, New York University. Formerly, he was Dean of the basic medical sciences at State University of New York at Stony Brook and director of the National Cancer Institute. He is a member of the Institute of Medicine of the National Academy of Sciences, of the National Council on Radiation Protection and Measurements and of the International Commission on Radiological Protection. He is a specialist in the pathology of ionizing radiation and the biomedical effects of low-level radiation, radiation risks and decision-making.