Safety Reports Series
No. 42

Safety Culture in the Maintenance of Nuclear Power Plants

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SAFETY CULTURE IN THE MAINTENANCE OF NUCLEAR POWER PLANTS

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SAFETY CULTURE IN THE MAINTENANCE OF NUCLEAR POWER PLANTS

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FOREWORD

Safety culture is the complexity of beliefs, shared values and behaviour reflected in making decisions and performing work in a nuclear power plant or nuclear facility. The definition of safety culture and the related concepts presented in the IAEA literature are widely known to experts. Since the publication of Safety Culture, issued by the IAEA as INSAG-4 in 1991, the IAEA has produced a number of publications on strengthening the safety culture in organizations that operate nuclear power plants and nuclear facilities. However, until now the focus has been primarily on the area of operations.

Apart from operations, maintenance in plants and nuclear facilities is an aspect that deserves special attention, as maintenance activities can have both a direct and an indirect effect on equipment reliability. Adverse safety effects can arise, depending upon the level of skill of the personnel involved, safety awareness and the complexity of the work process. Any delayed effects resulting from challenges to maintenance can cause interruptions in operation, and hence affect the safety of a plant or facility.

Building upon earlier IAEA publications on this topic, this Safety Report reviews how challenges to the maintenance of nuclear power plants can affect safety culture. It also highlights indications of a weakening safety culture. The challenges described are in areas such as maintenance management; human resources management; plant condition assessment and the business environment. The steps that some Member States have taken to address safety culture aspects are detailed and singled out as good practices, with a view to disseminating and exchanging experiences and lessons learned. Although this report is primarily directed at plant maintenance organizations, the subject matter is applicable to a wider audience, including plant contracting organizations and regulatory authorities.

The IAEA wishes to acknowledge the work performed by the consultants, the good practices highlighted and the proposals submitted by experts in Member States, aimed at strengthening safety culture in the area of nuclear power plant maintenance.

The IAEA officers responsible for this publication were B. Hansson and K. Dahlgren Persson of the Division of Nuclear Installation Safety.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

Strengthening the safety culture in nuclear organizations has been a topic of IAEA meetings, workshops and publications [1–6]. However, in most cases the focus has been on the operating organizations that run the nuclear power plants. Yet maintenance in nuclear facilities is unique and needs special attention. Thus, it was decided to develop a report on safety culture in maintenance.

The following are some reasons why maintenance in nuclear facilities requires special attention:

(a) Maintenance has an indirect effect on operational safety, based on the level of skill of the plant staff and on the:
 - Knowledge of the personnel involved in operational activities;
 - Use of calibrated and approved tools and instruments;
 - Technology approved for maintenance and operating procedures/instructions;

 These three elements need to be in harmony to achieve the proper results.
(b) The complexity of the work performed, involving different disciplines (for plant staff and contractors alike).
(c) Special work constraints such as:
 - Special isolation of components;
 - Components that are not accessible during plant operation;
 - Work in a radiological environment in accordance with the as low as reasonably achievable (ALARA) principle;
 - Involvement of regulatory or independent bodies during in-service inspection, surveillance tests, etc.
(d) The delayed effects of maintenance work, resulting from low quality work not being seen until the startup process, which can cause an interruption or delay in startup.
(e) Cost reductions for improving competitiveness in a plant fleet that grows older and needs more attention in the area of maintenance.

1.2. OBJECTIVE

The purpose of this report is to present experience and good practices in order to strengthen safety culture in the maintenance area and contribute towards the improvement of safety culture in organizations operating nuclear power plants. Discussions about safety culture problems and their underlying causes, and uncovering the levels of culture and differences in culture among plant staff and contractors, were important parts of the meetings held to prepare this report. It is expected that it will serve as a basis for future development of the services provided by the IAEA in this area.

This report discusses the challenges to safety culture in the maintenance area. Good practices that could highlight weaknesses were also discussed. Areas of concern, which pose a challenge to safety culture in maintenance, include the maintenance mission, organization, personnel, communication, contractors, ageing, cost effectiveness, regulatory oversight, change in ownership, unions and political decisions. When plants enter into a more competitive economic market, there is greater pressure to optimize costs in the area of maintenance. These pressures, combined with less educated, experienced and qualified personnel, further impact the area of safety culture in maintenance.

1.3. STRUCTURE

Maintenance challenges can be divided into four areas, namely: maintenance management; human resources management; plant condition assessment; and business environment. These domains were chosen for practical reasons. Sections 3–6 feature examples of good practices and weaknesses in each of these four domains. Section 7 puts forward a structured method for self-assessment and some ideas to further improve the safety culture in maintenance. Section 8 deals with maintenance indicators and gives examples of good practices in this area.

2. SAFETY CULTURE IN MAINTENANCE

The function of plant maintenance is to preserve and restore the inherent safety, reliability and availability of plant structures, systems and components for reliable and safe operation. Maintenance in nuclear installations has specific characteristics that put demands on the way maintenance activities are organized and carried out. These characteristics contribute to the possibility of severe consequences, technical complexity and delayed effects of maintenance.

Safety culture is the complexity of beliefs, shared values and behaviour reflected in making decisions and performing work. The presence of a strong safety culture in maintenance contributes significant value to the safe operation of a plant. With respect to plant maintenance, safety culture means keeping the maintenance process on track and in control at every stage of plant performance. Plant management supports this by monitoring, evaluating and making decisions on all important aspects (safety, technical and financial) of plant performance as well as on the consequences of operational activities. Furthermore, plant management establishes safety priorities based on the safety and quality policy of the plant. As regards the performance of maintenance, the basis for a good safety culture lies in the way tasks are conducted and on the qualification of personnel. When there is a strong safety culture, maintenance staff excel in the preparation and execution of the tasks in compliance with the safety, quality and technical specifications. In terms of qualification, personnel are certified, organizations are qualified and maintenance technologies are approved. The personnel element is crucial for the continuous improvement of safety culture and this, in turn, enables each individual to contribute towards achieving the overall goals.

The development of safety culture is a process of evolution in the plant organization, based on such elements as:

— Willingness of plant management to apply, and thus demonstrate, the principles of a strong safety culture, as well as their consistent handling of conflicts concerning safety culture issues;
— Everyday efforts and good practices of maintenance staff, including the application of a learning process;
— Special education and training of personnel;
— Procedures focused on mission goals that are rooted in the safety culture.

Safety culture is an attribute of the whole plant, and thus a strong safety culture in maintenance is a vital part of safe plant operation. The structured approach of maintenance needs clear roles and responsibilities: to identify and study problems; to make decisions on safety priority; to prepare and schedule maintenance activities; and to achieve a very high level of performance using approved documents, with supervision and control of quality. Thus the safety culture will be exemplified in all aspects of maintenance.

3. MAINTENANCE MANAGEMENT

3.1. MISSION

The mission of a maintenance organization is to ensure that plant equipment and systems operate when needed and that equipment breakdowns or defects are rectified in a timely manner and seldom reappear. The primary reason a plant or facility utilizes a maintenance management programme is to prevent equipment failure. Where that failure cannot be prevented, the same programme is designed to restore the failed component to its design, operable condition. Management involvement in the control of maintenance activities ensures that applicable maintenance practices uphold a strong safety culture, while ensuring reliable facility operation. Management's fundamental maintenance actions are found in three critical areas that include:

— The roles and responsibilities of the first line of supervision in the safe execution of management's policies, programmes and procedures;
— A work control system that provides the means to manage work safely;
— A preventive and/or predictive maintenance programme that prevents or economically constrains corrective maintenance, and is continually adjusted to maximize the reliability of the operable equipment.

The objectives of a preventive maintenance programme are to prevent facility equipment breakdowns and to maintain the equipment in a satisfactory condition for normal and/or emergency use. The programme is well defined and periodically reviewed for effectiveness. A good preventive maintenance programme is a living programme, and is constantly adjusted to maximize the reliability of the operable equipment. Many factors are considered in establishing an effective and efficient balance between the application of types of corrective, preventive and, where appropriate, predictive maintenance. A proper balance of corrective and preventive maintenance may include, at one extreme, no preventive maintenance for equipment that is allowed to run until it fails. However, consideration of such a failure may be influenced by the need to not adversely impact facility operations or the health and safety of the public. The 'run to failure' strategy could unintentionally cause workers and contractors to feel that this procedure is to be generalized in the plant, as they often are not privy to the discussions that lead to the selection of such a strategy. At the other extreme, for equipment whose failure can limit safe or reliable operation, extensive preventive maintenance may be necessary. The purpose of the facility's preventive maintenance programme is to eliminate or minimize corrective maintenance for equipment not previously designated to run to failure.

An organization focused on an effective safety culture maintains a balance between preventive and corrective maintenance, with supervisory oversight at every step of the process. The maintenance organization has to promote a different ethos for diagnostics, involving prevention, instead of a ‘firefighter’ type rapid response. In a maintenance organization designed to prevent equipment failure, the exposure to variation is greatly reduced. However, the repetitive nature of preventive maintenance has a tendency to lull workers into complacency, thereby again increasing the exposure to safety risks.

3.1.1. Examples of good practices associated with the maintenance function

At some plants, a systematic approach is adopted and diagnostic measurement of equipment performance is carried out before planned maintenance and after completion of work. This contributes to the assurance that maintenance has been performed, and thus helps verify the technical condition of the equipment. The diagnostic programme addresses important technological systems of the plant. Maintenance diagnostics include monitoring and analysis of vibrations of rotating components and thermography (using an infrared camera) of electric busbars and electric equipment, including generator stators. Technological systems and components important to the safety and reliability of the power plant are diagnosed before the commencement of overhauls, and the results are regularly assessed at defined intervals according to a plan. For example, all pumps are tested after they have undergone maintenance.

Some plants have programmes to encourage participation of the entire staff in upgrading plant operation. These programmes have included training on systematic analysis and solution of problems, by means of simple statistical tools such as Pareto diagrams and cause–effect diagrams. Improvement groups of about eight members have been established to start the programme and used to familiarize the staff in solving basic problems and to improve safety. These programmes have been determined to be of excellent educational value.

At some plants the processes and procedures for readiness for operation have been improved by involving operation and maintenance personnel. Special groups, involving the various disciplines, work together to develop new processes and procedures. These plants have invested great effort in the introduction of these new procedures by raising the consciousness of staff and explaining the purpose behind the changes. Furthermore, the plant staff has been trained in aspects of nuclear safety and safety barriers in the defence in depth of the plant to support discussions in the groups mentioned above. The use of the new processes has been followed up and evaluated using special performance indicators.

3.1.2. Examples of weaknesses associated with the maintenance function

The challenge to safety culture in a maintenance organization designed to merely ‘fix’ equipment failures is the constant exposure to many types of repair. The attention to different types of failures in itself increases the risk to safety due to the inability of the plant to provide a standardized level for all repair activities. Constant repairs tend to create a firefighter mentality among the workers, which is further bolstered by both the feeling of satisfaction after the repairs are successfully completed and the ‘rewards’ or praise following a job well done. These feelings contrast starkly with the otherwise mundane and systematic approach of preventive maintenance.

If first-line managers come to the attention of upper management through a series of successful ‘fixes’, they will indirectly reward the firefighter mentality. The workers or organizational units might feel rewarded due to a misconceived perception that they have ‘saved the plant’ from an extended shutdown or that they have reduced costs. They might also receive heightened distinction and be prominent among the plant staff. Upper management needs to be cautious about such a development, striving for a more systematic safety approach in favour of preventing failures rather than fixing them. If upper management rewards repairs over preventive maintenance, it will convey the wrong message to workers and jeopardize proper development of the plant over the long term.

Additionally, problems can occur due to unclear responsibilities between the engineering and maintenance departments, and the perceived antagonism between maintenance and operations. The lack of documented, long term planning and unclear goals for maintenance are also significant potential weaknesses.

3.2. WORK MANAGEMENT

The purpose of work management is to ensure that maintenance is performed correctly as planned, scheduled and coordinated. The planning function is designed to provide consistency in instructions and procedures for workers during assignments in order to return the equipment to its original and operable condition, and to avoid introducing any hardware changes that have not been engineered into the equipment and/or system. The type and detail of planning will vary with the categorization of the equipment. Safety, health, environmental concerns and production capability are the primary drivers of categorization. However, these plans are useless in management terms if there is no way to adequately schedule the maintenance task or account for the necessary coordinated support from other organizations. Work management is the administrative process used by the plant to organize various departments into an effective team to identify, prioritize, plan, coordinate, execute, test and properly close out work activities.

Work management systems can be divided into two primary types, with the level of planning detail and rigour of adherence being the main differences. For those with hardware that has a direct effect on the health and safety of the public, the environment, or production, a prescriptive and instructive form of work control is indispensable for management to ensure the highest degree of quality control over maintenance. For those types of components that have little or no direct effect on the health and safety of the public, the environment, or production, a routine form of work control is more practical for management to monitor quality control. Work management incorporates both operating and outage unit work. It is a process for the efficient empowerment of a strong safety culture. In other words, it allows at all times for a safe balance between economic issues and safety issues.

During normal operations, a safety message is easier to reinforce and maintain due to the continuous nature of the work process. However, during outage periods, a greater emphasis on production may hinder a good safety attitude.

Outages can also be organized in different ways. One process uses an outage schedule as an extension of the normal work control process. Another mechanism is to segregate the outage organization into a project management function.

Normal work control has the potential to negatively affect safety culture through complacency in performing routine work activities. Project management, on the other hand, has the potential to negatively affect safety culture due to its greater emphasis on production milestones.

Clearly written and well understood procedures can be of significant benefit in promoting a strong safety culture. They are a mechanism which identifies to the worker the prescribed action for a specific activity. Used properly, procedures are a good supervisory tool and a way to control documentation and retention of knowledge.

Procedures are normally not presented as a paper exercise, but are a means of continuous communication and transmission of lessons learned. They are simple and understandable. Procedures are not in excess, but are sufficient to support preventive and corrective maintenance activities. They are prescriptive to support important steps, but flexible enough to allow for the best use of worker skills in areas that do not call for detailed instructions. Sufficient maintenance procedures may be available to identify what to do during unexpected situations.

To maintain a strong safety culture, procedures should be developed with the concurrence of the affected maintenance organization. In this connection, work management can address the following issues:

- Job planning, including writing proper instructions and/or procedures for the maintenance activity;
- Proactive planning, incorporating analysis of risks for disturbances and continuous awareness of what could go wrong;
- Specification for close-out purposes;
- Mechanisms to deal with contractors;
- Interdepartmental, intercraft and work team coordination;
- Operational prioritization;
- Planning of shutdown and startup and associated coordination;
- Maintaining an updated schedule of work activities for unplanned shutdowns;
- Pre-job briefings;
- Ensuring accurate control and documentation before performing the task, during the task and upon completion of work activities;
- Openness to early warning signals, delays, disturbances, etc.;
- Clear accountability at all stages of the process;
- Procedures for handling work activities which cannot be finalized as planned;
- Providing for post-maintenance testing.

3.2.1. Examples of good practices associated with work management

Maintenance modules are good tools for corrective maintenance. The modules provide a readily available library of standard work instructions for routine corrective maintenance activities. These modules only need minimal additional information when used in planning a job. The module library is saved on a planning database, which can be accessed by planners and the shift maintenance coordinator. These modules can be used for about 40% of corrective maintenance on mechanical and electrical equipment. The priority for developing modules is based on the importance to plant safety, and the intent is to expand the number of modules to include additional corrective maintenance tasks. The use of standard modules for routine corrective maintenance activities improves the availability of safety related systems by allowing work to be planned and executed more quickly.

The use of systematic analyses of maintenance activities has developed through the years. Methods like preventive MTO (man, technology, organization) analyses and FMEA (failure mode event analysis) are used in a systematic way with the involvement of maintenance engineers and workers to identify possible risks or problems (and their consequences) that might arise during the performance of the work. These analyses have contributed greatly to the development of work processes and methods. Workers are also better prepared for the work and they obtain 'ownership' of the work methods used.

Some plants have started to make use of approaches such as TPM (total productive maintenance, initially developed for manufacturing plants) to involve front-line operators in the ownership of minor maintenance work that can be done within carefully constructed guidelines. The process calls for careful design and clear guidelines to ensure that the work done does not inadvertently challenge safety and that inadvertent modifications are not made to the plant. Benefits include, as mentioned before, greater ownership of minor maintenance work by operations staff and timely resolution of minor defects without having to use the full work management process.

Policies are normally established for the early identification and procurement of spare parts, materials and services. Procedures are developed that specifically describe the responsibilities of the station personnel involved in the procurement function. Controls are developed and maintained throughout the procurement process to help obtain parts, materials and services in a timely manner. Deficient or non-conforming items are segregated from accessible conforming materials and deficiencies resolved in an effective and timely manner. Quality assurance records are controlled and maintained to provide documentation of acceptability for qualified spare parts and materials and to ensure traceability of parts and materials.

Several plants are using methods for planning and recording the radiation dose to personnel that are linked to specific work activities and system operations. This provides a history of exposure data for maintenance work and allows for a continuous process of improvement at the level of work planning, preparation and execution. The data can be used for cost–benefit decisions in terms of dose reduction.

For plants which by design have more than the minimum number of redundancies built in or available (multi-unit sites), it can be safe enough and reasonable to perform planned maintenance with the plant in normal operation. Work will have to be carefully planned and prepared, and carried out with special safety evaluations and precautions applied. This approach to maintenance is clearly safer than performing unplanned corrective maintenance at a moment dictated by a component failure or problem. Unplanned corrective maintenance is very often done with little or no planning in detail, with limited labour and skill, and with questionable technical support. Planned on-line maintenance avoids many of these handicaps. In addition, planned maintenance makes better use of personnel and provides a higher quality of work.

3.2.2. Examples of weaknesses associated with work management

Weaknesses related to work management issues include the following:

- Failure to consider the safety culture of contractors who do not normally work at the plant.
- Lack of significant overview and protective controls. Without such controls, on-line maintenance — a very effective tool — has the potential to affect safety.
- Lack of effective prioritization of work, which can influence the distribution of maintenance resources and the allocation of those resources to appropriate equipment.
- Poor documentation and configuration control problems, which are the result of an ineffective work management process.
- Inability to process permits and clearances on time, which can delay needed maintenance work.
- Lack of work activity ownership, which has an impact on the effective coordination of job activities.
- Lack of clear accountability for the maintenance work management system databank and for delivering maintenance work, which contributes to the buildup of an uncontrolled maintenance backlog.

4. HUMAN RESOURCES MANAGEMENT

4.1. ORGANIZATIONAL ISSUES

A strong safety culture is supported and sustained by the maintenance organizational structure. Every country and the utilities within that country organize maintenance in a fashion that best suits their particular needs. Whatever design structure is used, the following key factors should be incorporated to foster the safety culture of the plant:

- One designated individual (e.g. the field supervisor, foreman or lead worker) should be accountable at all times for the work being performed. This includes job coordination, use of procedures, clearances or permits, material used and personnel work practices. This accountability, and the responsibilities involved, should be written down, clearly defined and communicated.
- Field supervision, involving periodic observation of the work activity, is necessary. For more complex jobs this supervision may need to be continuous. Regardless of the case, field supervision provides consistency in the application and support of safety and quality standards.
- Precursors of negative trends in safety and safety culture need to be tracked and periodically reviewed with workers. Where appropriate, process and procedural corrective action need to be instituted to prevent a recurrence of these negative trends.
- The structure should allow for contractors to be educated in a plant's safety standards. If they are to work on plant equipment, the safety standards that the contractors need to follow should be the same as those followed by plant personnel. Long term partnerships with contractor personnel are encouraged in support of this effort.
- Post-job briefings are very effective in supporting the policy of collating the lessons learned and in enhancing safety culture.
- Additionally, the organization can allow for some work activities to be conducted using a matrix of specializations (for example, systems, components and individuals with skills in several areas of a discipline or with multidisciplinary skills).

4.1.1. Examples of good practices associated with organizational issues

The implementation of optimization and upgrade process programmes can foster cooperation between departments that support maintenance activities. This includes a centralized documentation area and a branch in charge of purchasing spare parts for nuclear safety. These groups have not usually been very highly motivated because in the past they were usually kept out of the loop with regard to nuclear safety aspects.

At some plants, significant problems had developed between the operations and maintenance departments. For example, work requests written by operations staff had prioritized daily maintenance activities without consideration of maintenance priorities.

Based on the success of a common outage project organization, the plant expanded the experience, using the project function, to include the operating unit as well. The main objectives sought not only to improve the relationship between maintenance and operations, but also to anticipate daily activities, to provide good advice to each branch, and to:

- Better employ staff during the work day;
- Make sure that risk analysis is done properly and involves the appropriate department supervisors and workers to ensure short, medium and long term planning;
- Better follow up on anomalies and works requests;
- Inform departments on the results of each activity;
- Detect good practices in order to motivate staff to provide feedback experience from each department;
- Give to the operations department a very clear picture of the actual status of the plant.

Some plants have set up multidisciplinary teams that work towards a common goal. For example, one approach involves the setting up of ‘fix it now’ teams to address emerging defects in the plant. Such teams might include health physics, operations and maintenance personnel having the desired skills to complete plant maintenance quickly and reliably. Such an approach minimizes the number of standing defects and reduces safety challenges.

4.1.2. Examples of weaknesses associated with organizational issues

Weaknesses related to organizational issues include:

- Lack of teamwork and poor interfaces between departments involved in the operations and maintenance processes;
- Failure to clarify responsibilities following changes in the organizational structure;
- Lack of or inadequate interaction with the regulator concerning organizational changes;
- Lack of anticipation of what organizational changes may imply;
- Cognitive overflow syndrome, i.e. initiative overload, accumulation of assignments;
- Information directives that are not clearly written or understood.

4.2. COMMUNICATION ISSUES

Communication is a significant element of the safety culture in maintenance. There are many ways to communicate the safety message. One mechanism can be the corporate message usually found in directives or procedures. Another is the periodic written or verbal direction delivered by plant management. The most common form is daily communication from the first-line supervisor. Each method may have a different audience and level of delivery, but all are consistent in the safety message. Regardless of the delivery medium, the following topics can be considered in delivering and sustaining a message that fosters a strong safety culture. The following are the most important points to communicate, applying to both plant and contractor personnel:

— Clear goals and objectives regarding the technical aspects of the repairs and their safety implications;
— Circumstances and conditions under which staff will work;
— Whom the staff will be working with, and from where their support will be coming;
— A briefing or description about the complexity of the work and of the critical steps to be undertaken, especially if there is only one chance to get it right;
— The necessity to provide feedback on procedural changes or any problem encountered during the maintenance activity.

Pre-job briefings need to include safety issues as well as technical instructions.

The presence of supervisors in the field may be sufficient to ensure that the workers' view is captured. Improved oversight and coaching may lead to more effective resolution of problems.

4.2.1. Examples of good practices in communication

Certain plants have adopted a general strategic plan under the leadership of the senior manager of the company, aimed at adapting the organization to a predetermined corporate model that guarantees the competitive position of the plant in terms of safety and costs. Safety culture, striving for excellence, delegation, teamwork, participation, communication, competitiveness and long term foresight are issues included in the long term strategic plan.

Pre-job briefings

Some plants have introduced a comprehensive programme of pre-job briefings in three or more steps, depending on the complexity of the work. First, a pre-job briefing is held at the preparation stage, involving planners, radiation protection personnel and an assigned foreman. The second briefing is done by the foreman for his or her staff in the workshop, while the third is done at the work site with the workers. If contractors are involved, they are permitted to participate as if they were plant staff. In the briefings, as a minimum the associated safety and industrial safety risks are discussed, as well as expected work results and all necessary safety and industrial safety precautions.

Precursors: Reporting near misses

There are plants that have programmes to specifically address the reporting of near misses. They encourage workers to express what could have gone wrong (before safety related events there are always precursors to which no one reacts). Reporting one's mistakes is considered a positive contribution. These plants refrain from blaming workers, and recognize that decisions of upper level managers can be at the root of problems. Human performance investigations are performed with an open mind, not to accuse people. An important part of the investigation is encouraging workers to describe any near misses.

At some plants staff are not only encouraged but also expected to report all 'events', even minor ones. These range from minor personal injuries and 'near misses' in the operation and maintenance of the plant to more serious breaches of operating rules and other statutory provisions. Staff who make mistakes or errors and quickly report them are not blamed, penalized or subjected to disciplinary action. However, anyone who makes a series of such mistakes or errors, even though well intentioned, may be subject to capability procedures, which may lead to further training or reassignment to different work. Anyone who knowingly violates a procedure, rule or instruction or who fails to promptly report any such event is subject to disciplinary action. This includes not using written work procedures as expected.

Sometimes a human factors expert (HFE) is permanently employed by the plant to improve operational communication during maintenance activities. A special one day training programme is conducted in which all identified communication weaknesses leading to misunderstandings and consequently to mistakes are discussed. The HFE is also in charge of analysing incidents and feedback experience, observing good practices in the field of human performance and proposing solutions. At all times open dialogue is a priority and the HFE is not to be considered as a police officer. He/she is also in charge of informing management about the repetitive 'low signals' sent by workers that can lead to more significant weaknesses. Some plants develop a human performance network to increase the attention to human performance issues in the field. In some cases each department representative is given up to three weeks of training on this topic.

Some plants have such an MTO network, and the persons in the network serve as MTO 'ambassadors' in the organization to convey human factors related messages to staff engaged in daily work, as well as to pick up the 'low signals' mentioned above. They also support preventive MTO evaluation of working methods as well as plant modifications.

4.2.2. Examples of weaknesses in communication

Weaknesses in the area of communication include:

- Lack of diverse means of communicating management expectations and standards to the workforce, which can restrict the safety culture message;
- Not conducting, or poorly communicating, pre-job briefings;
- Too much top–down communication, and failure to communicate at the appropriate level of the workforce;
- Failure to show trust in the workforce;
- Lack of a suitable environment for good two way communication;
- Failure to question, accept or follow up on unpleasant messages;
- Very rigid communication channels limiting the flow of information;
- Failure of top management to communicate a high priority message on safety and back it up with action.

4.3. PERSONNEL EXPERTISE AND LEARNING

One of the major challenges that maintenance organizations will face in the near future is the age gap amongst personnel. The current generation of workers matured with the plants, giving them very good knowledge of the plant systems, components and work environment. In recent years dramatic changes have affected maintenance organizations, and the current generation is either retiring or being replaced by contractors or new personnel with less experience. Moreover, many countries are experiencing difficulties in recruiting younger professionals into the nuclear field (for example, as a result of the uncertainties in the political environment of nuclear power). The following discussion will emphasize two aspects. First, the unique challenge posed by generational changes at the management and staff levels. Second, the issue of enhancing or maintaining professionalism. Professionalism encompasses a combination of qualities, including a healthy respect for the unique nuclear technology, and great care as well as conservative, thoughtful decision making on the part of plant staff.

Generational changes in the workforce

The existing plant management team has to develop ways to prepare new people, provide training and build up a professional staff responsible for the overall safety of the plant. It is desirable for nuclear utilities to establish cooperative style programmes with colleges and universities to attract and recruit employees. Senior management needs to clearly define future personnel needs and support education programmes in colleges and universities.

As experience is lost, it is important that a mechanism for knowledge retention be put in place. Information technology can play a key role in this regard. Where possible, this mechanism needs to be established in a formal manner. One option is to create a documented, in-depth interview programme combined with a coaching and mentoring programme. Programmes also need to maintain and promote a high level of 'ownership' and involvement in the retention of knowledge for older personnel.

Enhancing and maintaining professionalism

Safety culture in maintenance has to address an intrinsic dilemma, namely maintaining a creative, open minded and questioning attitude, while at all times sustaining conservatism in relation to reactor safety, accurate documentation and design conformity. It is important that plant personnel have up to date knowledge of plant configuration and equipment at all times, and that they are aware of the implications of their actions.

Ideally, the maintenance professional knows how to treat, share and communicate lessons learned within his or her work team and contribute to the rest of the organization (again, information technology can be of vital assistance here). Professionals know or are trained to translate minor events into generic issues. Another paradox may exist here: on the one hand the maintenance professional deals daily with concrete equipment problems, but on the other hand he or she is expected to think in the abstract to be able to relate minor occurrences to broader generic issues.

To ensure that professionalism is maintained or enhanced, it is important that maintenance organizations have clear responsibility and accountability for work done and that they ensure that their expectations are clearly communicated. Additionally, an awareness of safety aspects and the consequences of improper actions need to be taken into account, specifically, the safety implications of confusing the nuclear power plant unit or train.

Communications, teamwork, pre-job briefings, walkdowns of field activities, and giving and accepting feedback (i.e. open reporting) are all good examples of a strong safety culture in maintenance.

A core team of personnel with a thorough knowledge of systems and components important to safety is a necessary foundation for a strong maintenance organization.

4.3.1. Examples of good practices associated with staff expertise and learning

Some plants use a systematic management monitoring programme covering the work performed at the plant, conducted by senior and mid-level engineering staff of the organization. Each supervisor is responsible for one activity per month and drafts a report following a checklist, where he or she notes the deficiencies observed and suggests proposals for improvement. Section managers then analyse deficiencies and decide actions to be taken within a determined period of time. A certain number of issued and concluded improvement proposals would need to be fulfilled every quarter. The intent of such a programme is to improve safety and excellence in education by providing technical advice when the work is performed, gathering objective data on the work performed and comparing them with expected data. The programme:

— Detects latent technical and organizational problems related to work performance;
— Improves understanding of problems related to work performance;
— Assists personnel and improves human relations;
— Encourages personnel to contribute with their suggestions and concerns.

Certain plants arrange for training sessions to focus on safety culture issues in relation to the analysis of events or the introduction of a new procedure. It is important that safety culture training be directed not only at the group leader level but also at the craftsman level. Safety culture has to be taught in a practical way so that individuals can relate it to their specific situation.

At some plants, the maintenance manager notes disturbances and feeds them back to the relevant organizational group and individual. This is one channel by which the safety culture is enhanced, since importance and visibility are accorded to the event. However, importance and visibility also have to come from the field in a formal and established manner.

Succession planning for the replacement of retiring personnel allows significant time for the introduction of new positions for all predicted employee changes over the next 20 years. The duration of the introductory period depends on the position and varies from one to eight years; every employee currently at the plant is named in the plan. During this time, the expertise is transferred from the incumbent to the new employee. The plan is reviewed by the Board of Directors on a regular basis and approved in the budget process.

4.3.2. Examples of weaknesses associated with staff expertise and learning

Weaknesses related to personnel expertise and learning include:

- Lack of a skilled workforce;
- Lack of a personnel development programme;
- Failure to attract new talent to the nuclear industry;
- Lack of a staff rotation and succession policy;
- Too much emphasis on staff numbers and insufficient consideration given to the transfer of knowledge to new employees;
- Insufficient attention paid to older employees taking on new technologies and practices (skill set changes);
- Lack of support by unions, sometimes affecting the mix of skills in plants.

4.4. CONTRACTOR ISSUES

Plants use contractors as an additional workforce to supply skill sets that are not normally available in the current workforce of the plants. The use of contractors has increased dramatically in the industry. As a result, it is desirable that safety culture considerations apply not only to the organization, but to the contractors as well. Because of the variety of contractors, the following factors are key to maintaining the safety culture of the plant:

- Contractors are qualified to do the job, and the plant ensures that their qualifications are updated;
- Contractor staff members receive good training not only in basic nuclear knowledge but also in plant specifics, quality assurance (QA) and radiological protection, and in safety aspects related to their specific jobs;
- Supervision from in-house personnel may vary in detail, depending on the activities and the type of contractors involved in the job, but should always be in accordance with safety standards;
- The maintenance organization should keep a set of systematic criteria to generate milestones;

— Contractors follow and comply with plant regulations that impact on their jobs;
— Contractors ensure that they have proper internal coordination;
— Contractors are evaluated by the nuclear power plant (e.g. quality, safety, human performance issues);
— Contractors are encouraged to share their experience after an outage in an open and frank manner;
— Long term relationships with contractors may be a good solution to support a strong safety culture. This includes the definition of common objectives for contractors and plant staff.

4.4.1. Examples of good practices associated with contractor issues

Some good practices associated with contractors include the following:

— Certain plants have developed quality and safety programmes to ensure that the proper safety message is passed on to contractors. Too often contractors do not know the functions of equipment they have worked on, nor the reasons for tagging them. This kind of training programme is compulsory for craftsmen doing safety related work. It includes 40 hours of basic training. In addition, each individual receives a 'passport' that guarantees a minimum level of quality and safety knowledge, QA qualifications, dose records, medical examination dates and quality test results performed at other plants in the country. These kinds of programmes enhance safety awareness and professionalism and result in a more stable workforce.
— At some plants special attention is paid to the communication channels between the contractors and those who manage the outage. For example, the outage management team holds a meeting with the contractors two months before the outage to explain the main phases of the outage, its duration and the important works to be performed. Also, a meeting is held between the maintenance branch and contractors before the start of outage activities. The safety and quality teams participate in order to strengthen the discussion on nuclear safety aspects (holding on average 15–20 meetings).
— Special attention is paid to the surveillance and control of contractors. For example, some plants are relying on a new category of staff, called job 'checkers'. They have a strong background in maintenance and have a special mission to follow contractors in nuclear safety activities. They do their checking in accordance with a special procedure called a quality plan. In addition, at some plants a special check is also performed by a

safety team on the use of contractors during outages. If weaknesses are identified, a formal letter is sent to the contractor, who is given time (most often one month) to answer and submit proposals for corrective actions.

4.4.2. Examples of weaknesses associated with contractors

Weaknesses associated with contractors include the following:

- Lack of the requisite skills and plant experience of new staff introduced by the contractor as the older staff retire;
- Lack of stability in the relationship between the contractor and the plant;
- Lack of 'ownership' in the work done in the plant by the contractors;
- Failure to monitor the work of contractors;
- Failure to organize free discussions with contractors at the end of the job;
- Failure to reinforce consistent standards;
- The tendency of contractors to 'cascade' work to subcontractors without appropriate qualifications and controls;
- Failure to ensure that a sufficient number of workers familiar with a plant are sent to work on projects there.

4.5. TRADE UNIONS

Where trade unions exist in an organization, they can communicate directly with individuals involved in maintenance. Different maintenance trades and skills may be represented by different unions; changes to working arrangements may involve the agreement of unions for their successful implementation. The relationship between individual unions and between unions and the management of an organization can affect the attitudes and behaviour of all concerned. For example, resistance to change can make it difficult to implement new maintenance strategies and can have an adverse effect on safety culture. Resistance to change can also lead to frustration on the part of management and staff, and to a breakdown in communications and the failure to follow processes or to implement new strategies.

One challenge involves arriving at a mutual understanding of the essential characteristics of the safety culture; this may be achieved by developing a partnership arrangement to deal with safety thinking and to address maintenance issues. The use of a joint committee of union and management representatives to develop a set of ground rules for a partnership working across an organization can be supplemented by that group also monitoring the implementation of any partnership agreement at a local level and, where necessary, taking part in joint communications to the workforce to address emerging issues. The support of union officers can lead to a more focused approach across plants and to the timely implementation of changes.

Company, plant or department level discussions could be held where the management or unions might identify a possible safety problem, with the joint group then developing a solution which could be jointly communicated to the workforce. Issues associated with implementation can be addressed jointly.

Union representatives are also in a position to identify significant concerns to management on a non-attributable basis — thus allowing an individual to highlight a safety concern without any fear of retribution. (Such a fear might be considered a negative aspect of the culture that needs to be addressed.) Union representatives can thus help improve company learning and can also coach individuals.

Trade union representatives can also be involved in developing safety training and improving behaviour and attitudes — where possible helping to develop new approaches to break barriers between different skill groups.

4.5.1. Examples of good practices associated with unions

Good practices associated with unions include the following:

- Some countries have regulations that call for the setting up of local safety committees that involve union representatives. These can be used proactively to identify safety concerns and implement new strategies.
- Some utilities have involved union officials at the national level in developing changes to their maintenance organizational structure. Such an approach leads to the introduction of a more uniform approach to maintenance across the utility’s plants in a more timely and effective manner than if the utility tried to impose changes locally.

4.5.2. Examples of weaknesses associated with unions

Some weaknesses associated with the involvement of unions include:

- Lack of consideration for the role that unions can play in relation to safety culture;
- Antagonistic relationship between unions and management;
- Inter-union adverse relationships.

5. CHANGES IN PLANT CONDITION AND TECHNOLOGY

5.1. AGEING OF THE PLANT

The age of the world's nuclear fleet means that plant ageing has become an important issue for the industry. Moreover, many plants are applying or thinking of applying for licence extensions or upgrades. In these matters, the issue of ageing is crucial.

Ageing of systems, structures and components (SSC), if not effectively managed, can have a very significant negative impact on:

— Plant safety;
— Plant performance (including economic viability);
— Life extension.

These adverse effects represent a challenge for operation, maintenance and engineering support organizations who, in order to keep and improve their effectiveness, have to follow up on technological progress, maintain a good knowledge of physical degradation mechanisms and be aware of internal and external experience. This needs to be done through continuous learning of new technological developments and the application of these technologies with the aim of anticipating ageing and unexpected events [7].

The implementation of a comprehensive monitoring programme is desirable to determine the ageing status of important systems and components. An understanding of the original design stipulations (background used for design input) and a comparison of actual degradation mechanisms with the assumptions made in the design are necessary for specific components in order to identify their expected life. Continuous adaptation and support will be needed for the monitoring programmes. Ageing issues are to be included in the Periodic Safety Reviews that are normally carried out at ten year intervals. A comparison and check of compliance with up to date safety requirements have to be done and can necessitate corrective actions.

It is necessary that strategies be evaluated to replace obsolete equipment or equipment no longer supported by manufacturers. Arranging for a secure lifetime supply of stock, secure manufacturing capability or for identifying replacement solutions, including the qualifications needed to comply with the design criteria, are good solutions to this problem. As a result of these strategies, changes may be necessary in: material; designs based on maintenance experience; processes and procedures of the maintenance programme, including inspections; and other areas involving maintenance activities.

The effective and systematic management of ageing can be challenged by unclear support or even lack of understanding of plant ageing on the part of utility or plant senior management. Appropriate and timely information about predictions of the safety impact of ageing and the planned remedies to mitigate any impacts on safety should be given continuously to senior management. Senior management can then set the appropriate priorities.

5.1.1. Examples of good practices in the management of plant ageing

Some plants have developed and implemented a long term ageing management programme to effectively monitor and anticipate the status of equipment. The programme ranks the components of the plant according to several criteria such as importance to safety and production, the possibility that they can be substituted, and the consequences of failure. A list of 'components important to ageing management' should be provided. Degradation mechanisms can then be analysed for each of the components selected. The relevance of the degradation for each specific component is categorized into low, medium and high. As a result, a list of high relevancy component degradation mechanisms can be obtained. An evaluation of maintenance practices is made for all the selected components, along with verification of their capability to monitor or mitigate the degradation phenomenon. Corrective actions are then defined to improve practices that do not efficiently monitor degradation mechanisms. The ageing management programme provides very useful information concerning the active status of equipment and for long term maintenance planning.

Some noteworthy practices in the area of maintenance that support the senior management of an ageing plant are the following:

(a) Development by certain plants of a sealing programme, in which old packing materials using asbestos are replaced with substances that are free from asbestos and based mainly on graphite. The plant cooperates with several well known manufacturers of sealing and packing materials. Special attention is paid to the qualifications of employees, who are well trained and receive ongoing training in accordance with the new materials and techniques employed. A systematic approach to the replacement of sealing and packing materials in crucial safety systems enhances preparedness and contributes towards the improvement of the technical status of components. Through the extensive involvement of staff in the programme, the awareness of the importance of correct installation is raised.

— In other plants, a systematic approach and utilization of diagnostic measurement equipment before planned repairs and after completion of work are undertaken. These contribute towards the improvement of the maintenance performed, and therefore the technical condition of the equipment. This approach identifies trends in plant performance over the plant's lifetime, creating teamwork between different disciplines and deeper discussions about the conditions of components as well as of entire systems. Staff that perform related measurements are trained by the companies supplying the measuring devices and have long experience in this field.
— One instance involved the diagnosis of technological systems and components important to safety and reliability of the power plant. The results were regularly assessed against the long term prediction plan. Other components were diagnosed according to the plan before overhaul commenced. In addition, all pumps were tested and assessed after carrying out repairs. This way of working allowed plant staff to be continuously informed about the conditions of plant equipment and to take timely actions if adverse conditions were observed.
— Another plant implemented a periodic inspection programme which consisted of a systematic and periodic set of inspections of the plant carried out by company managers. For the purposes of the programme, the plant was divided into 12 areas, and 24 inspectors were appointed. Each area was reviewed once a month by two different inspectors. A checklist was followed and deficiencies were reported to a coordinator who, assisted by a deficiency correcting team, determined a solution or referred the matter to other levels in the organization. A follow-up of both open and closed deviations was established on a quarterly basis. In just a few months, a significant improvement in plant housekeeping was observed and the system of posters, warning signals and notices was renewed and standardized. Lighting was upgraded, as was access to many zones. Staff are now aware of these improvements and have achieved and maintained better working conditions. As work is being performed under improved conditions, dose levels are gradually decreasing. The staff feel more comfortable in their work activities and in fulfilling all work related requirements.

5.1.2. Examples of weaknesses in the management of plant ageing

Some weaknesses in the management of plant ageing are:

- Unclear support for, or even lack of understanding of the need for, ageing management from senior management;
- Lack of a long term overview in planning;
- Lack of condition monitoring of equipment important to safety and ageing;
- Lack of a plant ageing programme;
- Lack of consideration of the impact of current degradation on the long term ageing of plant equipment;
- Lack of specific degradation monitoring programmes, such as for erosion.

5.2. USE OF NEW TECHNOLOGIES

New technologies are becoming available in the power and nuclear power industries which can be used to improve the maintenance of plants. Maintenance organizations have an important role to play when additional or more complex methods are to be developed through research or by other organizations.

Maintenance organizations need to follow the development of new technologies and continuously evaluate those that can strengthen maintenance activities and bring about better results in safety, efficiency and transparency. It is important that nuclear maintenance professionals seek contact with other industries with similar challenges and that they promote further development in the areas of maintenance and safety that are of mutual concern. All users of new technologies need appropriate additional education and training. New technologies may include the three areas below.

Risk based maintenance strategies

Based on today's methods and results of probabilistic safety assessments (PSAs), it is acceptable and considered safe to measure and adjust maintenance strategies according to the frequencies involved and levels of risk (risk informed strategies). The risk informed approach gives better transparency and background for maintenance priorities and for the cost effectiveness of maintenance efforts (personnel, money, dose, waste). The IAEA has discussed this approach in greater depth in Refs [8, 9].

Knowledge of plant risk situation

Based on plant specific PSAs, it is now possible to run plant specific risk monitoring programmes. The programmes are easy to develop and are user friendly for the planning staff and for those responsible for day to day work (operations shift personnel, maintenance planners and supervisors). On-line risk monitoring supports the plant staff in the evaluation of safer maintenance practices in the day to day work. Job priorities and parallel work are more easily understood from the safety point of view. On-line risk monitoring makes the plant's overall safety condition better understandable to all involved personnel.

Use of advanced data handling, such as use of operations and test data to support the maintenance process

Normal plant operation and on-line testing produce a large quantity of system condition data, which can be used for detailed analysis of the performance of individual components. Traditionally most of these tests are done with specific accept/reject criteria that have to be met. Follow-up of trends or detailed analysis of the system response are done only in special cases.

It is now technically possible to read and store test data with adequate accuracy and traceability, and to use these data for more in-depth evaluation of performance degradation. The challenge has changed from 'not enough data available' to 'which of the many data now available shall be explored in more detail?'. The benefits of this approach will be that maintenance needs can be identified, planned for and applied before systems or components fail to meet specified performance.

5.2.1. Examples of good practices in the use of new technologies

(1) Utilization of diagnostic measurements in maintenance.

  (a) Inclusion of diagnostic measurements and evaluations in the normal maintenance process results in a better understanding of degradation histories. Diagnostic data are taken prior to and after planned maintenance. This enhances the understanding of the behaviour of components. It builds up knowledge about specific kinds of degradation and builds confidence in a condition based maintenance strategy. The maintenance planning group will learn to use diagnostic data for better timing of maintenance activities.

(b) Repetition of diagnostic measurements after completion of maintenance indicates whether maintenance has been done with the desired level of success and whether the requested technical condition of the component has been attained. At the same time it sets the reference for observation of equipment behaviour until the next maintenance cycle is due to be triggered.

(2) Computerized information and nuclear safety maintenance indicators. To improve nuclear safety in the maintenance field, it is necessary to determine whether there are any weaknesses, and the solutions that have been devised. To identify weaknesses, a significant number of maintenance indicators have been established, such as:

(a) An analysis of the link between the number of significant events and the seasonal period, including the day of the week;
(b) The number of work requests which are still pending;
(c) The average time needed to treat deficiencies;
(d) Inclusion of risk analysis in the maintenance process.

Including risk analysis steps in the planning phase of the maintenance of equipment important for safety is considered to be a good practice. A standardized method may be used, addressing all potential hazards (nuclear safety, industrial safety and radiation protection). The method is based on tools that are user friendly and transparent in application (work formulas, simple to use interactive computer sequences). For an overall risk picture at plant level, a PC based risk monitor programme may be used. The information from this planning phase is then used to verify that proper precautions are being identified and implemented.

5.2.2. Examples of weaknesses in the use of new technologies

Weaknesses in the use of new technologies include the following:

— Introduction of new equipment without the necessary skills or training for the workers;
— Introduction of new materials without consideration of the effects on older materials;
— Introduction of new materials and equipment without verification of plant design specifications and insight into plant safety needs.

6. BUSINESS ENVIRONMENT

6.1. COST EFFECTIVE STRATEGIES

A principle to bear in mind in the nuclear industry is that conceiving of safety only in terms of cost is unacceptable. Cost effective thinking considers safety in a responsible manner at all times.

The issue of cost effectiveness is a challenge to safety culture in maintenance organizations, which continuously have to strive to achieve the right balance between the cost of maintenance activities and plant safety. It is important that management ensures that plant staff are not being flooded with cost effective issues and that they provide 'escape routes' as necessary.

Cost effective strategies include avoiding excessive maintenance of the plant without compromising plant safety. The identification of the bottom line safety issues that cannot be compromised and of the safety issues that can be re-evaluated (engineering evaluations, PSA based evaluations, etc.) are helpful in this connection. Also, it might be necessary to provide maintenance with support to review maintenance programmes based on the risk informed approach (e.g. simplified reliability centred maintenance or the maintenance rule approach).

The optimization of staffing levels is also included in cost effective strategies. For this purpose, previous identification of the appropriate personnel resources and organizational practices is needed (process oriented organization, flexibility of staff, using individuals with multiple skills, etc.). Effective use of personnel and support with effective logistics are also necessary.

Cost–benefit analyses may include consideration of dose and waste generation issues. This can be implemented by setting up a dose and waste management budget. The budget data will be compared with actual performance and analysed and then appropriate actions have to be taken.

6.1.1. Examples of good practices in the use of cost effective strategies

The challenge today lies in economic targets that are just as important as technical and safety targets. At first glance, economic behaviour appears to be in conflict with safety considerations. Overly cost based strategies tend to reduce or eliminate all expenses that do not support production.

Maintenance in nuclear power plants involves a considerable number of inspection activities. Some of these inspections are obviously in support of safe and reliable operation of the plant, for example, inspections of such essential components as turbogenerator groups, the condenser, the cooling tower or reactor controls and instrumentation.

However, maintenance departments also have to perform inspections that are dictated by rules and regulations which were written and are applied to support nuclear safety. It has become a widespread practice to perform these inspections to the letter of the rules and regulations, and to leave it to some other body, presumably the safety authorities, to find out whether simple compliance with the rules is sufficient for nuclear safety.

The rules for in-service inspection have been developed over the past 20 years. Whenever a new or possible mechanism of degradation was judged to have a bearing on safety, the rules were expanded with new requirements and new criteria. On the other hand, few or no efforts have been made to reduce or even cancel inspections that support safety to a marginal extent or not at all.

The thinking and rationale behind this policy is that every effort has to be made to improve safety, without questioning the effort and associated risks (like dose burden to personnel or metallurgical damage to a well protected surface) and the resulting gain in safety.

In the meantime, progress has been made in some areas. For instance:

— It is no longer simple deterministic thinking that governs safety evaluations. The use of probabilistic approaches has become a commonly accepted practice. Probabilistic ranking is accepted for ranking deterministic evaluation. Probabilistic models also permit testing of the sensitivity of a specific safety aspect when compared with overall plant safety.
— Ageing mechanisms are much better understood now than they were at the time the rules for inspection were written. It is a good practice today to acquire a very specific picture of ageing and degradation for every individual plant.
— Commonly known degradation processes are evaluated against the design, materials, fabrication history and operations history of a plant. The results will indicate for one specific plant whether or not there are structures or components that are or might be subject to a well identified degradation process. On the other hand, several areas can be identified where no degradation or no significant degradation is to be expected.

Based on the degradation mechanisms known, it is now possible to evaluate the effects of such degradations (failure mode and effect analysis). These effects are then modelled to derive the probabilistic safety ‘picture’ of the plant. The results of modelling show a ranking of the safety impact of degradation at specific locations in the plant. It then becomes possible to highlight high priority safety items and separate them from other issues with lesser or no significant importance.

Armed with knowledge of the safety importance of a specific degradation area, an inspection programme can be identified which gives clear answers to a set of clear questions. This approach results in a set of in-service inspections that are based on:

— A degradation model that is unique to the plant and carefully worked out;
— A traceable evaluation of the effects of ageing and degradation;
— A traceable and commonly accepted ranking of the effects of degradation;
— A specifically worked out, target oriented, in-service inspection programme.

Such an approach also means that standard inspections, as prescribed today in rules and regulations, are reduced or eliminated completely if they have a negligible impact on overall safety. Furthermore, it means that inspections are carried out to answer questions that arise from a specific concern, and not just from a general feeling of uncertainty or scientific curiosity.

This approach makes it possible to justify expenses that are needed for a better response to a real and well identified safety concern.

6.1.2. Examples of weaknesses in the use of cost effective strategies

Possible weaknesses in using cost effective strategies include:

— Excessive reduction of preventive maintenance to save on costs;
— Lack of investment to modernize and sustain the plant equipment;
— Failure to maintain adequate safety considerations while using a cost effective strategy;

6.2. REGULATORY STRATEGIES

Regulators will come under greater pressure as the nuclear debate becomes a major political issue in many countries. Utilities may prefer to extend their plant licences rather than build new plants. Consequently, regulators will have more work and will tend to watch developments more closely, especially since public opinion may be opposed to further nuclear development. At the same time, in order to move away from the prescriptive approach, regulators and plant operators need to adopt new processes to deal with each other and to maintain confidence. The industry is dependent on the quality of this relationship.

A regulator who is given the possibility of verifying whether plant operation and maintenance are carried out with a safe and open attitude will be more inclined to accept the solutions proposed by the industry. Basic rules set by the regulator need to allow room for the development of new strategies that improve maintenance. The industry has to make continuous efforts in improving and adjusting maintenance strategies, methods and results to meet the needs for safe and economical operation, and to respect the expectations of the general public. It is important that this process be clearly structured and evaluated, both within the organization and with the regulator. Rulemaking by the competent authorities will then rely on a process that promotes a strong safety culture. This includes transparency in resolving issues that conflict with safety, such as economic or managerial aspects. On the other hand, excessive pressure by the regulator could lead to the loss of important data, to a poor reporting culture and to a poor safety culture.

6.2.1. Examples of good practices in the use of regulatory strategies

In one country, the regulator requires that the operator define its own arrangements for maintenance work and then monitors the operator against these arrangements. It is up to the operator to define and, if necessary, justify those arrangements to the regulator.

In another country, the regulator has developed a process and guidance resource document (guidebook) to assess maintenance programme improvements. The benefits of such a systematic assessment process in managing maintenance for improvement are that it provides:

- A basis to determine how well, and where, the maintenance programme is being improved;
- A basis to make decisions on where attention and resources should be focused;
- A basis of common understanding of the importance of effective maintenance programmes and the value of continuously improving the programme.

6.2.2. Examples of weaknesses in the use of regulatory strategies

Some weaknesses in the use of regulatory strategies include:

- Overly detailed and prescriptive regulations that may hinder innovation, and also lead to improvements that could exceed legal requirements, as well as reducing the sense of ownership and accountability for safety;
- Failure to recognize developments in the broader environment of the plant;
- Failure of the regulator to react positively to a no-blame culture;
- Lack of confidence between regulator and plant;
- Tendency of the station management to respond solely to regulatory findings rather than to the actual root cause.

6.3. CHANGE IN OWNERSHIP

A change in the ownership of a company can result in a change in the company culture, creating uncertainty for the workforce and for the company's contractors. In the maintenance area, it can lead to a change in the business environment, with increased pressure to reduce costs, to change work practices and sometimes to change the permanent contractors of the plant.

Efforts are needed to ensure that, at a minimum, the essential characteristics of a strong safety culture are included in the new company's approach to maintenance. Challenges brought about by the change also include the need for the workforce to have an understanding of the new owner's view of safety culture. A change of ownership can sometimes be an opportunity to refresh a safety culture and bring in new approaches and ideas to an otherwise insular plant. The new owner's expectations need to be clearly communicated and a mutual understanding of the new culture built up in the new organization. There needs to be a clear communication of expectations and commitments to safety.

The transition phase to the new environment occurs in such a way that there is no weakening of the safety culture. A process approach can be adopted in managing the transition phase with, where possible, a clear end point defined. The potential effects of the merger on personnel and maintenance processes and activities can be analysed, but a plan needs to be developed for the transition phase with special emphasis on safety aspects, including staffing, documentation, processes and communications. Where it is intended that staff take on new roles, consideration needs to be given to the timely training of personnel for these new roles. It may be appropriate to involve representatives of the workforce in discussions so that a greater acceptance of new approaches is gained and communicated (see Section 4.5 on trade unions).

6.3.1. Examples of good practices associated with a change in ownership

The regulator in one country has insisted that before any organizational change is implemented, the organization has an obligation to produce a ‘change management’ document identifying what changes are to be carried out in a plant and how they are to be managed. This includes the identification of relevant indicators that are to be selected so that they are sensitive to any adverse effects of the change on safety. These indicators are monitored on a regular basis in the plant and also by the regulator.

6.3.2. Examples of weaknesses associated with a change in ownership

Weaknesses in this area include:

- Failure to communicate changes in policy to the workforce;
- Distractions to the workforce caused by the change;
- Failure to monitor the effect these changes have on plant operations;
- The companies merging have different time horizons;
- Merger of the companies takes too long and the ‘prior organization’ still functions, causing a dual focus.

6.4. POLITICAL DECISIONS

External factors can have a significant effect on maintenance. Political decisions at the local and national level can lead to uncertainty and demotivation of personnel. There have been examples of political decisions (and indecision) leading to the untimely shutdown of plants or to the lack of necessary investment in these plants.

In particular, political decisions (and indecision) can be demotivating for individuals; these can lead to delays in decisions to invest in new equipment, processes or personnel and, in the longer term, to a deterioration in the plant condition and in its safety culture. Uncertainty concerning the future of nuclear power can lead to a lack of interest amongst the younger generation, leading to fewer individuals being willing to work in the industry, which in turn leads to an ageing workforce. It can also lead to a loss of external academic and industrial expertise whenever it is perceived that the industry may no longer be able to support the work.

Experienced and highly motivated personnel might leave the field of plant maintenance altogether and take with them the plant history and plant knowledge, which may not have been adequately captured. The attitude of individuals towards safety might change from being positive and concerned about safety to indifference: this might lead to a lack of plant care and safety. There are examples of plants where uncertainty about the future led to a lack of investment and a decrease in the maintenance work to such an extent that the safety culture was degraded, thus necessitating the involvement of the regulatory body and action on their part.

A company needs to consider having an overall process in place for handling the effects of political decisions — drawing the appropriate people together to consider the effects and then producing/modifying plans. Similarly, structured plans are desirable in advance of anticipated decisions; these plans are communicated to the workforce and other interested parties to reduce the effects of any uncertainty caused by political decisions. There needs to be an awareness of how to handle personnel concerns, sharing information and responding to concerns. The change process considers the effects on plant maintenance strategies. Dealing with and communicating changes in personnel can be accomplished in a structured approach.

6.4.1. Examples of good practices associated with external political decisions

Some utilities have introduced long term employment contracts (guaranteed employment for a period of time) to personnel and extended commitments to contractors to deal with individual problems. Furthermore, a clear strategy of 'business as usual' was introduced at one plant just at the time when the uncertainty about premature closure of the plant was being discussed. All investment plans were followed and planned maintenance was performed in accordance with short, medium and long term plans.

6.4.2. Examples of weaknesses associated with external political decisions

Weaknesses associated with external political decisions include:

— Lack of contingency planning that addresses the political environment;
— Lack of government long term strategies and planning;
— Lack of management awareness of the external political environment.

7. ASSESSMENT OF SAFETY CULTURE IN MAINTENANCE AND MEASURES FOR IMPROVEMENT

7.1. ASSESSMENT OF SAFETY CULTURE

Continuous learning is one of the characteristics of a strong safety culture in an organization. Continuous learning stems from assessment by the organization and different parts of the organization. It is also the result of feedback of experience between individuals and groups. Assessment can take different forms and be carried out at different levels of the organization. An important feature in this regard is that activities are assessed and, where deviations from expectations are found, are challenged and discussed, fed back to the relevant people and, where appropriate, remedied by corrective actions [8–10].

Because safety culture itself is a summary of attitudes, shared values, beliefs and behaviour, the identification of safety culture shortcomings is a multifaceted process [2, 5]. Broad agreement on the main characteristics of safety culture has gradually emerged in recent years based on research findings, lessons learned regarding the root causes of organizational failures in safety management and safety culture, and from the international collaboration of safety experts under the auspices of the IAEA [5]. In this process, five main safety culture characteristics with corresponding attributes have been identified as being related to safety performance.[1] These characteristics and their attributes can be used when performing either self-assessments and/or independent assessments by safety culture experts and peers. Table 1 lists these characteristics and their corresponding attributes.

As safety culture is a matter concerning the entire organization, an assessment using the five characteristics should start with a review of the organization's safety culture. Here, the commitment and continuous support of the senior management team is of paramount importance. Following this review, and as necessary, a focused analysis of attributes can concentrate on the maintenance area.

[1] These five safety culture dimensions comprise the basis for the review by SCART (Safety Culture Assessment Review Team), a service offered by the IAEA.

TABLE 1. SAFETY CULTURE CHARACTERISTICS AND THEIR ATTRIBUTES

Safety culture characteristic	*Safety is a clearly recognized value*
Corresponding safety culture attributes	— High priority is given to safety: Shown in documentation, communications and decision making. — Safety is a primary consideration in the allocation of resources. — The strategic business importance of safety is reflected in the business plan. — Staff members are convinced that safety and production go hand in hand. — A proactive and long term approach to safety issues is shown in decision making. — Safety conscious behaviour is both formally and informally socially accepted and supported.
Safety culture characteristic	*Leadership for safety is clear*
Corresponding safety culture attributes	— Senior management is clearly committed to safety. — Commitment to safety is evident at all management levels. — Visible leadership showing involvement of management in safety related activities. — Leadership skills are systematically developed. — Management ensures that there is sufficient and competent staff. — Management seeks the active involvement of staff in improving safety. — Safety implications are considered in the change management processes. — Management shows a continuous effort to strive for openness and good communication throughout the organization. — Management has the ability to resolve conflicts as necessary. — Relationship between management and staff is built on trust.

TABLE 1. SAFETY CULTURE CHARACTERISTICS AND THEIR ATTRIBUTES (cont.)

Safety culture characteristic	*Accountability for safety is clear*
Corresponding safety culture attributes	— An appropriate relationship with the regulatory body exists, which ensures that the accountability for safety remains with the licensee. — Roles and responsibilities are clearly defined and understood. — There is a high level of compliance with regulations and procedures. — Management delegates responsibility with appropriate authority to facilitate accountabilities. — Ownership for safety is evident at all organizational levels and by all individuals.
Safety culture characteristic	*Safety is learning driven*
Corresponding safety culture attributes	— A questioning attitude prevails at all organizational levels. — An open reporting of deviations and errors is encouraged. — Internal and external assessments, including self-assessments, are used. — Organizational and operating experience (both internal and external to the facility) is used. — Learning is enabled through the ability to recognize and diagnose deviations, formulate and implement solutions and monitor the effects of corrective actions. — Safety performance indicators are tracked, trended, evaluated and acted upon. — There is a systematic development of staff competencies.

TABLE 1. SAFETY CULTURE CHARACTERISTICS AND THEIR ATTRIBUTES (cont.)

Safety culture characteristic	*Safety is integrated into all activities*
Corresponding safety culture attributes	— Trust permeates the organization. — Consideration for all types of safety, including industrial and environmental safety and security, is evident. — Quality of the documentation and procedures is good. — Quality of processes, from planning to implementation and review, is good — Staff members have the necessary knowledge and understanding of the work processes. — Factors affecting work motivation and job satisfaction are considered. — Good working conditions exist with regard to time pressures, work load and stress. — Cross-functional and interdisciplinary cooperation and teamwork are present. — Housekeeping and material conditions reflect commitment to excellence.

A culture manifests itself at different levels, ranging from more tangible and visible manifestations to intangible and tacit basic beliefs and assumptions. A three level model, consisting of ‘artefacts’, ‘espoused values’ and ‘basic assumptions’, has been proposed when studying organizational culture [10] and this can be applied to safety culture as well. The difficulty in assessing a culture lies in the ability to capture the more intangible aspects. At the same time it should be recognized that these are at the essence of a culture and are what govern how people will act in various situations. Some of the attributes of safety culture are at the more visible level, whereas others are associated more with basic beliefs and assumptions. When assessing safety culture, therefore, no one method or tool will be able to capture all aspects and levels of the culture in an adequate way. It is thus recommended that a variety of methods and assessment tools be used.

The assessment can be conducted, and information collected, using the following tools:

— Questionnaires;
— Interviews;
— Focus groups;
— Observations;
— Documentation reviews.

7.2. MEASURES FOR IMPROVEMENT OF SAFETY CULTURE

The early detection of problems hampering safety culture will enable immediate diagnosis and initiation of effective remedial steps to rectify the situation. There is often a delay between the development of weaknesses in safety culture and the occurrence of an event involving a significant safety consequence. By being alert to the early warning signs, corrective action can be taken in sufficient time to avoid adverse safety consequences. These early warning signs have been further elaborated in Ref. [5] and are important for maintenance as well as for the entire organization.

The following section identifies examples of the use of self-assessment at different levels relevant to safety culture in maintenance, as well as measures to further enhance safety culture.

7.2.1. Examples of good practices associated with self-assessment and measures for improvement

Practical thinking tool — troubleshooting

By using the assessment tools described earlier, maintenance managers can assess whether their organization has safety culture shortcomings related to: maintenance management; human resources management; plant condition assessment; and business environment. These domains were chosen for practical reasons. The business environment today may have a special impact on safety culture in maintenance. In the assessment, signs of weaknesses (symptoms) are first identified. Second, these symptoms are examined for their relevance to safety culture. Third, actions which will help to resolve the particular shortcoming are sought. In Table 2, the application of this method is illustrated through examples taken from this report. Similar approaches may be used to cover specific plant situations.

TABLE 2. DEVELOPMENT OF SAFETY CULTURE IN MAINTENANCE

	Symptoms	Cause relevant to safety culture (examples)	Possible actions
Maintenance management	Unexpected events.	Poor communication such as: risks not understood by performer, or risk analysis results not communicated.	Risks should be systematic and presented at pre-job briefings.
	Lack of awareness of work not performed according to plan.	Lack of rigour and a prudent approach to work control.	Educate staff on the necessity of structured work. Use of an information system.
	Poor reporting of deviations.	Lack of questioning attitude.	Encourage staff to report. Improve feedback system.
Human resources management	Not enough recognition given to proactive personnel (and too much given to 'firefighters').	Short term thinking. Lack of a long term vision.	Promote systematic approach for long term planning.
	Cascading of work to subcontractors.	Lack of safety oversight and clear contractor–management approach.	Specify the contractual terms. Check that the subcontractor has demonstrated the requisite skills for the task. Quality and safety training are prerequisites.
	Conflicts with operations about work prioritization.	Lack of a clear understanding of the responsibilities between maintenance and operation.	Promote team building between maintenance and operations for a common understanding of the company's goal.

TABLE 2. DEVELOPMENT OF SAFETY CULTURE IN MAINTENANCE (cont.)

	Symptoms	Cause relevant to safety culture (examples)	Possible actions
Plant condition assessment	Many unresolved problems and long lag time to the solution.	Acceptance of a lower plant safety level. Demotivated ‘problem finders’. Deficient decision making and communication. Lack of sufficient resources.	Improve communication and control for follow-up of problems. Establish common priorities. Regular review of pending problems. Review the need for resources.
	Repeated failures (maintenance induced).	Poor root cause analysis and feedback system. Repeated failure accepted as normal.	Improve management control. Establish indicator for repeated failures.
	Poor foreign material exclusion (FME) practices.	Lack of awareness of consequences of foreign material effects.	Self control, independent verification and management supervision.
Business environment	Too limited perspective of management (only concerned with ‘surviving against the competition’).	Economic goals undermining safety priority (such as accepting postponement of modifications and maintenance).	Cost effective decisions are based on risk assessments and are in line with safety priorities.
	Errors and quality problems due to business environment changes.	Staff losing focus on their jobs.	Create confidence in the future. Staff should be informed and be involved in changes.
	Plant reacts only to regulatory findings.	Lack of ‘ownership’ for safety responsibility. Lack of initiatives in maintenance problem solving.	Promote proactive atmosphere to keep safety initiatives from the plant.

Behavioural safety programme

Behavioural safety programmes can be used for individual self-assessment and as an opportunity to coach individuals. For example, in several organizations such an approach is claimed to have led to a significant reduction in accidents.

In one organization, the programme has been rolled out to power stations. The programme involves communicating the process to team members across the plant (including contractors), telling them that they are likely to be observed by their peers and asking for volunteers within the teams. The observers are expected to carry out one to two observations per month lasting about 20 minutes each and making use of a standard check sheet. The sheet has been developed based on common events found to occur within the operating company; for each item identified on the sheet and observed, the observer is expected to identify whether the person observed was safe or unsafe. The observer is expected to give feedback to the observed at the end of the observation, and to try and identify the reason for any unsafe behaviour observed. All reports are returned to a central coordinator who collates them and identifies trends for further action. This process has been championed by the production manager. Initial reactions to it are positive because of high profile actions taken in response to the feedback received and people stopping unsafe practices performed by their colleagues.

Development and promotion of the STARK concept

In one plant, the STAR ('stop, think, act and review') concept has been taken a step further — to STARK, with the 'K' standing for c(k)ommunication. The word STARK in German and Swedish means strong, but in this context it means (using each letter): 'stop, think, act, reflect and communicate'. There were several reasons for developing this approach — some significant licence events, related to maintenance and operations, were caused by insufficient communication. STARK was also a way to focus on and strengthen communication in the organization.

A special project was established to handle its promotion and implementation — providing information to all managers; special tasks for the managers to involve their staff in carrying out analyses of how they could use STARK in their daily work; and substantive information, using various media, to personnel, e.g. meetings, posters and information newsletters with examples of how STARK could be used.

Indications that STARK was being adopted could be seen after some time in reports and procedures, and as a recommended check before doing daily work, such as maintenance work and operator rounds. In several reports of near misses, it was clear that STARK had contributed to avoiding an event.

Self-diagnosis and quality project in a maintenance department

At one plant, before embarking on a full, formal self-assessment process within the company (and prior to the potential involvement of the QA bureaucracy), it was considered useful to involve the staff in a self-diagnosis approach. This method had the advantage of involving maintenance personnel. The main parts of the project are outlined below:

- An auditor was involved in the maintenance branch for three months discussing with all personnel (from the worker to the section head) what weaknesses were observed by them. These were mainly: communication; organization; nuclear safety; training; documentation and equipment; or tools used by the staff;
- The strengths and weaknesses identified from the discussions were validated, prioritized and communicated to everybody in the maintenance department;
- Volunteers were requested from the staff for work groups to address the weaknesses found.

Inclusion of actions by the groups in the branch work plan then made global acceptance of them easier. Groups have been running for some time and most of the recommendations have been addressed. This quality project is now well established and workers are discussing with their management the possibility of setting up a new group to improve nuclear safety in their working activities. All the proposals identified were realistic and focused on real improvement in maintenance activities.

Evaluation of the plant maintenance programme

In several missions carried out by the World Association of Nuclear Operators (WANO), it was found that there was no overall evaluation process for the preventive maintenance programme in some power plants. This programme is usually developed in detail for all equipment for plant safety and reliability. The responsibilities are clearly defined. The progress of the preventive maintenance programme is usually evaluated once a year, but the indicators used do not assess its effectiveness.

Preventive maintenance results and the effectiveness of the preventive maintenance programmes need to be periodically evaluated at an appropriate level of management, and the results used to make programme improvements. This can be done in various ways, e.g. making use of a ‘systems’ approach, where a group of people, including an engineer, a maintenance specialist and an operator, sit down and evaluate the system.

In the following section preventive maintenance effectiveness criteria are proposed as potentially useful measures to be trended and monitored.

8. INDICATORS

8.1. GENERAL

Maintenance indicators have to be rooted in the overall indicators of the plant. The primary intent of developing performance indicators is to monitor systematically the effectiveness of maintenance on a uniform scale. Care should be taken in the identification of indicators, as they will ultimately address valid issues.

Some questions to ask: Are indicators developed with broad worker participation? Who is developing them? How are they developed? What is expected of the indicators? How are they evaluated? With what frequency are they applied? Indicators are dynamic and management should be aware of the need to upgrade the indicator values to allow for station improvements. Also, large groups of people should not be occupied with the generation and graphing of indicators.

Excessive focus on a single indicator can distract the analyst at the expense of other important safety considerations. ‘Ownership’ of the indicator should be clearly defined and the ‘owner’ has to be convinced of the effectiveness of the indicator.

The management of maintenance calls for effective mechanisms to be in place for monitoring the status of the maintenance programmes. Selected maintenance data are monitored and trended. A fundamental reason for data monitoring is to determine the extent to which maintenance goals and objectives are achieved. Data trends are necessary in the assessment process.

8.2. EXAMPLES OF GOOD PRACTICES ASSOCIATED WITH INDICATORS

Some plants have implemented a maintenance rule according to the criteria set out in the US Nuclear Regulatory Commission's 10CFR50.65 [11]. The scope of equipment to be identified and the risk significant systems were defined based on systematic criteria. A large number of performance criteria (such as the number of trips and events — similar to the WANO indicators) were defined at the plant level. Also, performance criteria (such as reliability and availability) were defined for each of the risk significant systems.

A historical review of the status of the systems was carried out and compared with defined performance criteria. Corrective actions were taken where systems exceeded their performance criteria. A method for daily tracking of the availability and reliability of equipment was implemented so that the plant focused its activities on addressing anticipated exceedance of the criteria. As the maintenance rule focuses on maintenance activities in risk significant systems and components, this contributed to the safe operation of the plant.

Other plants have developed their own sets of indicators to be used by senior management in the assessment process. Some of the reasons for developing these indicators are to identify technical/organizational problems, checking progress in meeting general goals, motivating and giving goals for craftsmen's teams and maintenance programme control. Examples of such indicators are preventive maintenance effectiveness, repetitive equipment performance problems, availability of spare parts, refuelling outage effectiveness, rework, work productivity, and supervisory effectiveness. All of these main areas of indicators have subindicators.

Another plant uses the WANO indicators in combination with selected indicators that they see as being important to enhance effective maintenance and a sound safety culture. Some of these indicators are: the number of unplanned outages due to equipment failures; the number of repetitive failures during a specific time frame; the number of preventive maintenance work sessions planned compared with the actual number performed; the number of corrective maintenance work sessions planned compared with the actual number performed; the number of failures in safety systems; and the number of hours of unavailability of safety systems. These indicators set a focus on safety and create awareness among the maintenance staff of the importance of the availability of safety systems. Furthermore, they promote a culture of doing everything right the first time around and self-checking when performing maintenance tasks.

Since the late 1980s, the IAEA has been actively sponsoring work in the area of safety performance indicators. The early activities focused mainly on exchanging ideas and good practices, but since December 1995, efforts have been directed at the elaboration of a framework for the establishment of an operational safety performance indicator programme. The development of this framework began with the consideration of the concept of operational safety performance in nuclear power plants. To ensure a reasonably complete set of operational safety indicators, a decision was made to work from the top to the bottom pursuant to a structure in which the top level would be operational safety performance and the next level would be operational safety attributes, from which a set of operational safety performance indicators could be developed.

In defining the key attributes, it was necessary to determine the fundamental elements associated with plants that operate safely. Three aspects were addressed — nuclear power plant normal operation, nuclear power plant emergency operation, and the attitude of nuclear power plant personnel towards safety. From these areas, experts isolated three key attributes that are associated with plants that operate safely:

— Plants operate smoothly;
— Plants operate with low risk;
— Plants operate with a positive safety attitude.

For each operational safety attribute, overall indicators, envisioned as providing an evaluation of relevant aspects of safety performance, were established. Associated with each of these indicators is a level of strategic indicators intended to act as a bridge between overall and specific indicators. Finally, each strategic indicator was supported by a set of specific indicators, which represent quantifiable measures of performance. Most of the specific indicators chosen as examples are already in use in the industry. The outcome of this work is discussed in Ref. [12].

9. CONCLUSION

Until quite recently, work in the area of safety culture had followed mainly from the experience gained and research carried out during the operation of nuclear power plants. It is theoretically and practically important to define additional features of safety culture that apply in particular to maintenance work. To do this it is necessary to highlight the features that distinguish nuclear power plant maintenance not only from the operation of these plants, but also from conventional maintenance work. Within the framework of this report, this analysis was carried out mainly through the collection, organization and presentation of experience based material from the plants. As a result, a rich description of safety culture issues in the maintenance domain has been achieved.

REFERENCES

[1] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Safety Culture, Safety Series No. 75-INSAG-4, IAEA, Vienna (1991).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Developing Safety Culture in Nuclear Activities: Practical Suggestions to Assist Progress, Safety Reports Series No. 11, IAEA, Vienna (1998).

[3] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Management of Operational Safety in Nuclear Power Plants, INSAG-13, IAEA, Vienna (1999).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Self-Assessment of Safety Culture in Nuclear Installations: Highlights and Good Practices, IAEA-TECDOC-1321, IAEA, Vienna (2002).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Culture in Nuclear Installations: Guidance for Use in the Enhancement of Safety Culture, IAEA-TECDOC-1329, IAEA, Vienna (2002).

[6] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Key Practical Issues in Strengthening Safety Culture, INSAG-15, IAEA, Vienna (2002).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Implementation and Review of a Nuclear Power Plant Ageing Management Programme, Safety Reports Series No. 15, IAEA, Vienna (1999).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Advances in Safety Related Maintenance, IAEA-TECDOC-1138, IAEA, Vienna (2000).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Applications of Probabilistic Safety Assessment for Nuclear Power Plants, IAEA-TECDOC-1200, IAEA, Vienna (2001).

[10] SCHEIN, E.H., Organizational Culture and Leadership, 2nd edn, Jossey-Bass Publishers, San Francisco (1992).

[11] NUCLEAR REGULATORY COMMISSION, Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants, 10CFR50.65, NRC, Washington, DC (1998).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Safety Performance Indicators for Nuclear Power Plants, IAEA-TECDOC-1141, IAEA, Vienna (2000).

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This report reviews how challenges to the maintenance of nuclear power plants can affect safety culture. It also highlights indications of a weakening safety culture. The challenges described are in areas such as maintenance management; human resources management; plant condition assessment; and the business environment. The steps that some Member States have taken to address aspects of safety culture are described and highlighted as good practices, with a view to disseminating and exchanging experiences and lessons learned.

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