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Good practices for cost effective maintenance of nuclear power plants

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

As a follow-up to earlier Technical Documents on Good Practices for Improved Nuclear Power Plant Performance (IAEA-TECDOC-498) published in 1989, and Good Practices for Outage Management in Nuclear Power Plants (IAEA-TECDOC-621) published in 1991, the IAEA has produced this publication focused on cost effective maintenance of nuclear power plants. As with the earlier reports, the overall aim of this TECDOC is to identify good practices in key aspects of maintenance management, and to communicate them in a way that the information can be used by utilities in Member States.

This publication is organized around five areas that were identified by the utilities and government organizations who contributed to this report as most important to them. They are:

- **Increasing production** through maintenance activities related to improved plant materiel condition, reduced duration of planned outages, use of on-line maintenance and reduced frequency of forced outages.

- **Reducing workload** through avoiding unnecessary regulatory burden and using reliability centered maintenance and condition monitoring.

- **Improving maintenance processes** through better planning and scheduling, use of information management systems, graduated work controls, and appropriate post-maintenance testing.

- **Improving productivity** through better teamwork, greater sharing of resources, and better radiation management associated with maintenance.

- **Measuring performance** of maintenance activities through such tools as performance measures and benchmarking.

The IAEA wishes to thank all participants and Member States for their valuable contributions. The IAEA is particularly grateful to the Government of the United States of America and Entergy Operations Inc. for hosting a consultants meeting on this topic from 25 to 29 March 1996.

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1. INTRODUCTION

The purpose of this publication is to describe good practices with respect to cost effective management of maintenance for nuclear power plants. It is not meant to be prescriptive, in that the practices described are not expected to have universal applicability to all NPPs. It also is not meant to be an exhaustive discussion of all issues related to NPP maintenance, but rather, focuses on recent developments in the field. The target audiences for this publication are primarily those managers and supervisors responsible for plant maintenance activities at existing NPPs. The publication may also be useful to: 1) those individuals and organizations that are initiating nuclear power programmes, 2) those who are planning to design, construct and operate additional NPPs beyond those that they currently operate, and 3) organizations that provide oversight or regulation of NPP maintenance programmes.

This publication is organized around the five main areas that were identified by the numerous utilities and government organizations who contributed their good practices. Shown below are these five main areas and the major topics addressed in each of these areas:

Increasing Production

- maintaining good plant materiel condition
- reducing the duration of planned outages
- performing on-line maintenance, where appropriate
- reducing the frequency of forced outages.

Reducing Workload

- avoiding unnecessary regulatory burden
- monitoring the condition of plant equipment as a basis for preventive maintenance
- using reliability centered maintenance.

Improving Processes

- better planning and scheduling
- using information management systems
- applying graduated work controls
- post-maintenance testing.

Improving Productivity

- improving human performance
- better teamwork
- more sharing of resources
- outsourcing/contracting
- improving radiation management.

Measuring Performance

- performance measures
- benchmarking.

It is noted that these topics do not explicitly address plant safety and reliability, or quality; areas that have justifiably received considerable attention by the nuclear power industry. However, experience has shown that efforts to improve the efficiency and effectiveness of NPP maintenance programmes have also led to improvements in safety and reliability of plant systems and to improved quality. This is the case because improvements in efficiency and effectiveness:

- focus maintenance and other resources based on their importance to safety and availability
- emphasize quality through doing work right the first time
- organize maintenance activities in such a way as to make the best use of limited resources
- provide an objective basis for decisions such as which components should be included in preventive maintenance programmes
- make the best use of tools such as information technology to provide more accurate and useful information to all levels and parts of the organization, thus improving the quality and safety of plant activities
- measure performance in areas such as safety, reliability and quality, and use this information to identify areas for improvement.

Some NPPs have found it beneficial to take a fresh look at maintenance management using a systems approach. As a result, the functions needed for maintenance management are determined and the processes to carry out these functions are identified in an effective way. When these processes are compared to existing maintenance management methods, they have almost always been found to be simpler, and more efficient, permitting the utility to achieve equivalent or improved maintenance results with fewer resources.

It should be recognized that a transition to more cost effective maintenance management systems is not without difficulties. Both organizations and individuals tend to resist change, necessitating considerable efforts and planning to implement improvements. Finally, it is important to recognize that for all of the good practices described in this publication there is one common need in terms of their success; that is a strong commitment of plant management to these efforts, particularly emphasizing clearly defined roles and responsibilities for their planning and implementation.

2. INCREASING PRODUCTION

This section describes those maintenance good practices whose principal focus is on increasing plant production. The primary way in which maintenance actions contribute to increased production is to improve availability, either through reducing the planned outage time for maintenance, or reducing the frequency of forced outages due to inappropriate maintenance actions. Four different areas were identified:

- improving plant materiel condition so that components and systems continue to perform their design functions,
- reducing planned outage duration through better planning and conduct of maintenance,
- increased use of on-line maintenance to reduce the need for work to be done during planned outages, and
- reducing the frequency of forced outages due to improper or inadequate maintenance.

2.1. PLANT MATERIEL CONDITION

In order to emphasize the importance of plant materiel condition, it is the first topic addressed in this report. It should be recognized that without good plant materiel condition, many of the other good practices described in this report cannot be achieved.

It is very difficult and expensive to recover from poor materiel condition. Thus it is important to put the plant in good condition at the beginning of plant life, and keep it that way. It is relatively inexpensive to maintain excellent condition, once it is established.

Visible **examples of poor materiel condition** include:

- **Leaks in mechanical systems**: pump seals, valves, fluid boundaries and connections, oil/lubricant and air systems, service water, etc.
- **Equipment operation off-normal**: vibration, noise, inoperable or off scale indicators, missing or loose fasteners, etc.
- **Housekeeping**: foreign material (FM) in unwanted places, no FM exclusion boundaries, poor cleanliness and orderliness, water/oil on floors
- **Equipment labelling**: missing, illegible or ambiguous tags, unwanted, outdated tags.

There are numerous examples of expensive and sometimes safety-related **consequences of poor materiel condition:**

- **Foreign material left inside coolant systems**: lead blankets, which melted and plated out on heat transfer surfaces, leading to early termination of plant operation, scaffolding/temporary work platforms causing damage to plant equipment, resulting in unplanned outages.
- **Taking the wrong equipment out of service**: missing or poor equipment labelling resulting in the wrong equipment being taken out of service for maintenance, causing plant shutdowns and loss of safety system functions.
- **Leaks in mechanical systems**: deaths and serious injuries have resulted from leaks in steam, and other high pressure or temperature systems. In other instances leaks of a "minor" nature have masked more serious deficiencies.

There are low cost, but important considerations in maintaining good materiel condition:

- adequate lighting
- cleanliness
- housekeeping
- painting
- protective coatings
- identification of material suitability for use in different plants areas (e.g., solvents, cleaners, lubricants), including use of color coding.

Management needs to establish high expectations with respect to plant materiel condition, and set a positive example in the plant (e.g., taking an interest, not accepting poor conditions, inspection/observation of conditions).

It is difficult to convince people that high quality, safe plant operations are in effect if poor condition of equipment/facilities is evident.

Managers should establish an attitude of zero tolerance for accepting defects that can be corrected now.

2.2. REDUCING THE DURATION OF PLANNED OUTAGES

2.2.1. Introduction

Most major maintenance activities are conducted during planned outage periods. In many countries maintenance (during planned outages) is primarily performed by contractors. Outages are the biggest reason for unavailability of the nuclear units. Also, during planned outages, a major portion of the maintenance costs are realized. In IAEA-TECDOC-621, Good Practices for Outage Management in Nuclear Power Plants, 1991, good practices concerning outage management were described. This section provides some details and discussions that complement the information in TECDOC-621.

2.2.2. Outage planning

Effective planning of outages makes it possible to achieve safety, quality, cost and availability targets. A good practice in outage planning consists of the following:

• long term planning:	>5 years
• middle term planning:	3-5 years
• annual/cycle planning:	1-3 years

Long and middle term planning are necessary in order to mimimize production losses (cumulative outage lengths) by scheduling maintenance and modification activities requiring long implementation time during an appropriate outage. To achieve high long term availability, it is important to organize outages in such a way, that activities which need more time than is needed for refuelling, are concentrated in specified years. By concentration in such a way, except for infrequent long outages, very short outages can be achieved. For this purpose, long range scheduling should consider all activities and components that could affect outage duration. For example, a German plant has scheduled major tests such as reactor vessel pressure tests and integrated leak rate tests in such a way, that they are conducted in parallel with the main electrical generator overhaul. Finnish plants alternate, in a long term concept, between pure refuelling outages and maintenance outages. With these approaches, there is a need for an outage, which is longer than for the pure refuelling needs, only every 8 to 10 years.

One long term planning practice that has been successful for some utilities is classification of outages as to refuelling outages, service outages and large service outages. For many of these plants, refuelling is performed once a year. Every two years a refuelling only outage is conducted, during which major maintenance activities that can not be completed within the time needed for refuelling are avoided (if possible). The main tasks for a such a refuelling outage are refuelling, and repairs and inspections that are needed on an annual basis. Some plants have been able to complete such refuelling only outages in as little as 10 days. Between each refuelling only outage is scheduled a service outage (once every 2 years). During a service outage, in addition to refuelling and repairs and inspections needed on an annual basis, major maintenance activities are scheduled. Some plants have been able to routinely complete such service outages in 20 to 30 days. At longer intervals, perhaps every 10 years, depending on plant design, a major service outage is scheduled. During this major service outage, in addition to the tasks performed during a service outage, major in-service inspections, and overhauls/modifications of major components are scheduled.

The long term outage concept should, if possible, be developed before the initial start of operation, because a later synchronisation of the outage activities could lead to an additional, one-time, effort. Usually, such synchronization is achieved in a relatively short time. Therefore, the long term outage planning concept can be considered also in plants, which have been in operation for some time.

The best time to consider long term outage planning is during plant design. With this approach it is possible to optimize the design to cut the costs.

For organizations with several units, long range planning should be synchronized between units to optimize resource utilization and meet generation obligations.

For an example of long term planning see Annex A.2.

Annual/cycle outage planning should be a permanent daily task. Planning for the next outage should begin, at the latest, immediately after completion of the preceding outage, with the preparation of an initial outage plan. Engineering and maintenance organizations, should use this initial plan as the basis for planning their work scopes. The outage co-ordinator should then use this information to generate the initial outage master plan. Most of the planning for the outage should be completed several months prior to its commencement. Experience has shown that with a good automated planning system, 90% of outage work can be planned and scheduled automatically, down to the level of issuing work packages.

2.2.3. Outage organizations

Both outage planning and execution should be organized optimally. Many utilities have found it to be a good practice for the outage organization to be a team based on a project organization approach. The establishment of a permanent outage co-ordinator has proven beneficial. The outage co-ordinator should lead the outage planning team, which should consist of team members having experience in operation, maintenance, radiation protection, quality assurance and modification planning. Also, it is a good practice to include a person qualified as shift supervisor in the outage planning team.

It has been found to be a good practice during an outage to have some shift operations personnel who are dedicated to monitoring plant systems and configuration control. Other operators are dedicated to support outage activities such as isolation of equipment for maintenance and post-maintenance testing.

2.2.4. Outage execution

Good practices in outage execution presuppose the following tools and policies:

- Management commitment and daily participation
- Co-operation with contractors based on long term contracts and mutual benefits
- Spare parts management based on modular replacement
- Computerized information management systems
- Scheduling based on risk assessments and outage length optimization
- Daily control of work safety conditions
- Daily reporting about the outage situation to every outage team member
- Reporting of outage experiences including human errors and lessons learned. Reporting of outage experiences should be completed within a month after the end of the outage
- Cost control measures.

2.2.5. Outage length and cost reduction

In many countries utilities have succeeded in cutting outage lengths and costs while simultaneously increasing plant availability, safety system reliability and work quality. This continued high work quality has been demonstrated, among other ways, through the low frequency of forced outages. This outage length reduction has been achieved through systematic studies and has been implemented gradually. Examples of proven methods for outage length reductions are:

- Increased use of on-line maintenance based on risk assessment studies (see Section 2.3)
- More effective use of information management systems (see Section 4.2)
- Improvement in the qualification of and co-operation with contractors
- Optimized spare parts management, especially increasing the use of changeable spare parts and modules
- Careful and extensive planning
- Reduction of regulatory burden (see Section 3.1)
- Benchmarking studies of comparable plants to identify areas for improvement (see Section 6.7)
- Increase in intervals of preventive maintenance based on condition monitoring (see Section 3.2), experience feedback and/or RCM studies (see Section 3.3)
- Investment in workshops, facilities, tools and plant maintenance equipment.

2.2.6. Co-operation with contractors

The role of plant vendors and other contractors is essential in power plant maintenance. For many utilities, particularly those with only a few NPPs, the size of plant maintenance organizations is based on maintenance needed for routine operations. During outages, the maintenance workforce increases to several times this size (from 500 to 2000 persons depending on utility practices and outage extent). For many utilities, during an outage, the majority of persons on site are contractors.

In order to enhance quality and to optimize costs, it is a good practice to consider the following:

- long term contracts (3 to 5 years) with main contractors
- maintain competition among contractors
- fixed price contracts with quality bonuses given directly to the people doing the work
- emphasis on education, job training and qualifications of contractor personnel
- selection of contractor personnel based on outage experience and qualification
- preplanning of activities together with contractors
- contractor personnel being considered equal members with utility personnel in outage teams
- contractor facilities, tools, offices and office equipment of high quality standards
- emphasis on quality of life for contractor personnel, particularly for plants which are a long distance from population centres (e.g., overnight facilities and social programmes)
- It may, in many cases, be beneficial for a utility to have direct contracts with its contractors, rather than one contractor and many subcontractors.

2.2.7. Spare parts and material management

Proper spare parts and material management increases the quality of maintenance and availability of the plant and its safety systems. With proper selection of spare parts, the possibility of long outages due to break downs can be reduced. When managing spare parts it is beneficial to classify stock according to the following categories:

- Materials and consumable goods (e.g. cables, piping, fasteners, electric and instrument equipment).
- Ordinary spare parts (e.g. pump motors, valve details, electronics cards, detectors, etc.).
- Complete modules, which make possible modular replacement (e.g. control rod-drivers, servomotors, valve actuators, diesel engines, transformers). These modules are serviced between outages in workshops.
- Spare parts which avoid long shutdowns (e.g. turbine shafts, main transformer). The costs of this type of spare parts can be weighed against the costs of breakdown insurance or reserve power contracts.

Material logistics and storage administration should be based on computerized information management systems. These systems should be integrated with other maintenance information management systems.

After 10-20 years of operation, plants have often experienced problems with the availability of spare parts due to technology developments and many original suppliers no longer being in business. It is an important task in spare parts and material management to be aware of the possible lack of spare parts and to find compensating parts or initiate necessary plant modifications.

In order to avoid delays in deliveries from storage to plants it is important that for all materials and spare parts in stock, quality assurance and regulatory inspections are completed and documented when the material is received in storage.

The following annexes provide examples of successful efforts to improve outage management:

- Annex A.1 Finnish example (TVO)
- Annex A.2 German example (Neckar)
- Annex A.3 UK example (Heysham).

2.3. ON-LINE MAINTENANCE

The performance of maintenance during power operation (on-line maintenance) has the potential to reduce the maintenance burden during outages. Thus, it may be possible to reduce the length and/or the costs of planned outages. However, these improvements must be considered in light of the possible safety significance of on-line maintenance.

Listed below are some of the advantages of on-line maintenance, both from the standpoint of work during outages, and during normal operation:

during outages:

- easier outage planning
- better overview due to reduced work load
- better work control by plant staff
- availability of full fuel element cooling capabilities

during normal operation:

- better control by plant staff due to reduced work load and less parallel work
- use of the most experienced or appropriate plant staff or experienced vendor staff for each task
- easier planning
- reduced probability of tagging errors.

The main arguments against on-line maintenance are that unavailability of systems and components during power operation may result in a reduction of plant safety status and/or increased availability risk, either due to reduced system availability or from the maintenance work itself. These arguments can be resolved by performing a PRA evaluation considering reduced system availability due to on-line maintenance. These PRAs can be done either by generic or case by case evaluation:

- Generic PRA results should be implemented in technical specifications particularly for preventive maintenance during power operation.
- Case by case evaluations should result in work order specific requirements for particular work. Case by case analyses normally need voluminous calculations from experts. To assist those analysts, expert software tools are developed in various countries to ensure correct analysis by operations or work preparation staff.

Justifying on-line maintenance of some systems may require compensatory measures. These may include either temporary or permanent additions of mitigating systems. For example, the addition of another diesel generator for station blackout concerns could be used to justify on-line maintenance of the emergency diesel generators. Other such mitigating systems include those implemented for severe accident management.

Present practices show, that the possibility for on-line maintenance mainly depends on plant design, especially the degree of redundant safety systems. Therefore, if on-line maintenance is envisaged by the operator, preventive maintenance should be a design aspect from the beginning. The design must consider also the following aspects related to on-line maintenance:

- capability for requalification after maintenance,
- possibilities for draining, filling and venting during power operation.

Negative influence on plant safety from preventive maintenance work itself must be prevented by effective work control. These controls should be consistent with those used for corrective maintenance.

2.4. REDUCE THE FREQUENCY OF FORCED OUTAGES

The following are several ways that utilities have found to reduce the contribution of maintenance to forced outages:

Long range modification/ improvement policy. A long range modification/ improvement programme to keep the plant in modern condition (consistent with cost-benefit considerations). Cost- benefit should be based not only the near-term return on investment, but also the long-term value of reductions in extended forced outages over plant life, continuing to meet regulatory expectations, and improved public acceptance. When the plant is in modern condition, purchasing spare parts is easier, and often less expensive. The numbers of defects are lower if the plant is modernized and thus the risk of forced outages is naturally lower.

Modern condition monitoring equipment. Purchase modern condition monitoring equipment and train people to use it. Condition monitoring equipment includes expensive surveillance systems with artificial intelligence as well as small hand held equipment. It may be difficult to show that the investment for larger systems is cost effective, but the investment may also be seen as insurance against extended forced outages (see also Section 3.2).

Monitoring and inspection policy. Maintain excellent plant materiel condition through a regular monitoring and inspection policy. Plant management should know the material condition of their plant especially, safety systems at all times, leaving as little to chance as possible (see also Section 2.1).

Appropriate preventive maintenance programme. The preventive maintenance programme should initially consider manufacturers' recommendations, but should also be based on experience in the nuclear industry and/or modern RCM methods to optimize service intervals. Thus, unnecessary forced outages can been avoided.

Sufficient spare parts and modules. Sufficient spare parts and modules must be maintained in stock. If a forced outage has occurred, replacing the faulty module can be completed more quickly and with higher quality than would be expected through in-place troubleshooting and individual component replacement. The faulty module can later be carefully serviced in the workshop in a quality manner.

Appropriate repair policy. When repairs are planned, it is good practice to evaluate whether it would be cost-beneficial to make the repair with improved material/equipment. Obviously, if improvements are made, they must be reflected in appropriate documentation. If, during normal operation, a potentially serious defect is identified, analysis may be able to justify provisional repairs, with final repair made during subsequent outages. If the defect has safety significance, engineering analysis is essential, and regulatory review/ approval may be required, depending on the regulatory requirements. If a provisional repair approach is to be taken, determinations should be made in advance of acceptable defects (e.g., cracks in materials) and what provisional repairs or monitoring will be done until final repairs are completed. Thus hasty actions are unnecessary if the defects are below calculated limits and these defects can be monitored.

Keep the backlog figures low. A high backlog of maintenance work is an indication of acceptance of a large number of defects in the plant. This has two negative consequences. First, it sends a message to plant personnel that operating with defects is acceptable, and second, these defects can potentially contribute to additional failures which can cause unplanned outages and have safety consequences. A large maintenance backlog may be an indicator of the quality of maintenance and work done during outages.

Work control. Modern computerized tools for work control provide the capability for monitoring compliance with limits from technical specifications. These tools can aid in avoiding maintenance work that causes unplanned outages. These tools also can ensure that correct work orders, work authorizations and tagging lists are used. Also physical barriers, color coding and locked rooms can help prevent work on the wrong systems, trains, or units (see also Sections 4.2 and 4.3).

Well trained and highly skilled plant staff. One of the most important contributors to avoiding forced outages is a well trained, highly skilled and motivated plant staff. When such personnel perform work using modern methods and have an attitude to accept only the best work results, the risk of forced outages is reduced (see also Section 5.1).

Contractors. Use of the same contractors and contractor personnel from outage to outage, and long term contracts ensure that a prompt response by a qualified labor force is available, if a forced outage occurs. Also, as indicated earlier, quality work during planned outages is important to avoid later defects, which cause unplanned outages.

Feedback from other similar units. Feedback from other similar units is most important. Often, agreements have been established with main suppliers to keep plants well informed of the situation of other plants. If a defect has happened in a unit, it should of course be evaluated in other similar units. Often, these evaluations have avoided forced outages. Meetings with similar plants are useful in exchanging information and comparing results.

Feedback from NPPs of different designs. Feedback from such NPPs is also important (though the technical solutions may be different). Often there are identical or similar components in such plants. Information about their behavior can be important. There are many international sources of information; the challenge is to find the potentially useful information. One solution is to have several utilities/plants rely upon one organization to make a selection of the most interesting issues and occurrences.

Incentives. Incentives for good plant operation results contribute to people avoiding disturbances during operation. They also improve individual attitudes toward the quality of both their own work and the work of others.

3. REDUCING WORKLOAD

This section describes those maintenance good practices whose principal focus is on reducing workload. This is accomplished by identifying and eliminating or modifying maintenance activities that have a small (or no) effect on safety. These activities may be administrative in nature or involve routine maintenance on plant equipment. Three areas are discussed:

- Reducing regulatory burden by modifying or deleting requirements that are redundant or that have a small effect on safety and are costly to implement.
- Optimizing the preventive maintenance program through techniques based on reliability centred maintenance (RCM) or other similar methods.
- Eliminating intrusive preventive maintenance activities through advanced condition monitoring.

3.1. REDUCING REGULATORY BURDEN

3.1.1. Purpose

Regulatory requirements may often lead to increased costs in the maintenance of nuclear power plants without a commensurate increase in safety. Various government authorities impose requirements which are aimed at protecting employees, the public, or the environment. Over the years, in many Member States, the number and cost of these requirements has grown substantially. Requirements are sometimes redundant or conflicting. Some unnecessary requirements are created by the plant owner's conservative interpretation of the regulations. Many of these requirements can be modified or deleted with negligible or no impact on either safety or the environment.(or the regulatory approach to maintenance can be changed to a non-prescriptive one). In fact, an actual increase in safety can be achieved. A concerted effort to identify opportunities for reducing regulatory burden can significantly reduce the costs of nuclear power plant maintenance. It should be noted that the suggestions provided in this section are applicable both to situations where regulators provide prescriptive regulations (e.g., "the licensee shall inspect the reactor coolant pump seals, as a minimum, every two years") and to non-prescriptive (or performance-based) regulation (e.g., "the licensee shall provide a maintenance programme to ensure that safety goals are met"). In both cases the success of such efforts is strongly dependent on continued dialogue with and justifications to the regulator(s). In general, regulators are interested in clear safety justifications. The plant operator must provide justifications for change based on operating experience, analysis and proven technology.

3.1.2. Sources of excessive regulatory burden

In order to reduce the regulatory burden while maintaining adequate safety margins, one must first identify excessive regulatory requirements. The nuclear regulator is not the only source. Other organizations that create requirements include numerous federal agencies, state agencies, insurance carriers, professional societies and the plant owners themselves. In some cases, guidance or standards, while not originally intended as "requirements" have, over time become requirements, either explicitly or implicitly. Opportunities for reducing regulatory burden can be found in a number of places, as described in the following paragraphs.

Sophisticated Tools

Many current regulations were originally developed in the 1960s or 1970s. They were based on the technology and equipment history available at the time. Sophisticated computer hardware and software available today make many of these requirements unnecessary. For example:

- Many plants now have probabilistic risk assessments (PRA) available. These tools provide information on the relative importance of plant systems and components. Regulatory requirements can be tailored to provide more stringent requirements on the significant equipment and reduce the requirements on less significant equipment.
- Information can now be captured, transmitted and permanently stored electronically. Requirements based on the management of paper documents are obsolete.
- The use of sophisticated non intrusive diagnostic equipment may eliminate some requirements for periodic overhauls.
- Recent information on the nature of off site radiation release following an accident can be used to justify reduction of regulatory requirements for equipment designed to limit off site releases.

Equipment history now available can demonstrate that test and overhaul requirements are overly conservative. For example:

- Instrument drift trending can demonstrate that calibration intervals can be extended.
- The setpoint tolerances for relief valves of ±1% was found to be too restrictive. The tolerance could be increased to ±3% with no adverse impact on safety.

"More is Better" Philosophy

Another source of excessive regulatory burden is a philosophy of "more is better". There is a tendency to require additional controls, require more reports, or collect additional data. Often, these additions do not benefit safety sufficiently to justify their cost. For example:

- In many cases, more than one review or inspection for any activity is redundant and adds little value.
- Requiring an inspection or review for all activities regardless of their importance makes the important inspections less effective.

Tools such as a living PSA can be used to tailor maintenance activities based on the safety and operational significance of the component/system/function (see Sections 3.2 and 3.3 for specifics).

Identification of Appropriate Corrective Actions

The reaction of plant owners or regulators to incidents and failures can also create an excessive regulatory burden. In general, a regulator will react to a serious incident by imposing regulations that are broad in scope rather than focusing on the specific causes of the incident. This is fully justified to prevent further incidents. However, there are opportunities to reduce the scope of these requirements following sufficient industry experience that demonstrates that the causes have been identified and appropriate corrective actions have been demonstrated to be effective. For example, following several failures of motor operated valves, the regulator imposed new requirements on a large population of such valves in the plant. After several years, the plant owners were able to demonstrate that the scope was too broad.

More common, however, are the excessive requirements created by the plant owner through the corrective action process. The plant owner takes corrective actions in response to equipment failures, audit findings, or regulatory violations. These corrective actions can be overly conservative. For example:

- A plant transient occurs when the operators were not aware of the full impact of the maintenance work they authorized. As a result the process is modified to require plant impact statements for all maintenance work.
- Post-maintenance testing was not adequate. The plant corrective action was to require an engineering review of all post-maintenance testing requirements.

It is noted that such requirements are not truly regulatory requirements as they are imposed by the plant owner, not regulators. However, often such requirements have their origins because of some event with potential regulatory impact.

Transfer from Construction to Operations Phases

Some quality assurance requirements during the construction phase of the plant can be inappropriately transferred to the operational phase. Typically, this will result in quality control inspection requirements that are not necessary for routine maintenance.

Co-ordination of Requirements

Some regulatory requirements are not well co-ordinated. Different requirements can be redundant or conflicting. This is more likely to occur when different regulatory organizations address the same issue. For example:

- The nuclear regulator, standard organizations, and insurers all have requirements for the reactor coolant pressure boundary, which are somewhat different.

- The nuclear regulatory and the environmental regulator are both regulating plant radioactive effluents.
- Emergency planning involves Federal, State, County and local agencies.
- The nuclear regulatory endorsement of national standards in regulatory guidance often includes additional requirements.

3.1.3. Reducing regulatory burden can and should improve safety

One objective of reducing regulatory burden is to reduce costs. A complementary objective is to improve safety. Based on continuing dialogue with the regulator(s) and appropriate justification, requirements that have little or no impact on safety are deleted,. other requirements are modified to actually increase safety and reduce costs.

Inspections and Tests

The most direct way to improve safety is to modify required inspections and tests such that equipment reliability and availability are optimized.

Conducting inspections and tests reduces the time that the equipment is available to perform its safety function. Required surveillance intervals should be modified to maximize equipment availability while maintaining an acceptable level of reliability. For example, one plant determined that reactor limitation system testing resulted in 2000 hours of unavailability for one of four channel per year with no history of a failure. The surveillance interval could be doubled with no impact on reliability, resulting in an overall improvement in safety.

Intrusive inspections increase the risk of equipment failure. Equipment is more likely to fail after it has been disassembled and reassembled. Modifying or deleting such intrusive inspections will increase equipment reliability and availability. Many such required inspections are based on manufacturer recommendations. These recommendations are often based on service levels completely different from those experienced in nuclear service. Intrusive inspections can also be replaced with non intrusive condition monitoring.

The excessive use of inspections reduces their effectiveness when they are really important, and can reduce the quality of work. When inspections are applied to all activities, regardless of their relative significance, the act of inspection becomes routine for both the inspector and the worker. Neither one will believe that the inspection is important. In addition, the worker may rely on the inspector to prevent or find mistakes. The overall quality of work could suffer. Management and workers should expect quality work and inspections should be reserved for those activities where the consequences of a single error are extreme.

Use of Resources

By eliminating requirements that have little or no impact on safety, more resources become available for those activities that do impact safety. Plant management can focus on significant safety activities with fewer distractions from insignificant activities.

3.1.4. A process for reducing regulatory burden

Successful burden reduction efforts use a standard process for identifying, prioritizing and reviewing initiatives, as well as for justifying their acceptance by plant management and regulators. An example of a process is provided in Annex B.1. The initial step is to identify initiatives that can lead to burden reduction. There are several effective tools that may be used to reduce the impact of existing regulations.

- The site specific PRA may be used to identify plant equipment that is safety significant. This typically involves the calculation of such factors as Risk Reduction Worth or Risk Achievement Worth to determine the impact that equipment has on core damage frequency. These results are reviewed by an expert panel to consider factors that are not included in the PRA such as containment integrity and shutdown risk. The expert panel can then categorize plant equipment into various levels of safety significance. The plant can then justify less stringent regulation of that equipment with low safety significance. For example, such an approach was used to justify eliminating or extending some periodic testing of motor operated valves in response to the USNRC's Generic Letter 89-10.

- Another tool is to add a performance basis to existing regulations. In this case, the frequency of performing certain activities can be based on the actual performance of the plant or equipment. For example, a recent revision to Appendix J of 10 CFR 50 (The US Code of Federal Regulations), allows a plant to adjust the frequency of performing containment leak rate testing based on actual performance. Penetrations with a history of successful leak rate tests may be checked less frequently. Containment integrated leak rate tests can be performed as infrequently as once every 10 years.

- A universal industry standard may be used to replace several redundant or conflicting regulatory requirements. For example, ISO 9000 provides an international standard for quality assurance. It may be used to replace similar regulations. Industry organizations can be used to draft standard methods for complying with requirements or addressing regulatory concerns. The Nuclear Energy Institute and ASME often serve in this capacity. Recently, the USNRC has acknowledged that MOV testing in response to Generic Letter 89-10 may be used to eliminate redundant tests required by ASME Section XI.

The most lucrative source for burden reduction initiatives (as with almost any improvement activity) will be the workers in the plant. They know activities that add little value. A critical review of plant process and procedures by worker teams will yield many suggestions for burden reduction. This effort is more effective when management has established a philosophy of adding value in all activities. Workers trained in process management through such programs as Total Quality are more likely to identify unnecessary activities. Workers should evaluate process steps to ensure that they are necessary to:

- reduce defects
- reduce costs
- improve productivity
- reduce cycle time.

This philosophy of adding value can also be applied to the identification of appropriate maintenance activities in all areas, not just those related to safety. These activities add value when the resulting availability and reliability optimize performance.

Once identified, initiatives may be prioritized based on the expected cost/benefit and the probability of success.

Initiatives should be reviewed to determine the appropriate method for changing or eliminating the regulatory requirement:

- The initiative may require a change to the basic regulatory requirement. In this case the plant must negotiate with the regulator. The US Nuclear Regulatory Commission established a process for handling "Cost Beneficial Licensing Actions" in its Administrative Letter 95-02 (see Annex B.2).

- The initiative may require a change in the plant's approach to satisfying a requirement. In this case, the regulation provides sufficient flexibility. The suggested change preserves compliance with the requirement at a lower cost.
- The initiative may only affect a commitment made to the regulator in response to a plant incident. In this case, the regulator may only need to be notified that the commitment is being changed.

There are two important aspects to this process. First, the process should emphasize communication with the regulator. Early communication with the regulator will allow time for identifying and addressing significant concerns. Second, the process requires feedback on the impact of the changes made. A primary objective is that plant safety is not degraded. Any indications to the contrary must be addressed immediately.

3.1.5. Verifications and inspections

Verifications and inspections are commonly used in many of the work processes in the nuclear industry. Verification can be defined as:

> *An act of documenting that the performance of a task or equipment configuration is in compliance with the station procedures and requirements. This is accomplished by a person other than the person who performed the task.*

Several different methods of verification may be used. the following methods are listed in order of effectiveness.

- Using a different method other than the initial activity (such as remote indication, functional testing, or post-maintenance testing) which fully demonstrates that the required activity has been performed.
- Using a second knowledgeable individual to effectively repeat the activity.
- Using a second knowledgeable individual to verify the activity prior to or during its performance.

Verifications can be excessive. Identifying verification activities that are unnecessary can be a source of considerable cost savings. Management must establish an expectation that all work is of high quality. Properly trained and experienced workers are capable of performing work correctly. When workers are held accountable for performing quality work, they will develop a habit of self-verification. One method of self-verification is called STAR.

Stop — Take time to pause and consider the intended action before beginning, be organized, focus concentration and enhance attention to the details of the task at hand. Be aggressively suspicious.

Think — Understand specifically what is to be done. Question the situation by trying to identify all available or unavailable information pertinent to the task. Anticipate the expected response and indication when the task is performed. Do not proceed in the face of uncertainty.

Act — Positively identify the correct train and component while physically touching the label, when possible, and verify the component's actual position.

Review — Observe and verify that the task was performed correctly, that the actual response is as expected and that the component/system is in the desired configuration to support the intended plant operation. If an unexpected response is obtained, take action as previously determined. Ensure actions are conservative.

If quality work is the expectation, and self verification is performed, then additional verifications are generally unnecessary. However, there are situations where additional assurance is necessary. Verifications by a person other than the individual performing the activity should be used when the risks or consequences of a single error are unacceptable. Typically, this occurs when the activity results in:

- a challenge to safety systems
- degradation of safety functions
- a unit trip
- excessive release of or exposure to radiation
- personnel injury.

Examples of activities that would typically require verification include:

- Use of a freeze seal to isolate equipment for maintenance, where failure of the seal would result in an unisolable leak of reactor coolant.
- Movement of spent fuel into dry cask storage.

The use of multiple verifications should be avoided. One verification by one individual is sufficient to provide the necessary assurance. Additional verifications or reviews increase the cost with no improvement in either the activity or in assuring that it was performed properly. Multiple verifications dilute responsibility; they make it less clear to a particular verifier what his/her responsibilities are in relation to the other verifiers.

The cost of verifications can also be reduced by the use of engineered controls to eliminate the risk of errors. Examples of engineered controls include:

- The use of keys and locks to prevent equipment from being operated inadvertently,
- The use of interlocks to prevent equipment operation until the necessary initial conditions have been met.

A thorough review of processes and work activities for unnecessary verifications, inspections, and reviews can identify significant cost savings.

3.1.6. Procedures

Procedures create an administrative cost burden through the effort required to draft, revise, review and approve them. If the number of procedures is excessive, there is an opportunity for reducing those costs.

Procedures should be used to ensure quality when:

- the activity is complex
- the activity is beyond the normal skills of the individual
- the activity is performed infrequently
- the sequence of the activity is critical
- the risks or consequences of performing the activity improperly are unacceptable.

Some activities that typically need written procedures include:

- functional testing of reactor protection systems
- disassembly of large components such as reactor coolant pumps or diesel generators
- performance of integrated leak rate tests.

Procedures should not be used as a substitute for adequate training and experience. Workers should be expected to perform routine activities without procedures. Requiring procedures for such activities unnecessarily increases costs and can actually degrade quality. The knowledge, skill and common sense of a worker cannot be replaced by a procedure. The worker must be allowed to apply these attributes to the job as required rather than mandating specifics in a procedure.

The plant should strive to achieve a proper balance of procedures. Too many procedures will unnecessarily restrict the workers and increase the administrative costs. The lack of procedures for the types of activities identified earlier (or poor procedures) will increase risks and decrease overall quality.

3.2. CONDITION MONITORING

Providing safe and reliable electric power is the mission of every utility. To achieve this mission, utilities are facing many challenges. There is pressure to control the rising costs associated with operating and maintaining plants, to assess the effects of aging on the safety and reliability of equipment and system and to protect the overall plant investment.

To meet these challenges, utilities must continue to update their approach to equipment performance assessment and maintenance. Application in aviation and naval industries show that carefully planned and executed predictive maintenance can reduce maintenance cost while enhancing plant reliability and safety. To realize the benefits of such a program, the proper tools need to be incorporated into the plant.

One such tool is the use of advanced monitoring and diagnostics. Plants have the opportunity to install such advanced systems during upgrades to plant systems, such as replacement of plant monitoring computers. The benefits of such systems, described below, must be compared to the costs of installation.

3.2.2. Advanced monitoring and diagnostics for nuclear systems

3.2.1.1. Integrated plant monitoring and diagnostics system requirements

The following paragraphs define some requirements that an integrated plant monitoring and diagnostics system must meet.

Obtain Sensor Data from Several Sources. Before component condition can be analyzed, the component must be monitored to obtain data on relevant parameters. The nature of monitoring and diagnostics dictates that this data must come from many sources and data transmission rates. For example, the plant process and response parameters, such as temperature, pressure, flowrate, and level, are an important part of the raw input to a monitoring and diagnostics system. The response time of these sensors is such that maximum sampling rates of on the order of one sample per second can be accommodated. These process and response parameters typically come from the plant computer, in which case digital data acquisition can be employed. In some cases however, supplemental temporary or permanent instrumentation is added (for example to monitor pressurizer surge line stratification). In this case, the data is analogue in form and must go through an analogue-to-digital conversion process before being used. In several applications, very rapid data, on the order of thousands of samples per second, are monitored. Examples include vibration and neutron noise data. Maintaining this data in time-based form requires too much storage. Therefore frequency transforms such as fast Fourier transforms, are performed to create a frequency spectrum for the data. This form of data is more amenable to data storage and transmission on modern data highways. Finally, data can be obtained from off-line sources, including specialized portable data collection devices and user supplied data such as design parameters or baseline performance data. An integrated plant monitoring and diagnostics system must be able to utilize data from all these sources in its operations.

Integrate Data from Diagnostic Subsystems of Varying Designs. For an operating plant, existing subsystems for specific monitoring and diagnostics functions may already exist. Any integration approach must take into account the existence of these individual subsystems. The design must be such that it is easy to write interface software to receive the data from the individual subsystems. This has a significant effect on software structure, particularly databases, as well as timing and priority of data acquisition for individual subsystems.

Interface with Existing Plant Computer and I&C System. An integrated plant monitoring and diagnostics system benefits greatly from an advanced distributed computer architecture using network technology. These are typically implemented for nuclear plants during plant computer and I&C upgrades. Thus an ideal time to consider a more integrated, comprehensive approach to plant monitoring and diagnostics is during or after a plant computer and I&C upgrade. If implemented as part of such an upgrade, it is easier to design in plant monitoring and diagnostics similar to a new plant. However, most such networked architectures have sufficient space to accommodate additional capability in the future, whether it be plant monitoring and diagnostics or other applications.

Integrated Analysis and Display of Monitoring and Diagnostics Results. One effect of the increase in the use of specialized plant monitoring and diagnostics is the need for one or a few engineers to learn the user interfaces and capabilities of several subsystems. One objective of integration should be to create a common user interface structure that can be accessed in a uniform way by all the constituent users (engineering, maintenance, operations, etc.), and that can be accessed at multiple places in the plant. There may be several subsystems providing calculations and results, but the effect should be transparent to the actual users of the system. Preferably, such an interface should use graphical descriptions extensively, to more efficiently utilize the user's time. A further advantage of an integrated graphical user interface is the possibility to combine the results and conclusions of individual diagnostic subsystems into more powerful, broader conclusions regarding the condition of the whole plant, and associated actions. For example, the integrated user interface could take data on fatigue from one system, combine it with corrosion information from another, and generate results on corrosion-fatigue. Similarly, diagnostic data can be automatically interfaced to maintenance software, to incorporate component data into maintenance planning.

3.2.2.2. Elements of integrated plant monitoring and diagnostics system design

Based on the requirements above, the key elements in the design of an integrated plant monitoring and diagnostics system design can be developed. Figure 1 shows a conceptual architecture of an integrated plant monitoring and diagnostics system. The diagnostics subsystems selected for the figure are intended to illustrate the range of integration configurations that need to be considered. Other systems can be integrated as needed. Again, starting with sensors and working up, this section describes the key design elements to meet the requirements developed in the previous section.

Sensor and Subsystem Processing. An integrated system takes advantage of highway concepts to transfer data and information in a cost effective manner. For some diagnostic subsystems, for example on-line valve monitoring, rotating equipment monitoring, and metal impact monitoring, high speed data acquisition requirements are present, with sensors that in some cases supplement those included as part of the normal plant design. In nuclear applications, an objective is to minimize the number of penetrations of the plant containment structure. To do this, sensor highways are used that allow hundreds of individual sensors to be grouped into one cable and one containment penetration. In some cases the sensor data goes into a hardware-based preprocessor that performs key operations such as frequency transforms before sending the data to the individual diagnostic subsystem. In other cases the diagnostic subsystem is equipped to perform the required functions. Other subsystems use data that can be obtained primarily from existing plant sensors on the plant data highway system. The data highway is typically used to communicate data from plant sensors to various processors and people that need it for individual purposes. A data highway typically has numerous "nodes" (workstations or PCs) through which the data can be accessed. Subsystems accessing data from the data highway will typically perform some processing and communicate results on the information highway. Finally, data for individual diagnostic subsystems can come from portable data acquisition equipment, such as wall thickness data for erosion-corrosion monitoring or data from valve stroke time tests. This data would either go into the individual diagnostic subsystem, or directly into the information highway.

3.2.2.3. *Selected nuclear plant monitoring and diagnostics applications*

This section focuses on a few monitoring and diagnostics applications, concentrating on issues specific to the nuclear power industry.

Transient and Fatigue Cycle Monitoring

Operating transients in nuclear power plants occur during plant heatup and cooldown, load changes, pressure tests and off-normal events. These transients cause thermal, pressure, and mechanical load fluctuations that can contribute to fatigue damage accumulation in many pressure boundary components and systems over the plant operating period. Fatigue is considered in the plant design through postulation and evaluation of specified number of occurrences of key normal and off-normal events.

The actual operation of plants does not match exactly the operation assumed during the design process. To address this, utilities maintain records of operating transients and in some cases associated fatigue to document design-operational conformance on an ongoing basis. Many utilities are implementing computer-based approaches to monitoring operating transients and calculating damage caused by fatigue. There are several reasons for this.

First, it is labor intensive and time consuming to collect operating transient data and assess its effect on a manual basis. The parameters needed to automatically track transients and fatigue reside in most cases on the plant computer, and can be accessed easily through a data highway or other means. Second, if a particular transient falls outside the design assumptions, it becomes necessary to document its effect on fatigue and show that plant condition was not seriously affected. This is much easier to do with a computer-based transient and fatigue cycle monitoring system. Without it, it is necessary to return to the original design basis calculations and modify them to accommodate the new transient, which is again time consuming and labor intensive. Third, in the USA, the stress versus allowable cycle curves that form the basis for fatigue design of plants there as well as many other parts of the world, are coming under additional scrutiny regarding the effect of pressurized water reactor environment on the curves. If these curves become more restrictive through industry research, it will become even more important to have an accurate record of transients and fatigue. In most component regions, the actual operating transients are less severe and fewer in number than assumed in the design on an overall basis. With an automated system to monitor transients and fatigue, it becomes possible to document the advantage gained from this and use it to offset any reduction in code fatigue allowable.

The basic elements used to monitor operating transients and calculate fatigue using plant operating data are:

- Data monitoring and screening to determine fatigue-significant transients.

  Use for Green's function-based transfer function concepts to calculate fatigue from plant data without the need for continual finite element analysis.
- Output and display of results.

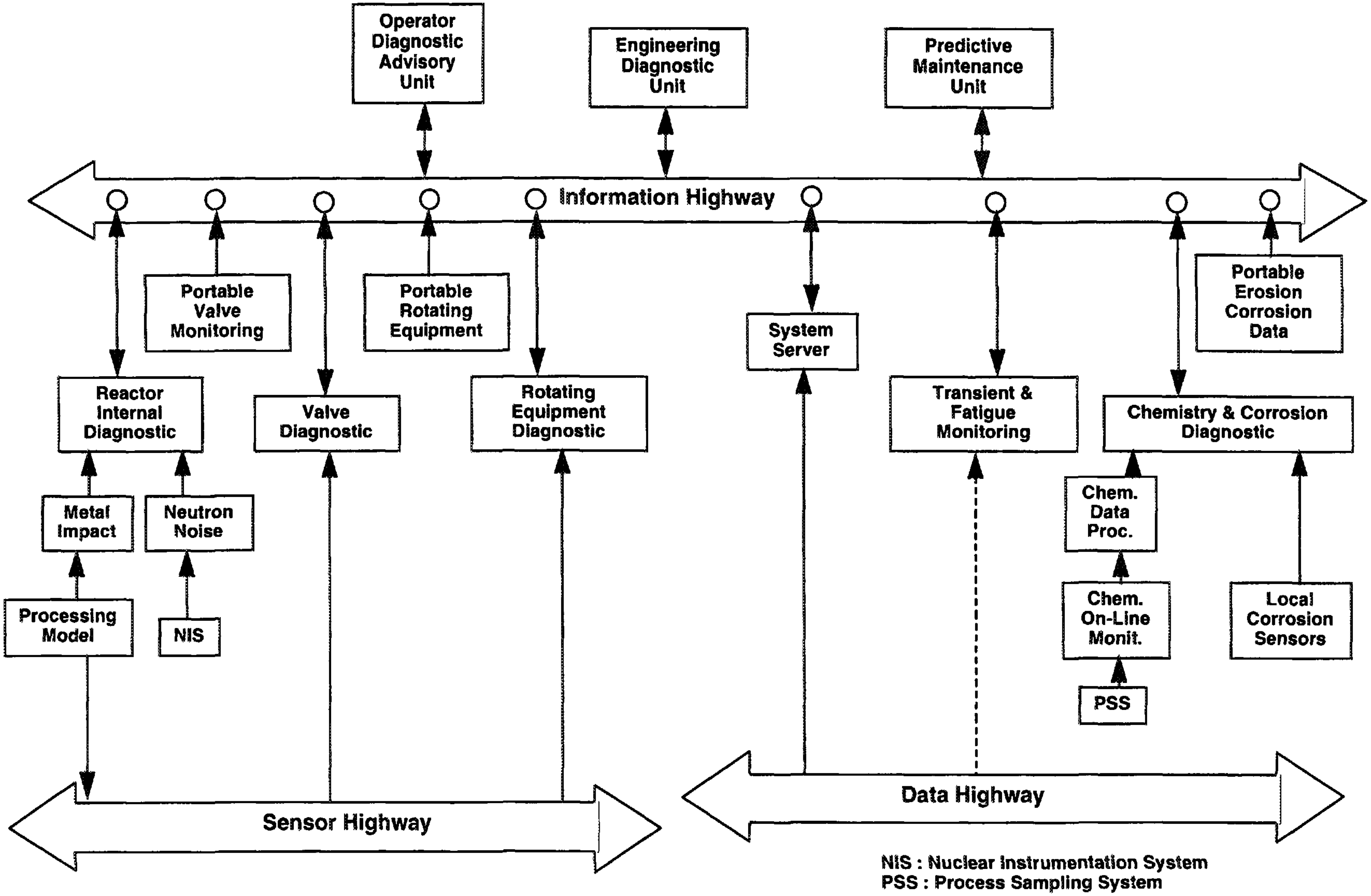

FIG. 1. Integrated plant monitoring and diagnostics architecture.

To be most effective, such systems are designed in a modular fashion. In this case, that means the data acquisition and screening functions are separated from the various data evaluation functions that can be performed. Such an approach can:

- Reduce cost by making specific modules available separately from a whole package.
- Make it easier to add related functionality in addition to fatigue calculation, such as transient cycle counting and reactor vessel integrity monitoring, which use the same type of input data as is required for fatigue calculation.
- Facilitate integration with an overall plant monitoring and diagnostics system architecture.

In most cases, sensors for transient and fatigue cycle monitoring are available from the plant computer. In some specialized cases, other data such as strain gages or externally mounted thermocouples can be used temporarily or permanently. A recent prominent example is thermal stratification in pressurizer surge lines.

Corrosion Monitoring and Diagnostics

This is another example of a system-wide degradation mechanism. It can be tracked in at least two ways. The first (for general erosion-corrosion) is through periodic wall thickness measurements taken at specific grid points on a component with a portable ultrasonic device. The second way is to install permanent corrosion probes at strategic points in the system. The second approach is used mainly in local regions for which detailed information is needed about the corrosion process itself. Since the mid-1970s, the industry has been working to provide a unique technique for detecting both the occurrence and type of corrosion that is occurring in a fluid system. To address component corrosion, one or more specially designed probes can be installed at locations where corrosion is most likely to occur. To address a system's global corrosion, selected locations are instrumented and data are correlated to provide an assessment of the corrosion occurring within the whole system. Added instrumentation monitors the response of the surface of interest against counter electrodes manufactured from material of the same composition as the component itself. None of the surfaces is externally polarized, thus providing that the observed data are entirely characteristic and entirely representative of the corrosion condition of the component.

The sensors signals change as a function of time due to changes in the chemical content of the fluid, flowrate, temperature, and corroded materials. The amount and type of corrosion occurring in the area of interest are characterized from signals transmitted to a data acquisition system for evaluation in real-time. Data appraisal is automated by special purpose software, and supported by a technical data base of prior applications. The technology uses time domain and frequency domain analysis of the signals to isolate the effects of system operating conditions, and identify the occurrence, magnitude, and type of corrosion (e.g., generalized, stress corrosion cracking, denting, pitting, etc.). This information is needed by plant operators and engineers for predictive maintenance, to improve control of plant operation to minimize corrosion, and verify compliance with probabilistic models.

The electrochemical potential and current noise techniques were initially developed in laboratory simulations of power industry and chemical process plant applications which involved localized corrosion of austenitic stainless steels and other materials. Further work in the early 1980s employed these techniques in determining the prevalence of crevice corrosion of stainless steel under hot concentrated nitric acid for the nuclear fuel reprocessing industry.

The technology has also provided similar instrumentation for use in Canadian nuclear systems for on-line evaluation of condensate chemistry excursions and for continuous monitoring of primary circuit decontamination procedures. Other projects have covered on-line evaluation of a laboratory scale steam generator tube plate crevice corrosion simulation; continuous measurement of stress corrosion cracking during cert. rig tests in high purity water; continuous evaluation of corrosion inhibitor performance during chemical cleaning; and control of corrosion in service water systems, heat exchangers, gas systems, oil and gas production, refining and petroleum systems, waste treatment and storage, and concrete.

The primary advantages of the electrochemical noise measurement technique are:

- The equipment provides a continuous indication of corrosion status. This allows conditions which led to active corrosion to be characterized. The instrumentation indicates when corrosion is active, not merely when laboratory data suggest that it may take place.
- The equipment enables the type of corrosion (uniform, pitting, stress corrosion cracking and corrosion fatigue) to be characterized, permitting timely and precise remedial actions to be initiated to mitigate the activity.
- The success of remedial measures can be evaluated immediately.
- Sensor probes are simple, robust, are not susceptible to temperature compensation errors or contamination by seepage of dissolved salts.
- Probes can be located deep within the component where the areas of concern are relatively inaccessible.
- If desired, the instrumentation can be multiplexed to several probes to provide an indication of corrosion status in various locations.

Reactor Internals and Core Structures Monitoring

This example illustrates how multiple diagnostic systems make use of the same types of inputs, thereby illustrating one of the advantages of an integrated system. Degradation in the reactor internals can be diagnosed using data on changes in neutron noise, which is monitored using in-core and ex-core flux detectors. This data is combined with data on other plant parameters such as local temperatures and pressures. The noise data requires high speed frequency-based analysis to put it in a form that can be diagnosed by an expert. Diagnoses typically performed include core barrel vibration analysis, core barrel to reactor vessel support integrity, and material degradation. Another degradation that can affect the reactor internals, as well as other natural debris collection points in the nuclear power plant systems, is impact from loose parts. Analysis of impact data has similar requirements to that of neutron noise, and these two applications have been combined in some system designs. To detect impacts, loose parts accelerometers are placed strategically at natural collection points. Metallic impacts within the reactor coolant system generate an acoustic pressure wave causing minute displacements in the component material. These displacements reside in a broad band of frequencies with finite resonant peaks above one kilohertz. The characteristics of an impact are determined by calculating the impact energy from the accelerometer signal. The energy is a function of things such as mass, impact velocity, the geometry of the impacting particle, the surface being impacted, the distance from the transducer, and background noise. The data for a particular impact is analyzed, and information is provided regarding estimated location and size of the loose part.

Valve Monitoring and Diagnostics

Worldwide nuclear power plant operating experience has shown that valve performance changes over time due to aging degradation of internal components. The US NRC requires that valves be monitored to assure that they perform according to design requirements. The regulatory requirements include:

- USNRC Bulletin 85-03
- USNRC Generic Letter 89-10 and supplements.

Some categories of valves typically used in nuclear plants include:

- motor operated valves (MOVs)
- air operated valves (AOVs)
- solenoid operated valves (SOVs)
- safety and relief valves (SRVs)

- check valves (CVs)
- pilot operated valves (POVs).

The unique nuclear plant considerations of radiation exposure during maintenance and testing, along with some valves that must cycle during normal operation, present special requirements. Therefore, both on-line and off-line (portable) approaches to data acquisition are used in valve monitoring and diagnostics. Since the total primary system valves exceed 200, it is not cost effective to monitor all of them on-line. Therefore, only a small selected group of valves are monitored on-line. The remainder are monitored with portable equipment and data transfer to a central system. Using monitored parameters, valve condition can be diagnosed by interpreting the signature of the parameters or comparing it to a baseline. More detailed testing using a portable system can then be performed as needed, and maintenance scheduled based on the diagnosis.

On-line valve monitoring provides the user with a continuous survey of the performance of valves in the plant. Valves can be networked into a single data-collection system that reads and catalogues the data according to the valve identification number. This approach helps comparison of acquired data with the baseline data for immediate evaluation and interpretation. Such an evaluation is valuable when determining when and what type of valve maintenance is necessary.

One-line valve diagnostic systems are typically comprised of a data acquisition system and a modified transducer signal conditioner module, which accepts input from various, permanently mounted transducers. Therefore, each valve monitored in the on-line system is instrumented with plant-specific sensors. The information needed to produce an on-line system is defined only after considering such factors as plant configuration, various regulatory agency requirements, and numerous valve/actuator types. However, typical sensors that are used for certain types of valves are:

- isolation valves:
    - actuator output torque
    - stem thrust
    - motor current
    - control switches

- throttle/control valves:
    - actuator output torque
    - motor current
    - control switches
    - stem position

- check valves (including swing, tilt, lift and duo-disc):
    - ultrasonic
    - acoustic
    - eddy-current

For diagnosis, on-line diagnostic systems for valves sometimes have expert-system rules that are applied to the variety of valve types and operating conditions. Conclusions regarding valve performance are based on these rules and on engineering judgments. For example, for motor operated valves the system is designed to monitor stem thrust to help answer the NRC generic letter 89-10 fundamental question: "During an accident situation, will the valve be able to close (or open) to perform its safety function ?" Graphical analytical techniques can allow for overlaying stroke traces from different tests on the same valve, as well as traces from similar valves. Such a pictorial representation allows an analyst to quickly identify changes in certain parameter trace characteristics that might otherwise go unnoticed.

On-line valve monitoring and diagnostics can be used to identify and quantify key phenomena related to ageing. Using check valves as an example, diagnoses can be made for:

- Free flutter: this condition occurs in a check valve when the flow in the system is less than that required to push the disk up to the backstop.
- Backstop tapping: as flow through a check valve increases, the disk eventually begins to tap against the backstop. This tapping can cause fatigue damage to the disc stud, stud nut, and hinge arm.
- Worn hinge pin: as free flutter continues to occur, the hinge pin eventually begins to degrade and wear as a result of friction from the contacting parts. This contact results in hinge pin wear over a period of time.
- Hinge pin and disc stud wear: additional degradation can be determined from stable flow, stroke, and leak tests. Excessive wear will degrade valve performance and may lead to leakage or failure of integral valve parts.
- Missing or stuck disc: the above phenomena can eventually lead to a missing or stuck disc. Such a condition can allow flow in reverse of the intended direction. This can lead to over pressurization, diversion from the intended flow path, or contamination.

Similar to on-line systems portable valve diagnostics systems use state-of-the-art advanced signal conditioning electronics, but implement the monitoring through an industrial grade laptop computer for data collection, and user-friendly software to collect and analyze data on key parameters associated with the operation of an MOV. The also use a wide range of transducers that can easily be installed and removed. Typical parameters monitored with portable systems include:

- motor power
- motor current
- torque and limit switch trips
- valve stem position
- stem thrust
- spring pack displacement
- actuator output torque
- system pressure and delta pressure.

Portable valve monitoring software often employs a relational database that stores all of the specification type information on each valve. When conducting a test on a particular valve, selecting the valve's tag number immediately makes available all of the pertinent valve and actuator information required to run the test. Systems are designed so data is easily downloaded for analysis. Additional information is provided in Annex B.3.

Rotating Equipment Diagnostics

The final example of nuclear plant monitoring and diagnostics applications is critical rotating equipment, such as the reactor coolant pump, turbine and generator. As in the other examples, the requirements is rotating equipment diagnostics are unique. This is high demand equipment that must reliably operate for months at a time. Malfunctions can develop quickly, impact the equipment, and cause extended forced outages. In such a case the addition of sensors and other monitoring devices can be easily cost justified. For example, specialized monitoring devices that have been developed for turbine-generator applications include end turn vibration monitors, air in leakage monitors, water induction monitors as well as shaft grounding system. In addition, continual, round-the-clock monitoring and evaluation is often used because malfunctions can develop quickly and unexpectedly.

To effectively monitor under such conditions, it is sometimes beneficial to have a communication link back to the equipment vendor, who can maintain a diagnostic rule base and provide quasi-real-rime evaluation and diagnosis on a 24 hour a day basis for several plants simultaneously. When several plants participate, all plants can benefit from ongoing enhancements to the diagnostic rule base and overall cost effectiveness is increased. This is one example of a diagnostic system that has qualified for reduction in insurance premiums from the nuclear insurers.

3.2.3. Conclusion

The benefits of condition monitoring are:

- confirmed safety assurance
- reduced number of forced outage
- Operations and maintenance cost reduction
- plant availability capacity
- plant ageing management
- operations, engineering, and maintenance integration
- reduced insurance cost.

3.2.4. Information sources with respect to conditioning monitoring

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3.3. RELIABILITY CENTERED MAINTENANCE (RCM)

3.3.1. Overview of RCM

Reliability centered maintenance (RCM) is a technique initially developed by the airline industry that focuses on preventing failures whose consequences are most likely to be serious. RCM was developed in the late 1960s when wide-body jets were being introduced into service. Because of the increased size and complexity of these aircraft, airlines were concerned that the continuing use of traditional maintenance methods would make the new planes uneconomical. Previously, preventive maintenance was primarily time-based (e.g., overhauling equipment after a certain number of hours of flying time). In contrast RCM is condition-based, with maintenance intervals based on actual equipment criticality and performance data. After adopting this approach, airlines found that maintenance costs remained about constant, but that the availability and reliability of their aircraft improved because effort was spent on maintenance of equipment most likely to cause serious problems. As a result, RCM is now used by most of the world's airlines.

In 1984 the Electric Power Research Institute (EPRI) introduced RCM to the nuclear power industry. Part of the motivation was that the preventive maintenance programmes at many nuclear power plants were based on vendors' overly conservative recommendations, without sufficient consideration of actual duty cycles or overall system functions. In other cases, too little preventive maintenance was performed on key components that had not been identified as critical, leading to failures that increased corrective maintenance costs and reduced plant availability. Also, utilities were concerned about unnecessary maintenance in terms of worker exposure to radiation.

In 1992, IAEA-TECDOC-658, "Safety Related Maintenance in the Framework of the Reliability Centered Maintenance Concept," was published. The following information concerning RCM is summarized from that publication.

The utilities which comprise the EPRI RCM Users Group have accepted the following definition for their use:

> *"Reliability centered maintenance (RCM) analysis is a systematic evaluation approach for developing or optimizing a maintenance programme. RCM utilizes a decision logic tree to identify the maintenance requirements of equipment according to the safety and operational consequences of each failure and the degradation mechanism responsible for the failures."*

The components of an RCM analysis include:

- defining the system boundaries
- defining the important functions of the system
- identifying the dominant failure modes and the effects of these failures
- determining the criticality of these failure modes and the associated critical components
- based on actual or potential equipment failure mechanisms, identifying applicable and effective tasks that can prevent the failures or reduce their likelihood.

The RCM analysis must incorporate specific plant experience and should also identify potential failure modes. These failures can be identified based on related industry experience and by use of analytical tools such as failure modes and effects analysis (FMEA), logic diagrams, or other methods. The analysis considers condition directed tasks and time directed tasks as well as testing and modifications. RCM can call for accepting failures after the consequences are well understood.

As a practical matter, a RCM programme must include those activities that are required to implement the RCM analysis results; that is, at least the processes of system selection for RCM analysis, RCM results evaluation and implementation by the maintenance staff, and an ongoing RCM living programme to assess effectiveness and update the RCM results.

In addition, a RCM Programme provides a flexible framework with which to introduce new PM tasks necessary to control new degradation modes (ageing) that will be discovered during the life of the plant. Finally, a RCM maintenance philosophy is one which bases all maintenance activities, as far as practicable, on selecting applicable and effective tasks for addressing critical failure modes for important system functions.

3.3.2. The EPRI and nuclear power plant approach on RCM

3.3.2.1. Pilot applications of nuclear plant RCM

In 1984, the Electric Power Research Institute (EPRI) and its utility advisory boards recommended that the usefulness of RCM be evaluated in trial applications to single systems at selected nuclear power plants. The first EPRI application of RCM was on the component cooling water systems of Florida Power and Light's Turkey Points Units 3 and 4. The study recommended 24 tasks that differed from the existing ones. A project team drafted changes to the plant procedures for the times directed and condition directed preventive maintenance tasks that were identified. This package of suggested PM changes was used in the evaluation of the plant PM programme at Turkey Point.

The application of RCM to the main feedwater system at Duke power's McGuire station began shortly before the end of the Turkey Point pilot study. The RCM pilot study team investigated the system as it was before modifications were made in response to operational problems and corrective maintenance early in the plant's life. The RCM study verified the appropriateness of major elements of the current PM programme. It developed desirable candidate condition directed tasks as replacements for existing time directed tasks and verified the need for modifications which the plant had identified by other means.

The third pilot application was conducted on the auxiliary feedwater system (AFWS) at Southern California Edison's (SCE) San Onofre Station. Unlike the normally operating systems that had been studied in the first two applications, the standby AFWS has functional redundancy, constraints on allowable outage time, infrequent operation, and frequent testing. Also, system failures are often not obvious until a demand for the system occurs. Therefore, this study offered a further test of the applicability of the RCM for a nuclear plant. The study recommended a net decrease in PM effort on the system with many PM tasks to be deleted, reduced in scope or changed from time directed to condition directed.

3.3.2.2. Large multi system nuclear plant RCM demonstration

As the next step in developing RCM for potential wide use in the nuclear industry, EPRI selected two host utilities for large scale RCM demonstrations. One demonstration was conducted at the Ginna nuclear power station. The other demonstration was conducted at San Onofre nuclear generating station, Unit 2. A principal objective of these projects was to implement RCM on a large number of plant systems at each plant as part of a PM evaluation programme. The projects showed both the cost effectiveness and the feasibility of the integration of RCM into the operating environment and organization of each power plant. They demonstrated acceptance of the RCM programme by utility personnel. These objectives were met concurrently with the utilities own objectives, such as:

- quantifiable reductions in maintenance cost
- realignment of maintenance resources to improve overall plant availability and safety
- producing a more favourable PM-to-CM cost ratio
- optimization of technical specification testing requirements
- providing a partial basis for life extension and licence renewal.

Both utilities viewed their RCM projects as one element of a larger maintenance improvement programme without clear boundaries. At Rochester Gas and Electricity Corporation's Ginna Plant, the following additional activities were underway:

- restructuring of the maintenance organization
- upgrading of the work control system
- upgrading of procedures
- development of a maintenance information system.

At SCE the plant had the following additional activities underway:

- PM audit task force for all systems
- technical optimization specifications
- maintenance basis documentation.

At both utilities RCM team members participated in the total maintenance improvement effort, and RCM became the maintenance philosophy that bound these diverse activities together. Both the Ginna and the San Onofre demonstration began in the Spring of 1988. All of the analyses on 12 to 20 systems were complete at each plant within two years.

Significant steps in each demonstration included:

- selection and prioritization of systems for RCM evaluation
- performance of the RCM analysis steps on the selected systems
- evaluation of the RCM recommendations by a multi disciplinary team or task force
- implementation of the RCM recommendations

- establishment of a system to rank and verify the RCM benefits
- establishment of procedures to update the RCM bases and recommendations with time.

The demonstration projects at San Onofre and Ginna are complete. Most of the objectives have been met, and the lessons learned are now available for the benefit of other utilities undertaking RCM activities.

3.3.2.3. Streamlined RCM analysis and development

The standard RCM system analysis process consists of several distinct steps which begin with system boundary identification and lead to RCM preventive maintenance recommendations. These are then compared to the existing PM program requirements and appropriate changes are incorporated into the PM program through proper implementation. However, approximately 60% of the time required to complete a standard RCM analysis was concentrated in two major steps of the process:

- Failure Modes and Effects Analysis (FMEA) - Identifying the system equipment that is critical for each system function.
- Logic Tree Analysis (LTA) - Used to identify the most applicable and effective preventive maintenance tasks to prevent the critical component failure modes and causes of concern.

Therefore, any major enhancement to the standard RCM analysis methodology needs to address these areas.

One common element in the function based streamlined RCM approaches is the preliminary evaluation of the importance of system functions. Standard RCM analysis performs FMEAs for all system functions regardless of their importance, but in streamlined RCM methods, system functions that have been identified as important are the only ones analyzed by an FMEA. Also, since I&C equipment generally supports multiple functions, these components would normally be analyzed in several FMEAs. The use of an Instrument Matrix alleviates the need for the duplication of this effort by consolidation of the I&C failure analysis in one matrix per system. Streamlined RCM techniques accounted for saving of up to 60% of the time required to perform the FMEA portion of the system analysis for systems of similar size and complexity. For these approaches to work successfully, the basis for determining system function importance must be very clear and objective.

To achieve efficiency and savings associated with the performance of LTAs to determine appropriate preventive maintenance tasks, the concept of a maintenance template was developed for a component type (i.e., pump, motor, etc.). For each generic component type a template was developed which identified the most applicable and effective preventive maintenance tasks and associated task frequency considering several component characteristics such as equipment frequency of usage, service environment, and functional importance. Each template recommends appropriate tasks for a component type in the categories of condition monitoring tasks, time directed tasks, and surveillance tasks. This provides the system analyst with a focused selection of tasks to aid in the decision of selecting the most appropriate preventive maintenance tasks for each component. The maintenance templates also provide an additional benefit of ensuring consistency between analysts in task selection. This can be difficult to achieve without definitive guidance when using many analysts with different experience levels. These templates have provided significant additional savings in the performance of a standard or streamlined analysis. They can be customized by the user to meet plant specific capabilities and maintenance philosophy. Once the user has incorporated plant specific information in the templates, the process of task selection becomes almost automatic and results in reduction of analysis time.

3.3.2.4. Evolution of RCM costs

Many different tools, guidelines, and lessons learned have been produced by EPRI during the last six years, as the industry has learned how RCM evaluations can be done more cost effectively. Since the introduction of RCM, the non-recurring cost of performing a standard RCM system evaluation has decreased from $100 000 per system in 1987 to less than $40 000 per system in 1992. Today a majority of nuclear power plants in the United States are investigating the use of RCM for preventive maintenance optimization. However there are still many plants that have decided not to proceed with a RCM program because of the significant cost involved.

In 1993, EPRI and PECO Energy Co. initiated a collaborative effort to built on the nuclear industry's experience and develop ways to perform RCM evaluations more cost effectively, so that a benefit can exist in applying RCM methodology to all plant systems. The initial objective of this project was to demonstrate a further factor of two reduction in non recurring RCM costs through streamlining the RCM process while maintaining a high quality product. The system analysis performed in the project has been completed at a cost less than $15 000 per system in 1994/1995 and this has exceeded the initial goal of a factor of two reduction in analysis cost. These streamlined techniques have been demonstrated on 60 plant systems at PECO Energy's Limerick and Peach Bottom nuclear power stations.

3.3.3. The experience of EDF with RCM

At Electricité de France (EDF) the RCM methodology has become the standard means of optimizing preventive maintenance programs. EDF decided to apply this method to all important plant systems (about 50). These 50 systems can be broken down to:

- about 20 safety related systems
- about 30 systems selected upon availability related system or with high maintenance costs.

The studies are being performed by:

- the maintenance department (mainly safety or availability related systems)
- the nuclear sites (mainly availability on cost related systems).

These studies include the use of nuclear experience feedback. All the nuclear sites (20 sites and 54 nuclear units) are participating in the RCM effort.

Implementation of RCM studies on nuclear sites. Each engineering site team is managed by a project manager. Each engineering site team includes about 10-15 specialists. The necessary duration to study a system has been 3 to 6 months, depending on system complexity.

Cost of the Studies

- about 2000 man/hours for safety related system (studies managed by the maintenance department)
- about 500 to 1000 man/hours for a site system study.

Results are significant as compared to the targets. RCM improved the definition of critical equipment. It also increased the efficiency of the main maintenance programs. The reduction of maintenance cost is expected to be:

- about 15% for most systems
- up to 30 % for some equipment of the secondary side (main turbine auxiliaries for example).

RCM living program. EDF expects that the RCM program described above will be completed by 1997. Subsequent to that, a RCM Living Program will be implemented. This program will utilize operating experience feedback and updated reliability data to make further improvements to maintenance.

Major Lessons of the EDF RCM Studies

The RCM methodology becomes the reference method. This methodology, which has been finalized with the pilot sites engineering units, is effective and is adaptable to systems ranging from the simple to the complex. Consequently, the methodology has become the standard method within the Nuclear Generation plants with respect to optimization of maintenance technical choices. It relies on a generic description of the equipment and their failures common to all French nuclear generating plants. For systems playing a part in safety, the safety-related systems in particular, the method is based upon Probabilistic Safety Analyses which have been developed and are updated as necessary.

The results are significant as compared to the targets. The methodology has always lead to an improved definition of the list of critical equipment and to a more efficient preventive maintenance programme. This should result in improved equipment reliability and, consequently, of nuclear power units safety and availability, even though it is very difficult to give a quantitative assessment of the impact. In light of the studies already carried out, it seems justified to reinforce the existing preventive maintenance on certain equipment and to reduce it on other equipment. In some cases, the reduction can be 20 to 30 % of the maintenance costs.

The nuclear power plants have the ability to carry out optimization studies. The pilot nuclear sites have accepted, without any difficulty, the methodology's concepts and have contributed to the final and concrete adjustment of the reference method. By means of the studies carried out and under the management of their site engineering units, sites have demonstrated their ability to assess the targets, carry out experience feedback analyses and optimize the maintenance programmes.

By means of this methodology, the sites are playing an important part in the development of preventive maintenance policies. The implementation by the nuclear power plants of this methodology on important systems should eventually enable, on the one hand, an improved control of the French national and local programmes, and, on the other hand, a quicker evolution of the programmes based on operating experience feedback.

The RCM methodology is a change in culture. RCM focuses on the functions and not on maintaining the equipment in its current state or repairing the equipment as such. Maintenance optimization entails a thorough perception of the targets linked to the functions provided by the equipment. It calls for a good knowledge of the required functions. Such knowledge and such an enhanced conscience should bring about positive consequences on the teams' daily behaviour. This change also involves operating experience feedback. The method underscores the value of the information required and shows all team members in concrete terms the significance of quality operating experience feedback in improving maintenance optimization. This methodology is an important tool for enabling diverse teams to achieve consistent results at diverse locations. It encourages various professions to work in teams.

3.3.4. RCM and nuclear power plant regulation

RCM has been developed by the nuclear power industry for the optimization of its PM programme. Since RCM has been successfully demonstrated for use by the nuclear power industry and has been applied by an increasing number of facility operators, regulatory and other industry organizations have taken a greater interest in understanding the benefits of RCM. The USNRC has proposed the use of reliability based PM evaluation methods (including RCM) as an effective basis for a nuclear plant PM programme. INPO has published a Good Practice document which describes the use of reliability based techniques for PM programme improvement (including the use of RCM). Regulatory organizations are thus recognizing the safety and operational benefits of RCM.

3.3.5. Transfer RCM results to similar plants

EDF and EPRI have developed RCM methodologies and RCM workstation software. EPRI has developed generic component templates which identify the most applicable and effective preventive maintenance tasks and associated task frequencies considering several component characteristics such as equipment frequency of usage, service environment and functional importance. Each template recommends appropriate task frequency and component type. Both EPRI and EDF methods can be used by similar plants without modification. Generic descriptions of components and failure mechanisms can be used by similar plants. Co-operation between utilities, EPRI, and/or EDF is an effective way to control the costs of RCM studies. This co-operation will also allow utilities to use improved methodologies as they begin RCM programs.

(Note: EPRI products are available to members free of charge. Non-members may purchase these products.)

3.3.6. Information sources on RCM

1. INTERNATIONAL ATOMIC ENERGY AGENCY, "Safety Related Maintenance in the Framework of Reliability Centered Maintenance Concept." IAEA-TECDOC-658, Vienna (1992).
2. JACQUOT, J., LEGRAND, P., ZWINGELSTEIN, G., "Development of reliability centered (RCM) methodology for the Electricité de France nuclear plants, - A pilot application to the CVCS system," EPRI Maintenance Optimization Group (EMOG), Boston, MA, August 28-25 1995.
3. DOUGLAS, J., "The Maintenance Revolution," EPRI Journal May/June 1995.

4. IMPROVING PROCESSES

This section describes those maintenance good practices whose principal focus is on improving processes. In general, process improvements lead to increased quality, reduced cycle times, increased productivity, and/or reduced costs. Four areas were identified:

- improved planning and scheduling leads to more efficient use of resources
- information management systems increase staff productivity and reduce errors
- graduated work controls tailor the maintenance process to the importance and complexity of the task
- an efficient post-maintenance testing program to reduce rework and improve reliability.

4.1. PLANNING AND SCHEDULING

If one analyses plants with good operational and outage results, it can be found, that special consideration is given to work planning in these plants. Good planning and scheduling is therefore obviously one of the key factors for effective maintenance. Good planning and scheduling promotes:

- Decreased outage time
- Smooth work during power operation
- Optimization of personnel resources and contractor needs
- Less potential for conflicts between maintenance and plant operation.

4.1.1. Kinds of scheduling

Different kinds of scheduling assist plant management to achieve these goals:

- Long range scheduling for outage optimization (see Section 2.2 for a discussion of long-range scheduling)

- Medium range scheduling (cycle/annual schedule) for power operation
- Short range scheduling (weekly/daily schedule).

4.1.1.1. Medium range planning and scheduling for power operation

The aim of medium range planning and scheduling is to integrate maintenance activities in an optimal way into plant operation. For this, it has been proven advantageous, to implement "maintenance windows". Maintenance windows are preplanned times within which maintenance is scheduled in particular plant areas (and is not allowed in other areas). By identifying such maintenance windows, it is possible to develop detailed plans for work within these windows. Experience shows, that using such maintenance windows reduces the conflicts between different tasks and that integration of maintenance with operation is simplified. These simplifications reduce waiting times and thus contribute to cost reduction. Because the maintenance windows are mainly established based on plant safety aspects, this concept is also a contributor to enhanced plant safety. For an example of medium range planning see Annex C.1.

4.1.1.2. Short range planning

For co-ordination and control of the maintenance when it is carried out, there is also a need for short range planning. It specifically fixes the time for work performance. This short range planning usually covers a time range of 1 to 7 days. In short range schedules, all activities are included, which could affect operation and work sequences in the plant, and which therefore have to be synchronized. These activities include maintenance, periodic tests, performance of plant tests, and plant conditions which deviate from normal plant operation. Because the short range plan is binding for all staff, and deviations can be only accepted in case of unforseeable occurrences in the plant, plant management should approve the short range schedule as well as any changes in the schedule. For examples of short range planning see Annex C.2.

4.1.2. Planning Organization

A substantial factor in the efficiency of the described planning activities is the consideration of all activities in the plant. This necessitates a centralized planning organization. The centralized planning is often included in the operations department or it is a separate organization reporting to plant management. Due to the close interconnections between outage and normal operation, it has been proven successful, to entrust this centralized planning group also with outage planning.

4.2. INFORMATION MANAGEMENT SYSTEMS (IMS)

4.2.1. Introduction

For effective plant operation and maintenance, computer aided information management systems (IMS) have become more and more important. Within an IMS, the modules for maintenance management are essential. The costs to acquire and implement an IMS are high. However, many utilities have found these costs to be justified for the following reasons:

Safety related aspects:

- reduced potential for human errors (exact data bases, conflict control capability)
- administrative control capability (quality assurance of planning and performance of work execution by means like sequence control and responsibility checks)
- more transparency of work flow, better and easier staff information
- schedule forecast and notification or initiation of repetitive (required) tasks.

Efficiency and cost aspects:

- effective support for plant personnel in the performance of complex tasks
- easy access to plant/component data, documentation by search functions
- more efficient conduct of routine tasks
- automatic documentation functions for life history, PRA data collection and evaluation
- reduction of paper handling ("paperless office")
- information transport by electronic mail, no need to sign personally e.g. in the control room.

Strategic reasons:

- significantly more transparency and insight for plant management into most plant activities
- capability for routine performance checks
- capability for a variety of efficiency evaluations
- capability for activity-based cost control
- large amount of available data reduces problem of personnel rotation (know how transfer).

4.2.2. IMS Functions

The efficiency of an IMS system depends to a great degree on the number of functions which are performed by the system. In practice there is an interrelation of all plant activities and the computer system should support all functions. The most modern systems can support:

- work planning
- tagging
- maintenance/equipment life time history
- malfunction/event reporting and control of their recurrence
- storing, listing of documentation including searching and presentation on CRT
- update of data and documents
- scheduling of repetitive tasks like preventive maintenance, functional tests (time based
- and/or based on running hours, starts.)
- outage planning
- health radiation planning and dose control
- training and qualification update and schedule control for retraining
- spare part management, storing and retrieval
- cost control and accounting
- management observations and evaluations.

Figure 2 shows the typical input/output data related to work actions which can be completely supported by an IMS.

4.2.3. Demands on IMS technology

There is much discussion among computer experts about hardware and/or software configurations of IMS systems. Existing systems clearly demonstrate that there are different ways through which the goals and features of a IMS can be achieved. On the market are fully integrated concepts (see Annex C.3 for a description of an example) as well as systems using several different programmes which are connected through mutually compatible interfaces The interfacing version is often selected by organizations who want to combine several existing isolated management systems into one system. An example of an interfacing system is provided in Annex C.4. The decisions must be made based on company overall computer concepts, existing soft ware modules, hardware capability and last but not least cost aspects.

Based on experience with various systems there are some essential features, which IMS system design should consider. These are:

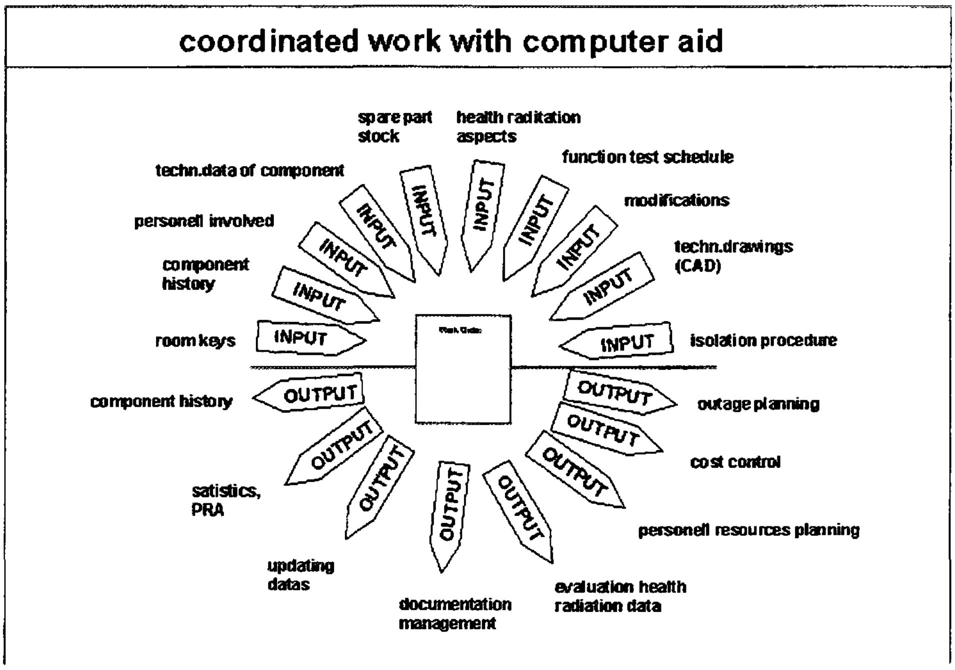


FIG. 2. Typical IMS input/output data.

- use of a non-redundant data base, that means a particular data exists only once in the computer system
- common, user oriented handling of all systems
- use of standardized terms and formats in all systems.

Several IMS systems have been developed in recent years and are available "off the shelf" for a reasonable price. Experience indicates that up to 80% of a system can be utilized without modification. It should be recognized, however, that the greatest cost of implementation of an IMS will be in developing a data base of high quality information for the IMS and in training plant staff to use the IMS. Some modification is necessary to customize the system to existing plant processes. In such cases, it may be more effective to change the plant processes to fit the system.

4.2.4. Management tasks related to IMS

The implementation of an IMS usually requires modifications of work processes. All processes should be re-evaluated and if necessary reengineered to achieve optimized business results with the investment in an IMS. One important point is a clear definition of responsibilities for data collection and/or data update. An uncontrolled modification of data must be prevented. Personnel training prior to the implementation of an IMS is essential. Experience shows that the optimal point for IMS implementation is shortly after an outage to allow a long training period" under more relaxed circumstances than during outage periods.

Implementation of an IMS system requires significant resources for several years for such tasks as component database development and validation. Such a system also requires extensive training of plant staff. The ongoing costs of running and maintaining the system are not negligible.

4.2.5. QA aspects of an IMS

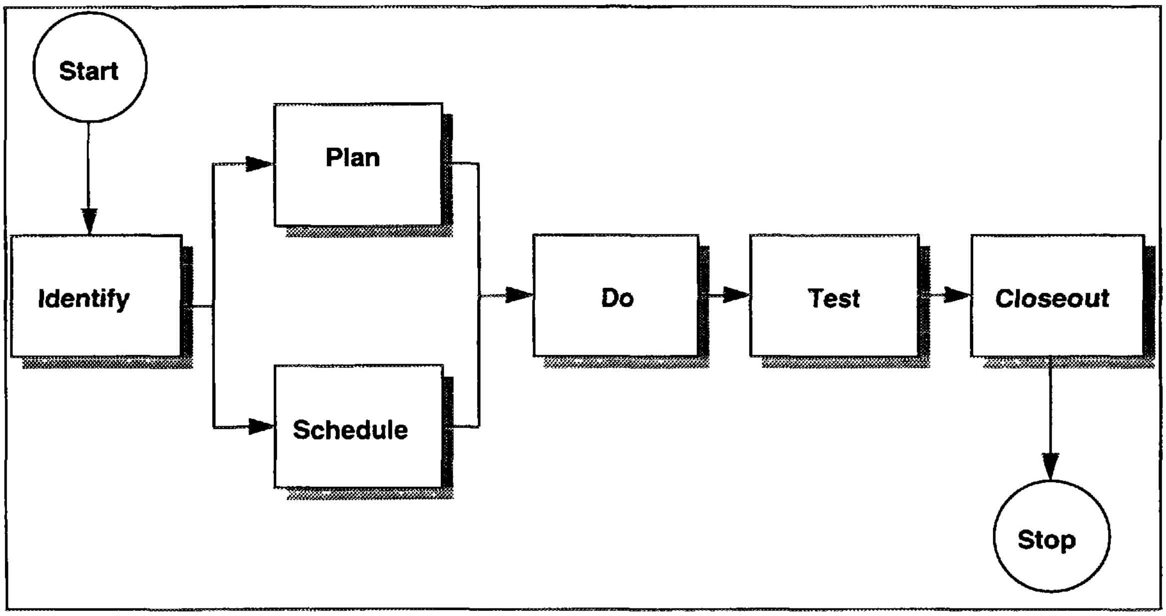
As mentioned before, an IMS allows control of work flow, gives easy supply for data evaluation, performs conflict controls and responsibility checks. This means, that a variety of administrative safety functions are supported by the IMS. Therefore it is essential, that the IMS system itself is designed and tested under appropriate quality standards like DIN ISO 9000.

One of the main problems related to IMS implementation is the initial data collection to establish the system. Very often the fear of the enormous effort and related cost for data collection hinder utilities in implementing an IMS. It should be mentioned therefore, that nowadays software tools are able to transfer existing data into an IMS data bank with low cost. The transfer can be made with QA checks and discrepancies evaluation. So the data transfer is also a good opportunity to "clean up" existing data bases. If a new plant is under construction it should be ensured (by contract or utility measures) that the data is collected and updated during construction and commissioning to achieve a satisfactory starting point for the IMS.

4.3. GRADUATED WORK CONTROLS

4.3.1. Purpose

Graduated work controls provide a means of tailoring the maintenance work control process to the significance and complexity of each activity. Typically, the work control process specifies the method of identifying, planning, scheduling, performing and closing a maintenance activity. This is demonstrated in the following flow chart.



Each of these process steps will require certain organizational reviews, completed forms and other process requirements. The process is designed for properly handling the most important and complex activities. Often, all maintenance activities must proceed through this process regardless of their importance and complexity. For routine, simple activities, many of these process steps are unnecessary. By designing the process with graduated work controls, workers become more efficient and the overall cost of maintenance is reduced.

4.3.2. Minor maintenance

One approach to applying graduated work controls is to develop a separate process for maintenance activities that are relatively minor in nature. A ***minor maintenance*** process is currently used at many nuclear power plants around the world.

There are several important aspects of minor maintenance:

- A screening process is required to ensure that minor maintenance activities are properly identified so that required work controls are not bypassed. Minor maintenance is not allowed if the activity affects a safety function or power generation.
- Workers must be trained to stop when the work exceeds the scope of a minor maintenance activity and proceed through the normal work control process.
- Minor maintenance would normally not require any documentation of work completion.
- Maintenance supervisors will typically schedule minor maintenance activities outside of the plant scheduling process.
- Minor maintenance should not require any special controls for industrial safety or radiological safety.

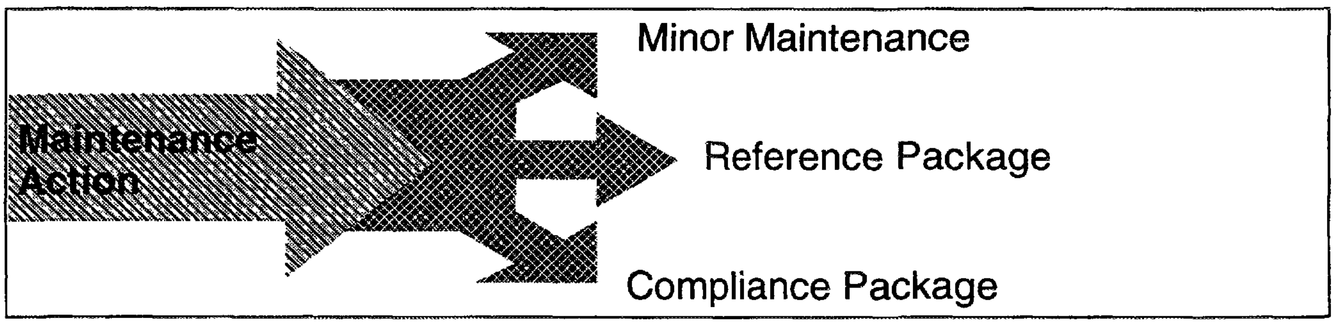
The minor maintenance process is used to rapidly correct minor deficiencies in the plant.

4.3.3. Graduated work controls

The use of a minor maintenance process only partially addresses the inefficiency of a single work control process. A more effective approach is to build graduated work controls into the process. Several different layers of controls can be created. The work control process can then be customized to each maintenance activity. The layers can be based on several criteria. For example:

- Does the activity affect a safety function?
- Does the activity increase the risk of a plant trip or transient?
- Does the activity require documentation or work history?
- Does the activity implement a change to the plant configuration?
- Is the affected equipment risk significant?
- Is the activity complex?
- Does the activity create a significant risk to personnel safety?

The number of layers in the process will depend on individual plant, company or regulatory requirements. However, too many layers will make the process difficult to understand. One example of graduated work controls follows:



Requirements	Examples
Minor Maintenance	
• Does not require a permanent plant record • Does not require a written procedure or instructions • Worker expected to use appropriate resources • record of work maintained in electronic database as appropriate	• Preventive maintenance on Balance-of-Plant equipment where there is no risk of a plant trip or transient • Tighten tubing fittings • Valve packing adjustments • Replace annunciator cards • Replace pressure indicators
Reference Package	
• Record will be maintained in permanent plant files • Activity does not require a written procedure or instructions • Worker expected to use appropriate resources	• Safety MOV limit switch adjustment • Replace disc on manual valve • Minor PM on safety equipment • EQ elastomer replacement • Replace a circuit board
Compliance Package	
• Record will be maintained in permanent plant files • Activity requires a written procedure or work instructions	• Reactor Protection System testing • Replace a main coolant pump seal • Overhaul an emergency diesel generator

There are several important aspects to implementing graduated work controls:

- Workers must be trained on the process and must understand when to apply increased controls when the scope of the activity changes.
- A screening process is required to ensure that the proper controls are applied initially.
- The process is made more efficient when unnecessary or redundant reviews and controls are eliminated entirely.

4.4. POST-MAINTENANCE TESTING

Post-maintenance testing or requalification tests check the performance of equipment or systems to ensure that they remain capable of performing their design basis functions following maintenance, modifications or operating events. Therefore, post-maintenance testing is effective in reducing rework and improving reliability. On the other hand, excessive or poorly coordinated testing increases costs without a commensurate improvement in reliability. Post-maintenance testing is generally applied in successive stages. It starts with testing of the component and ends with the functional test of the system.

Post-maintenance testing is generally conducted for one or more of the following reasons:

- to ensure the identified deficiency has been corrected
- to ensure that no new deficiency has been created by the maintenance action
- to demonstrate that the component/system meets its intended design function (such tests are sometimes called operability tests, or surveillance operability tests, particularly if they demonstrate a safety function).

Particularly at the end of a planned outage, when maintenance has been performed on a variety of plant components and systems, many utilities have found in it a challenge to complete post-maintenance testing in an efficient and effective way. Parts of the challenge are to:

- reduce unneeded testing, based upon low consequences of failure,
- avoid redundant testing,
- establish conditions suitable for functional tests (support system operation, etc.),
- coordinate activities among different plant organizations (e.g., operations and maintenance departments)
- coordinate scheduling and conduct of testing with the regulatory authority.

Through using the methods identified above, some utilities have made dramatic improvements in both the quality and time required for post-maintenance tests (e.g., reducing the time from completion of maintenance to power operation from five days to one day). Two keys to achieving such results are:

- an integrated, systems approach to the overall post-maintenance test program
- dedicated, long range planning and scheduling using an IMS as described in Section 4.2.

Operating experience feedback should be used to aid in decision making. For example, if the plant has never experienced leaks in a particular fluid system, and the safety consequences of such leaks, if they were to occur during startup, are minimal, then it would be clearly unnecessary to do a separate leak check of the system. Rather the leak check could be done as part of the operability testing. However, if there have been several past instances of such leaks, resulting in a need to terminate the startup and significant delays, then conducting a leak check prior to operability testing may be warranted. In this way, a value-added approach can be taken to determine whether the value to be gained from a particular post-maintenance testing is worth the cost in terms of time, radiation exposure, costs, etc. Obviously if there is a regulatory requirement to perform a particular test this requirement must be complied with. However, some utilities have demonstrated to their regulators through operating experience and analysis that there is little or no value in the particular tests (or even a negative consequence in terms of safety or radiation exposure) and as a result have had such test requirements relaxed.

Some utilities have found that they have created unnecessarily complex administrative systems. Bottlenecks have resulted because the system would not allow maintenance activities to be closed out unless post-maintenance testing was performed, even if the consequences of inadequate maintenance were minimal, while at the same time, plant conditions did not permit testing the component/system. Such unnecessary complexities have a negative effect on both safety and plant operations.

5. IMPROVING PRODUCTIVITY

Improving productivity is essential for the success of any NPP. There are five significant areas that should to be considered:

- Improving human performance
- Teamwork
- Sharing of resources and experience
- Outsourcing and contracting
- Improving radiation management.

5.1. IMPROVING HUMAN PERFORMANCE

The startup organization determines the plants initial performance by how well it integrates plant as-built design with plant processes, described by administrative control documents, and worker performance. The design and administrative controls are initially fixed at startup. From that point onward, achieving high standards of operational performance depends principally on human performance. Maintenance personnel are major contributors to operational performance.

Obviously, the design can be modified and administrative control documents can be revised after initial startup, so in a sense they are not fixed. In fact, the plant staff recommends and implements many such changes, large and small, during a plants lifetime. The results, whether expectations are met or not, depend on human performance, in this case, on maintenance personnel performance. Arguably, after startup, maintaining high quality or improving maintenance depends mainly on human performance. Consequently, as maintenance managers strive to improve maintenance performance by implementing the good practices contained in this document, they would do well to keep in mind that their success will be dependent on the performance of the maintenance staff.

This section discusses several ideas for improving human performance that have been implemented successfully by maintenance managers. They have noted that improving human performance (or maintaining it at high levels) depends on how well managers develop the following:

- competent staff (knowledge, skills and attitude - safety culture)
- efficient work management processes that facilitate successful task accomplishment
- planning that fosters interdisciplinary teamwork, eliminates interference and integrates work management processes
- supervision (team leadership) to help solve arising problems and engender worker competence
- adherence to management's expectations, which should be high (you only get what you expect).

Each of these key human performance success elements are discussed in the following paragraphs, with emphasis on maintenance.

5.1.1. Competent staff

The key to competent workers is effective training and stringent qualification. The paragraphs below describe some key elements used by nuclear power plants in the development of a competent staff through training. (Refer to IAEA Technical Reports Series No. 380, "Nuclear Power Plant Personnel Training and its Evaluation, A Guidebook," for further information about maintenance training.)

- A maintenance training program that is based on a systematic analysis of training needs is essential to the development of competent maintenance staff. In addition, maintenance staff performance feedback and industry operating experience must be effectively considered in establishing and maintaining the training program content. The training program content should aim at providing the worker with the knowledge and skills needed to independently perform assigned tasks and duties well. In addition, the content of the training program should include fundamentals training that instills respect for the unique character of the nuclear core. In particular, instilling an attitude that causes workers to stop and seek help when faced with uncertainty is an important task of training. The best training incorporates teaching workers to have a questioning attitude and a willingness to seek help when unsure. (Refer to 5.2 for information about the role of training in the multi-discipline team.) (Refer to IAEA Technical Reports Series No. 380, "Nuclear Power Plant Personnel Training and its Evaluation, A Guidebook," for more information on the systematic approach to training.)

- Maintenance management should take steps to verify that personnel assigned to perform maintenance tasks and duties are capable of performing them independently. Qualification on the basis of demonstrated skill and examined knowledge is an effective method that can assure the maintenance manager of staff competency.

- Maintenance management should be directly involved in maintenance training. They should be personally involved in evaluating the effectiveness of training. In addition, many maintenance managers have found presenting or discussing management's expectations in the training environment to be very effective. The maintenance manager should be the owner of the maintenance training program.

- Making training as real as possible enhances training results. Training should simulate real problems and should be performed in an environment that emulates real plant conditions. For example, students should work as teams using the same work control documents and procedures, techniques and protocol that are used in the plant. This includes continual reinforcement of management's expectations at every opportunity.

- Many maintenance managers effectively use the training environment for instilling their expectations and a personal safety culture into maintenance staff. In the continually monitored training environment there are frequent opportunities for positive reinforcement of desired behavior and for coaching when expectations are not met.

- Ensuring the continuing competence of maintenance staff requires periodic demonstrations of proficiency in performing a set of core and specific tasks.

5.1.2. Work management processes

The safe and efficient accomplishment of maintenance work depends largely on work management processes. Work management processes are usually described in administrative control documents and are the means by which managers control the performance of station activities(refer to Section 5.2 for methods to improve work management processes). From a human performance perspective they should consider the following:

- Work management processes should focus on facilitating safe, high quality work.

- Their audience should be a highly competent and motivated work force.

- They should avoid unnecessary redundant reviews and approvals. High quality work should be expected and built in. Every review and approval should be conducted as if it is the only one. Do not dilute responsibility.

- Work management processes should foster cross functional teamwork. Processes should be designed so that teamwork is a natural outcome. (Refer to Section 5.2 for further discussion of teambuilding.)

- Management is responsible for establishing and maintaining effective and efficient processes. However, the workers who use the process or who are the object of the process are in the best position to identify where process improvements are needed or how to accomplish the process more efficiently. Managers should encourage worker involvement in process improvement.

5.1.3. Planning

Planning is management's tool for optimizing process implementation. Proper and timely planning is essential to the successful performance of maintenance. Proper planning and careful plan implementation will ensure the effective integration of work management processes so that maintenance tasks can be started on time with safety built in (refer to Section 4.1 for further discussion of planning). The following are some key human performance objectives of planning:

- Most importantly, planning, whether performed months in advance by planners or by a multi-disciplined team just prior to job execution, should be used for off-line consideration of nuclear and worker safety. Consideration of safety related issues off-line can avoid forcing workers into making safety decisions under the stress of time constraints.

- Planning provides a timetable for effective and efficient integration of processes for accomplishment of tasks. It is management's tool for building in efficiency. For example, the conduct of compatible corrective and preventive maintenance while a system is out of service improves efficiency. It also affects the maintainer who can become frustrated and question management's credibility when related work on equipment is scheduled in series rather than in parallel.

- Management is responsible for providing workers with all the things they need to succeed. Planning provides the mechanism for management to carry out its responsibility. Continually performing maintenance tasks successfully (in accordance with management's expectations) is personally rewarding and satisfying. Continual success has a strong influence in maintaining positive attitudes.

- Effective planning allows workers to complete work when scheduled by eliminating process induced delays, thereby not encouraging workers to short-cuts because work time has been compressed and scheduled completion time looms.

5.1.4. Supervision

Supervision (coaching), whether conducted by a supervisor, team leader or team peers, compensates for shortfalls in worker competency, processes and planning. The following are some key elements of supervision from a human performance perspective:

- One of a supervisors main jobs is to intercede on behalf of the worker and to clear obstacles to successful job completion when they arise. In order to carry out this function, supervisors should be seen as the workers' main source of help. Supervisors must encourage workers to seek their help when faced with uncertainty or problems.

- Supervisors are responsible for verifying the competency of workers prior to task assignment or to provide compensation. Task assignments are normally made to workers who are qualified to independently perform the work assignment. In the unusual circumstances when this is not the case, the supervisor is responsible for providing direct supervision or other appropriate compensating action.

- As the direct point of contact with the workers in the field, the supervisor is responsible for communicating management's expectations and for reinforcing them. Implicit in this responsibility is the development of a safety culture within the work group.

- In order to be effective in carrying out their responsibilities, supervisors should be given adequate authority. They should have adequate authority to reward positive behavior and disciplinary authority that allows them to demand adherence to management's expectations. In addition, in order to be effective in solving workers' problems they should have authority to make on the spot changes, as appropriate.

- Traditional supervision by an assigned supervisor is being replaced with team leader and/or peer or team supervision in many utilities. In the discussion above, the term "supervisor" is used to mean any of these (refer to Section 5.2.2.4 for discussion of the formation of multi-disciplined teams).

5.1.5. Management expectation

Performance expectations describe management's standards and how they want work performed. Some key elements of performance expectations are:

- Standards should be high; but they also should be reasonable
- Clearly and effectively (repeatedly) communicated
- Reinforce positive behavior; include a system of rewards and celebration of noteworthy performance (refer to Annex D.2 for an example of a reward approach)
- Must not be compromised, especially by managers
- Require continual and consistent monitoring by everyone; managers, supervisors and workers
- In-house operating experience should be used to monitor trends. A deficiency reporting process, with low reporting threshold and worker participation in reporting, should be an important part of the in-house operating experience program. Management should work to create a non-threatening environment that encourages self-reporting.

5.2. TEAMWORK IN MULTI-DISCIPLINE GROUPS

Teamwork is one of the most important aspects of any group and in particular within a maintenance organization which has to bring to bear many different aspects and disciplines. Almost all NPP equipment depends on a variety of maintenance disciplines. For example, a pump to operate properly electrical, mechanical, control and instrumentation aspects are all important.

For effective maintenance, multi-discipline groups should be considered. These groups should operate in an organizational structure specifically designed to best utilize these arrangements. An example of such a structure is shown in Figure 3. The following sections describe reasons for considering multi-discipline groups for maintenance.

5.2.1. Improved efficiency

Multi-discipline team, by virtue of their organization and make up, are able to apply the necessary skills as one cohesive group. The following are details with respect to efficiencies that can potentially be realized through multi-discipline teams.

5.2.1.1. Reduction of interfaces and hand-offs

Often situations and problems arise during maintenance that start off with one discipline and end up with a solution involving another discipline. Typically a mechanical vibration problem may be monitored by an electronic condition monitoring system. Where separate discipline groups are involved, the individual groups have different priorities and concerns. Consequently interface and hand-off issues often arise which reduce the effective consideration of an overall issue.

5.2.1.2. Increasing productivity of individuals and teams

Where individuals have the ability to make use of the rapid deployment of all disciplines within their team or where they themselves develop and use such a capability it leads to greater productivity of both the individuals and their teams.

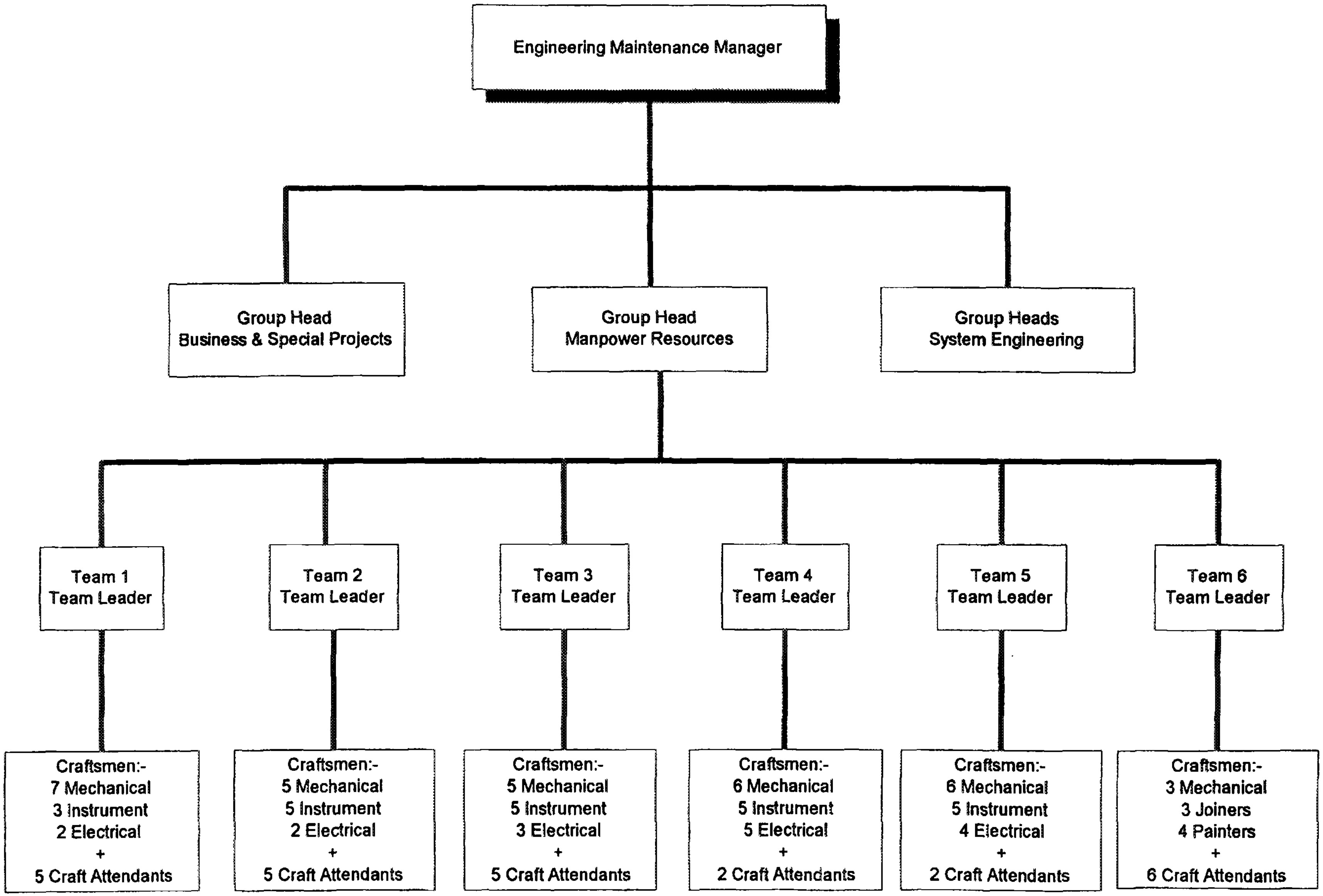


FIG. 3. Multi-skilled team structure.

5.2.1.3. Increased ownership of a maintenance task or system

As multi-discipline teams develop they inevitably become more closely associated with particular tasks and plant systems. This ownership improves the quality of the maintenance as a greater degree of ownership, understanding of plant history, and plant performance develops. Work areas or functions may be assigned to groups to reinforce this ownership (Figure 4 provides an example of such assignment). Where groups or individuals are task based rather than plant or system based the same advantages apply to the task.

5.2.1.4. Job satisfaction and skill broadening

As individuals recognize the efficiencies, flexibility and improvements that can result from multi-discipline groups, increased job satisfaction and motivation often result. Also, individuals have opportunities to broaden their skills to cover more than one aspect of a job or task.

5.2.1.5. Reducing costs and increasing flexibility

The increased flexibility brought about from multi-skilled teams often with skill broadened individuals working within the team leads to reduced costs. Individuals are able to identify opportunities for cost reductions.

5.2.2. Skill-broadening versus multi-skilling

There is often confusion concerning the differences between skill broadening and multi-skilling within the context of multi-discipline teams.

> **Multi-skilling** is where an individual is able to operate across a variety of disciplines over a wide range of tasks. For instance a multi-skilled worker would be able to maintain a complete fluid system covering its computer process controller, electrical system and mechanical equipment. While the concept of multi-skilled workers operating in multi-skilled teams is a desirable objective it is rarely practical within the maintenance environment because of the large and complex range of plant and systems within a nuclear power station. However, within the operational organization the multi-skilled worker is a practical possibility.
>
> **Skill broadening** is where an individual takes on additional duties related to disciplines other than his/her core discipline but related to the particular plant area or process within which they work. For example a skill broadened mechanical craftsman would be able to electrically disconnect/connect a pump motor for maintenance.

Within a maintenance organization a practical and achievable approach is to employ skill broadened individuals working within a multi-disciplined team. In this way individuals are able to retain a high degree of skill in a particular area yet at the same time having sufficient skills to maintain complete plant items. This enables tasks to be performed by a single person, encourages greater ownership of plant items or tasks, and reduces interface/communication problems. Also, increased efficiency can be obtained by self monitoring and self-surveying in radiologically controlled areas. When all of these arrangements are linked with a suitable reward and recognition policy it can improve the motivation and efficiency of individuals and groups.

Training for skill-broadening. For skill-broadening to be effective it is vital for there to be adequate training. There are two prime objectives for the training. Firstly, to provide the necessary skills needed to perform the tasks and secondly to provide sufficient understanding to know when a particular task is outside the competence or authority of an individual. Both aspects should be carefully considered when identifying a training programme and profile. Shown below is an example training profile to illustrate these objectives.

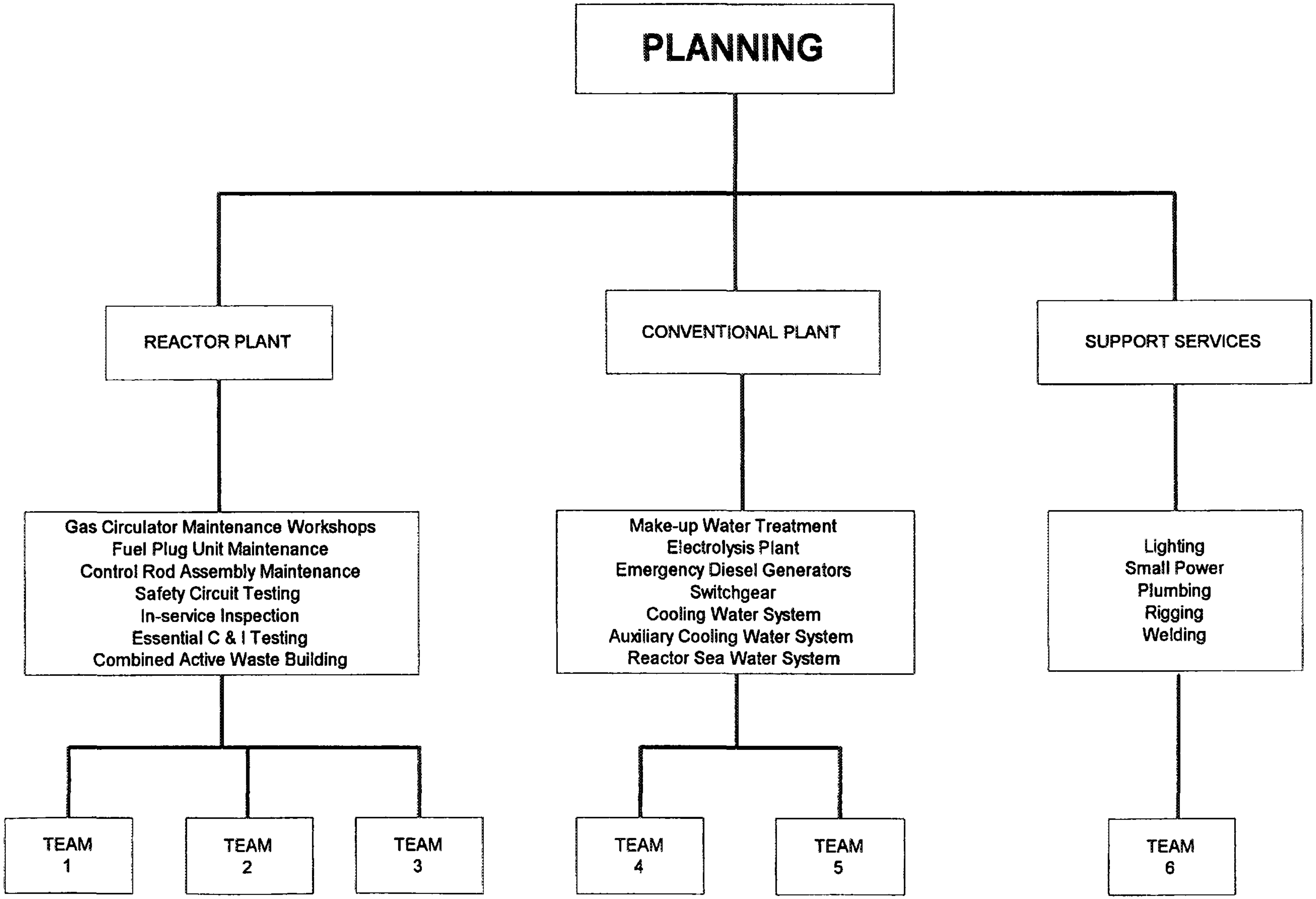


FIG. 4. Work area division.

Example Training Profile for a Multi-Discipline Team Member

General Training

- site induction
- competent person (electrical, mechanical and radiological
- muster procedure
- environmental awareness
- quality assurance awareness
- maintenance computer system use

Role-Related Training

- introduction to gas analysis system
- introduction to water analysis instrumentation
- closed circuit television use
- health physics instrumentation
- programmable logic control

Development Skills

- advanced use of the maintenance computer system
- national qualification in control and instrumentation
- presentation skills
- quality improvement process

Job-Related Skills

- work on high and low voltage apparatus
- protection equipment
- understanding electrical drawings
- measurement of pressure, level, flow and temperature
- soldering techniques
- lifting and moving
- commercial awareness (business practices)
- regulatory training

Damage Repair Team Skills

- breathing apparatus training
- movement in a damaged plant
- radio procedures
- radiological procedures
- use of fire extinguishers
- muster procedure
- damage repair methods
- heavy rescue methods

Individual Improvement

- training as identified by appraisal to improve the individuals ability in identified competencies

In addition to the objectives discussed in the preceding paragraph, other characteristics of a suitable training programme are that it should be:

- **Job based**. For training to be successful it is important that it is applicable to the tasks that the individual will perform at work. This is best ensured by a significant part of the training being job based and undertaken on the job itself. It is also acknowledged that in addition general training is required that can be efficiently conducted off job.

- **Industrially recognized**. Training should maintain high standards and be recognized as being at an appropriate level by other industrial units. Where possible an industrially recognized scheme or qualification should be sought. This provides an independent view of the appropriateness of training.

- **Up to date**. As technology advances training modules should be updated and individuals given refresher training to ensure they maintain standards.

5.2.3. Formation of multi-skilled teams

5.2.3.1. Balancing flexibility and ownership

When forming multi-discipline teams a balance needs to be made between the flexibility of the team being able to tackle any plant problem on the station and the need for ownership of a particular plant item or system. Where groups are fully plant item or system related it can result in a reluctance to work on other plant areas. One group can be struggling to cope with a difficult plant problem while another group is lightly loaded on a plant area with no problems. To cope with this situation individuals are often transferred from one team to another. This often results in tensions because of the inclusion of an 'outsider' on the team. Also, Team Leaders are often reluctant to release team members or reluctant to ask for help even when it is badly needed. Hence a fully plant or system based team can become on inefficient in use of resources.

An alternative is a task based team where maintenance tasks are undertaken by the team as they arise with the team owning the task rather than the plant/system. In this way teams are loaded appropriate to their current workload. Greater flexibility results from this organization but this is somewhat at the expense of plant/system ownership.

Therefore, in deciding the best organization a compromise is often required, balancing ownership with flexibility. For example, task based teams allocated and working within general plant areas like turbines/conventional and reactor plant provides a suitable compromise. It is recommended that the above aspects are fully considered and the balance required for a particular location and organization determined.

5.2.3.2. Team planning/empowerment

Within the framework of an overall plant programme the team itself is often best equipped to plan and direct the work to be performed. Self directing teams feel empowered and motivated. This also has the advantage of pushing decision making down to the lowest appropriate level.

5.2.3.3. Monitoring/measures

In order to determine whether efficiency is improving it is necessary to monitor performance. There are four significant areas that should be measured, they are cost, quality time and safety. The measurement parameters should reflect each of these. Typically, measures should include reported accidents, near misses, events due to maintenance, defects, rework, costs and time.

5.2.3.4. Team leaders

Any team needs a leader either in a formal or informal sense. The selection of the leader is vital to the success of any maintenance team. As well as technical competencies the maintenance team leader should be skilled in organizational, project management, people development, customer focus, influencing, communication and business management competencies. When selecting team leaders it is desirable to identify a post (job) profile to understand all the different facets of the role. Shown below is an example team leader post profile:

Team Leader Key Responsibilities

- ensure team activities support business plan
- maximize utilization of resources
- support, motivate and develop team
- ensure effective communication
- monitor performance against targets
- carry out team member appraisals

Team Leader Accountability

- ensure the maintenance plan is met
- authorize expenditure within agreed limits
- motivation and team performance
- initiate work process improvements
- safety and quality of work carried out by the team

- assist in team member selection
- manage safety and quality within the team
- assist in developing the business plan
- respond positively to customer needs

Team Leader Knowledge and Expertise

- experience in one or more maintenance field
- appreciation of the range of technical functions within the team
- competent to prepare budgets and remain within them
- competent to motivate and lead a team

Team Leader Authority

- authorize expenditure within agreed budgets
- resolve disciplinary matters within company guidelines
- commit resources consistent with business plan objectives
- assist with business plan preparation

Team Leader Flexibility

- the post (job) holder will be expected to carry out duties within their competence which may well be outside those duties normally associated with their position

Team Leader Qualifications

- nationally recognized supervisory management qualifications would be advantageous
- nationally recognized technical qualifications would be advantageous

The use of competency based selection interviews is a useful way of identifying suitable team leaders. Also, as part of the development of team leaders it is important for adequate training to be given in these areas. Dependent on the size of the team, a significant proportion of a team leader's time should be spent on the competencies identified above.

5.2.4. Training and qualification of maintenance personnel

For nuclear plant to be maintained safely and economically it is essential that maintenance personnel are suitably trained and qualified. Indeed in many countries this is a requirement of the regulator. This requirement should not only include employees but should also extend to contractors who undertake work. When considering training and qualification, the following should be considered:

- The basic skills/qualifications required for the job
- Knowledge of the plant area/particular components
- Knowledge of the safety issues related to the plant; nuclear, radiological protection and industrial
- Experience of the individual.

Where shortfalls are identified there should be a training plan/monitoring arrangement in place. For craft staff, consideration should be given to specific training for activities and for individuals to be qualified for these activities, particularly where analysis identifies a training need related to safety or plant availability.

5.2.5. Management expectations

One of the most important aspects of improving the maintenance process is the communication of management expectations. The setting of standards and the provision of feedback when those standards are not achieved is a significant tool in the motivation of teams to achieve goals. Often teams who only achieve low standards do so because a low expectation is set by management or the expectation of management is not clearly communicated to the team. The team leader plays a vital role in setting, interpreting and achieving management expectations.

5.2.6. Creating the right environment

When embarking on multi-disciplined team building, a mistake that is often made is to believe that selecting the right people and training on its own is enough to guarantee success. This is not the case. Unless we change the way in which we work and the environment in which this work is done, often the main gains are not achieved. Take the example of the fitter expanding his knowledge into electrical work. On his return from training, the only way forward is to ensure that his contribution to the team utilizes these new found skills. Considerable effort may be needed in making changes to the maintenance organization, validating new levels of competency, and coaching. One must consider the environment in which these newly formed teams must operate, this being both cultural and physical:

Creating the right cultural environment. In many companies, demarcation with regard to work tasks, no longer exist. Greater flexibility is demanded by both employer and employee. The freedom to develop and apply new skills in line with new technology and working methods is generally the norm. However, we still suffer from the cultural gap between management and manual workers. Unity of purpose is essential and it is important to recognize and acknowledge shared values. These values can be translated into company and individual organization goals which need to be communicated to all concerned. Each individuals contribution to these goals should be visible and appropriate recognition given to their achievements.

Creating the right physical environment applies to the plant and equipment on which the teams are to carry out the maintenance, as well as the area set aside for the supporting maintenance, commonly referred to as "office space". The office space layout should give consideration to the needs of the process and resist the setting-up of barriers, both physical and psychological, between inter-relating groups. Physical barriers traditionally used as the point for transferring work from the supervisor to the craftsperson should be removed. Instead, open areas for members of the team to discuss the priorities and the manner in which the work will be undertaken, should be created. This may not be restricted to the traditional office complexes, but may include areas set aside in workshops and plant areas where environmental conditions permit.

5.2.7. Development of teams

In a climate of constant change and the need for increased efficiency it is necessary for teams to continuously benchmark their performance against others and improve the way in which they work.

For development to be successful a model of change needs to be applied. Internationally, there are many models for change often tailored to the particular needs and culture of the country in which the plant applies. However, these should all have features that recognize the linkages between various aspects of the organization. The model shown in Figure 5 is a convenient and recognized tool for understanding the linkages.

Each of the features in Figure 5 can be considered as interconnected. For achievement of the shared goals all the features must move forward at a similar rate. If any one feature is neglected it will hold back the others. For instance, it is not possible to change the structure of an organization to an effective multi-disciplined team organization without changing the supporting systems in the organization and the skills of the staff within the team.

5.3. SHARING OF RESOURCES AND EXPERIENCE

One effective way to improve the maintenance management program is to share corporate resources. This section describes these maintenance enhancement measures and their basic policy while introducing some actual examples.

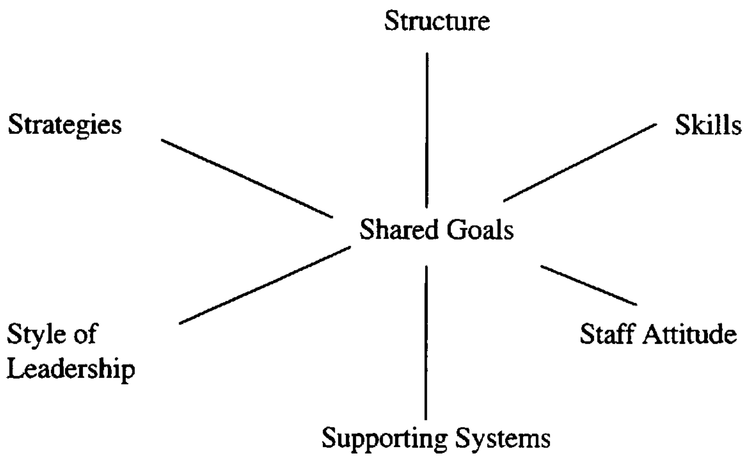


FIG. 5. "7 Ss" model.

5.3.1. Sharing of human resources

For the effective use of knowledge and resources, sharing of human resources can be recommended. This method will be beneficial not only for the utility itself but also for the employee . from the viewpoint of management, sharing of human resources will improve efficiency, while plant staff gain knowledge and career growth. At the same time, however, there remains some issues to be solved for the effective implementation of sharing of human resources.

5.3.1.1. Sharing methods

Sharing of human resources may be conducted in various manners: among sister units, other sites, head office and other utilities.

Among units. Sharing of human resources among units can be most easily and effectively conducted because of common characteristics in terms of the facility, equipment and experience. More efficient utilization of manpower can be achieved through deliberate planning of the power generation schedule so that the refueling outage and service outage at each unit will be conducted at different times.

Among sites

- **Personnel exchange among sites**. Assigning a person who has accumulated some experience for a certain period at another site may be effective for his own motivation as well as for utilization of his experience and technique. This method may be applied to the cases between a site and the head office as well.

- **Exchange of special task teams**. To capitalize on the internal knowledge base, each site may have one of special task teams such as refueling, reactor disassembly and reassemble team, diesel generator team, pump seal team, motor-operated-valve testing team and send the team to another site during outage periods. Each team should have more members than are required for an outage. This prevents the same people from having to work every outage at every site and supports a utility's effort to broaden the knowledge and skills of its employee.

- **Company-wide volunteers to supplement posts**. To facilitate this method, systematic handling and understanding of work load are essential; it is more effective to know exactly who in what section is specialized in a particular technique. When implementing this method, it is necessary to evaluate in advance how much extra load will be imposed on the remaining staff. Sharing common resources can be more than just for maintenance staff. An employee who volunteers as a shared resource can come from a unit's own support staff, from a sister unit's staff, or from headquarters, or another part of the Company.

- **Sharing of specially skilled personnel among sites**. It is not efficient for each site to have their own personnel with specialized skills. Thus, it is necessary to register employees with specialized skills to send them to a required site on request. This method may also apply to those who have gained expertise for specific problems in various trouble cases and large scale modification projects.

- **Sharing of routine activities**. Sharing of human resources can be enhanced by a method such that a site provides common routine activities such as training for radiation protection and reactor theory and modification engineering for another site. Even sharing of business functions is also possible. For example, sites located in the same state or prefecture can jointly deal with taxation procedures.

Between fossil and nuclear power plants. Fossil and nuclear power plants have a good deal in common with each other; for example, it is rather easy to exchange personnel in fields such as those related to electrical facilities and turbine systems. It is expected that exchange of management personnel as well as staff may enhance interchange of experience and induce innovative ideas from different viewpoints. However, to make this approach successful, the following items should be carefully considered for the employee who comes from a fossil power plant:

- safety culture of NPPs
- plant safety related systems and their design philosophy.

Among utilities. When it is not efficient for an utility to have engineers specialized in advanced technology, etc., sharing of the personnel among utilities may bring significant benefits. For example, a contract can be concluded between utilities concerning personnel assistance such that a utility may send an engineer specialized in seismic design to another utility. Personnel exchange in such a way can be achieved between a utility and a contractor as well in areas such as plant engineering.

5.3.1.2. Benefits of sharing

Sharing of human resources may not only lead to cost reduction for the utility but also bring many benefits to maintenance personnel. Maintenance personnel can broaden their experience in various types of equipment and tasks and improve their skills through personnel exchange between sites and utilities. In addition, an extension of opportunities for employees to work at all the sites may contribute to improvement of the company's experience base.

5.3.1.3. Issues to be solved and countermeasures for sharing

One of the biggest issues in such sharing is the difference in procedures and configuration between plants. Accordingly, it is necessary to enhance similarity among sites as much as possible by streamlining procedures. In addition, standardization such as preparation of a common training program may contribute to a solution of these issues. Standardization of radiation protection measures, equipment number and computer systems may be effective measures.

In addition, different labor rules are employed at each site in some countries. Sufficient consideration in advance is required in such a case.

5.3.2. Sharing of data and experience

The development of computer systems has enabled sharing of data and experience concerning operation, maintenance work, and facilities. Data sharing is commonly conducted between utilities as well as sites, and furthermore, international exchange has been active.

5.3.2.1. Operating experience feedback

To optimize plant maintenance program, operating feedback is essential. Sharing experiences is vital to make operating experience feedback effectively. This should be carried out by not only one company but also national, and international level including data bases and information provided by the IAEA, WANO, and INPO.

5.3.3. Sharing of equipment

Sharing of expensive equipment, such as that used for inspection is recommended in view of the potential cost reduction.

5.3.3.1. Special equipment

Special equipment such as that used for in-service inspection can be shared among units or sites by good coordination when planning for outages. The following are some examples of equipment which can be shared:

- Reactor barrel UT system
- Baffle former bolt UT system
- RV upper head nozzle ECT system
- SG ECT system
- Fuel rod inspection system
- RCC wear measurement system.

5.3.3.2. Spare parts

Materials for an outage and spare parts can either be stored at each site in a decentralized management system or shared among sites in a centralized management system. As for the decentralized management system, each site holds materials needed to allow for immediate response, even these materials commonly used among sites, thus resulting in inefficiencies. A centralized spare parts management system can potentially overcome these inefficiencies, while at the same time providing prompt and reliable service. Two alternative approaches have been used by utilities. The first is where an individual utility maintains a centralized spare parts centre for all of its NPPs, and the second is where a service organization provides a centralized spare parts centre for multiple utilities. Both of these approaches can potentially lead to the following benefits:

- reduction of the amount of work related to storage of spare parts and storage cost.
- reduction of the storage amount can be expected by means of pool storage of materials for each site.
- improved turn-over rate of materials may result in reduction of aged defective materials.
- establishment of management system attended by a full-time supervisor can improve quality control.
- volume purchases may reduce unit costs.

Annex D.1 provides an example of centralized management system for spare parts.

5.3.3.3. Modular replacement

For the purpose of shortening outage periods, modular replacement has been recently introduced at many plants. These modules range from electronic circuit boards to turbine rotors and diesel generators. Sharing of module parts among utilities could offer further cost reductions.

5.3.4. Training courses and facilities

Sufficient education and training courses and facilities for maintenance personnel are essential for good quality maintenance work. However, it is often expensive for a site or utility to provide sufficient education and training centres and facilities for themselves, and they may be forced to reduce the scale of education and training. Therefore, it is desirable to share the resources for education and training.

For the purpose of cost reduction, sites and utilities can share the training facilities by establishing a maintenance training center for common use. These facilities can also be utilized as mock-up facilities by maintenance personnel of contractors for the preliminary training. One training center should not necessarily hold all the facilities and courses; further improved efficiency can be expected through sharing them among utilities or by international cooperation.

There are international training centers for nuclear maintenance work that support technology transfer for utilities and their contractors through education programs in new concepts, processes and procedures. Such centres provide simulation of actual plant conditions by means of full scale mock-ups.

5.4. OUTSOURCING AND CONTRACTING

As an organization gets larger and the number of employees increases, reduced productivity may result. Also, an organization may find that it cannot perform functions that are ancillary to its mission as cost effectively as can those organizations who specialize in such activities. This section focuses on outsourcing and contracting as one of the measures to improve an organization.

5.4.1. Basic policy

> Note: The option of outsourcing all the operational tasks of an NPP including the responsibility for the operating license could be a cost effective approach for utilities who own only one or two units. The following discussion, however, does not address that case, but rather the situation where ancillary maintenance functions are considered for outsourcing.

An appropriate application of outsourcing can improve the efficiency of a maintenance program, while excessive outsourcing may cause degradation of quality and lack of the core competencies needed for maintenance of the NPP. In this context, it is desirable to apply the outsourcing method for the support services required for maintenance and operation of facilities, not for the main operating and maintenance tasks of a utility.

5.4.2. Examples of maintenance which have been outsourced by utilities

Work for which the volume fluctuates widely, making it uneconomical to maintain staff corresponding to the maximum work load, such as:

- services concerning checking the quality of stored materials
- transportation of materials to the site
- elevator maintenance
- operation and maintenance of demineralized water plant/supply.

Simple and repetitive service which does not require skilled judgement, such as:

- insulation services
- scaffold erection
- janitorial services/housekeeping
- site security

- grounds maintenance & landscaping
- radiological clothing laundry
- food service.

Those services requiring advanced professional knowledge, technique and ability that are difficult to keep internally, such as:

- welding
- non-destructive testing
- computer services and operation.

Those services desirable to entrust to the third party in view of the neutrality and objectivity, such as:

- Processing of meteorological record statistics
- Witness inspection by a neutral organization
- Services concerning registration of individual exposure data to the main registration center.

When considering outsourcing it is necessary to evaluate the economics in terms of the contractor labor cost, material cost, and expenses as well as the cost for management of contractors, and then compare this to the total cost of continuing to do the work internally.

5.4.3. Example of services which are not to be outsourced in principle

- Those services to be performed directly by the electric utility based on a law
- Services directly related to the responsibility of power supply and safety assurance
- Fundamental services in relation with operation of the company
- Those services may cause degradation of reliability among the customers and local community
- Services to be internally performed for the purpose of broadening employee's skill and keeping their experience and expertise.

5.5. IMPROVING RADIATION MANAGEMENT

The overall goals of a radiation management program in support of NPP. maintenance are:

- increased worker safety (i.e. reduced risk)
- increased productivity/resource utilization
- reduced costs.

In order to achieve these goals, particular focus is required in the areas of personnel dose management, contamination control and minimizing radioactive waste. Each of these areas is discussed in this section.

5.5.1. Personnel dose management

Maintenance Support is best provided by planning to optimize personnel dose, by a sound dose information management system, and by careful material selection.

5.5.1.1. Optimizing individual and total personnel radiation dose

Particularly during plant maintenance activities, both on-line and during outages, it is important to plan and organize work as to carefully manage both dose to the individual worker, and the total dose required to complete the work within the planned outage duration.

Overall adherence to the ALARA (As Low As Reasonably Achievable) principle leads to sound maintenance planning. Specific decisions need to be based on a balance of worker radiation dose expectations (i.e. risk) versus maintenance costs. To support sound planning, accurate and up-to-date data is required on radiological conditions at the work site, and on access routes to the worksite. The better the quality of information on gamma fields, neutron fields, surface and airborne contamination levels, local gamma hot spots and changing conditions, then the higher the level of confidence in the job planning process. The need for local radiation shielding provisions or local source term reduction actions to lower fields should be assessed and decisions made well in advance of the start of an outage.

Source term reduction is frequently an essential part of plans to reduce fields and hence dose and maintenance manpower. The primary heads and tubesheets of steam generators are often a prime focus for this approach. Chemical decontamination, water jet lancing and sometimes grit/CO_2 blasting and electropolishing are techniques that have been used effectively.

Some maintenance and inspection activities required on equipment and systems with high gamma radiation fields dictate the application of robotics and remotely controlled manipulators. This may be in addition to the use of local source term reduction decontamination. Many such robotic systems are available from service companies that can tailor manipulators to meet specific or routine utility needs. Planning decisions on the deployment of robotics must be made well in advance of the outage, so that equipment set up, checkout and the required communications links may be planned and rehearsed.

Where access to the worksite is particularly difficult, the use of a full scale mock-up may be appropriate to rehearse and optimize exposure times in high fields.

5.5.1.2. Provision of reliable, accurate and timely personnel dose information

An efficient and effective personnel dose management and monitoring system is a necessity if optimal outage planning and resource allocation is to be achieved. Not only will meeting regulatory requirements be enabled, but also realistic projections of staffing numbers by trade can be established and then tracked. This minimizes surprises and the need to remove a worker from an assigned task because his/her dose limit is being approached thus avoiding the resulting disruption to the work.

A variety of computerized capabilities are available that give virtual 'on line' updating of actual and projected dose commitments - particularly helpful for work in high radiation fields. Forward projection of "dose to completion" enables resource deployments and additions or deletions of staff to be planned well in advance of actual needs.

Although whole-body gamma radiation dose is frequently the main hazard and limiting concern for maintenance work, there can be circumstances where ventilated protective suits are needed and internal dose commitment is of major significance. Here again a timely, computer based capability for rapid processing of bio-assay and other sample data can greatly assist on going maintenance progress.

5.5.1.3. Material selection to reduce radiation dose

Particular attention should be paid to the specifications for materials in contact with reactor coolant and auxiliary reactor systems. Where replacement or substitute components and equipment are needed, emphasis on minimizing activation and activated corrosion products is required. Cobalt 60 reduction should receive particular attention, recognizing the lengthy acquisition time needed for low cobalt alloys.

5.5.2. Minimizing radioactive contamination levels and avoiding contamination spread

When systems and equipment are open for on-line or outage maintenance the risk of contamination is increased substantially. To manage this risk for the benefit of both worker safety and maintenance productivity and cost, a plant should develop and deploy rigorous contamination control procedures and practices as an integral part of maintenance work.

Good practices should typically incorporate pre-planned plant radiological zoning with reliable, user-friendly inter-zonal access control and monitoring; rubber areas, change areas for protective clothing removal and disposal, dose monitoring, waste management and a full suite of portable instruments. Particular attention to details of protective clothing and associated communications equipment invariably produces benefits.

Cleaning of rooms prone to loose contamination prior to an outage frequently pays off in faster, more cost effective and higher quality maintenance performance.

Having every regular staff operations and maintenance worker fully trained in radiation protection practices, thus reducing the need for health physics surveyors, is an approach used by some utilities with successful results. Where large numbers of contract staff are used for specific planned outages, this approach may be less attractive.

The use of electronic dosimetry, bar-coding and badges and similar techniques can all be used to reinforce a rigorous contamination control program. Having a pre-planned response capability to temporarily isolate and manage an area that inadvertently becomes contaminated is a prudent move.

Temporary local ventilation and filtration equipment can be deployed promptly to contain contamination spread. The use of local decontamination processes as a part of planning major maintenance of equipment such as steam generators; reactor coolant pumps, major heat exchangers, etc. can often be cost effective, reducing downstream dose, contamination levels, radwaste and yielding overall outage performance improvements.

5.5.3. Minimizing radioactive waste arising from maintenance activities

The volume and activity levels of radioactive waste arising from maintenance activities can be minimized by adhering to several basic planning principles.

The greatest opportunity to reduce radwaste generation is to prohibit entry to zoned areas of all wood, cardboard, paper and packaging for parts and consumables to be used in maintenance. This should be integrated with plans for staging parts and tools for maintenance, and may involve the use of alternate metallic supports to replace wood pallets for heavy items.

This investment of effort before entering a radioactive zone can lead to substantial downstream savings reducing handling, storage and disposal commitments.

The use of aluminum rather than wood scaffolding similarly shows benefits, and also reduces the fire loading with savings in insurance premiums.

Use of bar-coding on radwaste bags and containers is a technique that greatly facilitates source identification. This places "peer pressure" on the source unit to improve their planning efforts to match the best performing unit in the plant. The use of bag monitors also enables some waste to be scanned and declared "non-radioactive" for conventional disposal.

As well reducing costs, the above techniques are also useful in efficiently meeting regulatory requirements associated with radioactive waste storage, shipment and disposal.

6. MEASURING PERFORMANCE

The measurement of performance is vital in order to improve performance and reduce costs while at the same time maintaining a high standard of safety.

Measurement is a key aspect of managing performance because what can not be measured can not you cannot be controlled. Similarly, it is not possible to take corrective action unless there is feedback on the effects of any change. It is pointless to define objectives or performance standards unless there is agreement and understanding on how performance in achieving these objectives or standards will be measured.

Performance measures should provide evidence of whether or not the intended results have been achieved and the extent to which the maintain organization has produced that result. This will be the basis for generating feedback information.

6.1. OBJECTIVES

Before performance measures can be considered it is first necessary to recognize and understand the objectives of the company. An objective describes something which has to be achieved or at least aimed at. Objectives may define what the company is aiming to achieve and more specifically team objectives will identify a team's contribution.

Individual objectives define the results to be achieved and the basis upon which performance in attaining these results can be measured. They can take the form of target objectives or standing objectives.

6.1.1. Target objectives

Individual objectives can be expressed as quantified output or improvement targets or in terms of a project to be completed. With regard to project targets, such an example may be an outage being completed to within schedule and budget (refer to Annex E.1, Figure 1 for a typical progress chart).

Targets may be reset regularly, say once a year, or be subject to frequent amendments to meet new requirements or changing circumstances.

6.1.2. Standing objectives

Standing objectives are concerned with the permanent or continuing features of work. They incorporate or lead to defined standards of performance which may be described in quantitative or qualitative terms. Examples are:

- Quantitative -the number of outstanding defects (refer to Annex E.1, Figure 3).
- Qualitative - development of employee problem solving skills.

It is essential that any objectives are agreed on between all parties concerned. An agreed list of main tasks relating to the teams work/responsibilities may be used as the starting point for this agreement. It is then necessary to examine this list and agree on targets and standards on which performance will be measured.

6.2. MAIN OBJECTIVES OF MEASURES

There are two main objectives of measures:

- To measure the performance of the process or activity being undertaken. With regard to process performance, it is necessary to understand and where appropriate to map the process before deciding on performance measures/indicators. When the process is defined the appropriate measures/indicators can be developed which will provide dynamic monitoring of the process (refer to Annex E.1, Figure 4). Measuring of activities may include such examples as illustrated in Annex E.1, Figure 5.

- To act as a motivation to staff to achieve the goals of the organization. These measure may, if successfully achieved, result in some form of reward. Such a scheme is illustrated in Annex E.1, Figure 6.

Measures set the expectation of management and identify shortfalls in achieving the expectation, enabling corrective action to be undertaken.

6.3. PARAMETERS FOR MEASUREMENT

Typically, parameters for measurement within maintenance organizations should include time, cost, quality and safety. Such measures should be set against targets so that the rate of achievement can be identified. It is important to recognize the inter-relationship between the above parameters and to achieve the appropriate balance. Low cost while vital to any plant can easily be lost by poor quality or slow progress on a job/task.

6.4. CHARACTERISTICS OF MEASURES

It is important to agree on performance measures at the same time as objectives are defined. This is the only way in which a fair assessment of progress and achievements can be made, and the successful definition of performance measures will provide the best basis for feedback.

In general, when defining performance measures the following be considered:

- measures should relate to results not efforts.
- results must be within the maintainers control.
- measures should be objective and observable.
- data must be available for measurement.
- established measures should be used if possible or adapted where practicable.

There are several characteristics that need to be taken into consideration when deciding what measurements need to be made, they are:

- **Specific**. The measurement needs to be specific to the deliverable of the process or activity.
- **Simple to understand**. So that those working within the process/task are able to monitor what they are achieving.
- **Relevant to the process/task**. So a clear understanding of performance can be achieved.
- **Forward looking**. With a predictive element incorporated.
- **Timely**. So that corrective action can be taken.
- **Customer focused**. To enable the customers valid requirements are achieved.
- **Informative**. To provide relevant information.
- **Changing**. Static or slowly changing measures are not useful in improving performance.
- **Targeted at the correct level**. High level measures are not relevant to individuals working within a process.

6.5. COMMUNICATION OF MEASURES

The communication of measures is probably the most important aspect of improving performance. Various modes of communication are appropriate and should be matched to the individuals and groups the measures are to be communicated to. These groups are:

- the staff of the plant
- those who can influence the process/task
- the customers
- those who need to know how the process is developing.

To ensure others have the potential of benefiting from any improvements in performance identified by the measures, it is important to communicate the measures regularly and in a manner that is easily understood. Measures in pictorial form are very effective, as illustrated in Annex E.1, Figures 8, and 9. It may be prudent to correlate all the measures together in the form of an overview summary. This will aid the comparison of performance between teams, departments or organizations. Such an overview is shown in Annex E.1, Figure 8.

6.6. BENCHMARKING

When implementing activities for improvement at a site, considerations or ideas may be limited, and considerable time is needed to prepare improvement programs. Measures to solve these problems include the establishment of a committee including members from the head office and other sites; however, benchmarking of other companies and countries recommended as one of the most effective ways. Benchmarking means learning lessons from best practices of other companies or groups for the achievement of innovation at one's own company or organization.

The specific procedures of benchmarking include:

- comparing work performance with that of the best performing company in that field.
- finding practices which will bring about the best performance.
- analyzing causes of the gap between best practices and existing practice.
- working out a plan to reach the highest level of existing performance and then improve upon it.
- taking actions to continuously improve performance.

Companies or groups to be investigated and work processes to be analyzed for the purpose of benchmarking are essentially limitless. Therefore, various activities are expected from the staff level to the manager level. Benchmarking can be:

- **competitive benchmarking.** Comparison between competitive companies.
- **functional benchmarking,** Comparison of a specific work for some companies.
- **generic benchmarking**. Investigation of and comparison with companies in other industries than power generation.
- **internal benchmarking**. Comparison with other internal sections (including fossil power generation section).
- **international benchmarking**. Comparison with foreign utilities.
- **performance benchmarking**. Comparison with other utilities for the availability, cost and power generation performance.
- **process benchmarking**. Comparison focusing on work processes.

Activities for improvement of maintenance work performance will ultimately result in the improvement of work processes. Therefore, it is expected that process benchmarking will be most often conducted.

Annex E.2 provides examples of benchmarking processes, while Annex E.1, Figure 7 shows typical benchmarking measures.

ANNEX A
SUPPORTING INFORMATION RELATED TO INCREASING PRODUCTION

ANNEX A.1
OUTAGE PLANNING FOR TVO (FINLAND)

TVO in Finland has made dramatic reductions in the lengths and costs of its annual outages during the last several years, while at the same time improving or maintaining plant safety. (see Figure 1) One evidence of the high quality of maintenance work is shown in Figure 2, where the unavailability due to plant repairs has been very low. Plant management has identified the following as keys to these improvements:

Shortening of the Outage Critical Path

- very detailed planning of the critical path
- minimizing time needed for critical activities
- decreasing individual, time-consuming work
- minimizing the time needed for turbine overhauls
- advanced knowledge of plant construction
- three shift work

Administrative Routines

- advanced outage planning system
- utilization of computer-based maintenance system
- integration of activities and safety measures to bigger packages
- organizing special projects
- revising the bonus system
- Nordic cooperation

Development of Maintenance Methods

- optimization of preventive maintenance
- more preventive maintenance work during plant operation
- development of predictive maintenance

Well Trained Personnel

- same key persons and contractors
- repeated critical work
- training of both plant personnel and contractors
- cooperation with main contractors and suppliers

To ensure that reactor safety is maintained during outages the following methods are used:

- outage PSA
- Technical Specifications for outages
- review of outage safety for every outage made by the Nuclear Safety Office
- reactor safety time schedule
- rest effect cooling time schedule
- operational safety review of outage work through the work management system.

The TVO Outage Organization has the following characteristics:

- a full-time outage manager
- project organization for every planned outage
- an outage management group which holds regular meetings
- a long term outage planning group
- an outage planning group

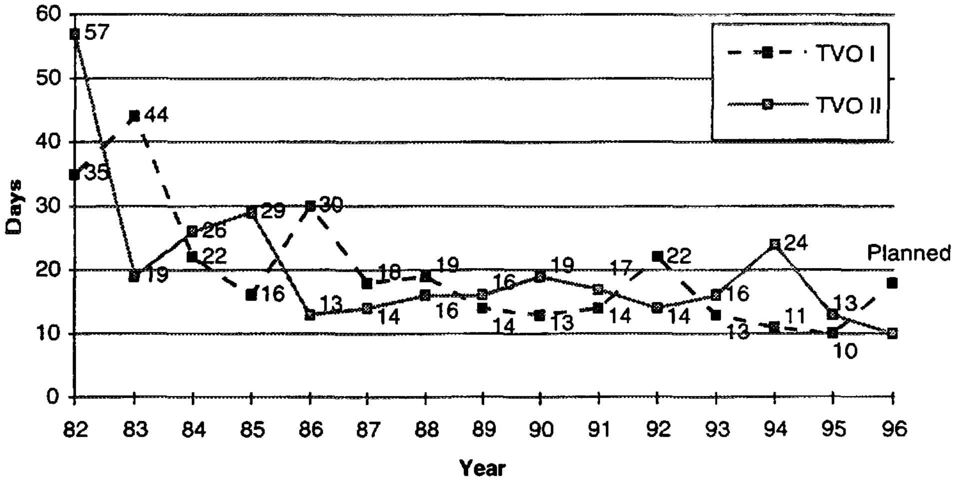
The outage management group is chaired by the plant manager; the secretary is the outage manager. This group provides general supervision, approves outage times and programmes, and provides decisions for significant problems. It meets once per month throughout the year, and weekly (or whenever needed) during an outage.

The long term outage planning group is chaired by the operations manager; with the outage manager as the secretary. This group is concerned with long term and middle term planning (3 to 20 years) including major overhauls and inspections, modifications/improvements, and the plant life time programme. They also follow-up and monitor outage performance/indexes. This group meets four times per year.

The outage planning group is chaired by the outage manager. It includes representatives from all organizations providing support during the next outage. It provides supervision of detailed planning, execution and reporting of outages. It meets once per month throughout the year, and twice per week during outages.

During an outage, daily meetings are held. They are chaired by the operations manager of the unit. In addition, special meetings are held on different working areas. A daily outage report is distributed to everyone on site.

TVO I/II
Length of Annual Outages



TVO I+II
Outage Costs and Manhours

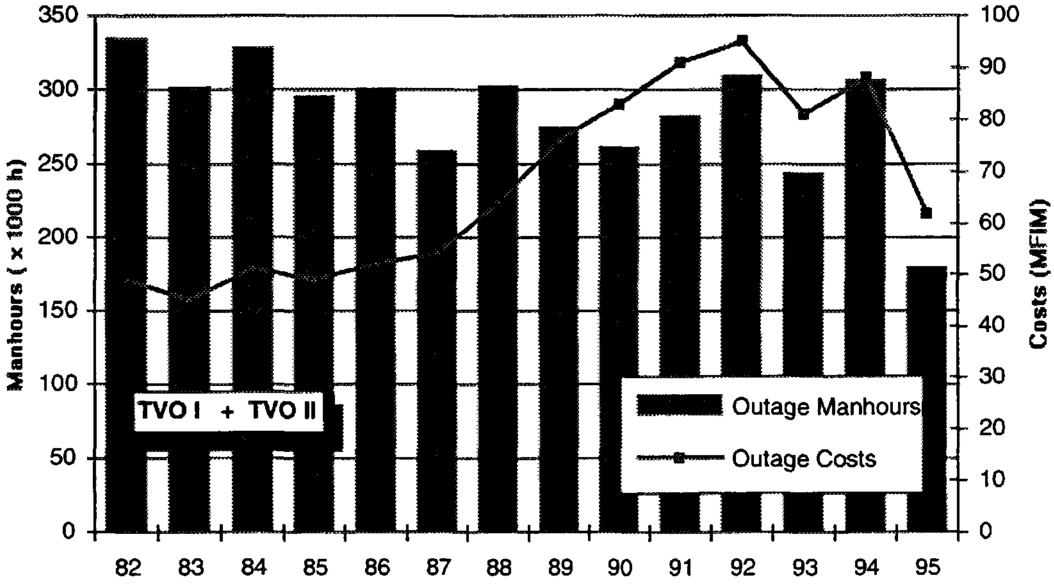
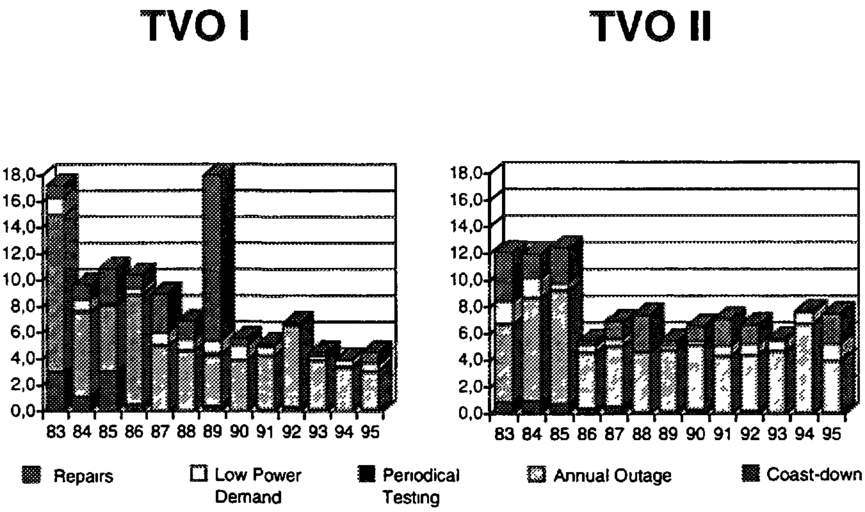


FIG. 1. Outage information.

TVO I/II - Annual Unavailability

Producton Losses 1983-1995



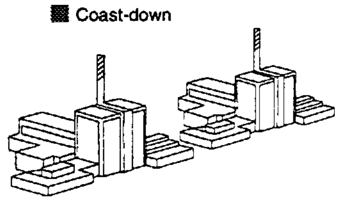


FIG. 2. Production losses.

ANNEX A.2
OUTAGE PLANNING FOR GKN (GERMANY)

Since the electric utilities in Germany's federal state of Baden-Württemberg collaborate on optimizing load scheduling for their nuclear power plants, the two units operated by GKN, Neckar I and II, can - apart from a few exceptions - always be run at full power during the summer months. Since 18-month operating cycles do not represent a cost effective alternative at the present time for economic reasons - any savings in outage cost are outweighed by higher waste disposal costs caused by lower burnup - short outages are extremely important for their 12-month cycles. Short outages are altogether more economical since about a third of outage cost is time-dependent.

Organization

The fact that responsibility for planning and execution of work at nuclear power plants is usually not in the hands of a single, central group poses one of the greatest difficulties which have to be overcome in order to achieve optimum outage performance. Until the mid-80s, outage schedules were generated - even at GKN - by simply stringing individual work items one behind the other. Subsequent optimization was only carried out to a very limited extent.

To improve this situation, GKN decided, at the time of initial startup of Neckar II, to set up a central outage planning group. Figure 1 shows how this outage planning group is related to other plant organizations. Since the maintenance organization at GKN is decentralized and because of the good experience gained with centralized job co-ordination during power operation of the plant, the new outage planning group was allocated to the subdivision "Operations Support". Outages are now planned by an outage planning manager who works on this job practically year-round and reports directly to the plant manager. Depending on his current workload, this outage planner receives support from the operations planning staff within this subdivision. Since specialized knowledge of the power plant is essential, only personnel holding qualifications as senior reactor operators are assigned for outage planning.

About three months prior to the outage, the outage planning team is joined by four senior operators to assist in detailed planning of equipment and system isolation.

The post of "outage planner" is, of course, in no way a substitute for the careful planning carried out within the departments responsible for performing the outage work. In fact, it can only start to be effective if all divisions and their specialized know-how are successfully integrated into the planning effort with genuine team spirit. The outage planning group assists the maintenance planning staff in preparing detailed time schedules and optimizes the individual work sequences. This results in the shortest possible outage schedule.

As outage times become shorter, particular attention must be paid to ensuring that all regulatory requirements are met in good time. Otherwise a danger exists that the power plant - ready to resume commercial operation from a technical point of view - cannot go back on line because clearance for restart has not yet been issued by the authorities. At GKN, this aspect is dealt with by the plant manager as part of his duties associated with overall co-ordination of the outage

Planning

Parallel to organizational changes, steps were also taken to optimize the actual planning process. Some of these that merit particular mention include:

-Detailed Definition of Work Scope

The basic requirements are detailed in the plant inspection and maintenance manual and are stored in a computer-based system for integral plant operations management.

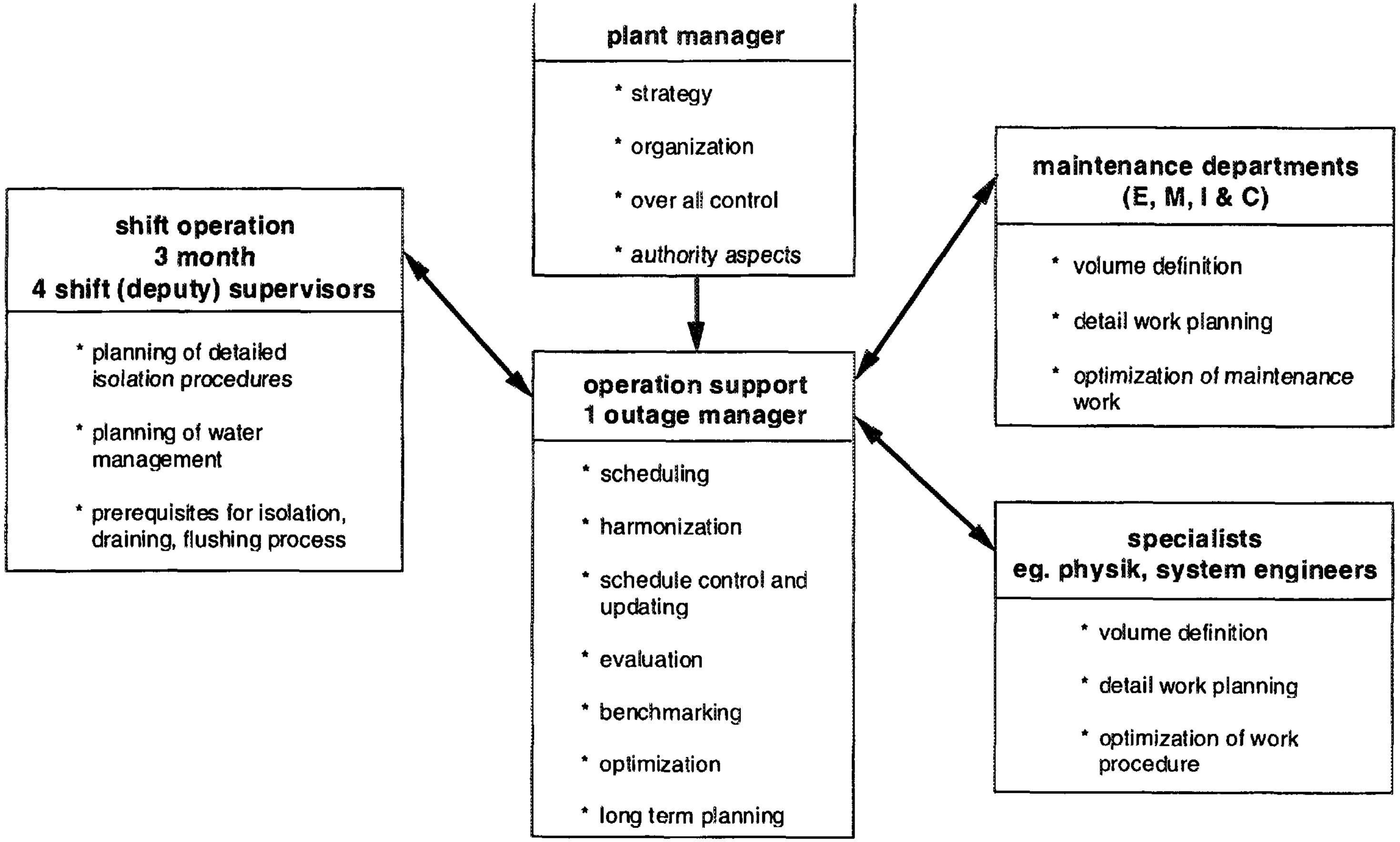


FIG. 1. GKN organization.

-Early Start to Planning

Figure 2 shows an example of the outage planning sequence. Immediately after the end of an outage, planning for the next outage starts with the preparation of a so-called "orientation schedule". This is geared towards long-term outage planning. The plant engineering and maintenance divisions use the schedule as a basis for planning their work scopes. The outage planner also uses it to generate the first "outage masterplan".

The next phase comprises fine-tuning of all activities so that overall in-house planning is finished approximately five months prior to start of the outage. Four months before the outage, the authorities confirm on the outage list that it contains all work relevant to plant startup. Thus detailed planning of the outage work and system isolation activities can proceed on a reliable basis.

-Best-Estimate Planning

Particularly good persuasive skills are needed to convince personnel of the benefits of "best-estimate" planning since every individual prefers reporting that an activity has been completed ahead of schedule rather than having to justify delays. Experience has shown, however, that additional time margins incorporated in the time schedule are utilized to a much lesser extent than delays actually occur. When best-estimate planning is applied, the overall need to correct planned work schedules during the outage therefore declines considerably. On the other hand, best-estimate planning also requires that the plant management is willing to tolerate delays due to unforeseeable problems.

Long-Term Strategy

Optimum outage planning must not be geared towards one-time success. It is not record-breaking outage times that count, but rather plant availability viewed in the long term. Some plants have gone over to alternating between short, strictly refuelling-based outages and longer inspection and maintenance outages.

Our approach to long-term optimization is founded on a different strategy: namely, to perform as many activities as possible in the "lee" of a mandatory critical path. Figure 3 shows an example of our long term outage plan.

Only three critical paths of this kind have been established:

- The refuelling-only path
- Refuelling in conjunction with ultrasonic inspection of the RPV and containment leak rate testing
- The major generator overhaul every eight years.

Since the relatively short refuelling path only permits maintenance work to be performed on one train of a multiply redundant system, safety systems are consistently inspected according to a "main redundant train" concept; i.e. in three of four redundant system trains, all that is done is to correct deficiencies and conduct stipulated in-service inspections, while performance of more extensive preventive maintenance work is confined to the so-called "main" redundant train.

This main redundant train concept makes it possible - despite short outage duration - for an extremely high level of plant safety to be guaranteed. At Neckar II, for example, three independent cooling systems are kept in service for fuel cooling; and during mid-loop operation, even all four safety-related cooling systems including six accumulators and one steam generator.

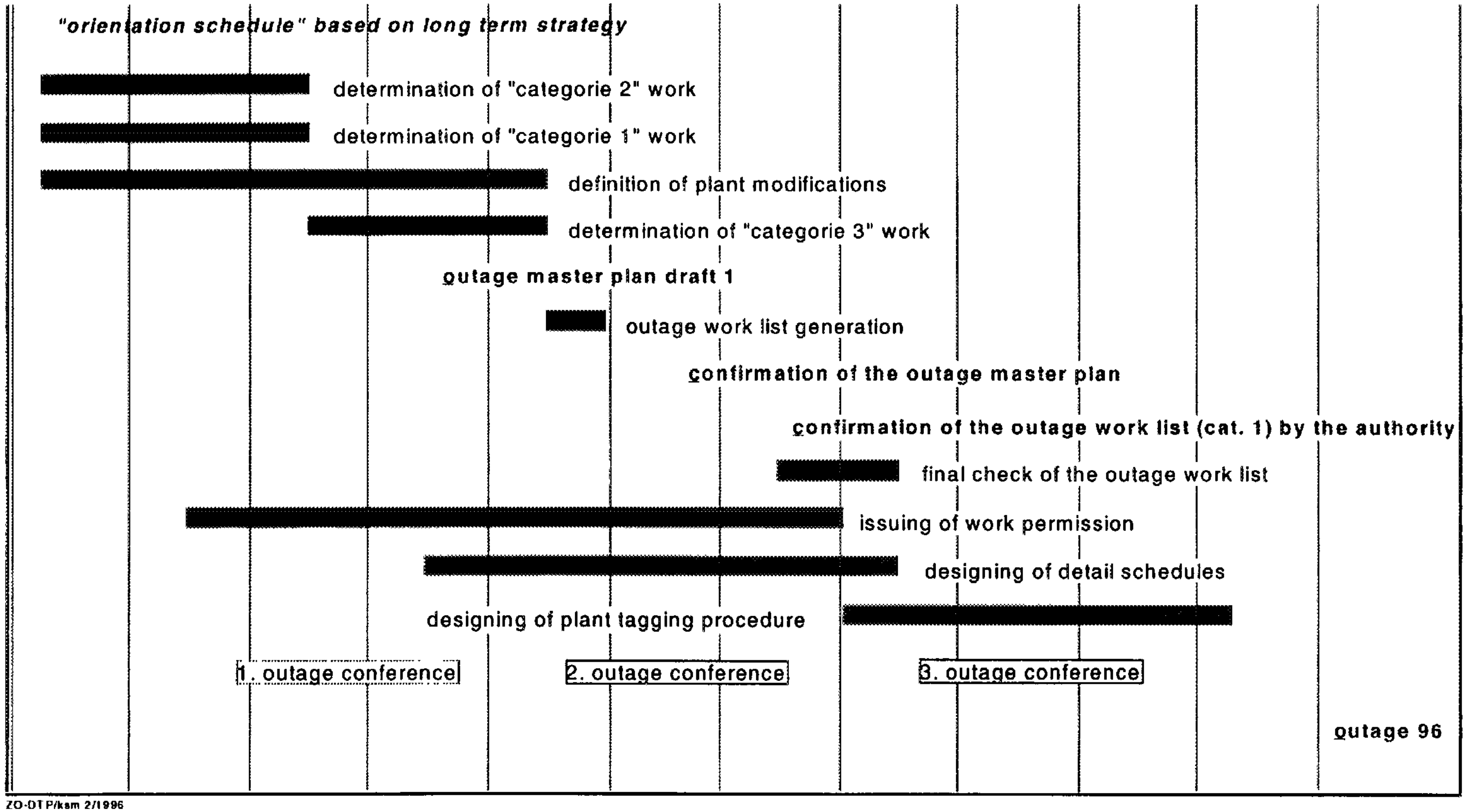


FIG. 2. Outage planning sequence

	PVT	PT-Nr.	period	out.90	out.91	out.92	out.93	out.94	out.95	out.96	out.97	out.98	out.99	out.2000	out.2001
estimate outage time									17 d	16 d	35 d	16 d	16 d	16 d	23 d
critical path									FE/red.	FE/red.	generator	FE/red.	FE/red.	FE/red.	prim. syst
mech. safety train 1/5		-	4a/4a			X				X				X	
mech. safety train 2/6		-	4a/4a		X				X				X		
mech. safety train 3/6		-	4a/4a	X				X				X			
mech. safety train 4/8		-	4a/4a		X			X			X				
electr. safety train 1/5		-	4a/4a			X				X				X	
electr. safety train 2/6		-	4a/4a		X				X				X		
electr. safety train 3/7		-	4a/4a	X				X				X			
electr. safety train 4/8		-	4a/4a	partly	partly		X				X				
Inspection MCP JEB10	MN	-	8a		(X)				X						X
Inspection MCP JEB20	MN	-	8a					X						X	
Inspection MCP JEB30	MN	-	8a	X						X					
Inspection MCP JEB40	MN	-	8a			X					X				
PC pressure test	MN	JA.10.6	8a/8a								X				
UST reactor vessel	MA	JA.10.7	4a/4a				X				X				
UST reactor vessel head	MA	JA.10.7	4a/4a		X						X				
NDT sack holes	MA	JAA11.7	4a/4a		X						X				
NDT bolts	MA	JAA12.7	4a/4a		X						X				
NDT nuts	MA	JAA14.7	4a/4a		X			X				X			
VT reactor internals	MA	JAC30.0	4a/4a	teilw.		X		X				X			
Test hold down springs	MA	JAC40.2	4a/4a	X											
VT sec. side SG 10	MN	JEA10.0	8a/8a						X						
VT sec. side SG 20	MN	JEA10.0	8a/8a					X							

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PT = periodic test
PRT = pressure test
NDT = non destructive test

UST = ultra sonic test
VT = visual test
ECT = eddy current test

PVT = resp. department for the test
a = per year
B = per fuel element change

IV = isolation valve
MSSV = main steam safety valve
MSRV = main steam relief valve
MSIV = main steam isolation valve

FIG. 3. Long term planning.

Execution

Short outages are only possible if critical-path activities are worked on around-the-clock. At Neckar, this work is carried out in either three 8-hour shifts or two 10-hour shifts.

Progress is monitored by constantly checking it against the time schedule .

The special circumstances associated with outage performance require adaptation of the shiftcrew structure. The operating crew is reduced to the absolute minimum of staff that is needed. These individuals are then solely responsible for monitoring the systems that are in operation and for configuration management. All other members of the operating crew work within a special shift schedule to support the outage planners in case of isolation procedures, function and requalification tests.

Acceptance of these changes in working conditions has to be achieved through motivation of the personnel, the bonuses paid for night-time and shift work already being sufficient incentive for many of the staff.

Benchmarking

Neckar II's 33-day outage in 1990 and 34-day outage in 1991 were not satisfactory since other Siemens-built 1300-MW PWR plants had completed outages of a comparable scope in only 27 days. This led to an intensive benchmarking study being carried out in which:

- Planning targets and actual execution times in the plant were analyzed and compared, and
- Benchmarking with other comparable PWR plants was conducted.

To facilitate comparison, individual phases were defined and then analyzed. The best results in each case were used as a basis for planning the next outage.

This optimization effort yielded certain modifications in the plant as well as certain procedural changes

The outage in 1995 was a typical standard outage. The critical path changes during fuel inspection to maintenance work with drained loop lines.

The process for optimizing outage times introduced at Neckar at the end of the 80s has led over the past five years to the results shown in Figure 4. These results are summarized below:

Unit I:	average outage length	40 days
	best achieved	24 days
Unit II:	average outage length	25 days
	best achieved	17 days

Apart from the fact that outages have been shortened, another particularly important achievement is that planning targets and actual execution times are continually moving closer together. The information and knowledge acquired from detailed planning allow reliable long-term planning to be implemented.

In fact, our goal for the future is to increase the availability of Unit I >90% and to keep the availability of Unit II at 93,5 %.

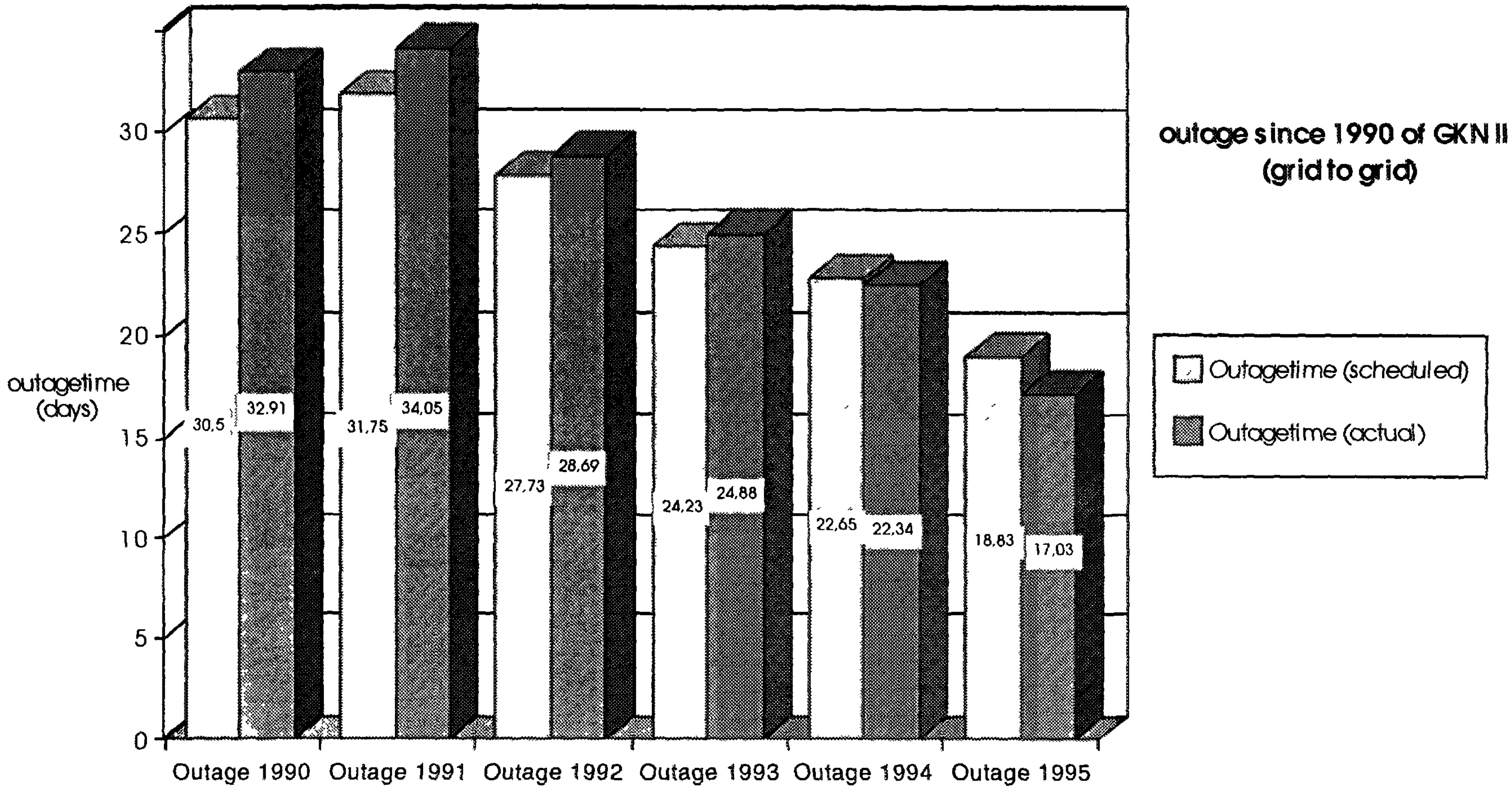


FIG. 4. Outage performance.

ANNEX A.3
HEYSHAM 2 OUTAGE IMPROVEMENTS (UNITED KINGDOM)

1. INTRODUCTION

Heysham 2 outage performance has greatly improved over recent years (see Figure 1). The following briefly summarises the most recent initiatives employed to aid this improvement. The majority of these were implemented following visits to nuclear power stations in Finland and Sweden.

2. OUTAGE IMPROVEMENTS

2.1. Permanent outage management team

The role of the Outage Manager was previously fulfilled by maintenance engineers temporarily seconded to that position for each outage. This led to a lack of continuity and minimal outage development work being carried out.

A permanent, full-time Outage Manager has been appointed and has a small, full-time team of planning engineers and support staff working for him. This team is supplemented by temporary seconded staff as required to aid outage development work.

Other individuals are identified to fulfil significant outage roles and are seconded into the outage team at the appropriate time prior to each outage. Any changes to the outage personnel are kept to a minimum in order to maintain continuity.

2.2. Outage planning

A different approach was taken to planning the last outage with the intention of challenging previously accepted work duration. This comprised three stages:

1. **Strategic Plan** - A strategic plan was developed within operating rule constraints and based upon know timescales for most activities. However, the main critical path activities such as turbine generator maintenance and reactor vessel internal inspection were excluded. This gave a projected outage duration of 35 work days. Work periods for the turbine and reactor work were then derived from this plan.
2. **Confirmation** - Task teams were formed and given the responsibility of confirming whether the planned work was achievable within the new restricted timescales and identifying any additional resources and/or changes to working practices that may be required. Formation of these team created commitment and ownership of the project. After a period of examining working practices and careful planning, all teams confirmed that the targets were achievable subject to certain conditions.
3. **Control Plan** - After receiving confirmation that the critical path activities could be achieved within the proposed timescales and that the conditions identified by the teams could be accommodated, the detailed outage control plan was produced reflecting the overall duration of 35 days.

2.3. Contractor partnerships

Heysham 2 has entered into partnering agreements with major contractors, an example of which is the turbine contractor, NEI Parsons. The companies work closely together with the objective of establishing and improving the performance standards for quality, safety and duration of planned preventive maintenance to their mutual benefit. One of the teams previously mentioned was jointly funded by NEI Parsons and Heysham 2. The team was comprised of Parsons engineers and was, several months prior to the most recent outage, to accurately plan the proposed outage work and develop working practices to improve their performance. The Parsons work force was identified earlier than in previous outages and was comprised of more permanent experienced staff. Work teams were formed and training provided as required in advance of the outage.

2.4. Maintenance techniques

Several potential improvements to maintenance procedures and equipment were identified due to the more detailed planning in specific areas. Examples of which are:

1. **Additional turbine craneage** - a condition of the turbine work being achievable within the reduced timescales was the provision of additional cranes and platform areas adjacent to the turbine. These cranes and platform areas were installed prior to the outage and were a great success. As a result of use during the outage further improvements in this area have been identified and are to be implemented prior to the next outage (see Figure 2).
2. **Generator rotor removal equipment** - the removal/replacement of the generator rotor was a critical path item and an air cushion or "hovercraft" device was developed by Parsons which reduced the time taken for this activity from days to hours (see Figure 3).

2.5. Outage office

The outage organisation personnel have previously been housed in temporary office accommodation which varied from outage to outage and was never large enough for all the staff involved. Because of this, an existing storage area has been converted to include a large open plan outage office (see Figure 4). the permanent outage team personnel occupy this office full time but during outage periods the office also accommodates many seconded staff, including contractor liaison engineers. This had led to a less fragmented organisation and greatly improved communication and team work.

2.6. Outage contractor welfare

Several improvement have been made to improve the welfare facilities for contract staff thereby increasing their commitment to their work:
1. locker and shower facilities, etc.
2. outage canteen - open virtually 24 hrs during outage periods serving the same quality of meals as in the staff canteen (see Figure 5).
3. additional reactor controlled area access; reduces congestion during outages thereby reducing frustration and increasing working time (see Figure 6).
4. snack bar adjacent to RCA access - seating area and vending machines immediately outside the reactor controlled area access (see Figure 7).
5. permanent contractor area - formally laid out area of contractor portable office and workshop facilities with services provided (see Figure 8). Contractors accommodation was previously randomly scattered around the site.

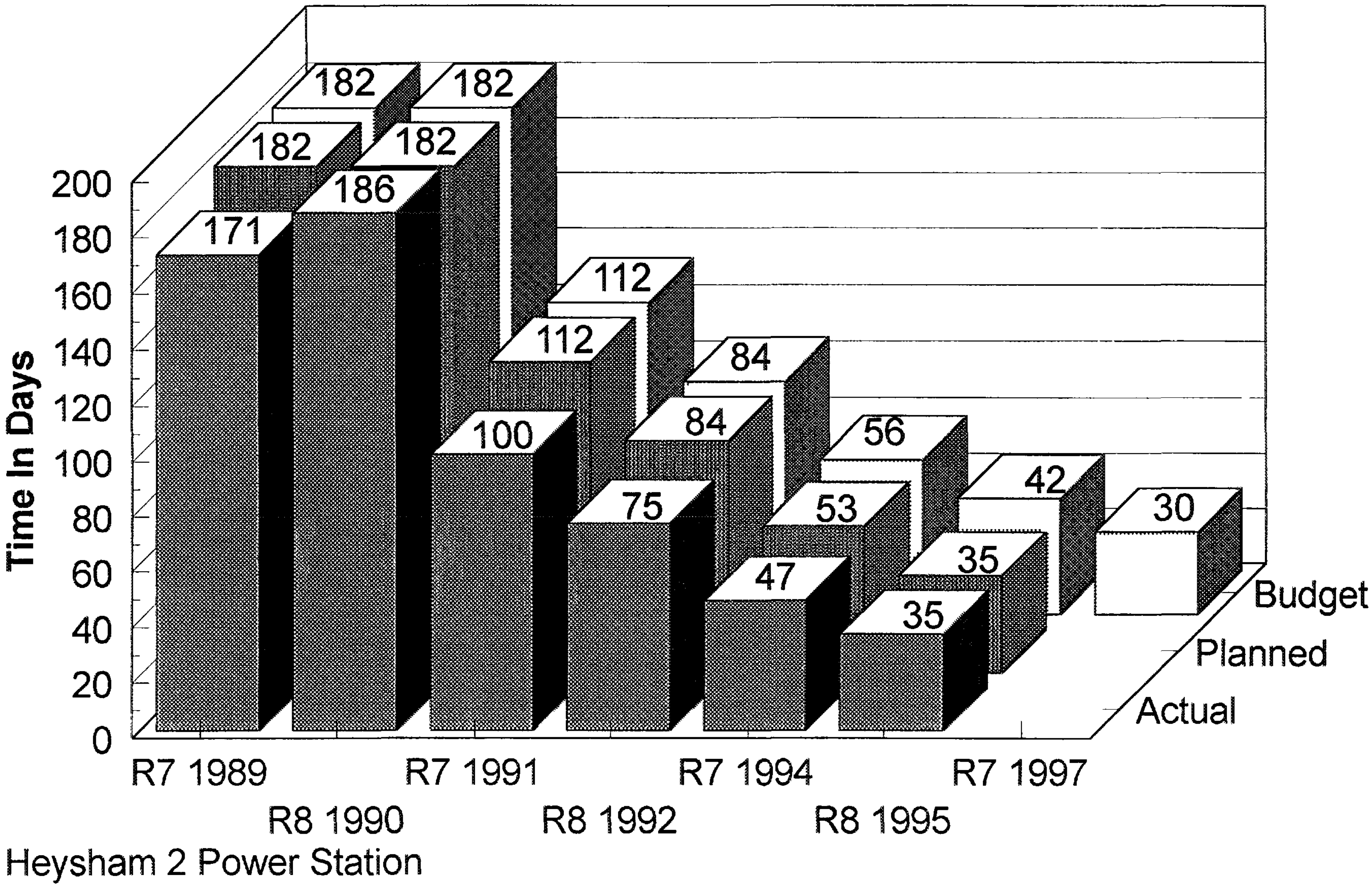


FIG. 1. Statutory outages.

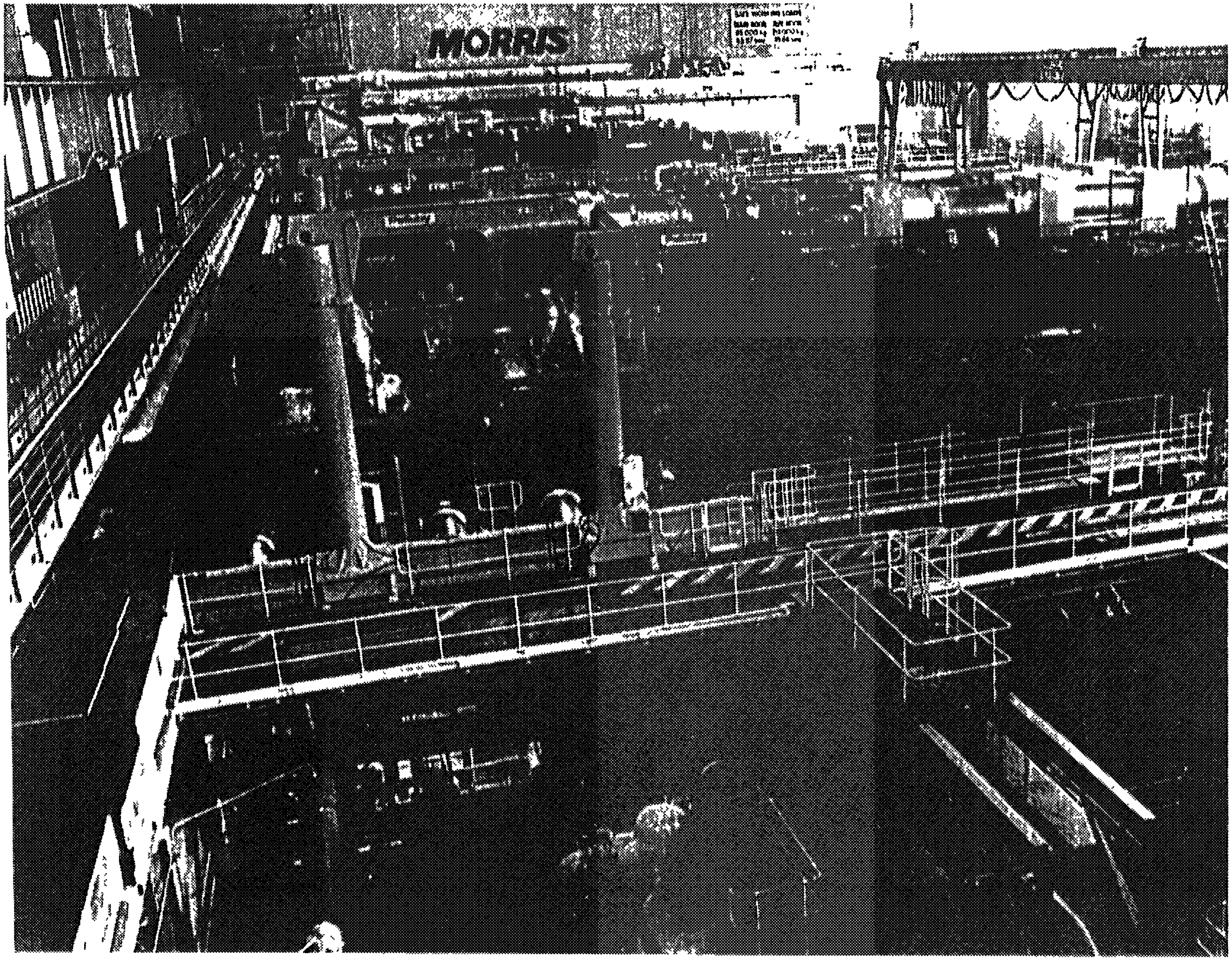


FIG. 2. Additional turbine cranes.

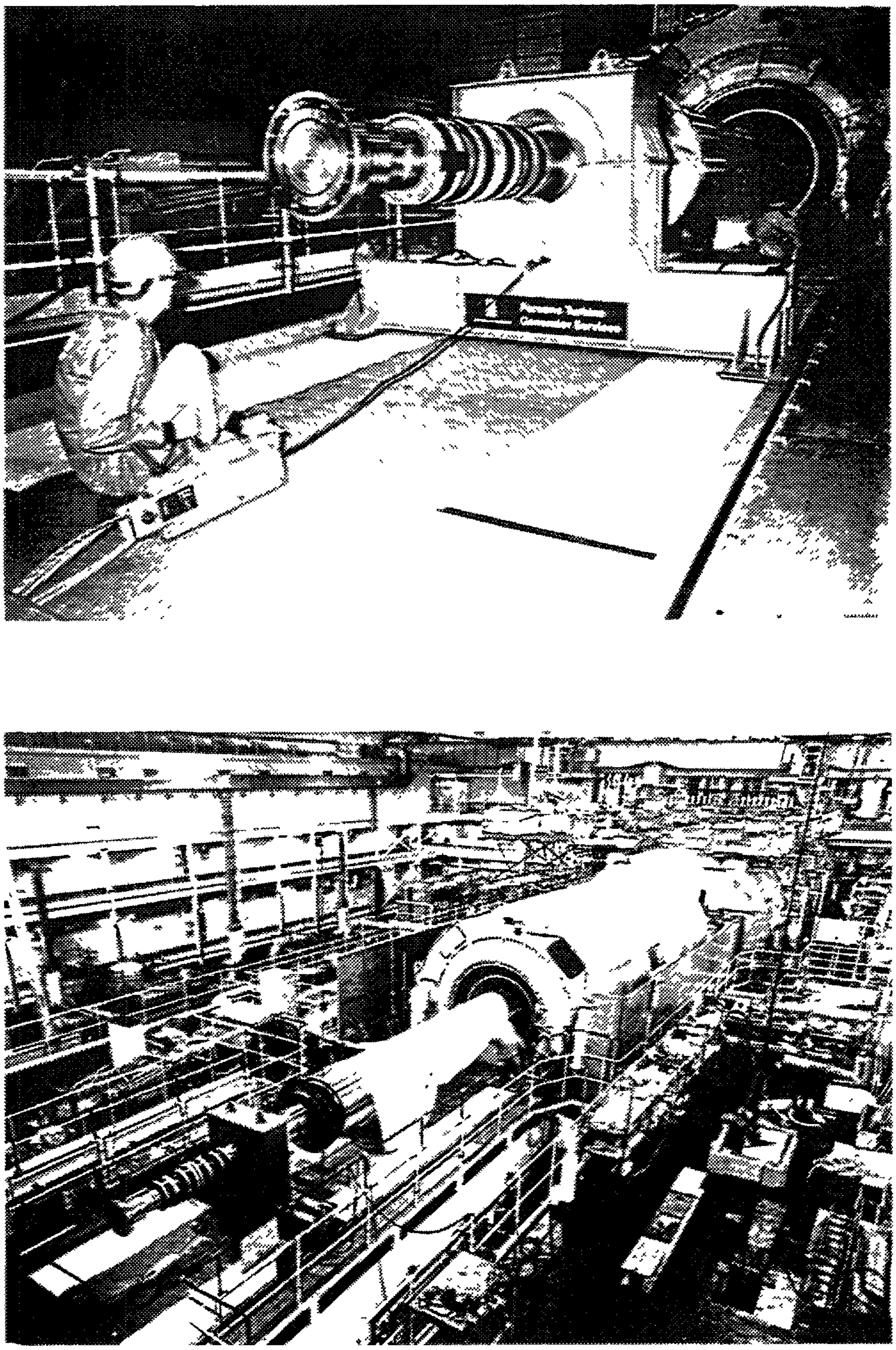


FIG. 3. Generator rotor being removed using new 'hovercraft' equipment.

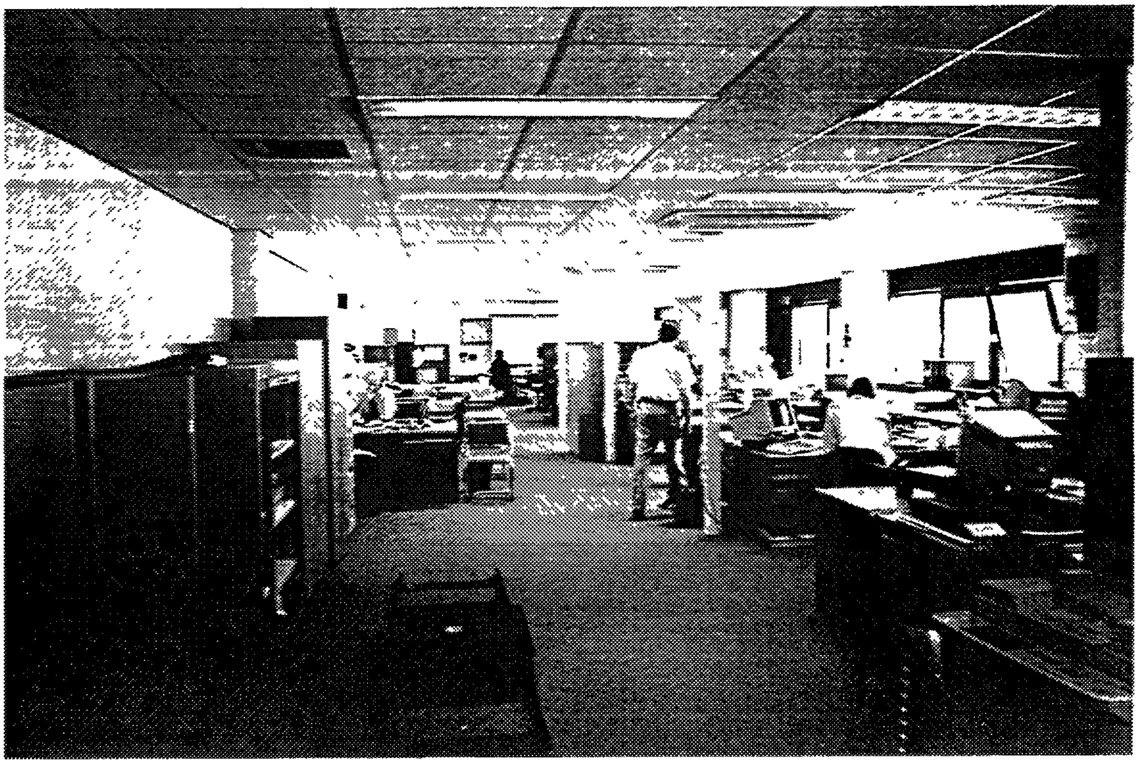


FIG. 4. Outage office.

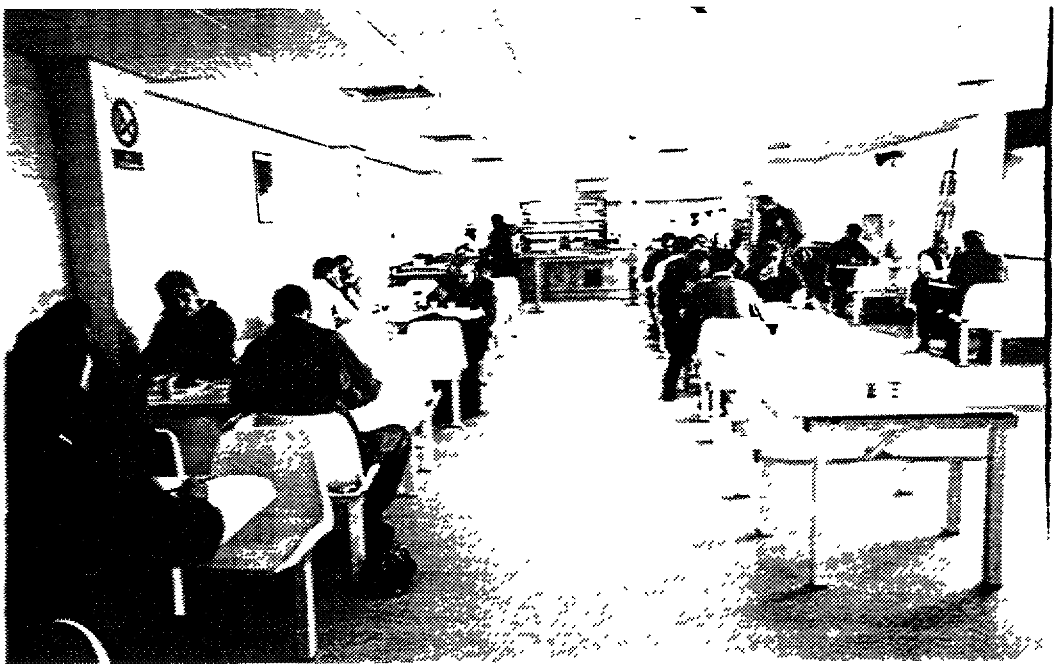


FIG. 5. Outage canteen.

FIG. 6. Additional reactor controlled area.

FIG. 7. New snack bar adjacent to RCA access.

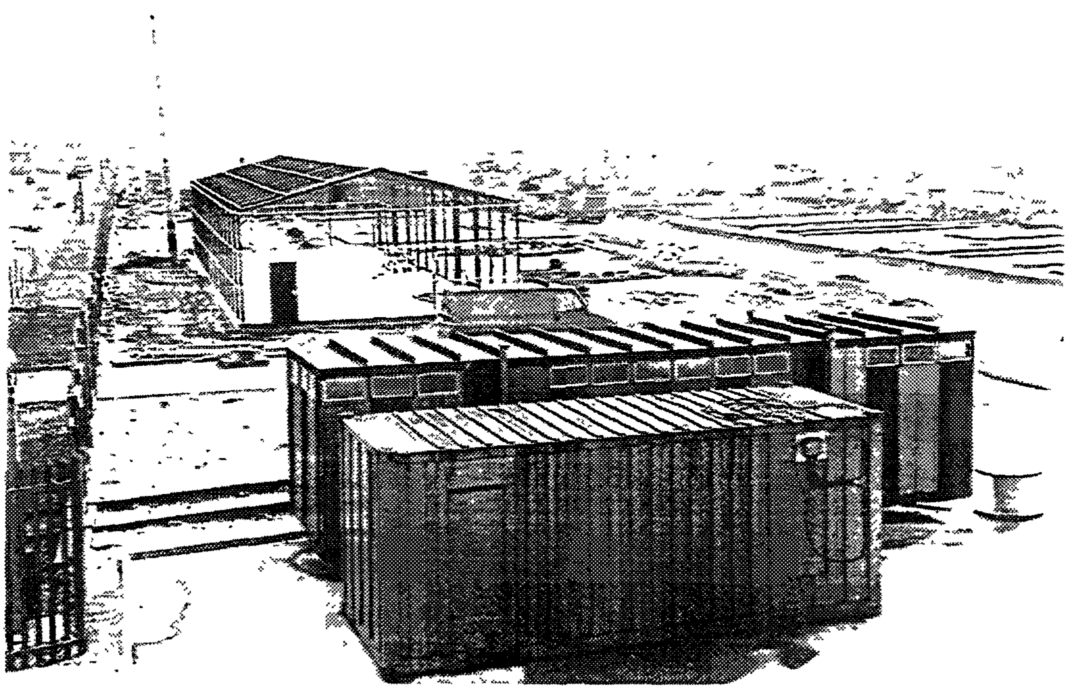
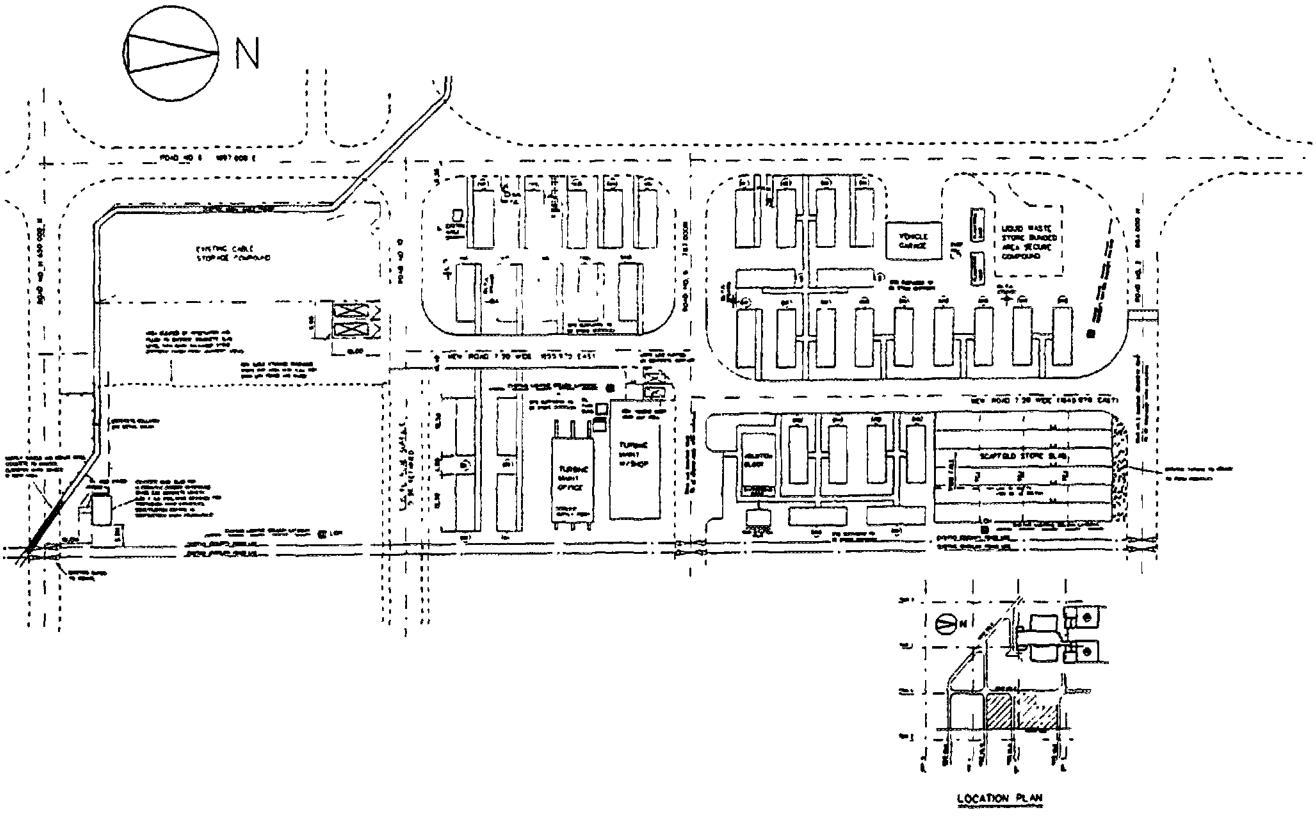


FIG. 8. Contractors laydown area.

CONTRACTORS LAYDOWN AREA - PLAN



ANNEX B
SUPPORTING INFORMATION RELATED TO REDUCING WORKLOAD

ANNEX B.1
ENTERGY OPERATIONS INC. BURDEN REDUCTION PROGRAM PLAN

1. PURPOSE

The Burden Reduction Program Plan serves as a roadmap to the EOI Burden Reduction Team. As such, it provides not only a footprint of where we have been but also plots a future course for where we want to go. While the background information on how the team came into existence will remain unchanged, the sections of the program plan dealing with future actions will constantly be reviewed and updated as necessary. Specifically under the section entitled Best In Class there are explicit initiatives intended to enhance improvement.

In short, the Burden Reduction Program Plan is both a historical and living document. Historical because it provides an account of the origin of the EOI Burden Reduction Team. Living because it contains current initiatives designed to accomplish specific goals.

2. INTRODUCTION

As the competitive environment for electric power generation has intensified, more and more utilities have initiated strong efforts to improve their economic performance. Entergy Operations, Inc. (EOI) has developed strategies to compete successfully in the new competitive environment. For EOI, improving economic performance becomes a matter of getting the most out of the resources available (i.e., optimizing production), making sure that the right work is performed (i.e., process improvement) and ensuring that resources are not being spent on unnecessary work (i.e., burden reduction).

In 1993 EOI undertook an effort that many considered to be not only unique to EOI but also to the entire nuclear industry. This effort was EOI's first formally recognized Regulatory Burden Reduction Program. Over the last several years, each EOI site has developed and implemented their own individual Burden Reduction programs. Without question these individual programs have been successful and in many instances instrumental in the sites meeting their challenging financial goals.

EOI management recognized the need to target the burden reduction effort for enhanced performance. While past successes has been achieved, achievement has been without the benefit of a unified, system-wide program. The general consensus of the EOI management team was that the time was right for the formation of a system-wide burden reduction effort. This system-wide team could best build on the past successes of each of the sites by leveraging EOI combined talents and resources. Thus in the last quarter of 1995, EOI management approved the formation of an EOI Burden Reduction Team. This team, chartered by the Licensing PEER Group, received the approval of the Quality Council.

The EOI Burden Reduction Team is a natural outgrowth of the philosophy of viewing ourselves as one company with five units rather than separate operating units. Through the efforts of the team, duplication at the various sites can be eliminated while gaining the immediate benefit of past experience from each of the sites' individual programs. Thus as we have seen, we not only learn from others mistakes but more importantly we immediately benefit from each others past successes.

While an anticipated team duration was not discussed in the charter, team members generally feel that the effort should not be viewed as a long term undertaking. Consequently, the team strives to create a process and minutes that simply becomes part of everyone's commonplace work habits rather than a perpetual need for the team. Fostering an environment where employees naturally question the value added by an activity and for those of little or no added value taking steps to eliminate the unwarranted burden is the desired goal. Once appropriately ingrained into the everyday work processes, the need for a dedicated EOI Burden Reduction Team will no longer exist.

3. ORGANIZATION

The EOI Burden Reduction Team was chartered by the Licensing PEER Group and endorsed by the Quality Council.

In accordance with the charter, the mission of the Burden Reduction Team is to:

1. Provide resources, structure and process to identify, develop and gain approval for burden reduction initiatives that will benefit multiple EOI sites.
2. Establish guidance for site burden reduction programs that provide a roadmap for increasing levels of success.
3. Identify and obtain resources outside Licensing to support burden reduction priorities.

From the charter, a couple of things are evident. First, the EOI Burden Reduction Team will deal only with issues that affect "multiple" sites. By multiple is meant more than one. While the preference is to have issues that are truly generic (i.e., affecting all sites regardless of reactor type), the fact is that the Team deals with numerous issues that are reactor specific (in other words PWR and BWR specific).

The other thing evident from the charter is that the EOI Burden Reduction effort is to compliment the individual site burden reduction programs not replace them. The EOI effort should be plugged into the site programs and should seek ways to assist in the accomplishment of site specific goals while at the same time being ever alert to not impeding the site's progress.

The team consist of representatives from each site including Echelon. Each member is devoted full time to Burden Reduction activities including both site-specific and system-wide items. Along with the individual site representatives, the team is composed of an executive sponsor, lead NRC negotiator and a team chairman. The roles and responsibilities for each of these individuals are covered in detail in the team charter.

The Licensing PEER Group serves as a steering committee for the EOI Burden Reduction Team. As such, they provide advice and assistance in the resolution of conflicting priorities and facilitate support from individual sites or departments.

While not explicitly covered in the charter, the team has adapted a long range vision to both provide guidance in the accomplishment of goals and as a yardstick for measuring success This long-range vision reflects the team's feelings that success is measured by as much a creation of a culture as it is by the accomplishment of specific activities. The Burden Reduction Team long-range vision is as follows:

The Burden Reduction Team will strive to create an environment in which:

- the safety benefit associated with an activity is understood and quantified to the extent necessary
- compliance is based solely on importance to safety of the activity
- implementation cost in excess of safety benefit is eliminated or modified.

4. PROCESS OVERVIEW

One of the first task the Burden Reduction Team initiated was the development of a process for administering suggested burden reduction items. provides a flowchart of the EOI Burden Reduction process. Discussed below are the major subtasks within the EOI Burden Reduction process.

Idea Initiation

One enters the process with the generation of a suggested burden reduction idea. The originator of the idea documents the suggestion with the completion of an evaluation form. The completed form is then submitted to a member of the Burden Reduction team for further processing. The responsible team member reviews the form for acceptability. First, is there enough information to determine merit of the suggestion? Given that the suggestion has merit, is there sufficient information to determine applicability to the other sites? This initial filter is provided to prevent overloading the process/database with nonessential requests. If sufficient information does not exist, then the team member is expected to work closely with the originator of the idea to develop an acceptable conceptual scoping document.

Following the acceptance of proposed burden reduction idea, the responsible team member enters the required information into the burden reduction database. At this point, each site is responsible for reviewing the idea for applicability to their particular site and noting the results of this review on the database.

Multi-Site Initiatives

Ideas that affect more than one site are classified as "multi-site" and so designated a lead site is assigned. Single site issues at this point exit the process and are pursued within the individual site's program. Regardless of classification, all acceptable suggestions remain in the database. All remain in the burden reduction database for historical/completeness purposes and to aid in the allocation of site resources between single and multi-site issues.

Short Term Initiative Prioritization

At this point in the process, the next logical step would be assigning priority. However, the team recognizes that on occasions there will be proposed projects that by their very nature are things we should just go do. Projects of this nature would only be hampered by remaining within the rigid constraints of the process. Projects of this type, the team denotes as "Nike". Following such a determination, the team simply encourages the originator to just go get it done. For projects of this type the role of the team is to monitor progress of the project, ensure that full benefit is achieved and to provide assistance when and as needed. Projects in this category generally include things that result in the removal of burden at the expenditure of minimal effort (e.g., less than one man-week).

Long Term Initiative Prioritization

Projects that continue on through the process are next reviewed by the team for prioritization. Prioritization is accomplished as a two step sub-process. Initial priority is established based on site needs (e.g., to support refuelling outages) and estimated cost benefit ratio (i.e., projected savings divided by estimated expenditures). This initial prioritization serves as a screening helping to ensure that we focus our final and more detailed prioritization on the areas of greatest needs and largest return on our investment. From this subset of projects, the team then completes its final prioritization based on consideration of all factors (i.e., initial prioritization, probability of success and availability of resources).

Priority List of Initiatives

As in other areas, the relative priorities of projects must constantly be reassessed. Also the final prioritization usually resulting in a general grouping of projects in terms of order of importance. The team makes no effort to work the projects or to adjust our activities "mid-stream" based on some hard and fast top to bottom ranking. Rather we use the prioritization of the projects to provide a sanity check for our current work activities. In other words, one should expect that at any given time there would be an appropriate mix of projects (i.e., high and median ranking) being actively pursued. The mix should not be too heavily weighted with lower priority projects. As another aid in keeping appropriate focus on burden reduction projects, the team has created a priority list of activities. This list represents a compiled set of activities where the team expects to expend a significant amount of effort over the next three to six months. The priority list is thought of as the team's "top issues" list. In essence the priority list is a short-term planing tool. As previously noted not all issues on the priority list would receive the highest ranking in accordance with the prioritization scheme but rather the list should reflect an appropriate mix of issues.

Burden Reduction Categories

When considering areas for potential burden reduction activities, the Burden Reduction Team stresses two things. First that the scope of activities that we are concerned with are broader than simply "regulated" activities. Second that when initially considering areas for consideration, there are no "scared cows".

When most individuals think of burden reduction, they naturally think of areas where there exist either a Technical Specification requirement or a specific 10CFR requirement. However, burden reduction is much broader than this and to limit oneself to thinking in only these terms could result in numerous missed opportunities. For the EOI burden reduction effort, activities fall into one of three categories:

1. regulated,
2. licensee imposed, or
3. burden avoidance.

Burden imposed through Technical Specifications, 10CFR requirements or license conditions are many times the only areas some individuals think of when you ask them to consider potential burden reduction activities. While it's true unwarranted burden has and is often imposed through legal requirements, it certainly isn't the only origin of burden that one should consider.

Recent experience has shown that much, if not the majority, of the burden now encountered by licensees is self - imposed rather than regulatory imposed. In many cases it's a misinterpretation of the requirements or the results of years of adding layer upon layer of commitments that results in the unwarranted burden. In some instances it may have resulted from an inappropriate response to a USNRC request. Whatever the cause, in many instances the licensee is to blame for the undue burden not the regulation or the regulator. It's also the licensee that can and must eliminate the unwarranted burden through the proper implementation of their own programs (e.g., 10CFR50.59, 10CFR50.54, commitment change process, etc.)

Finally there's the category of avoided burden. This is likely the most over looked and certainly the most difficult to measure. Included in this category would be such things as assuming a proactive position with regards to proposed new regulations or ensuring responses to NRC requests (e.g., Generic Letters) are appropriate and cost effective. It's doing the right thing now in order to avoid unwarranted burden in the future. The dilemma is that it is often very difficult to quantify the avoided future burden and thus adequately assess the amount of present effort justified in order to achieve the desired goal.

All three areas represent potential sources of unwarranted burden and thus potential sources of burden reduction activities. Each category has its own unique way of eliminating the burden (i.e., 50.90 submittals, petition for rulemaking., 50.59, 50.54, etc.) and degree of difficulty associated with the elimination of the burden. Consequently, it's important to completely understand which category you're dealing with and to ensure appropriate steps are taken in seeking approval to eliminate/modify unwarranted burden.

The team also stresses is that there are no sacred cows when it comes to *suggesting* burden reduction ideas. This doesn't mean that the team can and will work on anything and everything suggested. Realistically there are areas where the chances of success are slim, the political environment is not conducive to change or simply that EOI management has elected to continue the activity. As a consequence there realistically are scared cows. However, we should be willing to initially question the appropriateness of any item. If little or no safety benefit is realized as a result of performing the tasks and adequate technical justification exist to either change or modify the task, then, barring overriding factors, we should be willing to seek relief from this unwarranted burden.

Finally, it's necessary to briefly discuss the EOI Burden Reduction common database. The entire process is build around the ability of each team member to quickly and effectively communicate their decisions and actions with the other team members. To facilitate effective communication among team members and thus sites, it was first essential that all members talked the same language. To do this we need a common database. A common database allows each site to not only status their assigned burden reduction activities but to readily assess applicability of other issues to their site. As previously noted, the database is both historical and living. It provides documentation of what issues have been accepted and completed while providing current status of on-going activities.

5. BEST IN CLASS

Entergy is in the business of producing and selling a commodity - electricity. As a consumer of a commodity, the distinguishing characteristic is price. With the advent of low-cost independent power producers, co-generation, co-ops and transmission access, the customer now has more options than ever before. In the ever increasingly competitive electricity marketplace, nuclear generation must compete economically with other energy sources to remain viable. Nuclear, like all of Entergy, recognizes that the future belongs to the quality providers who can safely produce the lowest cost electricity.

Entergy is determined to be a major competitor--whatever form the new competitive environment takes. Thus in preparation for this new challenge, Entergy has launched specific initiatives within six key areas:

- Best in Class programs to become low-cost producers in fossil and nuclear generation organizations.
- Aggressively reducing costs and improving efficiencies in other business units.
- Reducing prices to be competitive with alternative sources of electricity.
- Building a new high performance culture that challenges and empowers every employee.
- Checking every aspect of its regulatory environment for ways to improve or streamline it.
- Making significant investments in electric energy businesses that should produce growth and returns superior to our core utility business.

Burden reduction plays a key role with regards to many of Entergy's six key areas (e.g., Best in Class, reducing cost and improving efficiencies, improved regulatory environment, etc.). However, like EOI, the Burden Reduction Team feels that the strongest commitment Nuclear can offer in helping to advance Entergy's competitive position is its balanced approach to Best in Class performance.

EOI's 1996-1998 Nuclear Business Plan has established the breathtaking challenge of being Best in Class by 1998. For Nuclear, this means being the best among similar types of plants while keeping the balanced focus on safety/regulatory, operating and cost performance. As outlined in the Business Plan, Best in class will be achieved by focusing EOI's attention and energy on three strategic areas:

- **Continued Balanced Perspective**
- **Maximized Sharing of Resources**
- **One Nuclear Station With Five Units**

Similar to the EOI Business Plan, the EOI Burden Reduction Team has agreed, within each of the three areas, to certain specific initiatives to aid in the achievement of Best in Class.

Continued Balanced Perspective

One aspect of this strategic area deals with EOI's long-standing view that Nuclear excellence is defined by top quartile performance in the three areas of safety/regulatory, operating and cost. For long-term success one must constantly maintain an appropriate balanced within all three areas. A balance must exist between the safety benefit associated with requirements and the cost of implementing measures to comply. While there is a responsibility to retain commitments and to implement changes that significantly improve safety, there is also an obligation on our part to seek changes where the cost of compliance is not supported by a commensurate safety benefit.

In burden reduction there is also the need to maintain an appropriate balance of both short-term and long-term activities. Short-term activities are often focused exclusively on imminent site needs such as the next refuelling outage or today's hot topic. However, short-term issues are seldom the leap forward in performance improvement. These are usually longer term issues that by their very nature require significant up front investment of time and effort.

1996 Initiatives

Continue to educate employees on the importance of burden reduction. Give presentations that encourage participation and accentuate the need to incorporate burden reduction into routine work activities.

Support site short-term needs (e.g., refuelling outage, etc.) while maintaining an appropriate mix of ongoing long-term activities.

Achieve a return on investment of at least 4 to 1. In other words for every $1 expended on reduce burden, there is at least a $4 return to EOI in terms of savings.

Maximize Sharing of Resources

For burden reduction the sharing of resources is larger than simply combining our work force, it's the sharing of our intellectual resources as well. It's the sharing of creative ideas, of expertise and of experiences. While the sharing of personnel is relatively easy, the sharing of intellectual resources is often times much more difficult.

The sharing of intellectual resources begins with providing a means for everyone to speak the same language - common database. It continues on with ongoing programs that seek out new and innovative burden reduction suggestions. It concludes by having a well established process for easily documenting burden reduction suggestions, for assigning appropriate roles and responsibilities and for statusing/tracking issues to completion.

1996 Initiatives

Develop a system-wide incentive program which encourages and rewards employees for generating acceptable burden reduction suggestions.

Complete development of the EOI common database and implement on the system-wide network.

Implement improvements in the burden reduction process for collecting and documenting burden reduction suggestions.

One Nuclear Station With Five Units

While similar to the sharing of resources, operating with the philosophy of one nuclear station with five units is at the same time different. This is a strategy of conditioning people to begin viewing problems from a much broader perspective. When faced with challenges or opportunities, employees must consider the implications at not only their particular site but at the same time all of EOI's sites. In addition, we have to build trust among the various sites/departments such that is no reluctance to allowing one site to assume the system lead for selected issues. In turn, these lead sites must make appropriate decisions that benefit the majority of sites. Work must be performed as much as possible one time for all sites thus eliminating duplication of effort.

1996 Initiatives

Continue to encourage the performance of burden reduction projects using the lead site role concept. Foster the acceptance of this concept by ensure all projects are completed on schedule and with indisputable quality.

UNITED STATED
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D.C. 20555-0001

February 23, 1995 GNRI-95/00048

NRC ADMINISTRATIVE LETTER 95-02: COST BENEFICIAL LICENSING ACTIONS

Addressees

All holders of operating licenses or construction permits for nuclear power reactors.

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this administrative letter to inform addressees about the cost beneficial licensing action (CBLA) program. The CBLA program provides a more expeditious review and increased NRC management attention for licensee requests that seek to modify or delete requirements that have a small effect on safety and are costly to implement. Participation in the CBLA program is voluntary. This administrative letter does not transmit or imply any new or changed requirements or staff positions. No specific action or written response is required.

Background

In April 1993, a CBLA Task Force was formed to study how CBLAs are handled and what changes should be made to the Office of Nuclear Reactor Regulation (NRR) review process to improve the timeliness and efficiency of reviews of licensing issues. Placing additional emphasis on processing CBLAs has the potential to improve safety by allowing licensees to shift resources from activities that have a small effect on safety to those that more significantly enhance safety. In December 1993, the task force issued its report, which included many recommendations for both the industry and the staff. Implementation of staff recommendations is ongoing.

The task force found that CBLAs are not new and that over the years many licensee requests seek to modify or delete requirements that have a small effect on safety and are costly to implement. However, before June 1993 the NRR priority ranking system assigned the lowest priority (priority 4) to many licensing submittals addressing items that affected safety an incrementally small amount without consideration of the licensee cost of implementation or restriction of operational flexibility. Although the CBLA task force determined that some priority 4 actions were being completed, licensees may have been discouraged from submitting these types of requests because of the low review priority they would receive. CBLAs in the revised priority ranking system described in the referenced June 6, 1993, memorandum from Dr. Thomas E. Murley, then Director, NRR were to be ranked priority 3 to ensure they were reviewed before priority 4 work items. Dr. Murley gave the NRR staff initial guidance on CBLAs and acknowledged that although the direct

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safety significance of CBLA issues was low, the staff should review the technical merits of any licensee proposal. As discussed in this administrative letter, the priority ranking of CBLAs will be further increased within the current priority 3 ranking, so that a CBLA will normally be worked before other priority 3 licensing actions.

Discussion

Even though many of the actions licensees request may be CBLAs in the broad sense, requested actions that affect safety by an incrementally small amount and are costly to implement or restrict operational flexibility should nevertheless receive a timely review. The staff has expanded the guidance in Reference 1 and is training both headquarters and regional staff on the definition and treatment of CBLAs. Attachment 1 is a list of questions raised during public meetings and staff training sessions, the answers to which contain further guidance. The staff will consider a licensing action to be a CBLA if it meets all of the following:

1. The licensee requests in writing that the licensing action be considered a CBLA. If a licensee chooses not to identify an action as a CBLA, the request will be ranked based solely on its safety significance and may be ranked priority 4.

2. The submittal is of high quality and establishes a sufficient basis to support an initial determination that the licensing action has a small effect on safety and will not require the staff to request additional information to make a safety judgement. Therefore, CBLAs will normally not require an extensive NRC technical review. Licensing actions for which CBLA consideration is requested that are not high quality submittals will be ranked as priority 4 until supplemented by the licensee.

3. The action normally would not be ranked priority 1 or 2.

4. The requested action is expected to save the licensee at least $100,000 in operating and maintenance (O&M) costs or capital expenses over the remaining life of the plant, not including replacement power costs. The submittal should include an estimate of the expected cost savings over the remaining plant life. As discussed in item 1 above, if a licensee chooses not to include cost information, the staff may consider the request priority 4 and will not consider it a CBLA. Most licensees routinely prepare this type of cost information as part of their internal cost/benefit analysis. The request to include a summary of this information in the submittal should not place any additional burden on licensees. No recordkeeping requirements are associated with this request.

5. The requested action should be plant-specific. However, a topical report will be treated as a CBLA if it meets the criteria contained herein and if two or more licensees submit documentation with the

topical report stating that they will reference the topical report and provide cost data demonstrating that the cost saving to each licensee is consistent with the guidelines in Item 4, above. Further guidance regarding the submittal of topical reports is contained in NUREG-0390, "Topical Report Review Status."

6. Submittals should be items which require NRC review and approval (not a 10 CFR 50.59 review or a change to a commitment that does not require NRC review and approval), and should have a current application not contingent on future circumstances.

A request that a licensing action be considered a CBLA is strictly voluntary. Once a licensee submittal is designated a CBLA, the staff will evaluate it as it would any other licensee submittal. The submittal will be evaluated on its technical merits, and safety will continue to be the overriding concern in any staff determinations. CBLAs will not receive automatic staff approval. However, CBLAs will be categorized as priority 3 and will be normally acted on by the staff before other priority 3 licensing actions.

To assist in developing the CBLA policy and tracking CBLAs, members of the staff have been dedicated to serve on a CBLA group for a limited time. The Regulatory Review Group (RRG)/CBLA group, led by Eugene V. Imbro, does not replace the normal process for reviewing and approving licensee requests. The RRG/CBLA group will give general CBLA policy guidance to NRC and licensee staffs, will track and trend CBLA submittal and approval data, and will work with the staff and industry to identify CBLAs for possible inclusion in the Standard Technical Specifications or for consideration as line item improvements to technical specifications. The RRG/CBLA group will also focus management attention on implementing the CBLA process within the staff. The NRC licensing project manager will remain the primary point of contact for all licensing actions including CBLAs. However, licensees should contact Mr. Imbro if they have questions on staff implementation of the CBLA program.

The CBLA task force developed early estimates of submittals of CBLAs and found that 300 to 400 more requests could be expected each year. However, the staff has not yet found a significant increase in the number of licensing actions received that have been designated by licensees as CBLAs, although the number has increased slightly. The RRG/CBLA group will monitor the CBLA submittal and approval trends and, if backlogs warrant, will review the program and make adjustments as necessary.

The Technical Specification Improvement program is similar to the CBLA program in that both can substantially reduce unnecessary regulatory burden. The conversion to the improved Standard Technical Specifications can save licensee financial and staff resources by relocating 30 to 40 percent of existing license requirements to licensee controlled documents. Licensees should note that conversion to the improved Standard Technical Specifications will receive higher priority than CBLAs and that such conversions may encompass a considerable number of potential CBLAs. While the benefits of converting to the new technical specifications are hard to quantify, licensee owners groups project annual savings of between $150,000 and $1.13 million per site from the program. In total, licensees for about 40 units are currently pursuing conversion to the new technical specifications. Like the CBLA program, participation in the Technical Specification Improvement program is voluntary.

The staff plans to hold a public workshop in the spring, 1995, to discuss the CBLA program with the industry. Details of the meeting will be forthcoming.

Voluntary Response Requested

The NRC requests that addressees include the following information with the licensing action submittal if they want the action requested in the submittal to be considered a CBLA:

1. A written request that the licensing action be considered a CBLA

2. Cost savings information--the amount saved (exclusive of the cost of replacement power) through the reduction in regulatory burden over the remaining plant life that would result from implementing the requested licensing action

Paperwork Reduction Act Statement

The requests herein for voluntary submittal of information are covered by the Office of Management and Budget, clearance number 3150-0011, which expires July 31, 1995. The public reporting burden for this voluntary collection of information is estimated to average 5 hours for each response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this voluntary collection of information, including suggestions for reducing this burden, to the Information and Records Management Branch T6 F33, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555-0001 and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-3019, (3150-0011), Office of Management and Budget, Washington, D.C. 20503.

This administrative letter requires no specific action or written response. If you have any questions about this letter, please contact the person listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

E V Imbro

Eugene V. Imbro, Director
Regulatory Review Group/
Cost Beneficial Licensing
Actions Programs
Office of Nuclear Reactor Regulation

Contact: Eric J. Leeds, NRR
(301) 415-1133

Reference:
1. Memorandum from Dr. Thomas E. Murley, Director, Office of Nuclear Reactor Regulation, to NRR Staff, "Priority Determination for NRR Review Efforts," June 6, 1993

Attachments:
1. Questions and Answers
2. List of Recently Issued NRC Administrative Letters

ANNEX B.3
SIEMENS VALVE PERFORMANCE CONCEPT: THE WAY TO CONDITION ORIENTED MAINTENANCE

Introduction

Around 20 000 valves are installed in a modern 1 300 MW Siemens NPP. Some 2 400 valves are actuated by electric motors and solenoids. Nearly 300 of these being safety related.

Among the approximately 2 100 incidents selected and stored in the Siemens database between 1980 and 1993, about one third involved valve problems, including their actuators, either as a primary or secondary factor [1].

The functional reliability of the active system, consisting of valves and actuators influences the safety and availability of NPPs. On the other hand the complex demands as well as the quantity require a considerable maintenance effort.

All these reasons show the necessity for an **Integral Valve Performance Concept**, which combines cost effective monitoring measures and maintenance efforts during the lifetime of the NPP with methods to improve safety and reliability.

Valve Performance Concept

Based on experience with valve and actuator qualifications we pursue two goals on the way to condition-oriented maintenance.

The first goal is to obtain **Function** during the lifetime with appropriate safety margins for actuator and valve.

The second goal is to obtain optimized **Maintenance** and inspection with respect to readiness for function and cost reduction.

A prerequisite for the performance concept is precise determination of the system requirements, the influencing factors of the power supply system and the instrumentation and control equipment.

A two step approach distinguishes between the **Ability for Function** and the **Readiness for Function** during the equipment lifetime (Fig. 1).

The Ability for Function of valves and actuators is verified only once for any single type of valve and actuator. It is a typical quantity in the design and is verified by calculation and a design evaluation. The basis for validation of the analytical methods are tests in the plants or on test rigs with full mass flow under normal and accident conditions.

Readiness for Function must be demonstrated individually for each valve and actuator repeatedly during their lifetime and is achieved by periodic testing and surveillance and suitable maintenance.

I shall explain the essential aspects of this concept concentrating on motor-operated valves (MOVs).

Ability for Function

The main point for consideration with respect to functional performance is always the determination of actuation forces or torques together with the necessary safety margins.

Considering the valve-actuator assembly as part of an overall system it is necessary to determine the essential influencing factors at the interfaces to other parts of the system.

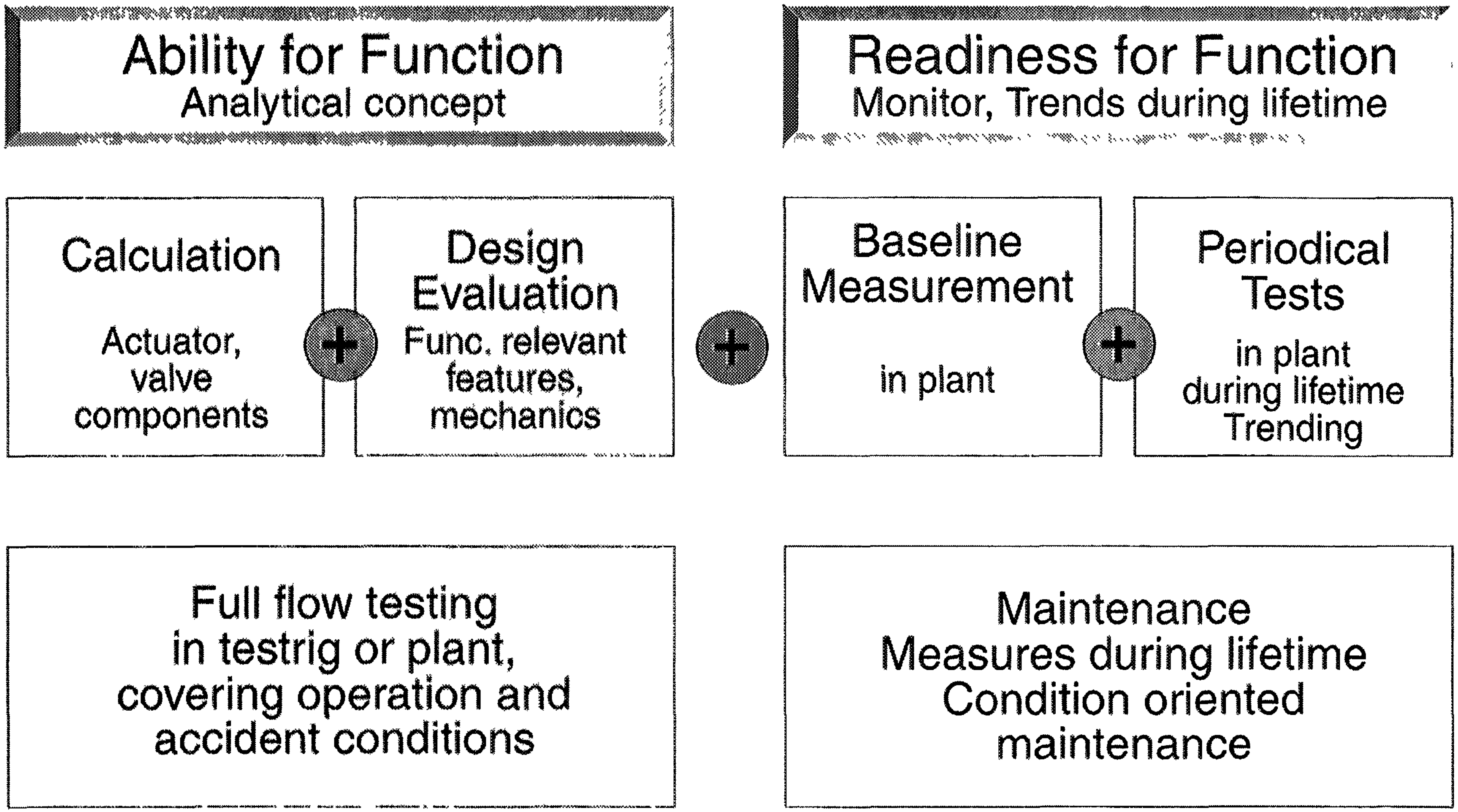


FIG. 1. Valve performance concept.

The most important factor for the power supply system is the input voltage at the motor. It must be ensured that the use of protective devices (fuses, bimetallic elements) does not lead to a reduction in actuator availability. Also the kinds of actuator control are important factors in the functional model.

Apart from pressure forces, only friction forces define the stem force and torque balance. This requires consideration of the tolerances of the influencing factors which exhibit considerable scatter. Derivation and validation of parameter scatter was performed in the course of tests and also required the definition of allowable boundaries by a well-founded method.

It was our goal to establish a simple calculation rule based on nominal values. Simultaneously-acting parameters with tolerances are taken into account through safety factors. For determination of the safety factors we chose the Gaussian approximation method with the propagation of random errors.

Besides the determination of actuation forces, a stress analysis of all parts on the load path is a necessary part of our analytical model.

For a complete analysis of the Ability for Function, the design evaluation validates the mechanical models used in the functional model.

The properties relevant to function are evaluated by:

- Analysis of applicability of existing test results (i.e. looking behind the mechanism of action).
- An evaluation of design elements. We look especially at the bracing of stem nut, pressure locking of the disk assembly and thermal binding.
- An evaluation of clearances and tolerances with respect to function and system demands (leak tightness).

This design evaluation allows a systematic similarity approach for valve types and design families.

The tilting behavior - exhibited by all gate valves - may serve to illustrate and explain the method used in this analysis (Fig. 2). The force exerted by differential pressure and the stem force lead to tilting of the disc during parts of the stroking cycle. At high loads this can lead to galling instead of sliding. The tilting moment (Fig. 3) is only dependent on the geometry of the design and the friction factor and can therefore form the basis for a similarity analysis. The contact stress is dependent on the differential pressure and the seat geometry. This detailed knowledge of the mechanism of action further enables a precise interpretation of periodic tests with adapted measurements.

A similar approach is adopted for pilot operated valves (POVs). The Ability for Function is analysed by fluid dynamic calculations for stroking behavior and the pressure response in the pressure chambers of the main valves. The time-dependent pressure response is the sensitive quality used to derive the actuation force as a principle property of the design.

Again tests with full mass flow under operating and accident conditions form the basis for the validation of calculation tools and allow a fundamental understanding on the time dependent valve performance.

Readiness for Function

The aim of the second part of the integral concept is the monitoring of deviations during the lifetime of valves and actuators. It is fundamental when modifying a maintenance concept, which is based on experience and practice in the direction of condition-oriented maintenance. However, it is necessary to use statistical methods for trending statements for the valve and actuator.

For monitoring of motor-operated valves (MOVs) we use the electrical actuator as a transducer by measuring the active power. Baseline measurements can be supplemented by additional mechanical values. The decision to monitor active power had been influenced by operational advantages as well as reasons of cost effectiveness.

- It is a measurement which is suitable for all kinds of MOVs.
- Monitoring is performed using the original power supply, instrumentation and control system.
- It is possible to include the shutoff elements.

Measurement from the motor control center (MCC) leads to a significant reduction in manpower, dose rate (ALARA) and allows monitoring to be performed during plant operation meaning that such work no longer need be postponed until the next power plant outage. Valves and actuators must not be taken out of duty for monitoring.

Power measurement is the key element in our expert system ADAM for monitoring and evaluating the test results automatically (Fig. 4) by comparison with design criteria. The analytical methods for the verification of the Ability for Function are now the instruments for determining the appropriate safety margin for the integral signal as well as for the individual influencing factors.

For periodic testing all influencing factors, which can deviate during lifetime are evaluated and are the basis for trending, namely:

- stem factor
- stuffing box friction
- actuator efficiency
- switch settings
- switchoff delay time.

Allowable tolerances will be derived from the analytical functional model and the design evaluation.

Comparable to the measurement of active power for MOVs is the measurement of pressure in the pressure chambers of POVs and the measurement of current for solenoid valves.

Of course this concept is not limited to baseline measurements and periodic tests. It also provides a fast tool for checking maintenance work. Today the technical prerequisites for continuous monitoring of valve performance are well known. The next step is a question of time and expenditure.

The compilation of all test data into databases will than permit qualified discussions regarding the prolongation of inspection intervals. Preventive measures such as inspections and changing of parts will be reduced and will lead to an optimized stock of spare parts.

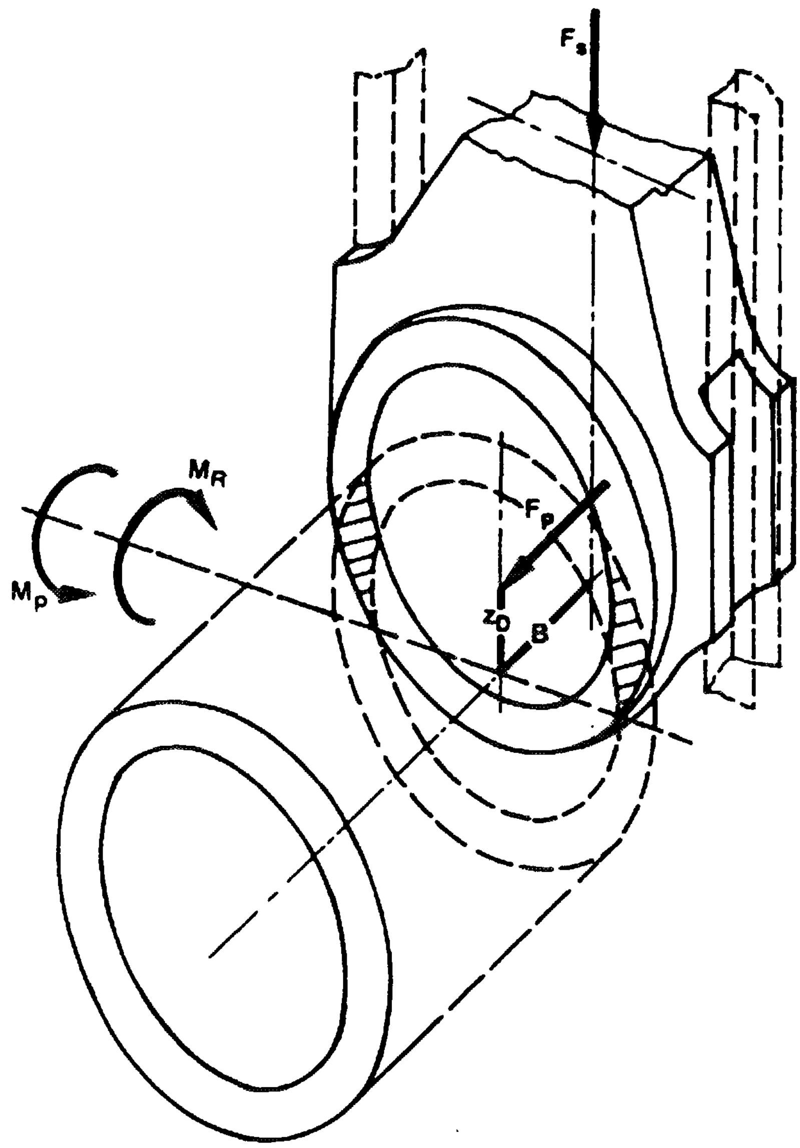
Working Sequence

First of all it is necessary to assess all safety related valves and their requirements during normal and accident conditions. Valves and actuators of same kind will be gathered into groups with enveloping tasks, to minimize the analytical effort for verification of the Ability for Function.

Baseline measurements together with evaluation criteria show compliance with the design. Periodic tests will be compared with the baseline measurement. The expert system ADAM now allows a direct judgement of the actual situation.

Conclusion

The Siemens Valve Performance Concept is an engineering method for improved safety and availability of nuclear power plants through evaluation of the Ability for Function and Readiness for Function during component lifetime.



Tilting conditions

$$\sum M = M_R - M_P$$

$$\sum M > 0 \Rightarrow \text{Tilting}$$

M = Moment
R = Friction
P = Pressure

FIG. 2. Ability of function design valuation.

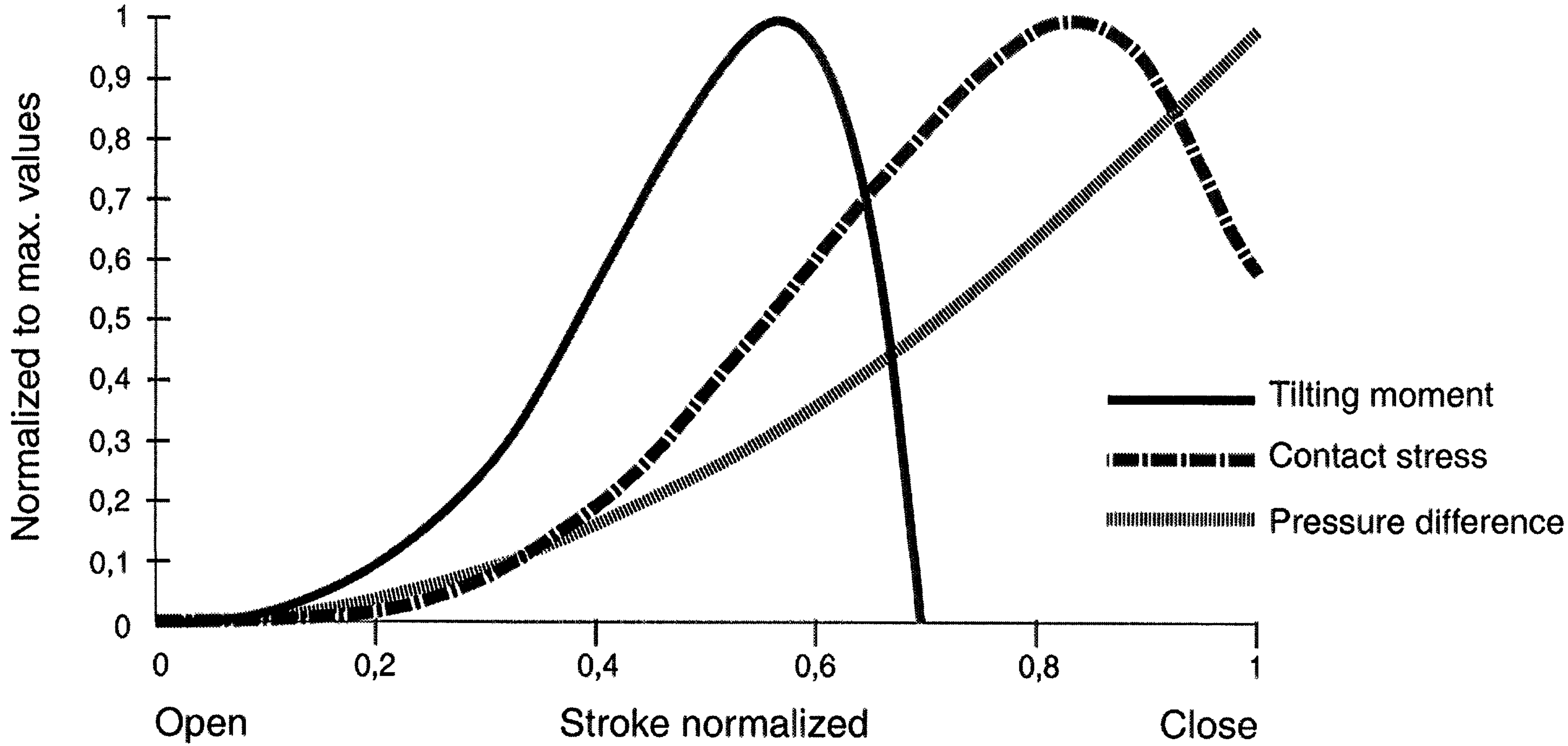


FIG. 3. Ability of function design valuation: gate valves.

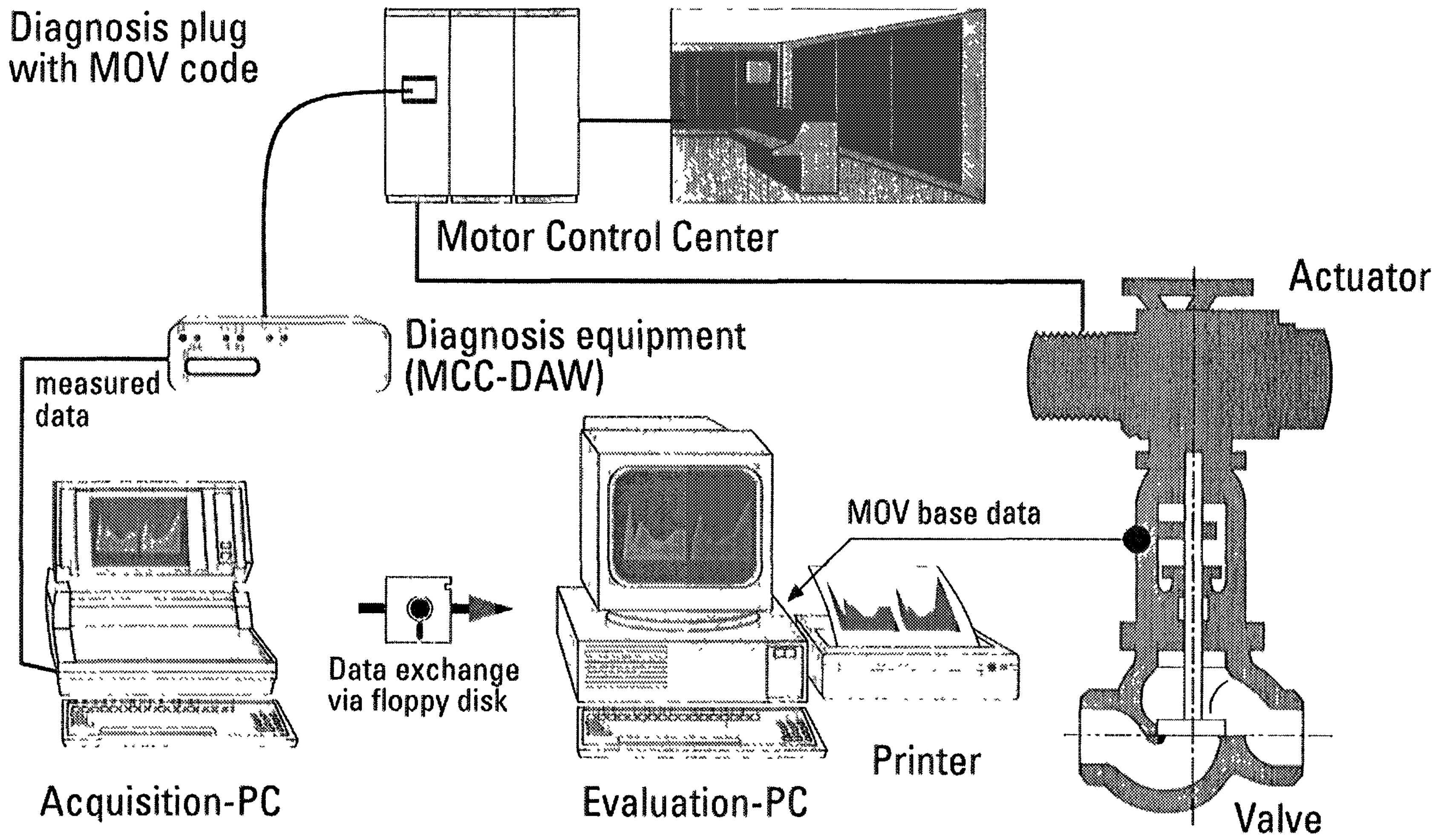


FIG. 4. Functional diagram.

What is now required are initial investments for calculations, diagnosis equipment, measures at the Motor Control Center and for the expert systems. The cost benefits will then be manifested during plant lifetime in decreased manpower effort, significant reductions in preventive measures for inspection, parts changing and in an optimized stock of spare parts.

References

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[2] "Review of Safety Related Valves for Design Basis Event" by Oskarshamn, Sweden, G.Denfors, N.Rauffmann, P.Kradepohl, Specialist Meeting on Motor Operated Valve Issues 25.-27.04.94, Paris.

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ANNEX B.4
STREAMLINED RCM COMPARISON STUDY

A comparison study was performed on the reactor water clean up system (RWCU) at the Peco Energy Limerick generating station. The major objective of this study was to improve streamlined RCM methods. The study conducted by three separated analysis on the RWCU system applying each of the streamlined method with a different analyst and with varying level of RCM experience. The comparison was performed with the following streamlined methods:

- streamlined classical process
- plant maintenance optimizer (PMO) streamlined process
- criticality checklist process.

Streamlined classical process

The streamlined classical process maintains the most similarity to the standard RCM process of the streamlined methods evaluated during this project. The two major differences from standard RCM are:

1. System functions are categorized in one of two areas:
   - important
   - non-important

Only the functions in the Important category go through the formal FMEA analysis. The components that support the non-important functions are evaluated in the Non-Critical Evaluation with the non-critical components from the FMEA analysis.

2. The Instrument Matrix can be used to evaluate:
   - all of the instruments in the system regardless of what function they support, or
   - only the instruments that support the *Important* functions.

The modified classical analysis was performed by an experience RCM analyst who was familiar with the process and knowledgeable on the RWCU system. This system analysis was completed in 100 man-hours.
The major factors contributing to the successful completion of the system analysis using the modified classical approach were:
1. analysis performed by an experience RCM analyst
2. use of the Instrument Matrix in a system that had a large percentage of I&C components.

Many of the functions for the RWCU system were identified as important; therefore, there was a no large benefit derived from the step in the analysis process which categorizes the functions. Increased analysis savings may be obtained on a system that has more non-important functions. The modified classical process is capable of excellent results with minimum loss of documentation since it closely follows the standard RCM process.

Plant maintenance optimizer (PMO) streamlined process

The PMO process is also very similar to the standard RCM process, but streamlines the process in a different manner than the streamlined classical process. The PMO process categorizes the system functions in the same fashion as the modified classical process. The major difference in this process is that the standard FMEA and LTA have been streamlined and combined into one record. the PMO process documents the most significant failure modes for a component (typically 3 for this project) and allows the analyst to document the most dominant plant effects (typically 3 for this project) in *one* component record. This component record is used to determine criticality of the component based on the various combinations of the most severe plant effects for the identified failure modes. If the component is determined to be critical the recommended PM's will be documented in the same record. These PM's can be identified through the use of Maintenance Templates or the standard LTA; however there is no formal LTA documentation available. In this process, the analyst must be familiar with the LTA process to ensure that ideal PM's for the documented failure modes are identified. It is also left up to the analyst to understand which failure modes cause the undesired plant effects so that only the important failure modes are addressed through the PM recommendations. Components that are identified as non-critical in the criticality analysis will be evaluated in the non-critical evaluation along with all the other system components that support non-important functions.

The PMO system analysis was performed by an inexperienced RCM analyst who was initially unfamiliar with the new streamlined process. The system analysis was completed using the PMO process in 140 man-hours. The same components in the RWCU system were critical in both the Modified Classical and PMO streamlined processes. This is attributed to the similarity and emphasis on the same steps in the analysis process.
The major factors contributing to the successful completion of the system analysis using the PMO process are:

1. The combination of all failure modes / plant effects into one record
2. Combination of the FMEA and LTA into one component record with less formal documentation.

It is expected that this process used by a more experienced RCM analyst familiar with the process could achieve results similar to be modified classical process. Another potential improvement could be realized through the addition of an instrument matrix as applied in the modified classical approach.

Criticality checklist process

Of all the streamlined processes used during this study, the Criticality Checklist process varies the most from the standard RCM process. In this process neither Functional Failure Analysis nor Failure Modes and Effects Analysis are performed. In the criticality evaluation, each systems component that is going to be analyzed goes through a checklist to identify if the failure of that component would cause any of the listed plant effects. If any of the checklist questions in the criticality evaluation are answered *yes* that component is *critical.* Components that are not critical go through a typical non-critical evaluation used in all the streamlined processes and the standard RCM process.
As with most of the streamlined processes, there is no formal documented LTA process for identification of PM tasks. The analyst must be familiar with the LTA process and also recommend PM tasks for failure mode / cause combinations that are considered worthwhile to identify or eliminate through the PM program. The Criticality Checklist system analysis was performed by an inexperienced RCM analyst who was familiar with the new streamlined process. The system analysis was completed in 100 man-hours. 90% of the same components were also critical in the modified classical and PMO process analysis. The difference was due to the fact that some mechanical system components such as relief valves have a functional failure to support overpressure protection in the other streamlined processes. In the criticality checklist the relief valves did not cause any of the detrimental effects that would classify the components as critical. However, these components did get identified for similar PM's through the non-critical evaluation process.
The major factor contributing to the successful completion of the system analysis using the Criticality Checklist process is application of predetermined criteria for component criticality. This process applied by a more experienced analyst could achieve results in the shortest amount of time possible, but you will have a lower level of documentation compared with the

streamlined classical and PMO processes. Another disadvantage is that due to no functional basis it may require additional efforts to provide the level of documentation required if RCM is used to support programs for NRC Maintenance Rule compliance. One possible improvements being evaluated is to identify system functions as performed in the other streamlined processes, and only perform the criticality evaluation for those components that support the important functions.

Conclusions

The number of critical components and the overall recommended preventive maintenance tasks for critical and non-critical components were very similar for all of the evaluated streamlined methods. It is important to note, that the use of streamlined methods provides a decreased level of documentation and that many of the streamlined features of the various processes increase the reliance on the analyst to mentally perform some of the steps that are well documented in the standard RCM process. The use of maintenance templates provides consistent guidance between different analysts and helps maintain the focus on the LTA process with reduced documentation. This evaluation demonstrated that the differences in results from each of the processes is very minor and in most cases can be attributed to analyst experience and preference. The level of documentation required to achieve the desired goals from any analysis needs to be taken into account when selecting a method for a particular use. As any process, some of the criteria used can be modified to place the proper emphasis on what is expected to be accomplished through the application of these processes. Allowing for the lower level of documentation coupled with the difference in analysis time and the overall PM recommendations, the streamlined analysis processes are clearly cost effective for many applications.

ANNEX C
SUPPORTING INFORMATION RELATED TO IMPROVING PROCESSES

ANNEX C.1
ANNUAL REDUNDANCY WORK PLANNING

The GKN II power plant in Germany utilizes four safety trains. Maintenance and functional test planning is made easier by dedicating work windows to specific trains. During train windows, work on other safety trains is prohibited, except in the case of emergent work on significant equipment. The "redundancy plan" is published to all departments in the quarter preceding the calendar year.

The following plan shows the correlation between safety train work windows and calendar weeks.

GKN - B | Redundanzplan 1994 | Block II

Januar		Februar		März		April		Mai		Juni	
1 Sa		1 Di	5/3	1 Di	9/3	1 Fr		1 So		1 Mi	22/1
2 So		2 Mi		2 Mi		2 Sa		2 Mo		2 Do	
3 Mo		3 Do		3 Do		3 So		3 Di	18/1	3 Fr	
4 Di	1/3	4 Fr		4 Fr		4 Mo		4 Mi		4 Sa	
5 Mi		5 Sa		5 Sa		5 Di	14/1	5 Do		5 So	
6 Do		6 So		6 So		6 Mi		6 Fr		6 Mo	
7 Fr		7 Mo		7 Mo		7 Do		7 Sa		7 Di	23/2
8 Sa		8 Di	6/1	8 Di	10/1	8 Fr		8 So		8 Mi	
9 So		9 Mi		9 Mi		9 Sa		9 Mo		9 Do	
10 Mo		10 Do		10 Do		10 So		10 Di	19/2	10 Fr	
11 Di	2/1	11 Fr		11 Fr		11 Mo		11 Mi		11 Sa	
12 Mi		12 Sa		12 Sa		12 Di	15/2	12 Do		12 So	
13 Do		13 So		13 So		13 Mi		13 Fr		13 Mo	
14 Fr		14 Mo		14 Mo		14 Do		14 Sa		14 Di	24/4
15 Sa		15 Di	7/2	15 Di	11/2	15 Fr		15 So		15 Mi	
16 So		16 Mi		16 Mi		16 Sa		16 Mo		16 Do	
17 Mo		17 Do		17 Do		17 So		17 Di	20/4	17 Fr	
18 Di	3/2	18 Fr		18 Fr		18 Mo		18 Mi		18 Sa	
19 Mi		19 Sa		19 Sa		19 Di	16/4	19 Do		19 So	
20 Do		20 So		20 So		20 Mi		20 Fr		20 Mo	
21 Fr		21 Mo		21 Mo		21 Do		21 Sa		21 Di	25/3
22 Sa		22 Di	8/4	22 Di	12/4	22 Fr		22 So		22 Mi	
23 So		23 Mi		23 Mi		23 Sa		23 Mo		23 Do	
24 Mo		24 Do		24 Do		24 So		24 Di	21/3	24 Fr	
25 Di	4/4	25 Fr		25 Fr		25 Mo		25 Mi		25 Sa	
26 Mi		26 Sa		26 Sa		26 Di	17/3	26 Do		26 So	
27 Do		27 So		27 So		27 Mi		27 Fr		27 Mo	
28 Fr		28 Mo		28 Mo		28 Do		28 Sa		28 Di	26/1
29 Sa				29 Di	13/3	29 Fr		29 So		29 Mi	
30 So				30 Mi		30 Sa		30 Mo		30 Do	
31 Mo				31 Do				31 Di			

Juli		August		September		Oktober		November		Dezember	
1 Fr		1 Mo		1 Do		1 Sa		1 Di	44/4	1 Do	
2 Sa		2 Di	31/2	2 Fr		2 So		2 Mi		2 Fr	
3 So		3 Mi		3 Sa		3 Mo		3 Do		3 Sa	
4 Mo		4 Do		4 So		4 Di	40/4	4 Fr		4 So	
5 Di	27/2	5 Fr		5 Mo		5 Mi		5 Sa		5 Mo	
6 Mi		6 Sa		6 Di	36/4	6 Do		6 So		6 Di	49/3
7 Do		7 So		7 Mi		7 Fr		7 Mo		7 Mi	
8 Fr		8 Mo		8 Do		8 Sa		8 Di	45/3	8 Do	
9 Sa		9 Di	32/4	9 Fr		9 So		9 Mi		9 Fr	
10 So		10 Mi		10 Sa		10 Mo		10 Do		10 Sa	
11 Mo		11 Do		11 So		11 Di	41/3	11 Fr		11 So	
12 Di	28/4	12 Fr		12 Mo		12 Mi		12 Sa		12 Mo	
13 Mi		13 Sa		13 Di	37/3	13 Do		13 So		13 Di	50/1
14 Do		14 So		14 Mi		14 Fr		14 Mo		14 Mi	
15 Fr		15 Mo		15 Do		15 Sa		15 Di	46/1	15 Do	
16 Sa		16 Di	33/3	16 Fr		16 So		16 Mi		16 Fr	
17 So		17 Mi		17 Sa		17 Mo		17 Do		17 Sa	
18 Mo		18 Do		18 So		18 Di	42/1	18 Fr		18 So	
19 Di	29/3	19 Fr		19 Mo		19 Mi		19 Sa		19 Mo	
20 Mi		20 Sa		20 Di	38/1	20 Do		20 So		20 Di	51/2
21 Do		21 So		21 Mi		21 Fr		21 Mo		21 Mi	
22 Fr		22 Mo		22 Do		22 Sa		22 Di	47/2	22 Do	
23 Sa		23 Di	34/1	23 Fr		23 So		23 Mi		23 Fr	
24 So		24 Mi		24 Sa		24 Mo		24 Do		24 Sa	
25 Mo		25 Do		25 So		25 Di	43/2	25 Fr		25 So	
26 Di	30/1	26 Fr		26 Mo		26 Mi		26 Sa		26 Mo	
27 Mi		27 Sa		27 Di	39/2	27 Do		27 So		27 Di	52/4
28 Do		28 So		28 Mi		28 Fr		28 Mo		28 Mi	
29 Fr		29 Mo		29 Do		29 Sa		29 Di	48/4	29 Do	
30 Sa		30 Di	35/2	30 Fr		30 So		30 Mi		30 Fr	
31 So		31 Mi				31 Mo				31 Sa	

GKN	work program	unit : II week : 20/96 page : 2 von 3

AKZ/KKS	equipment/system	red.	PVT/ coordinator	work perm. nr.	activity	mo	tu	we	th	fr	sa	remarks
CKE	computer for testing device		LTS/Averdick	95012266	commissioning of S5-criteria logic of CLH05	x	x	x	x			
FCB01	refuelingmachine		MA/Grausam	96000362	maintenance	x	x					
GDN	H2 SO4 control metering device		MN II/Bayer	96000541	substitution of valves	x	x	x	x			KAH und MI
MAY40 EC100	protection system for turbine		MK II/ Weygandt		turbine protection test			x				PG Š 100%
SAD40 AA004	louver damper	4	MI/Ziesak	95015455	lubrication	x	x	x				
KLE	fire protection valve		MNII/Kolleck	95008329	substitution of the trip device	x	x	x	x	x		M + W
KLB	fire protection valve		MNII/Kolleck	95010992	substitution of the trip device	x	x	x	x	x		M + W
SAD40 AN001	ventilator	4	MI/Ziesak	95015407	lubrication	x	x	x				
SAD40 AN002	ventilator	4	MI/Ziesak	95015451	lubrication	x	x	x				
SAD42 AN001	ventilator	4	MI/Ziesak	95015458	lubrication	x	x	x				
SMY	cable laying		LIA/Bächtle	95008505	cable laying in UYE	x	x	x	x	x		Fa. Siemens
XJA	emergency diesel engine		MN II/Meetz	95015575	preparation works	x	x	x	x	x		
XJA30 AG001	emergency diesel engine	3	MN II/Meetz	95015272	test run before maintenance					x		after diesel XJ40 is ready for operation
XJA40 AG001	emergency diesel engine	4	MN II/Meetz	95015238	maintenance (W 5)	x	x	x	x			MTU/MIW
XJN40 AP001	oilpump	4	Meixner		exchange	x	x	x				
XJV40 AP001	fuelpump	4	Meixner		exchange	x	x	x				
XKA40 AG001	dieselgenerator	4	Meixner		visuel inspection	x	x					

ANNEX C.3
THE APPLICATION OF INTEGRATED COMPUTERIZED PLANT MANAGEMENT SYSTEMS TO POWER STATIONS

"Integriertes Betriebsführungs-System" (IBFS)

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1. THE GOALS OF A COMPUTERIZED PLANT MANAGEMENT SYSTEM

For many years now the use of computerized data processing has been spreading at an ever increasing pace and as a result, now covers every imaginable application. Power stations have been no exceptions to this process. Here the introduction has taken place more or less in two stages:

- Initially, computerized data processing was used for process control (measurement, surveillance, control)
- For some times now, however, computers have also been employed in the technical/administrative areas.

This paper is only concerned with the second point.

The aim of data processing applications used in power stations so far has been the direct support of the organisational and operational processes that are normally performed by people.

This has resulted in a very wide field of applications, ranging from the processing of work permits, material control through to the preparation, revision and control of documentation.

Past experience has shown that the difficulties in conceiving and realizing such systems have lain in the complexity and the interdependence of the different applications. All these individual applications are in fact dependent on one another in many different ways and this interdependence must be reflected in the over all system concept.

The main aims of a computerized Operations Management System (e.g. the IBFS) can be defined broadly as follows:

- The Computerized Operations Management System (IBFS) must act as a tool to support the personnel in performing Operations Management tasks.
- It must support the planning, performing, and documenting of these tasks.
- It can take over various supporting activities which contain no scope for decision making (e.g. calculating, text editing, data review and transfer of information etc.).
- It must widen the operations personnel's decision making basis, increase the transparency of operations management processes and allow for the optimizing of these activities.
- It can and must not make responsible decisions itself.
- It can and must not replace man in any way!

As a result of the above points, the following individual goals of an Operations Management System can be established:

- Effective support for the operations personnel in the performance of complex and responsible tasks.
- Implicit observance of the applicable rules, regulations and guide lines within the framework of the computerized system.
- Quality Assurance of the planning, performance and monitoring of Operations Management procedures.

- Improvement in the safety of the plant and personnel.
- The monitoring of adherence to standard procedures using check lists.
- The ability to re-use procedures, developed in the past, when similar situations arise again.
    * Search mechanisms to locate the equivalent situations.
    * Analysis of sequential processes.
    * Experience feedback.
- Improved transparency of the operational activities using efficient search and review criteria.
- Improved communication by the use of electronic mail.
    * Transport of information instead of paper.
    * The employee´s "desk" is the next available terminal and is independent of his actual place of work.
- The automatic computerized recording and reconstruction of processes and events supported by an interface to the Documentation System.
- Schedule forecasts and the notification and initiation of repetitive tasks.
- Reliable expediting of unfinished processes and tasks.
- Reduction of errors of oversight by the use of simple computerized plausibility checks.
- Reduction of manpower intensive tasks (e.g. calculating, writing, evaluation).
- Direct evaluation of the plant process data with specific application to Operations Management activities.
- Automatic documentation of component life histories through a connection to the Work Permit System.

2. THE MAIN IMPLEMENTATION AREAS OF THE COMPUTERIZED OPERATIONS MANAGEMENT SYSTEM

A computerized Management Support System (IBFS) can be composed of several subsystems for various different applications, which cover the whole spectrum of requirements for the system.

No general rules can be made concerning the scope and completeness of the single elements that make up an Operations Management System since the structure and limits of the functions of the Subsystems can vary depending on the particular application.

The most important implementation areas which can reasonably be included in an operations management system are briefly presented in the following sections.

2.1. Plant Description System (Anlagen-Beschreibungs-System - ABSY)

The basis of any computer supported Operations Management system should be a Plant Description System (ABSY). This system includes the following subjects:

- The buildings and rooms in the plant.
- The individual plant components classified in a logical, hierarchical structure.

It must also be available to all other subsystems of the overall system for the purpose of exchanging information with those systems.

This system should have, on the one hand, an operations side covering the hierarchical system and component designation (Kraftwerk-Kennzeichensystem - KKS) including the associated design values and on the other hand, a hardware side which covers the installed components with their actual measured performance values.

In order to optimise the spare parts planning, it is important that on the hardware side of Plant Description System (ABSY) the possibility is available to categorize the components into specific types. For this reason it must be possible to break down the specification of the components if necessary, to the detail level of a spare parts list.

An example of the structure of the Plant Description System (ABSY) required to specify a particular object is shown in the attachments.

In order to be able to trace the movements and location of the individual components at any one time, the system must contain a section which records the hardware movements and their status.

Finally the Plant Description System (ABSY) should allow the assignment of documentation, surveillance testing, non-destructive testing and inspection and maintenance procedures to the relevant components and systems.

Every single report must be checked to ascertain if it is a Reportable Event (to the Regulatory Authorities). In addition it has to be decided if immediate measures must be taken by the shift or if the report can be given to the responsible department for further processing. In this case a relevant Work Permit will be initiated and given a priority rating by the responsible shift engineer.

The dates when surveillance tests are to be performed and the specified values to be achieved are contained in the system and if the requirements have not been fulfilled by the due date, the Work Permit process is automatically initiated.

A check list with the scheduling and the scope of the surveillance tests is kept by the computer. In most cases the tests to be performed are also described in detailed test procedures. These test procedures must therefore be attached to each computer produced Work Permit. In addition, the results must be systematically evaluated and documented (connection to the subsystems Defect Reports and Documentation).

The most extensive work necessary in the inspection and maintenance area is caused by the lubrication plan. The details of the lubrication tasks to be performed (lubrication point, lubricant, quantity, interval, necessary equipment and special features) are kept in the computer as a lubrication schedule in a similar way to the surveillance test procedures.

To ensure the timely preparation and scheduling of the surveillance testing and lubrication, it is necessary to prepare lists in various forms, e.g. daily, weekly, monthly, quarterly and yearly programs and schedules.

Advanced Operation Management Systems incorporate computer supported preparation, scheduling and expediting of planned outages within the framework of the Work Permit Planning. This subsystem should be able to co-ordinate all permits in the permit system, including the relevant priorities, in such a way that optimum work packages with regard to work requirements, system isolation planning, and resource allocation are generated.

As a result of integrating these outage permits into the Work Permit System, all Work Packages are registered on completion. The daily work scheduled and the work actually completed can be printed out in bar chart form.

For all Work Permits the technical evaluation and work preparation required by the Work Permit procedure is performed in the planning phase. At this stage the technical, personnel and material requirements are defined by the responsible shift engineer. The necessary safety measures, including System Work Release and arranging for the availability of tools, staging and spare parts is planned and initiated by the computer.

To allow the performance of the work permitted by each individual Work Permit, the work instructions and necessary paperwork, including the System Work Release sheets and associated tags required are prepared by the computer, printed out and made available the person responsible for the work.

The notification of the completion of the work performed under the permit should be made as soon as possible and in as much detail al possible so that the schedule and Permit Control System can be updated.

The review of completed Work Permits represents a very important phase of the process. Here the planned times are replaced by the actual times, the experience gained and any special features are documented. If necessary, all subsequent activities arising as a result of the work performed under the Work Permit are determined.

2.2. Work Permit System (Betriebliches Auftragswesen - BASY)

A further important application of the Operation Management System is the Work Permit System (BASY).

This application requires the computerized support of the Work Permit activities, starting with the initiating event, then the preparatory work and following through the whole process of the Work Permit in accordance with the valid maintenance procedures and regulations.

The initiating event can either be from a Trouble Report or from the results of planned surveillance or non-destructive testing.

All initiating events which require a Work Permit for their resolution lead to a Work Order Procedure which is characterised by the following phases:

- Information collection and organisation
- Planning
- Scheduling
- Performance of the work
- Evaluation.

The computer supported Work Permit System (BASY) should be able to do considerably more than simply collect and manage permit forms which are normally prepared using conventional methods. An up to date Work Permit System should allow the computer controlled planning of the Permit Procedure by the responsible technical departments involved in such a way that the personnel work interactively and in compliance with the QA requirements.

Efficient Work Permit Systems have, in addition, the following features:

- Only those components/parts can be processed which are contained in the Plant Description System (ABSY).
- Computerized presentation of the component identification, its exact place in the system and the room in the plant where it is installed).
- A computerized connection to the Material Control System. This allows the automatic reservation of spare parts while processing a Work Permit.
- All working papers and records produced by the computer are automatically recorded in the Documentation System.
- Records of all work performed on a component are automatically transferred to the life history file of that particular component.

The following can be considered as initiating events by the computer:

- Trouble Reports
- Surveillance testing
- Maintenance and inspection
- Work during planned outages.

Trouble Reports can be initiated by the following:

- Any employee (e.g. by calling the control room)
- Items in reports from routine checks in the plant
- Measures resulting from surveillance testing and inspection.

2.3. Material Control (Materialwesen - MAWE)

The following applications in an Operations Management System arise in the area of Material Control:

- The preparation and approval of purchase specifications and orders for equipment and services.
- The automatic print out of approved purchase specification and orders.
- The processing of warehouse deliveries, including the Quality Control and if necessary, the assignment to the Documentation System of documentation associated with the delivery.
- Stock Control.
- The reserving and preparation of materials for delivery to and withdrawal from the warehouse (including the booking of the material costs to the relevant job order).
- Stock review, carrying out of inventories and the transfer of information to the accounts department.
- The structure and management of the data base (material and suppliers) is the most important prerequisite for a satisfactorily functioning Material Control System.

In the material data base one should differentiate between the following:

- Spare and replacement parts associated with the plant
- Consumable materials.

In the case of the first item it is reasonable to transfer the management of the data base to the Plant Description System (BASY) since these parts are always assigned to a type category (using a list of descriptive features which are always the same for one particular type) and are anyway in the majority of the cases already installed in the plant.

The technical data should however, be available to the Material Control System in order not to break the system structure.

In this way it can be assured that only those parts will be stored which can actually be used in the plant. In addition, a rationalisation of the types of parts stored is achieved by the consistent assignment of the parts to type categories.

This System requires access via the computer to the Documentation System, the Work Permit System and the Plant Description System.

2.4. Documentation System (Dokumentations-System DOKU)

The documentation in a power station covers, among other things, the following areas:

- Technical description of the whole plant
- Licensing documentation
- Approved documentation for manufacturing, calculations and QC certificates
- Operations documentation
- Applicable rules, regulations and guide lines
- All correspondence.

An efficient and powerful computer supported documentation system is necessary in order to have an overview of this quantity of information and to be able to extract particular documents at will.

All documentation that has to be recorded and/or placed in the archives must be registered in the Documentation System. This means that each individual unit of documentation which is to be retrievable must be recorded in a record. This must include all identifying, classifying and descriptive data which are needed for the subsequent search and extraction of the relevant document.

In this connection it is extremely important that each document can be assigned to as many designating numbers as are needed. It should also be possible, using lists of contents, to combine any document with any other documents dealing with the same subject, as are needed.

The following features also normally belong to documentation management:

- Archiving of originals
- Management of microfilms
- Management of documentation on optical discs.
- Management of texts and text editing
- Management of CAD-Drawings and models.

Beside the actual documentation management the following can also be organized in the Documentation System:

- X-ray films
- Material test samples

The following are also areas of application:

- Rules, standards, regulations, guide lines
- Instruction manuals
- Internal and external document revision requests.

In this connection the so called "Regelmatrix" provides an effective means of comparing the regulations with one another and maintaining control over their revision status.

It is also an essential requirement of the Documentation System that it must have access to all the other systems of the Operations Management System. Practically no activity in a power station exists that does not, in one form or other, have to be documented. In this connection it is very important to have the capability of registering new documents in the Documentation System at the time when they are generated, to obviate the manual registration of the documents at a later date. This is above all the case for in-house produced documents (CAD or text editing) which must be registered by a suitable process at the time that they are generated. This requirement is also valid for all forms generated by the computer.

2.5. Acquisition and Management of Process Data

This heading covers the interface between the Operations Management System and the Process Computer or other equipment which provides process data.

It must be possible to make the relevant data from the process computer available to the Operations Management System so that the data can be utilized in the individual systems in order that any resulting t actions can be initiated.

3. THE MAIN PRINCIPLES OF A COMPUTERIZED OPERATIONS MANAGEMENT SYSTEM

The important conclusion to be drawn from this paper is that, although the Operations Management System is made up of a number of individual systems, these systems must work as an integrated unit.

The main features and constituent parts of an integrated computer system are shown in the attachments.

In practice it has been shown that if an overall concept is not defined at the start, no integrated system design can be achieved. To integrate independent, isolated systems at a later date is almost impossible. The only way to do so is to completely re-structure the individual systems.
The distinguishing features of integrated systems are that they have a central data bank and full communication between the system parts.

4. INTRODUCTION AND SUBSEQUENT DEVELOPMENT OF AN OPERATIONS MANAGEMENT SYSTEM

Once the decision has been made to install computerized support for an Operations Management System, the following plant specific organisational points must be clarified.

4.1. Organisational Pre-requisites for the Introduction of an Operations Management System

- A systematic structure for the designation of the systems, components, rooms, etc. is required.
- The subjects and processes to be addressed in an Operations Management System must also be organised in a logical structure.
- Clear internal plant organisation and procedures are required.
- A clear internal communications structure.

4.2. Software System Design

- Integrated overall concept from the start or
- Re-structure the existing individual computer supported systems.(see section 3).
- There should be a clear definition of the interfaces to isolated systems which are not being included in the Operations Management System.

4.3. Hardware Configuration

- Hardware design which is suited to the working environment and application.
- Open system architecture in order to provide for a wide range of hardware which must, however, be compatible (computer, terminals, PCs, work stations, printers, plotters, optical discs, etc.).
- Network design
- Consideration for further system extensions.

4.4. Data Volume and Organisation

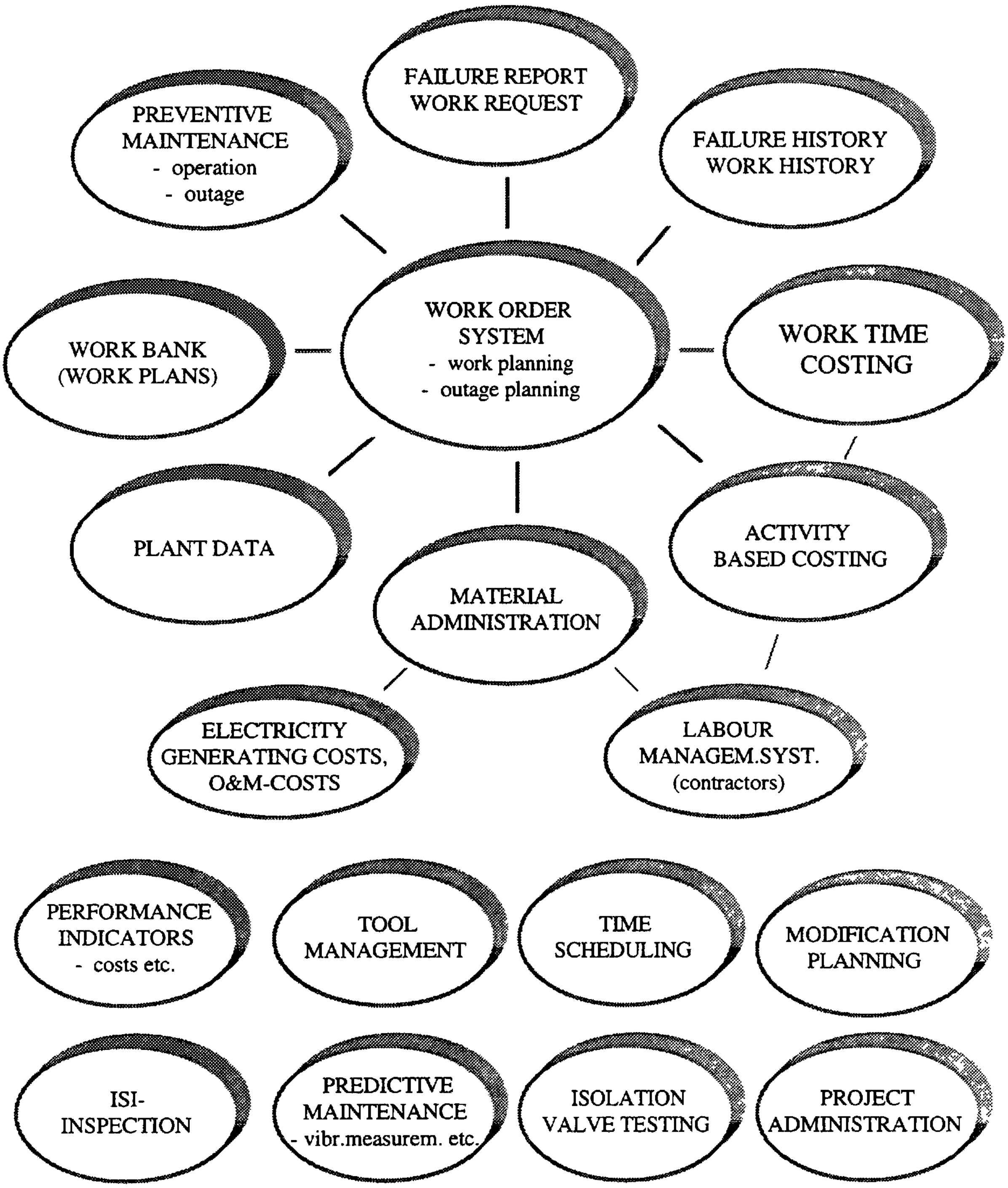
- The availability of good quality and accurate data is of crucial importance if an Operations Management System is to be effective.
- Because of the considerable data volume the data transfer should be by electronic means if at all possible. If necessary the data can be subsequently corrected by hand.

4.5. Development strategy

- An Operations Management System must be introduced in stages such that the user retains an overview of the system and can one stage before moving onto the next.
- The first system to be introduced should be the most important subsystem.
- The addition of further systems should only take place when the previous systems are already functioning acceptably.
- Special emphasis must be placed on personnel training.

ANNEX C.4
FINNISH (TVO) EXAMPLE

MAINTENANCE INFORMATION MANAGEMENT SYSTEM



MAINTENANCE INFORMATION MANAGEMENT SYSTEM

- **WORK ORDER SYSTEM**
  - Includes systems to control maintenance works done during plant operation and outages. System includes work planning and work permit planning (plant safety and health safety) of maintenance works.
- **FAILURE HISTORY / WORK HISTORY**
  - Includes failure and work history data and programs to work up it to easily utilized form.
- **FAILURE REPORT/WORK REQUEST**
  - Includes failure report and work request which can also be done manually.
- **PREVENTIVE MAINTENANCE**
  - Includes system to manage the periods and execution times for periodically done works (preventive maintenance tasks, inspections etc.).
- **WORK BANK (WORK PLANS)**
  - Includes model works (work plans etc.) for periodically done works (preventive maintenance tasks etc.).
- **PLANT DATA**
  - Includes base data for plant systems, equipment, components and parts.
- **MATERIAL ADMINISTRATION**
  - Includes base data for spare parts and materials in stores and warehouses and routins for warehouse and purchasing functions.
- **ACTIVITY BASED COSTING**
  - Includes tools to manage maintenance and operation cost using activity based costing. System includes planning, budjeting and cost accounting of maintenance and operation activities.
- **WORK TIME COSTING**
  - Includes working time follow-up systems for own and contractor personnel.

MAINTENANCE INFORMATION MANAGEMENT SYSTEM

- **ELECTRICITY GENERATING COSTS, O&M-COSTS**
  - Includes electricity cost budgeting and reporting. Includes also investments and improvements.
- **LABOUR MANAGEMENT SYSTEM (contractors)**
  - Includes administration of working periods of contractor personnel (personnel data, working time, health physics training times etc.)
- **PERFORMANCE INDICATORS**
  - System is used to product maintenance and outage statistics.
- **TOOL MANAGEMENT**
  - Includes base data for tools and routins for tool lending from stores.
- **TIME SCHEDULING**
  - Includes tools for time schedule planning and resource optimization for work made during operation and outages.
- **MODIFICATION PLANNING**
  - Includes administration routines for planning and execution of plant modifications and projects.
- **ISI-INSPECTION**
  - Includes in-service inspection planning and reporting.
- **PREDICTIVE MAINTENANCE**
  - Includes predictive maintenance and condition monitoring systems (vibration measurements etc.).
- **ISOLATION VALVE TESTING**
  - Includes reactor containment isolation valve leak rate reporting and follow-up.
- **PROJECT ADMINISTRATION**
  - Includes general project administration system.

ANNEX D
SUPPORTING INFORMATION RELATED TO IMPROVING PRODUCTIVITY

ANNEX D.1
EXAMPLE OF CENTRALIZED SPARE PARTS MANAGEMENT

Many utilities in the USA and several other countries (see Table 1) use the Nuclear Parts Center operated by Framatome Technology, Inc. in Virginia to obtain necessary spare parts for their nuclear power plants, instead of maintaining their own inventories. The Center stores about 3000 parts commonly used in NPPs such as valves, filters, motors and connectors. Utility personnel can, from their own computers, access the supply status of parts and place orders for delivery.

1. Operation of the Nuclear Parts Center

Utilities provide information to the Center on the parts they need and their estimated frequency of use. The Center analyses the specifications for these parts to develop a common specification agreeable to utilities that are interested in a particular part. The Center also evaluates the economics of storage quantities.

The Center than procures the parts. The procurement specifications of nuclear grade parts follows 10CFR50, Appendix A and QA requirements of ASME. These specifications include QA procedures during fabrication, and acceptance testing to be done by the Center.

Accepted parts are stored in racks. Smaller parts are stored in transparent polyethelene bags to avoid dust and to provide easy identification. During storage, parts are periodically inspected in accordance with QA procedures, and removed if they exceed their maximum allowable shelf life.

The Center is capable of receiving requests for delivery or inquiries seven days a week. When a request is received, the Center ships the parts within 24 hours through an ongoing relationship with a shipping company. Documentation, including any QC certificates required, are provided with the parts. At the same time, an order for replacement stock is generated automatically, if the number in stock reaches designated levels.

2. Uses of the Center

The Center frees utilities from writing special procurement specifications for individual orders, as well as the need for individual acceptance tests. In addition, because of higher turnover, less inventory is wasted because of expiration of shelf life, and fewer parts remain of the shelf to become outdated. Economies of scale have enabled utilities to obtain parts from the Center more economically than if they purchased directly from vendors/manufacturers. The sharing of the spare parts system also has shortened the average storage time for parts, thus saving money. The fact that the Center has grown is an indication that it is successful both from the perspective of utility customers and Framatome Technologies.

One of the biggest utility concerns with respect to sharing such a system is "Who helps me when all the inventory of a particular part is exhausted? In order to avoid this risk, an individual utility can ask the Center to keep a specified quantity of particular parts in inventory, for an additional charge. In order to keep costs down, the Center tries to minimize such requests. If another utility places an order for a particular part that is on hold for another utility, upon agreement with the utility, the part can be released.

3. Teamwork

In many cases, the original equipment vendor may have little incentive to solve equipment problems, or in some cases, even to continue to supply spare parts. The Center has teamed with groups of utilities in co-operative procurement efforts that reduce costs and provide an incentive for the manufacturer to provide upgraded and dedicated products, or, if this isn't possible, to develop alternate sources of supply.

TABLE 1. UTILITIES USING THE NUCLEAR PARTS CENTER

Alabama Power	Nebraska Public Power
American Electric Power	New Brunswick Electric
Arizona Public Service	New Hampshire Yankee
Baltimore Gas & Electric	New York Power Authority
Boston Edison	Niagara Mohawk Power
Carolina Power and Light	Northeast Utilities
Cleveland Electric	Northern States Power
Commonwealth Edison	Omaha Public Power
Connecticut Yankee	Ontario Hydro-Canada
Consolidated Edison	Pacific Gas & Electric
Consumers Power	Pennsylvania Power & Light
Fairyland Power Co-op	Philadelphia Electric
Detroit Edison	Portland General Electric
Doel - Belgium	Public Service Elect. & Gas
Duke Power Company	Ringhals - Sweden
Duquesne Light	Sacramento Municipal Utility District
Electricite de France (EDF)	Southern California Edison
Entergy Operations	South Carolina Elect. & Gas
Florida Power & Light	Southern Nuclear
Florida Power Corporation	Tennessee Valley Authority
General Public Utilities	Texas Utilities
Georgia Power	Toledo Edison
Gulf States Utilities	Union Electric
Houston Light & Power	Vermont Yankee
Illinois Power Company	Virginia Power
Iowa Electric	Washington Public Power Supply System
Limitorque Corporation	Wisconsin Electric
Laguna Verde - Mexico	Wisconsin Public Service
Maine Yankee	Wolf Creek Nuclear Ops

ANNEX D.2
EXAMPLE INCENTIVE SYSTEM

The following information is description of the bonus/incentive system performance measures that have been used successfully by TVO in Finland.

The annual quality premium is determined every autumn for the coming year. Organization units propose their own indicators. Proposals are handled in co-operation committee and finally accepted by the board of directors. The quality premium is paid to every employer . Payment is done once a year in January. Maximum amount of the premium corresponds to about three weeks salary. The status with respect to the premium are published and prominently displayed throughout the plant every month (Figure 1 on the following page shows an example of what is displayed). The following briefly describes different indicators for 1996.

Production indicator. Indicator is separate for the people working only in unit 1 or unit 2. Other personnel will follow an average value. The indicator will be zero, if availability of the unit is under 90 %. (Maximum value is 60 hr. salary, when availability is 96 %).

Productivity increase. Indicator will follow the improvement in productivity. Amount of MWhr divided by working hours is the main measure. (Two percentage improvement will give maximum premium of 10 hr. salary).

Cleanliness and order. Indicator will follow the cleanliness and order situation in the plant units, workshops, storage and offices. Cleanliness index will be documented by the walk down inspection of a special committee. (Maximum premium 10 hr. will be achieved when index shows 95 % at the end of the year).

Operation and maintenance costs. Indicator follows operating and maintenance costs of the company. (When savings compared with the annual budget are over 5 % maximum premium of 10 hours salary will be achieved).

Activity based costing. Indicator follows ABC situation in different groups and activities. (Cost savings of 5 % and about 1 % accuracy in budgeting will give maximum 10 hours salary).

Profit centres own indicators. Organizational units have the right to have their own indicators with a maximum value of 40 hours salary. This indicators varies a lot depending the work nature of the unit e.g. operation, maintenance, engineering, information, administration etc. The general aim of these indicators is to support continuos improvement policy in the organization units.

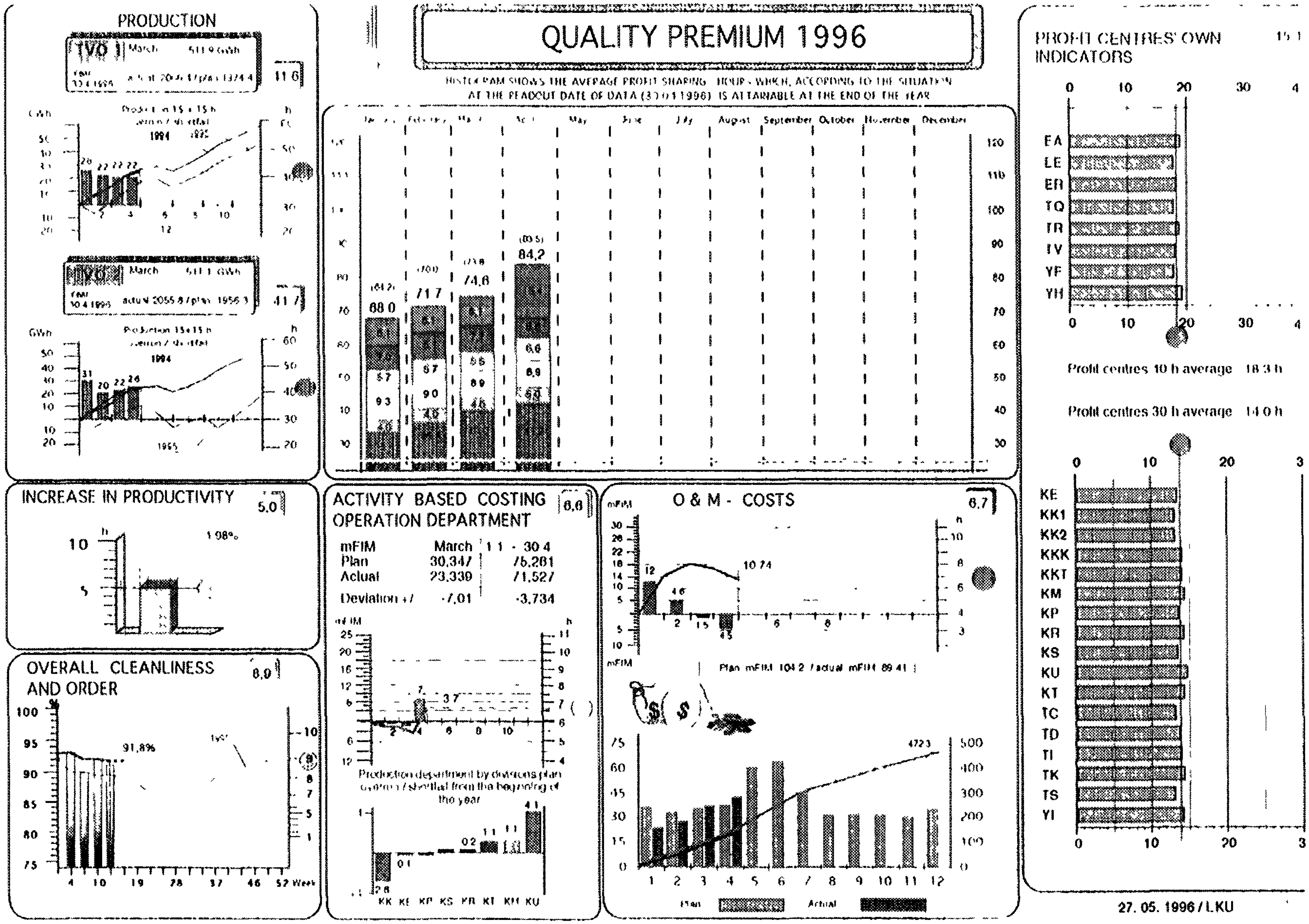


FIG. 1. Graphical representation of bonus system.

ANNEX E
SUPPORTING INFORMATION RELATED TO MEASURING PERFORMANCE

ANNEX E.1
PERFORMANCE MEASUREMENT EXAMPLES

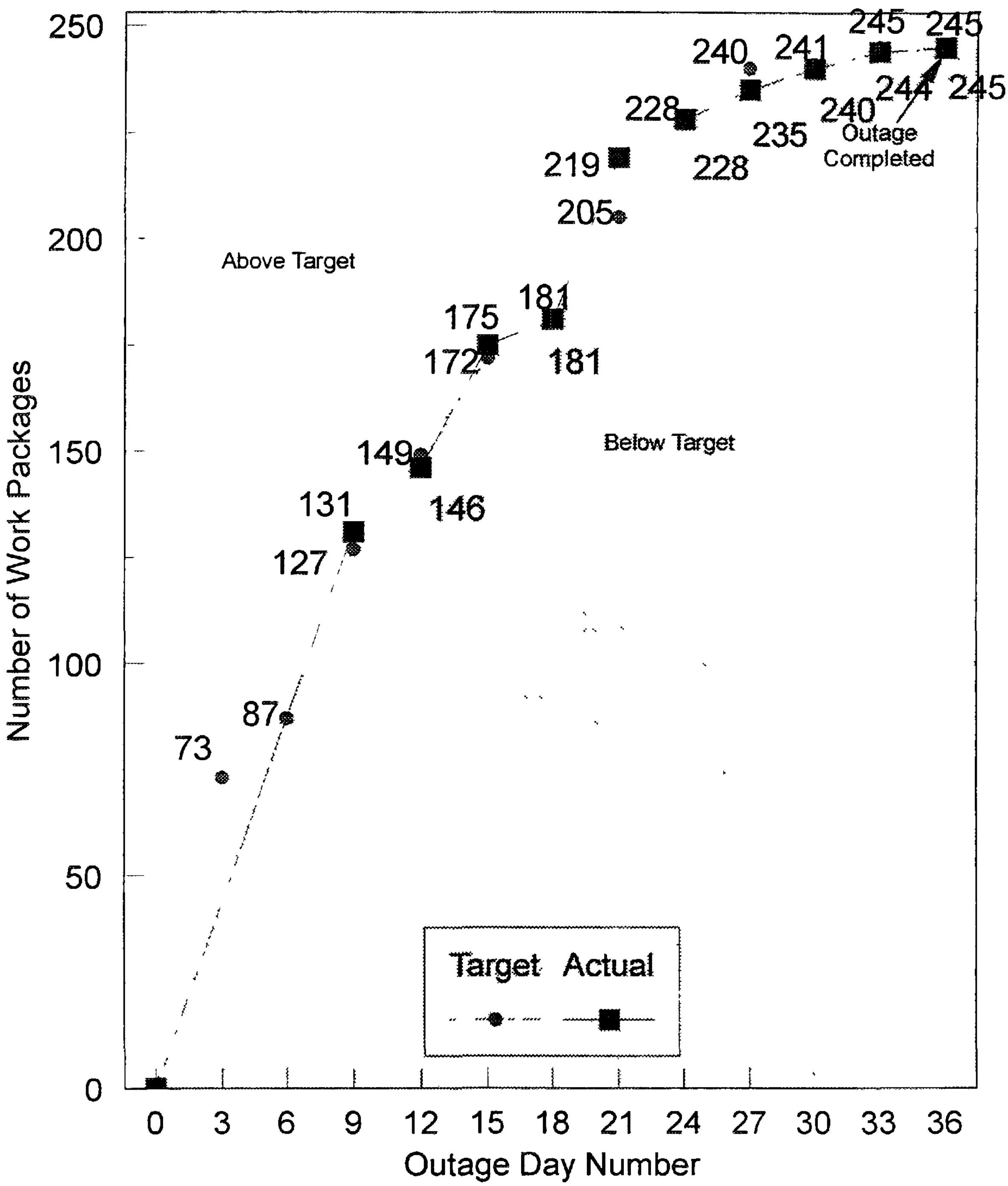


FIG. 1. Outage progress.

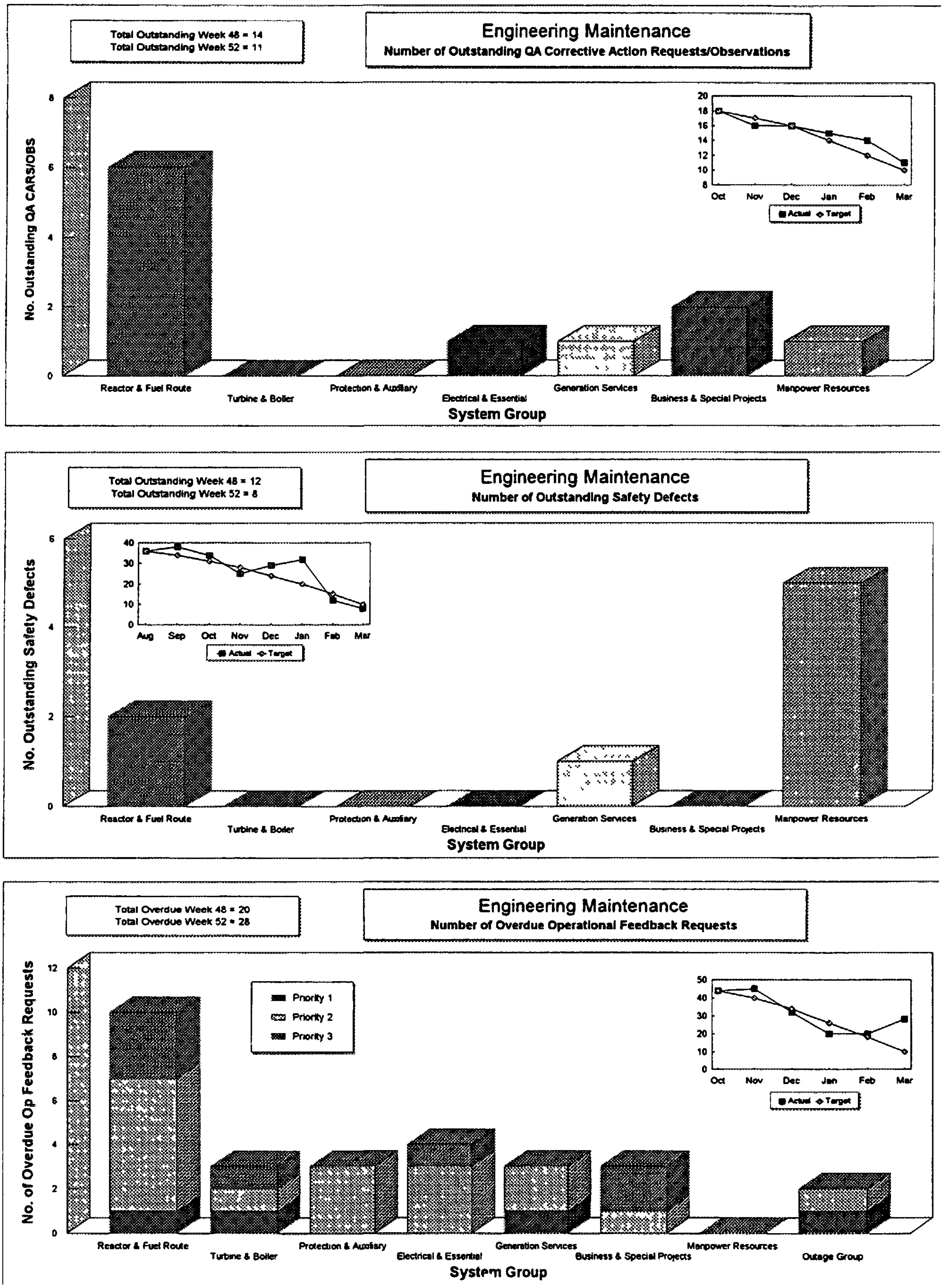


Fig 2. Review of outstanding actions.

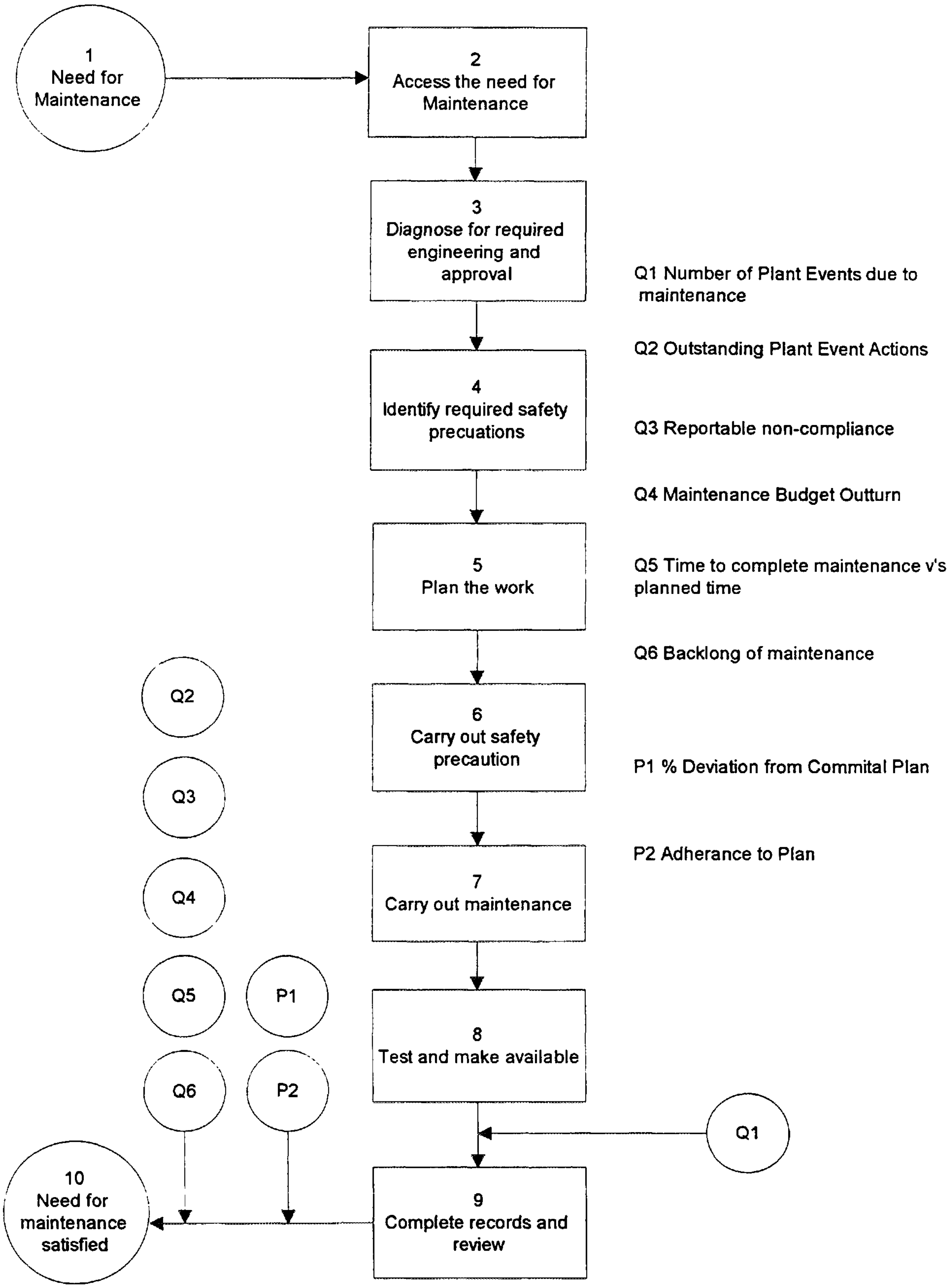


FIG. 3. Routine and defect process map.

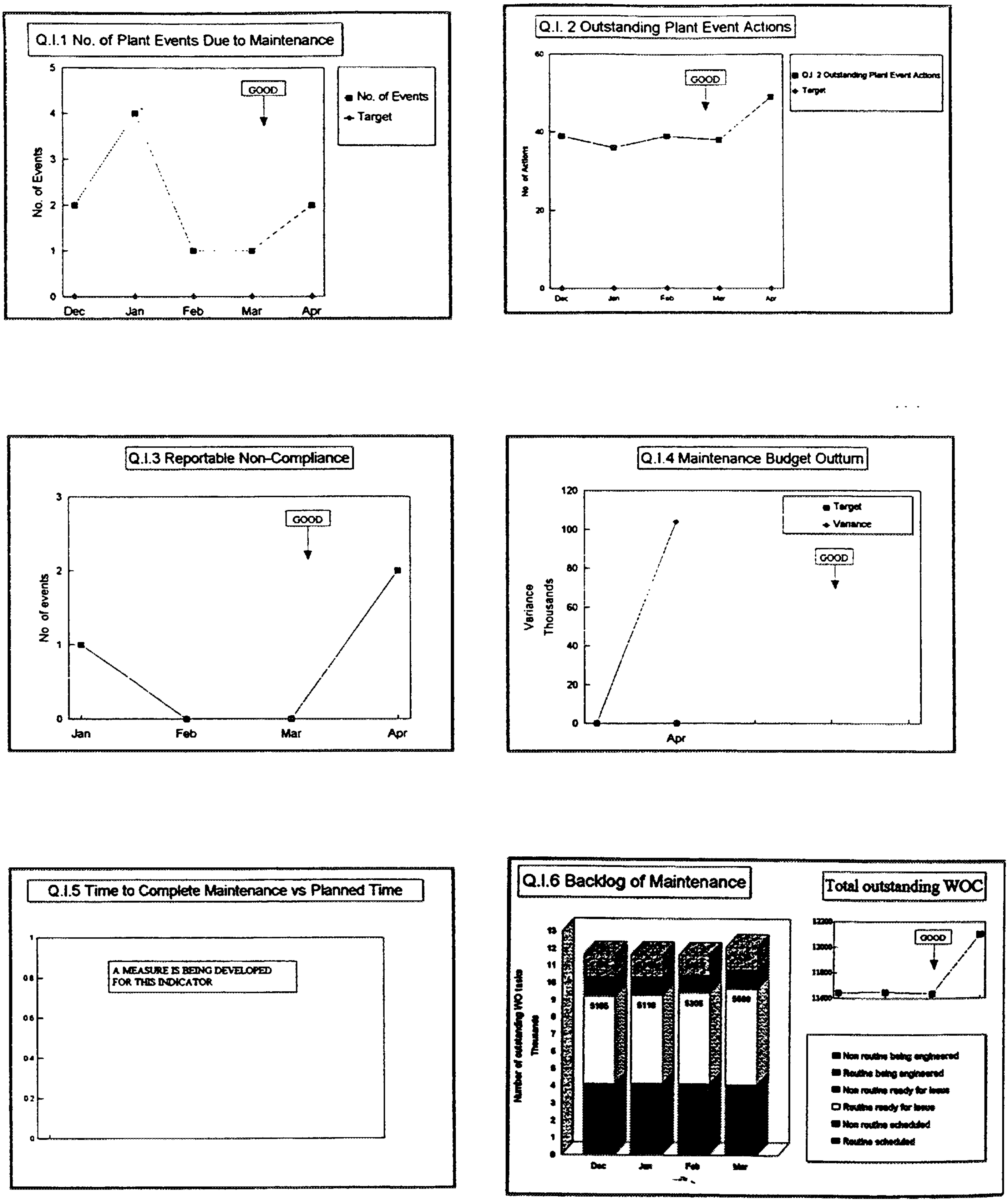


FIG. 4. Status information.

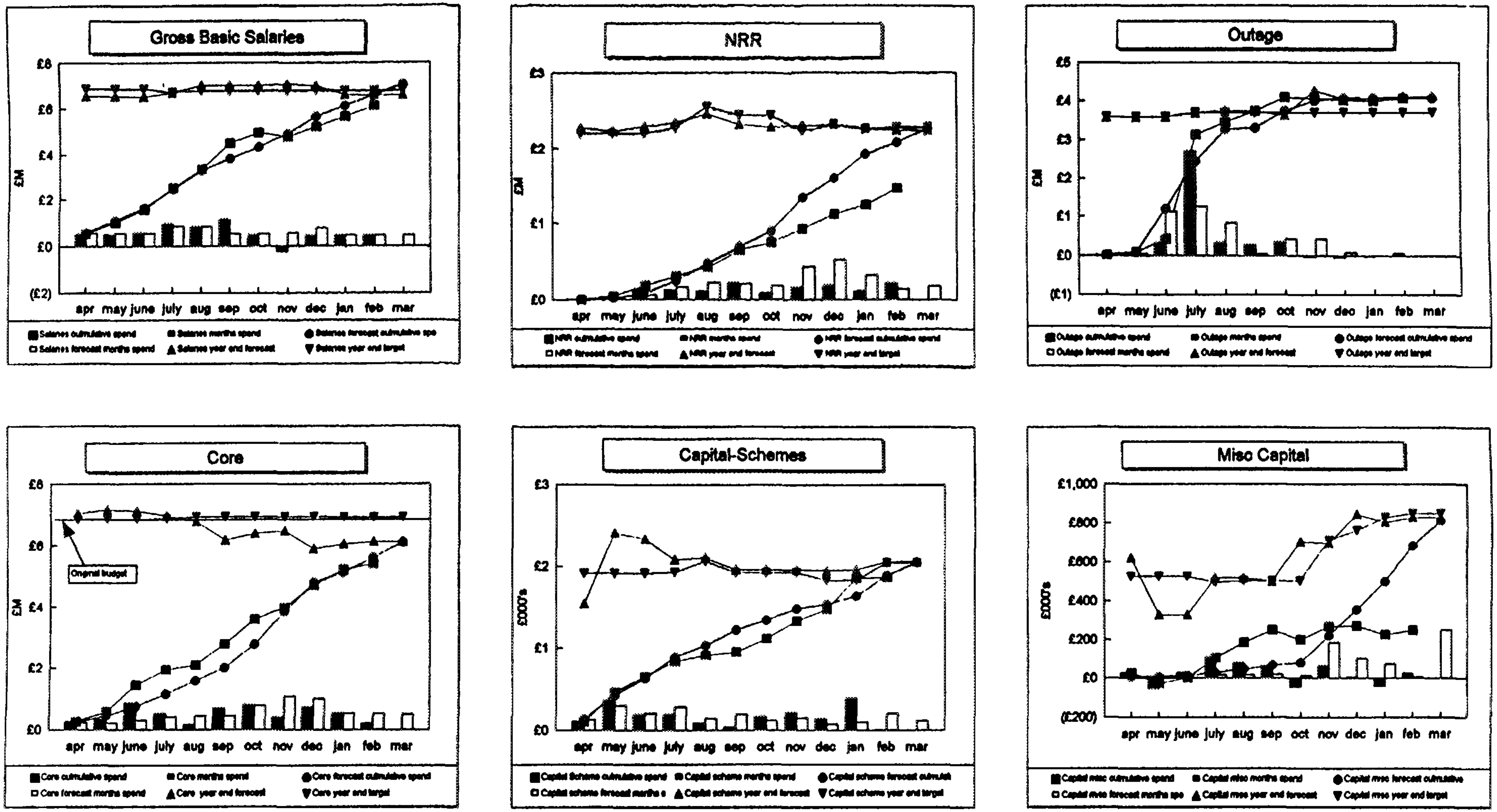


FIG. 5. Review of financial progress 1995-1996.

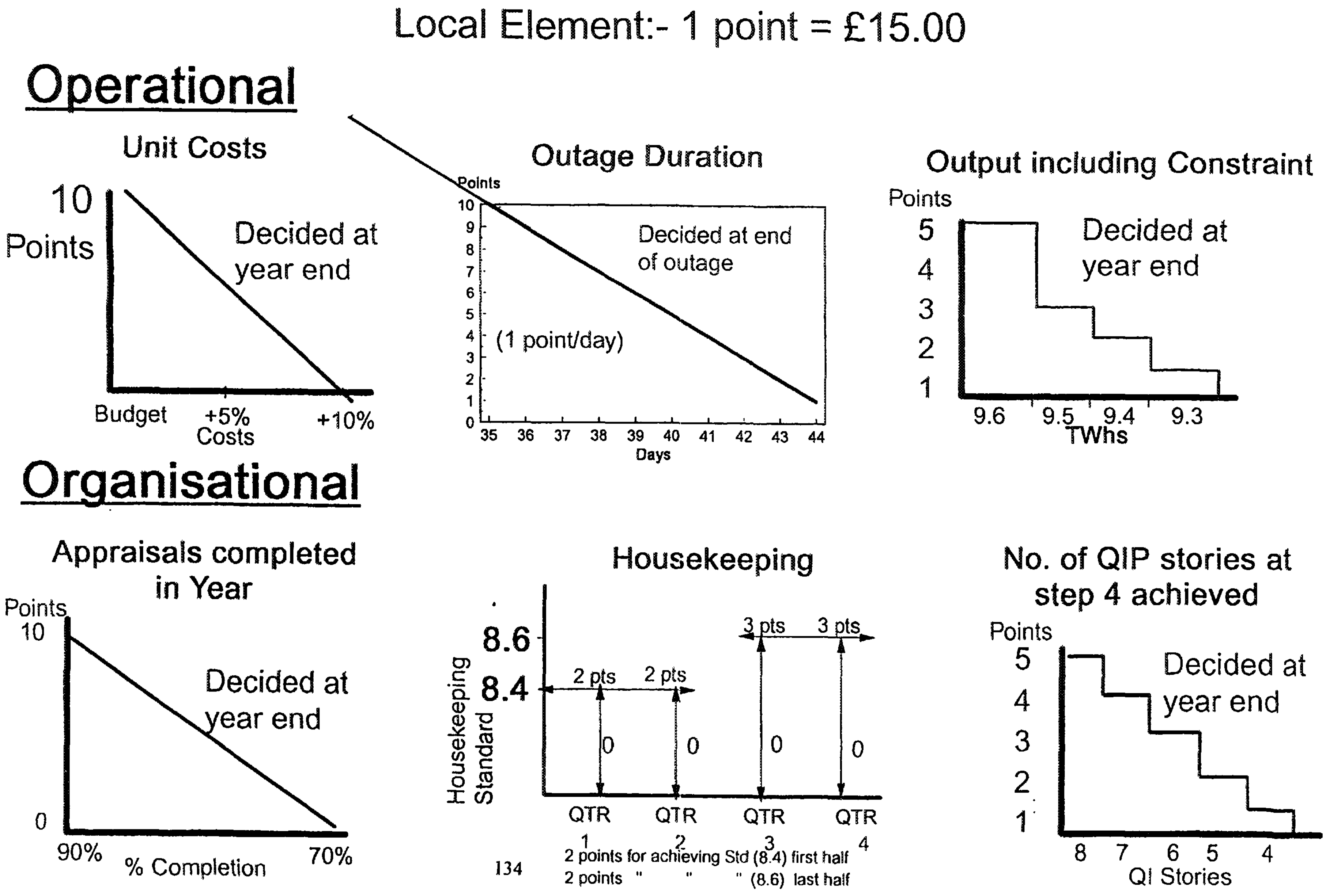


FIG. 6. Gainshare elements 1995-1996.

Reporting Month: December 1995

	ANO-1	ANO-2	GGNS	RBS	W-3
Unit Capability Factor	↑ 81.3	↑ 72.5	↑ 76.9	→ 98.3	↑ 82.3
Unplanned Capability Loss Factor	↑ 5.3	→ 10.4	↑ 6.6	→ 1.4	↑ 5.0
HPSI / HPCS Unavailability	→	→	→	→	→
EFW / RCIC Unavailability	→	→	→	→	→
LPSI / RHR Unavailability	→	→	→	→	→
Emergency A/C	→	→	→	↓	→
Thermal Performance Index	→	→	→	→	→
Fuel Reliability Index	↑	→	↓	→	→
Chemistry Index	→ 1.1	↓ 1.6	→ 1.2	→ 1.0	→ 1.3
RadWaste Volume Generated (CuFt)	→		→	→	→
Collective Radiation Exposure	→	→	→	→	→
Industrial Safety Accident Rate	→	→	→	→	→
Unplanned Scram Rate (per 7000 hrs)	→	→	→	↑	→
Number of Scrams 1995	↓ 2	↓ 2	↓ 5	→ 0	→ 1

Green arrow indicates meeting goal, red arrow indicates not meeting goal, up arrow indicates improving trend, and down arrow indicates adverse trend. The number in the upper right hand corner of each box is the current YTD value.

FIG. 7. Performance indicator status.

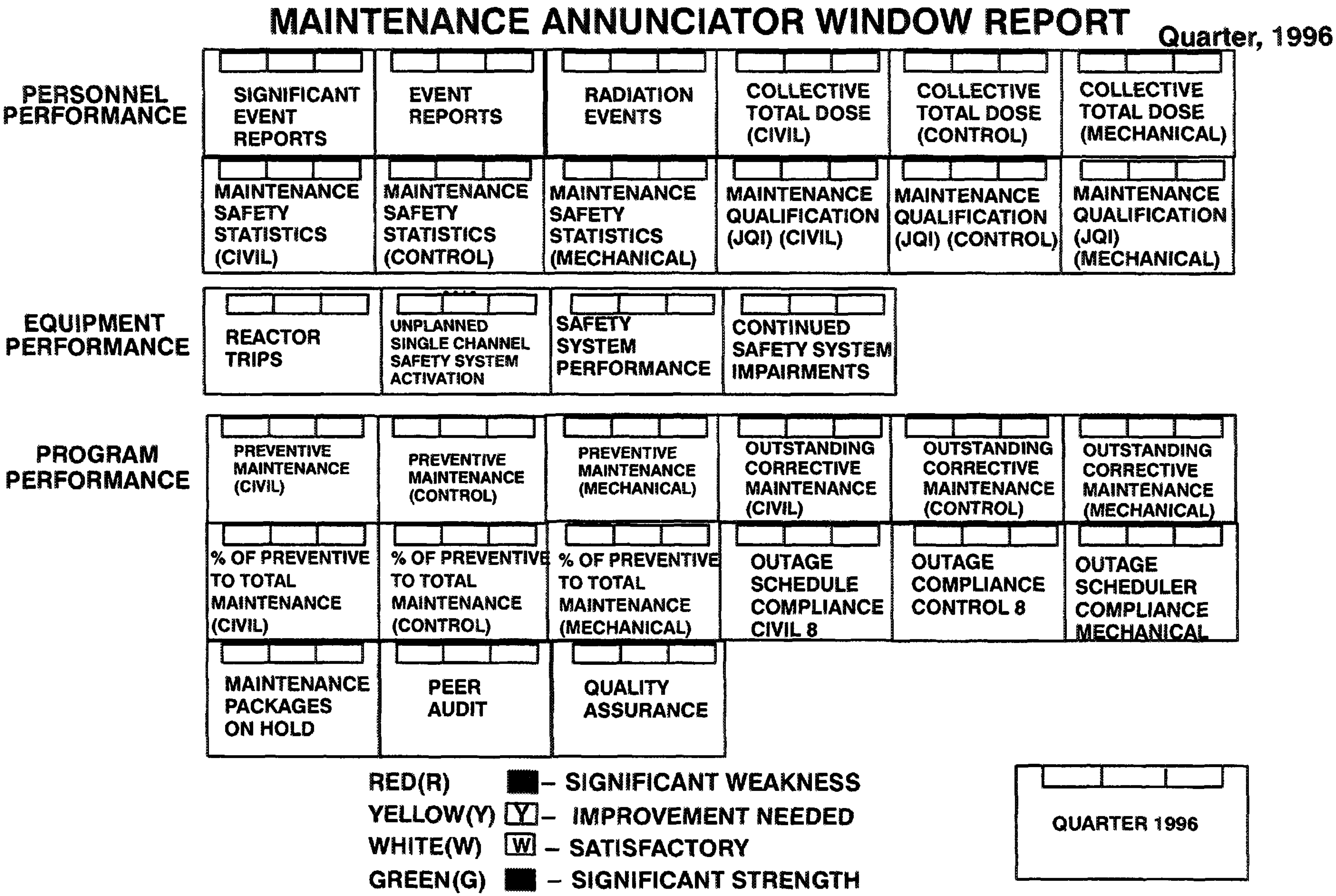


FIG. 8. Maintenance report.

INDICATOR	JUSTIFICATION	CRITERIA	
Personnel Performance			
Significant Event Reports	To determine if/what corrective action by maintenance is required	Green – No SER's last 2 Quarters White – 1 SER last quarter	Yellow – 2–10 SER last Quarter Red – >10 SERs last Quarter
Event Reports	To determine if/what corrective action by maintenance is required	Green – ≤5 E/Rs last 2 Quarters White – ≤5 E/Rs last Quarter	Yellow – 6–15 E/Rs last Quarter Red – >15 E/Rs last Quarter
Radiation Events	To determine radiation statistics for maintenance by Civil, Control, Mechanical and compliance to radiation procedures	Green – <5 Events White – 5 – 10 Events	Yellow – 11–20 Events Red – >20 Events
Total Dose – Civil/Control/Mechanical	To determine the monthly total dose for Civil, Control, Mechanical	Green – ≤90% of exposure goal and meets year to date goal White – ≤100% of exposure goal	Yellow – ≤125% of exposure goal Red – ≥ 125% of exposure goal
Maintenance Safety Stats – Civil/Control/Mechanical	To determine the safety statistics for maintenance by Civil, Control, Mechanical	Green – No LTA, MTA, and <2 minor accidents in the last 2 Quarters White – No LTA, MTA, and <2 minor accidents in the last Quarter	Yellow – No LTA/MTA, and <5 minor accidents in the last Quarter Red – 1 or more LTA, >1MTA or >5 minor accidents in the last Quarter
Maintenance Qualification (JQI) – Civil/Control/Mechanical	To determine if department trailing requirements are being met to attain 100% JQI for Civil, Control, Mechanical	Green – Average JQI for last quarter ≥ 95% White – Average JQI for last quarter ≥ 90%	Yellow – Average JQI for last quarter ≥80% Red – Average JQI for last quarter <80%
Equipment Performance			
Reactor Trips	To determine maintenance involvement with reactor trips and to identify ways of eliminating maintenance contributions	Green – No maintenance reactor trips last 2 quarters White – No maintenance reactor trips last quarter	Yellow – 1 maintenance reactor trip last quarter Red – >1 maintenance reactor trip last quarter
Unplanned Single Channel Safety System Activation	To determine maintenance involvement with unplanned single channel safety system activations and to identify ways of eliminating maintenance contributions	Green – 0 activations in last 2 quarters with contribution from maintenance performance White – 0 activations in last quarter with contribution from maintenance performance	Yellow – 1 activation in last quarter Red – >1 activation in last quarter
Safety System Performance	To determine if there is a substantial increase or decrease in the number of SST failures and the maintenance involvement	Green – Number of SST failures during quarter <.5% White – Number of SST failures during quarter <1%	Yellow – Number of SST failures during quarter <1.2% Red – Number of SST failures during quarter >1.2%
Continued Safety System Impairment	To determine the percentage of continued Safety System impairment for non-scheduled SST's	Green – <1% White – >1%–<2%	Yellow – 2–5% Red – >5%

FIG. 9. Performance monitoring example (page 1 of 3).

INDICATOR	JUSTIFICATION	CRITERIA	
Program Performance			
Preventive Maintenance – Civil/Control/Mechanical	To determine how effectively we manage our overall preventive maintenance program – Civil, Control, Mechanical	Green –PM items overdue <1% and no call–ups exceeding 3 cycles White –PM items overdue <2% and less than 3 call–ups exceeding 3 cycles	Yellow – PM items overdue <4% or less than 5 call–ups exceeding 3 cycles Red – PM items overdue <4% or less than 5 call–ups exceeding 3 cycles
Outstanding Corrective Maintenance – Civil/Control/ Mechanical	To determine the outstanding true DR's in excesss of 90 days not requiring an outage, Civil, Control, Mechanical	Green –Number of corrective mtce deficiencies greater than 90 days <250 White –Number of corrective mtce deficiencies greater than 90 days <300	Yellow – Number of corrective mtce deficiencies greater than 90 days <400 Red –Number of corrective mtce deficiencies greater than 90 days >400
Percentage of Preventive to Total Maintenance – Civil/ Control/Mechanical	To determine if we are doing an appropriate amount of preventive maintenance to optimize equipment performance, Civil, Control, Mechanical	Green –>70% for last 2 quarters White –>70% for last Quarter	Yellow –60 – 70% for last Quarter Red –<60% for last Quarter
Outage Schedule Compliance – Civil/Control/Mechanical	To determine how effectively our maintenance program contributes to the overall success of outages – Civil, Control, Mechanical	Green –≤95% scheduled duration and 100% completion White –≤100% scheduled duration and 99% completion	Yellow –≤110% scheduled duration and 98% completion Red –>110% scheduled duration and 98% completion
Maintenance Work Packages on Hold	To determine the percentage of Maintenance Work Packages on hold and identify the reason	Green –<2% of Maintenance Packages on hold and not ready to work White –>2%<5% of Maintenance Packages on hold and not ready to work	Yellow –>5%<10% of Maintenance Packages on hold and not ready to work Red – >10% of Maintenance Packages on hold and not ready to work
Peer Audit	To determine station maintenance performance with regard to peer findings and actions on previous commitments	Green –All commitments ahead of schedule White –All commitments on of schedule	Yellow –1 Commitment behind schedule Red –>1 Commitment behind schedule
Quality Assurance Assessment	To determine out ability to address and resolve issues identified by various audit organizations	Green –The number of QA, AECB, NOCD, and WANO open issues <10 and zero overdue White –The number of open issues >10 but <15 and zero overdue	Yellow –The number of open issues >15 but <25 or <5 overdue Red –The number of open issues >25 or >5 overdue

FIG. 9. Performance monitoring example (page 2 of 3).

INDICATOR	JUSTIFICATION	CRITERIA
Non–Annunciating		
Quality of Operation and Maintenance Involvement	To determine if corrective action will be taken by mtce staff to improve overall station performance	In support of Annunciating Windows
Work Ready (Achievable Work) Backlog	To determine the amount of backlog existing by not planned	In support of Annunciating Windows
Equipment/Parts/Materials below reorder point	To measure the Reorder point for all equipment, parts and materials	In support of Annunciating Windows
Overtime History	To determine if staffing and budget levels are appropriate and to monitor compliance to OHN and Station Policies on Limits to Hours of Work	In support of Annunciating Windows
Budget Performance – Civil/ Control/Mechanical	To get out budgets more in line with our actual needs	In support of Annunciating Windows
Number of Deficiency Reports not Verified	To determine the number of deficiencies that have not gone into the WMS system and no corrective action can be started. If a deficiency report has not been verified, a work package cannot be produced and the work management process cannot be started	In support of Annunciating Windows
Number of Deficiency Reports being Generated against Invalid Equipment Codes	If we do not measure invalid equipment codes, all other indicators based on measurement of equipment codes will have their integrity jeopardized	In support of Annunciating Windows

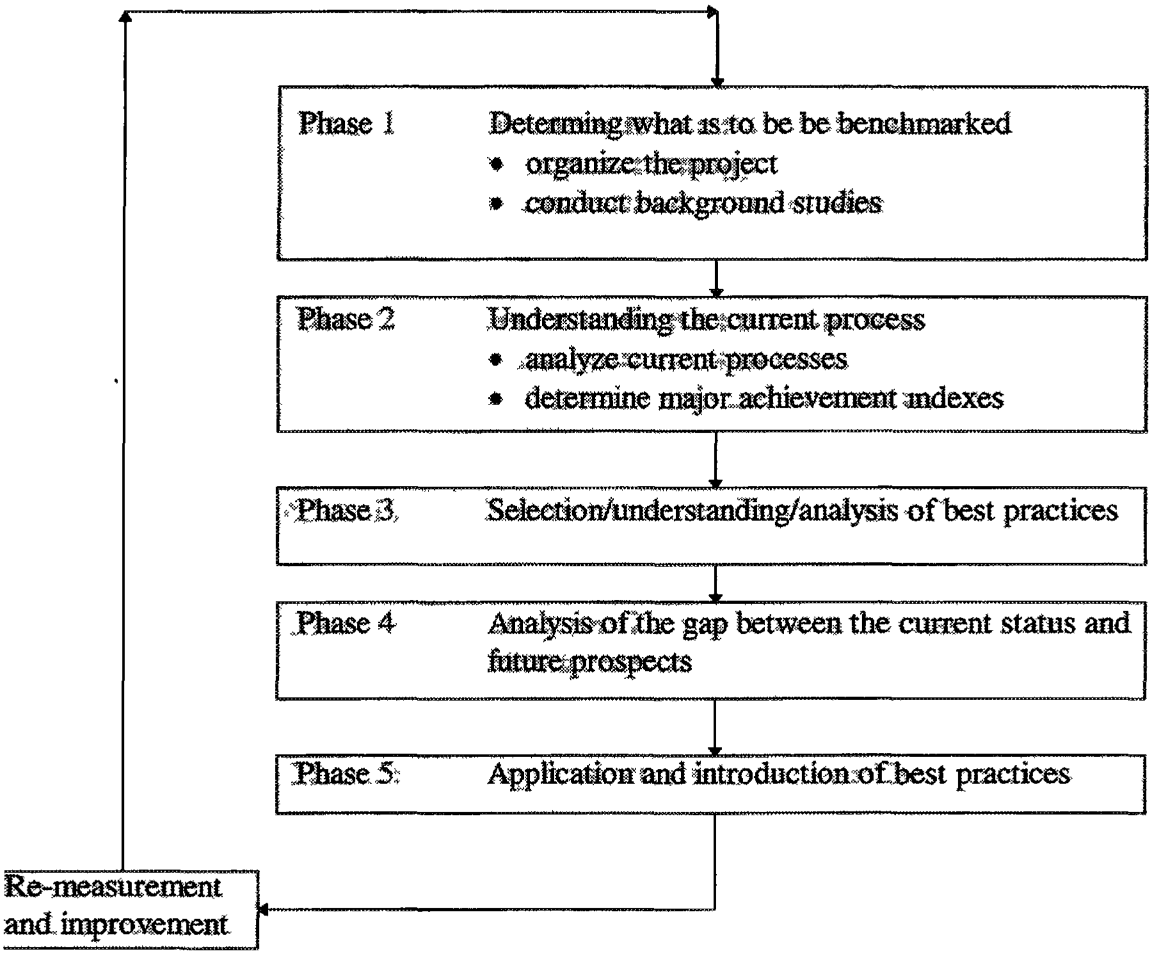
NOTE: ADMU: Applications & Data Management Unit.

FIG. 9. Performance monitoring example (page 3 of 3).

ANNEX E 2

BENCHMARKING EXAMPLES

Shown below is a flowchart of typical benchmarking



The following pages provide examples of benchmarking used for nuclear power plant activities

Example of Benchmarking for Outage Optimization

The German utility GKN determined that its Neckar 2 unit's 33 day outage in 1990 and 34 day outage in 1991 were not satisfactory since other Siemens built 1300 MW plants has completed outages of comparable scope in only 27 days.

This led to an intensive benchmarking study in which:

- planning targets and actual execution times in the plant were analyzed and compared, and
- benchmarking with other comparable PWR plants was conducted.

The results of this study are summarized in Figure 1. To facilitate comparison, individual phases were identified and then analyzed. The best results in each case were used as a basis for planning the next outage.

This optimization effort yielded certain modifications in the plant as well as certain procedural changes. Figure 4 of Annex A.2 shows the reductions in outage duration achieved, with the outage in 1995 completed in only 17 days.

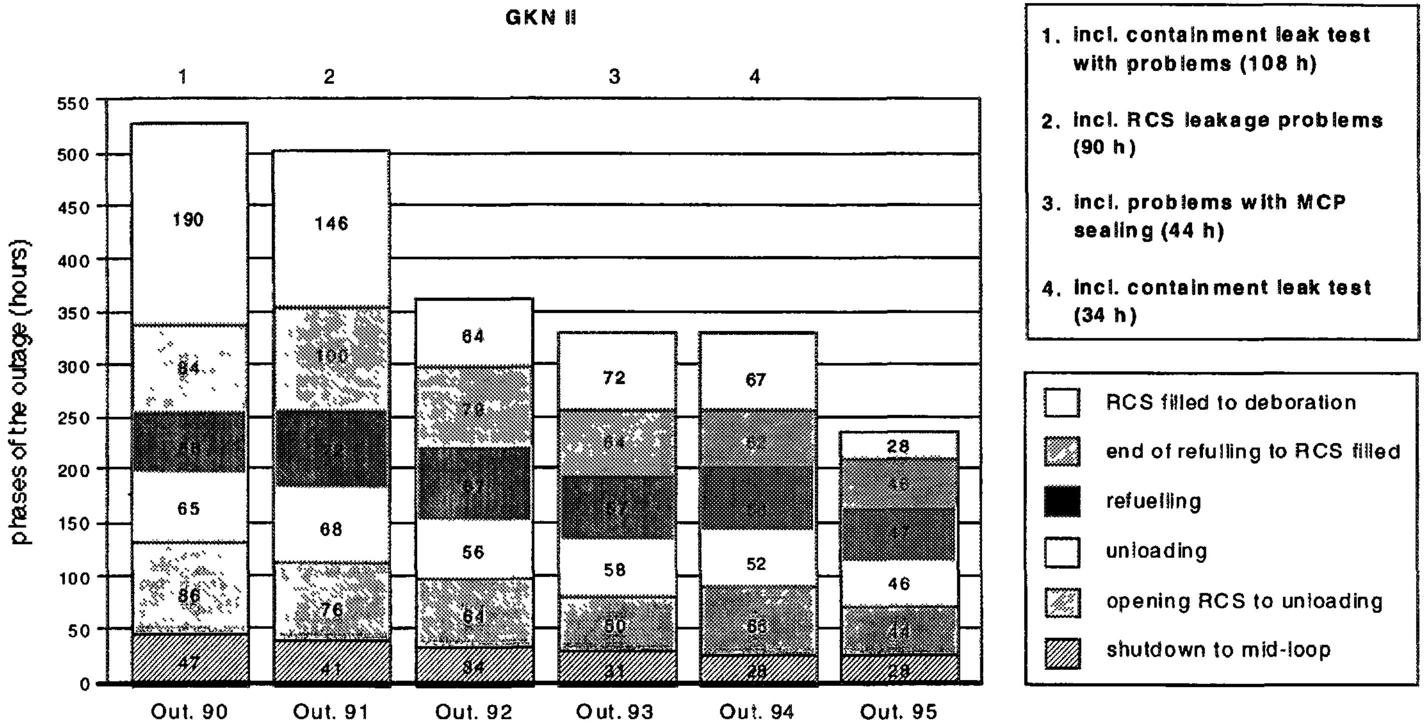


FIG. 1. Benchmarking results.

The following table shows the results of a Kansai Electric Power Company/Westinghouse joint benchmarking study to optimize plant outage activities. The last column shows the targets set from this study for a 26 day outage (breaker-to-breaker).

Outage Segments	All Plants (average-hrs)	Top 3 Plants (average-hrs)	Top 5 Plants (average-hrs)	26 Day Outage
Offline to Mode 5	31.4	11.7	13.6	18
Mode 5 to Mode 6	142.2	54.7	62.6	64
Mode 6 to core offload complete	156.5	92.8	97.1	100
Defueled (offload to 1st assembly from spent fuel pool	355	62.5	76.7	96
Core reload	153.5	50.3	51.8	55
Reload complete to Mode 5	126.6	59	64.6	75
Mode 5 to Mode 4	298.5	83.4	94.6	108
Mode 4 to synchronization	179.7	88.6	94.6	108
breaker-to-breaker total	1443.5 (60 days)	503 (21 days)	555.6 (23 days)	624 (26 days)
Mode 4 to synchronization	188.3	78	82	84
Synchronization to 100% power	163.8 (68 days)	581 (24 days)	637.6 (27 days)	708 (29 days)

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