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Nuclear power plant outage optimisation strategy

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FOREWORD

The competitive environment for electricity generation has significant implications for nuclear power plant operations, including among others the need of efficient use of resources, effective management of plant activities such as on-line maintenance and outages.

Nuclear power plant outage management is a key factor for good, safe and economic nuclear power plant performance which involves many aspects: plant policy, co-ordination of available resources, nuclear safety, regulatory and technical requirements and, all activities and work hazards, before and during the outage.

This technical publication aims to communicate these practices in a way they can be used by operators and utilities in the Member States of the IAEA. It intends to give guidance to outage managers, operating staff and to the local industry on planning aspects, as well as examples and strategies experienced from current plants in operation on the optimization of outage period.

This report discusses the plant outage strategy and how this strategy is actually implemented. The main areas identified as most important for outage optimization by the utilities and government organizations participating in this report are: organization and management; outage planning and preparation, outage execution, safety outage review, and counter measures to avoid extension of outages and to easier the work in forced outages.

This report was based on discussions and findings by the authors of the annexes and the participants of an Advisory Group Meeting on Determinant Causes for Reducing Outage Duration held in June 1999 in Vienna. The report presents the consensus of these experts regarding best common or individual good practices that can be used at nuclear power plants with the aim to optimize.

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CONTENTS

1. INTRODUCTION

The present generation of operating nuclear power plants (NPPs) have reached a high level of reliability and confidence in their safe performance. Under the current market conditions, it is important to assure that they are also competitive in all aspects, i.e. with respect to high availability, environment preservation and costs.

One of the factors, which directly influences availability and costs is the outage duration and resources used. Plant outages are shutdowns in which activities are carried out between disconnection and connection of the unit to the electrical grid. Therefore, outage is the period where significant resources are expended at the plant, while replacement power must be purchased to meet the utility's supply obligations.

Outage management is a complex task which involves in respect of the plant policy, the co-ordination of available resources, safety, regulatory and technical requirements and, all activities and work before and during the outage.

Each plant/utility develops its strategy for short term, middle term and long term outage planning. Extensive efforts are usually directed towards detailed and comprehensive preplanning to minimize outages, avoid outage extensions, ensure future safe and reliable plant operation and minimize personnel radiation exposures. All these elements are part of the plant outage strategy. Nevertheless, how the plant strategy is implemented is a key to the success of optimization of outage period.

Planning and preparation are important phases in the optimization of the outage duration which should ensure safe, timely and successful execution of all activities in the outage. The post outage review will provide important feedback for the optimization of the next outage planning, preparation and execution.

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

Although, most of the main components of a nuclear power plant are designed for plant lifetime operation, some equipment might need to be updated or exchanged in a plant operating for as long as 40 or 60 years. Refurbishment programmes are being planned as far as applicable as long term activities and in accordance with cost benefit analyses and their importance to safety and availability. It is a key factor for outage optimization to coordinate refurbishment programme and long term outage planning.

This TECDOC outlines some aspects and main issues to consider when optimizing outage duration. It also gives guidance to outage managers, operating staff and to the local industry. Planning aspects, as well as, examples and strategies experienced from current plants in operation, enables better understanding and performances of the necessary measures.

As a follow-up to a series of technical publications related to good practices for outage management and cost effective maintenance published in 1989 [1], 1991 [2] and 1997 [3], the IAEA has produced a more focused technical report on good practices for optimizing safe outage which aims mainly to identify good practices in short term aspects of outage management: outage planning and preparation, outage execution and post-outage review. As in the previous reports, this report contains seven sections. This introduction contains preliminary remarks. Section 2 presents issues to consider in the strategy for outage optimization. Section 3 presents identified good practices on 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 in the process of optimising outages. Section 6 presents causes and countermeasures to avoid extension of outage duration, and Section 7 presents fundamentals for forced outage management.

2. OUTAGE OPTIMIZATION STRATEGY

The plant management, in general, should establish clear and long term goals and programmes for all main plant activities. The key issues for outage optimisation strategy are as follows:

- Nuclear safety supported by a good safety culture,
- Continuous improvement management policy,
- Optimisation of maintenance and inspection programmes,
- Personnel policy of the plant supporting effective performance,
- Outage experience feedback system,
- Economics.

Nuclear safety

Safety measures should be prepared and implemented through the entire operating lifetime of the plant and for all conditions (operation, off normal and accident). The outage period should be considered as part of operation, because certain functional systems fulfil their specific duty under these conditions, such as cooling the fuel and preventing radioactive release to the environment.

When optimising outage duration and costs, nuclear safety should not be challenged and if possible improved. The safety configuration should be considered during outage planning and preparation, and monitored during execution of outage.

Safety culture should be fostered to always support plant personnel in setting up first safety.

Management policy

The plant management strategy should provide means for continuing improvements, including long, medium and short term planning, ownership, good engineering, workmanship culture and keeping the plant in good condition.

A refurbishment programme should be available as a long term activity. Refurbishment programmes should take into account safety and environment improvements, plant lifetime extension and outage optimization. Execution of refurbishment activities should be planned in such way that they have a minimum effect on the outage duration.

Maintenance and inspection

An efficient computerized work control system is a key tool for managing and shortening the outage duration. Maintenance and inspection strategy should include on-line maintenance policy, advanced equipment monitoring philosophy, design improvements to optimise outage duration and programmes for interchange of components and equipment during outage.

Maintenance and risk-oriented inspection programmes should be optimised based on experience, condition monitoring and reliability centred maintenance.

Personnel policy

Personnel policy strategy should aim to support an effective outage performance. Important issues to consider are training of own staff and contractors, incentive programmes fostering safety culture, and long term partnership contracts with contractors.

Outage experience feedback

The outage experience feedback system should include review of own outage performance and evaluation of outage experience feedback from other plants. Benchmarking is a helpful tool for optimising outage performance.

Economics

An economic study should be performed to choose the optimal positioning and length of the various types of outage based on electricity market situation, available resources, plant design, and requirements of safety authorities.

Systems for budgeting and cost follow up should be used to control the outage cost.

3. IMPLEMENTATION OF OUTAGE OPTIMIZATION STRATEGY

The plant outage strategy has to be carefully implemented to enable the development of a comprehensive and effective work programme, to minimize outage duration in connection with the improvements in safety, quality and costs. This section discusses the five main aspects to consider when implementing plant outage strategy: (1) Nuclear safety (2) Organization and management, (3) Planning and preparation, (4) Execution and (5) Post outage review.

3.1. Nuclear safety

The outage period should be considered as part of plant operation, therefore the operability of needed systems and functions should be assured and planned. Tools for monitoring the configuration of the plant should be implemented. Outage probabilistic safety analysis (PSA) is a good tool to overview the overall safety level during different outage phases. Other tools are risk monitors, schematics over actual planned operational status, and shutdown safety check lists.

A safety culture should be developed within the plant staff. Every employee should be sensible to identify problems and deviations from the normal plant conditions during outage. A good reporting system should be implemented to improve the safety culture and enable problems, failures and near miss events to be prompted and adequately reported. Resources should be allocated to take actions to solve reported issues.

The regulatory environment is subject to changes and leads to more and stringent requirements. To enable the plant operator updating safety related systems that are based on extended requirements, the license owner has to act in a pro-active way and get the agreement of the respective authorities for the updating process.

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

3.2. Organization and management

The plant strategy should create mechanisms to enable all plant management levels to be involved in the outage planning, preparation, execution and review. Responsibilities within the organization should be clearly defined. Management expectations should be well communicated to the staff. Objectives and goals should also be clearly established and communicated.

Organizational and management principles applied in outage management should be based more on process and quality management procedures than on those procedures applied in multi-layer hierarchical organizations. Good examples of implemented processes are shown on annexes (see Annex F).

Self assessment processes on plant level as well as on individual level should be enhanced and a questioning attitude fostered to make organization sensitive in a proactive way to forsee disturbances and avoid extensions.

Cross-functional expertise is necessary to take responsibility for equipment as well as for maintenance, control, scheduling and engineering that have direct influence on plant performance.

Extensive training and retraining programme should be implemented to keep plant and contractor staff motivated and up to the latest state of the art of the plant technology during outage. The operating and maintenance personnel should be ready to react correctly in case of malfunctions, incidents or accidents that could occur at any time.

A job rotation programme inside the owner's organization should be considered. A comprehensive knowledge of the complete plant eases the understanding and communication especially at interfaces.

Outage organization

Different outage organization depending on the plant infrastructure, organization culture and other factors have been implemented by the operators and utilities. Many plants do not change their organization during outage, the same individuals are in charge of on-line maintenance and outage. Others have a separate but temporary outage team or a permanent outage structure. Each plant chooses the organization that will give the best results with respect to the organization culture.

The need of coordinating the efforts with all players has led to radical changes in the method of outage organization for some utilities. There are two predominant outage organizations: (1) permanent outage structure and (2) outage project team. The organization that has been most efficient, so far, is the outage project team which comprised of staff from the different plant departments, e.g. maintenance, operations and engineering.

An outage project team co-ordinates the outage planning and execution and brings together all the personnel involved in the outage, which report to a decision making unit headed by the plant manager. In particular, the team includes a co-ordinator for each major function and/or equipment that is under maintenance, test or inspection during outage. The co-ordinator makes the bridge between the operations and maintenance departments and the outage project team.

The outage planners and co-ordinators should take ownership of the identified problems to ensure by proper counter measures and optimum management efforts to identify and solve the problem in the shortest time possible. Maintenance department designates the staff responsible for component maintenance. The designated engineer (called component engineer) tracks the components performance, prepares and reviews maintenance programmes taking into account operating experience, and plans the components maintenance.

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

Contractors

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

The incorporation of external contractors needs a specific workload breakdown with identification of interfaces and responsibilities. Nevertheless, the utility project outage team encompasses the overall preparation, planning, management, contracting, financing as well as all technical features.

As the contractors are normally coming from, and used 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 interest of long term contract arrangements with experienced service companies or with the main plant supplier should be assessed. Utilities should choose between the development of their own capabilities for outage work and/or arranging support from external companies to improve their outage performance.

Different outsourcing approaches may be utilized for the maintenance, modifications and/or refurbishment.

The type of outsourcing depends on various parameters including capability and experience of owner's staff. The choice in this matter is an important subject that has to be decided by the operator rather early. In general, the more the contract responsibilities are sub-divided, the higher would be the risk for good outage performance.

Usually it is a good practice to use long term contracts with partnership relations including deep ownership of the contractors for outage tasks. When establishing long term contracts it is important to preserve a competitive market situation. The use of local industry capability is also preferable and cost effective.

3.3. Outage planning and preparation

Outage planning involves many different issues such as co-ordination of available resources, scheduling, safety, regulatory and technical requirements and, all activities and work before and during the outage.

For each outage period a detailed plan for execution should be prepared well in advance, including all 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 efficient, safe and successful execution of outage plan, the planning of activities should further consider the local conditions inside the plant, radiation level, industrial safety, necessary outside support, and internal and external information media.

Increased use of on-line maintenance could significantly reduce the duration of the outage, when the design and the regulatory requirements enable such a procedure. On-line maintenance makes it possible to keep safety systems operable during outage and enables more effective maintenance and better utilisation of critical resources.

Reliability centred maintenance (RCM), Risk-informed inspection and testing have been identified as good tools for optimization of maintenance activities. Condition monitoring must also be used.

The in-service inspection programme is officially specified in the respective codes and should be performed on a long term basis. Good knowledge about potential degradation and ageing programme should support the development of effective inspection programmes, and accordingly maintenance programmes.

3.3.1. Range of planning

According to the plant strategy, outages are planned on long, medium and short term. These plans differ in time, level of details and scope of activities.

In the *long term planning*, the plant establishes the occurrence and duration of outages according to the fuel management, equipment ageing, need of major backfittings and refurbishment. The long term plan optimises plant availability to the grid, total outage duration and cost estimates. In order to optimize the different outages duration over longer time period heavy and time consuming work should be allocated to specific outages. It allows flexible planning and distribution of workload during a period varying from 5 to 10 years. It also includes preliminary cost and budget estimates in the frame of the expected scope of supplies and services. Annex E presents the long term plan used at TVO 1 and 2 NPP in Finland.

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

The *short term plan* is the detailed planning for the next outage. A good current practice is to start the short term planning for the next year outage 4 to 6 months before starting the current year outage. Another practice is to start detailed planning at the beginning of the new cycle.

In long and medium term planning, special attention should be paid to fuel cycle optimization. Most of the utilities regard a 12 month fuel cycle as economically optimum. Some utilities have lengthened the fuel cycle up to 18 or 24 months. The fuel cycle optimization depends on the electricity market situation.

These plans should be included in the plant budget and financial decision making process. Working with these different plans is the key to optimize the outages.

In the medium and long term planning, it has become a good practice to categorize the outages in three or four types with the objective to minimize the total outage time. The outages may be categorized into four different kinds:

- Refuelling only, which could be worked out in 7 to 10 days,
- Refuelling and standard maintenance, which could be worked out in 2 to 3 weeks,
- Refuelling and extended maintenance, which can last for one month,
- Specific outage for major backfittings or plant modernization which could take more than one month.

In case the utility operates several nuclear power plants, a reference outage is defined as a generic outage including common activities to all outages. The reference outage could be for instance, a refuelling and standard maintenance outage.

When planning using reference outage, special attention should be paid to activities not regularly included in its scope of work. These activities which have the potential to be on the critical path, could extend the length of the outages. An assessment of these activities should be made.

3.3.2. Detailed planning and preparation of outage

A certain number of activities should be considered and planned in sufficient advance to the outage. Each activity should be seriously assessed on its potential to extend the outage target and to prevent unplanned outage during power plant operation.

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

- Pre-outage milestones including planning, materials, schedule development, external services contracts, clearance preparation, ALARA reviews, design issues, regulatory issues, etc.,
- Outage duration for all 3 phases: shutdown, execution of work and startup,
- Final scope of work/activities,
- Outage schedule, including the main outage schedule and work and safety related schedules (separate schedules for systems, reactor, turbine, startup, etc.). Those schedules shall comply with the main outage schedule. For each activity in the critical path, a separate schedule is made.

— Work packages, including work orders and permits, instructions and procedures, materials, spare parts, consumables, human and material resources, special tools, post-maintenance testing and startup programmes, etc.

The working details should be described for the respective activity incorporating planning time, procurement, manufacturing, preparation of the plant, the expected workload, safety measures, necessary support and quality assurance programmes. The availability of the hardware in due time is as important as the preparation of the software including licensing documentation.

It is good practice to prepare clear schedules for systems in maintenance and for systems that have to be in operation or in standby mode. Another good practice is to manage a large amount of an effective daily workforce up to 1200 people.

3.3.3. Processes and tools for outage shortening

Current good practices for shortening outages during planning and preparation are:

— Work scope predictable up to 95% and about 5–10% added work,
— General proactive planning attitude: anticipating unexpected problems which could impact nuclear safety, schedule and costs (see RASP in Annex G),
— Early execution of planned inspection of system and components to help avoiding outage extension,
— Proper and adequate re-scheduling of activities assessing nuclear safety and other risks,
— Revision of frequency of inspections based on experience,
— Streamlining activities without influencing safety,
— Integration of unit startup tests,
— Freeze outage scope three to ten months before the outage start date,
— Reduction of exposure by planning efficient decontamination processes and use of mock-ups while in compliance with ALARA,
— Utilization of computerized tools and robotics,
— Usage of modern scheduling and engineering tools, e.g. CAD, Primavera, OPX2 or similar software,
— Improved co-ordination between outage and operations team,
— Usage of international and own experience,
— Benchmarking with other similar plants to optimize outage activities and scheduled time,
— Qualification and training of contractors on safety culture and work procedures,
— Involvement of the contractors from the early steps of outage preparation,
— Identification of critical work areas from the scheduling point of view,
— Preparation of site locations, workshops and offices for contractors,
— Actions to prevent short comings of materials and human resources,
— Walk-downs of preparation team (coordinators, system engineers, contractors including foremen) to the working place to overview equipment and discuss requirements for outage activities.

Some design modifications could also be carried out to minimise outage time depending on the reactor type, such as:

- Modifications on refuelling machine,
- Fuel leak detection by mast sipping,
- Support bridge at refuelling floor,
- Easily removable insulation,
- Local cranes,
- Permanent working platforms,
- Special turbine rotor cooling system allowing earlier start of turbine work,
- Hydraulic turbine bolting and turbine inspection holes,
- Inspection devices enabling inspection without dismantling components,
- Support water storage for efficient water handling during outages.

3.3.4. Mobilisation of human, material and equipment resources

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

- Optimizing the mobilization of human and material resources,
- Signing all contracts according to the outage preparation schedule and in good time, before outage start,
- Planning and training in-house and outside human resources in advance,
- Implementing incentive programmes for staff focusing on outage performance, e.g. incentives for outage schedule, quality, cost and safety,
- Identifying shared resources and possible joint ventures in case of major backfittings,
- Checking for and reserving, material, spare parts and consumables available on site, at least 2 or 4 months before the outage start,
- Sharing human and material (cranes, hoist, special tools, etc.) resources in the utility and among utilities.

3.4. Outage execution

Objectives for good and efficient outage execution are, safe operation of the unit during outage, disturbance free operation of next cycle, execution of the outage according to schedule and budget, good industrial safety and low dose rate.

Planning the outage is the foundation of success for managing the outage execution in an optimal manner. It is of importance that the same team responsible for outage planning will manage the execution. Detailed schedules for preparation and execution should be developed and frequently updated.

The outage project team can be built from operating and maintenance staff. In case the utility operates several units, a separate engineering group acts for outage preparation and execution. In such a structure the interface between the operating personnel, maintenance and repair groups with the outage staff has to be carefully organized.

Prefabrication of parts of modifications, control and assembly of tools, training of personnel including motivation aspects, job training, acceptance of spare parts and materials should be prepared in good time before the outage start. Most of the radioactive and other waste from a nuclear unit are produced during outage. Measures should be planned and executed to minimize the waste volume. A good practice is to establish standardized environmental system such as ISO 14001.

The next sub-sections outline good practices or measures in the areas of co-ordination and communication, work control management, and radiation and industrial safety.

3.4.1. Co-ordination and communication

Co-ordination

The co-ordination between the outage participants, operations, electrical, instrumentation and control (I&C), mechanical, health physics, contractors and the respective execution and commissioning staff is the fundamental precondition for successful execution of work (See Annex F, Figure F.2).

Formal daily meetings are organized to keep the staff actually informed on the status of the plant. These meetings must be attended by the plant management and the key personnel and should be short. In the daily meetings, problems should be identified and delegated to the responsible team leader.

A clear delegation of responsibility has to be established and documented by the top management of the plant. The role and duties of the Regulatory Body should be clear and well understood by all people involved in the outage.

One of the most important tools to communicate and resolve daily problems is the Daily Co-ordination Meeting supervised by the outage manager. In order to get the right focus on the daily co-ordination meeting the important problems and concerns should be highlighted and the main workflow (95%) must be handled in the normal work control management. The main issues discussed in this meeting are:

- Work progress, delays and status of activities on the critical and sub-critical path,
- Updating the schedule for following days,
- Technical, administrative and environmental problems,
- Health physics.

Apart from the Daily Co-ordination Meeting, other meetings are also held to follow up the outage execution. Plant management meetings should be arranged at least once a week. In case of problems, ad hoc management and technical meetings should be arranged.

Communication

Staff involved in the outage should be well informed. Mechanisms to communicate status and progress of outage should be implemented. Modern electronic media should ease the communication inside the plant and with the headquarters. Short bulletins or reports distributed to the personnel familiarises the entire staff and enables rather early countermeasures. Special dispositions, such as daily meetings could be adopted to improve relation between operation and maintenance personnel. Walk-downs by the outage and plant management to follow up plant status are good means of communicating management expectations and monitoring the situation in the plant.

It is good practice to inform the contractors about the outage progress. It is also important to co-ordinate their work sites and get their feedback on the work schedule.

The flow of information from and between the various activity centres should avoid conflicts in the process and acts as a management tool with clear delegation of responsibility and assignment of work.

It is important to create mechanisms to promote safety culture, foreign material exclusion and high level house keeping to all personnel involved in outage execution. The distribution of daily reports to all outage participants is another good practice.

Means of communications could be outage progress reports disseminated through newsletters, Intranet, video systems etc. Some utilities have used wall posters to motivate outage staff and communicate outage progress.

Another good practice is to prepare and distribute an outage information handbook with all needed information including: outage plan summary with critical path, objectives, goals, telephone directory, security, emergency signals used, meeting reports, parking lots, restaurants, etc.

3.4.2. Work control management

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

Supporting the control room to handle work permits is needed during outage execution due to the large work volume. A special team, built up with staff from the Operation and Maintenance departments, should schedule, prepare and perform an important amount of tag-in, tag-out and line-up (more than 400 per day at the beginning of the outage). Such a good practice could be also used for tests before startup (see Annex F).

The different activities during the outage are specified in the form of approved work permit and work orders which need clearance before the work can be started. The handling of work control procedures allow to control the entire outage work programme. A good practice is to assign an operation co-ordinator and more work permit assistants than is usually required during operation.

The responsibility for clearance and signing of the protocol after finishing the work including functional tests should be clearly delegated to the qualified and experienced plant staff. The work control process is an excellent tool for receiving a clear picture of the status of the plant, especially when the maintenance, tests or inspections have been performed by contractors. Within that process, deficiencies or further actions needed could be introduced in the working programme.

It is a good practice to have an adequate computerised information system including:

- Work order and permit administration,
- Project planing,
- Material and spare parts management,
- Plant technical data,
- Plant operation and maintenance history,

- Radiation dose control,
- Personal database,
- Account control.

The use of a computerized database enables better handling of the complete work programme and allows fast access to the whole documentation. A cost control by activity and for the complete outage can be integrated into the data bank. Such a system has the further advantage to store essential information to be used in the next outage.

3.4.3. Radiation and industrial safety

Good house keeping, clean environment of the working places and low dose rates are important requirements for safe, efficient and in-time maintenance which enable optimization of outage duration.

During outage execution, radiation safety is one of the most important aspects. The ALARA principle should be applied in outage planning, preparation and execution.

Daily radiation monitoring and electronic dosimeters help to assure that dose limits will not be exceeded. It also helps to decide if additional provisions for cleaning, decontamination and installation of temporary ventilation and filtration are required. Provisions such as removable shielding or special decontamination processes should be selected and qualified already during the planning phase.

Collective dose rates received by plant staff and contractors personnel during plant operation and maintenance periods should be controlled, recorded with great care and followed up during the outages.

Industrial safety requirements recall many provisions during the outage. Some of them are part of work scope and their fulfilment depends on workers attitudes. Individual workers 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 can be established to monitor the personnel performance and quickly identify potential problems.

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 provide feedback to further optimise the next outages.

The post outage review should consider:

- Achievement of objectives, goals and budget,
- Technical status of the unit after the outage,
- Evaluation of a list of problems and contingencies,
- Events occurred during outage and on the first period of operation after outage,

- Complete analysis of outage execution performance indicators, such as effective use of working time, waiting hours, availability of support, volume of radioactive and other waste, collective dose, industrial accident, etc.,
- Evaluation of contractors performance,
- Identification of possibilities to shorter work processes,
- Identification of technical or administrative measures enabling an earlier plant restart,
- Analysis of shutdown and startup procedures,
- Analysis of working procedures, organizations and safety culture attitude,
- Transfer of outage experience feedback to other units,
- Other suggestions and recommendations for the next outage.

Following outage analysis, action plans should recommend solutions such as:

- Elimination of unnecessary activities by reduction of component maintenance and inspections,
- Alternatives for shutdown and startup procedures.

Special attention should be given to causes leading to outage extensions such as delays of material deliveries including documentation testing, commissioning and restart problems. To prevent such delays during the next outages, countermeasures could be initiated for continuous update of the time schedule assisting the management in earlier identification of delays. Section 6 discusses causes and countermeasures for outage extension.

A review report should be prepared including a summary on above mentioned aspects from which lessons can be learned and applied in the next outage.

A good practice is to have the full outage report ready latest one or two months after the outage to provide feedback in time to improve the next outage. Another good practice is to arrange a meeting with the main players in the outage to discuss their experience and improvements.

4. OUTAGE SAFETY REVIEW

The outage preparation and execution process should contain outage safety reviews in different organisational levels and of different independent levels.

Outage safety reviews should apply to the whole process: outage planning, preparation and execution, including the entire work scope, test and inspection programmes, shutdown and start up activities. The reviews should identify and take into consideration possible risks. The reviews should be conducted by an internal independent part of the outage organisation reporting directly to the plant management.

All arising safety related problems during 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 organisation, plant management should take the necessary decisions to implement issues coming from safety outage reviews.

Prescribed safety reviews in the regulatory environment should be incorporated in the planning of the outage and planned in a timely manner which enables results from such reviews to be incorporated in the preparation and execution phases with as little as possible disturbance.

The safety reviews should be done in a proactive way to identify safety concerns in an early stage of preparation. In that way, the reviews contribute to a higher awareness of reactor safety concerns throughout the whole outage preparation and execution.

5. ECONOMICS

Plant design, resources, safety requirements and electricity market conditions should be considered in the economic study performed to choose the optimal length and positioning of the various outages.

Respective technical analysis and financial provisions should be organized in due time and would constitute the basis for the realization of all proposed updating and maintenance measures during plant life. Decisions on the financial provisions should be taken by the plant management or the board of the utility. One main goal in the decision making process should be the optimization of plant availability and outage duration.

Long term budget planning and financing provisions and the budget for short term outages should be held sufficiently flexible to enable the plant management optimizing the outage.

Early cost estimates are essential for a successful optimisation of outage. Cost estimates should take into account all needed internal and external expenditures, and financing. All different parties should be considered in the cost estimates, e.g. contractors, spare parts, materials, own staff salary, and other running costs. A good practice is to follow up the cost on a daily basis and to predict the final cost.

Improving the overall economics of a nuclear power plant requires a comprehensive understanding of the relationship between O&M spending and the performance of the plant. It should be recognized that there is a real cost associated with poor performance (lost opportunity for receiving revenues, higher than necessary cost to generate, etc.) as well as the corrective maintenance cost associated with repairing equipment. In addition, there is a mutual interaction between O&M spending and the performance of the plant. Too little pro-active (preventative) O&M spending results in a high frequency of unplanned breakdowns with high corrective maintenance cost and high cost associated with unavailability. The practice of too much O&M spending can put the plant past the point of diminishing returns.

The goal, therefore, is not to minimize O&M cost or to maximize performance (availability, etc.) but rather to minimize the total cost by optimising the O&M cost. In order to achieve this potential improvement, however, individual day-to-day decision making should be enhanced (bottom-up). Typical improvement methodology consists of three basic steps:

- Identification: identifying all potential improvement options to address plant problem areas,
- Evaluation: the economic justification and prioritisation of options identified,
- Implementation: the choosing of the economic optional option and the comparison of expected to actual results.

By following this type of process the best use of the plant's limited resources (money, time, manpower) will allow the plant to optimize its cost and performance.

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

6. EXTENSION OF OUTAGE

Outage extension is the increase of outage duration beyond the planned time if this happens after the outage plan is frozen. It is a negative effect that should be avoided because it causes unplanned energy loss, requires additional manpower, increases outage cost and may result in the production of additional radioactive waste and increase the collective dose exposure.

Generally, if the outage is planned and managed accordingly, the extension of the outage may be initiated by a reason that has been discovered during the outage. With the increase of NPP operating experience, the risk of outage extensions could be reduced. However, it may be recognized that while optimization of planned outage duration is desirable, making the planned outage shorter may increase the probability of the outage extension due to minimization of margin for resolving unexpected problems in given time.

To handle these unexpected events, the plant management should make efforts from the very beginning in the outage planning phase to predict and prevent outage extensions by using proactive engineering approach, questioning attitude, proper motivation and operating experience feedback programme results. The most frequent causes and their counter measures to avoid outage extension are listed in section 6.1 and 6.2. These causes should be used in the plants self-assessment process to assess the probability that similar causes can occur.

6.1. Causes for outage extensions

The following are some of the causes of outage extension commonly encountered:

(1) Non identified system or equipment or component deficiency
- lack of condition monitoring and trending
- equipment or component failure during outage execution
- ISI programme and tests results

(2) Quality of work performed
- lack of quality consciousness and procedure usage
- poor quality of material
- lack of mock up structures
- lack of skilled or trained manpower
- improper work execution control
- casual attitude to work execution resulting in waste of working time
- improper implementation of Foreign Material Exclusion (FME) programme

(3) Deficient outage management
- lack of leadership and control over the plan activities
- lack of motivation
- lack of budget

- late order of equipment, material and spares
- insufficient cooperation among the parties
- deficiencies in interdisciplinary communication
- quality control deficiencies

(4) Regulatory impacts
- last moment regulatory requirements added
- misinterpretation of regulatory requirements

(5) Failure of inspection or special maintenance tools (lack of preventive maintenance of special tools)

(6) Inadequate spare parts or lack of spare parts

(7) Inadequate vendor support
- lack of technical support and unreliable sub-contractors
- lack of equipment or material supply or late delivery

(8) Deficient outage planning
- under estimation of activity duration or work force
- improper scheduling of work activities
- support activities (scaffolding, etc.), tools, materials not clearly defined
- plant status prerequisites, work permits and approvals not clearly defined
- Operational Experience Feedback (OEF) programme results were not taken into account or OEF actions were not adequately implemented while planning re-occurring outage activities.

6.2. Countermeasures to avoid outage extension

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

(1) Improve condition monitoring by:
- reviewing and revising the condition monitoring, trending and preventive maintenance programmes using industrial experience
- conducting ISI programme on critical components in the initial phase of outage.

(2) Improve work quality through:
- development of quality consciousness among the employees and put quality check/hold points in the maintenance procedures
- pre-qualification of the spares and supplies
- development of mock-up facilities based on the industrial experiences
- training/re-training of the manpower to be deployed
- strict control of work execution to avoid extension;
- early warnings on critical items or milestones
- analysing time spent on work to increase effectiveness
- applying proper workers motivation such as incentives and awards
- development of the FME programme based on the latest industrial experience.

(3) Improve outage management by:
- implementing management and project management development programmes to strengthening the leadership and control of outage activities
- establishing clear goals, responsibilities and ownership
- implementing self-assessment processes on plant and individual level
- prioritising activities according to their sensitivity and selectivity

- strengthening safety awareness and culture
- conducting organizational development programmes with cohesive approach and motivation
- promoting a "do it right the first time" approach
- anticipating of budgetary requirements and ensuring allocation of the same
- preparation of well documented quality assurance (QA) and quality control (QC) programme for the outage activities with the help of QA/QC group
- listing and ordering spare parts to assure their availability at warehouse well in time based on the past experiences
- interdisciplinary communication on critical subjects, support, approvals, tools, etc.
- using of fixed teams of very experienced specialists for critical jobs (integrity checking, etc.)

(4) Anticipate regulatory requirements based on in-house and industrial experiences

(5) Ensure reliable inspection and maintenance tools through:
- pre-qualification of special inspection and maintenance tools
- redundancy of special tools

(6) Spare Part Policy
- QC of received material well in advance
- spare part storage control system
- partnership with vendors
- joining a pool for common spare parts or inventory management

(7) Deploy reliable and experienced contractor or subcontractors by:
- seeking international nuclear industry help through international networks
- establishing long term partnership
- providing timely and clear purchase orders, signing the contracts and controlling the process development

(8) Improve outage planning based on in-house and industrial feedback by:
- setting-up clear goals
- defining outage milestones and freeze dates for different phases of outage
- proactive planning and scheduling, i.e. predicting and considering possible problems and planning in advance the time for corrective actions
- considering OEF programme and plant history files during the planning phase.

The list of causes and countermeasures could be used for self-assessment of plants own performance and in that way identify areas for improvement in optimising outages.

7. FORCED OUTAGES

When a plant experiences a forced outage shutdown or 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 people to rush and get the plant back on line. Management should insist on the same requirements of safety, quality and schedule as during planned outages. Management should ensure enough time to analyse shutdown causes and to develop a strategy to work out the unplanned outage, including planning, preparation and safety evaluation.

It is a good practice to carry out a list of prepared maintenance tasks to be performed in the event of unplanned shutdown. This list should include instructions, work orders, work permits, need of spare parts, special tools, materials, human resources, etc.

The fundamental principles of rigorous schedule reviews to assure safety system availability still apply. In most cases the list of maintenance to be performed in a forced shutdown is easily managed and not complex.

Most of the issues and good practices outlined in this report, especially those for outage execution, could be applied in case of forced or unplanned outages.

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Annex A
LONG TERM PLAN USED AT TVO 1 AND 2, FINLAND

1. INTRODUCTION

Teollisuuden Voima Oy (TVO) operates two almost identical BWR units on the Olkiluoto island on the west coast of Finland. The net electrical output of each unit is 840 MW. Consequently, these units have been named Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2). The units have been designed and delivered by the Swedish company ABB Atom.

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 1980's, reaching 90 percent. The average load factor of the past ten years (1988–1997) for both units has been about 93 percent. The unplanned energy unavailability is typically less than 2 %. Refueling outages are carried out in the spring when there is a lot of hydropower available in Finland.

TVO has made good results in realizing short and effective annual outages. A prerequisite for short outages without risking the nuclear safety is the plant design itself. The Olkiluoto units have safety systems with 4 x 50 per cent 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 preparations needed before unloading can be commenced.

The subjects of outage safety planning are criticality safety, residual heat removal and preserving 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 for large bottom leakages. Separate time schedules are provided for co-ordination of the work with respect to these three safety aspects.

To reach a high level of safety, it is essential that the personnel taking part in the maintenance activities is motivated, well trained and familiar with the plant design and relevant procedures. The paper deals with the education and preparatory training of TVO´s and subcontractors´ outage personnel.

2. OVERALL OUTAGE MANAGEMENT STRATEGY

The main objectives of outage management of TVO are as follows:

- Restoring plant quality and performance,
- Ensuring shutdown safety,
- Improving future performance,
- Implementing plant modifications,
- Minimizing conventional and radiological hazards,
- Minimizing waste generation,
- Minimizing outage scope,
- Optimizing outage duration.

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

The Technical Specifications (Tech. Spec.) can be seen as a set of operational safety rules and criteria, which defines the allowed operational range from the safety point of view. The content of the Tech. Spec. for Olkiluoto 1 and 2 was changed in 1986, when a separate chapter "Conditions and limitations for cold shutdown and refueling outage" was written.

If exemptions from the rules given in the Tech. Spec. 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 guide YVL 1.13 (regulatory guide for nuclear power plant outages), the utility has to submit for approval or information large number of documents to the Regulatory body (The Radiation and Nuclear Safety Authority, STUK) well in advance of the outage. During the outage, there are up to 10 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.

2.1. Plant operational states and outage types

There are two basic types of planned outages for Olkiluoto nuclear power plants: the refueling outage and the service outage. The refueling outage mainly consists of refueling, corrective maintenance, periodical inspections and tests required by the Technical Specifications and maintenance according to the preventive maintenance programme for annually overhauled components. Typical duration is 9 days for Olkiluoto BWRs. The service outage can be either normal or extensive and includes in addition to the refueling work all major plant modifications or upgradings. The service outage duration varies between 14 days (normal, including the opening of turbine) to 20 to 30 days (extensive, including major modifications) for Olkiluoto BWRs. An example of the refueling and maintenance outages is shown in Figure A.1.

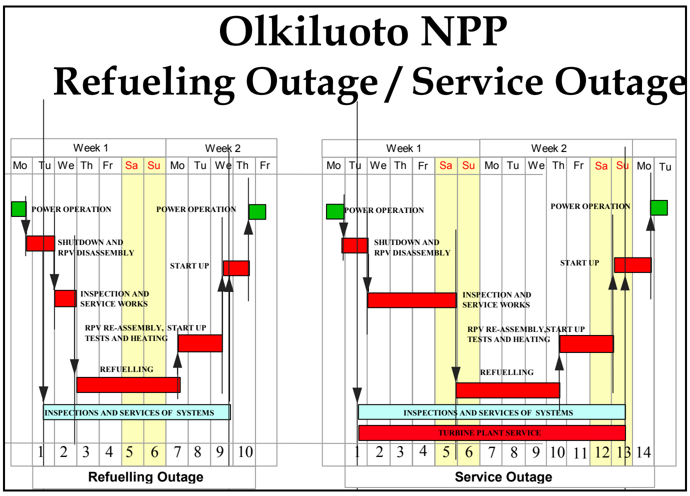

FIG. A.1. Olkiluoto nuclear power plant refueling/service outages.

As an operational state, a refueling outage is characterized by an interlocking of control rod manoeuvring, 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 reactor protection system is switched to the neutral O-position no control rod withdrawal is possible. The switch can also be set in B-position which is used during refueling. In this case withdrawal of individual control rods or entire scram groups is permitted in conjunction with tests and rod drive service.

When the mode switch is in either of positions 0 or B, the operating mode may be identified as "shutdown". The shutdown mode may be divided into hot shutdown, cold shutdown or reloading

Plant shutdown — as compared with 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 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 refueling but may also be required to permit certain maintenance which cannot be performed when the reactor is hot and pressurized.

The refueling 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 refueling shutdown takes place when the reactor lid bolts are loosened.

In the refueling stage the mode switch is set in the B position as explained above.

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, good condition monitoring and detailed maintenance planning are needed. Good trend supervision and detection of failures at 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 (termography, oil analysis, motor operated valve testing etc.) are essential in determining the condition of the power plant units.

Today, 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 right objects.

The proportion of corrective maintenance has been less than 10 percent of the total annual maintenance man-hours. Preventive maintenance and inspections make about 60 percent and modifications and improvements about 30 percent (during the past few years this percentage has been higher because of the modernization project)

The Olkiluoto BWR units are equipped with fourfold safety systems, and some preventive maintenance in safety systems can be done during operation. For example, preventive maintenance of the emergency diesel generators, containment spray system, auxiliary feedwater system and 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 with a proper spare parts policy and detailed risk studies. All critical items to be inspected are analyzed 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 done 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, emergency diesel engine etc. has increased over the years. During the outage components are replaced and they are serviced after the outage in workshop conditions.

2.3. Refueling programme and strategy

Olkiluoto NPP units are operating with twelve months fuel cycles and about one fourth of the fuel is replaced during every outage.

According to the standard schedule, fuel design and optimization work starts rather early, about 2 years before bundle fabrication. Usually the lead time before loading the fuel into the reactor is 3 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 needed cycle length at full power, followed by the 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 7 years.

The purpose of the refueling 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 refueling includes a total of 600–700 fuel assembly transfer operations in a typical quarter reload case. This consists of the following parts: 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 sufflings inside the core; reloading the temporarily removed fuel assemblies and loading about 130 fresh fuel assemblies.

Factors that help in minimizing the time needed for refueling operations are careful optimization with a special computer programme, a semi-automatic refueling platform and constant careful supervision of all refueling operations.

2.4. Outage scheduling

Planning of outages is done on 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 put on the careful study of the critical path activities (see Figure A.2).
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.

The planning period of the next outage is one year. The holdpoints (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 can be done. 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 made according to the planning schedule. The main time schedule specifies the critical path of the outage. The amount of other schedules depends on the scope of outage works (reactor and turbine time schedules, schedules for bigger repair 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 and allowed 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 done during outages and by contractor personnel. The availability of competent resources is assured by the existence of certain "key persons" in TVO's staff and by having long term contracts with plant vendors and main service companies.

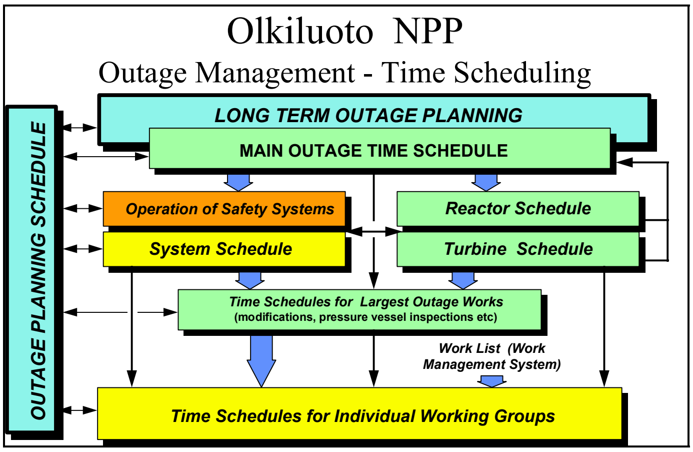

FIG. A.2. Outage management — Time scheduling.

Multi-cycle fixed price contracts are also used. About 1000 outside workers from about 100 different companies participate in the annual outages while the number of TVO's own outage personnel is around 300. Over 70 percent of the contractors' personnel have experience of previous outages.

The co-ordination of the planning and execution of outage work is always the responsibility of TVO, and it is done in a "partnership" arrangement with the main contractors.

2.5. Training

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

Maintenance personnel knowledge, training and qualification, and performance 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 nonstation maintenance personnel are equivalent to those of station 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 perform tasks independently.

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

2.6. Radiation safety considerations

Radiation protection training is intended to provide workers with the pre-requisites to work in the controlled area, and it also aims at contributing to the accomplishment of radiation protection objectives. The training is given to permanent and temporary workers working in the controlled area. Training provided for employees working in the controlled area includes applicable parts of radiation legislation, fundamentals of radiation and radiation risk, instructions for work in the controlled area and information on dose monitoring. The employees 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 means of correctly focusing the radiation protection. TVO uses digital RAD-80 and RAD-51 dosimeters. TL-dosimeters serve as the official personnel dosimeters. A dosimeter must always be worn by persons working in the controlled area.

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

- Name of employees,
- Radiation conditions in the working area,
- Requirements concerning measurement of dose rate, surface contamination and airborne activity,
- Exposure assessment and
- 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 workers.

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 people work in such a way that they are exposed to less radiation. At TVO, both are being done.

A project called DOSE has been started to decrease the concentration of cobalt-60 in the reactor water by all available means. The most effective way is to replace a material used to seal certain valves, stellite, with cobalt-free material. The replacement of valves containing stellite is in progress.

3. OUTAGE MANAGEMENT CONTROL

The TVO outage organization has the following characteristics: a full-time outage manager, an acting outage co-ordinator 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 is chaired by the plant manager and this group provides general supervision, approves outage times and programmes, and provides decisions for significant problems.

The long term outage group is chaired by the operations manager and it is involved in long term and middle term planning (3 to 20 years) including major overhauls and inspections, modifications/improvements, and the plant life time programme. They also follow-up and monitor outage performance indexes.

The outage planning group is chaired by the outage manager and it includes representatives from all organizations working with the next outage. It provides supervision of detailed planning, execution and reporting of outages.

The outage manager co-ordinates all activities concerning outage planning and execution and the acting co-ordinator (one of the shift supervisors) co-ordinates all activities that take place during the outage (work permit /plant safety planning etc.).

The safety office is located on site, as well as the technical support staff. About four months before outages, which are scheduled to take place in springtime, safety office reviews the outage schedules set up by outage co-ordinators 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 (RHR), emergency core cooling (ECCS) and electric power supply and important works vital to preserving of water inventory. The second one shows the availability of reactivity control systems. As a result of this review, the safety office prepares a memorandum on the residual heat removal capacities during outage and on the safety of the main jobs. This memorandum is also discussed in the On-site Safety Committee.

Outage plans and the execution of outage and all safety-related activities must be approved by the regulatory body. During the outages up to 10 inspectors from the regulatory body are at the site and available 24 hours per day if necessary.

3.1. Design modification control

The management of plant modifications has been described in the Operational Phase Quality Assurance Manual. YVL guides issued by the Regulatory Body (STUK) give requirements concerning planning and implementation of modifications. Safety related modifications are reviewed and approved by relevant authorities after internal approval by TVO. The YVL guides also specify the contents of documentation which has to be submitted for approval.

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

In connection with safety related system modifications or otherwise important modifications, reliability analysis (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's own personnel or by outside contractors.

Work planning activities (work permits and work orders etc.) are always made by TVO's personnel according to the plant procedures. All modification plans, irrespective of the originator, are reviewed and approved by responsible organizations and persons in 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 send pre-inspection documentation for approval.

STUK gives approval for the manufacturer, construction and manufacturing plans, quality assurance and quality control plans etc. 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 the installation of the modification. STUK issues commissioning inspection protocol. Test programmes are part of the pre-inspection documentation. Conduct of tests is witnessed by STUK inspectors depending on the nature of the modification and 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. Updating schedule is dependent on the need of documents in operation and maintenance of the system after modification. The system descriptions in the FSAR are updated as a campaign once a year. Changes to plant documentation under STUK control (e.g. Technical Specifications, FSAR) must be approved by STUK.

3.2. Control of work orders

Work planning activities (work permits and work orders etc.) are always made by TVO's personnel according to the plant procedures. During normal operation foremen responsible for executing the work are also responsible for detail planning of work orders. During the outage there is a special group (6 persons) doing detail planning of work orders. Outage manager is responsible for this activity.

The safety office reviews individual work orders for maintenance tasks during the outage and approves 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 Figure A.3.

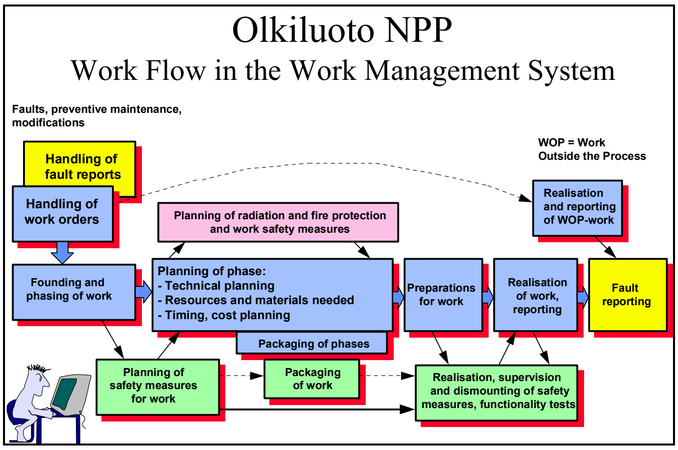

FIG. A.3. Work flow in work management system.

Main steps of the controls by outage co-ordinator/shift supervisors are the following:

- Prepare outage schedules important to safety according to Tech. Spec.
- Give out work orders important to safety of the outage according to approved time schedules.
- The shift supervisor is responsible for the Tech. Spec. and specially assigned requirements being fulfilled during the outage, even though the time schedule changes.
- Separate work orders are required, if identical tasks are performed in redundant safety systems.

3.3. Risk control

The utility TVO wanted to create a realistic view on the risk level also during the shutdown, startup and refueling outage conditions. Therefore, in the year 1990 the utility made a decision to extend the PSA (Probabilistic Safety Analysis) to the analysis of refueling, shutdown and startup. Improvements of the shutdown safety and perspectives for the future developments were identified.

Regarding the repair strategy, the objective is to avoid major unexpected repairs with a proper spare parts policy and detailed risk studies. All critical items are analyzed 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. For example, the safety office performs an independent review on the plant status before startup. Also the regulatory body performs its own supervision.

All outage activities are planned and performed according to the requirements laid down in TVO’s quality system. Activities are controlled by related procedures and instructions.

3.4. Quality assurance

The quality assurance engineers audit and routinely monitor different activities during the outages. The quality assurance office especially concentrate on controlling that the administrative measures are functioning as planned in order to assure that different work activities are planned and performed in a controlled and systematic manner. Also safety culture issues are addressed.

At the end of the outage the quality assurance engineers monitor and control that all organizational units have performed all their assigned checking and verification duties required to be done before the plant can be declared ready for startup. After all this has been done the quality assurance manager will give his approval and the final permission for the startup can be asked for from the regulatory body representative at the plant site.

The Outage Group, meeting twice a week during planned outages, collects and scrutinizes noteworthy incidents occurred during outage. It prepares a special report on them for operational experience feedback purposes. The regulatory body is informed about events and observations significant for the development of the quality system as well as measures taken there upon.

4. SAFETY ISSUES

The primary safety functions to be monitored are residual heat removal, pre-serving of water inventory and maintaining criticality safety.

The residual heat removal (RHR) function shall tolerate a single failure of active components and the pool water temperature shall not exceed 60°C. The initiating event taken into account in the assessment is normally a loss of offsite power with simultaneous failure of one diesel generator.

Emergency core cooling system (ECCS) has to be single failure tolerant to preserve water inventory while work is performed in a place which is connected to the primary circuit below the top of active fuel and which can not be isolated from the primary circuit. The maintenance of internal main recirculation pumps involves the risk for a large bottom leakage during outage. Special arrangements have been implemented to cover this safety issue. One example of these arrangements is closing 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 rather low importance in PSA. A shutdown margin of more than one per cent 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 three per cent. The shutdown margin in connection with an erroneous removal or manoeuvring of one control rod is calculated in advance after each fuel transfer operation. Owing to this, changes of the fuel transfer list without repeating the calculations are allowed only during unloading phase of refueling.

Also availability of power is important for core cooling and decay heat removal. A sufficient power availability even in case of a loss of offsite power with simultaneous failure of one diesel generator shall be assured.

The TVO units have safety systems with 4 x 50 per cent capacity and consistent physical and electrical separation. However the Shutdown Cooling System used during outage for residual heat removal has 2 x 100 per cent capacity and the redundancies have common pipelines. Due to problems with IGSCC (Inter granular stress corrosion cracking) and thermal stresses, which have made frequent reparations necessary, the availability of the Shutdown Cooling System during 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 prior review/study done by the safety office.

The availability of the important safety systems is shown in the main control room by means of magnetic tags which are visible to all in the control room.

The most important Emergency Operating Procedure deals with 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 is concentrated 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 interlockings 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 pumps maintenance.

Of course, all the normal routines like limitation of access to several electrical divisions at the same time are followed also during shutdown.

A lot of attention is paid to preventive fire protection during outages. Workers, doing so-called hot work like welding and cutting, must have a special license to do that work. Each hot work must have a hot work permit. Special fire patrol personnel control that hot work are carried out in a safe way. There have not been any remarkable fires during outages.

If exemptions from the rules given in the Tech. Spec. 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.

The safety office reviews individual work orders for maintenance tasks in the outage and approves those important to the safety.

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. A thorough outage documentation makes it easy to identify strengths and weaknesses. Information on abnormalities and suggestions for improvements, received from both our own and contractor personnel, are especially taken into account. Sufficient and timely information to everyone involved in outage activities is essential for successful performance. Before the outage, everyone should get both their own work information and an overall impression of how they can contribute to good outage performance. TVO gives out information both to own and contractor personnel by having general information outlets and special meetings together 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 as well. An outage report is prepared one month after the outage at the latest.

Clear and well defined performance indicators for different outage functions exist in order to follow up yearly outage performance. Human errors are followed and analyzed 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. Also a separate report is written after every outage. In order to develop outage activities, all deviations from normal routines are analyzed by both the "Operating Experience Group" and the outage planning staff.

The "Operating Experience Group" evaluates all the feedback information for relevance to TVO. If considered useful, a proposal for modification is written.

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 the ABB Atom in Västerås.

All unintentional deviations from the Technical Specifications will be reported to the national authority.

6. TVO's SHUTDOWN EVENT PSA

Shut Down Event PSA (SEPSA) complements level 1 PSA as a part of the living PSA model. The utility was interested in performing a probabilistic safety analysis due to several reasons, among which one could mention open containment during refueling, short refueling outages with numerous overlapping maintenance tasks, continuously shortening outages, missing automatic start of safety systems, unavailability of some safety systems due to maintenance of auxiliary systems and forebodings on the importance of human errors. Because the containment is open, a severe core damage could lead to significant release of radioactive materials to the environment. The study was performed during 1990–1992. The first results showed that the contribution of the refueling outage on the annual core damage risk was of the same order of magnitude as the contribution of the 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 showed in the year 1997 that the assumptions of the utility before SEPSA study were correct. The contribution of refueling to the core damage frequency (CDF) was reduced below 1 %, but still its contribution to the large early release frequency (LERF) was about 30 %. The latest level 1 PSA extension including the fire Common Cause Initiators (CCIs) during outages was added to the PSA model in 1998.

The total manpower required to accomplish the SEPSA was approximately three man-years. The project team consisted mainly of utility's own personnel strengthened with an expert in human factor assessment.

Besides the severe nuclear risks the utility was interested in other risks, too, e.g. significant extension of outages. They were evaluated as a by-product of the event tree sequences, not severe enough to lead to core damage. The following plant damage states have been considered: Mechanical fuel damages, Local criticality, Overheating of concrete structures of pools, Core uncover, Spent fuel uncovery in spent fuel pools, and Severe core damage.

Thermal hydraulic analyses made during the SEPSA project, showed that all operating modes with critical reactor should be included in power operation mode PSA (Fig. A.4). Thus SEPSA covers only the subcritical operating modes. The duration of each of the shut down operation modes is the average value from the recent five years before updating the study (1991–1995). The average refueling duration was approximately 378 hours (below 16 days).

Only five different plant configurations were separately modelled in SEPSA. They are based rather on the decay heat production and the integrity of the primary circuit than the unavailability of systems due to maintenance. The unavailability of components due to maintenance and systems is 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 five last refueling outages, and it was modelled in the fault trees in subsystem level. Three different sizes of leakage below core and seven above core were modeled with separate event trees. Their frequency was based on human error analysis of maintenance tasks. The mechanical causes of failure are insignificant as compared to the human factor. Each configuration has its own event tree, loss of residual heat removal as the initiating event. Loss of external grid is included in the transients without its own event tree.

Fire CCIs were modelled with the separate "external" event trees, which were developed from RHR event trees (states T0-T4). A single fire initiating event can be applicable for one or even to all RHR states T0-T4.

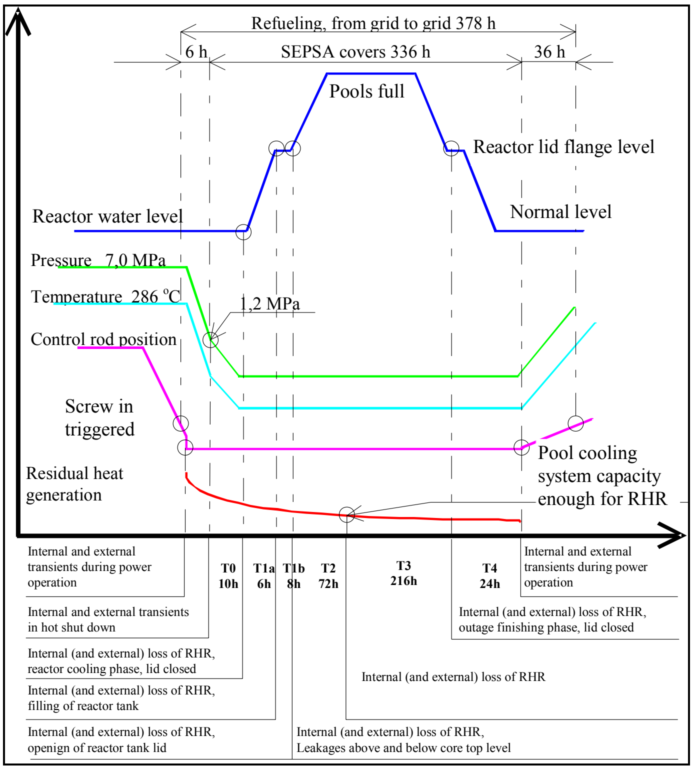

FIG. A.4. Thermal hydraulic analyses, made during the SEPSA project, showed that all operating modes with critical reactor should be included in power operation mode PSA.

Special studies were carried out for the unwanted local criticality events, for the over pressurization 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 air atmosphere in the containment. The importance of criticality events is minor, but accidents caused by loss of heavy loads are among the major contributors of the mechanical fuel damage risk causing a minor release.

Another interesting aspect is the temporal behaviour of the risk level (Fig. A.5) The beginning of a refuelling outage is important from the risk point of view. There is a risk peak during the water filling of the reactor tank and during the first three days of maintenance activities. The potential of overfilling followed by the loss of RHR explains the former one. It was significantly reduced with modifications in procedures based on a result of the SEPSA study:

Filling of reactor tank above a certain level is no more 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 the startup and shutdown is three times higher than the average risk level during the power operation. Latest PSA upgrade showed that fire CCIs have minor impact to the overall CDF during outage period.

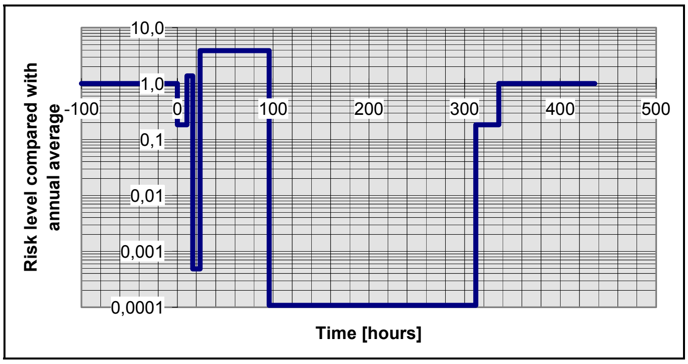

FIG. A.5. Risk level during the refueling outage as a function of time.

Several actions taken during and after the SEPSA decreased the dominant risk contributors significantly (Fig. A.6). The lower personnel access door is kept closed during the critical phases of the internal main recirculation pumps overhaul, as mentioned earlier. Mechanical cotter pin installed in the plugs of the penetration of the internal main recirculation pump axis prohibit inadvertent lifting. In order to prohibit the cold overpressurization the use of auxiliary feed water piston pumps for reactor filling is no more 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 SEPSA.

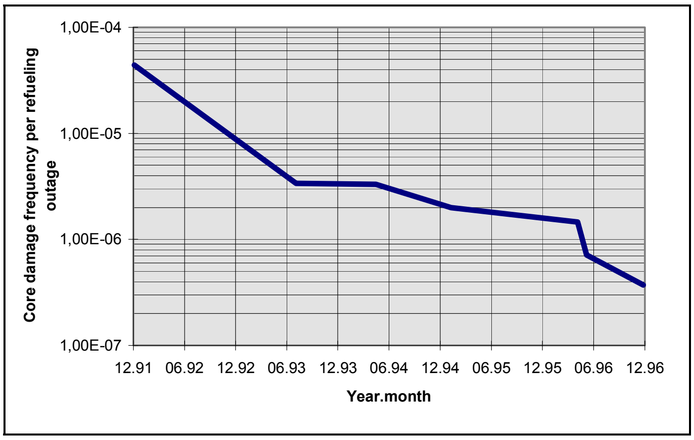

FIG. A.6. Core damage frequency in refueling outage has significantly decreased when issues identified in SEPSA project have been fixed.

Note: Extracted from the paper Olkiluoto 1 and 2 "Safety Practices during Planned Outages in TVO, Finland", published, by Marjo Mustonen, Seppo Koski, Mikko Kosonen, Risto Himanen, Mauri Hakola. (Proc. of ICONE 8, 8th International Conference on Nuclear Engineering, April 2–6, 2000 Baltimore, MD, USA)

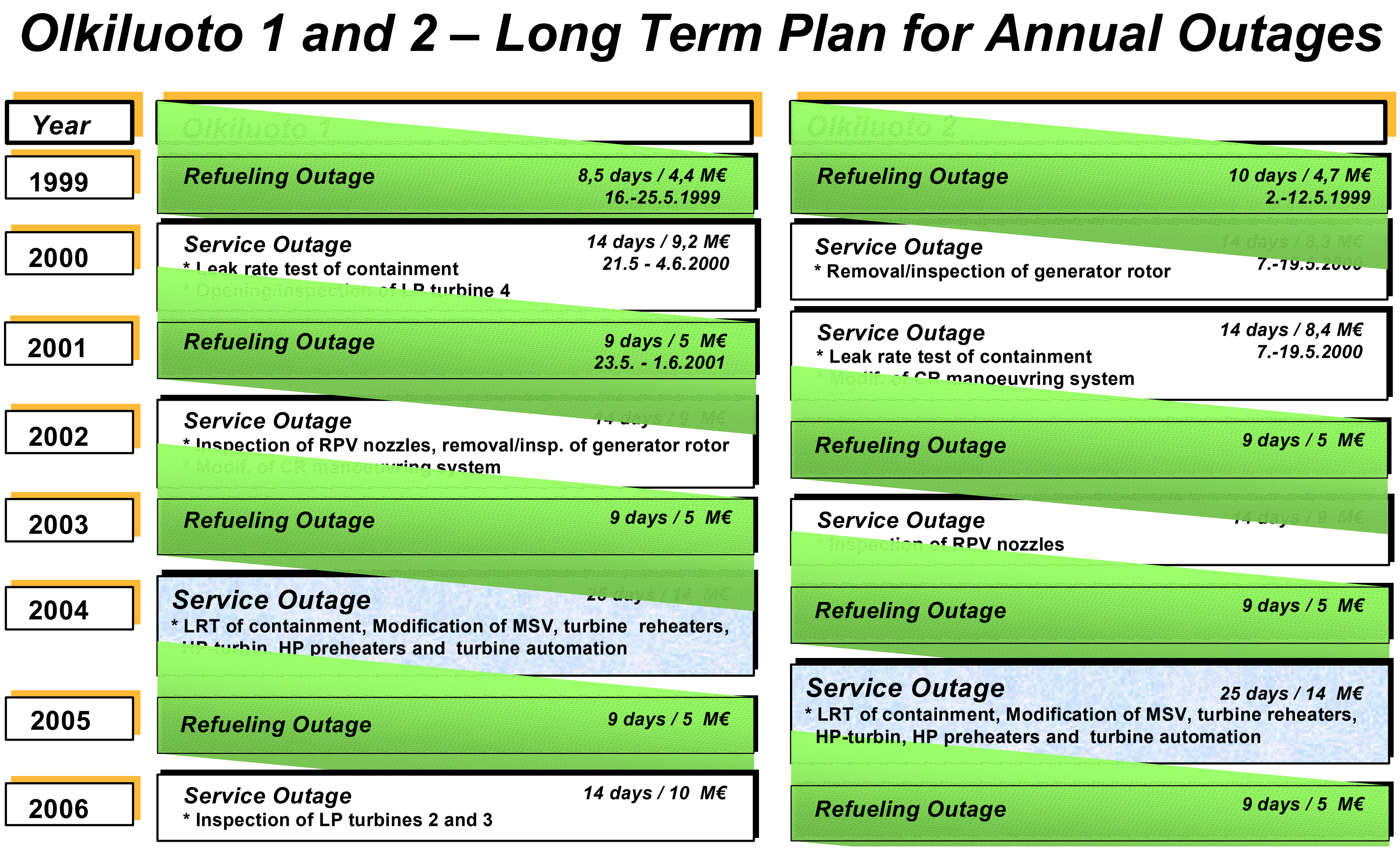

FIG. A.7. Long Term Plan forAnnual Outage for Olkiluoto NPPs.

Olkiluoto 1 and 2 - Annual Outages 1992-1999

Year	Olkiluoto 1	Olkiluoto 2
1992	***Service Outage*** ***22 days / 8,4 M€*** *Exchange of Reactor Core Grid*	***Service Outage*** ***14 days / 6,9 M€***
1993	***Service Outage*** ***13 days / 6,2 M€***	***Service Outage*** ***16 days / 7,3 M€***
1994	***Service Outage*** ***11 days / 5,0 M€***	***Service Outage / Modernization*** ***24 days / 10,0 M€*** *Exchange of Reactor Core Grid and Generator* *Service/Inspection of LP turbines 1 and 2*
1995	***Refueling Outage*** ***10 days / 4,6 M€***	***Service Outage*** ***13 days / 6,0 M€***
1996	***Service Outage / Modernization*** ***20 days / 13,1 M€*** *Exh. of Generator, LP turbines 3-4 and turbine control / safety system, 2 new safety valves, mod. HP turbine...*	***Refueling Outage*** ***11 days / 5,9 M€***
1997	***Service Outage / Modernization*** ***18 days / 10,8 M€*** *Exc. of LP turbines 1-2, Main transforme, Generator Circuit Breaker, Scroud Head/Steam Separators...*	***Service Outage / Modernization*** ***18 days / 11,4 M€*** *Exch. of LP turbines 3-4 , turbi control/safety system, scroud head/steam separators, 2 new safety valves....*
1998	***Service Outage / Modernization*** ***15,5 days / 11,8 M€*** *Exc. of Main transformer, Generator Circuit Breaker, Mod. of HP turbine and Steam Reheat System...*	***Service Outage / Modernization*** ***19 days / 14,8 M€*** *Exc. of LP turbines 1-2, Main transformer, Generator Circuit Breaker, Mod. of HP turb., Steam Reheat Syst…*
1999	***Refueling Outage*** ***8,5 days / 4,4 M€*** *Repair of core spray pipes, mod. of 2 RIP's electr.syst.*	***Refueling Outage*** ***10 days / 4,7 M€*** *Repair of core spray pipes, mod. of 2 RIP's electr.syst.*

FIG. A.8. Annual Outage for Olkiluoto NPPs.

Annex B
KEY ISSUES TO CONSIDER IN OUTAGE PLANNING, PREPARATION AND EXECUTION, TVO, FINLAND

OL1/OL2 - Outage Planning

— Long term planning:	about 10 years
— Middle term planning:	about 3 years
— Detailed planning of following outages:	1–2 years careful study of the critical path activities
— Planning during outages:	new defects schedule revisions

OL1/OL2 - Outage Types: Short/Long Outage Cycle

— Refuelling Outage:	ca. 10 days
— Service Outage:	2 to 3 weeks normal or large

- Outages follow each other in sequence
- Optimization of Outage Costs and Production Losses

OL1/OL2 - Outage Types

— Refuelling Outage:	Refuelling Repairs Annual service, tests and inspections according to the Technical Specifications
— Service Outage:	Refuelling Outage work tasks Major overhauls, service and inspections Modifications and improvements

TVO - Outage Organization

- Outage Manager (full time)
- Outage Co-ordinator in Operation
- Plant Meeting (Outage Management Group)
- Long Term Outage Planning Meeting
- Outage Planning Team
- Outage Execution Team for every annual outage

TVO - Outage Execution Team

Outage Manager:	General management
Outage Planning Team:	New defects, schedule revisions
Outage Co-ordinator in Operation:	Operational safety, work permits
Maintenance Teams:	Maintenance, inspections, modifications
Modification Project Teams:	Execution of major retrofits
Support Teams:	Safety,radiation protection, chemistry, security, fire protection, material administration, personnel welfare, IT-services, waste treatment etc.

TVO - Outage Personnel and Execution

- Long term contracts with plant vendors
- Affiliated Finnish companies with special training for TVO components
- Own competent resources on critical areas, good supervision
- Fixed price / quality premium / multi-cycle contracts
- Outage logistics / high standard and sufficient capacity of welfare facilities
- Workshops, tools etc.

OL1/OL2 - Reactor Safety During Outages

- Outage PSA
- Technical Specifications for Outages
- Independent safety review for every Outage, carried out by the Nuclear Safety office
- Reactor Safety Time Schedule (criticality)
- Shutdown Cooling Time Schedule
- Operational safety review of outage work in the Work Management System
-

OL1/OL2 - Short Outages: Key Issues

- Long Term Outage Planning
- Advanced plant concept
- Investment policy — keeping the plant in modern condition
- Investments to facilitate short outages
- Repair and spare parts policy
- Detailed work planning and supervision
- Effective use of advanced data processing systems
- Appropriate outage support services
- Low radiation levels
- Experienced personnel on key areas
- Long term contracts with plant vendors and important service companies
- Finnish affiliated companies with special training for TVO components
- Quality premium system
- Continuous improvement policy

Annex C
OUTAGE PREPARATION, PLANNING AND EXECUTION AT BOHUNICE NPP, SLOVAKIA

The organization of works during the general maintenance and refueling at NPP Bohunice, Slovakia, focus on collaboration between operation and maintenance departments.

The general maintenance is prepared by a special group of approximately 25 people which is called a General Maintenance Committee. The head of this committee reports directly to the plant manager. The committee consists of employees from various departments. The committee meetings are organized in compliance with the requirements which have to be met. This committee must prepare all materials, spare parts, documentation and contracts for overhauls.

All the planned maintenance activities, which have to be done during general maintenance, are compiled by a co-ordination department which belong to Operation Division.

The Co-ordination department prepares preliminary maintenance schedules for the primary systems, secondary systems, electrical systems, and I&C systems.

These schedules are prepared in co-ordination between the Operational, Technical Support and Co-ordination departments.

There are seven shifts of control room operators at NPP Bohunice, six of them work in a shift and the last one /No. 7/ acts as a technical support. Members of seventh shift are licensed as an operators in control room.

Technical Support prepares schedule for unit shutdown, tests of interlock and automatics, unit startup, systems in a stand-by mode.

Preliminary schedules are updated and the final schedules are prepared. These final schedules are prepared in such a way that all the actions are logically organized, timing, nuclear safety requirements and technical standards are met.

One day before the unit shutdown all activities are managed by a special team — a Regime Group. The Regime Group consists of the head of the group, the heads of maintenance groups for primary, secondary and electrical systems, representatives from departments which are responsible for mechanical equipment, for electrical equipment, for I&C systems, shift unit supervisor and the maintenance department representative.

The head of Regime Group reports directly to the Operation Division Manager. The regime group has daily meetings and during these meetings the evaluation of the schedule is carried out. On the basis of this evaluation the goals for the next day are determined.

The regime group is not allowed to make decisions on extending the outage, only the general maintenance committee can do it. When we have this problem we must ask the head of GMC to call a meeting to find a solution, if it is necessary to move startup time or if there is a very serious change in the schedule for the general maintenance. The regime group is active until the first generator is connected to the grid.

Annex D
EXAMPLES OF OUTAGE EXTENSION AND CORRECTIVE ACTIONS IN DUKOVANY NPP, CZECH REPUBLIC

This annex provides a description of events at Dukovany NPP, including causes and corrective actions that resulted in extension of a planned refuelling and maintenance outage.

B.1. Unit, year commercial: Dukovany 3, 1987

Reactor type (size): PWR (440 MW(e))
Event date: 1997
Refuelling outage

Event 1: Leakage in the isolation valves of the pressurizer relief valve

Summary:

In addition to the existing pressurizer safety valves, a pressurizer relief valve was installed at the Dukovany 3 as part of an upgrading project during the 1997 refuelling outage. Post installation tests were performed successfully at a low pressure during the unit startup according to the implementation plan. However, during a subsequent inspection of the pressurizer relief and safety valves at the operating pressure in Mode 3 (hot standby), leaks were discovered at the isolation valves 3YP10S50, 3YP10S51. The unit had to be cooled down again to repair the valves.

Causes:

(1) Leakage of valve 3YP10S51 was due to excessive closing torque at the valve stem and
(2) Leakage of Sulzer valve 3YP10S50 was due to incorrect tightening of flange bolts.

Corrective measures:

- An appropriate torque for closing the valve 3YP10S51 was determined.
- An administrative measure was taken to prevent a human factor error causing this deficiency.

Event 2: Leakage at the main flange of a reactor coolant pump

Summary:

During the unit startup after the 1997 refuelling outage, a leakage was discovered at the reactor coolant pump (RCP) YD15D01 during a routine walk-down. The plant management decided to return the unit into the Mode 5 (cold shutdown) to repair the leak.

Cause:

- Leaky main flange of the pump due to insufficient tightening of the bolts. The bolts may have loosened due to thermal dilatations as a result of repeated cooling down and heating up the reactor coolant system (RCS) during the unit startup.

Corrective measure:

- The necessity to tighten the RCP main flange bolts will be assessed after each RCS cooldown, and the bolts will be possibly tightened depending on results of the assessment.

B.2. Unit, year commercial: Dukovany 1, 1985

Reactor type (size): PWR (440 MW(e))
Event date: 1998
Refuelling outage

Event 1: damage to the bearings of two reactor coolant pumps (RCP)

Summary:

During the start of the RCP 1YD15D01 to commence the RCS heat up after the refuelling outage, the bearings of RCP motor got seized. The pump was subsequently stopped. The RCS heating continued with other five RCPs operating. During the RCS heating, the temperatures of bearings of the RCP 1YD13D01 motor were slowly increasing, which indicated a similar problem as with the 1YD15D01. After completion of the RCS pressure test, the heating was interrupted and the RCS was cooled down to repair the bearings of both the 1YD15D01 and 1YD13D01 motors.

Causes:

— The bearings were insufficiently lubricated, because the reactor operator introduced the lubricating oil into the bearings shortly (about 15 seconds) before the pump start. This procedure was applied to the pumps YD13D01, YD15D01 and YD16D01.

Corrective actions:

— The written procedures for operation of RCP and RCP oil system were amended.
— The responsible operations personnel was informed about the event and trained in performing the amended procedures.

Event 2: Leaky isolation valve of the pressurizer relief valve

Summary:

The unit was in started up mode after the refuelling outage. During the RCS pressure test, a leaky flange of the isolation valve YP10S51 was discovered. After returning the unit into the Mode 5 (cold shutdown) due to the repair of the RCP bearings (see the previous event), the flange was additionally tightened.

During the repeated RCS pressure test after completing the repairs, it was determined the leakage was persisting. Therefore, the RCS pressure and temperatures were reduced and the leaky flange of YP10S51 was welded using a sealing weld.

Cause:

— Inadequate sealing of the flange.

Corrective actions:

— The flange has been provisionally welded; during the next planned outage, the sealing system will be redesigned.

Annex E
PROCESS DEVELOPMENT IN SWEDEN

The following two figures from Forsmark Kraftgrupp AB illustrates the possibilities within process development. Figure E.1 shows the recent developed maintenance process used to achieve effective maintenance.

Figure E.2 illustrates the very important 'work control management' where a computerized system is used to control: (1) work is fully prepared to request work permit, (2) work permit is ready for use, (3) getting work permit and (4) signing off the work permit as ready for operation.

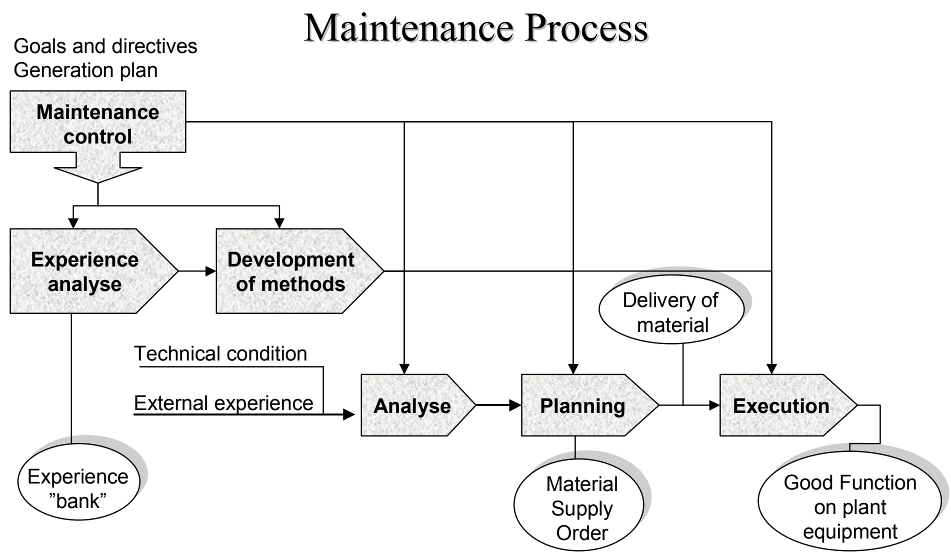

FIG. E.1. Maintenance process.

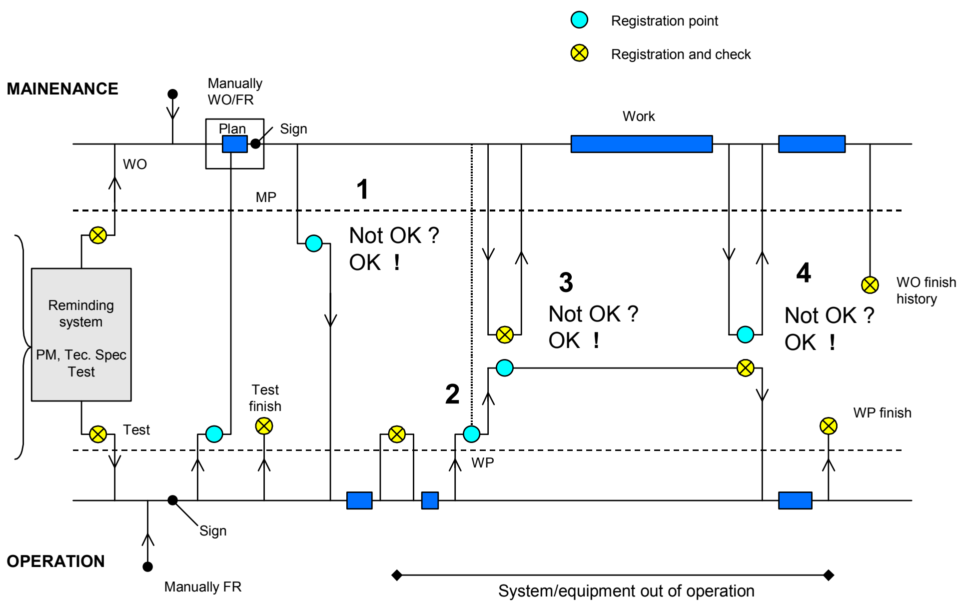

FIG. E.2. Work control management.

Annex F
REFUELLING OUTAGE PROJECT PREPAREDNESS CALLED STOP PROJECTS (RASP) USED IN BARSEBAECK NPP, SWEDEN

Background: Why RASP?

Our experiences of the 90-ies have made us realise the importance of a high rate of preparedness for taking care of unforeseen problems discovered during the outages. After consecutive short refueling outages, as an average three weeks, time consuming problems appeared in the form of rebuilding of suction strainers of the core spray system, tightening of leakages in the containment, IGSCC-cracking in Reactor shut down cooling system and Main recirc. system and last year as cracking of the Core spray support system.

What has been done:

From the mid 90-ies on BKAB we have developed preparedness comprising:
- Identified risk areas and risk validation,
- Description of most probable defects,
- Preparation of most appropriate project model and establish and summon up project organisation with nescessary deputies aiming at taking care of primary system problems,
- Identified requirement of consultants, hired people, special equipment as robots etc.,
- Extensive internal and external information in order to establish general mental preparedness.

How to develop this further?

The cost hunting and demand on rapid measures have led to the opposite. In our model of severe Stop Projects we press on the fact that the Starting Process is of major importance for the results. If you start the project calmly and systematically, you will gain shorter total time and lower cost. Beyond this a higher quality is reached through the work.

A prepared Analysis Group is immediately activated when a major problem is found. The group consists of experts of planning, fault investigation, material, testing, strength analysis, plant installation measures and is led by the Project Manager. Their task is to analyse the problem extension, find ways of attacking and present a proved project plan. The scope of a joint plan is a specified description of task and a realistic time schedule comprising critical path and a plan of supporting papers for approval to the authorities, SKI.

Controlling paper is a structured pattern for all supporting papers internally, to accredited reviewing body and to SKI.

A joint co-ordinator for all supporting papers for co-operating NPPs is assigned.

The project plan will initiate the Stop Project. A daily project meeting is going on at 09.00 – 10.00. The sub projects In-service Inspection and Fault Investigation, Design & Analysis and Plant Installations report to the meeting. All the managers and staff required to bring the project forward (e.g. Production, Support and Information) participate in the meeting.

Information from the meeting is transferred promptly to the Refueling Outage meeting and to the internal web intranet.

Summary

A major fault found in the primary circuits or internals of the reactor will be taken care of seriously by the prepared Analysis Group and Stop Project Organisation. All levels of the NPP management and staff will be activated. The joint Analysis Group shall get the time and support required to make possible to enter the right track in the project. The structure of supporting papers is a joint controlling document. All people in the plant organisation will gain simultaneous and updated information from one daily meeting. This will generate a maximum of time and cost effectiveness. If generic faults are found the members of the Analysis Groups will participate in each other’s work in order to enter the corresponding tracks.

Annex G
EXAMPLE OF PRACTICES ON OUTAGE PREPARATION IMPLEMENTED BY EDF, FRANCE

1. Three months before the outage:

— Make a tour of the installations accessible (Fuel Building, Nuclear Auxiliary Building, Turbine Hall, Pumphouse) to list the unplanned Work Orders. This gives "the Operator's agreement" which then enables filling in the required conditions, to be associated with interventions already scheduled and to channel the Work Orders to the right departments. This allows integrating the unplanned events in outage activities.
— Draw up activities called "pre-unit outage". Make the request, if necessary, for permission to work on Sundays. This request is to be made for the year.
— Make sure, with the vendors, even other sites, that spare parts which have been disassembled are available.
— Have the organizational chart filled in with those in charge of outage.
— Anticipate startup meetings 2 months before application of the works.
— Open relations with the Regulatory Authorities.
— Draft prevention plans.

Some activities are referred to as "pre-unit outage". Certain sites have an operational guide which provides an inventory of activities that have or can be carried out before shutdown. It also specifies the responsibilities for preparation and execution, and justifies or comments these activities.

2. From 2 months to 1 month before the outage:

Take advantage of a hot shutdown (foreseeable shutdown at weekend) for 16 to 20 hours, to carry out the tasks mentioned hereafter. This reduces restrictions imposed at the start of outage due to the limited number of people in the Reactor Building (corresponding to the number of people who can enter the personnel air lock).

— Visit of the Reactor Building to pinpoint the leaks, or indications such as deposits or traces of boron through an examination of the valves.
— Make a check of the supporting elements. At the start of outage, the primary cooling modifies position of the supporting elements which distorts measurement representativeness. It is therefore advisable to make these checks during this hot shutdown.
— Inspection of the electrical system of the Reactor Building polar crane and remember to take an oil sample for analysis.
— If necessary, set pressure of the Main Steam System valves.
— Turbine testing because, with longer and longer unit fuel cycle extension (stretch out), these tests become difficult to monitor at the end of cycle.
— Do not forget to make an inventory of the blind flanges and clamps which will be used during unit outage.
— Operating status of Reactor Building lighting.
— Operating status of the Over Heated Water System.

3. From 1 month to 15 days before the outage:

In general, proceed with checking equipment installed in fixed stations which could be used on the outage critical path, especially :

(1) Check the sound operation of handling devices :
- Turbine Hall cranes + doors
- Pumping House cranes and gantry cranes
- Fuel Building cranes
- Spent fuel pool bridge.

(2) Preparation of the Fuel Handling and Storage System, Fuel Building :
- Check availability and working of the various fuel assemblies or RCCA handling tools
- Check availability and sound working of the fuel control devices
- Operate the Fuel Handling and Storage System kinematic configuration in real time, as well as proximity detectors where failure causes slow speed of the transfer car
- Programme sufficiently early inspection of the upending device, as the transfer compartment takes some time to decontaminate.

4. From 15 days to 1 week before the outage:

(a) PERSONNEL
Provide for personnel training on mock-up or on testing stands, for the following operations:
- installation of the Steam Generator nozzle dams, and drain plugs
- multistudy tensioning machine use, reactor vessel, steam generator manhole
- control rod drive shaft latching and unlatching handling tool.

(b) EQUIPMENT

(1) Filter and demineralize water from the Reactor Cavity and Spent Fuel Pool Cooling and Treatment System tank whatever the activity measured (aim : limpidity of the water).

(2) In the event of the unit operating in "fuel cycle extension", the use of the de-aerator and the head tank of the Boron Recycle System to degas primary circuit water requires making an analysis of the boron concentration (risk: core blanketing following boration).

(3) Watch over the condition of tools and mobile handling resources planned to be used right at the start of outage.

(4) Check, verify and prepare the following equipment:
- hoses for temporary links
- the multistud tensioning machine
- steam Generator nozzle dams (sizing and leaktightness)
- the electronic load cell of the polar crane
- CRD unlatching handling tool (provide 2)
- nozzle dam screw driving machine (provide 2)
- gripper for fuel handling machine (provide 2)
- blind flange of temporary cable penetration (NDT – control, etc.)

"VERY COLD WEATHER" PERIOD

Various site works are held up by the cold weather. Sufficient auxiliary heating should be available. Critical works are:

- Dye penetrant checks, which cannot be made at less than 10° C (Main Steam System, turbines, etc.)
- Metrological checks on the Auxiliary Feedwater System.
- Development of the radiological films which cannot be made with rinsing water temperature at less than 15° C.
- Turbine work. In this case, the situation is worsened by shutdown of the heating systems due to electricity supply cut-off, and by the repeated opening and shutting of doors in the Turbine Hall. The oil temperature is sometimes too cold for certain operations.

"VERY HOT WEATHER" PERIOD

Certain sites have created "Very hot weather" instructions to protect installations, and mainly the electric panels, from high ambient temperatures in the summer. During unit shutdown, it is advisable to give special attention to the preparation and realization of electric panel tag-in , to avoid disturbances in the required operation of equipment.

CONSUMABLE

The work teams complain about insufficient supplies of consumable in the general workshop. It concerns the poor quality of certain supplies or out of stock (penetrating oil, acetone, string, batteries, lapping compound, etc.).

5 From 1 week to uncoupling:

- Start purification of the primary. Provide for filters in consequence.
- Plan the inventory of the provisional links which must be installed or be withdrawn in order to carry out the degassing and oxygenation. Make sure that these operations are shown precisely and accurately in the unit outage planning schedule.
- If considerable works are planned on the Turbine Generator, which could become critical, provide low load operation so as to reduce cooling time of the metal structures.
- Carry out, just before and just after trip, turbine tests (leaktightness of valves, offset behaviour, machine deceleration and vibrations check).
- Setting up a "unit in outage" and "unit in service" markings.

6. Safety during unit outage

A dedicated Committee for Safety during Unit Outage is responsible for making sure the general operating rules are met before finalising each important stage for startup of a unit. For this purpose, it ensures that all the required functions are available and that all the operations, the responsibility of the various departments, have been correctly carried out. It gives a decision on the handling of deviations detected. In this way it is a guarantee of unit performance for the Operator. It enables anticipating most of the checks before status change.

Annex H

INADVERTENT SAFETY INJECTION RESULTED IN PERSONNEL AND REACTOR BUILDING CONTAMINATION IN CHINA

Unit:	GNPJVC (GNPS) Unit 1, P.R China
Year Commercial:	1994.2
Reactor Type:	PWR 984 MW(e)
Reactor Manufacturer:	FRAMATOME
Turbine Manufacturer:	GEC-A
Plant Designer:	EdF (Electricité de France)
Event Date:	24th April 97
Event Criteria:	Safety Injection Personnel Contamination
Cause Categories:	Work planning / Written procedure / Verbal communication / Supervisory method
Malfunctioning System:	Reactor protection system
Reference:	None

SUMMARY:

While performing periodic test on Reactor Protection system, the X-channel of the safety injection system initiated due to instrument fault. The I&C technician requested the control room operator to re-block the injection signal by using a key-lock switch in the control room, the control room operator misunderstood the instruction and re-set the key-lock switch causing both X, Y channel of the safety injection signals to actuate, resulted in safety injection and startup of diesel generator. The unit was in refuelling outage with pressurizer manhole opened. The safety injection caused overthrow of the primary circuit through the pressurizer manhole and caused external contamination of 5 workers and parts of reactor building.

EVENT DESCRIPTION:

On April 22, the unit was in refuelling outage, I&C technicians were preparing work package for the reactor protection system periodic test T2.

RPR energized on April 23 while pressurizer (PZR) manhole was still opened, which should have been closed before energizing RPR in accordance with the outage schedule. Work supervisor began to perform T2 with the agreement of the shift supervisor. During test preparation, the signal of "X, Y protection logic non conformance" appeared. The test was then postponed.

The following day, the test was re-tried for several times and not successful. The test was stopped at procedure step 24 due to X, Y logic deviation. At the same time, the X channel failed to block signal P11 (Primary coolant pressure lower than 139bar) which actuated X-channel safety injection signal (RPB057LA).

I&C staff tried to terminated the test T2 by pressing T2 tester reset button as procedure required but failed. The test was then put on hold. After analyzing the cause of safety injection signal, I&C technician asked the control room operator to re-block the injection signal with the key-lock switch RPB056CC. The operator misunderstood the instruction and re-set the key-lock switch causing both X, Y channels of the safety injection signals to actuate, resulted in safety injection and startup of diesel generators.

Immediately the main control room operator blocked P11 signal immediately. But failed as there were a 5 minutes lock-in delay after safety injection actuated, which is design feature. The operator then proceeded to stop safety injection pump by isolating the power supply resulting in a safety injection duration: 3 min. 6 sec.

CONSEQUENCE:

- The event postponed the outage re-start for 3 days,
- 5 persons had external contamination,
- Part of the reactor building were contaminated (550 square meters),
- Collective dose increased by 15.59 m-mSv for decontaminating,
- Solid waste: 4 cubic meters.

The event is scaled as INES 1.

ANALYSIS / COMMENTS:

During periodic test T2, X channel blocking failure led to X, Y channel deviation and low pressure safety injection actuated, as well as blocking indicator light went out.

When P11 signal recovered, the test staff did not perform risk analysis while facing abnormal situation, and did not inform main control room operator. Their ambiguous order made operator respond for wrong action and caused safety injection train B actuated.

DIRECT CAUSE:

- The test procedure of T2 was unavailable when primary coolant system opened during refuelling outage.
- It was a procedure violation that RPR energized before pressurizer manhole closed
- The staff performing RPR test did not make comprehensive risk analysis as well as adequate work preparation.
- Operator did not follow the procedure for using keys on sensitive equipment.

ROOT CAUSE:

Operators lacking of inquisitive attitude and management weaknesses contributed as root causes:

1. Staff unfamiliar with test condition, and potential consequence, lack of questioning attitude.
2. Staff failed to investigate anomaly, fail to perform risk analysis and take necessary measures.
3. Main control room operator ignored key regulation and potential risk when resetting trip signals on sensitive equipment.
4. For management weaknesses:
   - Management regulation/corrective action are not implemented as required,
   - Test procedure deficiency,

— Management weakness in outage scheduling,
— Violating administration procedure.

CORRECTIVE ACTIONS**:**

- Outage schedule:
  To strictly obey authorization sheet for schedule change in outage.
- Test procedure deficiency:
  Modifying procedure by adding unit status required in test and signature of MCR operator.
- Test equipment failure:
  To issue modification request for T2 test.
- Inquisitive attitude:
  While working on QSR (quality safety related) equipment or significant QR equipment, risk analysis must be made by filling an analysis sheet. When performing important or risking operation, a written order should be given.
- Violation of key management regulatory:
  To label a risk warning note on key cabinet (see attachment) and to train operator how to use blocking key as a procedure "key blocking specification".
- Management issue:
  Training on "operation administration policy" provided to all operators.
  An archive to record improper practice is established to review staff performance.

ATTACHMENT RISK WARNING NOTE

1. Do you know the rules for blocking key?
   Please use the key as key procedure required
2. Do you know what risk exist using the key?
   Please make a serious risk analysis and take related measure to avoid unexpected consequence
3. Do you know the conditions to use the blocking key under various operation status?
   Please refer following condition when you using the key:
   (omit)

Annex I
MONITORING SHUTDOWN SAFETY AT KRSKO NPP, SLOVENIA

Krsko nuclear power plant is a Westinghouse PWR, 664 MW electrical gross power.

Nuclear safety is the most important concern during outage preparation period as well as during outage execution and has significant impact to outage optimization process.

In NPP Krsko, ORAM programme is used to asses nuclear safety status during planning and scheduling process. Any deviation from allowed safety level in the outage schedule requires rescheduling with purpose to improve nuclear safety level. That process is continuous during outage planning phase.

During outage performance, special procedure dedicated to nuclear safety is used to monitor level of nuclear safety any time. Procedure is named PLANT SAFETY DURING SHUTDOWN and give very detailed instructions how to assess nuclear safety during any phase of the plant outage.

In general procedure have to ensure that all shutdown safety functions will be maintained during outage to prevent fuel damage or radioactive release to environment. Shutdown safety functions are:

— Reactivity control
— Shutdown cooling
— Inventory control
— Spent fuel pit cooling
— Electric power availability
— Cooling water and other vital support systems
— Containment integrity and cooling

Requirement for operable equipment is different for any of nine (9) very precisely defined shutdown states which are:

— RCS closed and water solid
— RCS closed and SG tubes water filled
— RCS open, SG tubes drained, SG closed
— RCS open, SG tubes drained, SG open, SG nozzle dams installed
— Reactor vessel head is on, RCS is open, SG nozzle dams installed
— Reactor vessel head removed, upper internals not removed
— Cavity flooded, internals removed, no fuel movement in progress
— Cavity flooded, fuel movement in progress
— Core de-fueled.

Table I.1. Procedure for shutdown safety assessment

SHUTDOWN SAFETY FUNCTION * not applicable for a Shutdown State 9	Points required	Points achieved
REACTIVITY CONTROL (REC)	3	
Boron Concentration and SR Nucl. Inst. Operability in accordance with TS (2)		
BAT, BA pump, Emergency Boration Flowpath, Charging Pump, Charging Flowpath (1)	SAT	UNSAT
RWST, Charging Pump, Charging Flowpath (1)		

SHUTDOWN SAFETY FUNCTION * not applicable for a Shutdown State 9	Points required	Points achieved
SHUTDOWN COOLING (DHR)	3	
RHR Train A (1)		
RHR Train B (1)		
Rx Cavity level > 7m above Rx Flange and Upper Internals removed (1)	SAT	UNSAT
Alternate Cooling Methods available (1)		

SHUTDOWN SAFETY FUNCTION * not applicable for a Shutdown State 9	Points required	Points achieved
INVENTORY CONTROL (INV)	3	
RWST OR VCT with BAT and RMWST, Charging Pump, Charging Flowpat (2)	SAT	UNSAT
RWST, SI Pump, CL and HL Injection Flowpath (1)		
Rx Cavity level > 7m above Rx Flange and Upper Internals removed (1)		

SHUTDOWN SAFETY FUNCTION	Points required	Points achieved
SPENT FUEL PIT COOLING (SFP)	5	
SFP Pump #1 (1)		
SFP Pump #2 (1)		
SFP Heat Exchanger #1 (2)	SAT	UNSAT
SFP Heat Exchanger #2 (2)		

Table I.1. (cont.)

SHUTDOWN SAFETY FUNCTION	Points required	Points achieved
ELECTRIC POWER AVAILABILITY (ELE)	3	
Supply from DG1 / DG2 (1–2)	SAT	UNSAT
Supply from 400kV / 110 KV grid (1–2)		
Rx Cavity level > 7m above Rx Flange and Upper Internals removed (1) (SFP level during Shutdown State 9)		

SHUTDOWN SAFETY FUNCTION	Points required	Points achieved
COOLING WATER AND OTHER VITAL SUPPORT SYSTEMS (SUP)	4	
SW and CC Train A (2)	SAT	UNSAT
SW and CC Train B (2)		
Stand-by SW and CC Pump aligned to protected train (1)		
Rx Cavity level > 7m above Rx Flange an Upper Internals removed (1) (SFP level during Shutdown State 9)		

SHUTDOWN SAFETY FUNCTION * not applicable for a Shutdown State 9	Points required	Points achieved
CONTAINMENT INTEGRITY AND COOLING (CNT)	3	
No RCS Reduced Inventory condition (2)	SAT	UNSAT
No Rx Configuration Changes in progress (2)		
Containment Closed (1)		

Table I.2. Procedure for plant shutdown states and required equipment — During plant startup Shutdown State 2* appears instead of Shutdown State 2

Shutdown State	TS Mode	REC	DHR	INV	SFP	ELE	SUP	CNT	ACTIVITY	PLANT STATUS
1	5	1 CS RWST BAT 1 SR	2 RHR 1 SG	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW 1 AF	NO	RCS cleanup, press reduction	RCS closed and RCS water-solid
2	5	1 CS RWST BAT 1 SR	2 RHR 1 SG	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW 1 AF	NO	RCS draining to CL+170cm	RCS closed, SG tubes filled
2*	5	1 CS RWST BAT 1 SR	2 RHR 1 SG	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW 1 AF	YES	RCS degassification and filling	RCS closed, SG tubes empty
3	5	1 CS RWST BAT 1 SR	2 RHR feed & spill	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW	YES	PRZR opening / closure, RCS draining to CL+20cm	RCS open, (SG tubes drained), SG closed
4	5	1 CS RWST BAT 1 SR	2 RHR feed & spill	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW	YES	RCP to/from backseat Open/closing of SG, N.Dams inst./deinst.	RCS open, (SG tubes drained, SG open, N. Dams installed)
5	5	1 CS RWST BAT 1 SR	2 RHR feed & spill	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW	YES	RCS level change betw. CL+170cm and CL+20cm	Reactor vessel head on, RCS open, (Nozzle dams installed)
6	6	1 CS RWST BAT 2 SR	2 RHR feed & spill cavity fill	1 SI 1 CS 1 MW	1 Pmp 1 Hx	1 OFF SITE 2 DG	2 CC 2 SW	YES	Rx Vessel Head and UI removal/instal.	Rx vessel head removal/off, Upper internals not removed
7	6	1 CS BAT RWST 2 SR	1 RHR > 7m level	1 CS >7m lvl 1 MW	1 Pmp 1 Hx	1 OFF SITE 1 DG	1 CC 1 SW	YES	Preparations for defuelling, Activit. after refuelling	Cavity flooded, Internals removed, No fuel movement
8	6	1 CS BAT RWST 2 SR	1 RHR > 7m level	1 CS >7m lvl 1 MW	1 Pmp 2 Hx	1 OFF SITE 1 DG	1 CC 1 SW	YES	Core defuelling and refuelling.	Cavity flooded, Fuel movement in progress
9	0	N/A	N/A	N/A	1 Pmp 2 Hx	1 OFF SITE 1 DG	1 CC 1 SW	NO	Activities with fuel inside SFP	Core de-fuelled

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