IAEA-TECDOC-1806

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IAEA-TECDOC-1806

Nuclear Power Plant Outage Optimization Strategy 2016 Edition

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NUCLEAR POWER PLANT OUTAGE OPTIMIZATION STRATEGY
2016 EDITION

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2016

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Printed by the IAEA in Austria
Ocotober 2016

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Nuclear power plant outage optimization strategy : 2016 edition. / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2016. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1806 | Includes bibliographical references.
Identifiers: IAEAL 16-01071 | ISBN 978–92–0–107816–2 (paperback : alk. paper)
Subjects: LCSH: Nuclear power plants — Maintenance and repair. | Nuclear power plants — Reliability. | Plant maintenance.

FOREWORD

The goal of maintenance at a nuclear power plant is to ensure that nuclear operators have the use of all systems necessary for safe and reliable power production and are able to keep these systems available and functioning reliably. Traditionally, most maintenance activities are performed during refuelling and maintenance outages, which always require a great deal of attention and planning because they are the main cause of nuclear power plant unavailability and are responsible for a large proportion of the operational and maintenance costs of a facility.

In recent years, there have been significant changes in the electricity producing industry, and the electricity market itself has also undergone major changes. This has led to a situation in the nuclear industry in which more and more plant managers are required to reduce their operational and maintenance costs and to increase plant availability while continually meeting the increasing number of safety and regulatory requirements.

Nuclear power plant outage management is a key factor for good, safe and economic nuclear power plant performance. Good outage management practices cover many different areas: plant policy, the coordination of available resources, nuclear safety, and regulatory and technical requirements both before and during the outages.

This publication is an update of IAEA-TECDOC-1315, Nuclear Power Plant Outage Optimisation Strategy, which was published in 2002, and aims to communicate good outage management practices in a manner that can be used by operators and utilities in Member States. The good practices described and the examples of strategies and experiences from current plants in operation on the optimization of outage periods will be of benefit to outage managers, operating staff and local industries involved in the planning aspects of a nuclear power plant. In addition to a discussion of a plant outage strategy and how this strategy is actually implemented, the main areas identified as most important for outage optimization by utilities and government organizations include: organization and management, outage planning and preparation, outage execution, safety outage review, and countermeasures to avoid the extension of outages and to facilitate the work performed during forced outages.

This publication represents a general consensus among experts of the best common practices that can be used at nuclear power plants to optimize outages. It should be recognized that outage optimization is not just a reduction in outage duration, but a long term strategy to reduce the cost of electricity generation by balancing the trade-off between maintaining plant systems to ensure reliable operation during the operation cycle against the cost of lost generation while performing maintenance during outage conditions. Some best practices have the potential to reduce outage duration with no trade-off during the operating cycle by improving work efficiency during the outage.

The IAEA is grateful to the experts and their Member States for their contributions. The IAEA officer responsible for the preparation of this publication was H. Varjonen of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

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

Every nuclear power plant operating organization develops its own strategy for short, middle and long term outage planning. Extensive efforts are usually directed towards detailed and more comprehensive pre-planning to optimize outage duration and avoid outage extensions while at the same time ensuring safe and reliable operation of the plant in the future and minimizing radiation dose to personnel.

Important factor that directly influences availability and costs is outage duration and quality of execution. Planning and preparation are a few of the most important phases in the optimization of an outage duration, which should ensure safe, timely and successful execution of all activities before and during an outage.

Outage management is a very complex task which involves many aspects of plant policy, such as the coordination of available resources, plant safety, the Regulatory Body, technical requirements and all activities and work before and during an outage.

All these elements are part of a plant outage strategy. How plant strategy is implemented is one key element in the successful optimization of outages. Outage optimization itself is a key issue which has many aspects. Reduction in the duration of planned outages can mean that more inspection and maintenance activities are planned to be done as on-line maintenance.

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 and practices 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 as long as 40, 60 or even 80 years. Refurbishment and ageing management 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 programmes with long term outage planning.

This TECDOC outlines some of the main aspects and issues to be considered when optimizing an outage duration. It also provides guidance to outage managers, operating staff and to the local industry. Planning aspects, as well as examples and strategies developed at operating plants, can provide a better understanding of the necessary measures. This TECDOC is an update of IAEA-TECDOC-1315, Nuclear Power Plant Outage Optimization Strategy [1]. This update describes in more detail the whole outage optimization process as well as providing examples of good practices from Member States' nuclear power plants.

As a follow-up to a series of technical publications related to good practices for outage management and cost effective maintenance published in 2007, [2] 2006, [3] and 2004, [4]. The IAEA has produced these technical reports which are more focused on good practices for optimizing safe outage and aims mainly to identify good practices in short term aspects of outage management: outage planning and preparation, outage execution and post-outage review.

2. OUTAGE OPTIMIZATION STRATEGY

The duration and costs of an outage should be optimized to achieve the best possible result, without compromising personal, operational, or environmental safety. The best possible result is in an overall reduction in the cost of electricity generation over the life, or remaining life, of the plant. This requires balancing the best possible capacity factor against the cost required to achieve an optimal level of performance given the expected payback period for investments. Optimization of outages is a continuous process. It is driven by corporate and plant goals as well as regulatory requirements. Due to changing market conditions, a periodic review of the long term strategy may be required.

While there are numerous aspects to consider in outage optimization, this report presents five to be considered when developing or improving an outage optimization strategy:

(1) Nuclear and industrial safety;

(2) Organization and management;

(3) Planning and preparation;

(4) Execution;

(5) Post–outage review.

This section describes why each of these aspects are important in outage optimization and discusses practical implementation of outage optimization strategy.

The key issues for outage optimization strategies are taking care of nuclear safety which is supported by good industrial safety and nuclear safety culture.

A company's management policy of continuous development can also be considered an important factor in outage optimization and evaluation of it. Continuous improvement in maintenance programmes and development of in-service inspections may achieve good results in outage optimization.

During outage planning, preparation and execution, it is very important to follow a process and to intervene during these phases to avoid possible problems and pitfalls and to achieve the best possible result. The nuclear power plant good personnel policies can be a positive contribution to the outages for efficient performance.

To ensure that staff and subcontractors have a focused commitment to the nuclear power plant outage, various reward systems or incentives may be introduced. Good cooperation with operation and maintenance personnel makes it possible to achieve better results of the outage optimization.

After outages, it is extremely important to get feedback from all personnel who were involved in the outages. Operating experiences, which are collected during the outages, are also very useful in improving and developing future outages in order to achieve better results. Collected and useful operating experience should be stored in a system, which is easy to use and available for all. Sharing operating experience between nuclear power plants should also be a high priority in an effort to continually look for best practices.

2.1. NUCLEAR AND INDUSTRIAL SAFETY

A key issue for the outage optimization strategy is ensuring nuclear and industrial safety. This is supported by a good nuclear safety and industrial safety culture as well as their continuous improvement and development.

Safety measures should be prepared and implemented throughout the entire operating lifetime of the plant and for all conditions (operation, abnormal and accident). The outage period should be considered as part of operation, because certain functional systems fulfill their specific duty under these conditions, such as cooling the fuel and preventing radioactive release to the environment. Probabilistic safety analysis has shown that core damage risk during certain refueling stages is as significant as on-line risk. Refueling outages involve additional staff who may not be as familiar with the plant, special care must be taken to ensure contract staff are aware of nuclear safety requirements and participate in ensuring defense in depth is maintained

Nuclear safety includes maintaining plant configurations that support defense in depth availability of safety systems, minimization of radiation exposure (ALARA principle) and minimization of shutdown risk. Shutdown risk, safety systems and key safety parameters should be continually shared with all outage workers. Further information can be found in Section 3.4.8.

When optimizing outage duration and costs, nuclear safety should not be challenged and if possible the nuclear safety should be improved. The safety configuration should be considered during outage planning and preparation, and monitored during execution of outage. After the outage, shutdown risk should be evaluated to make recommendations for future outage plans to reduce overall outage risk.

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

High standards are maintained for industrial work practices and the work environment in order to achieve high levels of personnel safety.

2.2. OUTAGE ORGANIZATION AND MANAGEMENT

At every plant, an outage organizational structure should be created to provide effective execution of all outage processes. Interfaces with organization departments that are responsible for functions that affect the outage processes should be clearly established and understood.

The plant management, in general, should establish clear and long term goals and programmes for all main plant activities.

2.2.1. Outage personnel training policy

Personnel policy strategy aims to support effective outage performance. Important issues to consider are training of all outage staff. In addition to general training, some special training should be given to certain people, such as maintenance personnel who account for complicated and high risk jobs, control room operators and outage control center (OCC) personnel.

Contractors are typically necessary to make up for shortfalls in permanent worker numbers and expertise in focused areas. Therefore, contractors should be trained and qualified according to the utility's training and qualification programmes.

Utilities assume ultimate responsibility for ensuring safety and quality, so the establishment of sufficient supervisory oversight of contractor activities is desirable.

Establishing long term contracts for major work programmes, if practical, and incentive programmes, assist in fostering a safety culture, and long term partnership contracts with contractors. At some utilities the long term contracts are combined with an effectively operated bonus system which can have a positive influence on work quality and accountability.

2.3. OUTAGE PLANNING AND PREPARATION

Outage planning involves many different challenges, such as coordination of available resources, scheduling, safety, regulatory and technical requirements and all activities before and during the outage.

Optimal timing and length of different types of outages should be determined on the basis of the electricity market structure and rules and recourses which are available during the outage as well as the plant design. In more competitive energy markets, it is more and more important that outages are planned as efficiently as possible and carried out more precisely and more economically. By using advanced IT tools during outages, it is possible to achieve better results in outage optimization, Further information can be found in Section 3.3.9, [5].

2.3.1. Economics

The economic challenge in using electricity, which is produced by nuclear, renewable, or other competitive energy recourses, has a significant role in the future use of nuclear power plants (NPPs) but also possible planned lifetime extensions. For this reason production costs should be driven as low as reasonable, without compromising NPPs safe operation.

In developing and executing the strategic and operational objectives, plant managers must adopt and express fluently and consistently all goals and business objectives that reduce unnecessary costs. Optimization of outage costs is one key element in maintaining the competitiveness of nuclear–generated electricity compared to other energy sources.

From the view of the NPP operator, the effectiveness of electricity generation and the availability of the plant can be improved by shortening outage duration. Performing an economic study will aid in choosing 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. The most important factor for minimizing outage cost is likely to be the market price of electricity in the NPPs local area. The market price for electricity may be driven by varying seasonal demand for electricity or the availability of competing electrical generation. Additionally, the availability of supplemental contract workers may need to be coordinated with other NPPs to spread out the impact of too many concurrent outages competing for resources.

Sufficient early assessment and review of the cost of outages is an integral part of cost effective management. Improving the overall economics of an NPP requires a comprehensive understanding of the relationship between operations and maintenance.

Cost effective outage planning basis should not therefore, be a maintenance cost minimization or maximization of performance of nuclear power plant, but rather to maximize the long term profitability, while preserving the nuclear power plant high safety and confidence of stakeholders.

2.3.2. Modifications and renewal strategy

Safety improvement and modernization programmes are an important part of medium and long term outage planning and large investment projects are best fitted together with the outage strategies. Outage related projects are better managed by utility personnel and progress reviewed periodically together with everyone involved.

Guidelines for plants and instructions for investment project execution are essential.

A project plan defines project scope, execution time, operational state, and planning and implementation resources and describes the procedures for monitoring progress during design and implementation.

The project manager’s responsibility is to ensure that cooperation with line organization and the outage planning department is comprehensive and effective during the whole lifetime of the project.

Significant modification implementations would be better done at one unit/year, in order to gain experience from assembly, startup and operation of new equipment or systems so in case of any problems, only one unit suffers the consequences.

2.3.3. Maintenance strategy definitions

2.3.3.1. Overview of maintenance strategies

Maintenance, which aims at keeping equipment reliable and functional, is essential for the long term, safe and economic operation of NPPs.

The main stages (or process phases) of maintenance include strategy definition, preventive work programme definition, work scheduling, work planning, execution, and experience feedback. The maintenance strategy must be adapted to the stakes, the preventive maintenance programme must be methodically optimized, scheduled work must be carefully planned, necessary skills must be maintained, and feedback based on experience must be efficiently organized [4, 6].

Plant maintenance programmes are based on four defined strategies; predictive, preventive, combined and corrective maintenance. Each piece of equipment belongs to one of these strategies based on the selected maintenance tasks of the equipment. Maintenance tasks are based on equipment criticality classification, equipment type, operational conditions, operating hours, operational experiences and other possible requirements.

Online maintenance strategies are found and implemented at the plants on two different basis or some kind of mix of them. The first is an equipment level criticality classification based on maintenance strategy principals (Ex. INPO AP-913), the second is a probabilistic safety analysis (PSA) approach which is founded on a system and safety function level configuration risk assessment [7].

2.3.3.2. Predictive maintenance

Predictive maintenance is based on the equipment condition and performance. During the maintenance monitoring period tasks equipment are available. Based on the collected information corrective actions will be defined. Condition monitoring can be on–line or off–line depending on equipment type and criticality.

More so than in the conditional maintenance, it is necessary to master the technology and the behavior of the concerned equipment in its normal conditions to consider the possibility of such maintenance strategy.

It is based on the analysis of the evolution of technical parameters that describe the equipment conditions and detect potential degradation. This type of maintenance is more precise than the conditional maintenance because it is used to anticipate and better predict when maintenance intervention should be carried out but it is more complex to implement.

Condition based maintenance tasks are for example:

- Process parameter monitoring;
- Vibration monitoring;
- On-line inspections;
- Surveillance programme;
- Thermography;
- Acoustic emission;
- Oil analysis.

2.3.3.3. Preventive maintenance

Time based maintenance, which is used for the components where condition based maintenance is not justified. During maintenance the equipment is unavailable.

Time based maintenance tasks are for example:

- Periodic overhaul;
- Periodic inspections;
- Oil change.

2.3.3.4. Combined

Combined equipment strategy covers the most critical plant equipment in criticality classes 1 and 2. Part of the criticality class 3 equipment may also be included within the scope of this strategy. A combined strategy consists of predictive, maintenance conditional and scheduled tasks.

2.3.3.5. Corrective maintenance (run to failure/run to maintenance)

Equipment in this strategy does not have any pre-planned preventive maintenance tasks. Only visual observation rounds are used to track the equipment condition. Functional failures are allowed in this strategy.

In this strategy, components are deliberately allowed to operate until they fail or break down, at which point reactive maintenance is performed. No pre-planned maintenance is performed on the components up until the failure event. RTF components can be repaired or replaced without causing production or safety issues to the plant.

2.3.3.6. Equipment criticality classification

The objective is to identify critical components for the plant production and safety. Optimal maintenance strategy for the equipment is based on this classification. Classification is used in planning of maintenance programmes and spare part strategy. All components are normally classified in one of the three or four classes. Classification is based on production, safety, availability and authority requirements for the equipment taking into account maintenance and replacement costs. The classification is evaluated and can be changed based on the periodic review of maintenance strategy taking into consideration the maintenance and operational experiences.

2.3.3.7. Maintenance programme optimization

Optimization of maintenance programme is a continuous process. It is driven by corporate and plant goals as well as authority requirements. The main goal of the maintenance programme optimization is to focus the resources in the right areas to ensure plant safety and reliability for the short and long term operation. More details for maintenance programme optimization can be found from IAEA publication [4].

Strategy to evaluate correct operational state for work.

Quantity of on-line maintenance is depending on plant design, policy and regulatory requirements. Plants that perform less on-line maintenance are those which have less well controlled outage durations, due to work overload during outages.

Every work completion and timing should be evaluated for technical specification, PRA, production losses, nuclear and personal safety. Preventive maintenance work operational status should be defined to plant information system and this should be continuous re-evaluated, furthermore, based on operational experiences and Key Performance Indicators (KPIs).

Examples of criteria for on-line maintenance are:

- Nuclear safety related systems and components that have several redundant backups, allowing for one redundancy at a time to be taken off-line without an unacceptable increase in the risk associated with unavailability of the safety function;
- Nuclear safety related systems and components whose availability is essential during shutdown, startup and outage;
- SSCs which are not essential to the safe and reliable operation of the plant.

Work, which can be done safely without unacceptable increase of safety and production lost risk during operation, must be done during operation!

2.4. 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. A primary measure of successful outage execution is how closely final outage duration matched the planned outage duration. Section 3 will provide recommendations for improving outage execution, but the key factors usually come down to communication. Effective communication of work status, priorities and issues will always be critical to outage execution.

2.5. POST–OUTAGE REVIEW

After outages, it is extremely important to give feedback for all personnel who are involved in outages. Operating experiences, which are collected during the outages, are also very useful to improve and develop the future outages to achieve better result. Collected and useful operating experience should be stored in a system, which is easy to use and available for all.

Sharing operating experience with other utilities will benefit the entire nuclear industry. Lessons documented from previous outages should be reviewed just prior to the start of each new outage.

2.5.1. Outage operating experience

A corrective action programme (CAP) should be developed to assist in the management of the corrective actions. The extent of the CAP should be determined based on the significance, impact, number, and complexity of the problems and corrective actions to resolve the findings. The CAP report should be written by the persons/organization that was assessed or where the event occurred. CAP should be approved by the manager and authorized to provide the resources (funding, personnel and time) needed to implement the corrective actions successfully within the time specified in the plan.

A prioritization process should be developed based on the significance, complexity, and impact of the findings in determining the sequential order for development and implementation of the corrective actions. Other factors (i.e., resources and costs) should also be considered. The prioritization process may include numerical prioritization of each individual finding or establishing a number of priority categories.

All required resources (funding, personnel, time, and materials) should be determined to successfully complete each corrective action. This will also have a major impact on scheduling of the corrective action.

A systematic process should be developed for tracking and reporting the status of each corrective action to successful completion [4].

Most nuclear power industries have a CAP to identify any plant problem or issue, evaluate its causes, establish corrective actions and review the effectiveness of such actions. The CAP is a process designed to deal with the reported problem as depicted in Fig.1.

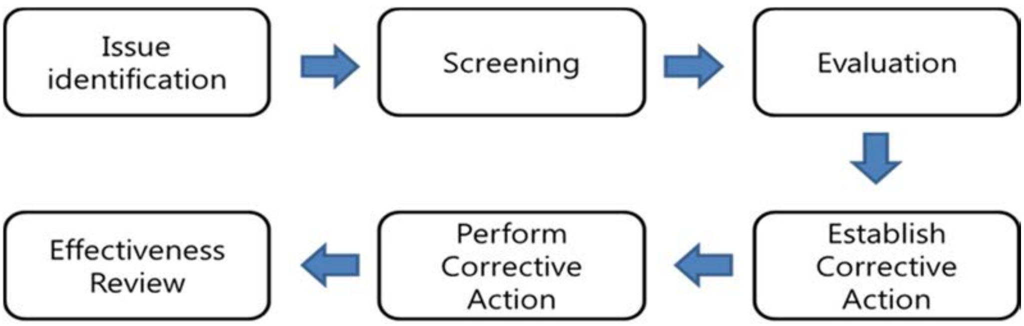

FIG. 1. Simplified process of a typical CAP.

A brief explanation of each module of the process as follows:

- *Issue identification*: Anybody working at the plant identifies a condition that does not meet requirements or that can be improved. The form used in the problem identification is often called the condition report though other names are sometimes used also. This identification can be any kind of problem, event or adverse trend that affects plant safety, reliability, operation and regulatory requirements. All reported issues should be documented in either a computer database or on paper to review and track to completion. All the relevant data and evidence are collected and documented on the condition report as practical.

- *Screening*: All issued condition reports should be reviewed first to determine if the reported issue affects plant safety, technical specification limitation, operability and/or reportable issues to the regulator. The issue should also be reviewed for quarantine, prompt investigation and immediate actions. When an issued condition report requires field work, a work order should be created.
- *Evaluation:* The evaluation is performed depending on the level of significance determined by the screening committee. Most CAPs include detailed trending codes which, when assigned correctly, will identify trends in the level 4 events which may be more significant than the events appear to be individually.
- *Establishment of corrective actions:* When the cause of the failure is identified, an appropriate corrective set of actions should be established to correct the adverse condition of the system, structure or condition and solve the cause of the failure. The corrective actions should be documented and entered in an action tracking system to be monitored and tracked against assigned due dates.
- *Completion of corrective actions:* Corrective Actions with proposed due dates are forwarded to assigned supervisors for assignment within their work groups. It is expected that persons assigning actions will review the action and proposed due date with the assigned supervisor prior to forwarding the actions. The supervisor reviews the action, and if the due date and action are agreeable, assigns them to an individual. If for some reason, the action cannot be completed as assigned, the action can be reviewed and approved to issue an alternate action or duration. Note that any alternate actions should receive the same level of analysis, review and approval as the original action which is replaced. When the worker has completed the action, it is routed to the supervisor for approval. If approved, the supervisor progresses the action to the closed status using the features of the computer tracking system.
- *Effectiveness review*: For all root cause evaluations, an effectiveness review will be conducted at a point following completion of all associated corrective actions. The effectiveness review should determine if the desired change was accomplished and that no new problems were developed as a result of the corrective actions. The acceptance criteria for the effectiveness review should be established at the time of the evaluation, and based on best industry practices [4].

The outage experience feedback system should include review of own outage performance and could also include evaluation of outage experience feedback from other plants. Effectiveness in gathering and applying lessons learned from outages and other experiences is essential for continued improvement and long term success. Management uses the gathered information, regarding problems and successes from recent outages, to improve performance of the following outages. It is important to measure the effects of actions being taken. Efficient performance indicator system should be operated fostering the evaluation and comparison the outages performances.

Benchmarking is a helpful tool for optimizing outage performance. For example, excursions, comparing processes with similar plants or reactor types. For more specific areas of improvement, benchmarking could be considered with a whole different business area, e.g. improvement of feedback gathering with marketing company.

Comparison and share between the different operators' practices in the main steps of an outage and the optimization strategy: short term aspect of outage management but also middle term and long term aspect of outage management. In the short term aspect of outage management, the benchmark can be focused on the practices on outage planning and preparation, outage execution (intervention quality, etc.) and post–outage review (how to evaluate an outage, only KPIs, a dedicated report, etc.?).

To provide history of the outage, an outage report should be created including the key activities, lessons learned, outage critique and actions taken including an effectiveness review.

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 and industrial safety, (2) Organization and management, (3) Planning and preparation, (4) Execution, and (5) Post– outage review.

3.1. NUCLEAR, RADIATION AND INDUSTRIAL 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 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.

- Keep and evaluate safety margins;
- Defence in depth plan;
- Protected equipment programme;
- Safety recommendations, i.e. from WANO;
- Daily safety analysis or risk assessment.

It is important to develop safety culture amongst staff at the plant. Every employee should be able to identify possible problems and deviations from normal plant conditions during outage. A good reporting system will improve safety culture and ensure that problems, failures and near miss events are promptly 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 licence owner has to act in a proactive way and get the agreement of the respective authorities for the updating process. Quality assurance measures implemented throughout the planning, preparation and execution of the outage will help enhance the quality of the work and support nuclear safety.

Good housekeeping, a clean work area and low dose rates are important for safe, efficient and in-time maintenance to ensure optimization of an outage duration.

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

Daily radiation monitoring and electronic dosimeters help to assure that dose limits are not 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 during the planning phase.

The collective dose rates of both plant and contractors' staff received during plant operation and maintenance periods should be monitored and 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 fulfillment 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 personnel performance and to quickly identify potential problems.

Specific industrial safety criteria:

(a) An industrial safety programme with specific objectives and clearly defined policies, procedures and responsibilities is developed and implemented.
(b) Safety committees are established that include participation by personnel at all levels of the organization.
(c) Managers provide the resources, training and equipment needed to implement the organization's industrial safety programme properly.
(d) Leaders promote industrial safety by setting strategic goals and objectives and by monitoring and coaching workers to improve safety performance. They actively communicate with the workforce, enforce established standards and are held accountable for the industrial safety performance in their work groups.
(e) Personnel understand what is expected of them regarding industrial safety and perform work in accordance with established industrial safety standards and expectations. They are accountable for their behaviors and actions related to industrial safety.
(f) Supplemental personnel are accountable to the same (or equivalent) standards as utility personnel. A communication process is established to ensure supplemental workers understand industrial safety standards and performance expectations. Service contracts include industrial safety requirements; and the selection of a supplier is, in part, based on an evaluation of the supplier's ability to deliver the product or service safely.
(g) Personnel receive training to acquire the necessary skills and knowledge to perform work in a safe manner. Initial and continuing training topics include industrial safety programme requirements, protective clothing and equipment use and hazard recognition and mitigation to prevent injuries.
(h) Industrial safety is integrated into station planning processes, including the work control and engineering design change processes. Plant modifications are designed and installed as needed to improve personnel safety.
(i) Permanently installed and portable safety equipment (including fume hoods; safety showers; eyewashes and fire protection equipment) is maintained, inspected and tested periodically to confirm it is readily available and functions properly.
(j) Personnel protective equipment and clothing (including items such as respirators; safety harnesses; fire-rated clothing; hard hats; work gloves; eye and hearing protection) are available, stored appropriately, maintained and inspected prior to use.
(k) Personnel select the correct safety equipment for the task. Personal protective equipment and other safety equipment are used appropriately.
(l) Prior to work, personnel ensure that the appropriate warnings and barriers to injury are in place for their safety and the safety of others. This includes ensuring

that equipment is in a safe condition and that appropriate permits and permit requirements are in place. The safety constrains for working in clean working areas or tanks and closed work areas are clearly defined and taken in the consideration.

(m) Personnel select and use the appropriate and inspected tools for the work being performed.

(n) Materials and equipment in work areas are stored and controlled to maintain safe housekeeping standards and minimize the potential for injuries.

(o) Bulk chemicals, compressed gases, corrosive agents, organic chemicals and cleaning agents are labelled and stored properly and are controlled and handled consistent with the hazard classification and safety data sheets to prevent improper use and to protect personnel.

(p) Safety hazards are identified and reported using appropriate station programme, such as the corrective action process, so they are visible to both workers and managers. Hazards are evaluated in a timely manner and actions to mitigate or correct hazards are developed and given the appropriate priority.

(q) All injuries and near miss events are reported and evaluated, as appropriate. The causes and corrective actions of investigations are communicated as appropriate to reduce the potential for repeat events. Corrective actions are developed to prevent recurrence and improve the industrial safety programme.

(r) Individuals proactively report low level incidents, coach coworkers and correct conditions when substandard behaviors or conditions are identified.

(s) Performance measures are defined and are used by managers to determine industrial safety trends and establish future direction. A means is implemented to collect, evaluate, correct and reinforce safety behaviors rapidly during periods of high work activity such as refueling outages.

(t) Benchmarking, self-assessments and audits are used to evaluate and improve industrial safety and performance.

(u) Industry operating experience is reviewed regularly and is used to improve performance and the industrial safety programme.

3.2. OUTAGE 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. Senior management should ensure outage managers have the required level of influence in setting station priorities prior to the outage. Management expectations should be well communicated to the staff. Objectives and goals should also be clearly established and communicated. Outage should be viewed as a station priority, not just a work management priority. All plant personnel should feel they are part of the outage [8].

Managers should make an effort to be the leaders and should develop the best qualities of personnel. They should understand and appreciate the significant operating experience lessons and be aware of the associated events that provide the lessons. In addition, important operating experience from significant events should be used to shape the organizational culture.

Maintenance personnel should be engaged in station projects and initiatives to improve plant, equipment and work processes. Maintenance personnel should be involved in solving emergent equipment problems.

Organizational and management principles applied in outage management should be based on process and quality management procedures rather than on those procedures applied in multilayer hierarchical organizations.

Preventive maintenance implementation should be a station priority. The station management team should monitor implementation and leaders enforce accountability at all levels.

Work management processes should be well defined and performance should be routinely measured, trended and critiqued. Corrective actions to close performance gaps should be identified and tracked to completion. Workers and support personnel should participate in post-job critiques of completed work.

Maintenance and other site managers should create an effective means of feedback that promotes continual improvement in station and supplemental personnel performance.

Cross-functional expertise is necessary to take responsibility for equipment as well as for maintenance, control, scheduling and engineering that have a direct influence on plant performance. Maintenance personnel should recognize the importance of the equipment being maintained to operations and plant safety.

Extensive training and retraining programmes should be implemented. Maintenance personnel should have good site awareness to prevent inadvertent equipment actuation, misposition or damage, as well as to prevent injury to self and others. As such, a strong nuclear safety culture should be created and continually supported that each individual accepts the unique responsibility inherent with using nuclear technology. 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. For example, outage managers may have previous operations experience as well as maintenance or work management experience.

Maintenance and other site managers should provide oversight of supplemental personnel on a regular basis, especially during critical work activities and when supplemental personnel perform work independently.

3.2.1. Outage organization

Different outage organizations have been used 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 an 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 outage management personnel have to be able to coordinate the plant maintenance, renewals and project activities with the outage strategy taking into account safety and operational considerations. Aiming this special goal the outage organization has to be furnished with the proper authorities and expertise in the outage planning and execution phase also. In many plant organizational structures outage management is based on an effective outage organization which is an equal independent partner of the operation, maintenance and technical divisions. Due to the parallel roles and responsibilities it is beneficial that the same organization is in charge of the planning and execution activities, but most utilities apply extended and strengthened staff during execution phase.

The need for 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: permanent outage structure (see Fig. 2) and outage project team (see Fig. 3). At the moment it seems the more efficient organization is the outage project team which comprised of staff from the different plant departments, e.g. maintenance, operations and engineering.

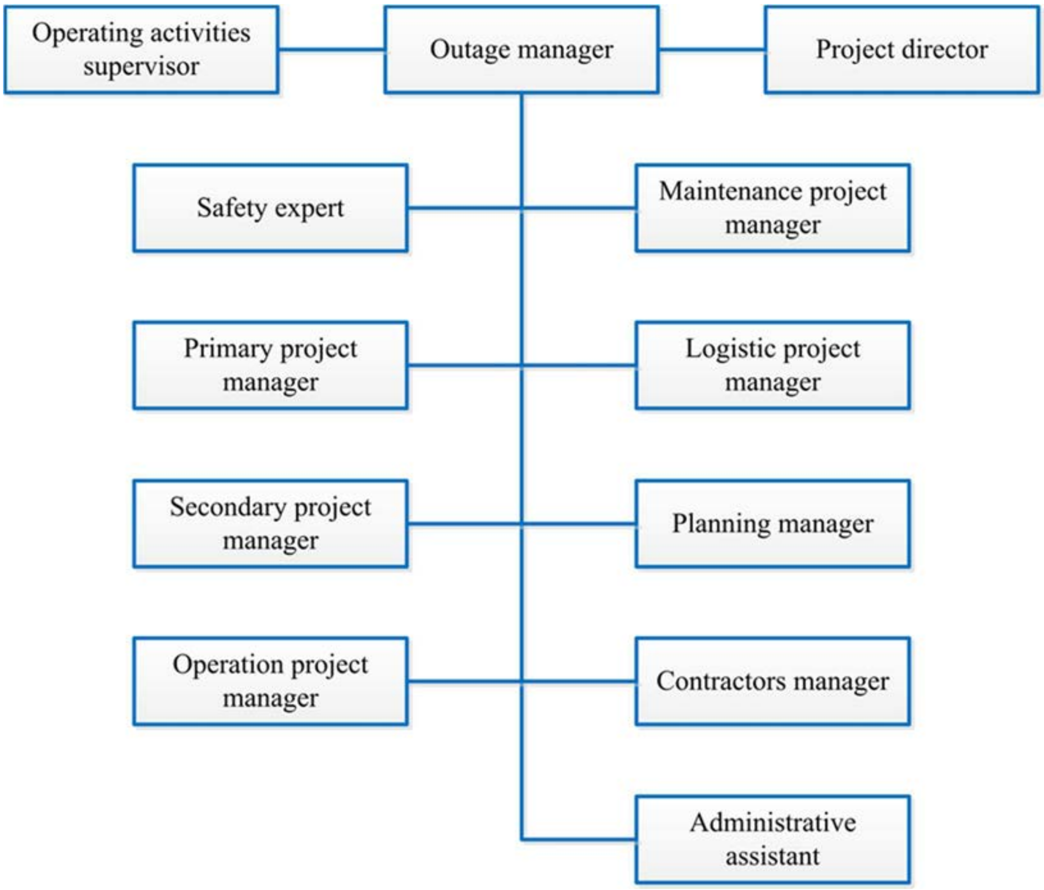

FIG. 2. Example of permanent outage structure.

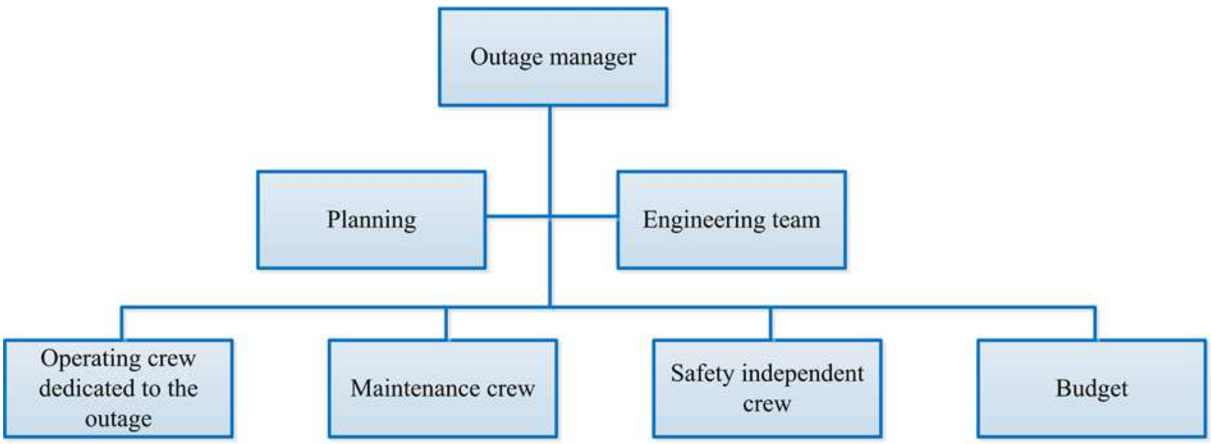

FIG. 3.Example of project outage team.

The OCC should work to prioritize schedules and coordinate resources using real time data exchange. This allows better and more consistently deliver services safely, with high quality, and on schedule. This ability helps to achieve outage performance goals and improve the ability to immediately respond to emergent issues.
An OCC coordinates the outage planning and execution and brings together all the personnel involved in the outage, which report to a decision making steering group headed by the plant manager. In particular, the centre includes a coordinator for each major function and/or equipment that is under maintenance, test or inspection during outage. The coordinator makes the bridge between the operations and maintenance departments and the OCC.

The outage planners and coordinators 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. Responsibilities and working methods of outage organization should be guided in plant specific procedures.

Institute of Nuclear Power Operations (INPO) document on AP–913 method: definition of the component engineer at component team [7].

The component engineer monitors at least components which are classified according to the requirements.

The component engineer knows its equipment, knows the “as found” state of the equipment through regular visits; he participates in the assessments conducted on these equipment, if necessary. In addition, he develops and analyzes data from the operating and maintenance experience feedback concerning its equipment; he may propose actions in order to improve the reliability of components and optimizes the preventive maintenance programmes.

OCC, operations and other key organizations should screen new work collaboratively to determine the appropriate priority and classification of an identified deficiency based on its safety significance, operational impact and effect on emergency preparedness. Priorities should be well defined, communicated and adhered to. Previously prioritized work should be periodically re–evaluated based on the aggregate impact of deficient equipment or operational conditions.

Periodic reviews of backlogs should be conducted to verify appropriate priorities are in place. These reviews should focus on understanding and managing the aggregate and individual impacts of the backlogs.

Resources should be confirmed and committed to complete the scheduled work. Committed resources should be monitored by the OCC and gaps should be identified and closed to support the scheduled work. Shop supervisors should inform the OCC as soon as possible if activities from the schedule need to be revised. This will ensure dependent task resources are effectively used. Continuous review of the schedule is required to identify possible schedule conflicts or shortfalls in resources. This is especially true when new work is added to the schedule or when works starts to slip on the schedule.

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.

3.2.2. Contractors relation

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 developments 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. Also the responsibility of the plant and contractors should be clearly defined; and senior contractor managements should supervise their outage preparation and worker performance station staffs still should provide oversight for contractor's work.

Contractors should be made aware of management expectation and outage performance, and should be trained and qualified according to utility's training and qualification programmes, and actively participating outage preparation and feedback to improve outage execution and management. Because of distinction between nuclear plant and other industries, it is necessary to provide training for contractor personnel of nuclear safety, human performance tools such as procedure-compliance, self-check, pre-job briefing and post-job debriefing, etc.

Usually it is a good practice to use long term contracts with partnership relations including deep ownership of the contractors for outage tasks. The use of local industry capability is also preferable and cost effective. Normally, frequently changing the contractors will increasing management cost and increasing safety, quality and schedule control. When establishing long term contracts it is important to preserve a competitive market situation. And contractors, incentive programmes fostering safety culture, and long term partnership contracts with contractors.

Key performance indicators (KPI) should been setup to evaluate the contractors work, and when applicable, if the plant satisfied with the results of KPIs, contractors will receive the premium which preset before outage.

For ensuring continuous competence and quality of work, the ratio of new contractor employees versus experienced should be balanced. Correct ratio should be considered in contracts. It is also good practice to provide contractor personnel accommodations, catering, transportation and leisure programme.

The performance of contractors is important to achieving outage objectives and goals. So it is good practices to establish a strategic partnership with main contractors, who will share utility's vision and safety culture, and have deep ownership and accountability. It is also important to systematically assess contractors competency including management and technical ability compare to the market. According to assessment result, replace contractors if necessary, but don't recommend frequent changing of contractors.

Since these contractors may have obligations to other nuclear power plants, it may be necessary to negotiate the level and timing of contractor support early to ensure contractor availability. It may also be necessary to coordinate with these other nuclear power plants that share resources to ensure contractor availability.

3.2.3. Key performance indicators

Prerequisite for performance indicators are, that the plant has defined processes to ensure sufficient and correct initial data collection for plant information systems. This database is used to form necessary KPIs for outage planning, implementation and post evaluating.

Measuring the success of outages can be divided into three areas; planning, implementation and post evaluation.

3.2.3.1. Measurement of outage planning

For outage planning measurement, following initial data is needed:

- Outage type;
- Outage date and duration;
- Main work;
- Packages and schedules;
- Planning orders;
- Work orders;
- Resource reservations, spare parts and prefabrications;
- Budget;
- Schedule for pre-outage planning (see Chapter 3.3.3);
- Comparable initial data from the previous same type of outage.

Utilizing the database above, outage planning success, status and effectiveness describing KPIs can be formed, for example:

- Planning order on time/late delivery and comparison to year of reference [e.g. %, pcs];
- Readiness of resource reservations, spare parts and prefabrication [e.g. %, pcs/total];
- Amount of work in different type of work classes (PM, corrective and modifications) [e.g. %, pcs/total];
- Planned cost forecast [e.g. €/$/];
- Amount of resources and comparison to year of reference [e.g. %, pcs].

Reference and more details in Loviisa case study Annex V.

These KPIs should have defined target values, which actual values will be monitored. Deviations should be investigated and, if necessary, define corrective actions.

3.2.3.2. Measurement of outage implementation

For outage implementation measurement, following initial data is needed:

- Critical path;
- Section schedules;
- Isolations;
- Radiation doses;
- Package schedules;
- Resources;
- Work orders;
- Work hours;
- Costs;
- Work related accidents / near misses;
- Foreign material exclusion.

Utilizing the database above, outage planning success, status and effectiveness describing KPIs can be formed, for example:

- Critical path tracking [e.g. d,h,min];
- Section schedule progress [e.g. d,h,min, %];
- Work readiness (not started/started/ready) and comparison to year of reference [e.g. %, pcs/total];
- Amount of unplanned works [e.g. %, pcs];
- Packages readiness [e.g. %];
- Radiation dose tracking, planned vs. actual and forecast [e.g. manmSv];
- Amount of contractors [e.g. total, personell/d];
- Amount of work related accidents [e.g. %, pcs];
- Budget tracking and forecast [e.g. €, %];
- Additional work during outage [e.g. %, pcs, pcs/total];
- Work moved to next outages [e.g. %, pcs, pcs/total];
- Number of foreign material (removed/remained) [e.g. pcs].

These KPIs should have defined target values, which actual values will be monitored. Deviations should be investigated and, if necessary, define corrective actions.

3.2.3.3. Measurement of post-outage evaluation

For post-outage evaluating measurement, following initial data is needed:

- Observation / special reports;

- Operational experience reports;
- Actual schedules;
- Feedback;
- QA-reports;
- Work hours;
- Costs;
- Radiation doses;
- Work orders.

Utilizing the database above, outage planning success, status and effectiveness describing KPIs can be formed, for example:

- Work specific production losses, caused by delays [e.g. MWh, €];
- Amount of feedback for different sections [e.g. pcs];
- Number of deviations according QA-audit results [e.g. pcs];
- Estimated vs. actual costs [e.g. %, €];
- Estimated vs. actual radiation doses [e.g. %, manmSv];
- Planned vs. actual work hours (normal/overtime) [e.g. h, %];
- Planned vs. actual schedules [e.g. h, %];
- Number of re-work [e.g. pcs, %].

These KPIs should have defined target values, which actual values will be monitored. Deviations should be investigated and, if necessary, define corrective actions in short and long term planning period.

3.3. OUTAGE PLANNING AND PREPARATION

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 utilization of critical resources.

Reliability centered 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 back fittings and refurbishment. The long term plan optimizes 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 I presents the long term plan used at Teollisuuden Voima Oyj (TVO) 1 and 2 NPP in Finland.

The *medium term plan* is used to coordinate the outages of all plants and take into account electricity market 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 back fitting / 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 10 to 12 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 even 24 months. The fuel cycle optimization depends on the electricity market situation. The cost of fuel enrichment could also have an impact on the economically optimal fuel cycle.

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:

- Refueling only, this could be worked out in 7 to 18 days;
- Refueling and standard maintenance, which could be worked out in 14 to 23 days;
- Refueling and extended maintenance, this could be worked out in 15 to 40 days;
- Specific outages for major back fittings or plant modernization which could take more than 40 days.

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 refueling 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 of 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, meetings, no return points etc.;
- Outage duration for all three 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;
- Using online application modules of modern scheduling and engineering tools the synchronism of the main schedule the sub schedules and the work packages can be easily provided;
- 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 and 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.

Small group activity for detailed work sector preparation should be considered. It’s a guided and coordinator managed group which takes responsibility for a specific work sector; pressure vessel, electrical work, valves, PCP, diesels, etc.

This group reviews all work from its own area, checks scheduling and isolations, makes necessary planning and work orders, spare parts mapping, ensures prefabrications, resources, safety, risk assessments, readiness and impact to other work. Generally, this group takes responsibility for the whole work sector.

Small group is a selection of experts from various departments, which are relevant to prepare the concerned work section as wholeness, such as: radiation control; mechanical, automation and electrical maintenance; technical specifications engineering; scaffolding; work planning; outage planning and logistics.

Small group meets regularly, reviews readiness and possible issues and defines corrective actions if necessary.

Annex III Case study; "Turbine modernization in normal refueling outage at Loviisa 1 in 2014".

3.3.3. Outage scheduling

The critical path is the longest necessary path through an outage. A task on the critical path cannot be started until its predecessor is completed; if it is delayed, the entire outage will be delayed, unless the following task is completed faster than planned. The risk of outage extension could be reduced by carefully monitoring critical path, and work that has a risk to become a part of it.

Outage scheduling begins by defining the main work, which is the basis for a main schedule. The critical path is determined from the main schedule. Other schedules are made based on the main schedule. Besides the entire above, package schedule is based also on safety charts (see Section 3.4.7).

A package system (AKA system window) is created to aid outage work management. All plant process systems are divided into packages. Work packaging is aimed to intensify work management and outage control. Package is isolation, emptying and de-isolation plan for sub process, which is completed as wholeness. Safety measure packages ensure plant and industrial safety during work execution.

Necessary schedules for outage progress tracking:

- Outage planning schedule (Case study see Annex III);
- Main schedule (process logic);
- Shutdown schedule;
- Startup schedule;
- Schedule for reactor maintenance work;
- Package schedule;
- PCP maintenance schedule;
- Steam generator / primary circuit work schedule;
- Emergency diesels maintenance schedule;
- Electrical systems maintenance schedule;
- Safety systems (train) flow charts;
- Other significant work or project schedule if needed.

3.3.4. Planning modifications and renewals

It's recommended, that the projects are coordinated by utility personnel, 'turnkey' is not suitable for NPPs. Projects should be identified while establishing medium and long term plans. Project readiness for outages should be checked periodically and milestones and no return points should be defined. Scheduling should be done together with outage planning and suppliers. Communication between the project office and outage planning is important, to define starting renewals and modifications early enough to optimize scheduling. Responsibility for the interfaces should be clear and amount of incoming contractors should be defined for better management of contractors and logistics.

It’s good practice to implement modifications done at one unit / year, to get experiences from assembly, start up and operation of new equipment or system and in case of appearing problems, only one unit suffers.

Work that can be done safely during operation be supposed to be done during the operation.

3.3.5. Processes and tools for outage optimization

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;
- Early execution of planned inspection of system and components to help avoid 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;
- Procedure for scope change (additional work after scope freeze);
- Projects and renewals could bring work, which have never done before, and are therefore challenging to schedule, so it’s recommended prepare to reorganize schedules resources and priorities to handle situation, where critical path work are going faster than excepted;
- 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 coordination between outage and operations team;
- Maintenance programme optimization;
- Work group activity (see Section 3.3.2);
- 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 minimize outage time depending on the reactor type, such as:

- Modernization of refueling machines;
- Fuel leak detection by mast sipping;
- Support bridge at refueling 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.

3.3.6. Mobilization 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 back fittings;
- Checking for and reserving, material, spare parts and consumables available on-site, in early stage enough before the outage start;
- Sharing human and material (cranes, hoist, special tools, etc.) resources in the utility and among utilities;
- Assigning additional coordinators for specific work areas if necessary, e.g. crane usage or pressure vessel work.

More details for procurement engineering and supply chain to support operation and maintenance can be found from IAEA publication [9].

3.3.7. Outage readiness

The objective of a review of outage readiness is to verify that the preparation work is in accordance with established plans and procedures and that the outage can be executed as planned. The review is a structured procedure during with information regarding the status of the outage preparation work and risk associated with both the preparation and execution of the outage is gathered and analyzed. A combination of self– and independent assessment shall be used for the readiness review.

The review of outage readiness could, for example, be performed 18, 12, 6 and 3 months prior or even more frequently when approaching to the start of the outage, based on which type of outage that is going to be performed: refueling, maintenance or modifications outage.

One objective of the readiness review process however is to assure that the relevant projects, engineering programmes etc. have been assessed by a project challenge process.

The general objectives of the readiness review are to judge if the outage can be executed as planned. More specific the readiness review shall focus on the following issues:

- That the objectives of the outage is clearly defined and understood by involved parties;
- To review the progress of the outage preparation work. Shall include a review that vital milestones as specified in the outage planning and preparation process have been met;
- Review that preparations are sufficient both regarding maintenance work, plant modifications and other work to be performed during the outage. For plant modification projects a health check is performed independent of the readiness review. The focus of the readiness review is to ensure that project health checks have been performed with acceptable outcome. This review will, together with the review of the progress of the outage preparation work, give the outage manager and relevant safety oversight level the possibility to exclude work that are not showing sufficient progress;
- Review the process for scope control and the stability of outage scope;
- Check that all safety related issues such as safety shutdown plans have been reviewed in a timely manner;
- Review the organizational readiness, which includes roles and responsibilities, processes and procedures for preparation and execution of the outage, staffing plans, finalization of outage specific preparations such as operational instructions etc.;
- Review that relevant procedures are being followed and that previous identified actions have been performed.

3.3.8. Risk analysis

Risk management is defined as the process that identifies analyzes and manages risks in the business. The process does cover mitigation actions in order to minimize both the probability and the consequences of events with negative impact on the goals as well as actions in order to maximize both the probability and consequences of events with positive impact on the goals.

For each outage a risk assessment shall be performed. The risk assessment shall consist of both a quantitative (where the consequences in the form of outage prolongation or additional costs) and a qualitative analysis (where the risks are identified and the consequences for each risk are described).

The qualitative risk analysis is the process during which risks are identified and their effect and probability to affect the objectives are evaluated. The risks are prioritized and the objective with the analysis is primarily to identify actions in order to reduce the risk.

The quantitative risk analysis will mainly be used in order to evaluate the total risk exposure for the fleet and to judge if mitigating actions needs to be taken on fleet level. The analysis shall define the probability to reach the stated targets as well as describe the total risk exposure (expressed as outage extension) for the outage and the possible reserves that may be needed.

3.3.9. IT tools

A user friendly IT-system that supports the first line users is essential for a safe and effective outage.

To set up the amount of IT support during outages is a good practice to do classification on your IT-system to set up the requirements for the availability of your system etc. Specify the requirements for restart of the system in case of an IT-system shut down. A back-up procedure to handle the situation if the system will crash should be considered.

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

- Work order and permit administration;
- Preventive maintenance;
- Planning and scheduling;
- Project planning;
- Material and spare parts management;
- Plant technical data;
- Plant operation and maintenance history;
- Radiation dose control;
- Personal database;
- Account control;
- CAP, experience reporting;
- Key performance indicators.

If the system doesn't include the essential parts from above, there should be a very well integration between each IT tool to simplify the work for the user.

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. OUTAGE EXECUTION

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. Is it recommended to establish and efficiently operate in three shifts an OCC involved the all affected organization members. (see Chapter 4)

Prefabrication of parts for 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 is 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 coordination and communication, work control management execution of the maintenance, and ensuring, and radiation and industrial safety.

3.4.1. System/component preparedness and handover

The timely and proper preparation of the maintenance of equipment is relevant and important for effective outage execution. The clearances of the components and the preparedness of work areas have to be checked on in the field before starting of work activity. In some structure a particular group led by the OCC is responsible for these tasks.

3.4.2. Information in the field

Staff involved in the outage should be well informed about the outage progress. Mechanisms to communicate status and progress of outage should be implemented and guided. It is useful to prepare sub schedules for the main work processes providing the all work phases involved personnel on the workplaces located wall posters or information screens or portable online workflow IT tools could be efficient and usable tools to help the orientation and cooperation of the affected workers. (see Chapter 3.4.10) Some operator applies monitors or interactive electronic surfaces representing the basic outage information of outage: actual unit configuration, main and sub–schedules of critical path, workflow status, delays, radiation maps, crane timetables, industrial safety cautions or even providing optional access and usage the plant technical data base. The work documentation package could also contain supplemental information for workers. Another good practice could be to provide the staff with small size outage information brochure.

3.4.3. Foreign material exclusion

It is important to create mechanisms to promote safety culture, foreign material exclusion (FME) and high level housekeeping to all personnel involved in outage execution. The management should continuously enhance, demonstrate and control the expected work ethic and behavior of high level of housekeeping and removing debris during an activity to prevent accumulation of foreign material.

For minimizing the challenges and hazards to shutdown safety the plant should establish a protected equipment programme specifically applicable to shutdown conditions. The protected equipment (equipment or systems that operate to support a key shutdown safety function, including support systems) should be clearly defined and controlled and supplied with specific labels and physical barriers. The safety requirements and expectations for protected equipment's have to be clearly communicated.

As another key element of safe work conditions a separated clean work zone has to be formed and maintained around the dismantled primary and secondary systems/equipment. The used spare parts and tools should be registered and the pre– and post–serviced state of components has to be controlled.

As a good practice some utilities established comprehensive foreign material management (FMM) system. In this structure there are responsible FMM programme manager and FMM coordinators belonging to specified departments to own, to implement, and to develop the FMM programme. In this case the FMM activities are planned, the involved personnel are trained and the usage of FME devices is well controlled. The used FME tools are also regulated, registered and stored according to the FMM programme.

Foreign material management in nuclear power plants is summarized in an IAEA publication [10].

3.4.4. Configuration monitoring and online risk analysis

The CR and the OCC staff should be well informed about the actual state of the operational and maintained systems. Depending on the leadership level (managers, section heads, coordinators and group leaders) a weekly, daily or more frequent meeting system has to be implemented to promote the information flow. An effective system configuration and/or risk monitoring application also can be useful tool for support the decision making process.

Basically there should be different types of outage meetings effectively operated in the plant. The purpose of these meetings is to ensure the station is aligned in its priorities and knowledge of actual outage status. The outage advancements, the main technical information are reported, and the plant level decisions are made on the daily and on extraordinary management meetings. It is beneficial if there is always a senior manager onsite or in standby for controlling and overseeing the activities in the different outage periods. The outage organization conducts outage coordination meetings/day involving the OCC staff and the affected coordinators managing the outage execution. Usually daily sub meetings are also needed involved the OCC coordinators and the work group leaders to manage the detailed work processes. Generally shiftily operational meetings are held for reviewing the operational events history and safety aspects.

Some utilities have implemented comprehensive reporting rules for the workers in the field. These practices foster that the OCC team (and management if needed) can be well informed and also help to take proper countermeasure if needed or to prepare for the next task of the critical path. For example the 10/30/60 minutes rule stipulates the reporting requirements for the worker and workgroup leader after identification an unexpected problem during maintenance. 10 minute rule mean that, if the worker can't resolve in issue in 10 minutes, then he has to contact to supervisor. The -30 minute rule prescribes that the workgroups have to inform the OCC personnel about the advancement before completion their work phase. The -60 minute rule prescribes that the workgroups have to inform next work group 60 minutes before they finish current work phase.

The OCC personnel and the managers should routinely monitor work progress in the field. These routine checks will help ensure work standards and communication is maintained.

It is a good practice that the OCC staff applies a daily re-evaluation procedure of the existing outage configuration and estimates the effects of the planned interventions and corrective actions. To prepare a daily risk report using affective system configuration and/or risk monitoring application can be useful tool for support the decision making process and handling the unexpected deviations from the outage plan.

3.4.5. Management on the field

The regular attendance of the managers in the field demonstrates the attention of leadership to the work activities and contributes to the strengthening of safety culture, concerning the key aspects:

- Industrial and radiation safety;
- Fire protection;
- Pre-job briefing;
- Documentation usage;
- FME;
- Error prevention tools and behaviors;
- Housekeeping, "Clean–As–You–Go" principle.

Use of a formalized manager field report sheet is suggested.

The manager behavior in the field should not be restricted to the role of control. It is also important that the leaders communicate and encourage the responsible and disclosed attitude of own employees and coworkers:

- Awareness, ownership and accountability during the different work phases;
- Questioning attitude;
- 'Near Miss' and Event Reporting (field information feedback using LLE report);
- "No–blame" Stipulation.

3.4.6. Handling of deviations, rescheduling during outage

The plant should implement standards for how to handle any deviations from the existing schedule encountered during an outage. Safety review for those works, which are added during the outage should be taken into account e.g. decay heat removal capability, inventory control, electrical power availability, containment closure and system status control. The procedure should contain and cover the following areas:

- Criteria for cases when rescheduling is needed (unexpected events that affect workflow on critical path, safety configuration change and the safety aspects, maximum time delay on critical path);
- The minimal range of the identifiable milestones and critical points (heat removal path, operable loops and loop changes, configuration changes of residual heat removal (RHR), safety systems and electrical power supply, the new points of reactor, primary, secondary and auxiliary systems maintenance critical path, the changes in test structure, heat up and physical startup critical points);
- Rearrangement of the priority of resources (human resources, spare parts, tools and materials);
- The re-planning and timing of sub–schedules and remaining work packages according to the main schedule and priority allocation;

- The efficient manners of communication and delivering information to all involved personnel;
- Risk assessment.

Guidance for handling rescheduling during outages should be provided including; at what point it's needed, how to deliver information to all involved, rearrangement of resources, (UMM) etc.

It's recommended identify work (risk list), which have higher risk to effect the length of the outage and prepare a "plan B".

When rescheduling is needed during the outage, all safety related problems should be reviewed, how they affected to the safety.

3.4.7. Risk assessment

The outage activities have to be sufficiently reviewed to ensure they would not result in a loss or potential loss of a key safety function requirements for schedule reviews should be clear. The revised outage schedule should be reviewed with the same level of rigor as the original schedule. A reassessment should be done when schedule durations or conditions change, identify the potential higher risks of outage extensions. It is recommended to compile a risk list containing the relevant hazards of the new schedule and prepare a "plan B" in case, actuation of the optimized schedule fails. It is important to fully understand the impact of a work, or scheduling work at an inappropriate time. It is a good practice to use risk monitor tool creating detailed risk profile and implement a PRA based risk daily evaluation or at the decision making points.

3.4.8. Defence in depth plan

Outage work should be scheduled in a way that equipment in one train is under work and the other trains are in operation.

Daily safety charts (Sea water flow charts, Safety systems flow charts), shows which processes have to be in operation and comply with Tech specs.

Daily safety charts should be done by outage planning with operation unit and approved with cross check by all above and Tech specs office.

Safety charts gives frames to packets and schedules.

Detailed scheduling, packets and daily safety charts are good practice assure sub criticality and decay heat removal.

3.4.9. Coordination and communication

The coordination 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.

A communications strategy should be implemented as a part of the outage organization.

Formal daily meetings are organized to keep the staff informed on the status of the plant. These meetings must be attended by 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 coordination meeting supervised by the outage manager. In order to get the right focus on the daily coordination meeting the important problems and concerns should be highlighted and the main workflow (approx. 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 and new work orders;
- OHS, fire and nuclear safety situation.

Apart from the Daily Coordination Meeting, other meetings are also held to track the outage execution. Plant management meetings should be arranged when needed or at least once a week.

In case of problems, ad hoc management and technical meetings should be arranged.

It is important to provide effective communication tools and encourage staff to use them, for better knowledge of the progress of the outage and decreasing the lag between work phases and improving wrench time.

One way to simplify & streamline the coordination and communication is to implement the OCC.

3.4.10. Information

Staff involved in the outage, both plant personnel and contractors, should be well informed about the safety situation and the plant status. Mechanisms to communicate status and progress of outage should as well be implemented. Modern electronic media should ease the communication inside the plant and with the headquarters. Short bulletins or reports distributed to the personnel familiarizes 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 coordinate their work sites and get their feedback on the work schedule. The flow of information from and between the various activity centers should avoid conflicts in the process and acts as a management tool with clear delegation of responsibility and assignment of work.

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.

3.4.11. Work control management

An efficient process and procedure for work control management supported by a 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 operations department to handle work permits is needed during outage execution due to the large work volume. A multi discipline team from operations and maintenance should schedule, prepare and perform an important amount of tag–in, tag–out and line–up. The team should take consideration of nuclear safety, industrial safety and equipment reliability. Such a good practice could be also used for tests before startup.

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 coordinator and more work permits assistants than is usually required during operation.

There should be extra focus at those permits / activities that could affect nuclear safety and industrial safety.

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.

3.5. POST–OUTAGE REVIEW

The outage organization shall at latest 3 month after execution of the outage provide the outage management with a post-outage experience report including e.g.:

- Summary of the outage including actual schedules;
- Achievement of objectives, goals and budget;
- Technical status of the unit after the outage;
- Evaluation of a list of problems and contingencies;
- Post–outage plant problems caused by work activities during the outage;
- Complete analysis of predefined outage KPI:s, such as plan accuracy, waiting hours, percentage of rework, rate of unplanned works, delays, rate of lag work, incidents that affected or could have affected safety systems, volume of radioactive and other waste, collective dose, industrial accident, near misses, 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;
- Particularly successful ideas used;
- Work that could not be executed / postponed.

The outage experience report should be used by outage management to analyze and determine their expectations for subsequent outages. The analysis concentrates on the identification of opportunities for improvements in safety, quality and productivity, reduction of radiation exposures, reduction of failures and identification of successes. They should also develop corrective action plans identifying actions for correcting the root causes of a problem. Actions should be measured and indicators should be monitored.

The experiences from the post–outage action plan may advantageously be used for the following year readiness review.

Share outage experience with other plants and countries.

3.6. 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 analyze shutdown causes and to develop a strategy to work out the unplanned outage, including planning, preparation and safety evaluation.

Each plant should have clear procedure for roles and responsibilities of decision making and detailed description of their duties for forced outages.

If during the normal operation of nuclear power plant has emerged defects or failures which could not be repaired immediately during operation and those works should put on backlog list, these works must be planned and prepared in such way that implementation is possible within a short waiting period in unplanned shutdowns. It is a good practice to carry out a list of prepared maintenance tasks to be performed in the event of unplanned shutdown. If in this backlog list, the operators prioritize the works in order to take into account the safety issues, it would be easy to fulfill a list of prepared maintenance tasks. 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.

4. OUTAGE CONTROL CENTRE

In recent years, it is a nuclear industry good practice to establish an OCC to manage and coordinate the multiple work groups to smoothly execute many outage activities in the field, and to solve the unforeseen problem and issues timely.

OCC members come from Outage Management Department, Operations Department, maintenance department, Technical Department, Safety Department, Chemical Department and main contractors. The OCC is the center of outage management. Typical members and responsibilities are e.g.:

- Outage Manager comes from the Outage Management Department, responsible for the outage process, including outage preparation, execution and feedback. Responsible for the outage steering group's strategies and indicators, including outage safety, quality and duration requirements.
- Operations Manager comes from the Operations Department, responsible for the outage operation management, assist outage manager to coordinate and control outage operations activities.
- Conventional Island Manager comes from Outage Management Department, assist outage manager to coordinate and control conventional island activities, as an agent when outage manager is absent.
- Nuclear Safety Manager come from nuclear safety Department, responsible for the examination and surveillance of outage activities independently, ensure it according with technical specification requirements.
- Quality Control Manager comes from Technical Department, responsible for quality control management, assist outage manager to arrange quality defects issues during outage.
- Industrial Safety Manager comes from Safety & Quality Management Department, responsible for Industrial safety organization and management, assist outage manager to supervise and manage industrial safety of outage activities.
- Post–maintenance Test Manager comes from Operation Department, responsible for Maintenance test management, assist outage manager to organize Maintenance test activities and verify the outage quality.
- Planners come from Outage Management Department, responsible for outage plan management, assist outage manager to arrange outage activities and control outage schedule. Normally, there are three planners, two in charge of nuclear island, one for critical path, one for the others; the other one for conventional island.
- Maintenance coordinators come from the maintenance department and main contractors, responsible for coordination of maintenance activities.

OCC personnel are selected before the outage and senior plant management will approve the organization. OCC members are trained prior to the outage to clearly understand management expectations, outage goals and performance, and the OCC's responsibilities. OCC personnel will participate in both outage preparation and execution.

During preparation, OCC members should meet period to discuss scheduling, critical path and trace preparation plan in detail.

During the outage, OCC members spend much of their time physically in the OCC. The OCC is typically located in the protected area to be close to work control, the plant and work activities.

The OCCs responsibilities are e.g.:

- Outage activities are tracked, monitored closely;

- Maintain focus on nuclear, radiological, and industrial safety;
- Monitor critical path and near critical path outage progress intensely;
- Look ahead to prepare for upcoming milestones, activities, and evolutions, then make sure workers are informed of important activities;
- The status of key activities is communicated frequently and clearly to staff involved,
- Establish outage priorities;
- Emergent issues are identified and assigned to the responsible team to be addressed promptly, ant to report to senior managers in a timely manner;
- Evaluate emergent work items for implementation during the outage and for their effects on shutdown safety.

The OCC holds daily meetings to clearly communicate critical and near critical path status, major work that may impact nuclear safety and conventional safety, emergent issues, and protected equipment status. The OCC will work round the clock and update the critical and near critical path scheduling 2 or 3 times each day. When practical, video surveillance will be installed in the OCC office to track and monitor the progression of field work. The OCC will also release outage progression to staff involved in the outage, the means including emails, intranet, bulletin board in field and internal television.

Normally, the OCC will quickly resolve most issues encountered during execution of outage in the field. If any problem should require senior management involvement, the outage manager will report to the outage steering group promptly.

4.1. ADVANCED TECHNOLOGIES

The current technologies employed at most NPPs to communicate critical information are slow, inaccurate at times, and rely on the physical presence of outage staff and key personnel to obtain and validate critical system and work progress status information. Today, the majority of outage communication is done using processes and technologies that do not take advantage of advances in modern communication technology. Some common communication practices include runners that deliver paper based requests for approval, radios, landline telephones, email, desktop computers, daily printouts of the schedule, and static whiteboards that are used to display information. There are large amounts of static information displayed and the information requires regular evaluation to determine its validity. These current processes for controlling information are also labour intensive, and as NPPs attempt to reduce staff, these manual and disconnected processes have potential to become more difficult to manage. The current methods of displaying and tracking information will likely be inadequate to process the increased use of real time information that will be available with the growing use of handheld mobile technology, automated work packages (AWPs) (also known as electronic work packages [EWPs]), computer based procedures (CBPs), or computer programmes that passively track work completion and readiness. In general, the commercial nuclear industry has not yet taken full advantage of advancements in modern mobile technologies that enable communication, collaboration, real time data streaming, and information sharing to and from the field.

Discussions with outage experts across the industry have identified areas of need that will have the biggest return on investment. It has become clear to the research staff that communication and collaboration technologies could be used to improve schedule management, resource allocation, and emergent issue response. This report focuses on recent efforts made in developing a suite of outage technologies to support more effective schedule management. The most common approach is for a utility to develop a master outage schedule months in advance using the NPP's existing scheduling software (e.g., Primavera P6). Typically, during the outage, the latest version of the schedule is printed at the beginning of each shift. Idaho National Laboratory (INL) and its partners are developing technologies that will have capabilities such as automatic schedule updating, automatic pending support notifications, and the ability to allocate and schedule outage support task resources on a sub hour basis (e.g., outage micro scheduling). This report also describes the scheduling challenges that occur during outages, how the outage scheduling technologies that INL is developing help address those challenges, and the latest developments on this task (e.g., work accomplished to date and the path forward).

Previous INL reports have described various advanced outage functions that will become available through application of technology. These advanced functions are described here as they will be leveraged in new schedule monitoring tools or graphics. Technology improvements can enable OCC functions that include, but are not limited to:

Real Time Collaboration for Emergent Issues–Using multi touch monitors and high quality audio and video conferencing equipment deployed in various coordination centers, staff can simultaneously work on complex problems by sharing real time pictures, diagrams, schedule information, and notes. This technology also facilitates communicating the product(s) of the collaboration effort to the OCC, subject matter experts, managers, or other stakeholders. An electronic record of the resolution of the issue assists in knowledge management and future use of the information. The use of communication technologies has potential to reduce the need for face to face meetings, saving time, and the richer data may increase the level of comprehension of complex problems.

Real Time Work Status–The use of CBPs and AWPs allows the OCC staff instant status of work packages and procedures. These systems also allow outage managers to call up and view the actual steps of a work package or procedure as they are completed or to simply notify the OCC automatically when certain activities, tasks, or subtasks are completed. When tied into scheduling software, CBPs and AWPs provide a real time picture of schedule adherence. Portable wireless cameras installed near critical job sites that feed to the OCC also allow outage managers to remotely monitor job status without relying on field workers to call in status updates, thus allowing them to focus on work completion with little or no interruption that ultimately should reduce the time required to complete the task.

Automatic pending support notifications–Utilizing embedded triggers in CBPs and AWPs, notifications to support staff can be automatically routed to required personnel via calendar, text, or email notifications at predetermined points in the work process, alerting them of pending tasking that requires their support. For example, a trigger may be set 30 minutes prior to a quality control (QC) hold point, notifying the assigned QC inspector of the upcoming required inspection. If the first resource (QC inspector) is unable to provide support in a reasonable time frame, the first resource would reject the notification and a follow on notification would go to the next resource, and so on until a resource (QC inspector) accepts it. Automated notifications allow the staff to perform more efficient resource allocation and real time planning.

Improved Communication of Discovered Conditions from the Field Using mobile technologies, field workers who identify issues in the field can set up an instant video conference with the OCC or a supervisor in the field at the point of the problem. This would provide the OCC staff with eyes on the issue and an instant understanding of the nature of the issue. It would also allow further interaction between outage managers and the person discovering the issue without having to physically go to the location. Further interaction may include directing the worker to send back additional video footage or an annotated photograph of the surrounding area or component or more carefully describing some aspect of the problem while providing a live video feed. This also provides an opportunity for the OCC to pull in other stakeholders in real time to make decision making a more parallel process versus a series process saving all involved significant time and physical effort. Other benefits are realized such as reduced radiation exposure, reduced exposure to physical hazards, efficiency, and overall safety of not have numerous staff entering the NPP to put eyes on the issue. Another advantage to remote collaboration is the ability for decision–makers who are not on-site (e.g., at corporate headquarters on business travel, or at home) to view the issue and make the necessary decision(s) without returning to the site to do so.

More Efficient Dissemination of Information from the OCC–Utilizing advanced conferencing software and large multi touch monitors, OCC managers can establish interactive status briefings in which stakeholders may participate from any location, onsite or offsite, using a variety of devices, including desktop computers, laptops, smart phones, and tablet computers. This anywhere/anytime capability should produce significant gains in efficiency and accuracy in communications.

Real Time requirements Monitor–Utilizing a combination of information pulled from the status of CBPs and AWPs, real time NPP status from the NPP computer, and NPP logs, OCC managers can more effectively and easily display status and readiness for key activities or tasks. These displays enable rapid analysis of state and status and expedite decision making.

Mobile Alerts–Utilizing a messaging system similar to instant messaging used by most smart phones, OCC managers could update NPP personnel when important milestones are met or NPP conditions change. For example, the system could provide alerts for events such as window closures, NPP risk level changes, protected system changes, or industrial or radiological hazards. These messages would consist of a simple statement of the condition, but also provide more detailed information for events that require it through use of an information icon. These messages could also be sent to handheld devices, desktop computers, and large screen displays throughout the NPP. This process would be much more effective and efficient than providing out–of–date information on static displays or printed material currently used at NPPs [11, 12].

5. OUTAGE SAFETY REVIEW

The outage preparation and execution process should contain outage safety reviews in different organizational 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 organization 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 organization, 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.

6. 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 optimization 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 proactive (preventive) 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 optimizing 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 prioritization 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, and manpower) will allow the plant to optimize its cost and performance.

7. EXTENSION OF OUTAGE

An outage extension is the increase of outage duration beyond the planned time 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 7.1 and 7.2. These causes should be used in the plants self-assessment process to assess the probability that similar causes can occur.

7.1. CAUSES FOR OUTAGE EXTENSIONS

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

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.

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 FME programme;
- Operational failures.

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.

Regulatory impacts:

- Last moment regulatory requirements added;
- Late approval from regulatory;
- Misinterpretation of regulatory requirements.

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

Inadequate or lack of spare parts.

Inadequate vendor support:

- Lack of technical support and unreliable sub–contractors;
- Lack of equipment or material supply or late delivery.

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 reoccurring outage activities.

7.2. 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.

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.

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 / retraining of the manpower to be deployed;
- Strict control of work execution to avoid extension;
- Early warnings on critical items or milestones;
- Analyzing 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;
- Reduce maintenance (maintenance optimization).

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;
- Prioritizing 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 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. and;
- Using of fixed teams of very experienced specialists for critical jobs (integrity checking, etc.).

Anticipate regulatory requirements based on in–house and industrial experiences.

Ensure reliable inspection and maintenance tools through:

- Pre–qualification of special inspection and maintenance tools; and
- Redundancy of special tools.

Spare Part Policy:

- QC of received material well in advance;
- Spare part storage control system;
- partnership with vendors; and
- Joining a pool for common spare parts or inventory management.

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; and

- Correct ratio of new contractors (max. 50 %).

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; and
- 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 optimizing outages.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Plant Outage Optimisation Strategy, IAEA-TECDOC-1315, IAEA, Vienna (2002).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Management Strategies for Nuclear Power Plant Outages, Technical Reports Series No. 449, IAEA, Vienna (2007).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Indicators for Management of Planned Outages in Nuclear Power Plants, IAEA-TECDOC-1490, IAEA, Vienna (2006).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for Optimizing Nuclear Power Plant Maintenance Programmes, IAEA-TECDOC-1383, IAEA, Vienna (2004).

[5] ELECTRIC POWER RESEARCH INSTITUTE, Effective Refueling Outage Preparation and Execution Guidance, EPRI Product ID: 1022952, EPRI, Palo Alto, CA (2011).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Surveillance, and In-Service Inspection in Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.6, IAEA, Vienna (2002) 74 pp.

[7] INSTITUTE OF NUCLEAR POWER OPERATORS, Equipment Reliability Process Description Revision 2, AP-913, INPO (2007).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2, IAEA, Vienna (2011) 50 pp.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities, IAEA Nuclear Energy Series No. NP-T-3.21, IAEA, Vienna (2016).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Foreign Material Management for Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.22, IAEA, Vienna (in publication).

[11] IDAHO NATIONAL LABORATORY, Development of Improved Graphical Displays for an Advanced Outage Control Center, Employing Human Factors Principles for Outage Schedule Management, (2015).

[12] IDAHO NATIONAL LABORATORY, Guidelines for Implementation of an Advanced Outage Control Center to Improve Outage Coordination, Problem Resolution, and Outage Risk Management, (2014).

ABBREVIATIONS

ALARA	as low as reasonably achievable
AWP	automated work package
BWR	boiling water reactor
CAD	computer-aided design
CAP	corrective action programme
CBP	computer based procedures
CCI	common cause initiators
CBS	computer based procedures
CDF	core damage frequency
CR	control room
ECCS	emergency core cooling system
EWP	electronic work package
FME	foreign material exclusion
FMM	foreign material management
FSAR	final safety analysis report
HP	high pressure
I&C	instrumentation and control
IGSCC	intergranular stress corrosion cracking
IRS	International Reporting System for Operating
ISI	in-service inspection
IT	information technology
KPI	key performance indicator
LERF	large early release frequency
LLE	low level event
LPC	low pressure condenser
NPP	nuclear power plant
O&M	operations and maintenance
OCC	outage control centre
OEF	operational experience feedback
OHS	occupational health and safety
PCP	primary coolant pump
PM	preventive maintenance
PRA	probabilistic risk assessment
PSA	probabilistic safety analysis

QA	quality assurance
QC	quality control
RCM	reliability centred maintenance
RCP	reactor cooling pumps
RHR	residual heat removal
RI	reactorinneslutning /containment
RPS	Rosatom production system
RTF	run to failure
SG	steam generator
SSC	system, structure and component
TECDOC	technical document
TG	turbine generator
UMM	urgent market message
WO	work order
WOP	work outside the process
WWER	water cooled, water moderated power reactor
YVL	Regulatory guide, Finland

ANNEX I.

LONG TERM PLAN USED AT TVO1 AND TVO2, FINLAND

I-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 880 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 Asea Brown Boveri (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, reaching 95 percent. The average load factor of the past ten years (2004–2013) for both units has been 94.9 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, RHR 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 coordination 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.

I-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 A.6 (Conduct of Operations at a nuclear power plant), 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.

I-3. 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 upgrading’s. 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 Fig. I–1.

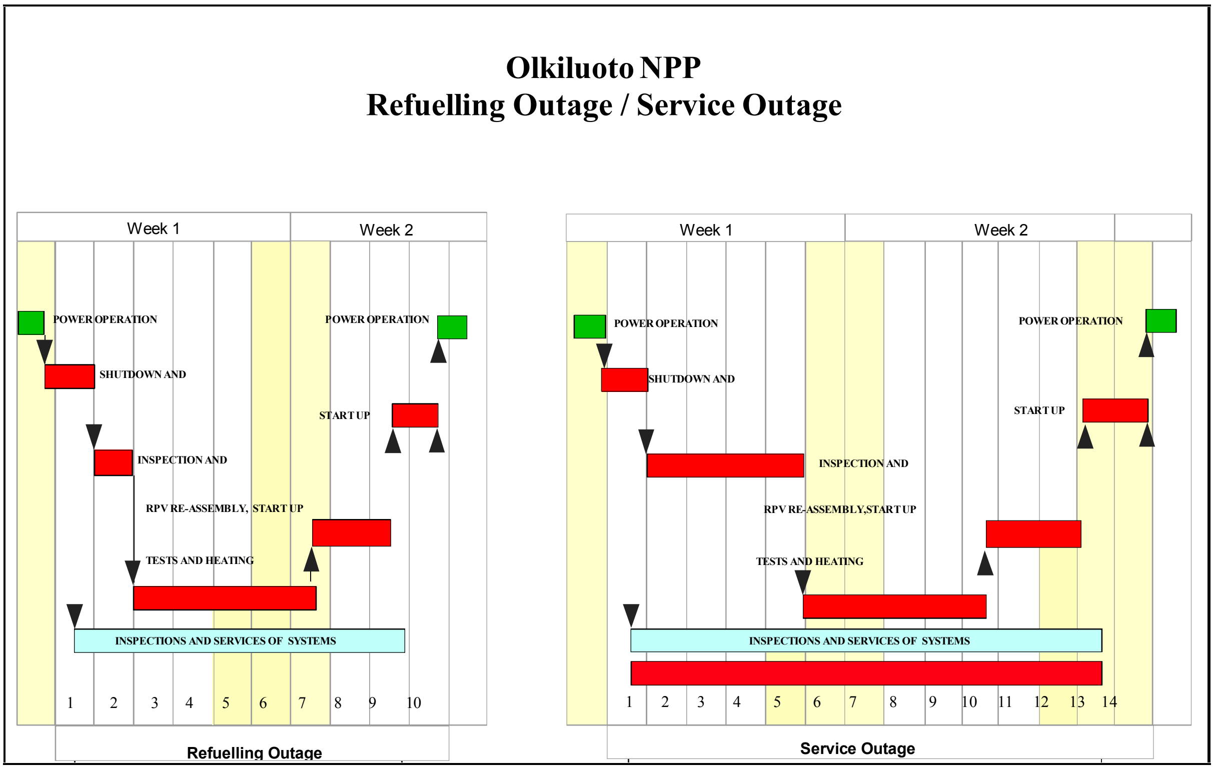

FIG. I–1. Olkiluoto nuclear power plant refuelling / service outages.

As an operational state, a refueling outage is characterized by an interlocking of control rod maneuvering, 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.

I-4. 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 (thermography, 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 analyzes 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 feed water 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.

I-5. 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.

I-6. 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 Fig. I–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 hold points (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 time 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.

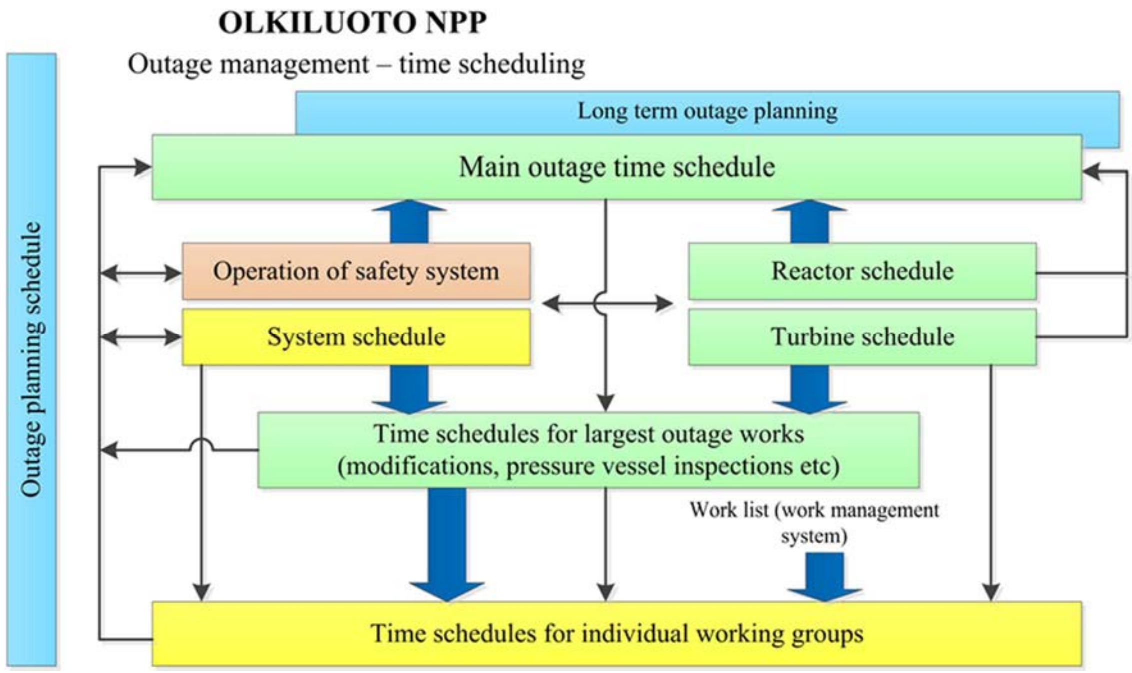

FIG. I–2. Outage management - time scheduling.

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 coordination 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.

I-7. 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 are 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 non–station 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.

I-8. 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, RAD–51 TR and DMC 2000S 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.

The company's own goal is to keep the collective annual dose below 1.0 manSv during years when one plant unit has a refueling outage and the other has a service outage. If the outages involve modifications that significantly differ from normal outages, the annual dose goal is below 1.5 manSv. Dose goals are defined separately for very extensive repair and service outages.

A project to decrease the concentration of Co-60 in the reactor water has been implemented.

The number of components containing cobalt in contact with primary circuit has been reduced more than 40% from the original level at both plant units. For future modifications guidance and implementation of the replacement programme for valves containing cobalt is continued. Purchases and modification planning take into account the goals for reducing cobalt.

Stellite balance will be reduced if whenever a need to replace components or equipment occurs. The use of other materials that create or may create significant activation products (such as Co-58, Sb-124, and Sb-125) will also be limited whenever possible.

I-9. OUTAGE MANAGEMENT CONTROL

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

The outage management group 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 coordinates all activities concerning outage planning and execution and the acting coordinator (one of the shift supervisors) coordinates all activities that take place during the outage (work permit /plant safety planning etc.).The safety office is located on–site, as 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 coordinators according to the rules given in the technical specifications. There are two important time schedules that are related to safety. The first one shows the unavailability's of the systems used for 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 RHR 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.

I-10. DESIGN MODIFICATION CONTROL

The management of plant modifications has been described in the Operational Phase QA 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, QA and QC 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.

I-11. 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 Fig. I–3.

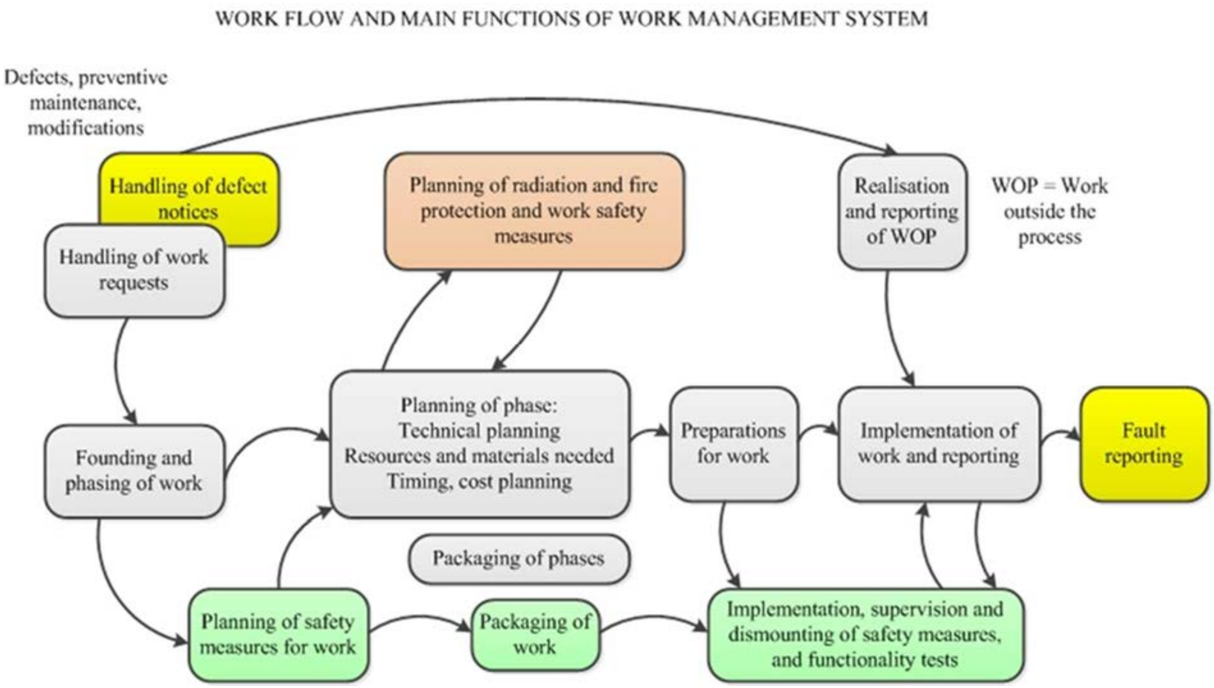

FIG. I–3. Work flow in work management system.

Main steps of the controls by outage coordinator/shift supervisors are the following:

- Prepare outage schedules important to safety according to technical specifications;
- 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.

I-12. 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 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, is 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.

I-13. QUALITY ASSURANCE

The QA engineers audit and routinely monitor different activities during the outages. The QA 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 QA 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 QA 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 OEF 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.

I-14. SAFETY ISSUES

The primary safety functions to be monitored are RHR, pre–serving of water inventory and maintaining criticality safety.

The 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't 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 maneuvering 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. 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 RHR 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 RHR.

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 interlocking's 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.

I-15. FEEDBACK OF OUTAGE EXPERIENCE

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

Special attention is paid to the feedback from outages and the goal is to improve outage management continuously. Thorough outage documentation makes it easy to identify strengths and weaknesses. Information on abnormalities and suggestions for improvements, received from both 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 and MRPIS). There is also a common organization The Owners Group for Nordic BWR operators (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.

I-16. TVO'S SHUTDOWN EVENT PRA

Shutdown PRA complements PRA scope at level 1 as well being a part of the living PRA model. The utility was interested in performing a probabilistic risk analysis due to several reasons, among which one could mention open containment during refueling period, 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, severe core damage could lead to significant release of radioactive materials to the environment. The first study was performed during 1990–1992 called as SEPSA–project. The total manpower required to accomplish the SEPSA–project was approximately three man–years. The project team consisted mainly of utility's own personnel strengthened with an expert in human factor/reliability assessment.

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 PRA during 1995–1996. The level 2 PRA showed that the assumptions of the utility before the preliminary SEPSA study were correct in the year 1997. 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 %. Level 1 PSA extension including the fire Common Cause Initiators (CCIs) during outages was added to the PSA model in 1998. PRA model and analysis were updated in 2004–2005 corresponding to current outage practices (short refueling outage with and longer service outage). In 2014, extensive update of shutdown PRA has been performed including e.g. update of event tree modelling, initiating event frequencies and components unavailability due to maintenance.

Besides the severe nuclear risks the utility is interested in other risks, too, e.g. significant extension of outages. They are 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 uncover in spent fuel pools, and severe core damage.

Thermal hydraulic analyzes made during the first SEPSA–project, showed that all operating modes with critical reactor should be included in power operation mode PSA (Fig. I–4). Thus SEPSA covers only the subcritical operating modes. The duration of each of the shutdown operation modes is currently the average value from the recent seven years before updating the study (2006–2013). The average outage duration was approximately 238 hours.

Only five different plant configurations are separately modelled in up–to–date shutdown PRA. 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 is possible because of special features of the computer code is used in the modelling. The planned maintenance of the systems is mapped out from the previous seven outages, and it is modelled in the fault trees in subsystem level. Three different sizes of leakage below core and seven above core are modelled with separate event trees. Their frequency is 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 RHR as the initiating event. Loss of external grid is included in the transients without its own event tree.

Fire CCIs and other external event CCIs are modelled with the separate "external" event trees, which are developed from RHR event trees (states T0–T4). A single CCI event can be applicable for one or even to all RHR states T0–T4.

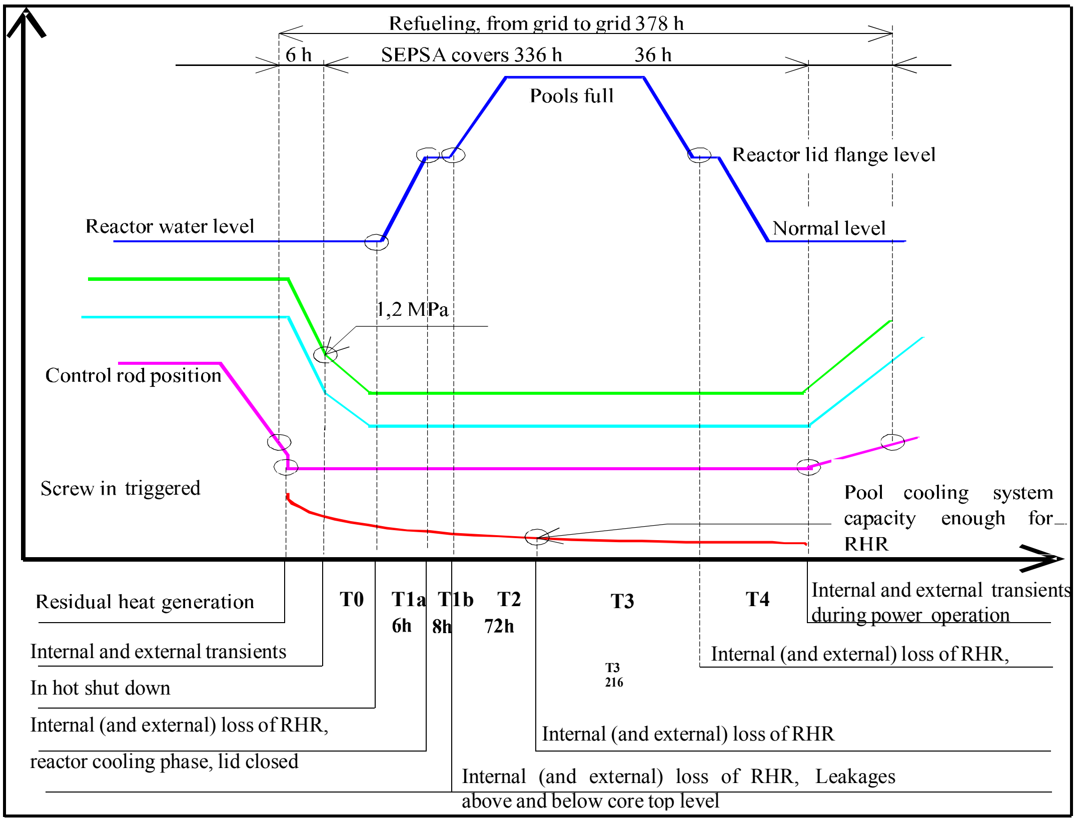

FIG. I–4. Thermal hydraulic analyses, made during the SEPSA–project.

Fig. I–4 showed that all operating modes with critical reactor should be included in power operation mode PSA.

Special studies are 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 behavior of the risk level (Fig. I–5) as a result first study. The beginning of a refueling 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. Later, it was significantly reduced with modifications in procedures based on a result of the first SEPSA study. The filling of reactor tank above a certain level is not allowed using piston pumps any more. 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 higher than the average risk level during the power operation.

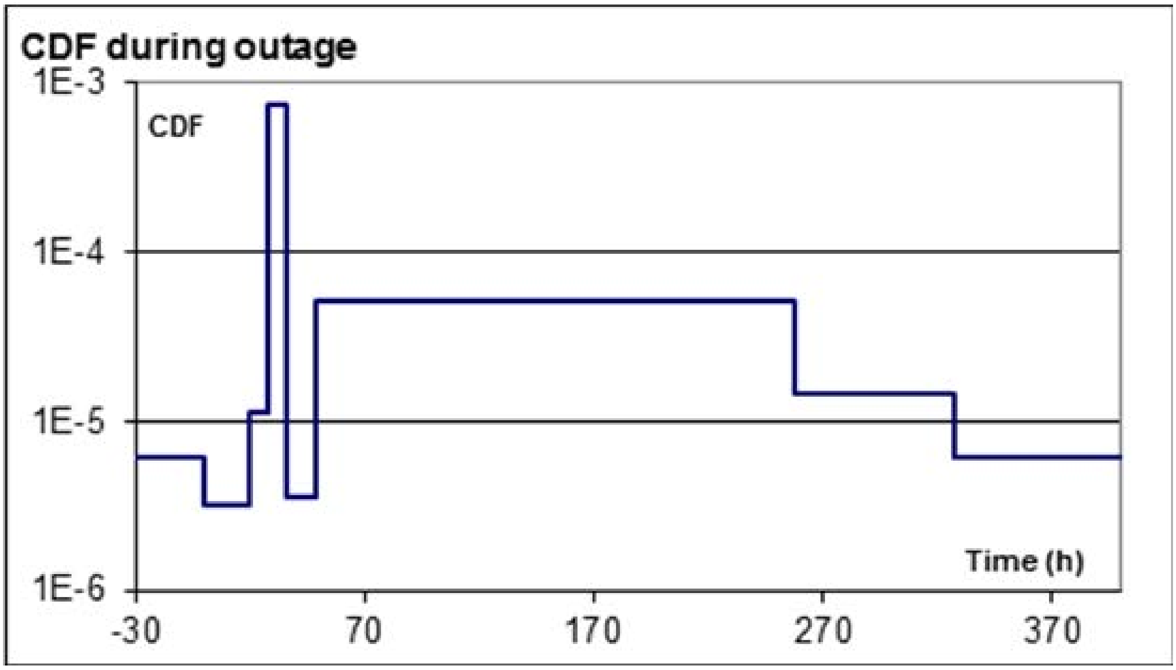

FIG. I-5. Risk level during the outage (first SEPSA results).

Several actions to improve shutdown safety have been carried through during and after the first SEPSA–project, which decreased the dominant risk contributors arising during the shutdown period significantly. The lower personnel access door is now kept closed during the critical phases of the internal main recirculation pumps (RCP) overhaul, as mentioned earlier. Mechanical cotter pins installed in the plugs are used during the internal main recirculation pump overhaul that prevents the inadvertent lifting. In order to prevent the cold over pressurization the use of auxiliary feed water piston pumps is no more recommended for reactor filling. In addition, the increase of spent fuel pool cooling capacity, improvements in timing of capping of safety and relief valves and in the inspection routines of control rods are examples of modifications that are implemented during the based on shutdown PRA results.

In addition, TVO has developed a PRA application to support outage schedule planning. This application utilizes the existing average outage PRA models to calculate momentary core damage and radioactive release frequency during the outage. This application was used in the planning outages in 2013 first time. As results of the assessment, several modifications were done in the outage time schedule. The PRA application utilizes the outage schedule printouts and the calculation of CDF/LRF is performed hour by hour throughout the whole outage. A risk profile for the outage as a function of time is the main result of the analysis (Fig. I–6). The example of the risk profile (blue line) is presented in Figure I–6. TVO has applied as internal risk criterion that average release frequency must not exceed 6E-9/h (red line) in this application.

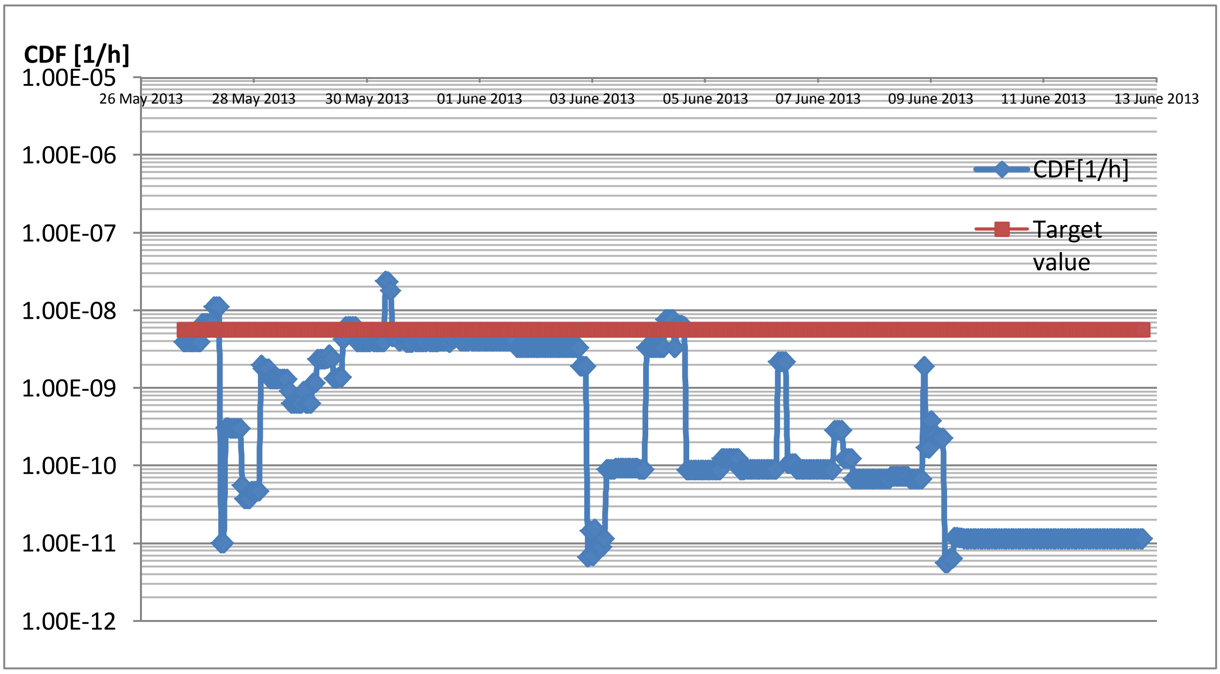

FIG. I–6. The risk profile.

Note: Extracted from the papers:

- 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);
  A PRA application to support outage schedule planning at OL1 and OL2 units, Hannu Tuulensuu (Proc. of PSAM12, Probabilistic Safety Assessment and Management, June 22–27, 2014 Hawaii, USA).

ANNEX II.

KEY ISSUES TO CONSIDER IN OUTAGE PLANNING, PREPARATION AND EXECUTION

II-1. OL1/OL2—OUTAGE PLANNING

Table II–1. OUTAGE PLANNING

Long term planning	About 10 years
Middle term planning	About three years
Detailed planning of follow outages	1–2 years carefully study of critical path activities
Planning during outages	New defects schedule revision

II-2. OL1/OL2–OUTAGE TYPES: SHORT/LONG OUTAGE CYCLE

Table II–2. SHORT/LONG OUTAGE CYCLE

Refueling outage	ca. 9 days
Service outage	2 to 3 weeks normal or large
Outages follow each other in sequence	
Optimization of outage Costs and Production Losses	

II-3. OL1/OL2–OUTAGE TYPES

Table II–3. OUTAGE TYPES

Refueling Outage	• Refueling • Repairs • Annual Service, tests and inspections according to the technical specifications
Service Outage	• Refueling outage work tasks • Major overhauls, service and inspections Modifications and improvements

II-4. TVO–OUTAGE ORGANIZATION

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

II-5. TVO–OUTAGE EXECUTION TEAM

Table II–4. OUTAGE EXECUTION TEAM

Outage Manager	General management
Outage Planning Team	New defects, schedule revisions
Outage Coordinator 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.

II-6. 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.

II-7. 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.

II-8. 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 III.

CASE STUDY; TURBINE MODERNIZATION SCHEDULE OPTIMIZATION 2014 IN LOVIISA 1

III-1. GENERAL

- Loviisa NPP's consists of 2 WWER 440 units, with two turbine lines per unit, each including one high pressure section and two low pressure sections.
- Target was to execute, both low pressure turbine sections preventive maintenance and modernization at Loviisa unit 1.
- Modernization included opening both sections, modification of diffusors and renewing of water visors.

FIG. III–1. Old diffusor 'water quide'.

III-2. CHALLENGES

- Supplier provided project execution in 40 days;
- Outage planned duration was 19 days 5 h (normal refueling outage);
- Lots of other work required crane at turbine hall; exchange of TG1 and TG2 HP – turbine KOS –bleed valves, TG1 generator stator wedging and renewing of rotor, repair of TG2 hydrogen leak;
- Generator stator wedging and renewing of rotor at same axle;
- 2 cranes are in parallel to turbine line;
- Project was a part of secondary side optimization programme, and were scheduled for normal refueling outage based on middle term (2 – 4 years) and long term (plant lifetime) planning;

- We got schedule from contractor, it was transferred into MS Project and the critical path was identified;
- Negotiations were conducted between contractor, other projects, plant turbine specialist, mechanical maintenance, operational unit and outage planning to optimize schedule, taking into account use of cranes;
- Work was examined phase by phase, and phases, which could be done simultaneously were recognized and rescheduled and task durations were optimized. Contractor had planned reserve time in many phases, which is not allowed, because the work is on critical path and steering of the outage is lost, if the project is finalized too early. Some phases were possible to do outside of isolation, and could therefore be removed from the critical path;
- Contractors shifts were optimized to ensure correct resources for every phase;
- We made common crane schedule for all turbine hall work. Prioritized turbine work first while synchronizing schedules between other work, that required crane usage;
- We made own work package (system window) with own isolation for turbine modernization to ensure on time start;
- Project readiness was reviewed monthly at outage meetings, no return points were selected.

III-3. RESULT AFTER OPTIMIZATION; 22 DAYS

FIG. III–2. UNIT 1, Turbine 1.

FIG. III–3. Low pressure turbines.

III-4. TURBINE SCHEDULE

- Made with MS Project;
- Red color shows critical path;
- Black lines shows tasks that required crane.

A crane schedule was made by sorting from turbine schedule and combining tasks from other schedules

III-5. RESULTS

- Turbine modernization was completed in schedule. Never before have two low pressure turbine maintenance and modifications been done in such a short time window;
- If project had been ordered as turnkey from contractor, production loss could have been approx. 108 000 MWh ➔ 4 M€.

FIG. III–4. Low pressure turbine with new ‘water quide’.

III-6. LESSONS LEARNED

- To further develop unscheduled crane usage, a crane time table was introduced for the 2015 outages, from where everyone can see prioritized lifts (critical path) and reserve cranes for own usage. This was found to be a good practice to decrease waiting hours;
- Based on these experiences, a crane coordinator was appointed for the 2015 outages;
- Contractors schedule should be evaluated critically, because there is often spare time and contractor may not have a knowledge, about which part of work must be done during isolation. Based only in the contractor’s opinion, this work could only be done during a long outage;
- Project’s real duration should be evaluated as early as it is assigned to middle term or long term planning, because contractors seldom have knowledge about the actual impact to the critical path.

ANNEX IV.

OUTAGE PLANNING SCHEDULE IN LOVIISA

IV-1. GENERAL

Annual outage planning schedule is monitored monthly at outage planning meeting. This schedule includes essential milestones and dates for outage planning.

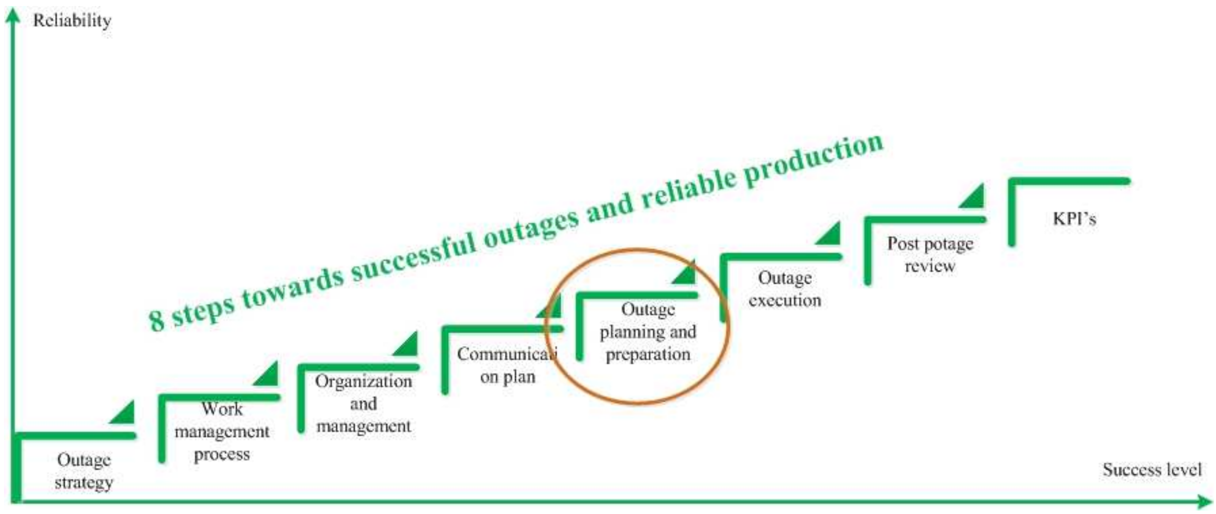

FIG. IV–1. Steps for successful outages.

IV-2. OUTAGE PLANNING SCHEDULE

- Annual outage planning schedule is made for whole Outage organization;
- Annual outage planning schedule consists significant tasks and milestones of short term outage planning and preparation. Outage specific schedule is created yearly basis;
- Schedule is check list, for ensuring, that all tasks are started and completed on time;
- Annual outage planning schedule is monitored monthly at outage planning meetings. Exceptions are handled via outage planning corrective actions programme. Outage planning department has a responsibility of outage planning schedule;
- Annual outage planning schedule have found to be valuable tool for decreasing risk of delayed actions.

IV-3. OUTAGE PLANNING SCHEDULE

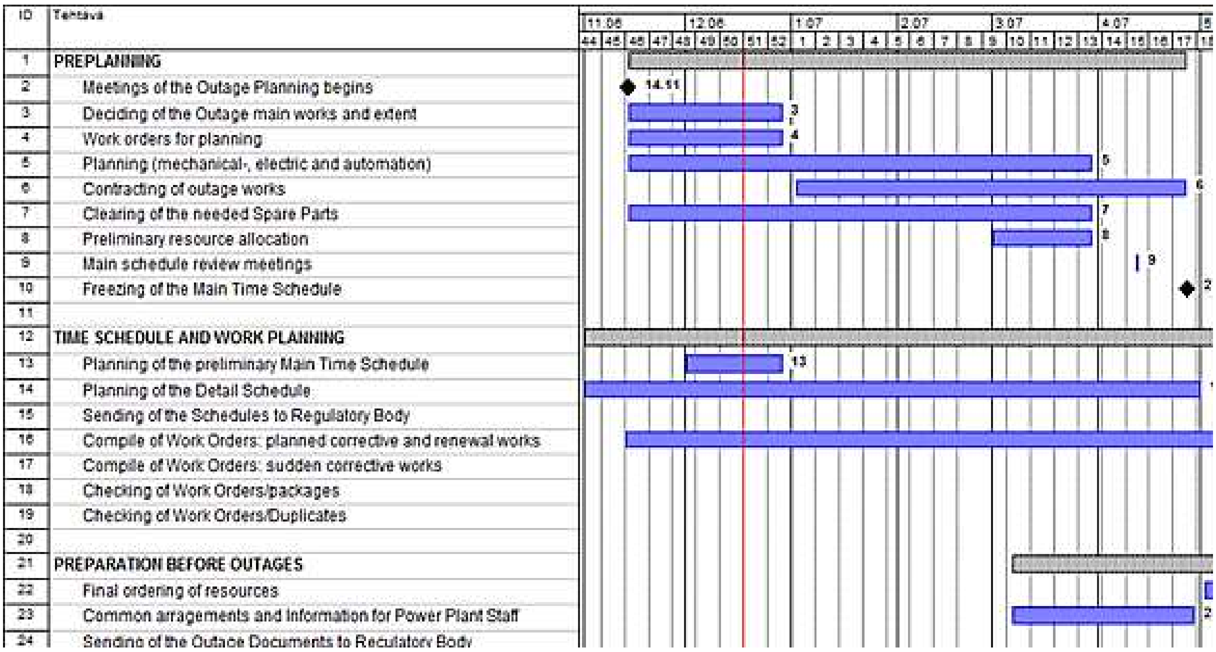

FIG. IV–2. Outage planning schedule.

IV-4. OUTAGE PLANNING YEARLY CLOCK

- Annual outage planning clock (checklist) is a visual tool made for task progress monitoring for outage planning department;
- Outage clock is a checklist, for ensuring, that all tasks are started and completed on time;
- Annual outage planning clock progress is monitored weekly at outage planning department meetings. Exceptions are handled via outage planning corrective actions programme;
- Annual outage planning clock have found to be valuable tool for decreasing risk of delayed actions and for Outage department resource planning.

IV-5. OUTAGE PLANNING YEARLY CLOCK

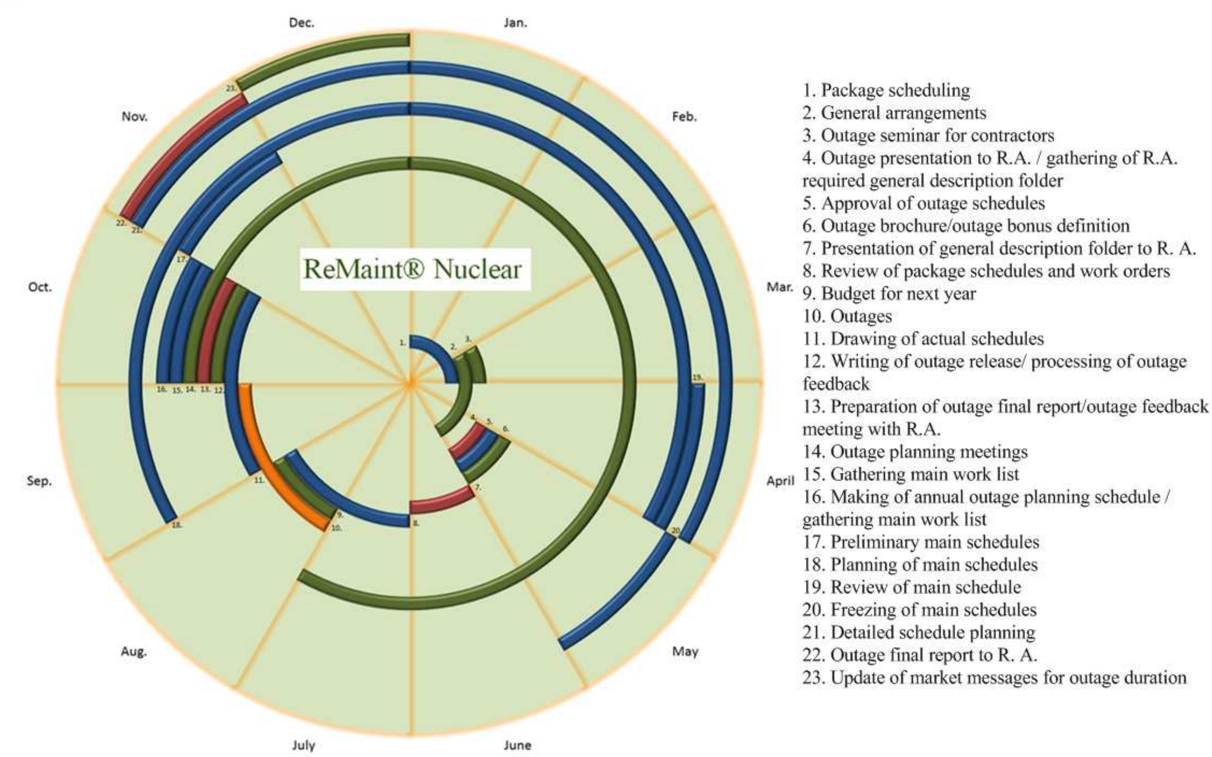

FIG. IV–3.Yearly clock for outage planning.

ANNEX V.

CASE STUDY; WORK ORDER MONITORING DURING OUTAGES AT LOVIISA NPP'S

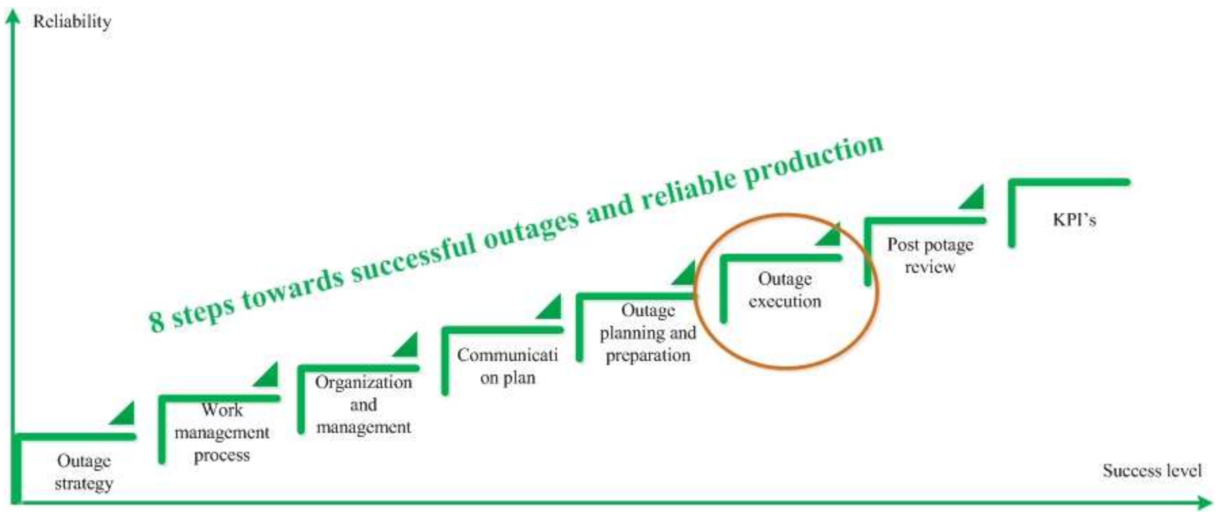

FIG. V–1.Steps for successful outages.

V-1. GENERAL

- Work order status tracking is a tool for monitoring whole Outage progress, by monitoring completion of the work orders;
- Work order status tracking is reviewed daily at morning meetings during the Outage and is presented in Outage daily report;
- Besides general W.O. tracking, also group–specific W.O. data KPI's can be monitored from this excel. Specific KPI's are made for all maintenance groups, QC and operation units;
- Actual is compared to reference Outage;
- These KPI's have found to be an effective way to track, that W.O. are started and finished on time and therefore whole Outage progress is effortlessly monitored and coordinated, despite of large amount of work orders.

V-2. DATABASE INFORMATION

Work order status tracking database consists of information listed below. Needed information is collected daily from plant information system to Excel:

- Planned Outage duration;
- Estimated amount of work orders;
- Finished W.O. / day;
- Dates;
- Outage day;
- Planned W.O. readiness;
- Actual readiness;
- In progress;
- Not started;

- Total W.O.;
- Estimated amount of work orders;
- S.S. starting permit;
- Ready for de–isolation;
- Readiness for year of reference;
- Total W.O. for year of reference;
- Not started %.

V-3. WORK ORDER MONITORING

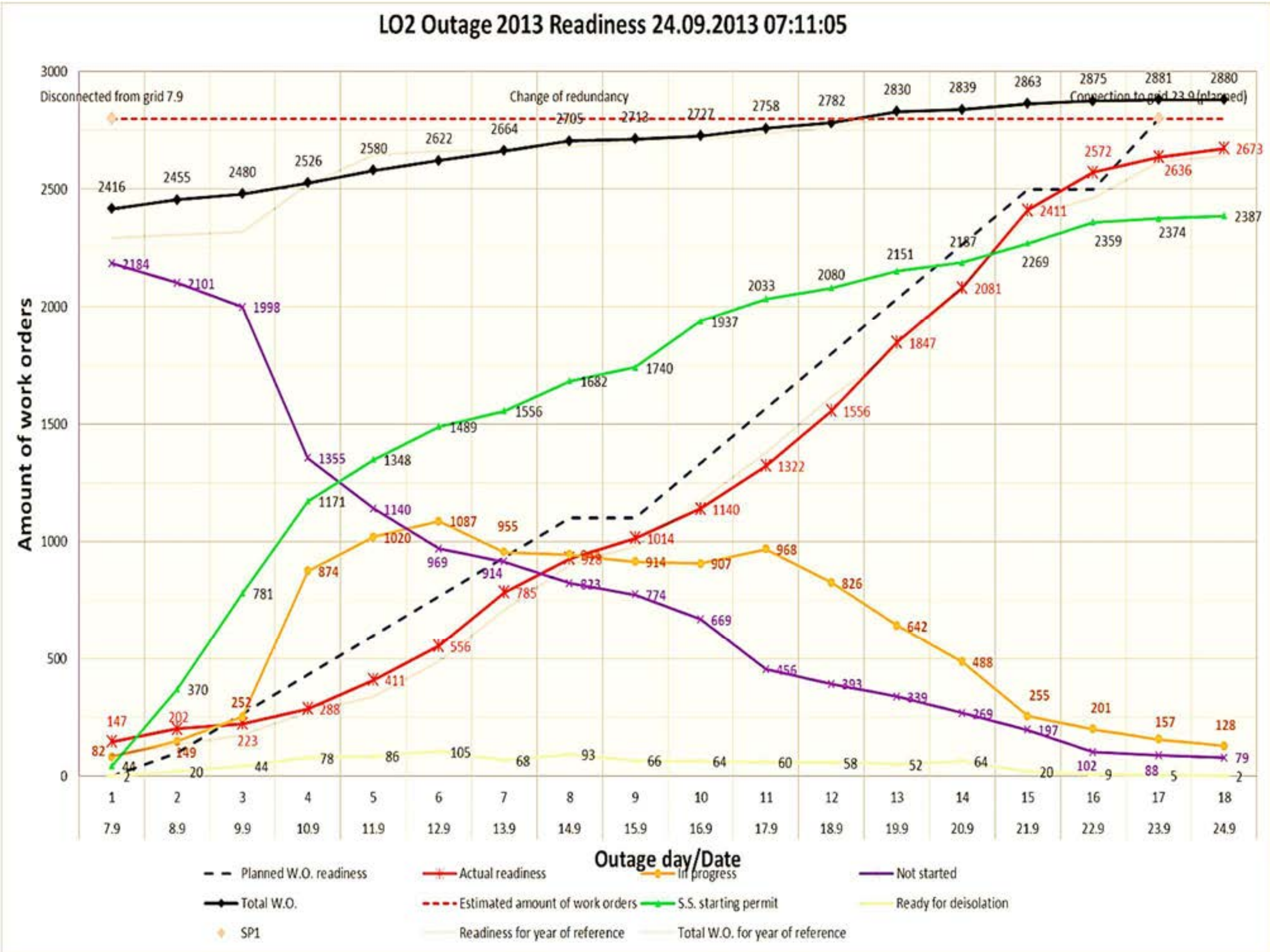

FIG. V–2. Outage readiness.

ANNEX VI.

LONG TERM OUTAGE PLANNING IN FORSMARK

VI-1. INTRODUCTION

The long term outage planning aims to ensure outage shutdowns at Forsmark. So that these are planned and performed in a safe way and that a downtime of 70 days of all three units can be included over time.

The instruction describes the long term outage planning Procedure with regard to activities, responsibilities, input and output data as well as connections to governing instructions.

VI-2. STRUCTURE

VI-2.1. Mandate

In accordance delegated process manager for long term outage planning.

VI-2.2. Target group

- Formal target group;
- Managers in Operation, Maintenance, Technical and Planning departments;
- Specified target group;
- Personnel who work with the Long term Outage Planning Process.

VI-2.3. Purpose

The aim of the instruction is to define the work process and clarify how Forsmarks Kraftgrupp AB works with long term outage planning.

VI-2.4. Prerequisites

Basic prerequisite is to apply 70 outage days per year and a 4–year outage cycle.

Three types of outage have been defined as follows:

(1) Short outage "Fuel Replacement Outage" (BB)

- Approx. 10 days (8 action days) at unit 1 & 2 and approx. 12 days at unit 3;
- Fuel replacement and periodic testing are governing and tighten up the schedule;
- Other maintenance and modification activities are secondary to fuel replacement.

(2) Medium–long outage "Maintenance Outage" (UH)

- Reactor and turbine maintenance tighten up the schedule;
- The number of days are determined depending on maintenance, as well as being limited by actions at other units, approx. 25 days at unit 1 & 2 and approx. 21 days at unit 3;
- Renewal activities are secondary to maintenance;

- Pressure testing of RI interval 3 years should be performed during Maintenance outage if the reactor maintenance is not governing.

(3) Long outage "Renewal Outage" (AÄ)

- Plant modifications tightens up the schedule;
- The number of days are determined depending on the number of modifications, as well as being limited by actions at other;
- Units, approx. 35 days;
- Maintenance activities are secondary to plant modifications.

The outage cycle of 4 years means that there is a fuel replacement outage every other year and between these years there is a renewal and a maintenance outage. For example, BB–UH–BB–AÄ–BB–UH–BB–AÄ.

VI-2.5. Process operators' roles, responsibilities and authorities

If a decision is made that this is a process, this point needs to be defined further.

VI-2.6. Connecting processes to long term outage planning

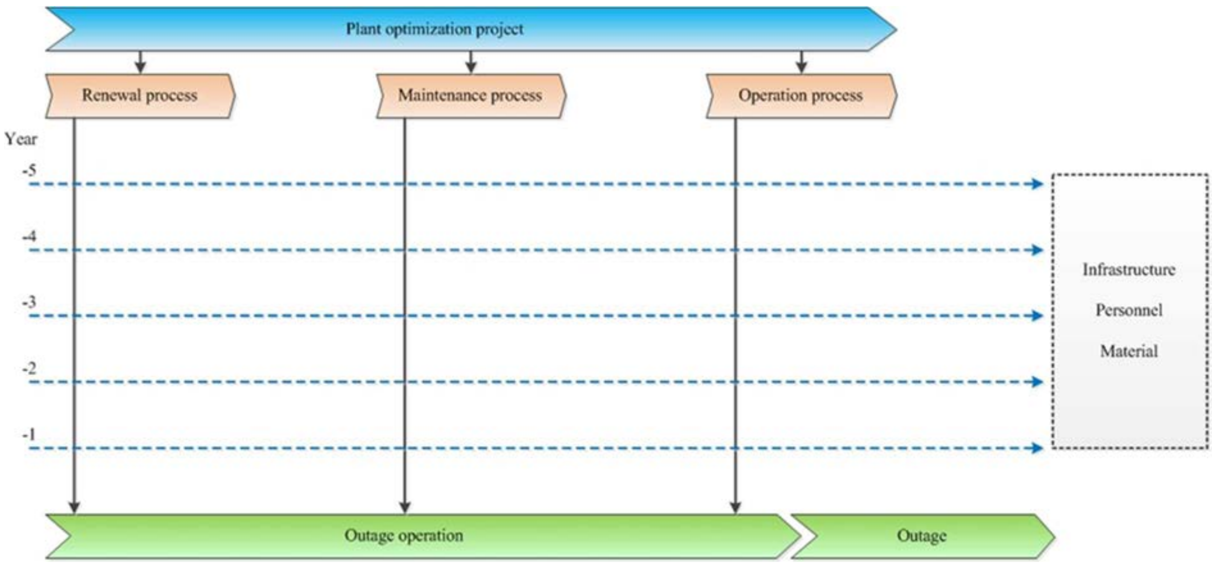

FIG. VI–1. Process relation chart.

- *Operation process:* Contributes to this process through outward delivery of operational basis. Also contributes with outward delivery to infrastructure, personnel and material;
- *Maintenance process:* Connects to this process through inward delivery of maintenance scope. Also contributes with outward delivery to infrastructure, personnel, material and therewith also to spare parts acquisition process;
- *Renewal process:* Connects to delivering process for planning of decided renewal measures. Also contributes with outward delivery to infrastructure, personnel and material.

VI-2.7.Information process

To obtain an overview of the scope and propulsion concerning the scope, templates are used.

There are two templates, one template for creating a scope plan for renewal, maintenance and operation activities. It is used from year –5 to implementation. A row in the scope plan for each project number. Maintenance measures and maintenance with construction support are handled by maintenance department. A row in the scope plan for each major maintenance measure that requires a lot of planning/coordination. Operational measures are handled by operations. The scope plan with be annexed to the reports and decisions that long term outage planning produce.

Instructions for filling in the scope plan are available.

The degree of fine–tuning will increase the closer we get to implementation.

Another template is available for following up activities, a preparation plan which is used from two years before outage project. The preparation plan should specify the time when the point will be finished.

Instructions for filling in the preparation plan are available.

VI-3. PROCESS DESCRIPTION

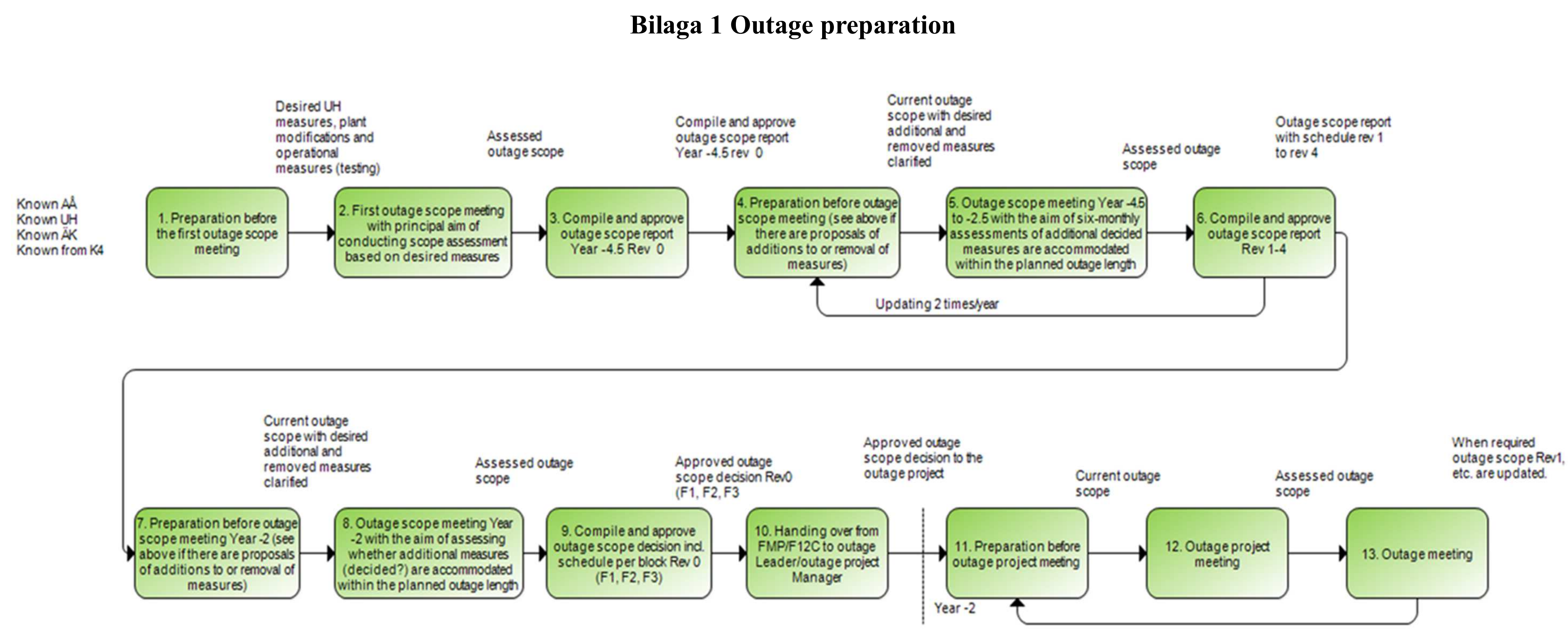

FIG. VI–2. Long term outage planning.

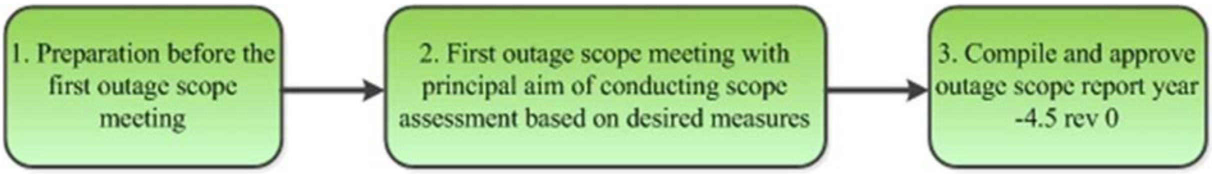

FIG. VI–3. Preparation of outage scope meeting.

VI-3.1. Preparation before first outage scope meeting

Table VI–1. COLLECT THE INFORMATION

Input data	Description	Output data
Known Renewal Known Maintenance Known inspections and tests Known production plan	Long term Planning prepares the documents needed and communicates to the operators concerned. Responsible departments go through and fill in known scope plan.	Desired Maintenance measures, renewal and operational measures (testing) compiled

- *Responsible:* Planning department.

VI-3.2. First outage scope

Table VI–2. ACTIVITIES FIVE YEARS AHEAD

Input data	Description	Output data
Desired Maintenance measures, renewal and operational measures (testing) are compiled	Facts are collected via questions based on the scope plan, where responsible departments are expected to be able to answer. The goal is to obtain information in all columns for each measure. Deviations are documented. An assessment of known scope accommodated within decided outage time shall be conducted.	Assessed outage scope

- *Responsible:* Planning department;
- *Participants:* Operation, Maintenance, Technical and Planning departments.

VI-3.3. Compile and approve outage scope

Table VI–3. ACTIVITIES FOUR AND A HALF YEAR AHEAD

Input data	Description	Output data
Assessed outage scope	Information from the scope plan is summarized and compiled into an outage scope report with deviations and risks. An outage scope report for all three units containing a schedule/unit. The outage scope report is approved by CEO.	Approved outage scope report rev 0 Input data for long term production planning

- *Responsible:* Planning department and CEO.

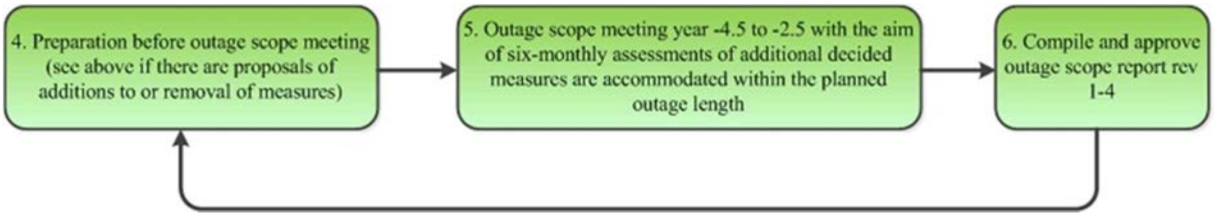

FIG. VI–4. Preparation of outage scope.

VI-3.4. Preparation before outage scope

Table VI–4. COLLECT INFORMATION

Input data	Description	Output data
Approved outage scope report Known change of outage scope Any change in long term production planning	Responsible departments go through and fill in the scope plan based on desired changes, additional measures or the desire to remove measures.	Current outage scope with desired additional and removed measures clarified.

VI-3.5. Outage scope yearly meeting

Table VI–5. CONTENT OF MEETING

Input data	Description	Output data
Current outage scope with desired additional and removed measures clarified	Review of the already filled in scope plan. Review will take place at least two times a year in the period –4.5 to –2.5 years prior to implementation of the outage. Facts are collected via questions based on the scope plan, where Responsible departments are expected to be able to answer. The goal is to obtain information in all columns for each measure. Plant changes shall be ordered according to deadlines, this means that big projects need to be ordered before it is 3.5 years until implementation (TG0–SI). Medium projects 2.5 years prior to implementation (TG0–SI). Small projects 2 years prior to implementation (TG0–SI). Deviations are documented. Assessment/co–planning in order to see whether known scope is accommodated within decided outage time shall take place. Activity owner shall be able to answer how many days the introduction in the plant is expected to take.	Assessed outage scope

- *Responsible:* Planning department;
- *Participants:* Operation, Maintenance, Technical and Planning departments.

VI-3.6. Compile and approve outage scope report

Table VI–6. COLLECTING INFORMATION

Input data	Description	Output data
Assessed outage scope	Information from the scope plan is summarized and compiled into an outage scope report with deviations and risks. An outage scope report for all three units containing one schedule/unit. The outage scope report is approved by CEO.	Outage scope report is approved rev 1 to rev 4 Input data for long term production planning

- *Responsible:* Planning department and CEO.

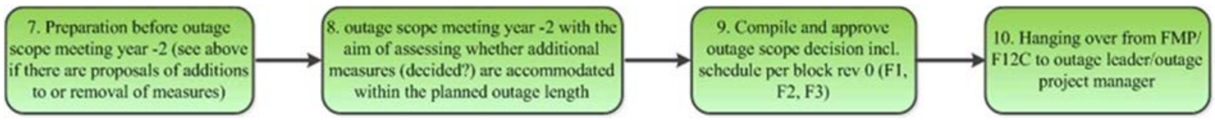

FIG. VI–5. Preparation before outage scope meeting.

VI-3.7. Preparation prior to outage scope meeting

Table VI–7. COLLECTING INFORMATION TWO YEARS AHEAD

Input data	Description	Output data
Approved outage scope report rev 4 Known change of scope	Responsible departments go through and fill in the scope plan based on desired changes, additional measures or the wish to remove measures.	Current outage scope with desired additional and removed measures clarified.

- *Responsible:* Operation, Maintenance and Technical departments.

VI-3.8. Outage scope meeting

Table VI–8. CONTENT OF MEETING TWO YEARS AHEAD

Input data	Description	Output data
Current outage scope with desired additional and removed measures clarified	Review of the already filled in scope plan, the goal is to obtain information in all columns for each measure 2 years before implementation all types of projects shall be ordered. Deviations are documented. Assessment/co–planning in order to see whether known measures are accommodated within decided outage time shall take place. Activity owner shall be able to answer how many days the introduction in the plant is expected to take.	Assessed outage scope

- *Responsible:* Planning department;
- *Participants:* Operation, Maintenance, Technical and Planning departments.

VI-3.9. Compile and approve outage scope decision incl. schedule per unit Rev 0 (UNIT 1, UNIT 2, UNIT 3)

Table VI–9. CONTENT OF REPORT

Input data	Description	Output data
Assessed outage scope	Information from the scope plan is summarized and compiled into three decisions with respective schedule. A decision with a schedule per unit. The outage scope decision is approved by CEO.	Approved outage scope decision Rev0 (UNIT 1, UNIT 2, UNIT 3)

- *Responsible:* Planning department and CEO.

VI-3.10. Handing over of outage scope decision from Long term Outage Planning to Outage Leader/Outage Project Manager

Table VI–10. CONTENT OF MEETING

Input data	Description	Output data
Approved outage scope decision Rev0	Annual activity which is synchronized with investment plan. Approved scope decision containing main schedules is handed over to each outage leader/outage project manager. The general preparation plan is also handed over. The meeting may be held for all three units or individually. At the meeting the outage scope decision is reviewed and the main schedules, as well as deviations. After the meeting the outage project Manager is responsible for ensuring that the scope decision is kept updated.	Approved outage scope's decision Rev0 to outage Leader/outage project Manager

- *Responsible:* Planning department;
- *Participants:* Outage Leader and Outage Project Manager.

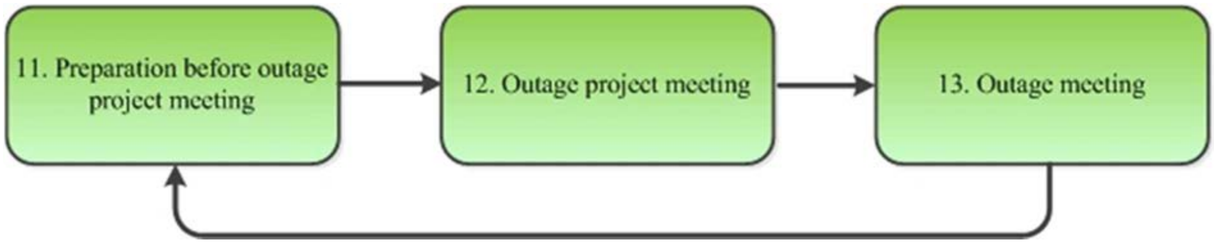

FIG. VI–6. Preparation of outage project meeting.

VI-3.11. Preparation before outage project meeting

Table VI–11. COLLECTING INFORMATION

Input data	Description	Output data
Approved outage scope decision Rev0 Known changes of scope	Responsible go through and fill in the scope plan based on desired changes, additional measures or the desire to remove measures. Outage project Manager fills in the general preparation plan based on the respect times that exist.	Current outage scope with desired additional and removed measures clarified. Current preparation template

- *Responsible:* Operation and Maintenance departmants, Technical Outage Project Manager.

VI-3.12. Outage project meeting

Table VI–12. CONTENT OF MEETING

Input data	Description	Output data
Current outage scope with desired additional and removed measures clarified Current preparation template	Facts are collected via questions in the scope plan, where responsible departments are expected to be able to answer. The preparation plan is reviewed with regard to deviations from respect times. Deviations based on the preparation plan are documented and action plans for deviations drawn up. *Scope assessment:* Renewed assessment of known measures is accommodated within decided outage time. Activity owner shall be able to answer how many days the introduction in the plant is expected to take. In the case of requests for changed scope they shall be raised at the outage meeting for decision.	Assessed outage scope Current outage scope with desired additional and removed measures clarified Current preparation template

- *Responsible:* Outage Project Manager.

VI-3.13. Outage meeting

Table VI–13. CONTENT OF MEETING

Input data	Description	Output data
Assessed outage scope Current preparation template	*Monitoring:* Review of documented deviations of and recommendations from outage project meeting. Review of documented deviations in the general preparation plan. *Scope assessment:* Based on recommendations from the outage project whether the outage scope decision remains or whether it needs to be revised is decided. The outage leader Approves the scope decision.	Updated outage scope decision where required

- *Responsible:* Outage Leader.

VI-3.14. Key Performance Indicators

Measurement of KPI for progress takes place in accordance with the operational plan.

ANNEX VII.

IPLEMENTATION OF THE PROJECT “REDUCTION IN DURATION OF BALAKOVO UNIT 4 PLANNED OUTAGE 2014”

VII-1. INTRODUCTION

The objective of the project is to reduce duration of technological processes due to internal production reserves and increase in labour productivity.

The goal of the project is to reduce the Unit maintenance duration from 98.5 days (level achieved at Unit 1 in 2012) to 70 days (ambitious level).

The low pressure condenser (LPC) of the turbine K–1000–60/1500–2 is designed to condense waste steam from low pressure cylinders of the turbine and to maintain the steam design pressure (vacuum) in normal operation modes, which is necessary for reliable and safe operation of the turbine plant.

Arrangement, dimensions and number: the turbine LPCs are of basement location, they have 14 m length, 10.5 m width and 8.4 m height. Mass of one condenser: 621 t. Number of installed condensers: 3 (one condenser under each low pressure cylinder).

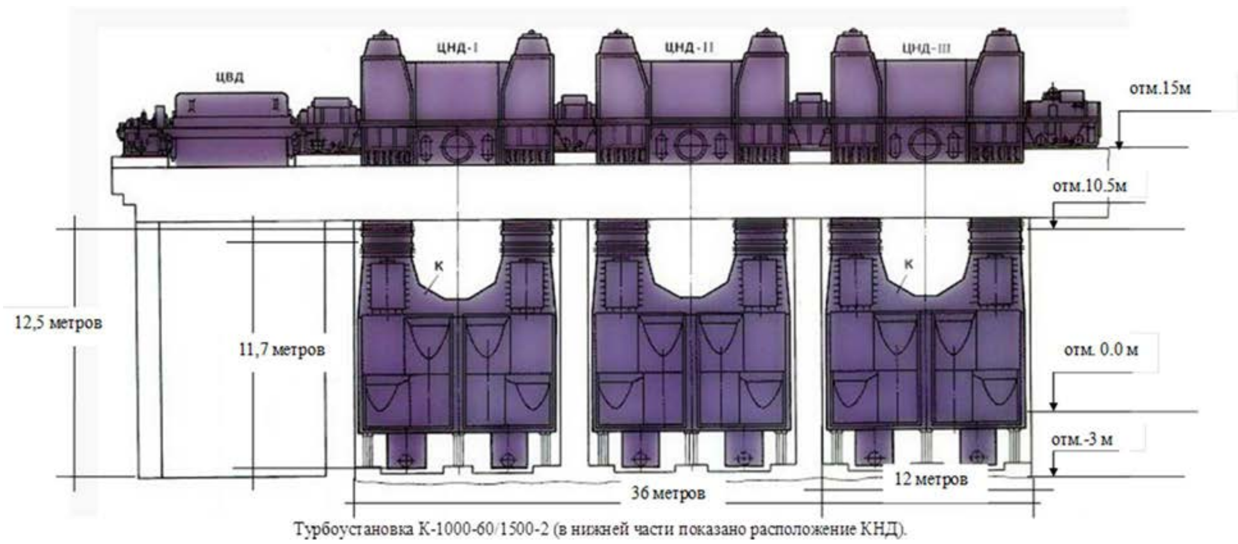

FIG. VII–1. Turboset K–1000–60 1500 (arrangement of LPCs is shown in the lower part).

The applied optimization tools are as follows:

- Exclusion of production losses related to pre–mounting preparation prior to start of operations at the Unit;
- Simultaneous (parallel) performance of LPC dismantling operations;
- Phased optimum distribution and utilization of human resources during work performance.

The risks of the Project:

(1) Untimely on–site delivery of turbine condenser modules and tooling:

- Untimely delivery of LPC–3;
- Planned delivery dates: 15.07.2014;
- Actual delivery dates: 11.08.2014;

In order to avoid slippage of the LPC–3 replacement schedule, additional personnel had to be involved for simultaneous (parallel) performance of operations for module consolidation and LPC–3 cutting.

– Untimely delivery of hydraulic jacks;
– Planned delivery dates: 15.08.2014;
– Actual delivery dates: 24.08.2014 – 1 set, 06.09.2014 – 2 sets;

In order to exclude slippage of the LPC dismantling schedule, additional personnel had to be involved in rearranging hydraulic jacks as well as hydraulic jacks with a lower hoisting height had (h=500 instead of h=700) had to be used.

(2) Lack of human resources in LPC–2 cutting phase;

In phase of LPC–2 cutting, a lack of human resources (cutters) was identified which resulted in a 2–day delay from the schedule.

In order to avoid delays from the LPC–2 cutting schedule, additional personnel had to be involved as well as a tool of the Rosatom Production System (RPS) called "production process smoothing" had to be applied with cutters' distribution to organize their round the clock work.

(3) Lack of human resources in LPC welding phase.

The LPC welding operations were performed by workers in two shifts by 8 hours, from 8:00 to 24:00. The adequate work from 0:00 to 20:00 was not organized (3–4 welders worked). The reason was the work performer's staff heavy load during LPC replacement at other plant units (LPC replacement at Novovoronezh Unit 5 and planned outages at other five nuclear power plants). Actual losses amounted to 2 days.

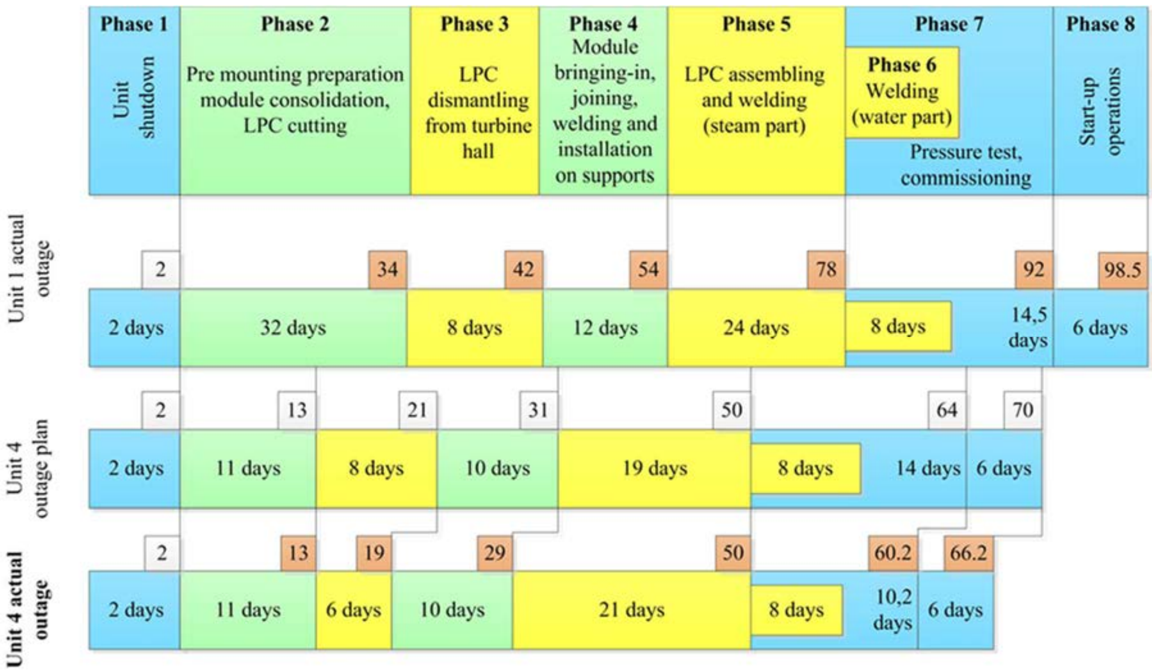

FIG. VII-2. Outage phases and duration.

The RPS tools used in work organization were as follows:

- "Detailed work planning by the hour";
- "Control of due dates" of detailed schedules;
- "Organization of work places according to 5S system": removal of unused tools from the work area, visualization of work progress and results on the maintenance site;
- "Flow cartography": cutting and welding diagrams;
- "Loss elimination": permanent identification of problems and implementation of production process improvements;
- "External adjustment": preparatory operations were performed prior to Unit shutdown which allowed reaching the expected result with lower staff number;
- "Quality incorporation in the production process, intelligent automatization": availability of unique specialized equipment;
- "Production process smoothing": redistribution of cutters and riggers in LPC cutting phase.

Phase 1: Preparatory work.

The following operations were performed prior to Unit 4 shutdown:

- A mounting site was prepared between Units 4 and 5 and its perimeter fenced;
- Wall panels between axes 5–8 were dismantles, and a barrier installed;

FIG. VII-3. Wall panels assembling.

Reinforcing structures were installed under floor slabs at elevation of 0,00 in axes 5–8 of the turbine hall as well as temporary supports and metal structures under condenser bottom;

FIG. VII-4. Temporary supports and metal structures.

A track for the caterpillar crane Liebher LR1350/1 of 350 t hoisting capacity was mounted;

FIG. VII-5. Hoisting mounting.

LPC–1,2,3 block–modules were consolidated;

FIG. VII-6. Consolidating modules.

- Pulley blocks were installed for dismantling of LPC covers and the receiving–dump device parts;

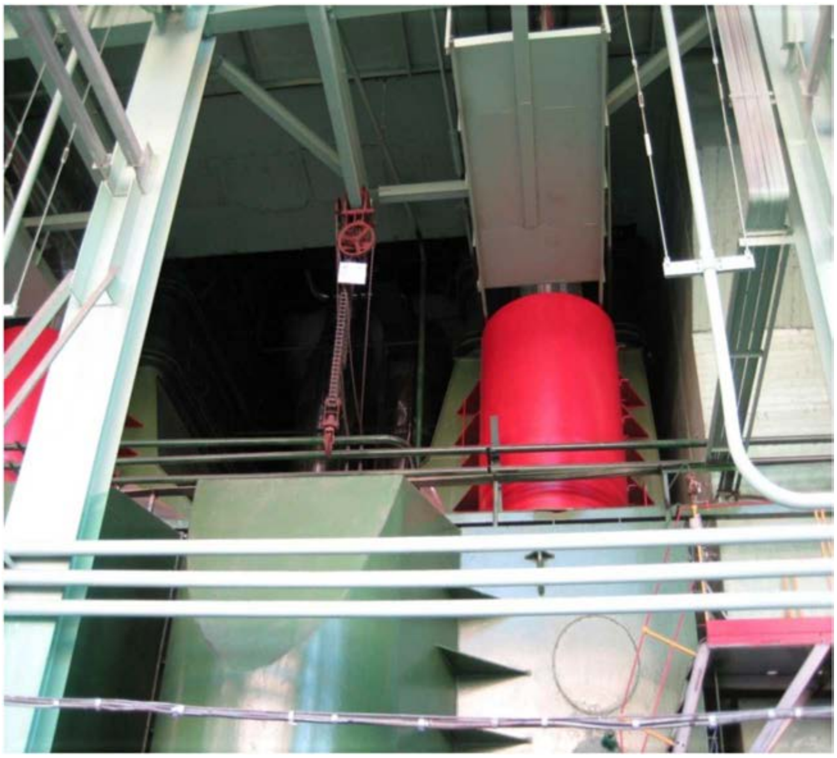

FIG. VII-7. Dismantling LPC covers.

- LPC water chambers were assembled.

FIG. VII-8. Assembling water chambers.

Phase 2: Condenser cutting.

Reduction in phase 2, plan/fact: 6/6 days:

- 1 day: due to cutters' placing ("production process smoothing");
- 3 days: due to use of mechanic rope saws ("quality incorporation in the production process, intelligent automatization");
- 2 days: due to reducing the number of tubing system crosscuts, one instead of two ("implementation of improvements") and application of plasma cutting technique ("intelligent automatization").

FIG. VII-9. Cutting equipments.

Phase 3: LPC dismantling from the turbine hall.

Reduction in phase 3: plan/fact: 0/2 day:

- 1 day: due to change in the technique for dismantling receiving–dump devices which allowed avoiding one displacement and one lifting of LPC rear parts (“loss elimination: exclusion of excess displacements” and “implementation of improvements”);
- 1 day: due to change in the crane travel track which allowed reducing time for moving the dismantled condenser parts (“implementation of improvements”). 12 parts x 2 hours = 24 hours (1 day).

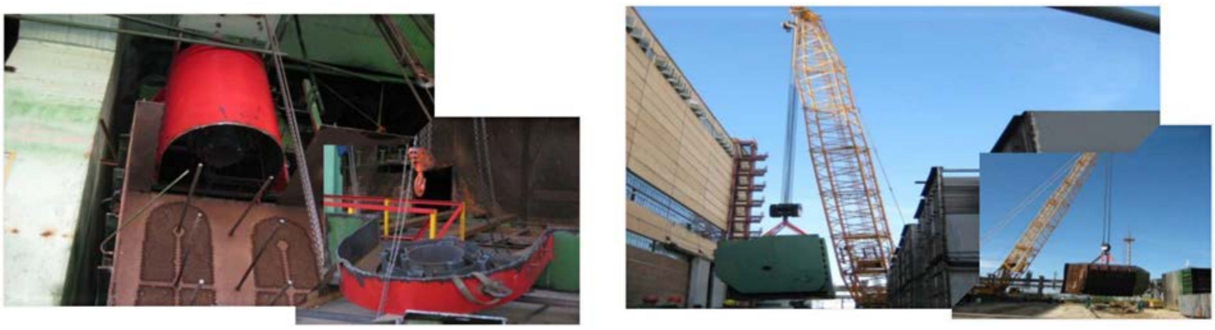

FIG. VII-10. LPC dismantling.

Phase 4: Modules bringing–in, joining, welding and installation on supports.

Reduction in phase 4: plan/ fact: 2/2 days:

- 1 day: due to modules quality manufacture and design modification (implementation of improvements at the supplier's);
- 1 day: due to modification of the technology for condenser shell lowering on the supports (instead of three descents of consolidated modules, one descent of the shell was performed) ("exclusion of excess displacements" and "implementation of improvements").

FIG. VII-11. Module assembling.

Phase 5: LPC assembling and welding (steam part).

Reduction in phase 5: plan/fact: 5/3 days:

- 2 days: due to welders' placing and definition of priorities at each LPC ("production process smoothing");
- 1 day: due to use of semiautomatic welding machines ("quality incorporation in the production process, intelligent automatization").

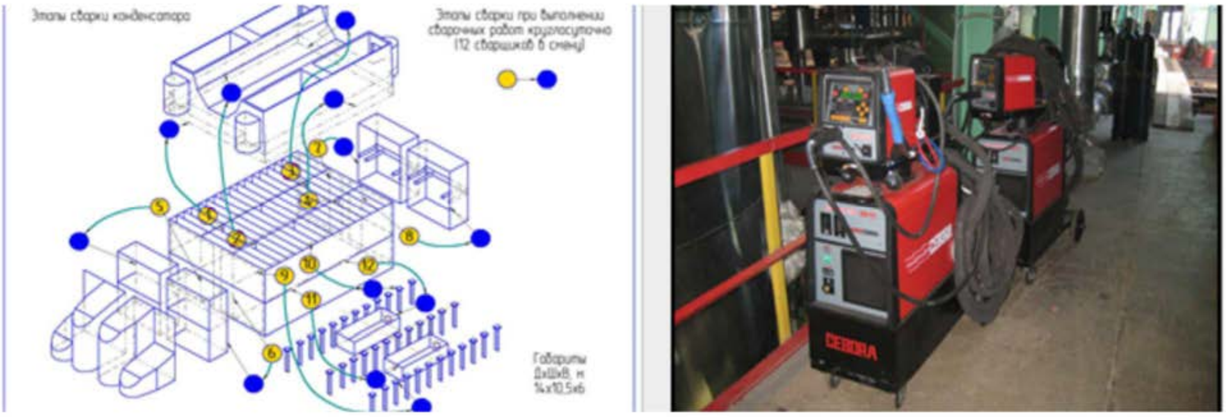

FIG. VII-12.Welding priorities and welding equipments.

On 19.10.2014, Balakovo Unit 4 was connected to the grid.

The Unit 4 overhaul with LPC replacement was performed for 66,2 days, time reduction amounted to 32,3 days from the best reached level during LPC change at Balakovo Unit 1 (98,5 days) in planned outage – 2012.

Additional power generation due to reduction in outage duration from the planned level came to more than 680 million kWh.

Labour productivity of the personnel involved in each phase of Unit 4 turbine condenser replacement during outage – 2014 was increased by 24% (as compared to Unit 1 turbine condenser replacement during outage – 2012).

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ISBN 978–92–0–107816–2
ISSN 1011–4289