COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
PRINCIPAL WORKING GROUP N° 1 EXPANDED TASK FORCE

MANAGEMENT OF MAINTENANCE OUTAGES AND SHUTDOWNS
SUMMARY OF REPORTS

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MANAGEMENT OF MAINTENANCE OUTAGES AND SHUTDOWNs

Summary of Reports

Prepared by the Principal Working Group N° 1
Expanded Task Force on Human Factors

June 1994

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COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA), is an international committee made up of senior scientists and engineers. It was set up in 1973 to develop and coordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee’s purpose is to foster international cooperation in nuclear safety among the OECD Member countries.

The CSNI constitutes a forum for the exchange of technical information and for collaboration between organizations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus on technical issues of common interest. It promotes the coordination of work in different Member Countries including the establishment of cooperative research projects and results to participating organizations. Full use is also made of traditional methods of cooperation, such as information exchanges, establishment of working groups, and organization of conferences and specialist meetings.

The greater part of the CSNI’s current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment, and severe accidents. The Committee also studies the safety of the nuclear fuel cycle, conducts periodic surveys of the reactor safety research programmes and operates an international mechanism for exchanging reports on safety related nuclear power plant accidents.

In implementing its programme, the CSNI establishes cooperative mechanisms with NEA’s Committee of Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regards to safety. It also cooperates with NEA’s Committee on Radiation Protection and Public Health and NEA’s Radioactive Waste Management Committee on matters of common interest.
MANAGEMENT OF MAINTENANCE OUTAGES
AND SHUTDOWNs

SUMMARY OF REPORTS FOR
THE CSNI/PWG1 EXPANDED TASK FORCE ON HUMAN FACTORS

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Background

The importance of management and organisational factors for safety improvements has
become increasingly evident. Operating experience gives numerous examples showing that these
factors are important contributors to incidents. Also, operators and regulators recognise that after
major technical problems have been resolved further improvements in nuclear plant safety lie in
the skills of the management and the organisation. However, the primary lesson from operating
experience is not simply the knowledge that management and organisational factors are important
to safety. This fact has been accepted since the inception of nuclear power, and the operating
assumptions of nuclear power plants include hundreds of opportunities, if not explicit demands for
management to make decisions, allocate resources, provide direction, or select and train personnel,
all in a manner consistent with safety. The lessons from experience, instead, is that management
is not always effective in doing these things. Management and organisational systems that work
well on a daily basis may still succumb to occasional mistakes. Management and organisational
systems that look good on paper or sound good when described, sometimes are inadequate in
practice.

In the work to be reported on here, which constitutes Task 2 of the three tasks within the
Expanded Task Force, the focus is on the importance of management and organisational factors
as they relate to the management of maintenance outages. The reasons behind this choice of topic
for further study was that it first of all appeared necessary at an early stage to limit the study of
organisational factors to one defined area of plant activities important to safety. Maintenance had
already been the topic of Task 1 and relevant basic information on maintenance practices had been
derived within the various participating countries. It was therefore considered important to make
further use of this information. The outage period is one that relies heavily on an effective
management and organisation of activities. It has recently also been recognised, e. g. through PRA
studies, that errors made during this period may involve more serious threats to safety than was
earlier recognised (1). Thus, there should be a potential for safety improvements regarding the
management of outages.

The emphasis of the work performed in the task force was at the outset also directed towards
looking at organisational effectiveness by stressing improvement and learning. The intention was,
thus, not to come up with recommendations on how utilities should design their management and
organisation approach, but rather to point at the importance of an improvement orientation on the
part of the utility as essential to plant safety performance. This view on organisational factors will
be further elaborated after the summary of contributions.
Structure and Content of Report Submitted by Participants

The work within Task 2 was initiated by agreeing upon a common outline for the contributions from each country. In essence the outline contained two main sections:

The first section dealt with key issues and topics, where brief descriptions were to be provided as they related to utility maintenance outages in each country. The issues and topics were:

- Regulatory context
- Outage philosophy
- Outage planning and scheduling
- Staffing and support
- Coordination and control
- Personnel and radiation safety
- Performance assessment
- Quality assurance.

The second section dealt with events illustrating important improvement activities. In this section events should be provided to illustrate the important problems and improvement initiatives associated with management of maintenance outages in each country. The events could illustrate several of the topics or issues described in the first section. In addition, these events were to address one or more of the following specific topics, which were identified by the group as common concerns associated with outages:

- Start-up activities after an outage
- Over-reliance on personnel skills
- Management of contractors
- Relations between maintenance and operations.

Participants were free to put more emphasis on one or the other of the two sections of this report i.e. on a more fully description of key issues and topics and/or on presentation and analysis of events.

Contributions were received from the following countries: Finland, France, Germany, Japan, Sweden, United Kingdom, the United States and from the two non-OECD countries, Hungary and Slovenia.

A complete adherence to the list of issues and topics was, however, not achieved. This should also be taken into account when reading the following summary of results, which thus is biased in terms of the completeness of information received in the various contributions. The results should be viewed more as examples of practices and improvement actions that can be associated with the management of maintenance outages than a complete picture of the factors considered most important in all the countries.

Key Issues and Topics - Summary of Contributions

Each member country was requested to provide brief descriptions of the above eight key issues and topics as they relate to utility maintenance outages in their country. In reviewing the material submitted it became apparent that much of the information could be organized into a general discussion relating to outage management strategies. Therefore, for the purpose of this summary review, the information on the planning, scheduling, staffing, coordination, quality assurance, and performance assessment of outages has been combined into an overview section on "outage management strategies".
Regulatory Context of Maintenance Outages

Although the management of maintenance outages and shutdowns is of common concern to the regulatory authorities in all the member countries, each has established requirements and practices to address their particular concerns. Both the nature and number of regulations relating to outages often vary from one country to another. Also, there are significant differences in the level of regulatory involvement in the outage process -- ranging from direct approval of each phase of the outage to general oversight and verification of compliance with the plant technical specifications.

For example, Finland and Japan require that the regulatory agencies STUK and MITI, respectively, take very active roles in the review and approval of the outage plan and the restart plan. These agencies are also involved in the verification of the quality of the outage activities. In Finland, as in a number of other countries, the utilities are required to submit a report to the regulatory authority summarizing the shutdown, the inspections and tests that were performed, and what improvements should be taken.

Although there are few explicit regulations or policies concerning outages in either Sweden or the United States, the Swedish Nuclear Regulatory Inspectorate (SKI) is actively involved by working with the utilities to review the restart plan and discuss any problems or faults that were identified during the outage. Before restart these faults must be clearly understood and remedial and control measures implemented. The United States Nuclear Regulatory Commission does not take such an active role in the outage planning. Rather, during the outage the NRC focuses on the quality and adequacy of work and conformance with the plant technical specifications and the plant procedures (such as the emergency, testing, maintenance, start-up, shutdown, and refuelling procedures).

Outage Philosophy

There appears to be an outage philosophy that is common to almost all utilities. This is the desire to conduct the necessary outage work as efficiently and effectively as possible. The need for proper planning, effective maintenance management, minimization of radiation exposure, and reduction of outage length are common objectives for utilities in almost all countries.

The highest priority at Japanese plants is to prevent abnormal events. In France the primary objective of the utility EDF is to ensure compliance with the regulatory requirements. Other EDF objectives include properly assessing the constraints and time requirements in the planning process, conducting pre-start reviews, and optimizing the outage time requirements.

The principal differences in outage philosophy revolve around the inclusion or exclusion of preventive maintenance tasks during the outage. In the United Kingdom, for example, little corrective maintenance work is postponed until the outage -- most of the outage work is preventive maintenance plus repair of defects found during inspections. In Finland, a well defined part of the TVO plant the preventive maintenance of standby safety systems has been moved to the operation period.

An important point in the outage philosophy in Slovenia and Japan is the systematic collection and assessment of performance data and the lessons learned from other plants in order to improve the outage process.
Outage Management Strategies

The management of outages involves properly planning and scheduling, obtaining the needed support, coordinating and controlling the activities, ensuring the quality of the activities, and assessing the outage performance to improve the process in the future. The four principal phases of the outage process that were discussed by the member countries were:

- long-term outage preparation
- outage planning and scheduling
- outage execution
- outage assessment and follow-up.

The following summary of the member countries' contributions focuses on the areas of concern expressed in their reports and the actions that are being taken to improve the management of outage.

Long-Term Outage Preparation

The process of establishing long-term outage preparations involves the consideration of the length and frequency of the outages, the contractor support arrangements, and the development of outage procedures and tools. In Japan the long-term basic outage plan takes into account the power generation plans for the next few years and the amount of special work deemed necessary to meet the long-term plan for ISI and facility reliability goals.

The frequency and length of outages is of concern to both the utilities and the regulatory authorities. In Japan the utilities are required to inspect the reactor system every year and the turbine system every two years. The nuclear units in the United Kingdom, with some minor exceptions, are required to undergo a maintenance outage once every two years. In other countries such as Sweden, France and the United States the frequency of the outage is determined by the utility and is usually tied to the refuelling cycle of the plant.

The length of the outage is generally determined by the utility or plant management and is a function of the outage philosophy and the amount and type of maintenance and modification work to be performed. For routine refuelling-related outages, the length ranges from 14-21 days at the Finnish plants, 30 days at the plants in Hungary, 80 to 90 days for Japanese plants, and 56 to 126 days for plants in the United Kingdom. The desire by United States utilities to minimize the outage time is of concern to the NRC since it has the potential to compromise safety requirements by possibly taking necessary redundant systems out of service at the same time (especially when decay heat is high) or by not fully or correctly performing required work tasks.

A related issue of concern is the possible use of staff or contractors that are not fully familiar with plant procedures or practices. Due to the extensive amount of work and limited time available during an outage, almost all utilities require some type of outside assistance. This is generally provided by contractors, but in certain cases such as France and some of the larger United States utilities, the support comes from within the utility's own outage support group. Long-term, stable working relationships are one way that many utilities have addressed this issue of contractor support.

The Japanese utilities are dependent on contractors during outages. They have established very stable, long-term contractor arrangements in which the original manufacturer of the critical plant equipment assumes responsibility for maintaining this equipment, performing much of the actual outage work and obtaining needed spare parts. The contractor is a full partner in planning the outage work.
Swedish and Finnish utilities have also developed long-term arrangements that ensure contractor and vendor support resources are available when needed. A cooperative arrangement among utilities was necessary because all outages in these two countries are scheduled during the summer months and there is the potential for conflict among the utilities for outage support. A separate organisation (KAS) was jointly created by the utilities to manage and coordinate long-term contractor arrangements. Swedish utilities have further, as a group, developed a vendor evaluation process, as well as requiring vendor companies to have a quality system that conforms to ISO 9001. In addition, some Swedish plants have arranged to have the same contract personnel each year.

Outage-related training of both contractor personnel and plant staff is being addressed in various ways in the member countries. In France there is an increasing awareness of the need for better outage training of plant staff in such areas as outage procedures, management skills and scheduling methodologies. Currently the French utility EDF is expanding its centralized training program to address some of these issues. Outage management guidance is provided by the United States utility organisation INPO to its member utilities and utilities are in the process of developing a standardised approach to radiation protection and general nuclear plant safety training to improve contractor knowledge and understanding. In Hungary, the contractor personnel must be trained and qualified and the contractor issued a license by the safety authority.

**Outage Planning and Scheduling**

The amount of time and effort devoted to outage planning and scheduling varies greatly from one utility to another. For some outage planning and scheduling begins just a few months before the outage. Others have a permanent outage planning staff that works year round and begins preparation work as soon as the last outage is completed. For example, planning begins 9 months before the outage at plants in Finland, 6 months out for Japanese plants, 3 to 6 months out for plants in the United Kingdom, and 3 to 5 months out for plants in France. There is a fairly widespread belief by the member countries that the more effective the planning and scheduling process the greater the potential for shortening the actual outage length.

With few exceptions, utilities in most countries cannot financially justify large, specialized, full-time, permanent outage staff. However, utilities in many cases establish a specific outage coordination group at some point prior to outage execution. The make-up of this group, however, varies significantly across countries. In Sweden, the outage planning group at one plant is comprised of experienced personnel from each of the relevant plant organisations. This planning coordination group determines "when" various activities are to be conducted in order to coordinate across the functional groups; the functional groups are responsible for determining "what" and "how" activities are to be performed, as well as determining what each activity consists of and how long it will take. In Finland, two outside contractors work with four plant staff planners to schedule the main jobs in parallel with other maintenance work. While in plants in Hungary there is a special outage maintenance committee and the maintenance department both prepares and performs the outage. Also, the principal effort to improve the outage performance at plants in Hungary are centered on the planning and scheduling phase, rather than the execution of the outage.

Utility sites in France typically have permanent specialized outage staff. At one such site, the permanent outage coordination group consists of 3 overhaul engineers, representatives from each plant department, and a scheduling staff of 15 persons. Other persons participate on a part-time basis with an increasing number of these persons moving to full time in the weeks immediately preceding the outage.
One concern the French have expressed is the level of detail of the outage schedule. Currently, French sites vary in terms of the detail of their schedules. One site, for example, recently decreased the level of detail in scheduling outage activities because it became clear that the rigidity of the schedule was making operators too oriented to keeping to the schedule, as opposed to ensuring quality performance. The site now only schedules key operating activities, rather than the 350 activities, many lasting as little as 15 minutes in length, that it used to schedule.

The design of the Finnish BWR plants greatly facilitates outage planning and execution. On the other hand, the design of the plants in Hungary (PAKS units -- late version WWER-440s with 6 loops and 2 turbines per unit) has made outage planning, scheduling, and execution a particularly difficult task.

Swedish utilities make sure that final plan has well-defined target dates and is clearly organized so as to be easily understood. The well-defined target dates contrast with the method employed by French sites where precise target dates are, to some extent, intentionally avoided by building into the schedule a margin between the anticipated end date of an activity and the ultimate limit when the activity must be concluded.

**Outage Execution**

There does not appear to be an agreement on the value of having the outage planning and scheduling group continue to be the responsible group for the execution of the outage. Even in France where the importance of permanent and specialized outage staff is emphasized, there are differing opinions among the sites as to whether continuity of staff across these phases enhances or detracts from effective outage coordination. The rationale for continuity of key outage staff is clear but, on the other hand, the coordination needs of outage execution differ from those of the planning and scheduling phase.

At most French sites the permanent outage coordination group and scheduling staff remains intact and in control through all stages of the outage. However, at least one site has chosen not to use a permanent outage structure and has opted instead to have a planning and scheduling group prior to the outage and a different coordination group during outage execution. To ensure coordination across the two phases of the outage, the leader of the planning and scheduling phase becomes the assistant to the person directing the execution phase. The different structure during execution is intended to enhance work group coordination.

At one Swedish plant the same outage planning group remains in control during the outage. This group is supplemented with an outage supervisor assigned to each outage shift and the system engineers become responsible for supervising contractors. At another Swedish plant the control of the outage switches from the maintenance component of the outage group to the production component. This, however, is not a drastic change since both components were part of the original planning and scheduling group and continue to be part of the outage coordination group during execution as well.

During the execution of outages in Japan the coordination function switches from the maintenance or engineering section that had primary responsibility during planning and scheduling to an outage group comprised of approximately 10 shift operators. The new outage group maintains close communication with the section that had responsibility for planning and scheduling. In addition, other plant staff, particularly the managers of the various sections, assist this coordination group and engage in supervising and verifying the work performed by the contractors. The contractors do all the actual outage work. Vendors supplying contractors and services voluntarily station a technical liaison at the utility so that vendor companies can be quickly contacted in case of unforeseen needs.

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At plants in the United Kingdom the outage planner will, in some cases, assume the outage coordinator role during execution. Although the planning section coordinates the preparation of work packages, the engineering department takes over the day-to-day management of work packages during execution and prepares maintenance instructions. The operations staff assumes responsibility for coordinating and controlling safe access to the plant by all groups and manages the plant's return to service. Maintenance staff carry out planned and corrective maintenance, implement small plant modifications, and assist in supervising contractors.

In Hungary, the maintenance department outage committee not only prepares for the outage but oversees outage execution. However, daily control is the responsibility of the outage coordinator who is the same person as the operations supervisor. Outage staff work around the clock and are located in a separate outage conduct center. Coordination of special outage staff and job groups are arranged by the special outage staff who report to the plant supervisor.

An important issue during the outage is proper coordination of the contractors, staff and activities. Numerous meetings with all appropriate individuals appears to be the most common method to ensure proper outage coordination. One coordination concern at a Swedish plant was the possible loss of information between the day and night shift. The coordination group generally works day shifts while outage work continues around the clock. Their solution has been to overlap shifts to allow individuals from both shifts to attend the coordination meetings where updates and changes are discussed. A night outage supervisor is also fully informed of all schedule modifications and the outage coordinator stays in close contact with this person.

French utility sites have found that when schedule disruptions occur that cannot be handled simply by increasing resources it is better to shift the entire schedule and delay work in order to leave the schedule intact, rather than attempting to resequence activities. Computer programmes for outage scheduling are seen by the French as a critical quality tool and even with the limitations of existing software, it has been shown that scheduling technology has improved outage performance over the past several years.

The value of computerised scheduling programmes are considered to be of significant benefit to the effective tracking, coordination, and communication of changes in the outage plan or schedule in both Finland and France. There is also an effort in France to improve the scheduling software so as to permit greater flexibility in making schedule adjustments during outage execution and to increase the ability of the schedule to function more as an action-signalling device, rather than merely as a consulting tool for monitoring outage progress. Currently scheduling adjustments tend to be avoided.

Coordination difficulties in Hungary largely stem from the fact that a large amount of information must be collected each day in order to coordinate and control work but plants do not have a good on-line computer system to help facilitate this process.

**Outage Assessment and Follow-up**

The assessment of the outage activities in order to identify areas and activities for improvement is considered to be an increasingly important part of effective outage management in almost all member countries. One major difference in the current assessment programmes is the point at which the performance is assessed. In France, for example, assessments are conducted after each significant outage task as well as at the end of the outage. In most other countries such as Japan, Sweden, the United Kingdom, and Slovenia, the assessments are done at the completion of the outage. The reason for the French approach is the desire to develop a real-time scheduling process and the need, therefore, for continuous performance assessment information during the outage.
A second important aspect of many of the outage performance assessment programmes is the transfer of lessons learned to other plants and utilities. In France, a large-scale operating feedback action covering all sites was implemented in 1989 by the EDF utility headquarters. It requires that an outage report be submitted to headquarters by all sites. A department within headquarters is responsible for disseminating outage feedback on a national scale.

In Sweden and Finland (TVO plants), evaluation reports are submitted at the end of the outage period to the KAS coordination organisation. This information is used by KAS to assist in improving the outage scheduling process for the Swedish and Finnish plants. In addition, the Swedish regulatory agency conducts a human factors analysis of all significant events occurring during outages. The results of this analysis are discussed with utility and plant management, and relevant information is disseminated to the other utilities. The utility also performs internal post-outage assessments to identify areas where improvement are needed.

In Japan, contractor and plant staff experiences are both incorporated into the joint contractor/plant planning of the next outage. The evaluation results are also reported to utility headquarters. Headquarters compiles and evaluates the results of outage performance assessment reviews from all its plants and feeds information for improving quality and shortening outage length back to the plants. Within one month of outage completion an evaluation report has to be submitted to MITI and MITI notifies all utilities of key items.

In the United Kingdom, outages are reviewed and a report is issued highlighting those experiences of relevance to future outages. The reports focus on major aspects, rather than detail, and these reviews, by their nature, tend to not contain quantitative information. Operating performance is assessed throughout the subsequent year through both normal and special inspections, particularly of start-up problems. This performance information is compared with results for previous years and, as such, is a method for indirectly assessing outage performance. The United Kingdom regulators want to improve the detail of outage performance assessment and the results of post-outage plant initiation and testing and to promote greater quantitative tracking of performance.

**Personnel and Radiation Safety**

A critical aspect in the planning and conduct of the outage activities for utilities in all countries is the minimization of radiation exposure and personnel injury. In many countries the level of radiation exposure during an outage is a significant measure of the performance of the outage. Another performance measure used in the United States and in other countries is outage lost-time accidents.

There are numerous programmes and steps by utilities to minimize the radiation exposure to personnel during outages. These include considering the radiation exposure issues early in the planning and task consideration process. Also, the use of decontamination, automation, shielding, special training, protective clothing are common to most utilities. In the United Kingdom dose reductions have been accomplished through modification of work practices and improved planning.

As a result of performance assessments and other types of feedback, the Swedish plants, as well as those in other countries, have identified a number of safety concerns and have modified their safety programmes accordingly. These concerns include open radioactive systems, the increased field activity and concentration of personnel, the inexperience of outside contractors, the transportation of heavy equipment, and housekeeping problems.
General Summary of Reported Practices, Areas of Concern and Improvement Activities

Regulatory Context of Maintenance Outage

- Variation in the nature and number of outage specific regulations,
- Differences in the level of regulatory involvement in the outage process.

Outage Philosophy

- Common philosophy to conduct the necessary outage work as efficiently and effectively as possible,
- Major differences is the inclusion or exclusion of preventive maintenance tasks during the outage.

Long Term Outage Preparations

- There is a concern that pressures to minimize outage time with the potential to compromise safety requirements by possibly taking necessary redundant system out of service at the same time or by not fully or correctly performing required work tasks,
- Concern of the possible use of staff or contractors that are not fully familiar with plant procedures or practices,
- Long-term, stable working relationships are one way that many utilities have addressed the issue of quality contractor support.

Planning and Scheduling

- Widespread belief that the more effective the planning and scheduling process the greater the potential for shortening the actual outage length,
- Level of detail of pre-outage scheduling and the corresponding degree of flexibility in scheduling during outage execution appears to be of concern,
- Emphasis placed on relations between work groups as the key coordination and control mechanism.

Outage Execution

- Different views on the value of continuity of outage staff across planning and scheduling and execution phases of the outage,
- Different approaches to the degree of permanence, specialization, and level of training of outage staff,
- Numerous meetings with all appropriate individuals appears to be the most common method to ensure proper outage coordination,
- One solution is to overlap shifts to avoid possible loss of information from one shift to another,
- One solution to avoid schedule disruptions that cannot be handled by increasing resources is to shift the entire schedule and delay work in order to leave the schedule intact rather than attempting to resequence activities,
- Scheduling computer programmes are considered by some to be a critical quality tool and have been found to improve outage performance in recent years.

Performance Assessment and Follow-up

- Major difference in whether assessment reports are done as part of activities during the course of the outage or only after the outage is completed,
- Several major or systematic programmes to provide lessons learned to other utilities.
Events Illustrating Important Improvement Activities - Summary of Contributions

This section was to consist of three parts in order to provide a clear understanding of the importance of certain outage management issues. The three parts included:

- A brief description of the event, providing the essential facts of the event,
- A review and analysis of the event using a systematic methodology, with the purpose to provide the reader with a systematic interpretation of the conditions and causal factors involved,
- A description of the conclusions drawn from the event by the utility and the regulator, along with a description of any improvement programmes developed or other steps taken to address the problems that were identified.

The summary of this section will be focused on identified problems and suggested improvement activities. For a description of the events and as well as the analyses and conclusions drawn in the contributions presented, the reader is referred to the complete reports submitted by each country.

One of the main purposes of applying a systematic methodology in the analysis of the events was to capture which "barriers" had been broken and then to see how these barriers could be strengthened so as to prohibit the incident recurring. A "barrier" is here seen as a function (be it technical and/or e.g. administrative) that had it been present it would have stopped the evolution of the incident (for a further description of the barrier-concept see e.g. 283 ). Although not all countries presented what type of methodology was applied for the incident analysis or referred to the concept of barriers, we will here try to summarize some of the most common suggestions for improvement.

Control of the Work Process

In general, the most common remedial actions taken have been to improve administrative controls of various kinds, all aiming at getting a better control of how the tasks are executed and verified. This included improving procedures, work orders, pre-requisite information, sign-offs of tasks performed, checking, independent control etc. These improvements involved both revising the content and redesigning the format as well as adding new procedures.

Training

The other most commonly suggested improvement action was improved training for various purposes. These efforts ranged from more large-scale initiatives including the introduction or improvement of maintenance training centers to the training of specific tasks. The concern was also how to improve qualification systems for maintenance personnel. Special efforts are introduced to improve the training of subcontractors, particularly in the safety requirements at the plant.

Planning Process

Several countries stress the importance of improving the planning process, especially to be aware of the linkages between various activities performed in terms of safety requirements. Also, to plan the length of the outage with particular care given to the 'realism' in time to perform tasks and in the sequencing of tasks regarding linkages to other ongoing activities.
Integration and Coordination

Improved integration and coordination of activities is handled in various ways. Mainly through different types of meetings. Some have an outage conduct team available around-the-clock. The possibility to check the status of scheduled maintenance work at any time was suggested. An important resource in this regard is computerised information systems, where also constraints associated with a particular task can be included.

Awareness of Overall Plant State

Another common problem is the lack of knowledge or awareness of the overall plant state among single craftsmen while performing their particular activity. Similarly, they may be unaware of the safety significance of their actions per se or in relation to overall plant state. The most common solution to this problem is to improve information, procedures, training and/or supervision of maintenance personnel and contractors.

Work Load

The work load of especially control-room personnel is recognised by several countries. Remedial actions are oriented towards a reduction of information overload from instrumentation e.g. solutions aiming at a reduction of alarms presented during the shut-down state. Also, limitations on maintenance work during shut-down and start-up modes and mid-loop operation have been suggested. Another is to reinforce the control-room team by extra personnel during the outage and to improve the routines for shift change-over. Amount of overtime is another factor that may reinforce the problems associated with a high work load, particularly if large amounts of overtime are combined with night work. Some countries restrict critical work tasks to daytime work. A proper organisation of work schedules and limitations to overtime and on performing specific tasks during night work can limit the negative consequences on worker performance.

Management of Contractors

Several actions are oriented toward improving the management of contractors. Some strive at reducing the amount of work by external contractors in favour of a permanent staff at the plant handling and particularly supervising all maintenance work - especially for work on safety-related equipment. The importance of special training of contractors to increase the understanding of safety considerations is recognised by several. Also, the importance of pre-job briefings and follow-up on contractors actions.

Assessment and Feedback

Some countries have recognised the need for improving the analysis of operating experience during outages by using more systematic analytical methods that will better capture root-causes, particularly with regard to barriers broken in the human and organisational system. In some cases a particular incident has given rise to a more thorough investigation with the purpose to get a better understanding of all the conditions relevant to the performance of the various tasks and thus for proper improvement programmes to be introduced. Another aspect of improving experience feed-back stressed by several countries is to point out to contracting personnel and single craftsmen the importance of reporting unexpected findings.
The Importance of a Learning Organisation for Safety

As was pointed out in the introduction, the emphasis of the work performed in the task force was at the outset directed towards looking at organisational effectiveness by stressing improvement and learning. This view on organisational factors have been used as a basis for the regulatory work performed in this area within the Swedish Nuclear Power Inspectorate (SKI). This work on the development and application of methods for the analysis of organisational factors relevant to safety were performed in collaboration with Dr. Jon Olson and Alan Chockie, Battelle Human Affairs Research Center (Seattle, United States). Although it was not directly a part of the work performed in the Task Force we will as a frame of reference in the following give a description of the factors that must be present in order for the nuclear power plant to be a learning organisation. The material is based on work performed by Battelle for SKI and partly also for United States Nuclear Regulatory Commission (see e.g. 4&5).

From a regulatory point of view one of the main expectations for the industry is that plant organisations will be able to identify the nature and causes of developing performance problems and will develop effective interventions to meet them. Also, that the plant organisation is proactive in assuring improved performance over time. Organisations of this kind have been characterized as “learning organisations” (see e.g. 6). The ability to learn is central to the plants ability to improve. Organisations learn when they can both sense and adapt to changes in external or internal operating contingencies, and thus be more efficient or effective. Learning organisations are considered to be inherently more successful, particularly in rapidly changing business environments.

Learning is, however, not automatic. Organisations, even from the same industry, vary considerably in their abilities to learn and adapt. Within the nuclear industry, there is the regulatory assumption that organisations can learn - that they can change to incorporate new knowledge, adopt improved technology, or accept higher standards of safety performance. As generic safety issues are identified, or as new organisational systems become available, nuclear organisations need to be able to learn and adapt so that the risk to public health and safety remains as low as possible.

Organisations that can learn can innovate - they can come up with creative solutions to unresolved operating problems (7). Issues facing the nuclear industry, such as aging of components, the embrittlement of materials subjected to radiation, and cross system interactions have yet to be fully understood and corrected.

Another way that learning from operating experience contributes to plant safety performance concerns the efficient use of plant resources. Plants that are able to avoid repeat errors are not only able to reduce the frequency of initiating events, but are also able to avoid the costs associated with repeated, but avoidable errors and failures. These costs savings can be directed toward innovation or improved practice in the way the plant is operating and maintained (8).

A third way that learning is potentially related to safety is through its effects on worker motivation. The learning process, as discussed below, requires open communication throughout the plant organisation. It requires individuals to be more highly involved in the identification of problems and the creation of viable solutions to those problems. The involvement of workers in this process can lead to other positive work values including attention to detail and increased acceptance of the organisation's goals, including safety. In a related sense, the ability of an organisation to learn is an ability that must be constantly exercised. Pathways of communication need to be maintained, trust between departments needs to be established, expectations for involvement need to be reinforced. An organisation that is not prepared to learn on a daily basis from operating experience is probably not in a favoured position to respond intelligently to a crisis situation.
To summarize, then, there are several ways that learning contributes to plant safety performance:

- By avoiding unnecessary, repeat failures, either through a review of the plant's own operating experience or through a review of outside experience and research,
- By fostering innovation and discovery to offset existing design deficiencies,
- By promoting work attitudes and behaviours that are consistent with safe performance in general.

The Process of Learning

Understanding the role of learning in nuclear power plant safety first requires a discussion of what is meant by learning. Several different, though related approaches can be taken to the concept.

Learning can be defined objectively at the organisational level in terms of organisational outcomes. An organisation can be said to have learned if it manifests a change in a particular outcome. From the safety perspective, an organisation has learned if it avoids repetitive errors and failures, either in terms of a general class of phenomena (e.g. a decline in the number of scrams) or a more specific class of phenomena (e.g. a decline in the number of scrams induced by poorly written operating procedures).

However, learning can also be manifested in other outcomes that may be more difficult to measure. For example, an organisation that searches its environment and learns from the operating experience of others, theoretical discussions by experts, and other sources may end up avoiding problems in the future that have not yet manifested themselves as events. Thus, the error or failure rate may not change, but learning has happened. While this aspect of learning is conceptually straightforward, it causes some significant measurement problems - how to assess the number of failures avoided. Understanding this type of learning may depend on the observation of learning-relevant behaviour.

This leads to the third perspective on learning - learning as a process. This perspective focuses on the various organisational processes that, if effective, lead to changes in outcomes. The various stages in the learning process can be described as in Figure 1.
Problem recognition

The ability to recognize that performance problems exist

Problem diagnosis

The ability to accurately characterize the nature of the problem

Solution formulation

The ability to come up with viable solutions to the problem

Solution implementation

The ability to put the solution into place within the organization and to support its effectiveness through the proper allocation of resources

Assessment

The ability to monitor the effects of the solution and to make adjustments as required by experience

Feedback

Fig. 1. The Learning Process
Problem recognition

The first stage in the learning process is problem recognition. In order to start the learning process, it is necessary to identify a deviation from a desired state. If everything appears to be working normally, or within expected parameters, learning is unnecessary, and learning behaviour is largely inefficient. If there is a deviation from expectations, however, both the stimulus and the need for learning may be present.

Plant organisations, however, vary considerably in the extent to which they are able and willing to notice that problems exist. Of primary concern is the value placed on problem recognition. A significant contrast is between those organisations that view problem recognition as a first step to improvement and those that view problem recognition as an impediment to the normal conduct of business.

Organisations may also vary in terms of the types of problems they are likely to recognise, also referred to as the "problem-space" that is searched to identify problems. When comparisons have been made between nuclear plant organisations (5) better performing plants have tended to be more inclusive. For example, better performing plants have well developed systems for considering human error as well as equipment failure. They are also more likely to include performance issues at other plants, and even other industries, in their identification of problems relevant to their own experience. Also, to consider errors by management as well as errors by workers as problems, and to focus on all major functional groups, not just the control room. Better performing plants also show a lower threshold for what constitutes a problem. Poorer performing plants, on the other hand, tend to narrowly focus on significant equipment problems, or only on problems that are called to their attention by the regulators.

Problem diagnosis

Once a problem has been recognised, it must still be systematically analysed if it is to be sufficiently well understood so that a reasonable solution can be devised and implemented. Although there is some overlap with the problem recognition phase, problem diagnosis activities go beyond the discovery of the existence of the problem to the clarification of what the problem is. The clarification of the problem has both a technical and organisational component. The technical basis addresses the cause of the failure, the precise nature of the failure, and the impact of the failure on other systems. To answer these questions requires cooperation and support from various groups and individuals. Three major aspects of problem diagnosis are:

- technical resources
- cooperation/coordination among plant functions
- credibility of the root cause investigator.

The availability and quality of the technical resources have a major impact on the process and results of the problem diagnosis. This requires support by trained or experienced engineering staff and well developed equipment history data. Associated with this is the need for formal and informal communication among plant groups and departments to support an open sharing of failure and cause information.

A third aspect is the need for "buy-in" on the process and results by the various impacted groups. To achieve this buy-in requires high credibility and trust of the individuals responsible for the root cause programmes. It also requires management commitment to the process and a general sense of ownership in the plant and equipment by the employees.
Solution formulation

Coming up with viable solutions to performance problems is the third stage of learning. As in the case of problem diagnosis, the development and implementation of solutions to operational problems have both a technical and an organisational basis. A key aspect of the development of technical solutions is the availability and quality of engineering support. But engineering is not the only source for technical solutions to problems. Many of the best organisations involve personnel from all or most other departments in the development and implementation of solutions. In these organisations the resources and mechanisms are provided to support such involvement.

Opening up the process to staff other than engineers has been found to lead to better technical solutions, since the people with hands-on experience frequently have information and insights not available to the engineering staff. These people are also frequently most aware of the operating history of the problem equipment, including its typical failure modes. Another advantage is that by involving plant staff in the development of the technical solution, they are more likely to assist in the implementation of the solution.

Solution implementation and allocation of resources

One of the most important aspects of the development and implementation of solutions concerns the size of the budget relative to need. Even in those organisations with, for example, effective maintenance programmes, the potential exists for having inadequate resources to develop and implement solutions to important operational problems. However, many of these organisations have taken steps to assure that, to the extent possible, resources were available for important improvements. These included:

- Systematic methods for establishing priorities among competing needs,
- Bottom-up budgeting,
- Group decision making concerning budget allocations,
- Widespread educating of plant personnel on the budgeting process.

The methods for establishing priorities included risk-based assessments (based on PRA, RCM etc) of the significance of the operational problem, cost-benefit analyses of alternative solutions, and detailed, forward looking performance goals to organize and direct budgets. These mechanisms helped assure that scarce resources were not being wasted on low priority items.

Bottom-up budgeting refers to expenditures being planned on the basis of inputs from those individuals and groups with first-hand experience in plant needs.

To help establish the plant priorities and to facilitate buy-in on the part of all plant personnel, many of the organisations used group decision-making concerning the budget allocation. In this manner they found they obtained the support across the organisation for those solutions that will be implemented and those that are deferred.

Personnel education is directed at informing them as to the nature of the budgeting process, and methods for determining the cost/benefit of improvement programmes.

Assessment and Feedback

The final steps in the learning process involve assessment and feedback. Once solutions have been identified and implemented, there remains the question of whether the solutions will be effective. Many of the implemented solutions will be less than optimal in their original form. To address this issue, organisations must have effective programmes to continually monitor key aspects of performance, and outputs of these programmes must find their way into decisions about
whether new solutions are needed (i.e. problem identification). These formal tracking systems involve technically competent staff with knowledge of the organisation as well as the plant. In general, these individuals serve as facilitators for improvements, monitor whether the improvement schedule is being met, and assist management in determining whether the corrective actions are effective.

Shaping the effectiveness of the formal systems are several organisational factors. First, the nature of vertical communication appears to be very important in assessment and feedback. Where information is not allowed to flow up to management, relevant facts on plant and program performance will not be available for management decision making. A common feature of the best organisations is the excellent horizontal and vertical communication with regard to definition of problems, solutions, and the assessment of the impact of solutions.

Another important organisational factor for assessment and feedback is the nature of interdepartmental relations. Where these relations are good, feedback on the effectiveness of new programmes or technical solutions can flow freely.
References


