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Management Strategies for Nuclear Power Plant Outages

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MANAGEMENT STRATEGIES
FOR NUCLEAR POWER
PLANT OUTAGES

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FOREWORD

More competitive energy markets have significant implications for nuclear power plant operations, including, among others, the need for more efficient use of resources and effective management of plant activities such as on-line maintenance and outages.

Outage management is a key factor for safe, reliable and economic plant performance and involves many aspects: plant policy, coordination of available resources, nuclear safety, regulatory and technical requirements, and all activities and work hazards, before and during the outage.

The IAEA has produced this report on nuclear power plant outage management strategies to provide both a summary and an update of a follow-up to a series of technical documents related to practices regarding outage management and cost effective maintenance. The aim of this publication is to identify good practices in outage management: outage planning and preparation, outage execution and post-outage review. As in the related technical documents, this report aims to communicate these practices in such a way that they can be used by operating organizations and regulatory bodies in Member States. The report was prepared as part of an IAEA project on continuous process improvement. The objective of this project is to increase Member State capabilities in improving plant performance and competitiveness through the utilization of proven engineering and management practices developed and transferred by the IAEA.

The IAEA officer responsible for this report was T. Mazour of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The current generation of operating nuclear power plants has reached a high level of reliability and increasing stakeholder confidence in their safe operation. Under the more liberal market conditions prevailing today, it is also important to prove that they are cost competitive.

One factor that directly influences availability and costs is outage duration and quality. Plant outages are planned shutdowns in which activities are carried out between disconnection and reconnection of the unit to the electrical grid. Outages, therefore, are the periods when significant resources are expended at the plant, while replacement power must be purchased to meet the supply obligations of the operating organization or owner(s).

A key lesson learned is that well-planned outages improve both safety and operational performance. This is the case because well-planned outages ensure that all work is completed in accordance with the required quality standards, that the work is appropriately verified and documented, and that the work is organized in an efficient and effective manner.

Each nuclear power plant operating organization develops its own strategy for short term, middle term and long term outage planning. Extensive efforts are usually directed towards detailed and comprehensive preplanning to optimize outage durations, avoid outage extensions, ensure safe and reliable plant operation and minimize radiation exposures to personnel. All these elements are part of the plant outage strategy. Nevertheless, how the plant strategy is implemented is a key to the optimization of outages. Well-planned and executed outages do, in most cases, lead to shorter outages, enhanced safety margins and improvements in the quality of work performed.

Planning and preparation are important phases in the management of a planned outage that should ensure the safe, timely and successful execution of all activities performed during the outage. Safety reviews and post-outage evaluations provide important feedback for the management and optimization of the planning, preparation and execution of the next outage.

The framework for conducting outages during the lifetime of a nuclear power plant is heavily affected by plant design and layout. The choice of fuel cycle length, desired mode of operation, maintenance periods for different components, requirements of authorities and the electricity market all affect the duration and frequency of outages.

Although most main components of a nuclear power plant are designed for the life of the plant, some equipment might need to be upgraded or replaced in a plant operating for as long as 60 years. Refurbishment programmes should be planned as long term activities in accordance with their importance to safety and availability. A key factor in outage management is the coordination of the refurbishment programme with long term outage planning.

1.2. OBJECTIVE

The objective of this report is to provide guidance and share lessons learned regarding the management of planned outages with outage managers, operating staff, technical support organizations and regulatory bodies.

1.3. SCOPE

The report addresses all aspects of outage management: planning, preparation, execution and post-outage review. Section 2 considers issues in the strategy for outage management. Section 3 identifies good practices for the implementation of the plant strategy during all stages of outage planning, preparation, execution and post-outage review. Section 4 presents key issues to consider in the safety reviews of outage preparation and execution. Section 5 points out economic considerations needed for outage management. Section 6 explains causes and countermeasures to avoid extensions of outage duration. Section 7 describes fundamentals for forced outage management. Section 8 contains titles and short descriptions of some related IAEA publications, while Section 9 provides a brief summary. Specific examples of outage management are provided in the appendices.

The report builds on and updates the information provided in IAEA-TECDOC-1315, Nuclear Power Plant Outage Optimization Strategy, and other IAEA publications identified in Section 8.

2. OUTAGE MANAGEMENT STRATEGY

Plant management should establish long term conceptual goals and programmes for all main plant activities. The key issues for an outage optimization strategy are as follows:

(a) Nuclear safety supported by a good safety culture;
(b) Management policy of continuous improvement;
(c) Optimization of maintenance and inspection programmes;
(d) Plant modifications and configuration control;
(e) Monitoring outage planning, preparation and execution;
(f) Plant personnel policy supporting effective performance;
(g) Operating experience feedback system;
(h) Economics.

Appendix I gives an example of an outage management strategy.

2.1. NUCLEAR SAFETY

Safety measures need to be maintained for normal, accident or severe conditions, over the lifetime of the plant. In general, these measures are identified in the operational limits and conditions for the plant. The outage period should be considered as part of operation, because certain functional systems fulfil their specific duties under these conditions, such as cooling the fuel and preventing radioactive release to the environment. Safety status control is a line management responsibility.

When managing planned outages, nuclear safety should not be challenged and, wherever possible, should be improved. The safety status should be considered during outage planning and preparation and monitored during outage execution. Outages that are well planned and executed should result in improvements in both safety and operational performance.

2.2. OUTAGE MANAGEMENT POLICY

The nuclear power plant outage management strategy should be clearly defined in a policy document. This policy should address long, medium and short term outage planning goals and objectives.

2.3. MAINTENANCE AND INSPECTION

The maintenance and inspection strategy should include an on-line maintenance policy, advanced equipment monitoring philosophy, design improvements to optimize outage duration and a programme for the replacement of components and equipment during outages. Maintenance and risk oriented inspection programmes should be optimized based on experience, condition monitoring and reliability centred maintenance. An efficient computerized work control system is a key tool for effectively managing outages.

2.4. MONITORING OUTAGE PLANNING, PREPARATION AND EXECUTION

Plant management needs to establish effective mechanisms to monitor outage planning, preparation and execution. These should include the establishment of suitable milestones and performance indicators, as well as effective means for the continual monitoring of performance based upon these expectations. Early identification of problems/issues is the most important factor in minimizing their impact on the outage.

2.5. PLANT MODIFICATIONS AND CONFIGURATION MANAGEMENT

Plant modifications need special attention to ensure that they achieve their objectives and that the changes in related documentation are also addressed.

2.6. PERSONNEL POLICY

The plant's personnel policy should support effective outage performance. Important issues to consider are training of the plant's own staff and contractors, incentive programme fostering safety culture, monitoring the workloads of individuals, mechanisms to identify and correct error likely situations, and long term partnerships with contractors.

2.7. OPERATING AND OUTAGE EXPERIENCE FEEDBACK SYSTEMS

Information on events and anomalies should be communicated within the operating organization and then, in accordance with established requirements, to the regulatory body, other operating organizations, research organizations, designers, contractors and other relevant stakeholders. The review of operating experience feedback should provide an input for long and mid-term outage plans.

An important element of the outage optimization strategy is the outage experience feedback system. It should include a review of the plant's own outage performance and an evaluation of outage experience feedback from other nuclear power plants. Benchmarking (comparison with previous outages and also with outage performance at other similar plants) is a helpful tool for optimizing outage performance.

2.8. ECONOMICS

The optimal timing and length of the various types of outage should be determined on the basis of the electricity market structure and rules, available resources and plant design. In more competitive energy markets, with emphasis on variable pricing, reliable and predictable performance is often rewarded more than minimizing outage duration.

Systems for budgeting and cost monitoring should be used to control outage costs.

3. IMPLEMENTATION OF AN OUTAGE MANAGEMENT STRATEGY

The nuclear power plant outage strategy needs to be carefully implemented to enable the development of a comprehensive and effective work programme and to optimize outage duration in conjunction with improvements in safety, quality and costs. Section 3 discusses the five main aspects to consider when implementing a plant outage strategy: (i) nuclear safety, (ii) organization and management, (iii) planning and preparation, (iv) execution, and (v) post-outage review.

3.1. NUCLEAR SAFETY

The outage period should be considered as part of overall plant operation; therefore, nuclear safety should remain the first priority. There should be clear requirements for the operability of systems necessary to ensure safety functions for each configuration of primary system and reactor core (Appendix II provides an example of shutdown operational limits and conditions for a PWR). Each activity in the outage plan should be specified in such a manner that factors that influence the operability of the safety systems can be recognized. Core cooling capability, inventory control, reactivity control, electrical power availability and the integrity of fission product barriers are safety functions which need to be addressed in the planning phase and continuously monitored in the execution phase.

Procedures to mitigate the consequences of degradation and to restore safety functions need to be developed and operators trained to use them. Procedures should specify alternative methods of ensuring core cooling capability. There should be specific requirements to ensure defence in depth when maintaining safety functions. Any deviations from the original outage plan should be carefully evaluated and approved. Control over the status of systems is essential for maintaining the operability needed to ensure safety functions. Tools for monitoring the safety status of the nuclear power plant should be implemented. An outage probabilistic safety assessment (PSA) is a good tool to use to provide an overview of the overall safety level during different outage phases (see Appendix I (Section I.6) and Appendix III). If an outage PSA is not used, some form of deterministic analysis should be performed. Other tools that could be used are risk monitors, schematics comparing actual and planned status, and shutdown safety checklists.

A strong safety culture should be developed amongst plant personnel. Every employee should be sufficiently attuned to be able to identify problems and deviations from expected conditions during outages. An effective reporting system should be implemented to enable problems, failures and 'near miss' events to be identified, corrected where appropriate and adequately reported. Resources should be allocated to allow action to be taken to resolve reported issues.

Quality assurance measures need to be implemented throughout the planning, preparation and execution of the outage in order to ensure the quality of work and to support nuclear safety.

3.2. ORGANIZATION AND MANAGEMENT

The nuclear power plant outage management strategy should include mechanisms to enable all plant management levels to be involved in the outage planning, preparation, execution and review. Responsibilities within the organization need to be clearly defined. Management expectations should be well communicated to the staff. Objectives and goals should also be clearly established and communicated. Pre-outage meetings at different levels and effective IT communications tools should be used to exchange relevant information and communicate expectations among all personnel participating in the outage.

Organizational and managerial principles applied in outage management should be based on an effective process and on quality management principles. Complex organizational structures should be avoided in order to facilitate decision making processes. Self-assessment processes at the plant level as well as at an individual level should be encouraged and a questioning attitude fostered to make the organization sensitive to deviations from planned activities and to avoid outage extensions.

Cross-functional expertise is necessary to take responsibility for equipment as well as for maintenance, control, scheduling and engineering that have a direct influence on plant performance. Initial and continuing training programmes should be in place to ensure that both plant and contractor personnel have the competencies needed for their assigned tasks during the outage.

A job rotation programme within the operating organization should be considered to widen individual experiences and competences. Comprehensive knowledge of the overall plant facilitates understanding and communication, especially at interfaces.

3.2.1. Outage organization

Different outage organizations, depending on the plant infrastructure, organization culture and other factors, have been implemented by operating organizations and utilities. Many plants do not change their organization structure during an outage. Other nuclear power plants have a separate but temporary outage team or a permanent outage structure. In either case, the organization that has proven most efficient and effective is an outage project team that comprises staff from the different plant departments, e.g. maintenance, operations and engineering. Appendices IV and V provide examples of nuclear power plant outage organizations.

An outage project team coordinates outage planning and execution and brings together all the players involved in the outage, which report to a decision making unit headed by the plant manager. In particular, the team includes a coordinator for each major function and/or piece of equipment that is under maintenance, test or inspection during the outage. The coordinator is the link between the operations and maintenance departments and the outage project team.

The outage planners and coordinators should take ownership of identified problems to ensure that appropriate countermeasures are taken and that optimum management efforts are utilized to identify the problem effectively and promptly and to resolve it. The maintenance department designates the personnel responsible for component maintenance.

All steps in outage planning, preparation and execution should be well documented. The documentation should be updated to specify the current status of the plant, especially in the case of exchange of equipment, system modification and maintenance work.

3.2.2. Contractors

The scope of work can be prepared and executed by plant staff, external contractors or a combination of both. External contractors often specialize in inspection and maintenance or repairs where special tools and processes are needed.

The incorporation of external contractors needs a specific work breakdown structure with interfaces and responsibilities identified. Nevertheless, the operating organization or utility project outage team should undertake the overall preparation, planning, management, contracting and financing of the outage, as well as assuming responsibility for all technical features.

As contractors are normally accustomed to work in other industries, a considerable amount of training should be given to introduce them to safety aspects, safety culture and self-assessment aspects of the plant.

The cost–benefits of long term contract arrangements with experienced contracting service companies, or with the main supplier, should be assessed. Operating organizations should carefully consider the trade-offs between the development of their own capabilities for outage work and/or arranging support from external contractors (or some combination of the two).

Different outsourcing approaches may be utilized for maintenance, modifications or refurbishment. The type of outsourcing depends on various parameters, including the capability and experience of plant personnel. The choice is important and has to be decided by the plant at an early stage. In general, the more the contract responsibilities are subdivided, the higher the risk to good outage performance.

Usually, it is a good practice to use long term contracts with partnership agreements, including the contractor taking full ownership for specified outage tasks (recognizing that the operating organization cannot delegate its responsibilities for plant safety and performance). When establishing long term contracts it is important to preserve a competitive market situation. The use of competent local contractors may enhance relationships with the local community.

3.3. OUTAGE PLANNING AND PREPARATION

Outage planning involves many different issues, such as coordination of available resources, scheduling, safety concerns, and regulatory and technical requirements for all activities and work undertaken before and during the outage. For each outage period a detailed plan for execution should be prepared well in advance, including all the necessary work files and support needed.

The outage plan should ensure plant safety during all phases of the outage. Besides all activity details required for the efficient, safe and successful execution of the outage plan, the planning of activities should further consider the local conditions inside the plant, radiation levels, industrial safety, necessary outside support, internal and external information media and other prerequisites.

Reliability centred maintenance, risk informed inspection and testing have been identified as good tools for optimization of maintenance activities. Condition monitoring should also be used.

The in-service inspection (ISI) programme is officially specified in licensing documents and related codes. Accumulated knowledge of potential plant degradation and ageing should support the development of an effective ISI programme and also maintenance programmes.

Best estimate planning (using realistic estimates of task duration) should be used especially when planning critical path activities. When best estimate planning is applied, the overall need to correct planned work schedules during the outage declines considerably. On the other hand, best estimate planning also requires that plant management be willing to tolerate more delays due to unforeseen problems (as there is no built-in margin in the schedule).

3.3.1. Range of planning

Outage plans should be developed for long, medium and short terms. In long term planning, the plant establishes the frequency and duration of outages according to the fuel management policy, equipment ageing, need for major backfitting, refurbishment and regulatory requirements. The long term plan optimizes plant availability to the grid, total outage duration and estimated costs. Long term plans are for 5–10 years and include preliminary cost and budget estimates within the constraints of the expected scope of supplies and services. Appendix I (Fig. 9) and Appendix VI provide examples of long term outage plans.

A middle term plan is used to coordinate the outages of all plants and take into account electricity markets needs. It is more detailed than long term planning and may cover a time period of 2–5 years. A middle term plan estimates the material and human resources needed and incorporates medium-sized backfitting/refurbishment activities in compliance with new industry standards and changes in regulatory requirements, e.g. technical specifications for steam generators.

A short term plan is the detailed planning for the next outage. A good practice is to start short term planning at the beginning of the next cycle.

These plans should be included in the plant budget and the financial decision making process. For long and medium term planning, special attention should be paid to fuel cycle optimization. Fuel cycle optimization depends on plant design, the electricity market situation, outage performance and fuel costs.

Outages may be categorized as follows:

(a) Refuelling only;
(b) Refuelling and standard maintenance;
(c) Refuelling and extended maintenance;
(d) Special outages for major backfitting or plant modernization.

In medium and long term planning, a key objective is to use a combination of the above outage types so as to optimize the total outage duration for the time-frame of the plan.

When planning an outage, special attention should be paid to activities not regularly included in the scope of work for this type of outage.

3.3.2. Communication with the regulatory body

Information should be provided to, and fully agreed with, the regulatory body before the work scope freeze, not only with regard to those activities that are work and inspection specific, but also for general activities. This results in improved safety throughout the outage. Information discussed might include any statutory regulatory requirements, concerns of the regulatory body, lessons learned and other feedback. Provided below is an example of how tasks are classified by one nuclear power plant operating organization, when considering regulatory body requirements:

(a) Class 1: Mandatory for execution of a restart as a result of licence requirements, or technical or availability needs.
(b) Class 2: Desirable that the task be performed but, if executed, it should be done under regulatory supervision. Task may be shifted to another outage because of time constraints or for other reasons, after a safety demonstration.

(c) Class 3: Task has no safety relevance. If the task is shifted to another outage, that decision need be made only by the operating organization.

Such categorization has advantages, especially for the restart permission process, because both parties involved have a clear agreement, prior to the outage, about the required work scope. Contact should be proactive and the plant should not wait until the regulatory body imposes particular requirements. There should be daily or weekly meetings during the period of the outage.

There should be openness with the regulatory body as well as with all personnel involved in the outage, with complete access being allowed to outage schedules and work management systems.

3.3.3. Detailed planning and preparation for the outage

All activities should be planned before the outage. Each activity, and particularly those added late in the planning process, should be assessed for their potential to influence the operability of the systems necessary to ensure safety functions and to extend the outage completion.

In the detailed planning and preparation, the following items should be considered:

(a) Outage preparation milestones, including: work scope freeze, planning, materials, schedule development, external services contracts, system isolation preparation, ALARA reviews, design issues and regulatory issues (Appendix VII provides an example of outage preparation milestones).
(b) Final scope of work/activities.
(c) Outage schedules for main work areas (separate schedules for reactor, turbine, safety systems and water coolant systems) and outage schedules for complex operation phases (shutdown, startup, time critical system isolations, surveillance testing, water management, etc.). For all activities determining the critical path a separate and detailed schedule should be prepared. All those schedules need to comply with the main outage schedule.
(d) Work packages, including: work orders and permits, instructions and procedures, spare parts, consumables, human and material resources, special tools and post-maintenance testing.
(e) Integration and compatibility of different work management and work scheduling tools.

(f) Other prerequisites for work to be undertaken as planned with regard to quality and time (e.g. lighting, power, water and air supplies, cranes).

The work details should be described for major activities incorporating planning time, procurement, manufacturing, preparation of the plant, expected work load, safety measures, necessary support and quality assurance programmes. It is good practice to prepare clear schedules indicating systems in maintenance and systems that have to be in operation or in standby mode.

3.3.4. Processes and tools for outage management

Good practices for management during planning and preparation are:

(a) Ensuring work scope is predictable above 95% confidence level and usually less than 5% added work;
(b) Freezing of outage scope three months before the outage start date (ten months in the case of major modifications);
(c) Maintenance of a proactive planning attitude and anticipation of problems which could impact nuclear safety, schedule and costs;
(d) Early execution of planned inspections of systems and components to help avoid outage extension;
(e) Proper rescheduling of activities, including reassessment of nuclear safety and other risks;
(f) Water and coolant management;
(g) Revision of the frequency of inspections on the basis of experience;
(h) Streamlining of activities without adversely influencing safety;
(i) Integration of unit startup tests;
(j) Reduction of exposure by planning efficient decontamination processes and use of mock-ups;
(k) Utilization of computerized tools and robotics;
(l) Use of modern scheduling and engineering tools (e.g. CAD, Primavera, OPX2 or similar software), which are well integrated with other management systems;
(m) Improved coordination between the outage and operations teams;
(n) Use of international and own experience;
(o) Benchmarking with other similar plants to promote successful management of outage activities and schedules;
(p) Qualification and training of contractors on safety culture and work procedures;
(q) Involvement of contractors from the early stages of outage preparation;
(r) Identification of critical work areas from the scheduling point of view;

(s) Preparation of site locations, workshops and offices for contractors;
(t) Actions to prevent shortages of materials and human resources;
(u) Walk-throughs by the preparation team (coordinators, system engineers and contractors, including foremen) at the working place to view the equipment and discuss requirements for outage activities.

Some design modifications could also be carried out to optimize outage duration and improve the quality of work, such as:

(a) Modifications to the refuelling machine;
(b) Modifications to the reactor vessel and internals;
(c) Fuel leak detection by mast sipping;
(d) In-core shuffling;
(e) Provision of additional working platforms on the refuelling floor;
(f) Use of easily removable insulation;
(g) Use of local cranes and hoists;
(h) Provision of permanent working platforms instead of temporary scaffolding;
(i) Provision of a special turbine rotor cooling system to allow earlier start of turbine work;
(j) Use of hydraulic turbine bolting and turbine inspection holes;
(k) Use of inspection devices to obviate dismantling of components;
(l) Provision of sufficient water storage for efficient water handling during outages;
(m) Provision of an improved primary coolant purification system.

3.3.5. Plant modifications and configuration management

Special attention should be given to plant modifications. To ensure that the construction, operation, maintenance and testing of the physical facility are in accordance with the design requirements, accurate information needs to be available on a timely basis prior to the start of the outage. Special attention should be given to training needs. For complex modifications, and if plant operation procedures have to be modified, the time needed for preparation and execution of classroom and/or simulator training has to be considered. It is highly recommended that a milestone be established to freeze the scope of modifications in the outage preparation schedule in order to guarantee that the modifications can be implemented as required.

3.3.6. On-line maintenance

Increased use of on-line maintenance makes it possible to provide greater redundancy in safety system operation during outages and enables more effective maintenance and better utilization of critical resources. This can also result in shorter planned outages and fewer forced outages.

3.3.7. Mobilization of human, material and equipment resources

Some good practices that should be taken into account during planning and preparation are:

(a) Just-in-time mobilization of human and material resources.
(b) Signing of all contracts according to the outage preparation schedule and well before the outage begins.
(c) Planning and training, in advance, of both in-house and external human resources.
(d) Implementation of incentive programmes for staff, focusing on outage performance (e.g. incentives for outage safety, quality, schedule and cost).
(e) Identification of shared resources and possible joint ventures in case of major backfittings.
(f) Identification and requisitioning of materials, spare parts and consumables to be available on-site, at least 2–4 months before the outage start.
(g) Sharing of human and material resources throughout the operating organization or between operating organizations (e.g. cranes, hoists, special tools, ISI technicians).
(h) Responsibilities and interfaces must be clearly defined when any reorganization is made during outages.
(i) Review of regulatory concerns/operating experience.

3.3.8. Monitoring of planning and preparation phase

Milestones for planning and preparation should be specified in the outage planning schedule. Milestones, examples of which are shown in Appendix VII, should include at least the following items:

(a) Critical path scheduled;
(b) Outage work scope frozen (maintenance and modifications);
(c) Outage personnel resources identified;

(d) Spare parts and consumable materials ordered and delivered to site on a timely basis;
(e) Work orders (work packages) planned and scheduled;
(f) Work permits and system isolation planned;
(g) Outage budget prepared and reviewed;
(h) Outage safety review completed.

Indicators related to specific milestones should be used to monitor progress during the planning and preparation phase and adherence to the outage schedule. Indicators should be of the ‘early warning’ type and based on real time reporting. Specific milestones and indicators should be developed to the level of responsible departments and individuals and should be adhered to strictly by everyone. A review of progress in achieving specific milestones should be undertaken regularly and supported by plant management.

The are several areas where performance indicators should be considered being used for plant outages. Owing to differences in plant designs and outage management approaches, such indicators have been found to be of more value when used within a nuclear power plant operating organization for trending and comparisons among its units than for national or international comparisons. The instances when performance indicators should be considered are as follows:

Before an outage:

(a) Outage organization established;
(b) Work scope defined on time;
(c) Modifications and work packages prepared on time;
(d) Contracts and spare parts identified as scheduled;
(e) Relevant planning completed on time.

During the execution of an outage:

(a) Schedule — actual compared with original;
(b) Doses — actual values compared with budget (for individuals and collective);
(c) Number of rework tasks;
(d) Number of reportable events;
(e) Number of tasks not executed;
(f) Number of unplanned tasks.

After an outage:

(a) Quality of outage work (e.g. schedule, rework, outage extension);
(b) Radioactive releases, waste volume and doses received;
(c) Outage costs — actual compared with planned;
(d) Human performance.

IAEA-TECDOC-1490, Indicators for Management of Planned Outages in Nuclear Power Plants, provides additional information regarding the development and use of such performance indicators.

3.4. OUTAGE EXECUTION

Examples of objectives related to outage execution are: keeping the plant within all operational limits during the outage, disturbance free operation of the plant during the next cycle and completion of the outage according to schedule and within budget. It is helpful if the team responsible for outage planning manages its execution. Detailed schedules for outage preparation and execution should be frequently reviewed and updated.

The interface between operating personnel, maintenance, technical support and repair groups needs to be carefully organized and monitored throughout the execution of the outage.

Most of the radioactive and other waste from a nuclear unit is produced during an outage. Activities should be planned and executed to minimize the volume of this waste. A good practice is to establish a standardized environmental system such as that described in ISO 14001[1].

The following subsections outline good practices regarding coordination and communication, work control management, radiation and industrial safety, and monitoring of outage execution.

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[1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Environmental Management Systems: Specification with Guidance for Use, ISO 14001: 1996, ISO, Geneva (1996).

3.4.1. Coordination and communication

3.4.1.1. Coordination

Coordination between the outage participants (personnel from operations, maintenance, chemistry, health physics, engineering and contractors) is a fundamental precondition for the successful execution of work.

Clear delegation of responsibility and authority needs to be established and documented. The role and duties of the regulatory body should be well understood by all personnel involved in the outage.

One of the most important 'tools' to communicate and to resolve daily problems is the daily coordination meeting. The main issues typically discussed at this meeting are:

(a) Work progress, delays and status of activities, particularly those on the critical path;
(b) Updating the schedule for subsequent days;
(c) Technical, administrative and environmental problems;
(d) Radiation protection issues;
(e) Clear identification of responsibilities for resolving identified issues, particularly those that cut across organizational lines.

Apart from the daily coordination meeting, other meetings should also be held to monitor outage execution. Plant management meetings should be held at least once a week. In the event of problems, ad hoc management and technical meetings should also be held.

3.4.1.2. Communication

Personnel involved in an outage should be well informed at all times. Effective mechanisms to communicate the status and progress of the outage should be in place. Reporting the results of outage activities should be an integral part of outage execution and not be regarded as optional. The flow of information between the various activity centres should avoid conflicts in the process while acting as a monitoring tool.

It is a good practice to keep contractors informed on outage progress. It is also important to coordinate their areas of work and obtain feedback from them on the work schedule.

Modern electronic media can ease communication within the plant and with headquarters. Short bulletins or reports distributed to all personnel can enable appropriate countermeasures to be taken at an early stage. Supervisors should organize prejob briefings. Plant walk-throughs by plant management during the outage are a good means of communicating management expectations and monitoring the situation in the plant.

It is important to create mechanisms to promote safety culture, foreign material exclusion and good housekeeping for all personnel involved in outage execution. Some operating organizations distribute an outage information handbook containing relevant information, such as: an outage plan summary with goals, objectives and critical paths; emergency signals to be used; security arrangements; a telephone directory and details on parking lots, restaurants, etc.

3.4.2. Work control management

Sufficient personnel must be allocated during an outage to enable all necessary activities to be undertaken and supervised to monitor the workload of individuals throughout the period of the outage itself, taking into account other routine plant operations that may continue at the same time.

The control and use of approved procedures must be accepted and adopted by all personnel involved in an outage, including contractors.

An efficient computerized work control system is a key tool for shortening outage duration. Work control systems (work orders and work permits) should be coordinated and should follow the same procedures as during normal plant operation.

Support for control room personnel in handling work permits is needed during outage execution because of the large work volume. Many nuclear power plant operating organizations have established special teams, comprising personnel from operations and maintenance departments, to schedule, prepare and perform a significant amount of tag-in, tag-out and line-up work at the beginning of the outage. Such teams could be also used for tests before startup (see Appendix V for an example).

The responsibility for clearance of equipment isolations, after finishing the work and post-maintenance/functional tests, should be clearly assigned to qualified and experienced nuclear power plant staff. The work control process is an excellent tool for providing a clear picture of the status of the plant, especially when contractors have performed maintenance, tests or inspections. Within that process, deficiency reports identifying further actions needed could be introduced into the work control programme for the outage. It is a good practice to have an integrated computerized information system to manage the outage, including:

(a) Work order and permit administration;
(b) Project planning;
(c) Material and spare parts management;
(d) Plant technical data;
(e) Plant operation and maintenance history;
(f) Radiation dose control;
(g) Personnel database;
(h) Financial control.

The use of a computerized database enables better handling of the complete work programme and allows access by outage personnel to all needed documentation. Cost control by activity and for the complete outage can be integrated into the database. Such a system has the further advantage of storing essential information for use in the next outage.

3.4.3. Radiation and industrial safety

Good housekeeping and low dose rates are important requirements for all outages. During outage execution, radiation safety is one of the most important aspects. The ALARA principle should be applied in outage planning, preparation and execution. Specific ALARA teams should be allocated for work where higher doses are anticipated.

For each outage a dose budget should be developed, based upon the work to be performed during the outage. As shown in Fig. 1, on a daily basis the actual collective dose should be compared with the planned dose in order to provide early identification of any ALARA issues.

Appropriate radiation monitoring procedures help to assure that dose limits will not be exceeded. Such measures also help to decide if additional provisions for cleaning, decontamination or installation of temporary ventilation and filtration are required. Precautions such as removable shielding or special decontamination processes should have been identified during the planning phase.

Collective doses received by nuclear power plant and contractor personnel during plant operation and maintenance periods need to be controlled, recorded with great care and compared with the predicted values during the outage.

Industrial safety requires many provisions during the outage. Some are part of the work scope and their fulfilment depends on personnel attitudes.

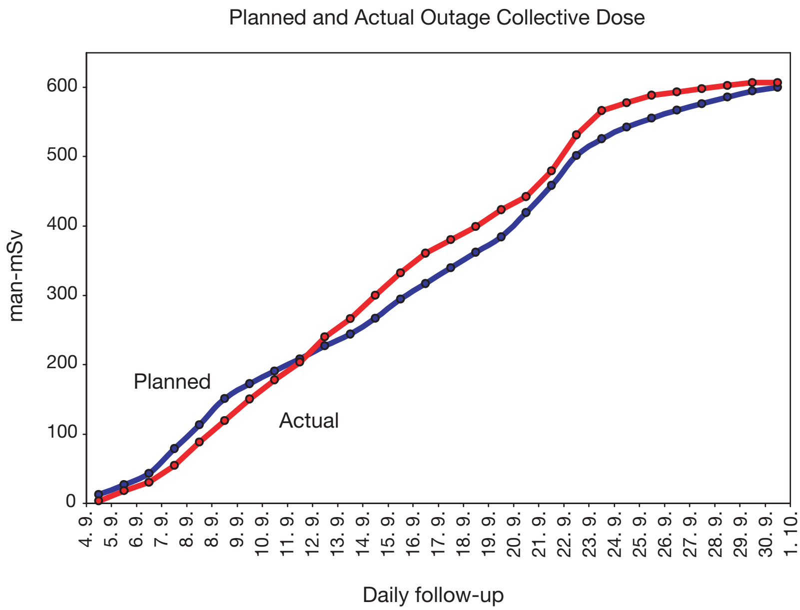


FIG. 1. Example of collective dose budget diagram.

Individuals should understand that they are responsible for their own radiological exposure and industrial safety.

During outage execution, corrective actions should be taken quickly when problems arise in industrial safety and radiological protection. For this reason, a rapid feedback system should be established to monitor personnel performance and to identify potential problems quickly.

3.4.4. Monitoring of outage execution

It is essential that the progress of an outage be monitored precisely and continually throughout the entire execution period. Progress needs to be checked against the milestones that were identified during the planning phase. Information on progress must be prepared and made available to relevant personnel on a regular basis.

Deviations from procedures or from critical paths, or milestones that are not being achieved, need to be reported immediately during the outage to enable appropriate decisions and any necessary actions to be taken.

3.5. POST-OUTAGE REVIEW

After the end of the outage, a review of the entire process is necessary to assess the work done and to provide feedback for further optimization of forthcoming outages. The post-outage review should consider:

(a) Achievement of objectives, goals and budget;
(b) Technical status of the unit after the outage;
(c) Evaluation of a list of problems and contingencies;
(d) Events that occurred during the outage and during the operating period after the outage;
(e) Complete analysis of outage execution performance indicators;
(f) Evaluation of contractor performance;
(g) Identification of possibilities to improve work processes;
(h) Identification of technical or administrative measures that could be improved;
(i) Analysis of shutdown and startup procedures;
(j) Analysis of working procedures, organization and safety culture attitude;
(k) Transfer of outage experience feedback to other units;
(l) Other suggestions and recommendations for the next outage.

Special attention should be given to events causing outage extensions, such as delays in material deliveries and documentation, testing, commissioning and restart problems. Section 6 discusses causes of outage extensions and countermeasures for avoiding them.

A review report should be prepared, including a summary on the above mentioned aspects, from which lessons can be learned and applied for future outages. A meeting with the main participants in the outage should be arranged to assist in the preparation of the review report and to discuss their experiences and suggested improvements.

A good practice is to have the full outage report ready at the latest one or two months after the outage to provide feedback in time to improve the next outage.

4. INDEPENDENT OUTAGE SAFETY REVIEW

The outage preparation and execution process should include independent outage safety reviews. The reviews should be based on a well-defined set of operational limits and conditions for shutdown states.

Outage safety reviews should apply to the whole process: outage planning, preparation and execution, which include the entire work scope, test and inspection programme and shutdown and startup activities. The reviews should identify and take into consideration possible risks. Operational safety experts that are independent from staff who had defined the outage programme and/or the work orders should conduct the reviews. The reviewers should report directly to the outage manager and plant management.

In preparing outage schedules, one of the two versions shown in Fig. 2 is normally applied. With version A, the executing departments (maintenance/engineering) produce an outage schedule which will be checked by the

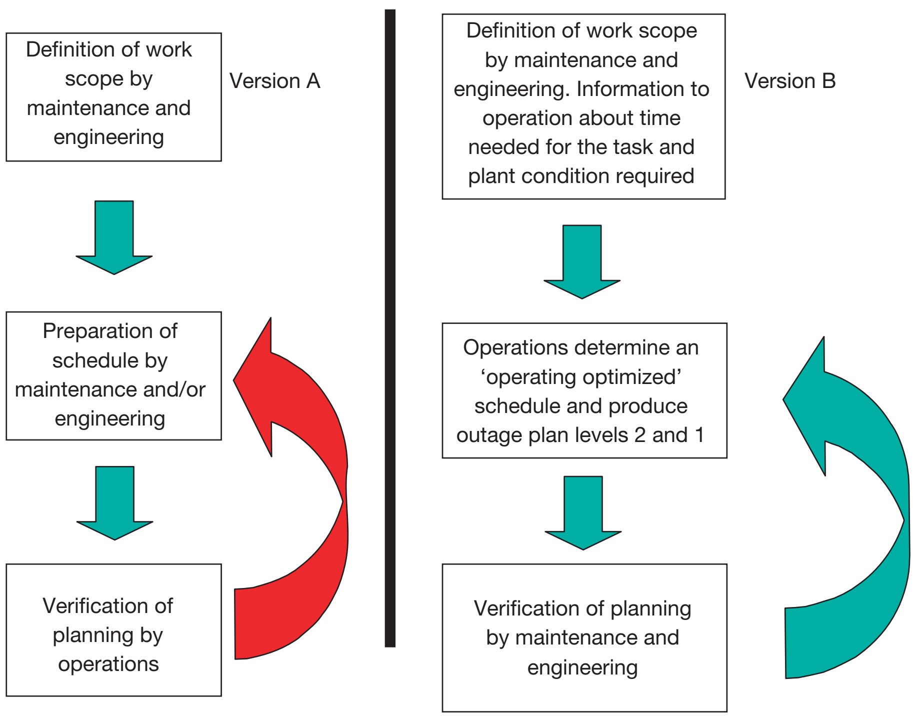


FIG. 2. Two outage safety review approaches.

operations department to confirm that it complies with the operational limits and conditions (OLCs). With version B, the operations department develops an operational and safety optimized outage schedule. This proposal is then checked by the maintenance and engineering departments to ensure that it meets their needs. Experience has shown that the number of corrections resulting from the safety reviews is normally less with version B than with version A.

When applying version A it is highly recommended that the operations department (responsible for operational safety) be involved early on in the planning process.

All safety related problems arising during the outage execution and how they affected the safety level of the plant should be reviewed. After the safety review by an internal and independent part of the organization, plant management should take the necessary decisions to address all issues arising from the review.

Safety reviews prescribed by the regulatory body should be incorporated in the planning of the outage, so that the results from these reviews can be effectively addressed. The safety reviews should be undertaken proactively to identify safety concerns at an early stage of preparation. In this way, the reviews contribute to a higher awareness of reactor safety concerns throughout both outage preparation and execution phases.

5. ECONOMICS

Nuclear power plant design characteristics and electricity market conditions (e.g. pricing and seasonal variations in demand) should be considered in the economic study performed to choose the optimal length and positioning of various outages. In more competitive energy markets, with emphasis on variable pricing, reliable and predictable performance is often rewarded more than minimizing outage duration.

Technical and safety analyses and financial provisions should form the basis for plans for all proposed updating and maintenance measures during plant life. The nuclear power plant operating organization management should take decisions on the financial provisions. One main goal in the decision making process is the optimization of plant availability and outage duration.

Long term financing provisions and the budget for short term outages should be sufficiently flexible to enable the plant management to optimize long term availability.

Early cost estimates are essential to the successful management of the outage. Cost estimates should take into account all expenditures and financing that are required. All parties should be considered in the cost estimates, e.g. contractors, spare parts, materials, own staff salaries and other running costs. At some nuclear power plants, the actual outage cost is monitored on a daily basis.

Improving the overall economics of a nuclear power plant requires a comprehensive understanding of the relationship between operations and maintenance (O&M) spending and the performance of the plant. It should be recognized that there is a real cost associated with poor performance (e.g. lost revenue opportunity, higher than necessary costs of generation, loss of stakeholder confidence in the organization) as well as the corrective maintenance cost associated with repairing equipment. In addition, there is a mutual interaction between O&M spending and nuclear power plant performance. Too little proactive (preventive) O&M spending results in a high frequency of unplanned breakdowns with high corrective maintenance costs and high costs associated with unavailability. However, in a publicly traded company, excessive O&M spending can jeopardize its financial position, particularly in competitive energy markets. The goal, therefore, should be neither to minimize O&M costs nor to maximize performance (e.g. highest availability, shortest outage duration) but rather to maximize long term profitability while maintaining high safety performance and stakeholder confidence in the organization. In order to achieve this goal, day-to-day decision making should include the following:

(a) Identification: The identification of all potential improvement options to address plant problem areas.
(b) Evaluation: The economic justification and prioritization of options identified.
(c) Implementation: The selection of the economically optimal option and the comparison of expected with actual results.

By following this type of process the best use of the plant's limited resources (financial, time, personnel) will allow the plant to optimize its economic, safety and operational performance.

The IAEA has developed, in cooperation with the Nuclear Committee of Electric Utility Cost Group, the Nuclear Economic Performance Information System (NEPIS) to support this optimization process directly by providing insight into each of the three steps listed above. In this first phase of its development, NEPIS focused on O&M costs.

Again, as was indicated earlier, in more competitive energy markets, with emphasis on variable pricing, reliable and predictable performance is often rewarded more than the minimizing of outage duration.

6. AVOIDING AN OUTAGE EXTENSION

An outage extension is the increase in outage duration beyond the planned time/date for reconnection to the grid (provided to the grid operator). Where outage planning is based on best estimates for task completion there should be some margin between the 'best estimate outage schedule' and the planned reconnection time/date provided to the grid operator. A reasonable value for this margin could be about 10% of total outage duration. However, the actual margin should reflect the nature of related risks, including the economic consequences of not being back on-line when planned. It should be recognized that the objective of achieving the minimum outage duration feasible is likely to lead to more outage extensions. Thus, the objective of optimizing outage duration (which considers issues such as the risks associated with outage extension, maintaining high levels of safety and maintaining stakeholder confidence) may be preferable.

Generally, if the outage is planned and managed effectively, most outage extensions are the result of an unfavourable condition discovered during the outage. With the increased use of nuclear power plant operating experience, the frequency of such unfavourable conditions should be reduced.

The most frequent causes of outage extension and their associated countermeasures are listed in the following subsections.

6.1. CAUSES OF OUTAGE EXTENSIONS

There are several causes of outage extensions:

(a) System or equipment or component deficiency not identified:
   (i) Lack of condition monitoring and trending;
   (ii) Equipment or component failure during outage execution;
   (iii) ISI programme and tests results.

(b) Quality of work performed:
   (i) Lack of quality consciousness and procedure usage;
   (ii) Poor quality of material;
   (iii) Lack of mock-up structures;
   (iv) Lack of skilled or trained personnel;
   (v) Improper work execution control;
   (vi) Casual attitude to work execution resulting in waste of working time;
   (vii) Improper implementation of a foreign material exclusion programme.

(c) Deficient outage management:
   (i) Lack of leadership and control over the plan activities;
   (ii) Lack of motivation;
   (iii) Lack of budget;
   (iv) Late order of equipment, material and spares;
   (v) Insufficient cooperation among the parties;
   (vi) Deficiencies in interdisciplinary communication;
   (vii) Quality control deficiencies.

(d) Regulatory impacts:
   (i) Last moment regulatory requirements added;
   (ii) Misinterpretation of regulatory requirements.

(e) Failure of inspection or special maintenance tools (e.g. lack of preventive maintenance of these tools).

(f) Inadequate or improperly stored spare parts.

(g) Inadequate vendor support:
   (i) Lack of technical support and unreliable subcontractors;
   (ii) Lack of equipment or material supply or late delivery.

(h) Deficient outage planning:
   (i) Work scope not precisely defined;
   (ii) Underestimation of activity duration or workforce;
   (iii) Improper scheduling of work activities;
   (iv) Support activities (scaffolding, etc.), tools, materials not clearly defined;
   (v) Plant status prerequisites, work permits and approvals not clearly defined;
   (vi) Operating experience feedback programme results not taken into account or operating experience feedback actions not adequately implemented while planning reccurring outage activities.

6.2. COUNTERMEASURES TO AVOID OUTAGE EXTENSION

Taking into consideration the causes of the outage extension mentioned in the previous subsection, the following possible countermeasures could be applied:

(a) Improvement of condition monitoring by:
  - (i) Review and revision of the condition monitoring, trending and preventive maintenance programmes using industrial experience;
  - (ii) Conduct of ISI programme on critical components in the initial phase of outage.

(b) Improvement of work quality through:
  - (i) Development of quality consciousness among the employees and deployment of quality check/hold points in the maintenance procedures;
  - (ii) Prequalification of spares and supplies;
  - (iii) Development of mock-up facilities based on operating experience;
  - (iv) Training/retraining of the personnel to be deployed;
  - (v) Strict control of work execution to avoid extension;
  - (vi) Provision of early warnings on critical items or milestones;
  - (vii) Analysis of time spent on work to increase effectiveness;
  - (viii) Application of proper workers' motivation schemes such as incentives and awards;
  - (ix) Improvement of the foreign material exclusion programme on the basis of operating experience.

(c) Improvement of outage management by:
  - (i) Implementation of management and project management development programmes to strengthen the leadership and control of outage activities;
  - (ii) Establishment of clear goals, responsibilities and ownership;
  - (iii) Implementation of self-assessment processes at plant, department and individual levels;
  - (iv) Prioritization of activities according to their importance;
  - (v) Strengthening of safety awareness and culture;
  - (vi) Conduct of organizational development programmes with a cohesive approach and motivation;
  - (vii) Promotion of a 'do it right first time' approach;
  - (viii) Anticipation of budgetary requirements and ensuring allocation of the same;

(ix) Preparation of well-documented quality assurance and quality control programmes for outage activities with the help of the quality control/quality assurance group;

(x) Listing and ordering of spare parts to ensure their timely availability at plant stores (based on past experiences);

(xi) Interdisciplinary communication on critical subjects (support, approvals, tools, etc.);

(xii) Use of fixed teams of very experienced specialists for critical jobs (integrity checking, etc.).

(d) Anticipation of regulatory requirements based on in-house and industrial experiences.

(e) Ensurance of reliable inspection and maintenance tools through:

(i) Prequalification of special inspection and maintenance tools;

(ii) Redundancy of special tools.

(f) Spare parts policy:

(i) Quality control of received material well in advance;

(ii) Spare parts storage control system;

(iii) Partnership with vendors;

(iv) Joining of a pool for common spare parts or inventory management.

(g) Deployment of reliable and experienced contractors or subcontractors by:

(i) Seeking of international nuclear industry help through international networks;

(ii) Establishment of long term partnership;

(iii) Provision of timely and clear purchase orders, signing of contracts and control of the process development.

(h) Improvement of outage planning based on in-house and industrial feedback by:

(i) Establishment of clear goals;

(ii) Definition of outage milestones and freeze dates for different phases of the outage;

(iii) Proactive planning and scheduling, i.e. predicting and considering possible problems and planning in advance the best time for corrective actions;

(iv) Consideration of the operating experience feedback programme and plant history files during the planning phase.

These lists of causes and countermeasures could be used for self-assessment and continuous improvement.

7. FORCED OUTAGES

When a plant experiences a forced outage or an unplanned outage, it is equally important to impose the same safety and quality standards on work being performed as during planned outages. The natural tendency is for personnel to rush to get the plant back on-line. Plant management should insist on the same requirements for safety, quality and schedule as those for planned outages. Management should ensure enough time is available to analyse shutdown causes and to develop a strategy to work out the unplanned outage, including planning, preparation and safety evaluation.

It is good practice to maintain an on-going list of prepared maintenance tasks to be performed in the event of an unplanned shutdown. This list should include instructions, work orders, work permits, need for spare parts, special tools, materials and human resources.

The fundamental principles of employing rigorous schedule reviews to maximize safety system availability still apply. In most cases the amount of maintenance work to be performed in a forced shutdown is not large, when compared with a typical planned outage. The good practices identified in this report, especially those for outage execution, could be applied in the event of a forced or unplanned outage.

8. SELECTED IAEA PUBLICATIONS AND THEIR RELATIONSHIP TO THIS REPORT

The IAEA has issued a number of publications in recent years that are related to outage management. Most of these have been published in the IAEA-TECDOC series. Publications in this series are generally considered to be of current topical interest but, through their specific nature, some or all of the information may be time sensitive. This report is intended to provide information that should remain relevant over a longer time. Provided below is a list of selected IAEA-TECDOCs relevant to outage management, along with an assessment of their current value to aid those responsible for this topic.

Nuclear Power Plant Outage Optimization Strategy
IAEA-TECDOC-1315 (2002)

This publication was used as the starting point for the development of this report. It includes a number of examples of outage management practices that are not fully addressed in this report and thus should be of particular value.

Good Practices for Outage Management in Nuclear Power Plants
IAEA-TECDOC-621 (1991)

Provides greater detail regarding outage management practices than those included in either IAEA-TECDOC-1315 or this report. Even though it was published in 1991, many of the examples provided continue to be relevant today.

Configuration Management in Nuclear Power Plants
IAEA-TECDOC-1335 (2003)

The processes described for improving configuration management practices have particular relevance for modifications that are made during planned outages and consequently this IAEA-TECDOC should be used as a source of information in this area.

Risk Management: A Tool for Improving Nuclear Power Plant Performance
IAEA-TECDOC-1209 (2001)

Describes an approach for the integrated management of production and safety related and economic risks in an effective way. This integrated approach is well suited to outage management decision making, particularly that relating to cost–benefit trade-offs for the margins included in scheduling and planning outages. Such techniques are particularly relevant in more competitive energy markets where the provision of predictable and reliable outages has very significant financial impacts.

Advances in Safety Related Maintenance
IAEA-TECDOC-1138 (2000)

Describes approaches to maintenance that take into account the plant as a whole and its global safety performance, rather than individual components and their individual performances. Practices emerging from the development of these concepts are results and risk based and include the use of PSA in maintenance decisions. Such tools can be used to assist in decision making regarding on-line maintenance and the scheduling of maintenance during planned outages.

Good Practices for Cost Effective Maintenance of Nuclear Power Plants
IAEA-TECDOC-928 (1997)

Focuses on five areas for cost effective maintenance: (i) increasing production through improved plant material condition, reduced duration of planned outages, use of online maintenance and reduced frequency of forced outages; (ii) reducing workload; (iii) improving maintenance processes; (iv) improving productivity; and (v) measuring performance of maintenance.

Good Practices with Respect to the Development and Use of Nuclear Power Plant Procedures
IAEA-TECDOC-1058 (1998)

Addresses lessons learned regarding effective methods for the development and use of nuclear power plant procedures, administrative as well as operational. It provides examples of proven methods for development and use of plant procedures, including those intended for use during outages.

Assuring the Competence of Nuclear Power Plant Contractor Personnel
IAEA-TECDOC-1232 (2001)

The objective of this publication is to assist nuclear power plants and other organizations to ensure that plant contractor personnel are competent to undertake their assigned tasks. Planned outages are the time-frames when contractors are used in greatest numbers. Thus, it has particular application to outage management.

Management of Procurement Activities in a Nuclear Installation
IAEA-TECDOC-919 (1997)

The objective of this publication is to address nuclear power plant operating organization needs, related to the proper control of fulfilment of contractual quality and safety requirements. As many of these procurement activities are conducted in support of outage management, this document has relevance for this topic.

Guidance for Optimizing Nuclear Power Plant Maintenance Programmes
IAEA-TECDOC-1383 (2003)

Addresses a broad range of maintenance and maintenance management issues, including those related to outage management, i.e. asset life management, risk informed maintenance, and techniques and tools for a maintenance optimization programme.

9. SUMMARY

More competitive energy markets have significant implications for nuclear power plant operations, including, among others, the need for more efficient use of resources and effective management of plant activities such as on-line maintenance and outages. Outage management is a key factor for safe, reliable and economic plant performance which involves many aspects, namely, plant policy, coordination of available resources, nuclear safety, regulatory and technical requirements, and all activities and work hazards, before and during the outage.

The IAEA has produced this report on nuclear power plants outage management strategies to serve as both a summary and follow-up to a series of publications related to practices regarding outage management and cost effective maintenance. Its aim is to identify good practices in outage management: outage planning and preparation, outage execution and post-outage review. As in the related technical documents, this report aims to communicate these practices in such a way that they can be used by operating organizations and regulatory bodies in Member States to improve practices regarding outage management.

Appendix I

OUTAGE MANAGEMENT STRATEGY AT OLKILUOTO 1 AND 2, FINLAND

I.1. INTRODUCTION

Teollisuuden Voima Oy (TVO) operates two almost identical BWR units on the island of Olkiluoto, off the west coast of Finland. The net electrical output of each unit is 840 MW. These units, named Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2), were designed and delivered by the Swedish company ABB Atom. Olkiluoto 3 (a 1600 MW(e) PWR unit) is under construction and planned startup is in 2009.

Both OL1 and OL2 produce energy at cost to the shareholders, mainly consisting of the Finnish pulp and paper industry. The load factor of both units has increased steadily during the first half of the 1980s, reaching 90%; the average load factor for the period 1995–2004 for both units has been about 95%. The unplanned energy unavailability is typically less than 2%. Refuelling outages are carried out in the spring when considerable hydropower is available in Finland.

TVO has had good results in realizing short and effective annual outages. A prerequisite for short outages, without risking nuclear safety, is the plant design itself. The Olkiluoto units have safety systems with 4 × 50% capacity and consistent physical and electrical separation. These inherent features allow preventive maintenance of safety system trains during power operation. The quality of maintenance work in safety systems is better too, since it can be done without pressure on the work schedule. The design of the reactor pressure vessel and its upper internals, as well as the permanent watertight connection between the reactor vessel flange and the containment, help to minimize the preparation needed before unloading can be commenced.

The subjects of outage safety planning are criticality safety, residual heat removal and preservation of the reactor coolant inventory. The last item is especially important since the units are equipped with internal main recirculation pumps, the maintenance of which may create risks of large bottom leakages. Separate time schedules are provided for coordination of the work with respect to these three safety aspects.

To reach a high level of safety, it is essential that all personnel taking part in the maintenance activities are motivated, well trained and familiar with the plant design and relevant procedures. This appendix deals with the education and preparatory training of TVO and subcontractor outage personnel.

I.2. OVERALL OUTAGE MANAGEMENT STRATEGY

TVO has an activity based management system approved by the Finnish regulatory body (the Radiation and Nuclear Safety Authority (STUK)). The system fulfils the requirements of Quality System Standard ISO 9001: 2000 and is certified by an accredited body (DNV Certification OY/AB).

The main objectives of outage management at TVO are to:

(a) Restore plant quality and performance;
(b) Ensure shutdown safety;
(c) Improve future performance;
(d) Implement plant modifications;
(e) Minimize conventional and radiological hazards;
(f) Minimize waste generation;
(g) Minimize outage scope;
(h) Optimize outage duration.

In order to meet the above objectives, TVO has an effective outage management system, consisting of strategy, outage planning, outage execution and post-outage review.

The technical specifications can be seen as a set of operational safety rules and criteria, which define the allowed operational range from the safety point of view. The content of the technical specifications for OL1 and OL2 was changed in 1986, when a separate chapter (Conditions and Limitations for Cold Shutdown and Refuelling Outage) was written.

If exemptions from the rules given in the technical specifications are necessary to carry out some tasks in a practical manner, then the safety office of the utility prepares an application for an exemption. The on-site safety committee handles all applications for exemptions before submittal to the regulatory body.

According to the regulatory guide for nuclear power plant outages, the utility has to submit for approval or information a large number of documents to STUK well in advance of the outage. During the outage, there are up to ten inspectors from STUK at the plant site. Although the supervision of outage activities carried out by STUK is relatively extensive, the regulatory activities do not normally cause any significant delays in the progress of outage activities.

I.2.1. Plant operational states and outage types

There are two basic types of planned outage for the Olkiluoto plants: the refuelling outage and the service outage. The refuelling outage mainly consists of refuelling, corrective maintenance, periodic inspections and tests required by the technical specifications and maintenance according to the preventive maintenance programme for annually overhauled components. A typical refuelling outage for Olkiluoto BWRs lasts 7 days. The service outage can be either normal or extensive and includes, in addition to the refuelling work, all major plant modifications or upgrading. The service outage duration varies between 14 days (normal, including the opening of turbine) to 20–30 days (extensive, including major modifications) for Olkiluoto BWRs. An example of the refuelling and maintenance outages is shown in Fig. 3.

As an operational state, a refuelling outage is characterized by an interlocking of control rod manoeuvering, so that only rods belonging to the same scram group can be withdrawn simultaneously. This prevents withdrawal of any two adjacent control rods.

Upon shutdown, all control rods are fully inserted. When the mode switch in the reactor protection system is switched to the neutral ‘O’ position, no control rod withdrawal is possible. The switch can also be set in the ‘B’ position that is used during refuelling. In this case, withdrawal of individual control rods or entire scram groups is permitted in conjunction with tests and rod drive service.

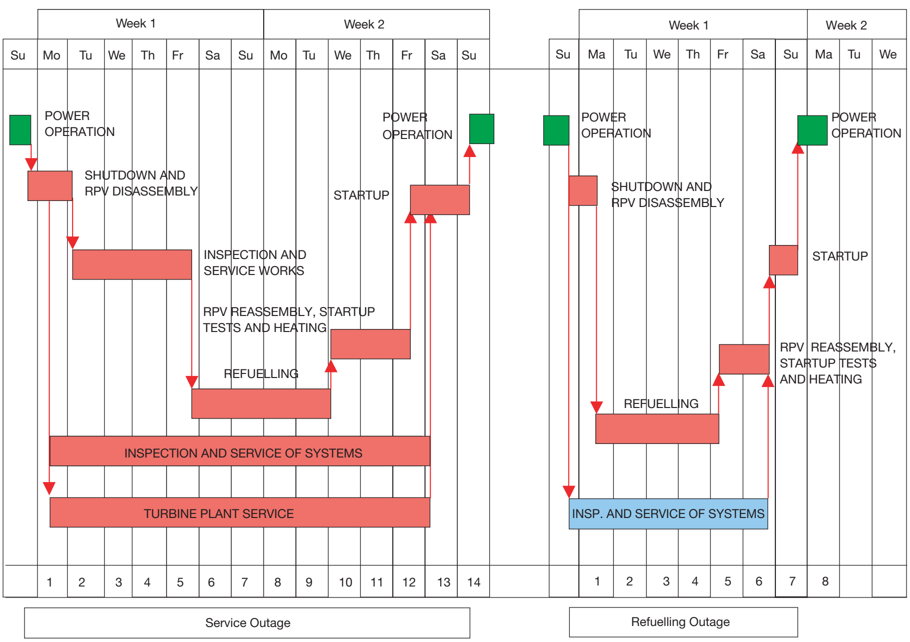


FIG. 3. Olkiluoto plant service/refuelling outages.

When the mode switch is in either position O or B, the operating mode may be identified as ‘shutdown’. The shutdown mode may be divided into hot shutdown, cold shutdown or refuelling shutdown.

Plant shutdown, in contrast to plant operation, implies that requirements on the operating staff in the control room may be eased. It also permits greater accessibility to controlled areas. In particular, the turbine plant becomes accessible for inspection.

Hot shutdown implies that the reactor is kept at the operating pressure and temperature. This mode differs from the hot standby mode in which control rods may be withdrawn. Furthermore, access to the reactor containment is possible during hot shutdown but not during hot standby.

Cold shutdown implies that the reactor is cooled down to atmospheric pressure and essentially ambient temperature. Cold shutdown is normally undertaken only for refuelling but may also be required to permit certain maintenance activities which cannot be performed when the reactor is hot and pressurized.

Refuelling shutdown is a prolonged cold shutdown during which the lids are removed from the reactor and from the containment vessel. The transition from cold shutdown to refuelling shutdown takes place when the reactor lid bolts are loosened. In the refuelling stage the mode switch is set in the B position as explained above.

I.2.2. Management strategy

The policy of TVO is to carry out preventive maintenance measures effectively at the right time to avoid failures and unplanned shutdowns and to operate the plant units at high efficiency. To achieve this goal, condition monitoring and detailed maintenance planning are needed. Close monitoring of trends and detection of failures at an early stage is one of the main principles. Identifying existing or potential problem areas by advanced vibration monitoring, a careful follow-up of process efficiency, chemistry and other process parameters, and the use of other predictive methods (thermography, oil analysis, motor operated valve testing, etc.) are essential in determining the condition of the plant units.

Currently, the main part of the maintenance consists of periodic inspections and overhauls. The intervals between major overhauls are being extended and the availability of a unit is improved by using predictive maintenance methods and adopting the concept of condition based maintenance. Various analyses are used to optimize and to allocate maintenance measures to the correct objects.

The proportion of corrective maintenance has been less than 10% of the total annual maintenance person-hours; preventive maintenance and inspections comprise about 60% and modifications and improvements about 30%.

The Olkiluoto BWR units are equipped with fourfold safety systems and some preventive maintenance in safety systems can be undertaken during operation. For example, preventive maintenance of the emergency diesel generators, containment spray system, auxiliary feedwater system and the low pressure injection system is performed during operation. However, most of the annual maintenance is done during the annual outages.

The objective is to avoid major unexpected repairs by having a proper spare parts policy and by undertaking detailed risk studies. All critical items to be inspected are analysed in advance to determine acceptable defect levels and to plan provisional repair methods for continued operation. Final repairs, which usually aim at improving the design, are carefully preplanned and executed during the next outage.

By means of an optimal spare parts policy it is possible to keep up the quality of maintenance work undertaken during the relatively short outages. The number of complete component replacement units, such as generator rotors, control rod drives, turbine blades, servomotors, various pumps and valves, and emergency diesel engines, has increased over the years. During the outage, components are replaced and these are serviced after the outage under workshop conditions.

I.2.3. Refuelling programme and strategy

Olkiluoto power plant units are operating with twelve-month fuel cycles and about a quarter of the fuel is replaced during every outage.

According to the standard schedule, fuel design and optimization work starts quite early, about two years before bundle fabrication. Usually, the lead time before loading the fuel into the reactor is three years, because TVO has a fuel reserve corresponding to one year of plant operation at the site. The last phase in the design work includes the planning of actual reload for a certain operating cycle to reach the required cycle length at full power, followed by reactor core supervision and design work during operation. The time-span between starting the design work and the final discharge of the fuel from the reactor is about seven years.

The purpose of the refuelling is to load a new core configuration for the following operating cycle, according to the results from reload design calculations. This requires special planning and optimization, taking into consideration limiting conditions from other relevant outage works and various inspections. The refuelling includes a total of 600–700 fuel assembly transfer operations in a typical quarter reload case. This comprises: about 130 fuel assemblies totally removed from the reactor core; 100 assemblies temporarily removed from the core to the fuel pools for various reactor and control rod inspections and instrument replacements; 250 fuel shufflings within the core; reloading the temporarily removed fuel assemblies and loading about 130 fresh fuel assemblies.

Factors that help minimize the time needed for refuelling operations are careful optimization with a special computer program, use of a semi-automatic refuelling platform and constant, careful supervision of all refuelling operations.

I.2.4. Outage scheduling

Planning of outages is undertaken at three levels at the same time: long term planning (about ten years), mid-term planning (three years) and detailed planning of the next outage, where special emphasis is placed on the careful study of the critical path activities (see Fig. 4).

Long term planning is used to fit together the planned maintenance and inspection measures with modifications in order to minimize the total time needed on the critical path of outages. The plant life extension programme is also taken into consideration in the long term planning.

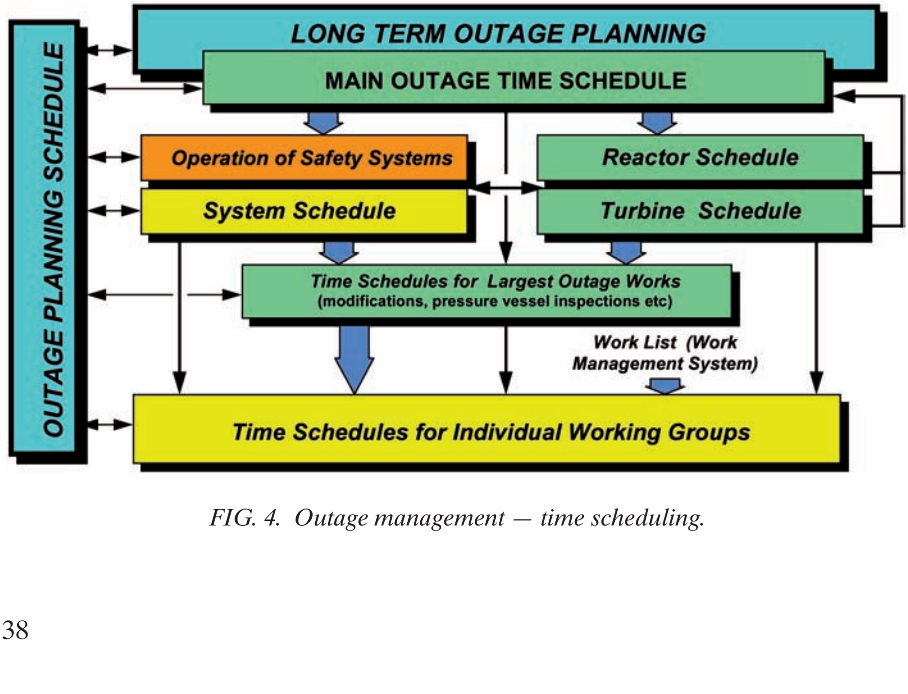


FIG. 4. Outage management — time scheduling.

The planning period of the next outage is one year. The milestones from planning to reporting and post-outage review are specified in the planning schedule. The detailed planning is started about one year before the outage, when the main critical activities and the main scope of the outage are determined and a preliminary time schedule prepared. The availability of the most critical spare parts must also be reviewed at the same time because of the possible long delivery times characteristic to the nuclear industry.

Outage planning is undertaken according to the planning schedule. The main time schedule specifies the critical path of the outage. The number of other schedules depends on the scope of outage works (reactor and turbine time schedules, schedules for major repairs and modification works and schedules for individual working groups).

Availability of the reactor safety systems during the outages is specified in the reactor safety system availability schedule while permitted working times are specified in the system schedule. Planning is assisted by modern and advanced computer based systems.

The main part of the maintenance is undertaken during outages and by contractor personnel. The availability of competent resources is assured by the existence of certain ‘key’ individuals amongst TVO personnel and by having long term contracts with plant vendors and main service companies. Multicycle fixed price contracts are also used. Normally 600–1000 outside workers (depending on the type and scope of outages) from about 100 different companies participate in the annual outages while the number of TVO outage personnel is around 300. Over 70% of the contractor personnel have experience of previous outages.

The coordination of the planning and execution of outage work is always the responsibility of TVO and is performed in a partnership arrangement with the main contractors.

I.2.5. Training

One important aspect in striving for a high level of safety during outages is the education and preparatory training of TVO and subcontractor outage personnel. It is essential that the personnel taking part in the maintenance activities are motivated, well trained and familiar with the plant design and relevant procedures. A special session on safety issues is arranged every year for subcontractor outage personnel. The outage information handout includes a separate chapter on safety.

The knowledge, training and qualification, and performance of maintenance personnel support safe and reliable plant operation. Maintenance is performed by, or under the direct supervision of, personnel who have been qualified for the tasks to be performed.

Continuous training effectively addresses plant hardware and procedure changes, infrequently used skills and lessons learned from in-house and industry operating experience.

The knowledge and practical abilities of contract maintenance technicians and other non-nuclear power plant maintenance personnel are equivalent to those of nuclear power plant maintenance personnel for the functions to which they are assigned. On-the-job training is used to provide necessary skills and knowledge prior to assignment to tasks that are to be performed independently.

For the operators, annual sessions on safety issues during outages are arranged. The plant simulator has not yet been used for the outage related training of the operators.

I.2.6. Radiation safety considerations

Radiation protection training is intended to provide personnel with the prerequisites to work in the controlled area and also aims at contributing to the accomplishment of radiation protection objectives. The training is given to both permanent and temporary personnel working in the controlled area. Training provided for personnel working in the controlled area covers applicable topics of radiation legislation, fundamentals of radiation and radiation risk, instructions for work in the controlled area and information on dose monitoring. The personnel must demonstrate in a written examination that they have sufficient knowledge of radiation protection.

The dose information provided by an effective work dosimetry system provides a means of correctly focusing the radiation protection. TVO uses digital RAD-80 and RAD-51 dosimeters. Thermoluminescent dosimeters serve as the official personal dosimeters. Persons working in the controlled area must always wear a dosimeter.

There is a radiation work permit for work performed in the controlled area. Radiological work permit planning can be undertaken effectively when all previous work permits, as well as the contamination and radiation data of all components and rooms, are registered on a computer. The radiation work permit provides, as a minimum, the following information:

(a) Name of employee;
(b) Radiation conditions in the working area;
(c) Requirements concerning measurement of dose rate, surface contamination and airborne activity;

(d) Exposure assessment;
(e) Special instructions and equipment.

The minimization of doses in short annual outages is based on effective scheduling of work and on minimizing the number of personnel.

Although the annual radiation doses at TVO are very low by international standards, on average 0.75 Sv per unit, they can and must still be reduced. There are two ways to achieve this, either by minimizing the radiation sources or by making personnel work in such a way that they are exposed to less radiation. At TVO, both ways are used.

An ongoing special project is to decrease the concentration of ^{60}Co in the reactor water by all available means. The most effective way is to replace stellite, a material used to seal certain valves, with cobalt free material.

I.3. OUTAGE MANAGEMENT CONTROL

The TVO outage organization has the following characteristics: a full-time outage manager, an acting outage coordinator in operation, project organization for every planned outage, an outage management group, a long term outage group and an outage planning group.

The outage management group (the plant meeting) is chaired by the plant manager and this group provides general supervision and monitoring of outages, approves outage times and programmes and provides decisions for significant problems. This group approves middle term and long term plans (3–20 years) which are based on the chosen outage policy, major overhauls and inspections, planned modifications/improvements and the plant lifetime programme.

The outage manager chairs the outage planning group which includes representatives from all organizations working with the next outage. It provides supervision of detailed planning, execution and reporting of outages. The outage manager coordinates all activities concerning outage planning and execution and the acting coordinator (one of the shift supervisors) coordinates all activities that take place during the outage (work permit/plant safety planning, etc.).

The safety office is located on-site, as are the technical support staff. About four months before outages, which are scheduled to take place in springtime, the safety office personnel review the outage schedules set up by outage coordinators according to the rules given in the technical specifications. There are two important time schedules that are related to safety. The first one shows the unavailabilities of the systems used for residual heat removal, emergency core cooling and electrical power supply and important works vital to preserving the water inventory. The second one shows the availability of reactivity control systems. As a result of this review, the safety office personnel prepare a memorandum on the residual heat removal capacities during the outage and on the safety of the main jobs. This memorandum is also discussed by the on-site safety committee.

STUK must approve the outage plans and the execution of outage and all safety related activities. During the outages, up to ten inspectors from STUK are at the plant site and available 24 hours per day if necessary.

I.3.1. Design modification control

The management of plant modifications has been defined in the activity based management system. The guides issued by STUK give requirements concerning planning and implementation of modifications. Safety related modifications are reviewed and approved by the relevant authorities after internal approval by TVO. The STUK guides also specify the content of documentation which has to be submitted for approval.

Concerning safety related plant modifications, the STUK guides require safety impact assessments to be made. Safety evaluations are performed either by TVO personnel or by outside contractors, depending on the nature and extent of the modification. When assessing the safety impact of the proposed modifications, assistance is obtained from the plant supplier, other suppliers and research institutes.

In connection with safety related system modifications or other important modifications, PSA is used to determine the impact of the modification on the safety of the plant. PSA studies are also used for comparing different alternative solutions when planning modifications. Safety evaluations of modifications are part of the pre-inspection documentation sent to STUK for approval. Depending on the nature and extent of the modification, it is designed by TVO personnel or by outside contractors.

Work planning activities (work permits, work orders, etc.) are always made by TVO personnel according to the plant procedures. All modification plans, irrespective of the originator, are reviewed and approved by responsible organizations and persons within TVO according to the plant procedures before they are submitted to STUK for approval. Purchase of safety related equipment is subject to STUK control. TVO has to submit all pre-inspection documentation to STUK for approval.

STUK gives approval to the manufacturer, construction and manufacturing plans, quality assurance and quality control plans. Both TVO and STUK perform audits and inspections at the manufacturer's premises before, during and after manufacturing, depending on the nature of the equipment to be manufactured.

Both TVO and STUK perform inspections after completion of the modification, STUK issuing a commissioning inspection protocol. Test programmes are part of the pre-inspection documentation. The conduct of tests is witnessed by STUK inspectors, depending on the nature of the modification and the tests. Test results concerning safety related modifications are subject to STUK review and approval.

Updating of plant documentation takes place in steps during and after the implementation of the modification. The updating schedule is dependent on the need for documents in the O&M of the system after modification. The system descriptions in the final analysis safety report are updated as a campaign once a year. Changes to plant documentation under STUK control (e.g. technical specifications) must be approved by STUK.

I.3.2. Control of work orders

Work planning activities (work permits, work orders, etc.) are always made by TVO personnel according to the plant procedures. During normal operation foremen responsible for executing the work are also responsible for detailed planning of work orders. During the outage there is a special group (six persons) responsible for detailed planning of work orders. The outage manager is responsible for this activity.

The safety office personnel review individual work orders for maintenance tasks during the outage and approve those important to safety.

Work planning is assisted by modern and advanced computer based systems. The work flow in the work management system is shown in Fig. 5.

The main control steps taken by outage coordinator/shift supervisors are:

(a) Preparation of outage schedules important to safety according to technical specifications;
(b) Allocation of work orders important to safety of the outage, according to approved time schedules;
(c) Designation of the shift supervisor as being responsible for the technical specifications and specially assigned requirements being fulfilled during the outage, even though the time schedule changes;
(d) Separation of work orders are required if identical tasks are performed in redundant safety systems.

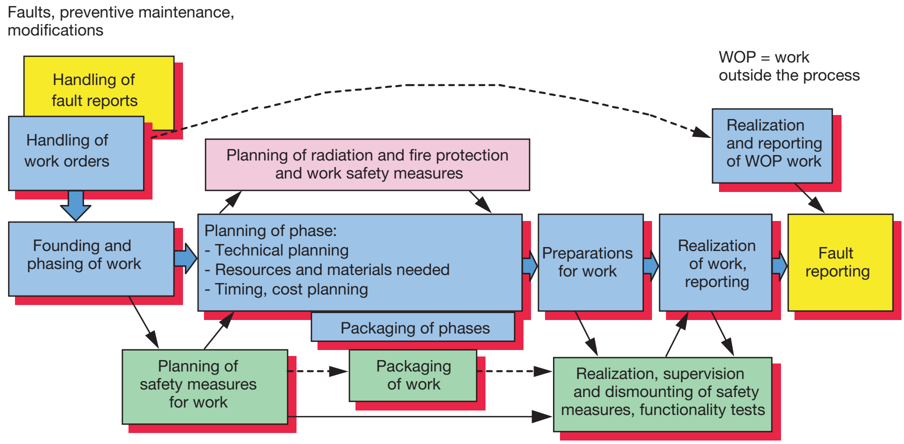


FIG. 5. Work flow in a work management system.

I.3.3. Risk control

TVO wanted to create a realistic view of the risk level during shutdown, startup and refuelling outage conditions. Therefore, in 1990 it made a decision to extend the PSA to the analysis of refuelling, shutdown and startup. Improvements in shutdown safety and prospects for future developments were identified.

Regarding the repair strategy, the objective is to avoid major unexpected repairs by having a proper spare parts policy and by having undertaken detailed risk studies. All critical items are analysed in advance to determine acceptable defect levels and to plan provisional repair methods for continued operation.

The operational organization, especially the shift supervisor, bears the main responsibility for safety. An independent review of outage safety matters in general for every outage and an operational safety review of outage works in the work management system are made by TVO nuclear safety office personnel. For example, the safety office personnel perform an independent review on the plant status before startup. Also, STUK conducts its own supervision.

All outage activities are planned and performed according to the requirements laid down in the TVO activity based management system. Activities are controlled by related procedures and instructions.

I.3.4. Quality assurance

The quality assurance engineers audit and routinely monitor different activities during the outages. The quality assurance office personnel especially concentrate on ensuring that the administrative measures are functioning as planned, in order to ensure that different work activities are planned and performed in a controlled and systematic manner. Safety culture issues are also addressed.

At the end of the outage, the quality assurance engineers monitor all organizational units to ensure that they have performed their assigned checking and verification duties, which are required to be done before the plant can be declared ready for startup. After all this has been done, the quality assurance manager gives approval and final permission for the startup can be requested from the STUK representative at the plant site.

The outage group, meeting twice a week during planned outages, ‘collects’ and scrutinizes noteworthy incidents that have occurred during the outage. It prepares a special report on them for operational experience feedback purposes. STUK is informed about events and observations significant for the development of the quality system, as well as resultant measures taken.

I.4. SAFETY ISSUES

The primary safety functions to be monitored are residual heat removal, preservation of the water inventory and maintenance of criticality safety.

The residual heat removal function can tolerate a single failure of active components and the pool water temperature is not permitted to exceed 60°C. The initiating event taken into account in the assessment is normally a loss of off-site power, with simultaneous failure of one diesel generator.

The emergency core cooling system has to be single failure tolerant to preserve the water inventory, while work is performed in a place which is connected to the primary circuit below the top of active fuel and which cannot be isolated from the primary circuit. The maintenance of internal main recirculation pumps involves the risk of a large bottom leakage during the outage. Special arrangements have been implemented to cover this safety issue. One example of these arrangements is the closure of the lower drywell personnel access door to prevent draining of the reactor water outside the containment while critical tasks are under way.

An important element of shutdown safety is maintaining reactivity control, although criticality accidents due to component failures or maintenance errors have a rather low importance in the PSA. A shutdown margin of more than 1% has to be maintained during the whole outage, taking into consideration any active failure of a single component or any single human error. The shutdown margin after a single loading error, when all the control rods are in the core, is normally more than 3%. The shutdown margin, in connection with an erroneous removal or manoeuvering of one control rod, is calculated in advance after each fuel transfer operation. Owing to this, changes of the fuel transfer list without repeat of the calculations are allowed only during the unloading phase of refuelling.

Availability of power is also important for core cooling and decay heat removal. Sufficient power availability has to be ensured, even in the case of a loss of off-site power with simultaneous failure of one diesel generator.

The TVO units have safety systems with 4 × 50% capacity and consistent physical and electrical separation. However, the shutdown cooling system used during outage for residual heat removal has 2 × 100% capacity and the redundancies have common pipelines. Owing to problems with intergranular stress corrosion cracking and thermal stresses, which have made frequent repair work necessary, the availability of the shutdown cooling system during an outage has not been high. The fuel pool and auxiliary pool cooling system can be used as a redundant path for residual heat removal.

Unscheduled but planned unavailability of the systems shown in the safety related time schedules is, in principle, not allowed without a special review/study having first been undertaken by the safety office personnel. The availability of the important safety systems is shown in the main control room by means of magnetic tags which are visible to all personnel in the control room.

The most important emergency operating procedure deals with the loss of primary circuit leak tightness during maintenance of the main recirculation pumps. In this case, a large bottom leakage is generated and the accident management concentrates on preventing loss of water from the containment. Case specific plans are usually written for the yearly outages, e.g. to deal with possible loss in certain safety relevant systems during maintenance of another subsystem.

Single mechanical interlocks have been implemented to prevent removal of plugs from the recirculation pump openings. This is an example typical of shutdown conditions. The lower personnel access door of the containment is closed during the critical phases of the internal recirculation pump's maintenance.

All the normal procedures, such as limitation of simultaneous access to several electrical divisions at the same time, are followed during shutdown.

A great deal of attention is paid to preventive fire protection during outages. Personnel undertaking so-called 'hot' work, such as welding and cutting, must have a special licence to do that work. Each episode of hot work must have a hot work permit. Special fire patrol personnel ensure that hot work is carried out in a safe manner. There have not been any instances of major fires breaking out during outages.

If exemptions from the rules given in the technical specifications are necessary to carry out some tasks in a practical manner, then the safety office personnel of the utility prepare an application for an exemption. The on-site safety committee handles all applications for exemptions before submittal to STUK.

The safety office personnel review individual work orders for maintenance tasks in the outage and approve those important to safety.

I.5. FEEDBACK OF OUTAGE EXPERIENCES

Operating experience feedback from outages has been systematically gathered since 1992. TVO has not established a separate organizational unit for operating experience feedback but relies on a group of persons representing various disciplines. This ‘operating experience group’ processes experience feedback information further.

Special attention is paid to the feedback from outages and the goal is to improve outage management continuously. Thorough outage documentation makes it easy to identify strengths and weaknesses. Information on abnormalities and suggestions for improvements received from both the nuclear power plant and contractor personnel are especially taken into account. The provision of sufficient and timely information to all personnel involved in outage activities is essential for successful performance. Before the outage, all personnel should obtain both their own work information and an overall impression of how they can contribute to good outage performance. TVO gives information both to its own staff and to contractor personnel by having general information outlets and special meetings with different working groups.

Daily reporting is used to follow and supervise the progress of the outage. The report is prepared before daily morning meetings and distributed widely by data and information systems. An outage report is prepared at the latest one month after the outage.

Clear and well-defined performance indicators for different outage functions exist in order to follow up yearly outage performance. Human errors are followed and analysed carefully and ‘lessons learned’ procedures are developed.

During and after every outage, a comprehensive critique covering experience from all work and support groups is gathered. A separate report is also written after every outage. In order to develop outage activities, both the operating experience group and the outage planning staff analyse all deviations from normal routines. The operating experience group evaluates all the feedback information for relevance to TVO. If considered useful, a proposal for modification is written. All deviations from the technical specifications are reported to STUK.

TVO has access to several international operational experience databases (e.g. WANO, IAEA/IRS, IAEA MRPIS). There is also a common organization (ERFATOM) for experience feedback for the BWR operators in Finland and Sweden. ERFATOM is located in the offices of ABB Atom in Västerås, Sweden.

I.6. TVO SHUTDOWN EVENT PSA

As implemented by TVO, a shutdown event PSA (SEPSA) complements a level 1 PSA as a part of the living PSA model. TVO was interested in performing a PSA for several reasons, including open containment during refuelling, short refuelling outages with numerous overlapping maintenance tasks, continuously shortened outages, missing an automatic start of safety systems, unavailability of some safety systems due to maintenance of auxiliary systems and serious concerns over the importance of human errors. As the containment is open, severe core damage could lead to a significant release of radioactive materials to the environment. The study was performed during 1990–1992. The first results showed that the contribution of the refuelling outage to the annual core damage risk was of the same order of magnitude as the contribution of full power operation. Modifications in maintenance procedures were adopted and the analysis was thoroughly updated and included in the living PSA during 1995–1996. The level 2 PSA in 1997 showed that the assumptions made by TVO before the SEPSA study were correct. The contribution of refuelling to the core damage frequency was reduced to below 1%, but even so, its contribution to the large early release frequency was about 30%. The latest level 1 PSA extension, including the fire common cause initiators during outages, was added to the PSA model in 1998.

The total effort required to accomplish the SEPSA equated to approximately three person-years. The project team consisted mainly of TVO personnel, strengthened with an expert in human factor assessment.

Besides considering the severe nuclear risks, TVO was also interested in other risks such as a significant extension of outages. These were evaluated as a by-product of the event tree sequences and were regarded as not being severe enough to lead to core damage. The following plant damage states have been considered: mechanical fuel damage, local criticality, overheating of concrete structures of pools, uncovering of core, uncovering of spent fuel in spent fuel pools and severe core damage.

Thermohydraulic analyses made during the SEPSA project showed that all operating modes with a critical reactor should be included in the power operation mode PSA (Fig. 6). Thus, SEPSA covers only the subcritical operating modes. The duration of each of the shutdown operation modes is the average value taken from the recent five years before updating the study (1991–1995). The average refuelling duration was approximately 378 h (less than 16 d).

Only five different plant configurations were separately modelled in the SEPSA. These were based on the decay heat production and the integrity of

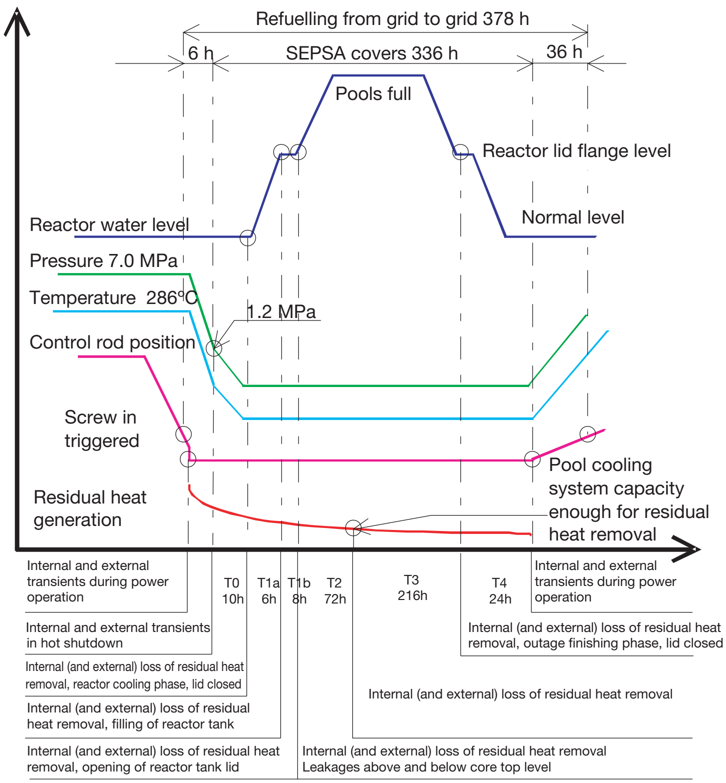


FIG. 6. Thermohydraulic analyses made during the SEPSA project showed that all operating modes with a critical reactor should be included in the power operation mode PSA.

the primary circuit, rather than on the unavailability of systems due to maintenance. The unavailability of components due to maintenance of the systems was modelled in the system fault trees. This was possible because of special features of the computer code used in the modelling. The planned maintenance of the systems was mapped out from the previous five refuelling outages and it was modelled in the fault trees at a subsystem level. Three different sizes of leakage below core and seven above core were modelled with separate event trees. Their frequency was based on human error analysis of maintenance tasks. The mechanical causes of failure are insignificant compared with those due to human factors. Each configuration has its own event tree; loss of residual heat removal being the initiating event. Loss of external grid is included in the transients without its own event tree.

Fire common cause initiators were modelled with the separate 'external' event trees, which were developed from residual heat removal event trees (states T0–T4). A single, fire initiating event can be applicable for one or all residual heat removal states T0–T4.

Special studies were carried out for the unwanted local criticality events, for the overpressurization of the reactor with steam lines filled with water, for the heavy load transport in the reactor hall and for the transients during short startup and shutdown periods with an atmosphere of air in the containment. The importance of criticality events is minor, but accidents caused by a loss of heavy loads are among the major contributors to the mechanical fuel damage that risks causing a minor release.

Time is another interesting aspect of risk level (Fig. 7). The beginning of a refuelling outage is important from the point of view of risk. There is a risk peak during the period of filling the reactor tank with water and during the first three days of maintenance activities. The potential for overfilling, followed by

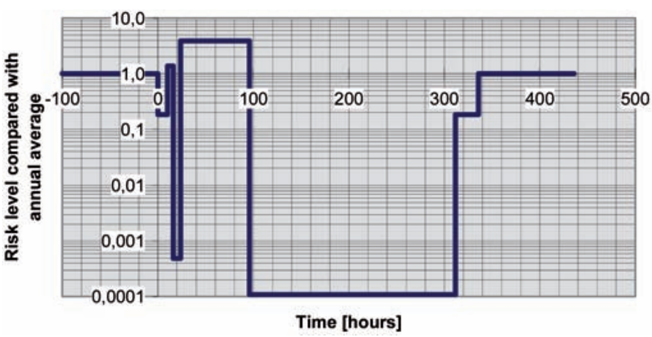


FIG. 7. Risk level during the refuelling outage as a function of time.

the loss of residual heat removal explains the former case. It was significantly reduced with modifications to procedures based on the results of the SEPSA study; filling the reactor tank above a certain level is no longer allowed using piston pumps. The latter risk peak is more difficult to reduce because it consists of several critical maintenance activities under the reactor pressure vessel. In addition, the average risk level during startup and shutdown is three times higher than the average risk level during power operation. The latest PSA upgrade showed that fire common cause initiators have a minor impact on the overall core damage frequency during the outage period.

Several actions taken during and after the SEPSA decreased the dominant risk contributors significantly (Fig. 8). The lower personnel access door was kept closed during the critical phases of overhaul of the internal main recirculation pumps, as mentioned earlier. Mechanical cotter pins, installed in the plugs of the penetration of the internal main recirculation pump axis, prohibit inadvertent lifting. In order to prohibit cold overpressurization, the use of auxiliary feedwater piston pumps for reactor filling is no longer recommended. Increase of pool cooling capacity, new timing of capping of safety and relief valves and the inspection routine for control rods were modifications implemented during the course of the SEPSA.

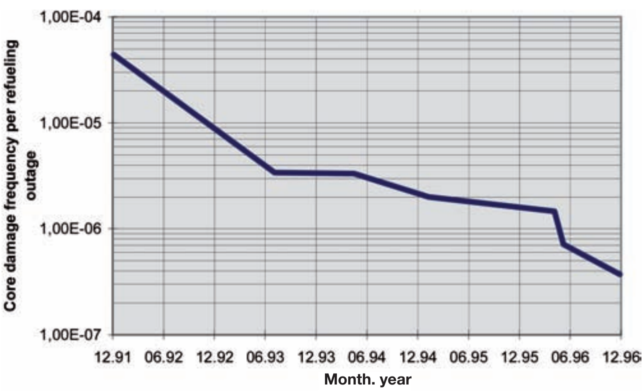


FIG. 8. Core damage frequency in refuelling outage has significantly decreased when issues identified in the SEPSA project have been fixed.

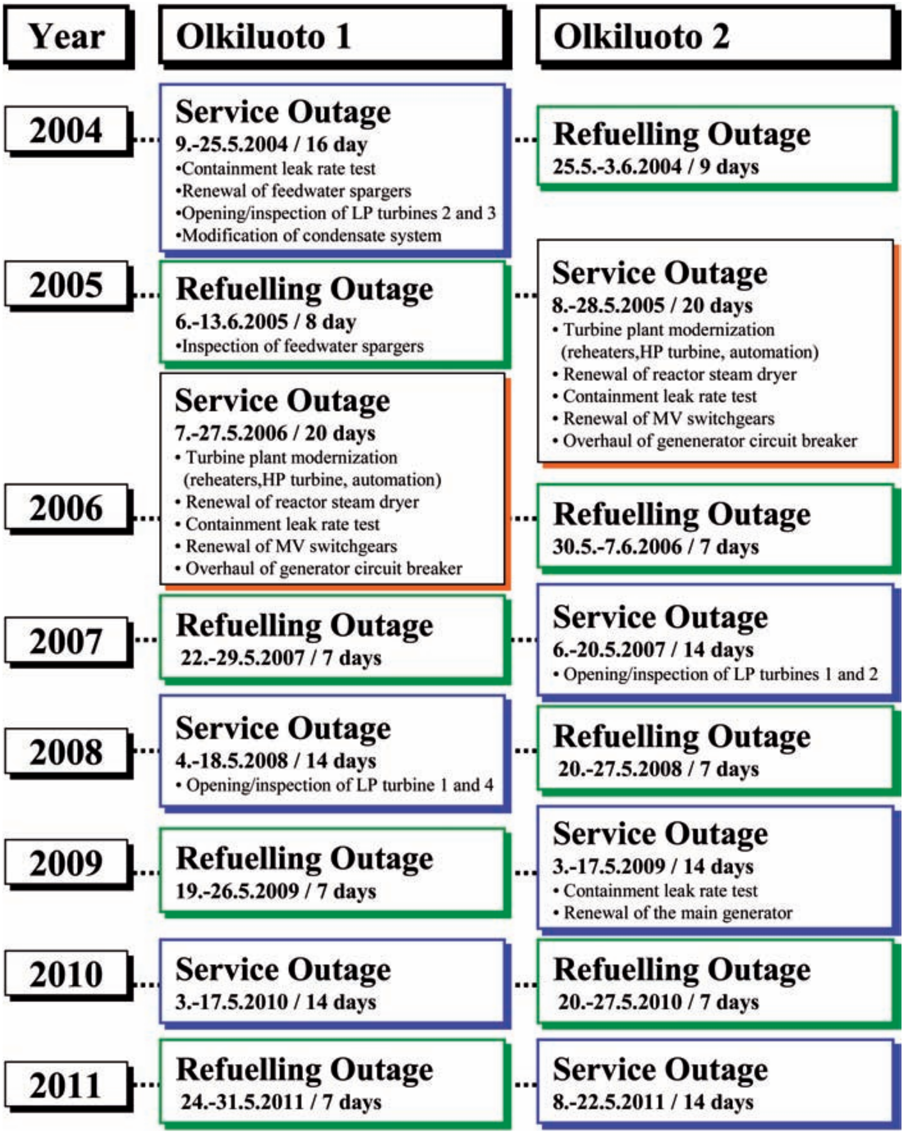
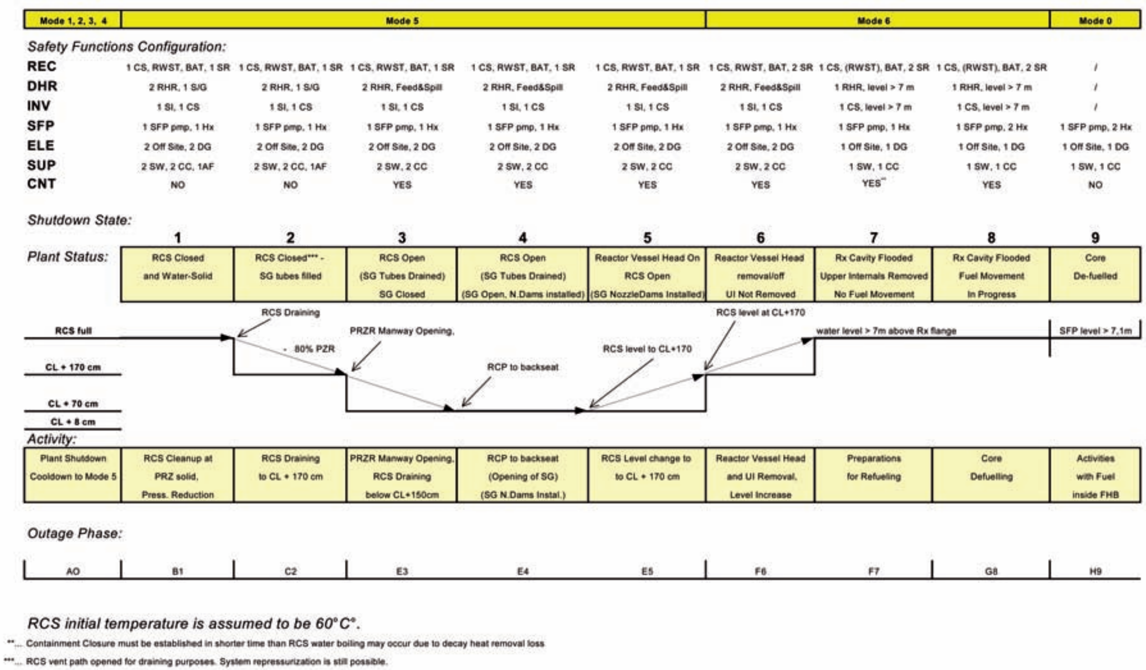


FIG. 9. Long term plan for annual outages (2004–2011) for Olkiluoto 1 and 2.

Appendix II[2]

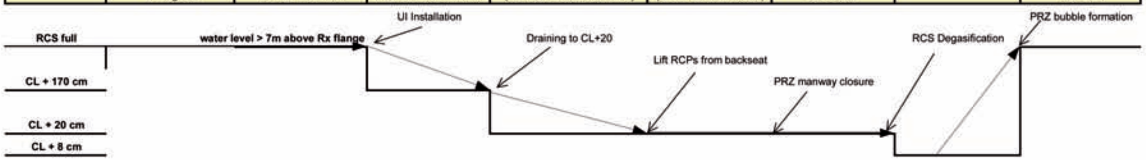
KRŠKO NUCLEAR POWER PLANT SHUTDOWN OPERATIONAL LIMITS AND CONDITIONS



2 Appendix II remains unedited.

KRŠKO NUCLEAR POWER PLANT SHUTDOWN OPERATIONAL LIMITS AND CONDITIONS (cont.)

	Mode 6			Mode 5					Mode 4,3,...	
REC	1 CS, (RWST), BAT, 2 SR	1 CS, (RWST), BAT, 2 SR	1 CS, RWST, BAT, 2 SR	1 CS, RWST, BAT, 1 SR	1 CS, RWST, BAT, 1 SR	1 CS, RWST, BAT, 1 SR	1 CS, RWST, BAT, 1 SR	1 CS, RWST, BAT, 1 SR		
DHR	1 RHR, level > 7 m	1 RHR, level > 7 m	2 RHR, Feed&Spill	2 RHR, Feed&Spill	2 RHR, Feed&Spill	2 RHR, Feed&Spill	2 RHR, Feed&Spill, 1S/G	2 RHR, 1 S/G		
INV	1 CS, level > 7 m	1 CS, level > 7 m	1 SI, 1 CS	1 SI, 1 CS	1 SI, 1 CS	1 SI, 1 CS	2 SI, 2 CS	2 SI, 2 CS		
SFP	1 SFP pmp, 2 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx	1 SFP pmp, 1 Hx		
ELE	1 Off Site, 1 DG	1 Off Site, 1 DG	2 Off Site, 2 DG	2 Off Site, 2 DG	2 Off Site, 2 DG	2 Off Site, 2 DG	2 Off Site, 2 DG	2 Off Site, 2 DG		
SUP	1 SW, 1 CC	1 SW, 1 CC	2 SW, 2 CC	2 SW, 2 CC	2 SW, 2 CC	2 SW, 2 CC	2 SW, 2 CC, 1 AF	2 SW, 2 CC, 1 AF		
CNT	YES	YES**	YES	YES	YES	YES	YES	NO		
	8	**7**	**6**	**5**	**4**	**3**	**2***	**1**		
	Rx Cavity Flooded Fuel Movement In Progress	Rx Cavity Flooded Upper Internals Removed No Fuel Movement	Reactor Vessel Head Off, Upper Internals Not Removed	Reactor Vessel Head On RCS Open (SG Nozzle Dams Installed)	RCS Open, (SG Open) SG U-tubes Drained (SG N. dams Deinstal.)	RCS Open SG Tubes Drained SG Closed	RCS Closed SG U-tubes Drained	PRZ level RCS pressurization RCP start		



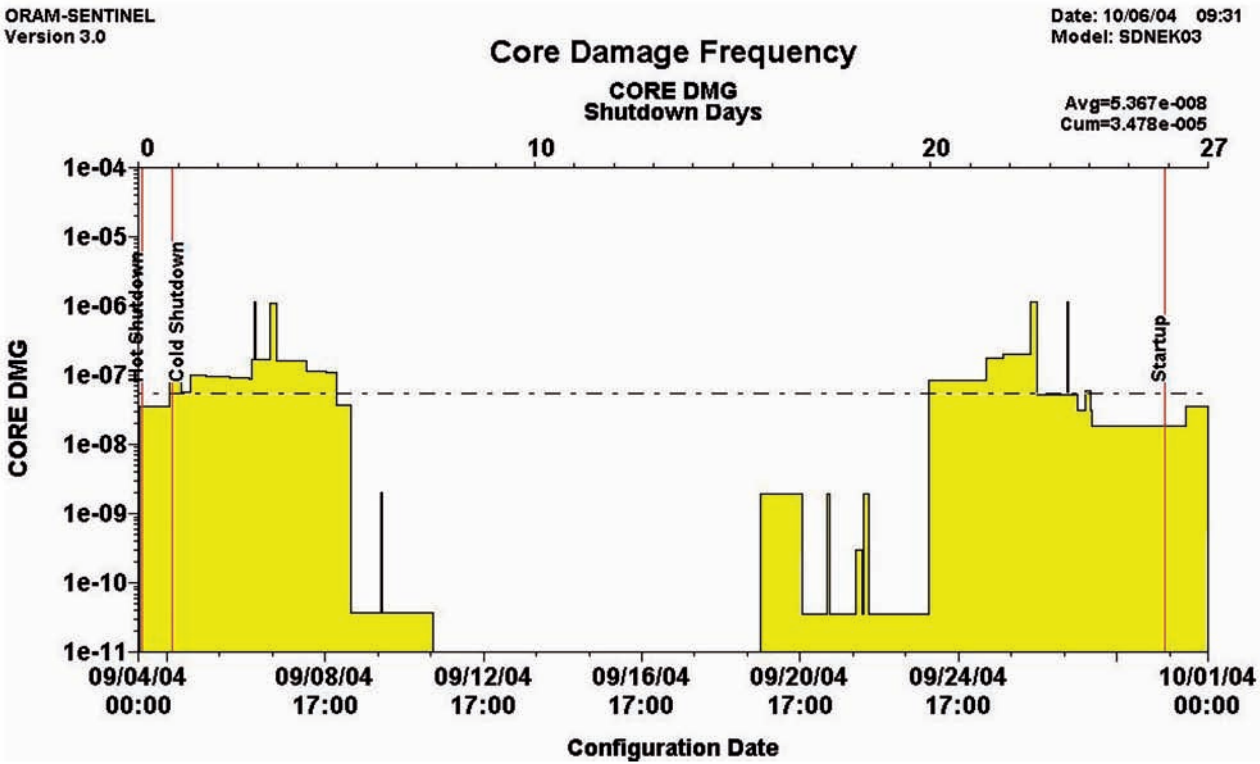
	Core Refueling	Preparation for Rx closure	Reactor Vessel Head and UI Installation	RCS Level Change to CL + 20 cm	RCP from backseat (SG N. Dams deinstal.) (Closing of SG)	PZR Closure	RCS Degasification RCS Level Increase	PRZ Heating Preparations for Startup	RCS Heatup, Startup to Synchronization	First Synchronization to Full Power
	I8	J7	J6	K5	K4	K3	L2	L1	M0	N0

**... Containment Closure must be established in shorter time than RCS water boiling may occur due to decay heat removal loss

***... RCS vent path opened for draining purposes. System repressurization is still possible.

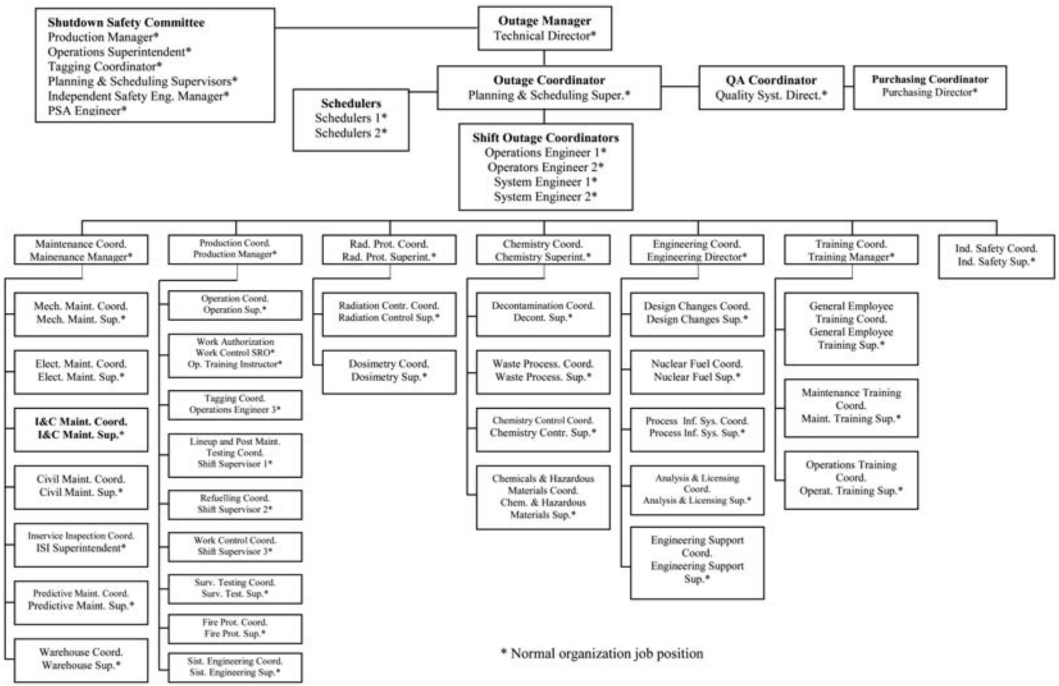
Appendix III

KRŠKO NUCLEAR POWER PLANT SHUTDOWN PSA CALCULATIONS



Appendix IV[3]

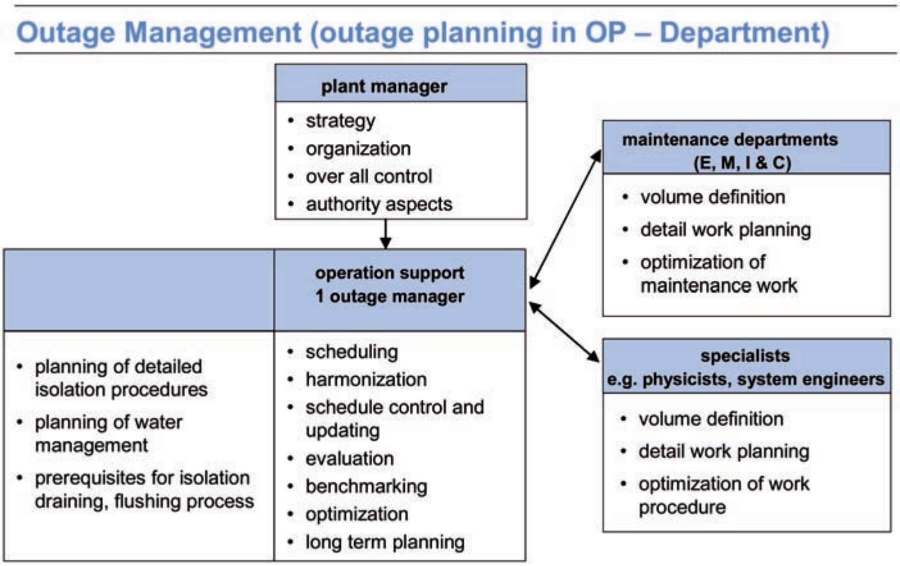
KRŠKO NUCLEAR POWER PLANT OUTAGE ORGANIZATION



[3] Appendix IV remains unedited.

Appendix V

NECKAR NUCLEAR POWER PLANT OUTAGE ORGANIZATION



Appendix VI[4]

NECKAR NUCLEAR POWER PLANT LONG TERM OUTAGE PLAN

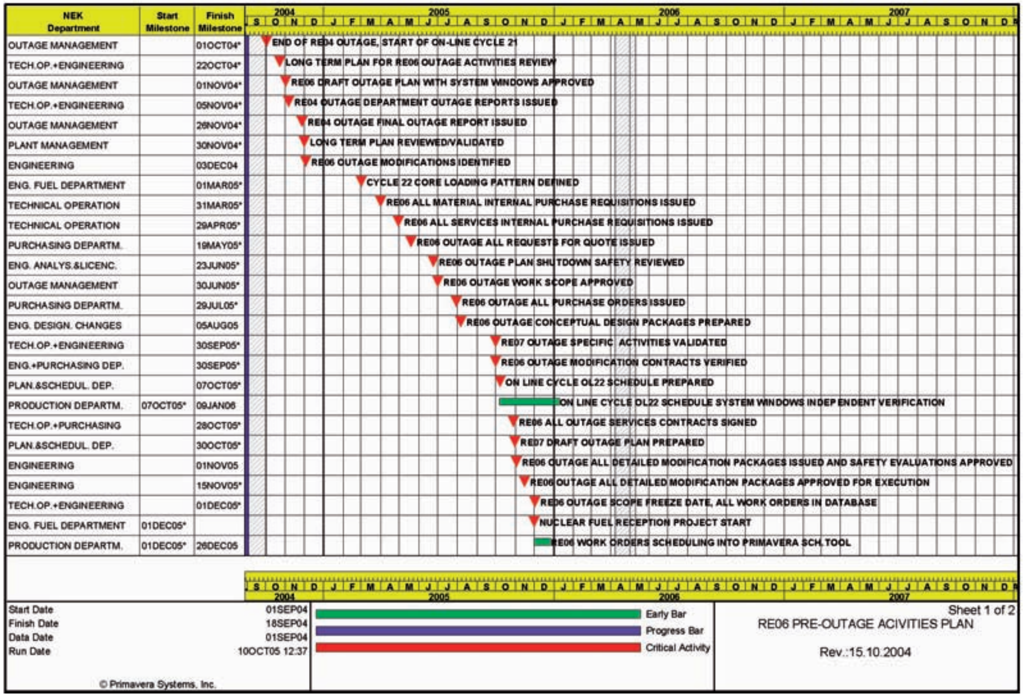
Main Activities for long-term Outage Scheduling

Year		94	95	96	97	98a	98b	99	00a	00b	01a	01b	02	03a	03b	04	05a	05b	6a	6b	07	08a	08b	09	10a	10b	11a	11b	12	13a	13b
On power maintenance safety train						3		2	1		4		3	2		1	2	4	3		2	1		4	3		2		1	4	
Main safety train M/E/I&C		3	2	1	4	3	3	2	1	1	4	4	3	2	2	1	4	4	3	3	2	1	1	4	3	3	2	2	1	4	4
Main generator outage	10y				X																X										
HP-turbine	8y				X								X											X7y							
LP1-turbine - disk check	6y		X										X								X6y								X6y		
LP2-turbine - disk check	6y			X									X											X7y							
SG-pressure test, SG 1-4	10y		1/2		3/4											1/2					3/4										
SG tube sheet flushing (all SGs)	8y						X													(X)											
RCS pressure test	10y				X																X										
RPV ultrasonic test	5y				X								X								X								X		
Eddy current test, vessel studs/bolt	5y				X								X								X								X		
Periodic test of vessel internals	5y				X								X								X								X		
Eddy current test, tubes SG 1	5y	X			X			X					X								X								X		
Eddy current test, tubes SG 2	5y			X				X								X								X							
Eddy current test, tubes SG 3	5y	X			X			X					X								X								X		
Eddy current test, tubes SG 4	5y			X				X								X								X							
Basic overhaul RCP10	8c		X										X																X		
Basic overhaul RCP10 motor	8y					X														X									X		
Basic overhaul RCP20	8c	X														X															
Basic overhaul RCP20 motor	8y	X														X															
Basic overhaul RCP30	8c			X														X													
Basic overhaul RCP30 motor	8y							X										X													
Basic overhaul RCP40	8c				X																X										
Basic overhaul RCP40 motor	8y				X																X										
Insp./NDT pressurizer/surgeline	5y				X								X								X								X		
Containment leak rate test	4y	X			X							X						X						X							X
Drained loop lines		X	X	X	X			X					X			X					X			X					X		
Work on primary isolation valves	8y	30/41	20/42	10									30/40			10/20								30/40					10/20		
Time critical work	X																														
Planned outage duration (d)		22,3	17	15,3	30,5	7,3	7,2	13,5	6,5	7,5	6,5	9	24	6,5	7,5	15	6,5	10	6,5	7,5	24	6,5	7,5	17	6,5	7,5	6,5	7,5	20	6,5	9

[4] Appendix VI remains unedited.

Appendix VII[5]

KRŠKO NUCLEAR POWER PLANT OUTAGE PREPARATION MILESTONES



[5] Appendix VII remains unedited.

KRŠKO NUCLEAR POWER PLANT OUTAGE PREPARATION MILESTONES (cont.)

NEK Department	Start Milestone	Finish Milestone	Milestone
TECH.OP.+ENGINEERING		02DEC05*	ALL OL22-ON LINE CYCLE ACTIVITIES IDENTIFIED
PLAN.&SCHEDUL. DEP.		23DEC05*	CYCLE 22 PRE-OUTAGE PLAN ISSUED
ENG. ANALYS.&LICENC.		05JAN06*	RE06 FINAL PLAN SHUTDOWN SAFETY ASSESMENT PREPARED
ENG. ANALYS.&LICENC.		08JAN06*	RE06 ALL REGULATORY REQUIREMENS IDENTIFIED-KNOWN
ENG. ANALYS.&LICENC.		09JAN06*	OL22 ON-LINE CYCLE SAFETY ASSESMENT PERFORMED
OUTAGE MANAGEMENT		09JAN06*	RE06 OUTAGE REV.0 PLAN APPROVED
TECH.OP.+ENGINEERING	09JAN06*	31MAR06	RE05 OUTAGE DETAILED PLANING AND RESOURCE SCHEDULING
TECHNICAL OPERATION		12JAN06*	OL22 ON-LINE CYCLE PLAN APPROVED
PLAN.&SCHEDUL. DEP.		13JAN06*	OL22 ON-LINE CYCLE SYSTEM WINDOWS IN WORK ORDER DATABASE
TECH.OP.+ENGINEERING	16JAN06*	06FEB06	RE06 OUTAGE WORK RECONCILIATION MEETINGS
PRODUCTION DEPARTM.	01FEB06	17MAR06	RE06 WORK PACKAGES EQUIPMENT CLEARANCES DEVELOPMENT
PLAN.&SCHEDUL. DEP.		03FEB06*	RE06 OUTAGE INFORMATION HANDBOOK ISSUED
ENG. FUEL DEPARTMENT	01MAR06*		NUCLEAR FUEL ON SITE
TECH.OP.+ENGINEERING		03MAR06*	RE06 ALL OUTAGE MATERIALS FOR WORK ON SITE
RADIATION PROT. DEP.		03MAR06*	RE06 ALL RADIOLOGICAL WORK PERMITS ISSUED
PRODUCTION DEPARTM.		03MAR06*	RE06 PLAN FINAL SAFETY REVIEW PERFORMED AND APPROVED
RADIATION PROT. DEP.		03MAR06*	RE06 ALL "ALARA" PLANNING PERFORMED
TECH.OP.+ENGINEERING		03MAR06*	RE06 OUTAGE CONTRACT SERVICES VERIFIED
ENGINEERING		03MAR06	RE06 ALL MATERIALS FOR MODIFICATIONS ON SITE AND STAGED
PLAN.&SCHEDUL. DEP.		24MAR06*	RE06 ISSUE FINAL OUTAGE SCHEDULE
OUTAGE MANAGEMENT		07APR06*	RE06 START
TECH.OP.+ENGINEERING	10MAY06*		OL22 ON-LINE CYCLE START

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Increasingly competitive energy markets have significant implications for nuclear power plant operations, including the need for the more efficient use of resources and effective management of plant activities such as on-line maintenance and outages. Outage management is a key factor for safe, reliable and economic plant performance and involves consideration of many aspects, before and during the outage. The aim of this report is to identify good practices and to communicate these in such a manner that they can be used by operating organizations and regulatory bodies.

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