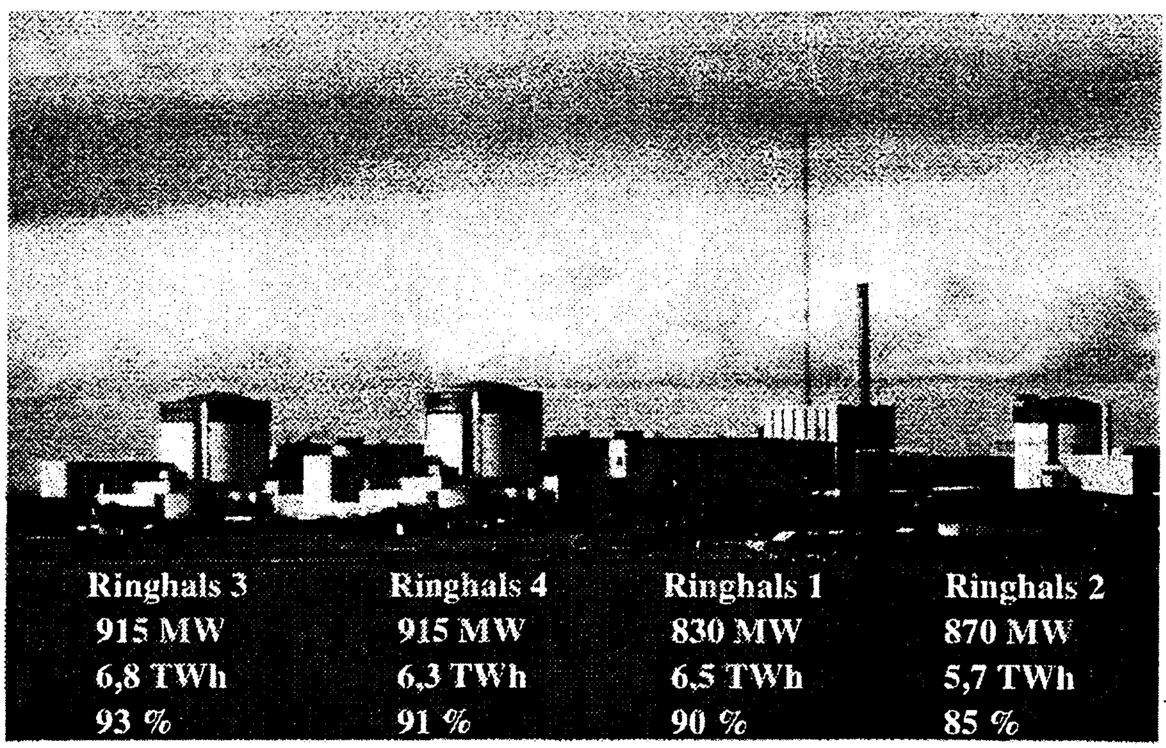
Control Room Tasks during Refuelling in Ringhals 1 NPP

RINGHALS RESULTS 1996

Total production 25,3 TWh (18% of Swedish electrical production)
Availability 90 %
Production cost 16 öre/kWh



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Operator performance during refuelling outages

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Abstract

This paper discusses the performance and tasks of the operators in the control room during refuelling outages.

Analyses of such events have, during the last years, shown that the risk for nuclear accidents is not negligible compared with the risk at higher reactor power levels. Some experts have the opinion that, due to mistakes during an outage, the risk for such accidents during the outage and other accidents later on during power operation is higher than in other plant situations. The high risk level is mainly a result of errors at maintenance actions and supervision of lining up of safety systems.

Most of the control rooms in existing NPPs were designed more than 10 years ago. At that time the activities and the tasks for the operators were not very well understood. Procedures for refuelling and other activities during the outages were not described very well. Often the utility organisation for refuelling outages was not established at the start of the control room design. Experience from operation during many years has shown that the performance of operators can be improved in existing plant, and thus risks be reduced, by upgrading the control room.
These issues have been studied as a part of the modernisation project for Ringhals 1, an ABB Atom BWR owned by Vattenfall AB in Sweden.

The paper will describe the working model for upgrading the control room and important issues to take care of with respect to refuelling outages. The identified issues will be used as the input for improving control room philosophy and the individual technical systems.

1. Introduction

The Ringhals 1 nuclear power plant on the West coast of Sweden is owned by Vattenfall AB. The plant is a two-turbine plant with a BWR of ABB Atom design with external recirculation pumps.

Construction was started in 1969. Up through 1995 the plant had produced 22,09 TWh with an average availability factor of 80%, and at a production cost of 0,15 Swedish crowns per kWh (less than 19 US$ per MWh).

Three PWRs from Westinghouse are also located at the Ringhals site.

The I&C systems and the other electrical systems were designed in the early 60s using the standard components that were available on the market at that time. As a consequence, the design of these components was already some 10 years old when the plant was commissioned. The logic for the I&C was built with relays, and the closed loop control systems were based on discrete electronics. The alarm system was, for the first time in Swedish NPP, computerised. Ringhals 1 was also the first nuclear power plant in Sweden to be provided with an on-line process computer for core supervision.

The anticipated lifetime for I&C equipment is about 25-35 years. After this time, the number of incidents and failures will increase and the equipment becomes obsolete. Such problems may jeopardise the power plant availability and also impact on safety .

Typical problems are:

- Ageing of material.
- Increased fault frequency.
- Spare parts are unavailable.
- Lack of technical support from original suppliers.
- Younger people are unfamiliar with older technology.
- Modifications are difficult.

During the 30 years operation of the Ringhals 1 plant, some separate I&C systems have been replaced by digital systems, but no structural changes have been carried out. Such an approach may result in an I&C with equipment from different suppliers and no standard for communication, MMI (Man-Machine-Interface) or maintenance strategy. A feasibility study shows that such piece-by-piece modernisation would enable extending plant operation for another 5 to 10 years. The expected lifetime for the plant as a whole is substantially longer than that, and therefore, a major modernisation for I&C and electrical equipment was decided in 1995.

Another conclusion was that, evidently, the control room wasn't designed to the best ergonomic principles at least as we know today. During the design very little operation experience was available which in turn made it difficult to design the control room in an optimal way. Especially it was concluded that, due to such lack of operating experience, the design does not support the control room functions during annual refuelling outages well enough.

2. Policy and implementation

The policy decided for the modernisation of I&C includes the following components:

- After completion of the modernisation program, the expected life time for the I&C shall be at least 15 to 20 years.
- The modernisation shall be carried out in steps during the normal annual refuelling outages.
- Modern, i.e. programmable, technology and video display work stations, shall be used.
- After the modernisation, the safety level shall be comparable with that of the latest built NPP in Sweden.

Based on this policy, a strategy for implementation was worked out. It was decided that the modernisation should be carried out during 6 outages starting 1997 and finishing 2003.

Another important decision was that each modernisation step shall be a part of the final I&C structure. As a logical conclusion it was decided that the final structure must be specified first, including determination of the sequence of the different upgrades. The design of the final structure depends on the I&C products available on the market, and therefore, several feasibility studies were carried out by different suppliers, both for the Ringhals 1 BWR and the Ringhals 2 PWR.

The main conclusions from these studies were:

- The number of suppliers must be drastically reduced since:
  1. open systems for communication do not exist, at least not with maintained functionality;
  2. in order to obtain an uniform and standardised operator interface, the MMI part must be designed and delivered by one supplier, and
  3. plant computers or other computers must be integrated in the new I&C structure.
- A co-operation agreement must be signed with one supplier.

Another important observation made during the studies was that the amount of work for the I&C and electrical systems will be comparable to that for building a new plant, but the implementation would be more complex.

In an existing plant constraints that must be taken care of are:

- existing buildings,
- implementation in steps,
- short outages,
- established operational and maintenance practise,
- mentality and qualification of the personnel,
- increased safety requirement level.

As a first step in the modernisation process, it was decided to initiate an extensive analysis phase to be carried out in co-operation with the selected I&C supplier in a typical top-down approach. For the Ringhals 1 BWR plant, ABB Atom was selected as the I&C supplier.

It was also decided that the existing plant simulator should be used not only for renewed operator training, but also for verification and validation of modifications prior to installation in the plant.

3. Analysis Phase.

The main objectives of the analysis phase were to develop plans for the modernisation and the implementation strategy, as well as establishing technical

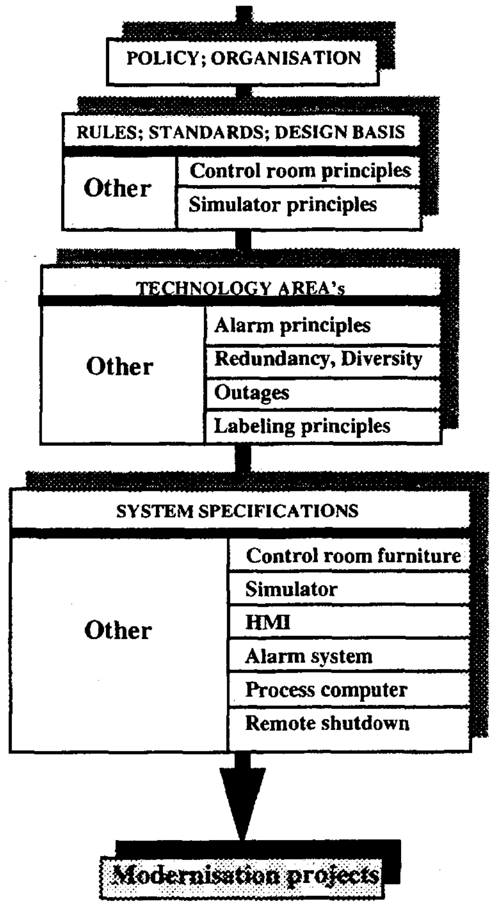

Table 1: Control room studies during the analysis phase

requirements. It should be carried out as a top-down project leading to a description of the requirements for the individual systems in the plant.

The analysis phase was divided into several stages, for definition or description of:

1. Policy, work organisation and general plant requirements.
2. Rules, standards and design basis.
3. Requirements for the different technology areas.
4. Specifications for every system in the plant.

The result from the analysis constitutes input for the modernisation of systems during several outages.

The input for the analysis phase was taken from:

- The original requirements. These were described in more details by a design basis reconstitution project called REDA [6].
- Operating experiences.
- New rules and standards.
- The selected programmable I&C system.

The study was carried out in co-operation between Vattenfall Ringhals and ABB Atom.

The study for the control room started with a review of the existing control room design through interviewing the operating and the maintenance personnel. The main goals for these first interviews were to:

- study the strong points of the existing control room,
- to review the weak points of the existing control room,
- to list new requirements or wishes.

During the same phase of the analysis study new rules and standards were evaluated. The impact on, and the use of the existing training simulator during the modernisation was also studied at an early stage. An important decision was to use the simulator not only for training but also for validation of new equipment before installing in the plant.

A special study was carried out for the refuelling outage on a technology level for defining control room philosophy and detailed specifications for the control room systems.

As shown in table 1 many other control room items were included in the study.

Documents were reviewed in different steps in both organisations and issued as Vattenfall documentation.

4 Outages studies.

For many personnel categories in a NPP, refuelling outages lead to a very high work load. Compared with normal operation the supervision of process systems is no longer the main task. In Sweden it is common practice that the control room personnel co-ordinates and supervises the refuelling and the maintenance. The working situation and the influence on the crew was subject to a study for the Ringhals organisation early in 1993 [5].

The study concluded that the mental stress for the whole crew was roughly a factor 2 higher compared with normal operation.

For the physical stress the average stress was also a factor 2 higher than for normal operation. However the physical stress differed highly between the control personnel categories. The field operators had a stress factor of about 3 times and the control room operators 2 times higher than normal (Figure 1)

Against the background of the following known facts it became obvious that the control room was not optimally designed for refuelling outages.

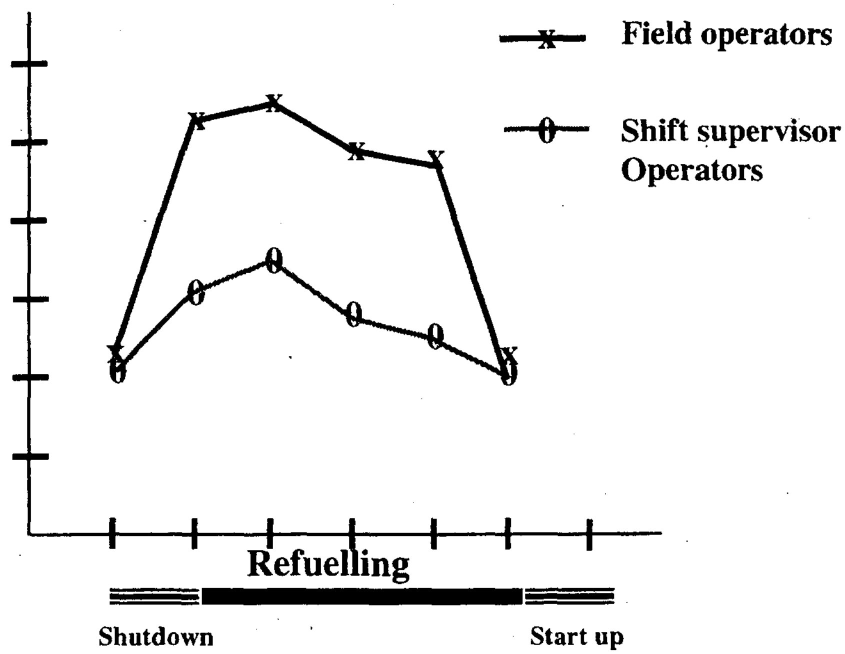

Figure 1: The physical stress of the control room crew during a refuelling outage [5]

The facts are:

- Ringhals was one of the first NPP's in Sweden and very little was know about the working procedures during refuelling. Furthermore during the design of the control room no operation organisation was established yet at the utility.
- The number of tasks carried out simultaneously is very large compared to normal operation.
- Each operator must keep track of a large amount of information and facts such as administrative procedures, safety barriers, Technical Specifications.
- The task for the field operators is mainly to supervise local components and to assist the maintenance personnel. It is therefore natural that the amount of work is increased heavily and especially the mental stress.

During the modernisation planning it was further observed that there is a risk that stress will increase in the future as the amount of work during refuelling is expected to increase. The workload for the refuelling remains the same ("fixed"), but more maintenance will be carried out due to ageing equipment and modernisation of equipment. (See figure 2) At the same time the pressure to shorten refuelling outages will increase due to economical reasons and deregulation of the market for electrical power. Normally, the length of a refuelling period is about three weeks.

For these reasons a special study was carried out at the end of the analysis phase to study how the design of the control room may be improved with respect to refuelling outages.

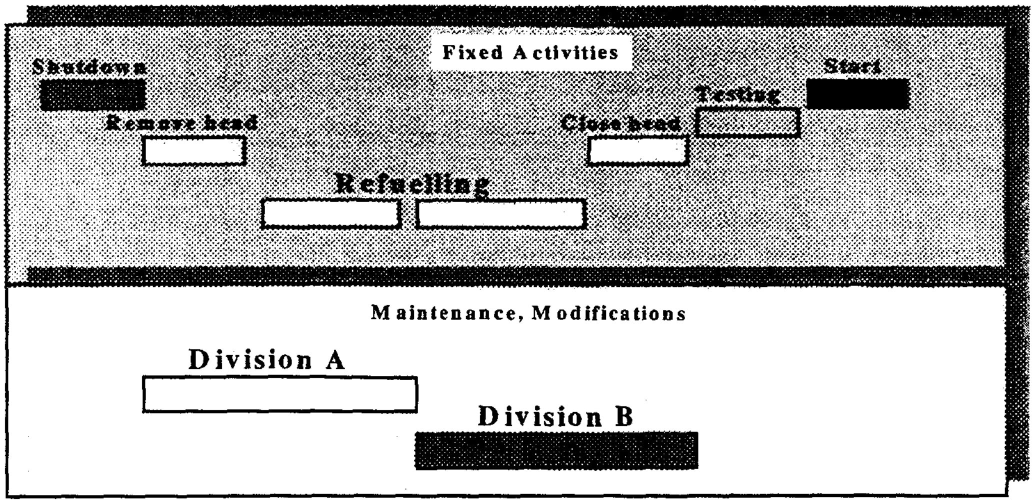

Figure 2: Activities during a refuelling (about 3 weeks).

The input to this study was:

- Reported events from Ringhals 1 but also from other BWRs.
- PSA studies carried out for refuelling outages.
- The Technical Specifications for the plant.
- Different reports from utilities or authorities.

However the most important input came from the plant staff.

This input was obtained by a series of interviews during September/October 1996. As the activities during a refuelling outage are carried out not only by the control room staff also other categories of personnel were also interviewed.

In total the following categories of personnel were involved:

- outage planners (1),
- shift supervisors (2),
- reactor and turbine operators (3),
- field operators (2),
- maintenance (2).

After the first interviews more informal follow-up interviews with key persons were carried out

The interviews were carried out and co-ordinated by a project leader from ABB Atom. For background information different types of documentation on planning, procedures and outage evaluations were studied before and during the interviews. The interviews followed a practical approach. Time limitations made it not possible to carry out an extensive study covering all aspects of an outage. In stead the most important aspects were studied and, most important, documented.

The first point of each interview was to describe the personnel task during the refuelling in or outside the control room.

During the interview various tasks were covered as :

1 Supervision of process systems.

During the outage several process systems must be in operation or must be lined up to start on request. For safety systems the requirements are specified in the plants Technical Specifications

Supervision of the required process system operation is difficult as the control room is not designed for a "subset" of the entire plant.

2 Alarm handling.

During the outage many alarms are generated through testing or other maintenance actions. Real and important alarms can be shadowed by such alarms. This has been reported during several outages in Swedish power plants.

3 Maintenance support.

Before maintenance and during the outage the systems must be lined up to make maintenance possible. A wrongly lined up system can jeopardise plant safety but also that of the maintenance personnel.

Before starting up the plant after an outage the systems must be restored and lined up for normal operation. Operational experience shows that there is an increased risk that the plant is started up without proper lining up of the systems due to human errors.

4 Refuelling.

Refuelling must be carried out in accordance with pre-planned procedures and sequences. At the same time as refuelling is carried out maintenance is done on the control rod drives beneath the reactor vessel in a BWR. Both types of work must be co-ordinated with each other. This has been identified as a risk by PSAs for refuelling outages. This activity is very time-consuming and can be made more efficiently by improving the control room.

5 Fire protection.

During the outage many maintenance activities, e.g. welding, increase the risk of fires. At the same time it is possibly that passive or active fire protection system are not in operation due to maintenance.

6 Critical activities.

For each individual outage special high risk activities were identified and analysed. Typical examples are maintenance in the reactor pressure boundary or lifting of heavy components. Such actions must be supervised by special procedures.

7 Communication.

Typical for an outage is that many people inside the plant need some type of communication with the control room crew. Often they contact the control room staff for information even if it is not necessary. Another observation was that for many process components only actuation from the control room was available even if this could be handled locally during testing. All these facts can be the cause for a higher stress as:

- much people are in the control room at the same time,
- the control staff must answer many telephone calls,
- communication with field operators for co-ordination of the testing can be heavy,
- at the same time they must supervise processes and actuate equipment.

8 Task analysis

During the interviews questions were asked regarding the task of the control room personnel and how the existing MMI (Man Machine Interface) is suited to these tasks.

The most important aspects for each task which were considered during the interviews were:

- the function of the existing control room and the use of the equipment within;
- the strong or weak points of the control room;
- the requirements for communication;
- the requirements for information;
- listing of time-consuming tasks;
- listing of tasks with heavy load on the memory.

5. Modernisation

Based on the interviews of the plant staff and the study by ergonomic specialist several improvements were proposed for the modernisation project.

The implementation of the proposals must be co-ordinated with the similar ones for other operation modes of the plant. Typical examples are the SPDS or the inoperable status indication.

Some of the most important ones are listed below.

5.1 Field operators.

As mentioned before the stress for field operators is especially high during refuelling outages. The main reason is that much information for their task is only available in the field. The new programmable I&C make it possible to present such information also in the control room. For this reason two video work stations special for field operators are planned in the control room. This opens up a possibility for improved "information sharing" between the personnel in the field and those in the control room. Another option is to display more information locally. This can be done by using several local workstations connected to the plants information network.

5.2 Inoperable supervision

In order to improve the supervision of safety systems the following modifications are proposed:

- An overview over systems that must be lined up for standby for each phase during the outage.

- A detailed status information about such systems.
- Computerised tools to analyse the consequences if components are taken out of operation and to provide information about such components.

A general wish was that for all information display there shall be an option to show more background information.

5.3 Process supervision.

During an outage safety systems must be in operation to meet the requirements for the following safety functions:

- residual heat removal,
- feed water to the vessel,
- reactivity control,
- limiting of radioactivity release,
- radioactivity supervision.

The operational status indication must be flexible. Flexible means that the amount of information is selected and displayed adapted to the requirements to the current situation.

5.4 Alarms

In order to reduce the number of non-essential alarms it must be possible to disconnect such ones in the control room. Instead such alarms can be used only for indication e.g. during testing of systems. An overview of the disconnected alarms is provided in the control room.

The remaining alarms are sorted in accordance with the tasks and the responsibility of the different operators.

5.5 Work permits

Maintenance can be carried out only if such is approved after lining up the systems by the operators. Much information is required to carry out such activities as flow diagrams, working procedures and descriptions, safety and risk analysis. A better tool can be provided by the programmable I&C which can use data from different computer system. Such tools will be investigated more during the modernisation process.

5.6 Fire protection.

In order to maintain the required level for fire protection it is important that fire alarms and the status of the detectors and circuits are indicated in the control room. In addition the building layout with the location of detectors shall be displayed together with the routes for manual fire fighting. The communication between the field and the control room is also very important.

5.7 Refuelling

During refuelling today much temporary equipment is installed in the control room for monitoring the refuelling sequence and to co-ordinate maintenance for the control rod drives.

It is a strong desire that such equipment shall be located permanently in the reactor operating desk which is a natural place for the reactor operator during a refuelling. As work is carried out simultaneously on the top and beneath the reactor vessel means must be provided in the control room to co-ordinate activities. Examples are interlocking of certain critical actuations, supervision with TV cameras, position indication of the refuelling bridge and display of all needed information in the same location.

5.8 Testing

During and after an outage many different type of tests are carried out to verify system functions. They are often time consuming and on the critical time path of the outage. In order to optimise the refuelling such tests shall be more automated by different application software. Test results are reported automatically through the computerised system.

5.9 Other

Other options for improvements during the modernisation are:

- tools for analysing and supervision of critical maintenance actions e.g. work on the primary system beneath the top of the core,
- means for reduction of the work volume of the control room staff e.g. more local testing after maintenance tasks,
- improvement of the communication between control room and the field,
- improvements for certain specific actions during an outage. This may result in many proposals for improvement of the detailed design of systems or procedures.

6 Conclusions.

The analysis phase has demonstrated that the top-down approach is very useful for interpretation of the overall plant requirements. It is nearly a "must" if a major modernisation is planned or other than the original requirements must be met. It was also very fruitful for specification and purchasing of systems. The co-operation of the utility and reactor designer brought in both operational experience and experience from later built plants.

As always in a project, the influences of proposed modifications on the SAR (Safety Analysis Report) and the Technical Specifications must be studied as early as possible.

During the analysis phase an observation made earlier was confirmed. The control room design for earlier NPPs is not optimal for refuelling outages. As the volume of work during such outage will increase in the future this can be a safety risk.

Event reports from Swedish NPP show an increasing number of human errors during maintenance actions. For this reason more attention shall be paid to the ergonomic design of tools to be used to carry out and to supervise maintenance and to line up systems for operation again.

For major modernisations the regulatory body shall be kept informed continuously from the start.

A general judgement is that the proposed modifications will reduce stress and make the plant more safe.

The proposed improvements for the different systems in the control room must be logical parts of the integrated control room philosophy as well for outages and for other plant situations.

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