THAI - CANADIAN
NUCLEAR HUMAN RESOURCES DEVELOPMENT
TRAINING PROGRAM

# EFFECTIVE TECHNIQUES
# IN
# MAINTENANCE
# OF
# NUCLEAR POWER PLANTS

## LECTURE NOTES FOR THE COURSE ON

# PEER EVALUATION TECHNIQUES

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# OSART EXPECTATIONS AND RESULTS IN MAINTENANCE

## 1.0 OBJECTIVE OF PRESENTATION

The effective techniques for managing maintenance are discussed. They include organization and administration, staffing and training, facilities tools and equipment and the use of resources and procedures. Self assessment techniques are enumerated and the importance of spare part management, post maintenance testing and maintenance history are included. In service inspection, root cause analysis and configuration control are discussed from the maintenance point of view. Preventive and breakdown maintenance are reviewed and effective work planning emphasized. Conduct of maintenance and material condition are included. A summary of OSART findings in maintenance conclude this lecture.

## 2.0 GENERAL

Maintenance can be considered to be an aggregate of those actions which prevent the degradation or failure of structures, systems, or components, as well as those actions which promptly restore these items to their intended functions following breakdown.

Proper maintenance of plant equipment is essential for the safe, reliable and efficient performance of a nuclear power plant. High quality maintenance should be encouraged by senior management by setting high standards, such as success criteria and performance indicators. Self assessment should be carried out, to determine if standards are as expected.

Effective maintenance can only occur with the support of operations in identifying defects promptly and accurately, and in providing the appropriate conditions for maintenance. Similarly, radiological control plays an important role by minimizing hazards. Chemical control impacts on maintenance by helping to optimize component life in aggressive environments. Engineering support of maintenance plays an essential role by ensuring that maintenance methods, tools and equipment and spare parts are optimized.

The selection and training of maintenance personnel should be well established so that a high quality of maintenance standards and activities can be achieved. Sufficient resources should be provided and the planning and progress reporting should be such that workload backlog is kept to a minimum.

Maintenance facilities and equipment should be sufficient to perform maintenance activities effectively. All maintenance activities from the planning stage to execution should be carried out in such a manner that the radiation exposure of both site personnel and general public is kept as low as reasonably achievable (ALARA).

## 3.0 THE ELEMENTS OF AN EFFECTIVE MAINTENANCE PROGRAM

### 3.1 Organization and administration

The organization and administration of the maintenance department should ensure the efficient and effective implementation and control of maintenance activities in order to ensure a high level of maintenance performance. The organization and staffing of the maintenance department, as well as the responsibilities of the different units and staff in maintenance, should be described in writing and be understood by all affected personnel. Good coordination among different maintenance groups (mechanical, electrical, instrument and control, and civil), and with operations and supporting groups, should be established.

Goals and objectives of the maintenance department should be defined within the plant policies, goals and objectives. The maintenance department policies, goals and objectives, and performance indicators should be comprehensive and consistent with station requirements. The goals should have numerical targets which are designed to improve performance where needed and are periodically reviewed with corrective action being taken as necessary. It is often the case that goals and objective programmes break down at this level in the organization.

A process should be in place and effectively used to keep maintenance policies and programmes consistent with current industry best practices.

Performance indicators should be established and reported in periodic reports. The performance indicators should focus on areas needing improvement. This should also apply to goals and objectives. The amount of rework might be one of the monitored items, as an example. Effective and high quality maintenance programmes should be implemented and maintained.

Managerial and supervisory involvement in maintenance activities must ensure that maintenance practices are effective in maintaining safe and reliable station operation.

Managers should explain their commitment to safety culture to their staff, and remind them that haste and shortcuts are inappropriate and adherence to written procedures is essential. Personnel should be encouraged to suggest improvements to safety, reliability, quality and productivity. The concepts of defense in depth and configuration control should be well understood and reflected in the safety culture of the maintenance organization.This would be indicated by items such as qualified and competent staff, use of self-checking and independent verification techniques, procedural adherence, doing the job right the first time, the use of appropriate maintenance skills, minimization of maintenance backlog on important plant equipment and use of appropriate materials and spare parts which ensure consistency with the original design concept through an effective quality assurance

Management should regularly review personnel performance and safety attitudes.

Interfaces with supporting on-site and off-site groups should be clearly defined and working well. Good coordination should exist among the various maintenance groups and an effective interface should be established with the operations department, the radiation safety department, technical support and other plant groups. Processes used between the involved groups should be oriented at identifying and resolving problems in an efficient manner.

Contractors involved with maintenance work and/or with plant modifications should be subject to the same criteria as plant staff. This applies to setting goals and objectives, organizational structures, professional competence and qualification of all involved personnel, and measurement of performance and evaluation and correction of findings. Management should respond effectively to safety infringements and violations of Technical Specifications or procedures.

### 3.2 Staffing and training

The organization, qualifications and number of maintenance personnel should be sufficient for the maintenance performed during the operation of the plant, the outage work to be performed by the plant's staff, and supervision of contractor's work during the outage. Staffing requirements must be established by reviewing the intended workload, based on historic needs and the predicted increases or decreases in workload due to new equipment or programs or changes to outage schedules.

Maintenance training and qualification programs must be developed to maintain the knowledge and skills needed to effectively perform maintenance activities. Special training provided to individuals should develop their craft skills and ensure qualification on equipment to which they are assigned to work. There should be a process which ensures that these qualification levels can be easily established and matched to the requirements of specific jobs.

The training programme should develop and maintain general knowledge of the nuclear power plant. The significance of items related to safety, safety risks involved in maintenance work and methods to minimize these risks should be included. This should include the use of mock up training.

The principles of self checking should be included in the training programmes. Independent verification is also an important concept to be used when the consequences of one individual making a mistake could be unacceptable.

Operating experience should be analyzed for maintenance lessons to be learned. These lessons should be subsequently incorporated in the training in a timely manner.

Maintenance management personnel should be actively involved in the design and review of training. This can be achieved by regular meetings between training and maintenance management and involvement in the training. This is an area which is often found to be in need of improvement.

### 3.3 Facilities, tools and equipment

The size and arrangement of maintenance facilities should promote the safe and efficient completion of work in a clean and orderly manner. Facilities should be provided for work on contaminated and non-contaminated equipment.

Contaminated refurbished equipment should be segregated and stored in a manner to prohibit cross contamination and minimize radiation dose.

Proper tools, equipment and consumable supplies should be available to support work, and if tools are contaminated they must be adequately marked and segregated. Special tools, jigs, fixtures, etc. should be identified and stored to permit retrieval when needed. Unserviceable tools and equipment should be controlled to prevent use.

Equipment should be made accessible for maintenance activities (platforms, scaffolding, etc.)

Lifting, rigging, scaffolding and electrical equipment should be identified, periodically inspected, stored appropriately and in good working condition when made available for use.

Adequate decontamination facilities for tools, parts, and equipment should be available and used to minimize radiation doses and exposure to contamination. Also remote controlled tools should be used, as appropriate, to minimize radiation exposures.

Measuring and test equipment should be calibrated and controlled adequately to ensure accuracy and traceability. Test equipment that is out-of-tolerance should be promptly removed from service and clearly labeled. Corrective measures should be taken where unreliable test equipment has been used. This should result in miscalibrated equipment being identified and appropriate corrective measures taken. A recent finding at an OSART mission found that this was not effectively done

Only chemicals and flammable materials which are needed and approved for maintenance activities should be retained and they must be suitably labeled and appropriately stored. Unwanted chemicals and parts should not be allowed to accumulate in maintenance areas.

Loading, lifting and transport equipment should be available for movement of heavy and/or large items. Heavy loads should not be transported over safety related systems and equipment.

### 3.4 Balanced use of resources

A proper balance of preventive and corrective maintenance provides a high degree of confidence that station equipment degradation is identified and corrected, that equipment life is optimized and that the maintenance program is cost effective. Preventive maintenance includes predictive, periodic, and planned maintenance actions taken to maintain a piece of equipment, so that it can meet it's design intent and extend it's useful life. It is performed prior to equipment failure, or to prevent future equipment failure. On some multi-unit plants which have a single resource for 'at power' and shutdown maintenance, it is important to manage maintenance resources to give the best balance between these often conflicting demands on maintenance. The maintenance resource must be evaluated over the course of the whole year and predictive /preventive maintenance must not be cancelled in order to complete outages on time.

### 3.5 Maintenance procedures

A policy governing the use of procedures and the handling of deviations from the procedures should be implemented and communicated to staff. Maintenance procedures and other work-related documents should identify preconditions, provide clear instructions for work to be done and should be used to ensure that maintenance is performed in accordance with the maintenance strategy, policies and programmes. They should be technically accurate, properly validated, verified, authorized and periodically reviewed. There should be an indication of when a procedure must be followed step-by-step or when it should be used for guidance. Action to be taken when a deviation or a conflict occurs should be given and the rules governing contractor use identified. The need for step by step sign off, self checking and independent verification should be identified. Documents that are used in lieu of procedures (such as excerpts from vendor manuals) should receive the same review and approval as procedures.

Detailed work instructions should include, where appropriate, qualifications required for usage, identification of the plant system and components to be worked on and specification of the necessary tools, material and equipment. Sufficient guidance should be given for the task to be performed in a safe, practical and efficient manner, including adequate drawings and illustrations, warnings of potential dangers to plant or personnel and clear specification of precautions to be taken. These should include environmental and seismic events and radiation protection provisions. Hold points should be identified where progress to the next step is dependent upon independent review. Inspection instructions and related acceptance criteria, including post maintenance and post modification testing should be identified.

A process should be in place to record the identification numbers of test equipment, torque wrenches and quality assured spare parts used during the activity

Priority should be given to amending and updating procedures in a timely manner. Temporary changes to procedures should be sufficiently controlled, including appropriate review and approval. These temporary changes should be promptly incorporated into permanent revisions when appropriate, limiting the number of temporary procedures and their lifetime

A mechanism should be implemented which enables users to feed back suggestions for the improvement of procedures.

Maintenance instructions issued to craftsmen should be compiled in accordance with quality assurance requirements and should point out the risk impact of the work on nuclear and personnel safety and identify the countermeasures to be taken and specify post maintenance/modification testing required. The required level of skill and methods of procedure use should be stated.

Human factors and ALARA principles should be considered in the preparation of maintenance instructions.

### 3.6 Self assessment, self checking and independent verification

A programme of self assessment should exist at the maintenance department level. This should be used to determine if maintenance is being carried out to the desired standard. A programme of self checking and independent verification should be incorporated at the working level.

Independent verification is part of the defense in depth philosophy.

It is used when critical operation or maintenance is being carried out. In this case, a mistake by one individual could disturb the plant configuration in a way that will have an unacceptable, immediate consequence to plant safety or reliability.

It is frequently a 'no cost' item, since two individuals will often be assigned to one job.

They have to be trained to independently verify prior to the work starting, and at critical stages during the work, that the following is true:

- they are on the correct unit
- they are on the correct system
- they are on the correct component

- they have the correct isolation
- they are following the correct procedures.

Many plant upsets could be avoided by effective independent verification. The chances of two well trained, competent individuals making the same mistake at the same time are remote, but it has happened.

Self checking is also a useful and effective technique to reduce human error. An example of one of several techniques to encourage self checking is to get all staff to do their work using techniques similar to those used by experienced control room operators. They always STOP, then THINK, then ACT, then REVIEW, because they have learned that one control room error can have immediate undesirable consequences. This is commonly known as the STAR technique.

### 3.7 Spare parts availability and storage

The provision of parts, material and services must support the correction of deficiencies and the timely return to service of equipment.

The proper care of spare parts, materials and equipment must occur from the time they are received at the plant, until they are installed in a system. In order to achieve this objective, the responsibility for procurement, receipt, storage and issue of spare parts and materials must be clearly defined.

Spares must be purchased to the same technical standards and QA requirements as the equivalent installed plant items. Items should only be obtained from suppliers who are approved in accordance with QA requirements. The material management facilities must provide adequate support to the plant resulting in parts and materials being available when needed in the plant.

Materials should be stored and identified in a manner that permits timely retrieval. Proper engineering approval is required for any deviations from design specifications for parts or material.

Storage facilities should be operated in a manner that takes into account special environmental requirements for storing certain components. In particular, preventive maintenance activities should be performed on certain spare equipment (e.g. rotating large electrical motors).

Spare parts with limited life should be stored separately and clearly marked to indicate acceptable periods of use.

Hazardous material should be properly segregated and adequate procedures should be in place to control its receipt and use.

### 3.8 Testing and verification

A verification program should be used to ensure maintenance is carried out correctly. Post maintenance testing should confirm that that the maintenance was performed correctly and the equipment met the design intent.

### 3.9 Maintenance history

Maintenance history should be used to support maintenance activities, upgrade maintenance programmes, optimize equipment performance and improve equipment reliability. Appropriate arrangements should be made for orderly collection and analysis of records and production of reports on maintenance activities. Maintenance history records should be easily retrievable for reference or analysis. The use of computerized maintenance history handling would facilitate this process.

### 3.10 In-service inspections

During the operational life of a nuclear power plant, pressure boundary components of selected critical systems and components, mainly those of the primary reactor coolant system, should be periodically examined and monitored for possible deterioration, in order to judge whether they are acceptable for continued safe operation of the plant or whether remedial measures are necessary to ensure pressure boundary integrity.

Appropriate reviews and analyses should be made and corrective actions taken when inspection results do not meet acceptance criteria. Documentation of ISI results must be accurate, complete, easily retrievable and accessible to other departments.

The frequency and extent of in-service inspection should be routinely reviewed as a result of experience feedback.

### 3.11 Root cause analysis

Systematic analyses should be used to determine the root causes of unplanned occurrences related to plant maintenance both with respect to equipment failure and personnel performance and near miss occurrences.

### 3.12 Radiation protection

A radiation and conventional safety program must be established and enforced. ALARA must be appropriately considered during outage planning and post outage review.

Training of personnel, including off-site manpower, in special techniques and radiological protection requirements must be effective. Maximum use should be made of mock-ups to verify the effectiveness of proposed techniques, to train personnel, and to ensure that radiation doses will be ALARA.

Radiation dose accumulation must be effectively monitored during performance of high-dose work; Planning and coordination of high-dose work should minimize radiation doses. Room for improvement is often found in radiation dose control and industrial safety control during OSARTs.

### 3.13 Configuration control

This subject is covered in another lecture in this series. For completeness it is also mentioned here. Configuration control can be affected by working on the wrong equipment or returning equipment to service without adequate testing, for example.

## 4.0 PREVENTIVE MAINTENANCE

The objective of a preventive maintenance program is to prevent or minimize equipment breakdown and to maintain equipment in a satisfactory condition for normal and/or emergency use.

Initially, a preventive program is designed based on manufacturer's recommendations, then as time progresses and working knowledge of the plant is obtained, the program should be continuously refined to optimize preventive maintenance frequency and content.

Predictive maintenance activities are part of preventive maintenance and should be used to monitor the condition of installed equipment and systems where appropriate. The results of predictive maintenance activities and surveillance tests should be properly trended to permit full effectiveness of the preventive maintenance and lifetime management programmes. Predictive maintenance activities can be carried out while the equipment is in service and are used to supplement and strengthen the preventive maintenance programme and enhance equipment reliability by utilisation of techniques such as vibration, thermography, oil analysis, temperature trends and acoustics. Predictive maintenance techniques are becoming more sophisticated and combinations of techniques are now being used to determine equipment status. Degraded or problematic equipment should receive appropriate focus and acted upon, e.g. a programme to monitor motor operated valves (MOV's) should be included.

Too little, or the wrong kind of preventive maintenance will make itself evident through premature equipment failure and the resultant unpredicted outages.

Too much preventive maintenance is a more insidious problem, but also important, since it increases costs and causes unnecessary equipment downtime. Hence the objective is to optimize the amount of preventive maintenance. A great deal of research has gone into this issue because of it's importance to successful nuclear power plant management. This has resulted in a number of approaches to the problem. Some are pragmatic and some are "high tech" involving many hours of engineering time. At the high tech end of the spectrum is reliability centered maintenance (RCM) involving detailed engineering analysis of each system and component.

The following basic issues need to be decided in order to determine what needs improvement in the preventive maintenance program which currently exists at the plant.

- which are the problem components at the plant?
- what is their maintenance history?
- what has been done to date to improve their performance?
- what is their impact on the reliability of the system they are in?
- what is the impact of the system on safe reliable generation of nuclear power?
- can their performance be enhanced by improved preventive maintenance? (perhaps a design change is the best solution)
- how do the failure rates of the component at this plant compare to the failure rates elsewhere? (is environment or maintainer skills an issue?)
- what are the priorities for resolving the identified issues? (this process can take a considerable length of time. One plant took more than a year to analyze the components on two systems.)

- what kind of a manpower and resource commitment is the plant able to make to this issue?

An overview of the elements of one successful predictive maintenance enhancement process is listed here. It consists of the following components:-

- problem component analysis
- problem component selection and prioritization
- system analysis
- system selection and prioritization
- system and subsystem boundary determination
- determination of system and sub system functions;
- determination of functional failures
- functionally critical equipment selection
- analysis strategy for critical and non critical equipment
- determination of failure modes and effects
- history review
- preventive maintenance task selection and implementation
- logic tree analysis
- preventive maintenance living program, which continuously reviews the effectiveness of preventive maintenance program and revises it.

Clearly this is not a process to be embarked upon lightly!

A further component which also needs attention, is the amount of unnecessary preventive maintenance being done. This can be determined by keeping records of the results of preventive maintenance inspections, and analysing the state of the equipment inspected. If repeated inspections indicate no deterioration, then the preventive maintenance program for that equipment should be re-examined.

## 5.0 BREAKDOWN MAINTENANCE

Some break down maintenance is inevitable. Preventive maintenance should absorb more than 60% of the maintenance man-hours available in a plant with a well balanced preventive maintenance program, but the balance will be breakdown maintenance.

Predictive maintenance techniques such as oil analysis, vibration and temperature can help predict the need for maintenance, but equipment sometimes fails with little warning, resulting in the need for breakdown maintenance.

It is important that the backlog of breakdown maintenance is kept under control, so that the plant does not slowly deteriorate to the point where safety and reliability are affected by the number of components either out of service, or leaking excessively, or not working correctly.

One plant had a target that the backlog should be no greater than the equivalent of one month of work by the maintenance department. Some critical defects would obviously be fixed on the day they occurred, but this would represent the average backlog. Some backlog is inevitable due to the need to plan work and obtain spare parts etc.

## 6.0 WORK CONTROL

The management of work should be recognized as a cross functional process, not unique to any one work group, but integrating the important activities of all work groups. Consequently, to be fully effective, the needs and concerns of operations, maintenance, technical support, radiation protection, procurement/stores, contractors and others should be considered and accommodated whenever appropriate, consistent with the long term operating strategy of the station. Since work control affects many aspects of maintenance, some items are discussed here which also appear in other areas of the guideline.

As the objective of the work management process is the sustained safe reliable and efficient operation of the station, staff at all levels should strive to achieve the short term, long term and outage work plans that are products of the work control process.

A comprehensive work planning and control system that considers defense in depth should be used to ensure that work activities are properly authorized, scheduled and carried out in accordance with appropriate procedures and completed in a timely manner. The work planning system should maintain high availability and reliability of important plant systems.

Effectiveness of the work control process should be monitored via appropriate indicators and corrective action taken when required and should take into account long term planning including factors such as plant ageing, maintenance history and operating experience.

Plant defects should be tracked to completion and records kept of work performed. These records should be accessible for review when necessary.

Good coordination should be established among maintenance work groups, operations, other support groups and external agencies where appropriate. Work scheduling should allocate parts, materials, resources and expertise at the appropriate time for completion of the preventive and corrective programmes The work control system should also ensure the availability of systems and equipment at the end of maintenance activities prior to changing the status of systems.

## 7.0 EFFECTIVE MAINTENANCE PLANNING

There are frequently pressing maintenance problems that require immediate attention. Maintenance management has to guard against developing a crisis mentality, where the maintenance work force is absorbed with the immediate problems. If this occurs, then it has the inevitable result of perpetuating itself, because activities which would prevent future crises are not dealt with effectively.

There must be a balance between the immediate needs and the long term needs, so that items which can be left until tomorrow are not forgotten completely, until they become a crisis themselves. It has been observed that management attention to the immediate problem is less important than management attention to the long term direction of the maintenance program. It is generally true that the immediate problem gets plenty of attention, in any case.

This means that there must be good management tools which measure and take corrective action on items such as:

- breakdown maintenance backlog
- preventive maintenance call up backlog
- plant material condition
- component refurbishing
- tool maintenance
- training completion
- test equipment calibration

This will help ensure that the appropriate balance is kept on a broad range of maintenance activities.

## 8.0 EFFECTIVE WORK PLANNING

It is important when equipment is taken out of service, that all the work which can be done on that equipment is properly planned. This avoids equipment being taken out of service unnecessarily, resulting in reduced equipment availability and increased vulnerability to a plant upset.

Historically, equipment may be taken out of service this week for a mechanical call up, next week for a control call up and two weeks later to complete maintenance which was waiting for spare parts. This is obviously inefficient use of maintainer and operator time. Work planning processes are required to minimize this problem.

### 8.1 Integrated operational planning

Integrated operational planning is a method of dealing with this problem, which has been applied in Canada.

This method applies to maintenance which can be completed with the plant at high power.

It requires that the plant is divided into a series of groups of equipment, which can be easily isolated, such as standby service water pumps or air compressors. These groups are called "functional equipment groups " (fegs)

All the equipment which can be worked on within these groups is then listed.

The planning group, with the assistance of assigned operators and maintainers, prepares packages of all work to be done on each functional equipment group, which includes both breakdown and preventive maintenance. These packages are well researched to ensure all spare parts are available, scaffolding is erected etc.

On a thirteen week rotating schedule, each of these functional equipment groups will be taken out of service and all required maintenance completed. This allows maintenance to be done in a more effective way resulting in significant improvements in efficiency.

## 9.0 OUTAGE PLANNING

Outage management organization and administration should ensure the effective implementation and control of maintenance activities during planned and forced outages.

The tasks and responsibilities of different organizational units and persons should be clearly defined in writing. This is especially important during outage periods, when the organization is temporarily modified.

Most maintenance work is done during the plant outages. Therefore, extensive preparation and detailed planning for planned outages should be accomplished and a tracking system should be used to monitor status and to ensure controlled execution of outage activities.

Tasks and responsibilities and interfaces between maintenance and other groups must be clearly defined. Procedures for managing additional workers must be adequate to ensure good work performance during the outage.

Sufficient resources must be provided to permit timely completion of maintenance and modifications important to safe and reliable operation.

Outage review reports should review the lessons learned and make recommendations for the next outage preparation.

## 10.0 AGEING OR LIFETIME MANAGEMENT

Ageing can be defined as the continuous time dependent degradation of materials due to normal in service conditions, which include normal operation and transient conditions.

The service conditions which contribute to ageing act in two ways:

- chemical and physical processes such as stress, strain, temperature, radiation, humidity and impact of chemically active liquids and gases
- factors which lead to degradation of functional capability such as service wear and corrosion, excessive testing and improper installation or maintenance.

The programme to manage the ageing process should consider such elements as :

- the degradation processes that could adversely affect plant safety
- the plant components that are susceptible to ageing degradation that could affect plant safety
- the adequacy of current methods used for inspection, surveillance, maintenance and testing to detect ageing problems before they affect plant safety;
- the keeping of appropriate records so that the ageing process can be tracked.

## 11.0 CONDUCT OF MAINTENANCE WORK

Maintenance should be conducted in a safe and efficient manner to support plant operation. Personnel should exhibit professionalism and competence. This will result in quality workmanship when performing assigned tasks.

Maintenance personnel should be attentive to plant deficiencies and responsive to correcting them. The goal of maintaining reliability of equipment and systems and optimizing material condition will thus be achieved.

The conduct of maintenance work in the plant must incorporate all of the programme elements related to the task being performed. For example:

- Use of maintenance procedures and work documents
- Use of tools and support equipment
- Foreign material exclusion practices
- Equipment isolation and tagging practices
- Control of materials, spare parts and replacement equipment
- Coordination of work activities with support groups such as radiological protection, quality control and stores
- Industrial safety practices (hard hats, scaffolding, safety belts, ear protection, safety glasses, confined space entries and unique hazards)
- Radiological safety practices, including the use of protective clothing, respiratory equipment, forced air hoods
- Work site cleanliness and orderliness and access to equipment.

Maintenance work should be started only after obtaining authorization, and it must be performed by qualified personnel. Procedures must be followed as required and procedural problems should be promptly resolved.

Managers and supervisors should routinely observe maintenance activities and ensure adherence to station policies and procedures. The work groups must be instructed on specific jobs, so that they are knowledgeable of any special requirements and are aware of the impact of their jobs on nuclear safety.

Contractors and other non-utility personnel conducting plant maintenance must operate under the same control procedures and to the same standards as plant maintenance personnel.

Appropriate personnel (e.g. operations, engineering and maintenance) must perform post-maintenance testing, must document and review the results and must return equipment to service only when the results of this process are satisfactory.

## 12.0 MATERIAL CONDITIONS

Planning, scheduling and coordination of maintenance activities must support optimum material condition, by ensuring that maintenance is accomplished in a timely manner.

The material condition of the plant should be maintained in such a way that safe, reliable and efficient operation of the plant can be ensured. Plant managers and supervisors should conduct frequent tours of plant areas in order to confirm that high standards are maintained.

Systems and equipment must be in good working order. Examples of this include the following:

- Fluid system leaks should be minimized
- Equipment should be appropriately protected from adverse environmental conditions
- Instruments, controls and associated indicators should be calibrated, as required to maintain accuracy
- Good lubrication practices should be evident
- Fasteners and supports should be properly installed
- Equipment, structures and systems should be properly preserved, insulated, and free of corrosion
- Cleanliness should be maintained throughout the plant
- Thermal insulation should be in good condition.

## 13.0 OSART EXPERIENCE

The maintenance area is increasingly recognized as a key area for safety, hence training has improved, sometimes through international co-operation. In some cases contractors staff employed for maintenance and outage tasks are involved in the plant training programme.

The cleanliness/housekeeping and material condition of plant structures and equipment have been improved and are generally good. However, some plants have numerous lower level material deficiencies that are not reported, including fire hazards. In these plants, there remains a cultural tolerance for material deficiencies.

Some maintenance organizations integrate some important safety principles such as systematic hazard assessment techniques.

Almost all plants have an effective programme for preventive maintenance and predictive maintenance is becoming more prevalent. These programmes often include a vibration monitoring programme and lubricating oil analysis. A motor-operated valve monitoring programme exists at some plants. However, several plants should enhance efforts to adjust preventive maintenance tasks and intervals based on nuclear plant experience and service conditions. They should also start to address ageing. Beyond traditional maintenance, a few utilities are beginning to develop a reliability-centered maintenance approach, that should result in safety improvement and improved efficiency. Despite significant interest in this concept , its development is slow because of the initial costly investment, hence there is an opportunity of establishing fruitful co-operation.

Outage management is being significantly improved by effective organizations. More and more, outage planning is conducted by a dedicated team, which includes operations representatives in addition to maintenance staff. This facilitates effective interfaces and enables management of the outage as a project. In some cases, these improvements lead to enhancing the operational safety, while reducing the shutdown duration, hence increasing the availability of the plant and its competitiveness.