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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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SAFETY OF MODIFICATIONS AT NUCLEAR POWER PLANTS

THE ROLE OF MINOR MODIFICATIONS AND HUMAN AND ORGANISATIONAL FACTORS

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14 December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 28 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the OECD member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; to promote the coordination of work that serve maintaining competence in the nuclear safety matters, including the establishment of joint undertakings.

The committee shall focus primarily on existing power reactors and other nuclear installations; it shall also consider the safety implications of scientific and technical developments of new reactor designs.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA) responsible for the program of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health (CRPPH), NEA's Radioactive Waste Management Committee (RWMC) and NEA's Nuclear Science Committee (NSC) on matters of common interest.

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EXECUTIVE SUMMARY

Operating experience repeatedly shows that changes and modifications at nuclear power plants (NPPs) may lead to safety significant events. At the same time, modifications are necessary to ensure a safe and economic functioning of the NPPs. To ensure safety in all plant configurations it is important that modification processes are given proper attention both by the utilities and the regulators. The operability, maintainability and testability of every modification should be thoroughly assessed from different points of view to ensure that no safety problems are introduced.

The OECD/NEA Committee on Safety of Nuclear Installations (CSNI) has recently addressed the issue of modifications by organising a "Workshop on Modifications at Nuclear Power Plants – Operating Experience, Safety Significance and Role of Human Factors". This workshop was undertaken as a joint effort of the Working Group on Operating Experience (WGOE) and the Special Experts Group on Human and Organisational Factors (SEGHOF), and it was held at the OECD Headquarters in Paris on October 6 to 8, 2003. The initiative to organise the workshop was taken by the WGOE and the SEGHOF based on findings from events and incidents due to modifications at nuclear power plants in the world and weaknesses experienced in modification processes.

During the workshop, the WGOE focused on the theme of "Minor Modifications and their Safety Significance", while the SEGHOF focused on the topic "Human and Organisational Factors in NPP Modifications". This report is based on material collected before the workshop, the workshop proceedings[1], discussions of the group of experts responsible for the arrangement of the workshop, and additional material collected by a consultant. The workshop was preceded by extensive preparations, which included collection of national surveys in response to questionnaires on modifications at the NPPs. Not all of these surveys were available at the workshop, but their findings have now been included in the present report.

The ultimate responsibility for plant safety lies with the licensee. Consequently, modification processes at the utilities are controlled by written procedures. The modification processes vary depending on the type and scope of the modification. Large modifications generally lead to fewer problems, because these projects are given a great deal of attention and resources together with flexibility in milestones and timing of activities. In contrast, minor modifications seem to, according to recent experience, represent a generic challenge because they are less likely to be recognised as safety significant. Similar kinds of challenges may arise during plant maintenance, when changes in the design or materials may be made without anyone recognising that the maintenance work has actually led to functional modification of plant equipment.

A modification process, in which possible safety influences are assessed early, may improve nuclear safety to a significant extent and, at the same time, reduce overall modification cost. Screening of intended changes can be used to estimate design and analysis effort required in the modification process. In the screening, it should be observed that system complexity sometimes may have unexpected impacts. Screening criteria should address the safety significance of the systems and components modified. Also, the impact of the changes on tasks performed by operators and maintainers should be assessed. Major

[1] OECD/NEA (2004). Modifications at nuclear power plants – operating experience, safety significance and the role of human factors and organisation, NEA/CSNI/R(2004)17.

modification projects should always include an analysis of both technical and human contributions to plant operability and maintainability as a part of their comprehensive review process.

It is important to create awareness and understanding of the potential safety impacts of modifications at NPPs. This awareness may be improved by collecting and disseminating information about modification-related events. Good results may only be achieved by integrating technical and human factors considerations in the safety assessment process for plant modifications on the utility level. Regulators have an important role in ensuring that modifications are acceptable, and that appropriate processes are followed. International agencies have a role in informing regulators and industry about the importance of using appropriate processes when modifications are planned, reviewed, designed, and implemented.

1. INTRODUCTION

1.1 Background

Modifications are a vital part of nuclear power plant (NPP) life. Reasons for them include, but are not restricted to, rectification of plant deficiencies, improvements of plant performance, adaptation to new regulatory requirements and the utilisation of new technologies. Modifications are a crucial step in the continuing effort of ensuring NPP safety, because they close the loop from operational experience to actual improvements in plant design and operation.

Plant modifications may however also introduce new problems if they are not implemented with the necessary caution and prudence. To minimise the problems modifications may cause, the design and implementation of each modification should be assessed both broadly and deeply to ensure that its impacts are analysed and understood. Nuclear power utilities have responded to this requirement on their modification processes by using written instructions, which are reviewed at regular intervals and updated when needs for improvements are detected. Regulatory bodies have, in a similar, way put attention on their own procedures for reviewing and accepting plant modifications.

Modifications at the NPPs are an ongoing activity and there are many reasons that more modifications may be expected in the future. One reason is the possibility of extending plant operational life. Another reason is that the availability of better design codes and measuring equipment gives opportunities to increase operational performance by upgrading the rated power output or improving plant availability. New regulatory requirements, such as those in the field of severe accidents, are also introducing a need for modifications. Finally the increasing obsolescence of certain components and systems, such as in the field of I&C and control rooms, also force NPPs into modernisation projects.

There is evidence from operational experience showing that plant modifications may introduce new threats to safety. This was the reason for OECD Nuclear Energy Agency (NEA) Committee on Safety of Nuclear Installations (CSNI) Working Group on Operating Experience (WGOE) and Special Expert Group on Human and Organisational Factors (SEGHOF) to address plant modification safety as a generic issue and to develop additional guidance for conducting the modification process in a careful and prudent manner.

1.2 Objective and scope

The aim of the report is to illustrate how deficiencies in the modification process can lead to shortcomings in design, implementation, testing and commissioning of modifications that may not be detected and corrected before their implementation. In fact such shortcoming may not even be detected before an incident makes the deficiencies obvious. One important objective of the report is to illustrate how lessons learned from designing and implementing plant modifications can be used to improve both utility and regulatory processes for handling plant modifications.

In considering the material collected before and at the workshop, it became obvious that it was necessary to put the findings into a larger context of modifications in general to make it more useful for people at power utilities and nuclear regulators. The report has been written to serve as general guidance for building up and carrying out activities connected to plant modifications, both at nuclear utilities and regulators.

Consequently this report addresses plant modification in general, but focuses on two specific areas that have been identified as priorities by SEGHOF and WGOE. These two areas are the following:

- minor or non-identified modifications that may have a major impact on nuclear safety,
- inadequate human factors considerations of impacts of the modification.

The problems observed in these two areas have a common cause in the sense that proposed modifications have not been assessed and scrutinised in enough detail to identify possible impacts.

Organisational changes represent another large area of modifications with their own considerations, but they are outside the scope of this report.

This report contains five main chapters. The next chapter identifies present NEA activities related to plant modifications and gives an account of the process that lead to the present report. The third chapter gives an account of typical modification processesfollowed by most nuclear utilities. The fourth chapter gives an overview of the regulatory processes that are used to ensure that proposed modifications fulfil regulatory requirements. Chapter five gives an account of lessons learned and the sixth chapter provides suggestions for possible improvements in the handling of modifications.

2. NEA ACTIVITIES CONNECTED TO PLANT MODIFICATIONS

2.1 CSNI and CNRA activities

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programs, and representatives from regulatory authorities. It was set up in 1973 to develop and coordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international cooperation in nuclear safety amongst the OECD Member countries.

CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review the state of knowledge on selected topics of nuclear safety technology and safety assessments, including operating experience; to initiate and conduct programs to overcome discrepancies, develop improvements and reach consensus on technical issues; to promote coordination of work, including the establishment of joint undertakings. Modifications have been touched upon in the CSNI programme of work earlier by its WGRISK (modifications based on the use of PSA) and WGOE (activities in member countries to upgrade sump strainers).

Earlier CSNI activities, which have relevance to modifications, include the following:

- A workshop on Approaches to the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms.
- A CSNI technical opinion paper has been written on Managing and Regulating Organisational Change in Nuclear Installations.

The NEA Committee on Nuclear Regulatory Activities (CNRA) has touched upon modifications as a part of its programme of work. Examples of that are as follows:

- The 1994 Workshop on Conduct of Inspections for Plant Modifications, Event Investigation and Operability Decisions,
- The CNRA Special Issue's Meeting in 2000 on Regulatory Aspects of Life Extension and Upgrading of NPPs.
- A report on Nuclear Regulatory Inspection of Contracted Work Survey Results.
- A senior CNRA task group produced in 2001 a publication: The Nuclear Regulatory Challenge of Judging Safety Backfits.

2.2 WGOE activities

The main mission of the working group on operating experiences (WGOE) is to analyse and develop insights from operating experience, and to communicate these insights to the CSNI, CNRA, and interested government and industry bodies. On an annual basis, the WGOE reviews and assesses the safety significance of operating events using information from probabilistic safety assessment of events when available, and makes recommendations on the basis of these reviews. WGOE also conducts special studies in areas of high safety and regulatory significance, and make recommendations to the CSNI and the CNRA

on the basis of these studies. The WGOE operates the Incident Reporting System in co-operation with the IAEA and monitors its application and modifies and improves the system as necessary. Finally, the WGOE sponsors and utilises specialised databases such as ICDE, COMPSIS, precursor analyses, and human performance.

The issue of minor or non-identified modifications (MiNIMs) was discussed at a WGOE meeting in 2001. At the meeting one example of recurrent events experienced in Belgium was presented. The first event was discovered at Tihange 3 and it involved cracks originating from the positive terminal of a battery cover, which lead to electrolyte leakage. At the meeting, similar events from other countries were presented and discussed. In the discussion of the events, it became evident that they were caused by a non-identified modification in the manufacturing of the batteries. Discussions at the meeting revealed that similar events had also occurred in France and Germany.

Based on these discussions, WGOE proposed to investigate minor or non-identified modifications that may impact safety. This proposal was accepted by the CSNI in 2002 and initiated a WGOE task force meeting in September 2002, at which time it was decided to prepare a questionnaire on MiNIMs to Member countries. At the same meeting, it was proposed to arrange a CSNI workshop on modifications.

The WGOE tasks on MiNIMs concentrated on the following specific items:

1) Specify the concept MiNIM - "minor or non-identified modifications that may impact safety"
2) Provide recommendations and guidance to prevent and be able to detect MiNIM events, by collecting and analysing them in order to answer the following questions:
    a. How was the anomaly detected?
    b. What were the direct and potential impacts on safety?
    c. Is this a specific or generic issue?
    d. Have effective measures to prevent MiNIMs been taken?
3) Gather and share international existing "good practices" in the area of MiNIM.

2.3 SEGHOF activities

The main missions of the CSNI special expert group on human and organisational factors (SEGHOF) is to improve the current understanding, to advance the utilisation of methodologies for human and organisational factor assessment and to address emerging safety issues in order to maintain and improve the safety of nuclear installations in member countries. In order to advance these aims, the group meets to exchange information and experience about safety relevant human and organisational issues; discusses in detail, compares and benchmarks programs in Member countries; indicates where further research is needed; and collaborates with other groups (mainly WGOE and WGRISK) as necessary.

Presentations and discussions at SEGHOF meetings have demonstrated the importance of integrating human factors considerations into NPP design and operation. If human factors issues are not given a proper attention, the consequence may be human errors in operation, maintenance, installation and testing of systems or components. Over the years there have been several safety significant events that can be attributed to deficiencies in the human-system interface at the NPPs.

Based on the proposal from WGOE to prepare a questionnaire and to hold a workshop on modifications, SEGHOF joined the activities by preparing a questionnaire focusing on human factors issues connected to plant modifications.

2.4 The two questionnaires and a summary of responses

The two questionnaires (cf. Appendix 4) were sent out to the WGOE and SEGHOF members before the workshop. Some responses were obtained before the workshop and provided valuable input to discussions. Before the end of 2004 written contributions to the two questionnaires were obtained from twelve countries.[2] The responses obtained clearly indicate the importance of modifications in nuclear safety and highlight the importance of the two selected areas of the workshop.

In the area of minor or non-identified modifications (MiNIM), which was addressed by the WGOE questionnaire, the responses can be briefly summarised as follows:

- Countries are using similar procedures in handling modifications, but there are no specific considerations of MiNIMs.
- All respondents were able to give examples of events with potential safety significance due to MiNIMs. In the event descriptions, the following examples of root causes were given:
  - changes in components, materials and spare parts by their manufacturers that with no notification to the NPPs,
  - insufficient analysis, sometimes linked to a lack of documentation,
  - no or insufficient pre-service tests,
  - inadequate communication between parties participating in different parts of the modification, inducing a lack of needed information.
- It is very difficult to detect MiNIMs before they are made obvious during an event.

Based on the results of the survey, areas identified for discussion by SEGHOF during the workshop were as follows:

- The importance of considering human factors in the modification process
- Improving the consideration of human factors and difficulties encountered
- Methods and tools for performing human factors studies and actions.
- The role of the regulator to improve detection of shortcomings due to modifications

Responses to the SEGHOF questionnaire can briefly be summarised as follows:

- There is general agreement among all respondents that it is important to take human factors into account when modifications are made for the following reasons:
  - Errors resulting from new deficiencies in the human system interface can be a significant contributing factor to NPP incidents and accidents.
  - Incorporating human factors principles ensures that the needs of users are considered. By considering the users, the system will be less prone to and more tolerant of human errors.
  - Factors that influence human performance must be understood and given adequate consideration throughout the life of a nuclear installation. By systematically considering factors which may impact on human performance, potential errors can be eliminated or reduced.
- To ensure the best results the human factors aspects should be considered early in the modification projects, but not all projects need the same investments in human factors resources.

[2] Belgium, Canada, Czech Republic, Finland, France, Japan, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom and United States.

2.5 The workshop

The "Workshop on Modifications at Nuclear Power Plants – Operating Experience, Safety Significance and Role of Human Factors" was held in Paris 6-8 October 2003.[3] It was attended by 55 experts from the industry, regulators and technical support organizations from 15 countries. The workshop programme consisted of plenary and parallel sessions. The specific themes of WGOE and SEGHOF were discussed in parallel sessions, where the joint plenary sessions focused more generally on the modification process. A total of 16 presentations were given by the participants (cf. Appendix 2). The presentations included descriptions of events related to modifications, development of guidance for the modification process and gave many examples of good practices. The results from the two questionnaires were distributed to the participants before the workshop.

During the first day of the workshop, all participants attended seven paper presentations. On the following two days, participants were separated into two parallel streams of presentations and discussions. The first stream focused on human factors and the second on operational experience. Both streams included three discussion themes, which were introduced with presentations. The themes were:

1. Human factors
    a. How to take lessons from feedback experience?
    b. How to improve the consideration of the potential impact of human and organisational factors impact in the modification process?
    c. Which tools and methods can be used for integrating human factor in the design process of a modification?
2. Operational experience
    a. Is it possible to set a reference basis to define which modifications, considered as minor, have to be taken into account because of their potential impact on safety?
    b. How to improve the national modification processes?
    c. How can the regulator and a technical support organisation help to improve detection of shortcomings due to modifications?

2.6 Additional material collected after the workshop

In assembling general conclusions and recommendations for the Workshop Proceedings it was decided to expand the material and to put it in the context of the whole modification process. This work was carried out by a consultant and included the following specific parts:

- Going through the workshop material and extracting relevant findings.
- Collecting of additional relevant literature in the field of plant modifications.
- Providing examples of instructions used at two NPPs available for broader international use (Appendix 6 and Appendix 7).
- Placing findings, conclusions and recommendations into the context of the modification processes typically found at NPPs and regulatory bodies.
- Lifting conclusions and recommendations to a more generic level to be acted upon by NPPs and regulators.
- Condensing findings, conclusions and recommendations concerning modifications to form an input for further NEA activities.

[3] OECD/NEA (2004). Modifications at nuclear power plants – operating experience, safety significance and the role of human factors and organisation, NEA/CSNI/R(2004)17.

3. MODIFICATIONS AT NUCLEAR POWER PLANTS

3.1 Types of changes and modifications

NPPs undergo many significant changes throughout their life-cycle. Plant modifications may be generated by internally or externally driven initiatives, which are due to operational experience or new regulatory requirements. Modifications may be aimed at improved safety or economic performance, or they may simply be aimed at replacing obsolete equipment. All modifications have the potential to introduce new challenges to safe and economic performance.

There is a large span of plant modifications ranging from major modernisations, where large parts of the technical systems are rebuilt, to small, simple modifications were only a single component is exchanged. Modification projects are usually categorised into discrete categories in order to facilitate planning and administration of the projects. A typical categorisation is to separate between large, medium and small modifications and to assign resources accordingly.

Technical modifications include the redesign of systems, changes of components and changes in materials. Modifications of process computer or I&C software is another large group of technical modifications. Changes in instructions, procedures and work processes are usually given the same kind of consideration as plant modifications. It is important to note that even simple changes of set points or limit values may have unexpected influences. Changes and modifications will always introduce the need for changes in documentation that in turn may affect instructions, procedures and other documentation.

3.2 Reasons for modifications

There are many reasons for plant modifications. The most important is that internal or external operational experience has demonstrated that some assumption in earlier safety considerations was observed to be invalid. One such example is the TMI accident, which demonstrated that small breaks in the piping of the primary circuit could present a serious challenge to plant safety. Another example is the clogging of the strainers, which occurred at a Swedish plant in 1992.

More specifically the need for modifications can arise from

- the physical ageing of plant systems, structures and components,
- obsolescence in hardware and software,
- feedback from operating experience within the station,
- lessons learned from event and incidents at other plant in the world,
- research that reveals problems with old solutions or presents new opportunities,
- changes in engineering methods and standards,
- opportunities for improvements in plant safety,
- changes in expected performance of the plant,
- changes in organisational and operational practices,
- changes in regulatory requirements.

In spite of their necessity, any change or modification always carry the risk of introducing new problems due to unexpected impacts. They also introduce additional burdens in the retraining of plant personnel. Modifications always carry additional costs through the need to modify plant documentation, including operating and maintenance procedures. Due to the possibility that a modification will introduce new problems, it is necessary to compare the costs and benefits of not modifying the plant with the costs and benefits of modifying it.

3.3 The plant design basis

Nuclear power plants are complex with many interdependent systems. Therefore, any change or modification has the potential to have unexpected consequences, simply because some mechanism of interaction is overlooked. The safety of NPPs builds on a design philosophy, which has been implemented in systems and components. If this design philosophy and the corresponding design basis is not documented and understood, a specific modification may be contradictory to the original design intent.

When a nuclear power plant is built, several vendors are typically involved. Vendors adapt their designs to the general design principles of the plant. Each of the vendor design areas can have an important contribution to plant safety in some specific operational regime. These contributions are not always documented in an easily accessible format and they may therefore escape later assessments when they are influenced by some specific plant modification. It is important that this design basis as expressed in documentation and knowledge of plant designers is maintained in the organisation operating the plant. Some countries require the establishment of a design authority, who is responsible for maintaining and updating the design basis.

3.4 A systematic approach

A systematic approach to plant modifications is necessary to reduce the risk posed by modifications. This means that a modification process should be established, which is documented in instructions and guidelines. Only then it is possible to ensure consistency, repeatability and traceability in the process. The modification process has to be adapted to the specific needs of a NPP, a site or a utility. There is, for example, a difference if the modification process should be adapted to a single plant, a multi-unit site or to a nuclear utility, which have many similar units at several sites.

In developing a modification process, it is important to distinguish between design and assessment activities. Design activities may be aimed at generating concrete design solutions or background material such as task analyses, or they may be aimed at producing plans for testing, implementation and commissioning of the modification. Assessment activities are aimed at ensuring that possible flaws in designs or plans are detected and corrected before the modification process is allowed to proceed. Decisions within the modification process are based on results from interlinked design and assessment activities. Concrete decisions may be to proceed or to stop the modification process or seek additional clarification.

The first and most important question in the modification process is to ask if the modification is necessary and useful. To answer that question it is usually necessary to do some initial design and planning and to assess these results. If a decision is made to continue, more detailed designs and plans will be produced and reviewed before the final decision to implement the modification is made. In the next step of the modification process the components to be installed are designed, produced and tested. An installation and commissioning plan is also produced and assessed. When the plan has been assessed and there is an agreement that it can be carried out, a decision to start the installation can be made.

3.5 The timing of modifications

Table 1. An example of priority levels assignned to plant modifications.

1	Modifications to assure/restore safety
2	Modifications identified in the strategic plan
3	Modification with a clear economic benefit
4	Modifications motivated by other reasons

The timing of specific modifications introduces another planning dimension. Modifications aimed at correcting some immediate safety problem can be urgent especially when the regulator has introduced a deadline for some problem to be fixed. Modifications that aim at correcting problems that have an influence on plant availability are also addressed with some urgency. A common approach at the NPPs is to assign priority levels, which govern the general timing of the modifications (Table 1). In the handling of urgent modification projects it is important to ensure that the breadth and depth of the assessments is not affected. The timing of a plant modification should must be integrated into the operational schedule of the plant. Some modifications can stretch over several years, where parts of the modification project are implemented during consecutive refuelling outages. Some minor modifications may be implemented during plant operation, but should in this case be scrutinised even more carefully, because they may increase the likelihood for disturbances. In spite of careful planning of plant modifications, changes to the plans are often required.

For a site with multiple units for which the same modification is planned, there is a choice of which unit should be the first in implementing the modification. Similarly if the modification is to be implemented on several units, the consecutive order must be determined. When the same modification is implemented on several units, operating experience should be use to improve each successive change.

3.6 Typical modification processes

Modifications at the nuclear power utilities are controlled by written procedures, which divide the modification process into distinct phases. These phases may include a proposal phase; a preplanning and assessment phase; a design and implementation planning phase; an implementation, testing and commissioning phase; and a finalisation phase (cf. Figure 1). All phases include design, planning, assessment and documentation activities. Through this process, a modification goes through several stages of refinement and finalization before it is implemented and commissioned. In this process there are typically several decision and hold points, where additional clarifications could be sought or where the modification could be returned to an earlier stage in the process.

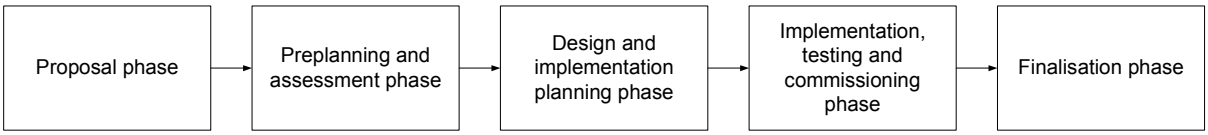


Figure 1. Phases in a typical modification process.

A proposal for a modification may enter from internal sources such as strategic plans and suggestions for improvements or they may come from external sources such as vendor suggestions, operational experience and research results. In the preplanning and assessment phase, costs and benefits of the modification are assessed. When the decision to proceed is made, the modification enters the design and implementation planning phase, and human and financial resources are allocated. In the implementation, testing and commissioning phase, preliminary plans are finalised, assessed and implemented. The finalisation of the

modification includes reporting and documentation activities, and it is usually extended to the end of the warranty period for the newly installed equipment.

3.7 Assessments and reviews in the modification process

There are many different assessments and reviews during the modification process by the utility to ensure that modification projects are handled with due caution and prudence. The most important review is connected to the initial screening of the modification and its classification in separate categories. There are many criteria for this screening of the modification such as

- safety impacts,
- technical scope,
- complexity,
- costs.

These criteria are typically combined into a general classification, which governs activities, decisions, authorities and responsibilities in the modification process. For example, large modifications may be controlled with a separate project handbook, whereas minor modifications may follow simplified implementation routes. It is important that the classification of modifications is based on thorough screening since it controls later stages of the modification process.

In large modification projects it may be necessary to redo a large part of the safety analysis report (SAR). In this case, general guidelines for safety assessments are relevant. For small projects, simple assessments of relevant areas and a more detailed assessment of possible impacts in selected areas can be enough. Plants typically use checklists to support these assessments (cf. Table 2).

Table 2. Typical checklists that can be used in assessment and review

Safety review checklist	Technical review checklist
1. List of documents and procedures to be affected. 2. Is the containment integrity affected? 3. Is the seismic analysis still valid? 4. Are radioactive releases foreseen? 5. Is there a need for environmental qualification? 6. Defence in depth, single failure criterion? 7. Fail safe, separation and redundancy? 8. Is the probability of an accident in the SAR affected? 9. Could it create the possibility of an accident or event not foreseen by the SAR? 10. Are the safety margins as described in the SAR and technical specifications affected?	1. Mechanical and electrical issues. 2. Fire protection. 3. Security and physical protection. 4. ALARA and environmental effects. 5. Industrial safety and chemicals effects. 6. I&C aspects (adequate instruments for monitoring, alarm signals, calibration, time constants, manual actuation). 7. Structural effects. 8. Operability and maintainability (operational modes, emergencies, ease of maintenance, operator training, procedures). 9. Analysis of failure modes. 10. Procedures affected applicable norms and codes.

Assessments and reviews are typically controlled by several specialised procedures and instructions such as:

- quality assurance and quality control,
- human factors,
- programmable equipment,
- procurement,
- inspections.

In the creation and updating of these instructions it is important to ensure that they are consistent with the instruction defining the modification process. An important aspect of the instructions is definitions of authority and responsibility for different parts of the modification process.

3.8 Maintaining and improving the modification process

The modification process itself is also the target for modifications and improvements. This typically takes place as a part of activities defined in the quality system. A common requirement at the NPPs is that work activities should be audited at regular intervals. Through audits, there is assurance that actual modification projects are executed according to the governing instructions. An audit will typically be performed by assessing a sample of modification projects. On the basis of the audit results, corrective actions may be proposed (cf. Figure 2).

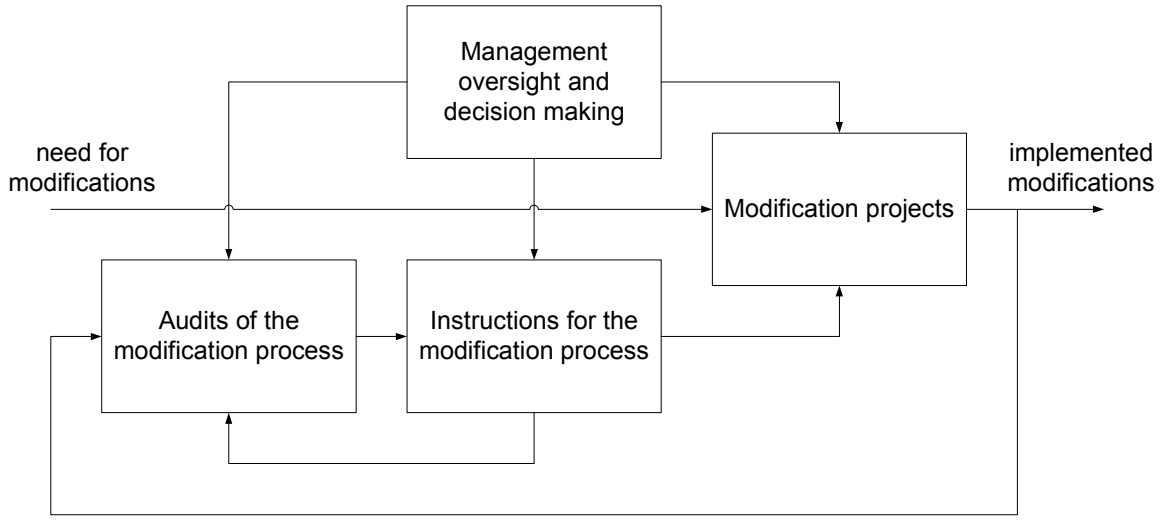


Figure 2. A diagram describing how the modification process is maintained and improved.

The responsibility for this process is typically given to the organisational unit responsible for modifications planning. When updating the modification process, it is important to collect views on strengths and weaknesses in the process from various departments, such as operations, maintenance and technical support. These may then be discussed in a suitable group of people to create suggestions for improvements. Finally, the instruction is updated, reviewed and ratified.

A common practice at the NPPs is to include a general assessment of modifications and their success as a part of the periodic safety reviews that are usually carried out at ten year intervals. Sometimes the nuclear power utilities may invite an independent review of their modification processes to get an outside view on possible improvements. Regulators may also audit the modification process and identify areas for improvement.

3.9 Tools to support the modification process

Nuclear utilities use various methods and tools to support their modification projects. Checklists and instructions are one important class of these methods and tools. Over the last years, however, a common trend has been to use computerised systems to support the modification process. These systems include, but are not restricted to the following:

- *Outage planning systems*. A system including functions for scheduling and keeping track of work activities during outages.
- *Configuration management system*. A system, which is used to manage the plant configuration in terms of component types, operational states, versions, etc.
- *Work order system*. A system used by control room operators to support the co-ordination of work activities at the plant.
- *Documentation handling systems*. A system to support modifications, archiving and distribution of instructions and other documents.

In addition, NPPs often use probabilistic safety assessments (PSA) to assess effects of modifications, computerised design codes to size safety systems, computer aided design (CAD) packages to produce drawings, and virtual reality (VR) packages to visualise various environments at the plants. Computerised checklists may also be used to support assessments and reviews.

3.10 Roles and responsibilities in modification projects

It is a common practice at the nuclear power plants to use outside vendors and contractors for medium and large modification projects. There are many ways in which outside contractors may be involved, ranging from carrying out small well defined tasks to turn-key deliveries of important systems.

Independent of the involvement of outsiders in the modification projects, it is important that the plant involves itself in actual work activities. Firstly, the responsibility for safety of the plant always lies with the holder of the operating license. Secondly, it is important to ensure that knowledge of the modified systems is transferred to plant operations and maintenance staff. Finally, the plant staff has to take the responsibility for the oversight of work activities at the plant during the modification project to ensure that agreed practices are adhered to in all phases of the implementation, testing, installation and commissioning.

The division of labour between plant staff, contractors, and vendors depends on many factors. The use of outside contractors and vendors has advantages, such as the use of their specialised knowledge and experience and the availability of trained personnel and specialised equipment. If there is a strong vendor with considerable understanding of the plant design base, the share of contracted work can be larger, but if it is difficult to find such vendors and contractors, the plant may be forced to carry out a major share of the work. Due to strategic reasons, some plants may opt for a larger share of the modification work to maintain and develop competency and skills within their own organisation.

3.11 Other considerations within the modification process

The early phase of the modification process. A typical observation in all design and construction projects is that the design freedom decreases and the cost of design changes increases with time. Therefore, it is important to take all design requirements into account and to foresee possible difficulties as early as possible in modification projects. For example, if violations of important design principles are discovered late, they may be difficult and expensive to correct. Similarly if some design deficiency is not detected and corrected before the implementation of the modification, it may introduce threats to the safety and profitability of the plant.

Organisational aspects. The assessment and review of the modification and the plans for their implementation should be extended to a large group of experienced people from different functions at the NPP. Some typical areas of expertise to be included are as follows:

- operations,
- maintenance,
- engineering,
- reactor safety,
- human factors,
- quality assurance,
- labour safety
- radiation safety,
- environmental impacts.

In circulating the modification plans for assessment and review, it is practical to restrict the scope of the review to the area of expertise for each participating person. On the other hand, it is equally important that someone takes an overall systems view on the whole modification project.

Documentation. It is essential that instructions for plant modifications are clear and easy to understand. However, it is difficult to write very detailed instructions, because such instructions have the tendency to become overly complex, and they may still not address all possible situations. It is also important that the instruction stresses the need for a thorough assessment of the modification early in the project.

4. REGULATORY OVERSIGHT

4.1 National regulatory systems

There is a large diversity in national regulatory systems. In some countries the regulatory requirements are detailed while in other countries they are more general. There are also differences in the regulatory involvement in the inspection of various activities at the NPPs. In some countries, regulatory activities include detailed reviews of the technical adequacy of the design. In other countries, inspections are focused on confirming that the utility's modification process has been followed.

Modifications always involve regulatory oversight. Independent of national legislation some types of modifications require regulatory approval before their implementation, such as modifications that change conditions in the operating license for the plant. Most regulatory systems require that the regulator is informed about upcoming modifications of lesser importance. The plants are responsible for producing the documentation for regulatory approval. Sometimes regulators ask for statements by an independent body to support the licensing process.

In practice, it is not possible for the regulator and its technical support organisations to keep track of all modifications that are planned or implemented at a NPP. Regulatory oversight therefore typically includes inspection both of the modification process itself and random checks of specific modification projects. The regulator may also require the NPP to do an in-depth review of large safety related modifications. In most countries audits of the modification process are carried out periodically.

The regulatory oversight of plant modification process is an important component in ensuring that no undue threats are introduced. Regulatory review and inspections should be sensitised to problems that may emerge in plant modifications to ensure that the oversight efforts are directed to problematic areas. It is also important to develop and maintain regulatory competency in the area of plant modifications.

4.2 Regulatory requirements

Regulatory requirements in the nuclear field are typically developed at several levels. At the highest level, national legislation on the highest level defines the preconditions that have to exist before a license to construct or operate is awarded. Specific conditions are found in more detail at lower levels in the legislation. At the discretion of the regulator these requirements can be further broken down to give more detailed guidance about how to implement required safety and security measures.

Regulators develop their own management and quality handbooks to ensure fairness and consistency in their oversight processes. At its most practical level, the regulatory oversight is implemented through assessments, inspections and reviews. Typical high level safety requirements have been developed through international co-operation over the years In the development of procedures of regulatory oversight it is important to ensure that they do not create unnecessary burdens for the NPPs.

Plant modifications are within regulatory control typically handled on two levels. Plant modifications that may challenge the original design principles, safety technical specification or other safety considerations, which have been defined in granting the operational license, will require regulatory approval. For lesser modifications, which still may have an impact on the plant safety, it is usual to require a notification in

response to which the regulator may decide on actions to be taken such as for example to require a regulatory approval or only to ask for additional clarifications.

4.3 Approaches for regulatory oversight of plant modifications

Most national regulatory approaches call for a classification of modifications. It is typical to use three safety classes, including one classification that does not require input to the regulatory body. The definition of these safety classes vary, but the following list gives a general impression of typical criteria that are used

1. *Regulatory approval is required*. Modifications for which a regulatory approval is required typically imply the preparation of material for the regulator together with a formal application for its acceptance. After due inspections of this material, the regulator can agree with or veto the modification. Typical modifications in this class have a large impact on the safety analysis report (SAR) or introduce new risk. This category also includes modifications involving new technologies for which little or no experience is available.
2. *Pre-inspection material is required*. For modifications, where pre-inspection material is required, the regulator decides on and informs the licensee about further actions based on this pre-inspection material. Such modifications are characterised in such a way that they have no direct impact on the safety analysis report (SAR), but there is a certain risk due to the modification process itself, the operation of the modified systems, or the qualification criteria and the necessary validation of the modification.
3. *Only information material is required*. Modifications for which only information material is required are not considered to be in the groups described above and it is assumed that the regulator will react if considered necessary. The information material describes the modification and the reasons for the classification of the modification. The account of these reasons may include reference to the safety analysis, operability and maintainability analysis, and assessments of impacts on procedures, radiation protection, human factors, spare parts, etc.

Small modifications below the third level can be made at the discretion of the NPP and they may include modifications outside the protected area and modifications with no impact on safety or availability of the plant.

The regulator must have the necessary competencies and skills available to conduct the review of applications for regulatory approval of plant modifications including operability and maintainability considerations. The first question to be answered in this process is whether or not the proposed classification of the modification is appropriate. The second question is if the information material supplied is enough for making required regulatory decisions. After these considerations, the subject areas influenced by the proposed modifications are assessed to determine if the modification is acceptable or not and which conditions may have to be fulfilled in implementing the modification.

4.4 A process based approach

When regulatory approval is required, plant modifications can be seen as two parallel processes: the modification process at the plant and the regulatory approval process. Depending on national regulation this process may consist of several parts in which different sets of documentation are supplied for regulatory inspections.

A process based approach for plant modifications relies on clearly described work activities which are coupled to each other in a logical order. Inputs and outputs from the work activities are defined and the control and resources for the work activities are specified. It is the task of the licensee to build a plant modification process that is logical and easy to follow. The regulatory process should then be interfaced to

this process with its own inputs and outputs to create a regulatory understanding of crucial components in the proposed modification. When this understanding has been obtained, it is easier to inspect the documents supplied and to assess compliance of the modification with regulatory requirements.

There are many benefits in using a process-based regulatory approach. It is for example:

- resource-effective for regulator, when confidence in the plant modification process could be used to allow a concentration on the main issues of the modification,
- easier to identify the necessary regulatory competencies and skills that are necessary in different phases of the process,
- easy to adapt to variations in different modification projects and practices as applied.

4.5 Regulatory follow-up of plant modifications

Most regulatory bodies follow-up on plant modifications. Follow-up is typically done both by inspecting specific modification projects and by inspecting the modification process itself. Inspections of the modification process may include an assessment of available competencies and skills, used resources, deviations between plans and outcome, etc. Findings are usually communicated in regulatory letters or inspection/ audit reports, in which requests for improvements may be made.

Many regulators follow up NPP activities using safety performance indicators. Examples of performance indicators connected to plant modification are as follows:

- the level of investments in safety improvements,
- the need for rework in plant modifications,
- deviations and observations identified in audit reports of the plant modification process.

The international Convention on Nuclear Safety that entered into force in 1996 has opened up a process, which is increasing the transparency of national safety regulation. The national reports that are written in response to the obligations of the Convention typically contain information related to plant modifications on a general level, such as modernisation programmes and safety improvements at the NPPs, changes in regulatory requirements, etc.

5. LESSONS LEARNED

5.1 General issues raised at the workshop

The workshop proved to be an important event in creating an understanding of modifications and their influence on NPP safety. The preparations before the workshop including the questionnaires and the responses collected gave an excellent basis for the presentations and the discussions during the workshop. The decision to document the results of this work proved to be important, because it gave the opportunity to place insights, practices and lessons into a larger context.

The main lessons learned from the workshop can be summarised as follows:

- Modifications are an important part of the continuous quest for improved safety through the utilisation of new knowledge and experience, but modifications also have the potential to introduce challenges to safety if they are not carried out with the necessary caution and prudence.
- Minor or non-identified modifications as well as inadequate consideration of human factors issues during modification projects are two important causes to events that have shown to present a threat to safety in several of the NEA Member countries.
- The likelihood of event related to modifications may be reduced by a broad and deep assessment of impacts of proposed modification together with careful planning of the modification project in all its phases of design, construction, installation, testing and commissioning.
- To ensure that modification process fulfils its purpose, it should be documented in instructions, the instructions should be understood and used, and the efficiency of the modification process should be audited, reviewed, benchmarked and improved on a continuing basis.

The presentations at the workshop gave examples of events and approaches related to modifications and various development projects aimed at providing guidance for the modification process. From that material the following more specific issues can be listed:

- There is a need for guidelines and tools to support the modification process in the areas of managing of the modification process, using digital I&C systems and incorporating human factors assessments.
- Research and development activities have the potential of bringing forward new and interesting methods and tools that can further improve the modification process. For example, PSA methods may be used for assessing specific modifications and virtual reality (VR) may be used to assess control rooms solutions, installation plans and radiation protection measures.
- It is important to involve different skills and competencies in the modification process in order to enable a broad and deep scrutiny of the impacts of the modification. This should involve at least operations, maintenance and safety staff in addition to people with the technical skills and competencies needed for the planning, designing and implementing a specific modification.
- Consideration of human factors issues in the modification process relies on involving users of the systems to be modified. Human factors analysis work should focus on the new or modified functions and tasks. The involvement of system users through use of human factors methods,

including operating experience review and validation testing, will improve the usability of the final design.

- In the assessment and review of modifications it is important to utilise available information and experience. This means assessments of events involving the systems to be modified, investigations of opportunities for additional improvements in these systems, and collection of experience from similar modifications at other plants.
- The modification process should include several assessments, reviews, tests, and hold and decision points to verify that the requirements are fulfilled and that the appropriateness of the modification is validated.
- Before the modification project is commissioned, operators and maintainers must be properly trained. Before the modification project is closed the lessons learned should be documented and there should be assurance that all instructions and other documentation have been updated.

5.2 Minor or non-identified modifications

Minor or non-identified modifications (MiNIM) in components, materials or spare parts have been shown to cause safety significant events. Collected events show that the modifications were not initially recognised as being safety significant, but they nonetheless introduced safety challenges (cf. Appendix 5).

Cases of non-identified modifications may emerge with spares that have been modified slightly by the manufacturer without informing the NPP. They may also emerge if materials in components, cables, lubricants, or seals are changed without proper notification to the plant. Events have demonstrated that there have been small changes between product series that were not recognised by the manufacturer. If a modification is not known by the NPP, it will evidently not initiate an impact assessment and may thus lead to unexpected behaviour, which is difficult to diagnose.

Non-identified modifications may also be introduced by maintenance actions in the following situations:

- spare parts are not fulfilling required specifications due to wrong storage conditions,
- human errors during installation due to unclear labelling of components or spare parts,
- inadequate quality assurance procedures.

Even when a modification is recognised and assessed, it is possible to overlook an important influence mechanism or to consider it unimportant. There is also the possibility that several small changes have a major impact on some important parameters. This has been seen in the development of fuel characteristics for the BWR plants, where gradual developments over the years resulted in the combined effect that one of the fuel feedback coefficients could move in an unfavourable region during certain plant transients. A similar problem is the cumulative effect of multiple small changes in the main control that are not the subject of an integrated analysis.

5.3 Human and organisational factors

The importance of human and organisational factors is broadly recognized. A common practice is to involve teams of human factors experts in large modification projects, but it seems that it is not equally common to carry out an in-depth human factors assessment for medium and small modifications. It may be possible for designers / engineers to carry out adequate human factors work for medium or small modifications if there is a clearly defined process and if there is they are trained about human factors and the process.

Although the importance of workers having a work environment and equipment that enable them to carry out their duties, human factors methods are not always applied during modification projects. Presentations and discussion during the workshop suggest the following types of problems that contribute to poor designs:

- there is a lack of understanding of HF and its benefits,
- the impacts of a modification on the HSIs are considered late in the modification projects, so there is less freedom to suggest and evaluate alternative designs,
- there is a reluctance to consider HF due to the unavailability of suitable specialists and/or tight time schedules and resources in the modification project,
- there is not enough guidance on how to incorporate HF in modification projects,
- there is a large focus on technical solutions to problems.

In assessing the need for human factors considerations, there is consensus that small and medium modifications do not need the same type of detailed scrutiny as large modification projects. At the workshop, presentations were given on different approaches for integrating human factors into the modification projects. These were focused on the screening phase of the modification project and on human factors methods and tools.

5.4 Lessons from events and incidents

Lessons from events and incidents could be assessed more generally to explore their relationships to modifications. One finding is that modifications, which are perceived as minor, may not get a proper allocation of economic and human resources. In a broader context this deficiency can be considered as a symptom of inadequate scrutiny of the modifications in different stages of the modification process.

An assessment of modification related events and incidents suggests the following shortcomings:

- the plant vendor or utility involved in the modification project does not have an appropriate knowledge of the plant design basis,
- the design implemented in the modification does not comply with specific requirements for systems and components in the plant design basis,
- instructions and documentation have not been properly updated to reflect the actual plant configuration after some plant modification,
- the implementation plan for a modification contains flaws in the timing or execution of specific work activities, which causes a violation of plant safety technical specifications,
- required quality assurance procedures have not been followed and/or inspections have been carried out in a superficial manner,
- un-notified modifications have been made in vendor spare parts, leading to the parts being outside their original specifications,
- the manufacturer does not have knowledge of the plant design basis and the utility does not understand the impact of the modification,
- there is a technical evolution of some system or component which has unexpected impact on another system or component,
- instructions that are created for installing, testing, and operating are not accurate enough and/or do not specify fall back procedures in the case of unsuccessful tests.

Modification related events and incidents often occur or are detected during outages because there are many ongoing work activities that have to be carefully co-ordinated. Time pressures during outages may also introduce additional stress on people to make activities more error prone. During outages there are many temporary changes taking place and temporary instructions used.

5.5 Installation and operability verification

Installation and operability verification, which are carried out as a part of the implementation, testing and commissioning phase of the modification process has shown to be error prone. Based on events, deficiencies in the planning of installation may lead to deficient installation, testing and commissioning instructions.

The operability verification, which is supposed to be done before the start-up after the modifications have been implemented, indicate the following generic failure mechanisms

- *Planning deficiency*. Incorrect, incomplete or unclear plans and instructions for installation, inspection, and testing phases. Deficiencies in coverage of start-up tests or installation inspections of modifications. Deficiencies in procedure, work order, operation order or definition of work scope.
- *Design deficiency*. Error or deficiency in design or documentation of the modification, used equipment or computer programmes.
- *Violation of procedures or work orders*. Violations due to insufficient knowledge, deficient information or inadequate management oversight.
- *Poor co-ordination, supervision or information transfer*. Poor co-ordination of work activities, inadequate supervision of subcontractors, deficiencies in information transfer between organisational boundaries, and weaknesses in the feedback of operational experience.
- *Insufficient knowledge*. Lacking training, specialist or cross-functional knowledge.

Experience from modification projects also indicates that tight time schedule and budgetary constraints have a tendency to increase the likelihood of errors in the modification process.

5.6 Introduction of new technology

The introduction of a new technology to replace inferior or obsolete technology represents a challenge of its own. The problem is that both the old and the new technologies often carry implicit assumptions that make it difficult to assess the impacts of the modification. This is especially true for the modernisations of the I&C systems and the control rooms at the nuclear power plants, where analogue hard-wired technology is substituted with digital and programmable technology.

One solution in the transfer from the old to the new technology has been to replace function for function or component for component, but the hidden differences in functions and HSI have shown to introduce difficulties. These difficulties are caused by a shift in the paradigm of control room and HSI design (cf. Figure 3). This shift in design paradigm actually implies the need for new methods and tools for design, review and testing.

Based on the experience in the application of the digital technology in I&C and control rooms the following generic lessons have been learned

- it is sometimes difficult to assess the impact of a modification on personnel performance,
- plant personnel often favour the old technology, but opinions usually change as confidence in the new system grows,

- the new systems show several examples of poor designs from a human factors standpoint,
- the new technology sometimes exhibit unexpected behaviour,
- people may not use the HSIs in the way designers expect,
- knowledge gaps in a modification project can be problematic,
- the involvement of plant personnel usually increases over time,
- it is often difficult to establish a vision about where a series of modifications will end,
- the new systems may change staffing, training, and procedure requirements,
- it is often difficult to co-ordinate the modification process with the corresponding training and operational requirements.

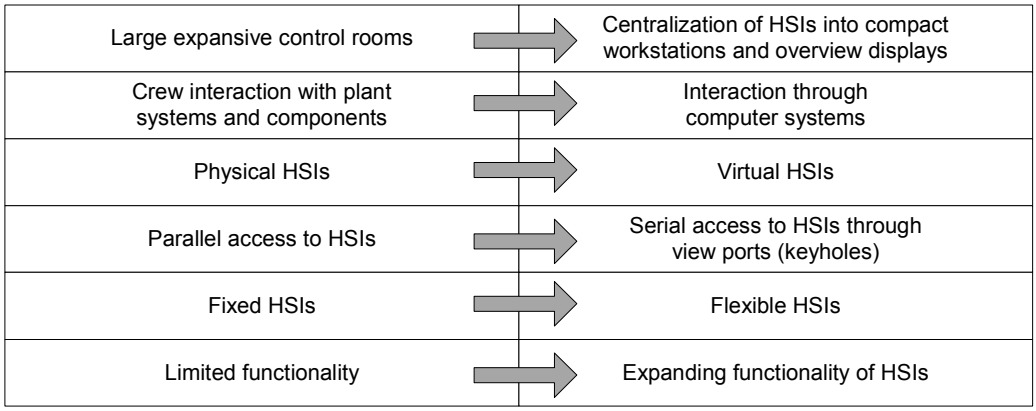


Figure 3. Development trends connected to the use of new digital technology.

5.7 Temporary modifications

One specific problem is connected to temporary modifications. However, there are many situations in modification projects where it is necessary to introduce temporary modifications. Temporary modifications may include, but are not restricted to, the following actions

- disabled alarms (annunciators),
- lifted leads,
- electrical jumpers,
- temporary set point changes,
- blind flanges or plug installation,
- floor drain temporary closures,
- temporary disablement of safety and relief valves,
- temporary pipelines installation,
- pulled circuit boards,
- temporary electrical connections.

Operational experience indicates two basic difficulties with temporary modifications. The first is that temporary modifications do not seem to go through the same kind of scrutiny and impact assessments as permanent modifications. The second is that temporary modifications have a tendency to be forgotten if they are not controlled and labelled in a rigorous manner.

There seem to be differences between plants in how temporary modifications are managed. In some plants, temporary modifications seem to be a part of the daily routines, whereas in other plants they are used much more sparingly. The dividing line between small and temporary modifications versus maintenance activities can be quite small.

5.8 Cost issues

Problems occurring in modification projects always generate additional costs when compared with the costs of implementing an adequate design from the beginning. The most serious problem is allowing a deficient modification to pass through all assessments, installation, and commissioning. Experience from events and incidents indicates that this has occurred and that it has taken a long time before the deficiencies have been detected. One reason for deficient modifications to pass all assessments, reviews, inspections and testing may be connected to a reluctance to spend the necessary resources up front in modification projects. Tight resource allocation may also encourage people to take shortcuts in the process.

Some of the reasons for added costs include the following:

- Rework costs to improve a design are incurred when problems are discovered after installation.
- Problems detected at plant start-up after installation of a modification lead to delays and unplanned outages.
- Problems with the usability of the design may lead to impaired plant and operator performance.
- Impaired operator performance may lead to human errors and corresponding costs connected to loss of power generation, increased regulatory scrutiny, and loss of public confidence.
- Inadequate scrutiny of impacts of the modification may lead to delayed regulatory approvals, project delays and increased costs to modify a contract at later stages of the project, lost opportunities to optimise the design, etc.

5.9 Reflections on available operational experience

Based on operational experience from modification projects, there are a few stages that seem to be more prone for errors than others. The list below gives a summary of some of the problems that can be seen in incident reports:

- Modifications are sometimes introduced without proper recognition and impact assessment.
- Modifications are sometimes implemented despite the fact that later assessments show marginal benefits.
- The initial screening of modifications is sometimes inadequate.
- The safety significance of a modification is sometimes not recognised. As a result, inadequate resources are allocated to the modification project.
- The breadth or depth of the assessment of impacts of a modification is inadequate, which leads to an important issue being missed.
- A heavy workload on design team staff may make work activities more error prone
- Deficient planning of resources for related modification projects have caused delays and corresponding time pressures, which have led to shortcuts in the modification process.
- Deficient training material and training of operators and maintenance personnel have caused human errors.
- The instructions and other documents connected to a modification project have not been updated.

Modification projects often take longer time than originally planned, which seems to be related to difficulties in foreseeing problems that could emerge in the process. Sometimes modifications seem to take place in a rather uncoordinated manner in small steps, which may suggest a temptation to unbundle related modifications to circumvent rigid regulatory procedures.

6. POSSIBILITIES FOR IMPROVEMENTS

6.1 A plant development plan

One good practice at the nuclear power utilities is to create a long term development plan for upcoming modifications. Such plans have the benefit of better co-ordination between various changes and modifications. A plan also makes it easier to ensure that modifications are consistent with the overall safety philosophy of the plant. When the development plan is updated in the normal planning cycles of the NPP, it is easier to identify the required resources.

Modifications should be reflected in the strategic goals as defined by the nuclear power plant. A policy document reviewing development needs as seen in a life cycle perspective of the plant, can assist with the long range planning. Such a policy document should aim at identifying crucial needs over the plant's life in order to set the stage for upcoming modernisation activities and modification projects. It is beneficial to create a consistent migration policy from the present state of the plant to a future condition. A plant development plan can also support the identification of opportunities for co-ordination of several related modifications and modifications among multiple plants.

6.2 The modification process

There is consensus that modifications may take different routes depending on their target and scope. In order to determine the most appropriate route, changes and modifications should be subject to careful screening early in the modification process. Screening should encompass technical, human and organisational issues in order to identify the appropriate scrutiny in the planning, design and assessment activities. To ensure consistency and auditability of the modification process it is advisable to create screening criteria in beforehand. Such criteria may for example include the following more detailed considerations:

- Assessed risks connected to the modification (nuclear, production, economic, environmental, personal safety and/or safeguards/security risks),
- Operational experience with the systems affected by the modification (disturbances and their causes, opportunities to improve the systems),
- Impact on human actions or practices (changes to the HSI, human error potential, needs for retraining, needs for writing new instructions),
- Impact on organisational issues such as team structures, work practices, co-ordination of activities, etc.
- Complexity of the modification (technical skills and competencies involved, interfaces between modified and non-modified systems, number of outages necessary for the implementation),
- Availability of station specific design guidance,
- Regulatory requirements.

6.3 Instructions used

The modification process is typically controlled by detailed instructions. This means that improvements in the modification process have to be reflected as changes in these instructions. Furthermore it is important to remember that single changes in the instructions usually do not solve the problems, because one important part is how the instructions are interpreted and used.

It is often beneficial to structure the instructions governing the modification process into one main instruction and several underlying instructions, instead of forcing everything into one large and complicated instruction. With a system of cross-references between different instructions it is still possible to obtain a structure that supports searches for and updates of specific instructions.

One important part in the optimisation of the modification process is to establish a process for obtaining feedback to improve future modification projects and the modification process. Most plants do regular reviews of their modification projects. One part can be taken care of by the regular audits and the other by safety reviews that the plants are carrying out. At many nuclear power plants, it is a common practice to use performance monitoring after modifications to track impacts of the modification. The modification process should be described with the necessary detail, but care should be used not to make it unnecessarily complex. Benchmarking of used modification processes between NPPs can be helpful in developing the instructions.

6.4 Handling of minor or non-identified modifications

The key issue in the handling of minor or non-identified modifications (MiNIM) is to be aware that there is a modification. Possible impacts of the modification may then be identified and assessed. This implies that the staff should be sensitized to changes that may signal the need for a closer assessment of components, materials or spare parts. This requires a well informed and competent staff, who by the help of various checklists, can react if something sounds wrong. The I&C and electrical systems are two specific areas, where more attention may be warranted, because possible impacts in these areas may not be easily detected and are often more complex than the first impression may indicate.

6.5 Assessment of human and organisational factors impacts

The incorporation of human factors in the modification process implies the systematic consideration of system user capabilities and limitations, (i.e. anthropometric, physiological, motor response, perceptual, cognitive, group interaction) through the application of human factors principles, methods and guidance. This is sometimes referred to as user-centred design. Human factors should be incorporated into modifications which impact on the activities and tasks of operators and maintainers.

When a plant regularly carries out in-depth human factors studies for various modifications, a usual spin-off is that these groups take initiatives to improveme other HSIs which may have caused problems in the past. At plants where there is an active human factors group, they are usually welcomed by different groups of people within operations, maintenance and technical support as a sounding board for possible improvements.

The costs for the human factors part of the modification project do not need to be extensive. The human factors effort has to come in early in the modification project to be effective. Human factors costs have been found to comprise 1% of the design budget when considered in early design, but escalate as the design progresses.

Some of the methods and tools used to ensure a proper account of human factors issues are for example:

- review of operating experience from the systems modified (past events, talk-throughs with operators and maintainers, information from similar designs at other plants),
- consideration of operability and maintainability aspects,
- function analysis (new functions, modified functions, function allocation between humans and automation),
- task analysis (new tasks, modified tasks, task demands, information needs, control actions, procedures, communication interfaces)
- use of human factors guidelines in design and review
- use of test scenarios on simulators or on specially designed work stations to verify and validate suggested solutions,
- user involvement in the modification process (assessment and review, preparation of instructions and other documentation, training)

One example of an instruction to support the human factors activities in modification projects is given in Appendix 7.

6.6 Modifications in a context

In placing plant modifications in the context of the full plant life, it is important to understand that they are necessary, but that they also may create problems if not handled properly. This understanding should be distributed to all parties of the modification process and there should be a responsibility for everyone participating in the modification process to bring forward any concerns.

The modification process itself should be governed by a systemic perspective with the understanding that there may be hidden influences that may create unexpected safety threats. This understanding should be paired with the necessary technical competencies and skills that are required in specific modification projects. In view of aging personnel at many plants world-wide, it is necessary to plan for specific actions to retain that knowledge over the remaining lifetime of the plants.

Modifications should never be carried out in isolation, but should always be placed within a long term strategy. This makes the planning easier in many ways. Firstly, the plan allows for a check of the internal consistency between planned modification projects and for ensuring that necessary resources are available over time. Secondly, it is easier to select the best timing for the modifications and to develop necessary methods and tools. Finally a strategic plan makes it possible to identify trends in a historical perspective to avoid the danger that several small modifications taken together put the plant or practises into some unfavourable region.

6.7 Potential areas for future CSNI activities

In addition to the two specific areas of modification addressed by WGOE and SEGHOF (i.e. minor or non-identified modifications (MiNIM) and inclusion of human and organisational factors), other related areas for improvements were identified. These areas may be addressed in forthcoming CSNI activities and they are briefly described below.

The analysis of events constitutes an important source of suggestions for improvements. An observation is that the analysis of events often is too shallow to reveal causes on a level where they could be acted upon, which may leave important needs for improvements undetected. It is therefore suggested to support all

efforts of plant data collection. An option would be to set up co-operative research projects, leading to a more extensive database and a deeper understanding of factors contributing to events and incidents, including those arising from plant modifications.

Operability verification has shown to be an error prone activity. Today operability verification is usually governed by administrative rules. The interfaces between operational routines and modification projects seem to increase the burden on people with an increased likelihood of errors as the result. Changes made late in the installation or testing plans seem to be difficult to handle. Possible improvements in avoiding errors include, but are not restricted to, improved condition monitoring, computerised support systems, additional measurement signals and alarms.

Another area for further work is assessing the availability and managing difference versions of spare parts over time. Slight design changes in components and parts may create incompatibility between versions of components. Certain spare parts may require specialised handling. A remedy to these problems may be to ensure that changes are communicated and that documentation and functionality of spare parts are addressed properly.

Temporary modifications are one specific class of modifications that require increased attention. Temporary modifications are often not subjected to an in-depth safety analysis due their provisional status and they may become permanent without sufficient assessments. Reliance on temporary modifications may force the operation and maintenance organisations into several rounds of modifications which are difficult to control. The temporary modifications should always be subjected to a technical review and, if they are safety related, also to a safety review. A good practice is to restrict any temporary modification to a maximum duration.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The WGOE and SEGHOF questionnaires together with the workshop have led to a better understanding of plant modifications and their influence on safety. The selected focus areas, minor or non-identified modification (MiNIM) and human and organisational factors are important because they have generated major safety related events. The initial preparation of the questionnaires, the co-operation between WGOE and SEGHOF, and the workshop and the documentation process, are a good model for similar joint undertakings in the future.

A thorough modification process that ensures screening, planning and implementation of modifications can save costs and decrease the likelihood of problems. Many countries use available guidelines (cf. Appendix 3) for the screening, assessment and review of proposed and planned modifications. A typical practice is to involve system users throughout the modification process. There is general agreement that smaller modification may take a simplified route.

The distinction between small, medium and large modifications, determines much of the efforts and resources that are allocated to its implementation. Large modifications typically show fewer problems than small and medium modifications due to the rigour applied.

Any modification in an operating NPP should be considered as a risk in itself and modifications should therefore be well justified. It is difficult to cover all latent functional relationships, failure modes and impacts of modifications without a well planned and comprehensive installation, testing and commissioning program. Distinct decision making, turn-over and acceptance procedures of modification projects can help in minimising the risks. Documentation of the activities in modification projects in their phases of proposals, preplanning, design, implementation and finalisation should take place in responsible organisational units.

Regulatory oversight has an important role in ensuring that the applied modification process at the NPPs is thorough and that a broad set of knowledge and skill is used in the assessment and review of modifications. The involvement of the regulator in the modification process depends on national regulatory approaches, but modifications that change the licensing conditions will always require regulatory acceptance. The thoroughness of the regulatory inspections of modification depends on the scope and target of specific modifications. A typical regulatory practice is to assess and inspect both specific modifications and the modification process itself.

7.2 Recommendations

An awareness and understanding should be created that modifications may cause problems if they are not given a proper attention. Additional guidance should be created both for the NPPs and the regulators to support their efforts in creating safe and efficient modification processes. CSNI activities within WGOE and SEGHOF are well placed to respond to this challenge. Future activities could aim at collection and dissemination of information about modification related events, creation of guidance for modification processes and arranging seminars and workshops for exchanging experience on plant modifications.

The modification processes used at the nuclear power utilities should be well structured and documented. They should include several assessments and reviews to ensure that possible problems are identified and corrected as early as possible in the process. The initial screening of modifications together with the classification of the scope of the modification is an important phase, which governs later phases. It is a good practise to analyse and approve modifications in a qualified team, which is independent of the modification project. In the design and assessment of modifications, it is important that the persons involved have a good understanding and knowledge of the plant design basis. Thorough planning of installations, tests and commissioning is important for avoiding unnecessary difficulties.

Changes in plans during a modification project are unavoidable, but they should be implemented with the same care and prudence as was used in the preparation of the original modification plans. The preparation of training material and the training of operators and maintenance personnel is an important part of all modification projects. A modification should not be closed before all influenced instructions and other documents have been updated. The lessons learned in modification projects should always be documented and the modification process should be audited at regular intervals.

Even if activities and tasks connected to modifications are contracted out the sole responsibility of the safety lies with the licensee. This means that licensees need an intelligent customer capability to ensure that plant modifications are thoroughly scrutinized when they are contracted out.

It is important that modifications do not escape recognition, which may imply that special alert functions are provided. It is important to sensitise personnel and vendors to small changes in components and materials. Minor and temporary changes present their own challenges for the NPPs. Small modifications do not need the same elaborate considerations as large modifications, but they still could be a threat to safety of if they are implemented without formal assessments.

Human and organisational factors expertise should be used early in all modification projects to assess impacts of proposed modifications. It is a good practice to establish an independent group of subject matter experts from different areas to assess alternative solutions for the human system interfaces.

Regulatory bodies should build up their own processes to license and review modifications. These processes should be governed by internal quality assurance procedures to ensure consistency and impartiality in the assessments and decision making.

APPENDIX 1. ABBREVIATIONS AND GLOSSSARY

Abbreviations

ALARA	as low as reasonable achievable
BWR	boiling water reactor
CAD	computer aided design
CCF	common cause failure
CSNI	Committee on the Safety of Nuclear Installations
EPRI	Electric Power Research Institute
HF	human factors
HSI	human system interfaces
I&C	instrumentation and control
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
INES	international nuclear even scale
INPO	Institute of Nuclear Power Operations
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
ISO	International Organization for Standardization
LCR	local control room
LOCA	loss of coolant accident
MCR	main control room
MiNIM	Minor or non-identified modifications
MTO	man technology organisation
NPP	nuclear power plant
PSA	probabilistic safety assessment
PWR	pressurised water reactor
SAR	safety analysis report
SEGHOF	Special Experts Group on Human and Organisational Factors
TSO	technical support organisation
USNRC	US Nuclear Regulatory Commission
VR	virtual reality
WANO	World Association of Nuclear Operators
WGOE	Working Group on Operating Experience

Glossary

validation	the process by which assurance is obtained that a certain system fulfils its function
verification	the process by which assurance is obtained that a certain system has been designed and constructed according to the requirements that have been placed and that tests have demonstrated the required functionality

APPENDIX 2. PAPERS PRESENTED AT THE WORKSHOP

The following papers were presented at the workshop[1]:

Chung, Y., Goo, C. and Cha, W., Regulatory experience of human factors for operating nuclear power plants.

Deutschmann, H., The Swiss modification process in nuclear power plants regulatory regime - regulator/operator process and experience related to events with safety impact.

Gregson, D., Marshall, E., Gait, A. and Hickling, N., Providing ergonomics guidance to engineers when designing human-machine interfaces for nuclear plant installations.

Kozak, A. and Malcolm, J.S., Bruce A Restart - Integration of human factors engineering into the refurbishment of a multi-unit CANDU station.

Jeanton, G., Electricité de France organization and process concerning modifications of nuclear plants.

Juan, P., Regulatory aspects of plant's modifications to PWR.

Laakso, K., Analysis of maintenance history for identification and prevention of human CCFs originating from modifications and maintenance.

Naser, J., Hanes, L., O'Hara, J., Fink, R., Hill, D. and Morris, G., Guidelines for control room modernization as part of instrument and control modernization programs.

O'Hara, J., Kramer, J. and Persensky, J., Identifying and addressing lessons learned from plant modification programs.

Quentin, L. and Niger, D., Taking into account of socio-organisational and human aspects into upgrade packages (technical or not).

Skjerve, A.B. and Skraaning, G., A classification of validation criteria for new operational design concepts in nuclear process control.

Soares, H.V., Schirru, R. and Alvarenga, M.A.B., Study on the utilization of the cognitive architecture EPIC to the task analysis of a nuclear power plant operator.

Vautier, J.-F., Tosello, M., Barnabe, I., Garandel, S., Paulus, V. and Papin, B., A micro-macro human factors approach to improve team working after an incident.

Werdine, H., Temporary modifications and minor changes - threats to safety?

Wild, V., Reported events in German nuclear power plants due to insufficient equipment labelling.

[1] OECD/NEA (2004). Modifications at Nuclear Power Plants – Operating Experience, safety Significance and the Role of Human Factors and Organisation, NEA/CSNI/R(2004)17.

APPENDIX 3. STANDARDS, GUIDELINES AND REFERENCES

Frequently used standards and guidelines

IEC (1989). Design for control room of nuclear power plants, IEC 60964.
IEC (1995). Nuclear Power Plants – Main Control Room – Verification and Validation of Design, IEC 61771.
ISO (1998). *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability*. First edition. Switzerland: International Organization for Standardization. Reference number: ISO 9241-11:1998(E).
ISO (2000). Ergonomic design of control centres – Part 1: Principles for the design of control centres, ISO 11064 - 1: 2000.
ISO (1999). Human-centred design processes for interactive systems, ISO 13407:1999.
USNRC (1994, 2002). Human Factors Engineering Program Review Model, U.S. Nuclear Regulatory Commission, NUREG-0711.
USNRC (1996). Human-System Interface Design Review Guideline, U.S. Nuclear Regulatory Commission, NUREG-0700.
USNRC (1997). Integrated System Validation: Methodology and Review Criteria, U.S. Nuclear Regulatory Commission, NUREG/CR-6393.
USNRC (1994). Human Factors Engineering Guidance for the Review of Advanced Alarm Systems, U.S. Nuclear Regulatory Commission, September, NUREG/CR-6105.

Relevant OECD/NEA reports

NEA/CSNI/R(2002)8. Approaches to the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms: Workshop Proceedings, Halden, Norway August 1999
NEA/CSNI/R(2002)9. Approaches to the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms - Summary and Conclusions of the Workshop, Halden, Norway, August 1999.
NEA (2004). CSNI Technical Opinion Papers - No. 5 Managing and Regulating Organisational Change in Nuclear Installations, Publication 05348.
NEA (2004). Nuclear regulatory challenges related to human performance, Publication 05334.
NEA/CNRA/R(1994)4. Proceedings of Workshop on Conduct of Inspections for Plant Modifications, Event Investigation and Operability Decisions. (1994: Helsinki), 1996. also referenced as: OCDE/GD(95)14.
NEA/CNRA/R(2001)1. Regulatory Aspects of Life Extension and Upgrading of NPPs - CNRA Special Issue's Meeting 2000 Report.
NEA/CNRA/R(2001)2. Regulatory Aspects of Life Extension and Upgrading of NPPs - CNRA Special Issue's Meeting 2000 to the Questionnaire.
NEA/CNRA/R(2003)4. CNRA - Nuclear Regulatory Inspection of Contracted Work Survey Results - Working Group on Inspection Practices.
NEA(2002). The Nuclear Regulatory Challenge of Judging Safety Backfits, Publication 03674 also referenced as: OCDE/GD(95)14

Other related references and literature

ANSI/NIRMA Standard CM 1.0 (1999) - Configuration Management of Nuclear Facilities
EPRI NP-3659 - Human factors guide for nuclear power plant control room development
EPRI (2000). Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms: Scoping and Planning Study, EPRI 1001066, November 2000.
EPRI (2002). Nuclear Power Plant Control Room Modernization Planning, EPRI 1003569, October.

EPRI (2003). Interim Human Factors Guidance for Hybrid Control Rooms and Digital I&C Systems, August, EPRI 1003696.
EPRI (2003). Critical Human Factors Technology Needs for Digital Instrumentation and Control and Control Room Modernization, EPRI 1007794, March.
Hendrick, H. (2003). Determining the cost-benefits of ergonomics projects and factors that lead to their success, Applied Ergonomics, 34, 419-427.
IAEA (1995). The Potential for Safety-Related Events After Upgradings and Modifications at Nuclear Power Plants, Report of a Consultants' Meeting Organized by the IAEA, Vienna, 1995, IAEA-J4-CS-23/95.
IAEA (2000). Software for Computer Based Systems Important to Safety in Nuclear Power Plants Safety Guide, Safety Standards Series No. NS-G-1.1
IAEA (2000). Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety Requirements, Safety Standards Series No. GS-R-1.
IAEA (2000). Safety of Nuclear Power Plants: Design Requirements, Safety Standards Series No. NS-R-1.
IAEA (2000). Safety of Nuclear Power Plants: Operation Requirements, Safety Standards Series No. NS-R-2.
IAEA (2001). Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations, Code and Safety Guides Q1-Q14, Safety Series No. 50-C/SG-Q. (Note: Currently being revised by IAEA)
IAEA (2001). Modifications to Nuclear Power Plants Safety Guide, Safety Standards Series No. NS-G-2.3.
IAEA (2001). Managing change in nuclear utilities, TECDOC-1226.
IAEA (2001). Modifications to Nuclear Power Plants, Safety Guide, Safety Standards Series No. NS-G-2.3.
IAEA (2002). Safety Assessment and Verification for Nuclear Power Plants Safety Guide, Safety Standards Series No. NS-G-1.2.
IAEA (2003). Periodic Safety Review of Nuclear Power Plants Safety Guide, Safety Standards Series No. NS-G-2.10.
IAEA (2003). Configuration management in nuclear power plants, TECDOC-1335.
IAEA (2003). Managing Change in the Nuclear Industry: The Effects on Safety, INSAG-18.
IAEA (2003). Maintaining the Design Integrity of Nuclear Installations Throughout Their Operating Life, INSAG-19.
IAEA (2004). Managing modernizations of nuclear power plant instrumentation and control systems, TECDOC-1389.
IEEE 1023-1988 (R. 1995) - Institute for Electrical and Electronics Engineering Guide for the Application of Human Factors Engineering to Systems, Equipment and Facilities of Nuclear Power Generating Stations (Note: Currently being revised by IEEE sub-committee 5)
INPO (1987) - Report on Configuration Management in the Nuclear Utility industry, Institute of Nuclear Power Operations, INPO 87-006
INPO (1992) - Guidelines for the Conduct of Design Engineering, INPO 90-009, Revision 1
ISO (2000, 2004) Quality management systems – Requirements, ISO 9001:2000, Quality management systems – Guidelines for performance improvements, ISO 9004:2000.
ISO (2000, 2000, 1999, 2004). Ergonomic Design of Control Centres, Part 1: Principles for the design of control centres, ISO 11064-1:2000, Part 2: Principles for the arrangement of control suites, ISO 11064-1:2000, Part 3: Control room layout, ISO 11064-1:1999, Part 4: Layout and dimensions of workstations, ISO 11064-1:2004.
Barry Kirwan, Les Ainsworth (1992) - Guide to task analysis, Micronite, ISBN: 0748400583.
USNRC (1983). A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control, U.S. Nuclear Regulatory Commission, August, NUREG /CR-3331.
USNRC (2000). Human Systems Interface and Plant Modernization Process: Technical Basis and Human Factors Guidance, U.S. Nuclear Regulatory Commission, March, NUREG/CR-6637.

USNRC (1994). Advanced Human-System Interface Design Review Guideline, U.S. Nuclear Regulatory Commission, Vol. 1, July, Vol. 2, July, NUREG/CR-5908.
USNRC (2004). Guidance for the review of changes to human actions, U.S. Nuclear Regulatory Commission, NUREG-1764.
USNRC (2004). Standard review plan: Human factors engineering, U.S. Nuclear Regulatory Commission, NUREG-0800.
USNRC (2004). Human factors engineering program review model, U.S. Nuclear Regulatory Commission, NUREG-0711, Rev. 2.
WANO (2002). Guidelines for Plant Status and Configuration Control at Nuclear Power Plants, GL 2001-04.

APPENDIX 4. THE WGOE AND THE SEGHOF QUESTIONNAIRES

I. WGOE Questionnaire on operating experience of minor or non identified modifications (MiNIMs)

The following working definition was adopted for the MiNIMs by the task force:

A minor or non-identified modification is a change not identified or inadequately neglected in respect to its potential impact on safety or plant operation. The modification may have to do with:

1. an item of equipment itself
2. its manufacturing process
3. its implementation, operating and maintenance conditions.

Based on the meeting of the task force, it was decided to launch a questionnaire to find out:

- how minor modifications are defined or identified in the member countries,
- how they are processed and analysed, in regard to their safety significance,
- how non-identified changes can be detected,
- how the situation could be improved.

With the preceding clarifications the following questions were asked:

A. Modification processes, definitions and various roles in your country

1) Description of the modification processes in your country and potential different levels related to safety significance and type of change

During the life of a power plant, changes due to modification are a natural evolution: manufacturers aim to improve their components/parts, the owners try to improve the efficiency of their plant and to make it easier to operate and the regulatory bodies sometimes demand modifications to improve the safety of the installations. For the personnel involved in the safety of NPP, some modifications do not seem to represent a change or at least, they sometimes believe the change is so small that it does not deserve particular attention. After such a judgement, the modification does not necessarily go through any safety analysis process.

a. In your country, is there a classification of modifications according to some criteria?
b. Do specific rules apply to modifications according to those criteria? Which exactly (you may use a drawing if you wish to demonstrate)?
c. Is every modification subject to a safety analysis and to an approval by the regulator?
d. Who performs the safety analysis of the modifications?
e. Is there any obligation for a manufacturer to declare every change made to its component and/or the licensee to declare it to the Regulator?
f. To which field does that modification concept applies:
   - safety function,
   - equipment,
   - operating procedure,
   - maintenance sequence,
   - software,
   - spare parts,
   - etc.

2) Knowledge of the modifications

Many modifications are implemented by manufacturers because of changes in the manufacturing conditions, due to company merge or technological evolution/improvement of components or parts under the pressure of economic competition.

a. Is the evolution of components or spare parts evolution monitored? In which way?
b. Who performs the monitoring?

B. Events dealing with MiNIMs

1) Detection

In many cases, MiNIMs and their consequences are only detected after being implemented. Please, give a short description about the detection in all cases.
From your experience feedback, how were the non-identified modifications detected:

a. occurrence of events (on the operator's plant or on other plants),
b. periodic testing,
c. requalification tests,
d. other organizational measure (inspection, qualification spot check …),
e. chance, other?

2) Events with potential significant consequences on safety due to MiNIMs

The objective of this item is to present some events representative of the consequences of a MiNIM

a. Briefly describe any events that have occurred in your country because of the non-identified consequences of a modification
b. What did the modification consist in: modification of the manufacturing process, of component, etc.? Was it an identified minor or a non-identified modification?
c. Which type of components, which kind of changes and parts of the organisation were involved?
d. What is the safety significance of these events?
e. Had a safety analysis been performed?
f. Could the problem have remained latent until a disturbance?
g. Has a common cause failure (CCF) been identified following a change of component or part?

3) Cause and corrective measures

a. What was/were the root cause(s)?
b. Were there other significant contributing factors?
c. Have you taken specific measures in your country in order to detect any previously non-identified changes in components or spare parts? Which kind of changes and by which organisation (e.g. regulatory, utility….)?
d. What other corrective measures have been taken?
e. Do you have further recommendations for corrective measures?

II. SEGHOF Questionnaire on the incorporation of human factors in the plant modifications process

1. Do you think it is important to take human factors into account in the design change process? If yes, what are the main reasons why you think it is important to consider human factors?

2. What regulatory requirements exist in your country regarding incorporation of human factors into the design change process? If you have regulatory requirements available, please attach them to the survey.

3. Which standards and guidelines are used by licensees to incorporate human factors into the design change process? Which ones are used by regulators?

   (a) For regulators, what actions do you take to ensure that licensees incorporate human factors into the design change process? If there is not sufficient integration of human factors, what actions are undertaken for improving it?

   (b) During the review, do you consider the methods and techniques used by licensees when incorporating human factors in the design change process? Describe the documents that licensees submit to the regulator for review.

4. What criteria do licensees use for deciding when to integrate human factors aspects into a design change (e.g. importance of modification for safety, economic reasons, major versus minor modification, etc.)?

5. At which stage of the modification are human factors aspects generally taken into account by licensees? For example, are human factors considered during conception, design, verification and validation, and/or during the installation through training, tests on site, or operating experience feedback? Which kinds of methods and techniques are used by licensees when incorporating human factors in the design change process (e.g. task analysis, operating experience review, function allocation, validation with simulator, etc.)?

6. What are the main difficulties that you have encountered when incorporating human factors into design changes in your NPP or your country?

7. What future actions would you suggest for improving the integration of human factors into design change processes that could be discussed during the upcoming workshop (e.g. exchange of experience, improvement of methodologies and techniques, more regulation and control, more information given to managers, more researches and studies, etc.)?

8. Are there any other topics related to incorporation of human factors in design change processes which you would like to see discussed during the upcoming workshop?

APPENDIX 5. NUCLEAR EVENTS DEALING WITH MODIFICATIONS

The following examples aim at demonstrating some of the problems connected to modifications that have lead incidents. Some of them demonstrate the need to consider minor or non-identified modifications (MiNIM) in the plant modification process and other more generally the importance of the screening and assessment of modifications. The examples were taken from the responses to the WGOE questionnaire, edited and shortened slightly to fit into the format of the report. The events have been made anonym to facilitate the distribution of the report.

Example 1. Electronic defect of logic board of switching

A PWR was in hot shutdown state; the physical tests following the outage for refuelling were in progress. An automatic reactor trip triggered by high nuclear flux on intermediate range channels is caused by a temporary loss of the vital 220 VAC Power System switchboard during the switching of electrical power source when performing train A diesel testing.

The incident was without real consequence on safety, because the loss of switchboard was only temporary. The application of incident operating procedures did not reveal any malfunction of protections.

In case of total loss of another switchboard, the protection and control signals can be re-supplied from the switchboard. The plant operator identified no potential consequence.

The expertise on the logical board in charge of the switchover, revealed the existence of a component not in conformance. After a search, the same non-conformance was detected and corrected on a second board of the same batch returning from in the manufacturer.

The origin of this component not in conformance is connected to the difficulty for the manufacturer to ensure the maintenance of these boards, because the corresponding components are not available any more. The manufacturer chose to replace the failed component by a different one without an evaluation of the impact of this modification, because the new component was supposed to be able to play the role of the old one in a certain range of configuration of voltages.

These boards are not tested in the factory. They were requalified on site by a test, which was satisfactory executed.

Example 2. Unavailability of temperature probes

The operator of a PWR puts a measuring channel in safe position in order to carry out the adjustment of a RCS temperature probe. The measurements collected by this probe enter the calculation of the thermal power by the protection system and the evaluation of the measurement of the nuclear power associated to the loop 4. Later the operator identifies a drift in this temperature probe and in a second reserve probe, which is intended to mitigate possible failures of the first one.

Several days later these two temperature probes are outside defined criteria and unusable. A crossing of probes is carried out by pulling a cable between a protection cabinet and a control cabinet in order to achieve a temporary replacement of the first probe.

This leads to an automatic trip of the reactor. The measuring channel was in a safe position and therefore the unavailability of the first probe initiated the automatic protection shutdown of the reactor. The incident

led the safety authority and its technical support organisation to question the restart actions and the continuation of power operation.

Due to the problem of simultaneous drift of temperature probes, the operator set up palliative measurements and a provisional modification in connecting a qualified cabinet to a non-qualified cabinet, with the aim of recovering the measurements of a temperature probe normally dedicated to the function of control. The requirements of qualification of the unit "temperature probe + protection cabinet" was not respected. There was then a risk to lose the temperature measurement of the protection probe in the event of seismic event.

Moreover, the operator did not apprehend all the risks related to this intervention. For example, the loss of the cabinet in channel B due to a fire could have led to the loss of the measurement treated in channel A.

Example 3. Non-compliance of polyamide ball bearing with requirements under accident conditions

During checks carried out as part of the implementation a series of requirements intended to ensure the durability of the qualification of equipment under accident conditions in PWR units, ball bearings with polyamide retainers were found in plant stores. They were intended to be used as spare part for the containment spray and safety injection pumps. As results of those findings, it was suspected that this type of ball bearing retainers could have been installed in this type of units.

The retainers of these bearings were of polyamide, whereas equipment qualification was acquired with metal ball bearing retainers. Therefore, durability of qualification under accident conditions was not ensured in the containment spray system and safety injection pumps. This shortcoming could not be revealed by performance of periodic testing as in normal environmental conditions, the pumps run perfectly well, without abnormal vibration and excessive temperature of bearings.

An investigation was begun at the plants in and showed that all similar units were affected by the problem, as a number of ball bearings with polyamide retainers had already been installed during maintenance operations on the containment spray and safety injection pumps. In the newer PWR units pumps are still equipped with the original bearings supplied by the manufacturers.

Uncertainty persists as to the ability of polyamide retainers would withstand the temperature and irradiation conditions encountered during operation in an accident situation.

The main consequence of the deterioration of a retainer is the destabilisation of the shaft line followed by loss of the pump and hence the safety injection or containment spray system. Further, it could lead to a latent common cause failure. These systems are necessary for maintaining the primary system water inventory, cooling the core and removing primary system heat during the post-accident phase of a LOCA.

In a search for root causes of this incident, it was established that if given in full, the reference number of a bearing covers the retainer type. If it is incomplete, it only establishes the type and dimensions of the bearing. For general industrial applications, manufacturers bring in bearings with retainers of polyamide, which they consider to be better, particularly as regards friction and inertia. The problem was that bearings with retainers of polyamide were supplied for the containment spray and safety injection pumps.

According to the licensee, the requirement to fit bearings with metal retainers was not included in the source documents used in the plants. The drawings, operating guides and maintenance instructions included no specific indications concerning the appropriate material for retainers.

Given the importance of the operability of the engineered safety feature equipment in post-accident situations and not being known whether polyamide could withstand the ambient conditions in which the engineered safety feature pumps might be challenged, the safety authority requested the licensee to bring all the units up to standard during the next refuelling outage.

Example 4. Failure to open a of secondary relief valve during annual tests: Possibility of common mode related to the use of a non suitable grease

When a periodic control of the setting of Main Steam System (MSS) valves was carried out with reactor at 100 % nominal power by the operator of a PWR, three valves were found to be outside established criteria:

- Significant gumming on two valves,
- Refusal of opening of the one valve at the time of the first two attempts.

At the time of a third attempt carried out after application of the criteria (drops power to 83 % nominal power and adjustment of the threshold of automatic trip to 92 % nominal power), the failing valve opened to 83,5 bar. These three valves were replaced by three valves of one of the units at the site.

Later when experts investigating the heads of the three valves they found the presence of traces of grease sticking and brownish colour to the right of the O-rings of the piston of the room of assistance. The grease has as a commercial name XXX. Its manufacturer confirms the loss of properties of this grease at temperatures above 65 °C. The technical specifications of grease XXX prescribes that its temperature of use is below 50 °C. According to the operator, the usual conditions of operating temperature of MSS valves are around 100 °C.

The grease XXX is used to facilitate the assembly of the O rings on the pistons of the valves. Its use seems to be justified by the fact that the grease recommended by manufacturer fulfils the products and materials usable in nuclear power plants requirements, but it is obviously not adapted to the operating conditions of these valves. After investigations of the valves of two units at the site, it was confirmed that the use of the grease XXX led to the blocking of valve.

This incident was classified on level 1 of the INES scale, because of the possibility of common mode failures.

In particular, following the experience feedback of the incident, the use of grease XXX was confirmed at another site, where the pistons of 5 valves distributed out of the 3 steam generators were lubricated at one outage. During a shutdown the operator replaced the grease XXX by the grease YYY (this grease, which had been used initially, is qualified up to 200°C). Other valves were lubricated with grease XXX since many years back; however no anomaly was detected during the various tests of these valves.

Example 5. Loss of the 2 source range channels due to inadvertent watering of the neutron pits during the filling of the reactor cavity

A PWR was in shutdown state for refuelling the operator noted the unavailability of the source range channels.

The operating technical specifications prescribe that, in shutdown states, at least one source range channel must be in service. However, after of the installation on the lids of unsuited joints, water entered into the pits of the source range channels during the filling of the reactor cavity, preliminary to the operations of core unloading. It caused the failure of the two channels by flooding of wires.

The reactor cavity was then emptied. The source range channels and the seals were replaced. Throughout unavailability, no disturbance affected the reactor and this event did not have any consequence for the safety of the installation.

The dimensional non-conformance of the seals mounted on the lids of the neutron pits (new seals are mounted at the beginning of each outage and the lids are removed after refuelling) had a double cause: there were erroneous references to the O-ring seals on the purchase order emitted by the service Provisioning and Transactions and adequate control at the plant store reception or the implementation was missing.

An error when writing the request for an article during the data-processing seizure caused a dimensional error on the order. Consequently, the specifications of provisioning of the seal were incorrect. With the exception of this particular batch, the deliveries of the supplier were correct; this one having taken part in the design engineering of the sealing of the lids and knowing consequently, which product was needed. Moreover, packing of the joints was opaque without any mention of dimensions or references to the manufacturer.

Lastly, concerning the controls, the maintenance operating documents of these seals specified a dimensional check in workshop of their internal diameter but did not require the control of the diameter of their ring.

Example 6. Loss of the LNG switchboard

One morning a PWR was operating at full power. The operator was running functional requalification tests on the three inverters for the continuous 220 V AC power switchboard. This board supplies power to the train A of the instrumentation and control system called “XXX”. This action was subsequent to a scheduled maintenance carried out the previous week. Requalification tests failed, causing the loss of the switchboard, which consequently led to the loss of the Train A of XXX, the loss of the 6.6 kV AC switchboards and of the safeguard switchboard, trip of one of the four reactor coolant pumps and reactor scram.

During the course of the event, despite the use of symptom based emergency procedures, operators had to deal with a complex situation due to the missing or inadvertent information (alarms) and the unavailability of some auxiliary operators in the main control room.

Since the loss of power supply, the charging pump, reactor coolant pump seal injection in the Train A Chemical and Volume Control System (CVCS) had to be shut down and remained stopped for 1 hr 25 min.

As the Train B of Component Cooling Water System (CCWS) was in operation during the inverter requalification tests, the event had no impact on the cooling of the auxiliary systems, in particular the thermal barriers of reactor coolant pumps. If this had not been the case, a loss of reactor coolant pump thermal barrier cooling at the same time as the loss of seal injection could have led to significant leakage due to the degradation of the seals of the reactor's main coolant pumps.

The root cause of this incident was an error in a maintenance operation, which consisted of replacing the capacitors on the inverter control circuits. Due to this error, requalification tests failed and the Train A of XXX sent inadvertent commands when power was restored to this unit.

Although this is not the first time that such an event has occurred, first analysis shows that there are specific conclusions to be drawn, involving various points: maintenance operations on the switchboard and

its inverters (general error in replacing capacitors), the possibility of spurious signal being sent by the XXX, incident management either on site or at a nation-wide level, and the application of procedures in an incident/accident situation.

Example 7. Trip of diesel generator

During testing at full power of an emergency diesel generator at a PWR, the diesel generator tripped due to the action of a protection device as a result of the excessively high temperature of the coolant in one of the engine cooling systems.

An investigation carried out revealed that the valve controlling the coolant temperature was defective. The internal assembly of the valve had separated from the stem because the joint between the two parts was poorly designed.

The same failure had already occurred on reactors of the same series. As a result, it was concluded that this failure was a potentially generic one, and the licensee declared it as such. The incident was classed as a Level 2 on the INES scale.

This incident was generated by a modification made to correct malfunctions observed on the originally installed thermostatic valves.

Although the modification was successful in correcting the faults, it made the valves less reliable, due to a design defect which was not detected during the course of the modification qualification procedures.

The fact that the generic nature of this new anomaly was detected at a later stage highlights the need to strengthen "technological monitoring" done by operators after modifications in order to ensure that any new faults caused by modifications are detected at an early stage and the question of whether they are generic is raised.

Example 8. Generic problems of high pressure emergency core cooling pumps

During long-duration tests of high pressure emergency core cooling (HP ECCS) safety injection pumps at PWR in through newly backfitted recirculation lines, the following problems were identified: 1) increased bearing temperature, 2) low pressure downstream pump hydraulic disc damage, 3) vibrations of a pump-drive set.

These problems resulted from inappropriate design, inaccurate manufacturing, and deficiencies during assembly. At the sister plant, such problems were eliminated immediately after commissioning. The plant licensee deserves credit for the intensive effort devoted to the solution of these problems after their detection. The problems are being solved by replacing the composition of the slide bearings, by additional oil cooling of the bearing, by increasing the coolant flow rate to the hydraulic disc, by modifying the disc contact surfaces, and by adding special supports to suppress vibrations. However, the ultimate resolution is expected from supplementing the axial bearing of the pump shaft.

The safety significance was that the degradation of systems required assuring primary coolant inventory and core cooling. Structural analysis of the material composition of the slide bearings of HDC pumps, according to appropriate codes and of a recommended new composition, was done. On the basis of the analysis of diagnostic vibration tests of the pump with unacceptable vibrations even after the installation of the new support, the replacement of the coupling was proposed that had had inaccuracies from manufacturer, and the adding of the pump bearing housing support by a new support that eliminates not only pressure, but also tension. The problem could have remained latent until a disturbance, because all six

pumps on one unit had identical problems, which implied that there was a significant degradation of safety function.

The direct causes of the problems of the HP ECCS safety injection pumps at the units of the plant. Analysis showed that latent equipment deficiencies in these pumps resulted in insufficient reliability during tests. The contribution to the existence of the latent weakness was inadequate preparation of the equipment prior to operation due to incomprehensive verification of operability and ineffective restoration of operability. The root cause was the deficiency of surveillance due to inadequate restoration of equipment operability because of inadequate implementation of improvements. The contributor to the existence of deficiency of surveillance was the management of the restoration process.

The following corrective measures taken were:

1. Additional cooling of the oil cooling system of bearings of the electric motor drives of the HDC pumps, were tested and implemented it at all HDC pumps at both units.
2. Long term operation of HDC pumps was verified.
3. Flow rates were increased in the line to the hydraulic disc and the pressure downstream the disc.
4. A design for the modification of the system was prepared by retaining the axial forces on the HDC rotor shaft by the addition of antifriction bearings.
5. The bearing housing was strengthened by a pressing support in order to reduce the vibrations of the HDC pump bearings.

Example 9. Change of diesel fuel

The final test for requalification after maintenance failed caused by a blocked controller for the fuel injection pump. The root cause couldn't be found, in spite of involving supplier and manufacturer. By chance, the injection pump manufacturer has been contacted: Nothing has changed, except a change to low sulphur diesel fuel. He was aware of the problem because of similar cases in smaller engines in the industry. Additional additives are necessary to assure functionality. The case has had a large potential for a common cause failure because the other diesels use similar type of injection pump.

Detection: Event and chance (root cause finding)

Lesson learned: The dependency was not contained in the specification because at the time of installation of diesels, no low sulphur diesel was in discussion. Fuels of emergency machines and lubricant of safety components should be monitored more closely specified or be tested by qualification tests and the supplier/manufacturer should better be involved in case of changes.

Example 10. Change of internal part of solenoid valve for diesel start-up device

A small change to an O-Ring seal on internals by the manufacturer, without adequate communication to the operator, led to a start-up failure of the emergency diesel. The root cause was difficult to find. The valve was assembled by the manufacturer, the plant delivery conformity test, a simple function test, hadn't detected the failure. Within the diesel system, the internal part was only slightly too slow to trigger the 3 way solenoid to shift correct. The failure was detected after many tests, using other solenoid valves and specific instrumentation.

Detection: Event and specific tests with special instrumentation.

Lesson learned: Operator relied too much on the QM system of manufacturer. Now, a better documentation is required and independent testing by the operator within the plant system will be performed.

Example 11. Trip of main generator lead to cavitation of feedwater pumps

Few years ago, the measurement device of condenser hotwell level should be improved by modification (weakness of the pneumatic controller with one transmitter). The operator installed 4 transmitters and a digital controller, using an average level of the 4 transmitters. The generator tripped at full power, caused by a failure of the hydrogen seal oil system, and the reactor run back to 60% was automatically triggered. Later, a reactor level trip occurred, followed by loss of main heat sink. The cause was the wrong response of the level measurement device; the controller released too much condensate to the feedwater tank, feedwater pumps cavitated and condensate pumps were shut off by low level. The test after modification had only been performed by 60% power, believing that the response could be extrapolated theoretically to 100 %. But in the event, performed at 100% power, the responses of the four transmitters were totally different, which caused the event. Shift personnel were surprised about that plant response and acted "ad hoc".

Detection: Experienced Event

Lesson learned: Qualification test after modification should cover a worse case; otherwise a latent failure with unexpected consequences can occur. Extrapolations to save tests under more stringent conditions should be used with care.

Example 12. Deviation from specified boron concentration for refuelling due to calibration error

Automatic boron titration needs a calibration which is based on manual laboratory results. The primary coolant has been borated, but due to a calibration error there was a deviation of minus 10%. It was caused by the cognitive error of two new technicians, that the depletion factor of a used standard solution was calculated as 1,08 (it could be 1.0 at the highest, i.e. no depletion). The two technicians worked together, therefore no independent review happened. Both were not adequately trained or experienced because in the 16 year operation of the plant in the past, no similar event occurred.

Detection: Experienced Event

Lesson learned: Changing personnel imposes a risk that mistakes can happen, because the procedure was adequate for the experienced operator but not for the new ones. This is difficult to control. It would be better if an experienced person leads the beginner for important safety tasks for as long as he has got the necessary competence and experience.

Example 13. Reactor start-up with degraded reactor shutdown system

Two changes had happened previous to the event:

1) The charging water valve in the control rod drive system was equipped with a motor actuator (without consultation of reactor supplier). The reason was to have, in case of ATWS, by closing that valve, the possibility to insert the rods manually. This change was notified and approved by the regulator.
2) Later, the operator experienced during start-up and shut-down many IRM (neutron flux) Scrams. By resetting the Scram signal, the accumulators became refilled automatically. The following Scram signal leads again to a fast control rod injection. This was found an unnecessary stress for the control rods, and the operator changed the operating procedure. After an IRM Scram, the charging valve was closed, the accumulators stayed unloaded and additional Scram signals had no consequences on the control rods. If the reactor was stable, the valve has to be opened. The regulator has been informed, but no formal approval was necessary.

Event Sequence: An IRM Scram occurred during start-up. According to the new procedure, the operator closed the charging valve. Start-up proceeded and the reactor went critical, with discharged accumulators (violation of technical specifications). Three and a half hours later, during shift turnover, the deficiency was detected. The event has attracted much attention by the operator and by the regulator and by the national Commission for Nuclear Safety.

Cause/Root cause: Ergonomic situation

Unfavourable Alarm concept for control rods: To monitor the control rods, a wall chart display of the core and the control rods is available in the main control room. Each control rod has a green and a red light. The red light has multiple functions and indicates:

- Accumulator failure
- Rod drift
- Disconnection
- Position failure
- Rod out position

All Alarms except "Rod out" can be reset. The reason for this is because the alarm system is not "dynamic", this means, without reset, one cannot identify whether a new alarm appears. Therefore, with the reset, all red lights of the discharged accumulators disappeared; only on yellow indication on the desk remained with the description "accumulator fault". The situation would be the same, if only one accumulator is unloaded, or 10 or all 149 of them.

There are more than 20 similar indications on the control room desk, and it is normal that after a Scram, some of them are indicating. In this case two others lit up. Considering the many activities during Scram recovery, overseeing this indication by the operators is not unlikely.

Alarm concept of the rest of the control room: It is different to that of the control rods since it has a dynamic system. It means that an alarm light can't be reset unless the reason for the alarm disappears. If there are also more criteria on one alarm indication, every new alarm arriving produces a flashing of the light. , The operator identifies it on the screen of the process computer and recognises it by the reset. The light remains on but the flashing is absent.

Unfavourable Procedures: The new procedure has been introduced, with sufficient information and training. It was not in the form of a check-list with signature of every step but it was in the form of a general guidance. Therefore, the critical step for the charging valve read: "Reopen of charging valve when reactor is stable". This is not an exact definition and open to different interpretations.

The general start-up procedure does not include an accumulator check if the downtime was shorter than 48 hours (this was here the case). Therefore, there was no back-up control in case that the operator failed to follow the procedure.

Not fully used Operating Experience: A few years before that modification, a similar event happened in another plant abroad (IRS System; Scram system unavailable during single road scram test). The regulator required from the operator an in-depth analysis to prevent recurrence.

The evaluation, after an initial insufficient version, was, after additional work, finally approved by the regulator.

But during the modifications of the operating procedure, which has in reference to the event high importance, the mentioned event has not been analysed. Therefore, the former analysis, after the modification, was practically useless.

Detection: Experienced Event

Lesson learned: Improve the Human Factor Engineering or ergonomic assessment on modifications, even if it seems at first that no reference exists. The affected plant implemented an independent review for all modifications with impact on operational safety by experienced shift safety engineers. As they have at least more then 6 years real operating experience (plant operator, turbine and reactor operator and shift supervisor), they should have the necessary competence to prevent the recurrence of similar events (Human Factor Engineering competence not required by regulation)

Example 14. Uncontrolled radioactivity release

The extractor has been operated dry and unloaded during night (this is abnormal, since normally it operates wet and loaded). This has produced abnormal particles (ca. 50 μm), which led to particulate deposit in the sensing line of the radiation monitoring system (particles not detected). The hydro-extractor was directly connected to the exhaust ventilation, but the filter was defect. By these main reasons, the uncontrolled radioactive release couldn't be detected. It was revealed by the periodic control of ground contamination in the vicinity of the plant. The event attracted large public and regulatory and international attention.

Detection: Periodic control of ground contamination (loss of defence in depth).

Lesson learned: The event revealed a specific phenomenon (abnormal particle deposition in sensing line) as a lesson learned for the nuclear community, and many latent failures in the plant. Uncontrolled changing of operation mode on such types of equipment may lead to an undefined situation. All operating modes on such types of processes should be verified by commissioning tests with specific instrumentation before routine operation.

Example 15. Fitting of unapproved Relief Valves to an Auxiliary Boiler

During investigation of an unrelated defect, the water side relief valve was removed from an Aux. Boiler and found to have a rubber seat, which had perished. This was compared with the equivalent valves on the other two boilers, which were found to be fitted with brass seats. Investigation revealed that the rubber seat valve was 'as fitted' and the valves with the brass seats were inadvertent modifications.

The manufacturers confirmed that they had supplied both types of valves for use on the Auxiliary Boilers.

The problem was caused by manufacturers changing the design of off-the-shelf components without declaring these changes, having previously advised that the change was a “like for like” replacement.

Causes – Unauthorised material substitution – changed design used for “like for like” replacement, Controls provided not adequate – manufacturers changes not declared prior to fitting new type of relief valve.

Actions- Review of ‘Approval for Design Change’ controls initiated.

Example 16. Inadvertent Modification to Gas Circulator Seal Oil Control Valve

A Seal Oil Control Valve was removed from a Gas Circulator. It was being replaced with a reconditioned spare valve from the manufacturer, when it was noticed that the valve seats on both the reconditioned valve and the valve that had been removed were not of the same detail as shown on the station drawing.

Discussions with the manufacturer revealed that this was part of an improvement made by them several years before. The change did not affect the design intent of the valve or its flow characteristics.

The modification had probably happened 25 years before. A retrospective Plant Modification Proposal was prepared and approved to allow the valve with the modified seat to be used.

Causes – Unauthorised material substitution – modification proceeded without approval, Standards not adequately communicated – the changed design was made by the manufacturer as part of a previous improvement.

Actions – Retrospective modification approval

Example 17. Unauthorised Modification to Essential Supplies system Diesel Generator by Manufacturer

The defective governor on Diesel Generator 2 was replaced with a spare which had just returned from overhaul by the manufacturer. The defective unit was returned to the manufacturer for overhaul.

Internal inspection at the manufacturers work identified that the governor oil was contaminated with engine oil. The manufacturer commented that the 'O' ring seals on the governors were superseded with a mechanical seal and all new governors are currently manufactured in this way.

Inspection of the newly installed unit on Diesel Generator 2 found that the 'O' ring had been replaced by the newly upgraded seal and had not been considered under the PMP process.

A review of the Procurement arrangements took place to advise suppliers that changes/upgrades/modifications require written approval from the System Engineer.

Whilst no authority was given to fit the revised seal design, the manufacturer could see it would be in the Station’s interests to have it and proceeded to carry out the work as part of the overhaul without question.

Again a retrospective PMP was raised to formalise the modification and to cover subsequent upgrading of the seal/'O' ring arrangement.

Causes – inter-team communication inadequate – no authority was given to fit the revised seal design, Cautionary information not included – The need for suppliers to advice of changes/up-grades was not realised at the time.

Actions – Retrospective PMP was raised to formalise the modification and review of Procurement arrangements to formalise requirements on supplier's advice changes/up-grades/modifications to System Engineers for approval.

Example 18. Water Quality Excursion when Blow-down Demineraliser Placed In Service due to changes in resin quality

A Steam Generator Blow-down demineraliser placed into service following replacement of the resin. The bed had been rinsed as per the Plant Operating Instruction (POI).

Increased conductivity values were observed in several locations, which indicated that contaminants had been released by the new resin. This was due to the manufacturing process not washing the basic resin polymer as extensively as previously, and therefore some leachables and bead fragments were not successfully removed.

This was not detected during the rinse-down process, as the rinse-down valve is upstream of the chemical monitoring equipment.

The reliance upon 'Nuclear Grade' resin, expected to be high quality, had failed. The supplier changed the specification form >95% whole beads to >90% whole beads without reference to the Station.

Causes – System alignment not verified (the alignment of demineralisers in parallel mode did not give any protection to a fault in the cation demineraliser)

Observed causes – Written procedures technically incomplete – rinse-down procedure in the POI did not allow monitoring of the water quality before placing the beds into service, written procedures unclear or complex wording – The POI for demineraliser operation can easily lead to misalignment of the plant, materials used do not meet specification – the reliance on 'Nuclear Grade' resin, expected to be high quality, failed.

Actions – The specification for Nuclear Grade resins to be upgraded to require a certificate of analysis for each batch
Valves that should be locked shut are to be brought into the 'grey lock valve' administrative lock-out system and cautioned.

Example 19. Insufficient power during LOCA condition from off-site power sources

Brief Description: The licensee identified that one of two offsite power sources (Line 4) could not provide the power required for a LOCA when the other source (Line 1) is out of service. The voltage on Line 4 during a unit trip with a LOCA, with Line 1 out of service, would decrease and actuate the degraded voltage relays (DVR) transferring the ECCS loads to the diesel generators. The voltage decrease is due to the additional load applied during a unit trip with a LOCA as compared to normal plant operation.

Cause: An inadequate analysis of an earlier design change, which increased the DVR setpoints, was the cause. The focus of the design change was to develop DVR setpoints which would ensure adequate voltage to plant equipment. The capability of the offsite power sources to maintain voltage above the DVR setpoints and preclude separation from offsite power during a unit trip with a LOCA was not thoroughly evaluated. Contributing causes were inadequate consideration of the design bases and inadequate communications between the licensee and the load dispatcher. Detailed requirements were not given to the load dispatcher, and the ability of the system and load dispatcher to maintain sufficient voltage on Line 4 during a unit trip with a LOCA when Line 1 is out of service was not verified.

Example 20. Failure of over-voltage coil of a relay

Brief Description: During the performance of under-voltage testing of 4160V switchgear, the over-voltage coil in a relay failed. This relay allows a safety bus to be re-energized following the removal of an under-voltage condition which caused the bus to shed loads. Licensee extent of condition reviews identified another improperly set relay affecting a different safety bus.

Cause: The cause was determined to be the failure to provide adequate design controls on the relay tap settings for protective relays controlled by relay setting orders. A contributing factor was the lack of a questioning attitude by personnel involved in the relay tap setting change, as a result of the historical method of control for relay settings.

Example 21. Insufficient chilling power during certain failure sequences

Brief Description: The licensee determined that two of five main control room and emergency switchgear room chiller motor control center feeder breakers could trip at degraded voltage levels.

Cause: The cause was determined to be a failure in plant configuration control. When the chiller compressors were replaced in one year, the station electrical load list was not updated for the increased loads. A subsequent design change package seven years later specified incorrect trip ratings based on the incorrect values from the station electrical load list.

Example 22. Deficiencies in post LOCA boron dilution flow

Brief Description: Prior to 19xx, the licensee's Emergency Operating Procedures (EOP) contained steps to align the alternate post LOCA boron dilution flow in the event of a LOCA and the failure of the primary dilution flow path. In 19xx the licensee recognized that for small breaks and some non-design basis scenarios, the existing guidance could allow this path to be aligned while reactor coolant system pressure and temperature were sufficient to overpressurize the piping in the flow path. Damage of this flow path could result in loss of long term decay heat removal capability. Therefore, in 19xx, the EOPs were revised to delete use of the alternate path during these scenarios. Six years later, the EOPs were again revised, and included steps to align the alternate dilution flow path without adequate guidance with respect to system pressure.

Cause: The root cause is inadequate documentation of a known problem. In 19xx, the issue of using the alternate dilution flow path for scenarios other than large break LOCAs was not addressed in the Low Pressure Injection Design Bases Document, or other appropriate engineering documents. As a result, operations procedure writers did not have a reference documenting that use of the alternate path was inappropriate in the given scenarios. A contributing factor was that, in the change made six years after 19xx, the steps containing inappropriate guidance were not identified as part of the change, and therefore, were not included in the review process.

Example 23. Lack of a qualified source of lubricating water supply

Brief Description: The licensee declared three safeguards vertical cooling water pumps inoperable for lack of a qualified source of lubricating water supply to the line shaft bearings. The lubricating water had been originally designed as safety-related but was downgraded in 19xx and subsequent physical changes did not maintain the original quality level. It was thought at the time that this independent source of water was not necessary for pump operability.

Cause: The cause was determined to be the incorrect assumption which was incorporated into the safety evaluation and allowed modifications to be performed without maintaining critical design requirements. For example, one of the design changes eleven years later utilized the piping and strainers of the Filtered Water System. However, the inclusion of these strainers introduced a new failure mode, the inability to backwash strainers in the event of a loss of offsite power. Several opportunities failed to catch the original mistake via different modifications and assessments, e.g. the Design Basis Reconstitution project, the Station Blackout project, and the self assessment of the cooling water system.

Example 24. Total loss of enhance shutdown system functionality on one group of rods

The Enhanced Shutdown (ESD) system was designed to ensure safe reactor shutdown in the event of the postulated simultaneous common mode seizure of control rod clutches. On detecting a reactor trip the ESD system drives 29 of the 57 control rods into the reactor core at twice-normal motor speed.

During routine maintenance of the ESD system of the second reactor at a site, in accordance with a new suite of maintenance instructions, a total loss of ESD functionality on the secondary group of 20 ESD control rods was revealed.

The failure affected both channels of the ESD system and was determined to be a wiring anomaly due to a design error introduced during a minor modification to the overall system.

The modification had been implemented and commissioned two years earlier. The testing of the modification, diverse testing following a switch replacement, the routine testing and system logger alarms revealed the design error, however, this information was not recognized as indicating a significant loss of system function and therefore the system remained in service.

This event highlighted a lack of rigor in the application of the management of design changes, safety case modifications and non-conformance assessment during commissioning and into the initial phase of operation. Additionally, the testing of the modification was inadequately conceived with respect to strategy and scope

Example 25. A common mode failure mechanism introduced to four redundant diesel generators

Replacement emergency diesel generator turbochargers were procured for plant X with the only significant difference between the original and the new turbochargers being a newer design wall insert. The replacement turbochargers were procured as commercial grade items and dedicated for use on the emergency diesel generators.

In the dedication process, a subtle incompatibility of the newer design wall insert with the older design turbocharger compressor blading was not detected. As a result, a common-mode failure mechanism was introduced to all four emergency diesel generators. On 12 June 19xx, a turbocharger compressor blade failed during a surveillance test on the Unit 2, 2A emergency diesel generator. The subsequent preliminary root cause analysis incorrectly concluded that the failure resulted from a manufacturing defect. On 27 June 19xx, an identical failure occurred on the Unit 2, 2B emergency diesel generator, and the common-mode failure potential was then recognized. Unit 1 was subsequently shut down, and Unit 2 significantly reduced power while maintaining a source of on-site power during turbocharger replacement on all four emergency diesel generators.

The common-mode failure mechanism affected the emergency diesel generators in a narrow range of electrical loading, normally experienced only during surveillance testing. This loading was well above the design-basis electrical loading that would accompany a loss of off-site power and certain accidents.

Station commercial grade dedication procedures were correctly followed when evaluating the purchased turbochargers for use on the emergency diesel generators. With the exception of the 17-hole wall insert, the turbochargers were identical to the replaced units and met the station's criteria for an acceptable substitute. Installation was handled as a minor modification. Critical characteristics for acceptance of the turbochargers primarily dealt with diesel performance parameters and were all met in test runs following installation on the diesels.

Example 26. Abnormal vibrations in high head safety injection pumps during tests

The unit was in hot stand-by after the planned refuelling outage. The annual tests of the reactor protection system were being performed. During a test with the High Head Safety Injection system, the common header of the four High Head Safety Injection pumps vibrated abnormally, and two 15 mm drain lines were ruptured and started leaking. The unit was cooled down for repairs.

The cause was a malfunction of two Line Break Protection valves, which did not close completely on demand. This caused them to become unstable and cause line vibrations when actuated during operation of the Safety Injection System. The basic INES rating is level 1. The causes of the event are: maintenance procedure for the valves not adequate; testing procedure for High Head Safety Injection System not adequate; non-conservative decisions made by Operations Manager; Lack of engineering follow-up of maintenance problems. After the event it was demonstrated that both check valves were unable to close fully because of an engineering error made during a minor modification.

Example 27. Several trips of the auxiliary emergency feedwater pumps

During the regular refuelling outage on one plant in the frame of safety upgrading process the auxiliary emergency feedwater pumps were relocated. After the successful post-maintenance tests the system was declared operable. However, during the next few days in process of unit start-up when performing different tests the auxiliary emergency feedwater pumps tripped several times.

Although every time the troubleshooting and the taken corrective actions seemed to give satisfactory results - the repeated start-ups right after the repair were successful - the pump trip occurred again in a few days when the next test was performed. During the load sequencer test the related auxiliary emergency feedwater pump tripped after the start-up. The other stand-by pump was tested immediately, but it tripped too.

According to the Technical Specifications that require to bring the unit into cold shutdown conditions in case of unavailability of both auxiliary emergency feedwater systems the operators started to cool down the unit. The trips of the auxiliary emergency feedwater pumps were caused by the protection signal "low cooling water flow to pump bearing". Deficiencies in design, preparation and construction of system modification caused common mode failure in auxiliary emergency feedwater system resulting in degradation of heat removal function. The low quality of troubleshooting led to the repetition of the event.

Example 28. Failing containment leak test

The modification of control circuits of several (138) air-operated containment isolation valves were scheduled for the one refuelling outage on the second unit of one plant in order to make them ready for operation with the new reactor protection system to be installed in the near future.

The modifications were carried out and the completed post-maintenance tests did not reveal any problem with the isolation valves. However the later conducted containment leak test failed due to uncontrolled re-opening of some modified isolation valves.

The conducted analysis indicated that due to the incomplete preliminary analysis and design work, the results of which were not revealed during the verification process the implemented modification led to degradation of the containment safety function. However, since the problem occurred during cold shutdown and was identified during a test the event had rather potential than real safety consequences.

Example 29. Shifting from hydrogen to helium as a coolant for the generator

At one plant a modification in shifting from hydrogen to helium as generator coolant was implemented as a test during an extensive testing and renovation programme, which took place for nearly four years. The motive for this test was to investigate if it was possible to eliminate hydrogen as generator coolant.

During the restart of the reactor at 19 % nuclear power a reactor scram occurred.
The event was caused by a two-poled short-circuit in the generator phase bushings. The short-circuit caused severe damage to one of the two generators. The stator as well as the rotor had to be replaced.

The root cause of the event was improper design and modification control. The dielectric properties of helium compared to hydrogen or air were not considered.

Example 30. Hydrogen explosion at the modified RHR piping

When a surveillance test of the high pressure core injection system (HPCI) was performed during operation at rated power at one power plant, the steam condensation pipe of the residual heat removal system (RHR), which branched from the HPCI turbine steam line, was ruptured. Consequently the HPCI pump turbine tripped, and the control room personnel received alarms indicating the actuation of fire detectors in the reactor building and “high-high radioactivity on reactor building ventilation monitors”. The reactor was manually shutdown.

Cause - It was concluded that the cause of the pipe rupture was hydrogen explosion due to the accumulated hydrogen and oxygen burning at the high point of modified piping.

Actions - To prevent hydrogen accumulation, the RHRS steam condensation pipe was deleted. It also was decided to provide relevant measures such as modification to avoid hydrogen accumulation or provide monitors for the locations where hydrogen might accumulate.

Observed causes – The modified piping portion was not subject to report to the regulatory agency and the design change control of the utility for the modification was not sufficient to identify its effect to the safety.

APPENDIX 6. ONE EXAMPLE OF INSTRUCTIONS FOR CARRYING OUT TECHNICAL MODIFICATIONS AT A NPP

Introduction

This Appendix gives an account of the plant modification procedure that is used at the dual reactor unit in Olkiluoto, which is operated by the TVO Power Company in Finland. This appendix reflects the content of the instruction 103321 in the form it was issued at 20.1.2004. The instruction comprises of a total of 32 pages and has therefore not been translated from Finnish in a one-to-one fashion, but the description below still contains the essential components necessary to make the plant modification process understandable.

The instruction 103321 is a general instruction that covers all nuclear facilities operated by TVO. It covers the whole time between the filing of a suggestion for a modification and the expiring of the warranty period of the modification. In the instruction the concept of plant modifications is used to mean a permanent modification that implies that earlier accepted documentation has to be changed to accurately describe plant characteristics. For example software modifications of the process computer, modifications of alarm and trip levels, as well as fuel and tool modifications are thus seen as plant modifications. A separate instruction covers non-permanent modifications. The instruction does not cover such modifications, where some equipment or constructions are brought back to their original configurations.

The responsibility for adhering to the procedure described in the instruction lays on each of the department, office and section heads within their own fields of responsibility. The *modification co-ordinator*[1] is responsible for carrying out the whole plant modification. The modification office is responsible for all concurrent plant modifications projects and sub-projects. The modification office is also responsible for updating the instruction.

General considerations concerning plant modifications

Needs for plant modifications come from many sources. Major plant modifications are written into the strategic plan. From there the plant modifications are concretised into medium-term and yearly plans. Plant modifications are according to their costs divided into three groups, small, intermediate and major modifications. The implementation decision for small modifications are made by the modifications meeting, for intermediate modifications by the technical meeting and decisions on major modifications are made by the operational committee, the senior management group or the company board.

The office responsible for the technical field considered by the plant modification is typically responsible for the budgeting of the project and forwards the investment proposals to the modifications office. The preparation group for investments prepares together with the responsible technical office the economic justifications for the technical meeting, after which the senior management confirms the investment budget.

The course of the work for a plant modification is described in the Enclosure 1. The following main phases can be identified in the plant modification process

- identification of the need for a modification
- action proposal
- pre-planning

[1] A specially appointed person, who is responsible for the specific plant modification.

- implementation planning
- installation planning and implementation
- finalisation, documentation and reporting

The scope of the handling of a plant modification is determined from case-to-case based on the classification for plant modifications. It is possible to adjust the scope during the progress of a plant modification project.

The management of modifications is carried out using a computerised tool in which normal project management tasks like opening of a project, division of the project into tasks, time scheduling, task follow up, resource planning, and reporting can be carried out. Action proposals, proposals for modifications, modification authorisations, handling of decisions and documents, etc. are written directly into this *modifications management tool*. Inspection decisions are also written directly into the tool.

The responsibilities for the plant modification and its sub-projects are defined in detail in a separate instruction.

Classification of plant modifications

Plant modifications are classified according to their type, safety class and technical scope. The type can be a plant modification, a change of plant spare parts or any other modification. Five safety classes are used according to the so-called YVL-guides defined by the Finnish regulator STUK.[2] The technical scope is applied only for plant modifications and they are classified into small, normal and large.

Modifications for which there is an evident implementation alternative can be considered as small. No pre-project plan is prepared for small modifications, but instead an implementation plan. For small modifications a modification co-ordinator is appointed, who is responsible for the progression of the project.

Modifications in any of the safety classes may be considered as normal. According to their technical scope they are intermediate projects, which need a broad handling. A pre-project plan is prepared for all normal modifications. A modification co-ordinator is appointed and if considered necessary, he[3] gets a project group to support him.

All modifications that to their technical scope are large modifications of plant system and usually also major investments to which work from several technical areas are needed are considered as large. For large modifications a separate project is always established. For these projects a modification co-ordinator is appointed as a project manager and a project group to support him in the control of the progress of the project. When deemed necessary a broader project organisation is established and in this case a separate project handbook is created.

Proposal for a plant modification

A modification is initiated by preparing an *action proposal*. The starting point may be a large project that has gone through various phases of preparation, it may be a small isolated work or change in used spares. Everyone in the TVO staff has the right and obligation to bring observed needs for modifications to be handled by preparing an action proposal.

[2] YVL-2.1: Nuclear power plant systems, structures and components and their safety classification, cf. http://www.stuk.fi/saannosto/YVL2-1e.html.

[3] The Finnish language does not separate between genders for pronominal. The word he should in the text be interpreted as s/he.

An action proposal is fed into the modification management tool. A reviewing request is sent to the necessary persons electronically. An action proposal describes issues such as: Work or problem, proposal for an action, plant state necessary for implementation, proposed time-table, cost estimate, budget number, etc. An action proposal may already contain an extensive material in enclosures, in which the work is described in more detail. On the other hand it may also be restricted to the description of a problem. An action proposal may contain a proposed co-ordinator for the modification and for the pre-projecting. The action proposal is sent to the immediate superior of the submitter.

Action proposals are evaluated by the immediate superior of the submitter, group leaders, section or office heads, and when necessary by experts from the target area. The submitter may follow the handling of the action proposal in the modification management tool. When necessary he is asked to submit additional information. If the action proposal is rejected, the submitter is informed of the decision. Evaluations and positions are written into the modification management tool and they are sent electronically to the next handler. Enclosures are sent by normal internal mail. When the office head of the submitter considers the action proposal to be strong enough and useful in its justifications he submits it forward to be processed by modification planning and further on for decision in the modifications meeting.

The modification meeting processes action proposals that have been accepted in the handling by the offices. The head of the office from which the proposal is coming introduces it to the meeting. In the meeting the necessity and profitability of the action proposal is evaluated critically. Also action proposals in which major changes have been made since the last modification meeting are returned to this stage for a re-evaluation.

The modification meeting has a broad participation from the operations and technical offices. The manager of the modification office acts as the chair and the office secretary as the secretary for the meeting. Additional office managers may be called in when necessary.

If the action proposal requires additional clarifications or analyses, the proposal is returned to the submitting office. If the proposal is rejected the submitting office is responsible for informing the submitter.

For action proposals that are accepted a modification classification is made. The pre-projecting organisation is assigned, the modification co-ordinator is appointed and the decisions are brought into the modification management tool. After this the modification office opens a project for the modification work.

All action proposals that have been handled at the modification meeting are reviewed at the modifications inspection meeting. The action proposals are reviewed at the same time as the pre-project plans. In the review the validity of the information is checked and designers are given additional information connected to the area of the modification. The inspection meeting documents the need for additions and clarifications as suggested from the participants. Comment are typically asked for on the following issues: Description of work, cost estimates, the classification of the modification, experiences from similar work, influences on documentation, needs for analyses, space requirements for the installation, time-schedule, etc.

Urgent modifications that should be implemented immediately to ensure the safety or the availability of the plant, are handled in such a way that the phases are carried out in parallel. In such cases it is especially important to ensure that the requirements of the modification process are fulfilled.

Regulatory handling

The regulatory handling is based on the YVL-guides or specific regulatory decisions concerning certain issues. The policy of TVO is that new regulatory requirements are applied to a degree, which is practically

achievable. In the application of new regulatory guides, STUK makes separate decisions for each of the guides. The regulatory handling depends on the safety classification of the modification. The modification co-ordinator is responsible for submitting material for the regulatory process. Depending on the classification of the modification, documents are submitted to STUK either for approval or for information. The regulatory handling of modifications in the documentation such as SAR, safety technical specifications, etc. is taken care of by the organisational units responsible for these areas.

Procurement

Procurements of resources, materials, equipment and spare parts that are connected to the modification project depend on the planning documents, which are made according to valid principles and procedures during the pre-projecting or implementation planning. Valid instructions are used for the procurements.

Method of implementing the modification

The modification office carries or contracts out the pre-projecting. When the pre-project plans are made, the best know-how of the TVO Company is used. Possible organisations carrying out the pre-project plans are the technical offices, the modifications office, some other office of TVO or an external organisation.

The implementation plan and the proposal for procurement and installation are parts of the pre-project plan. These are negotiated in co-operation meetings between the organisational units involved and they are confirmed in inspections and when necessary at the plant meeting.

The implementation planning is mainly made in the modification office, but the modification co-ordinator can also contract out work to outside organisations. The installation is typically carried in such a way that offices of the technical department implement large modifications and the maintenance offices of the operations department participate in the work. Normal and small modifications are implemented by the maintenance service office and the offices of the technical department and the modifications office participate in an expert role.

Source information for pre-projecting and implementation planning

The source information for the pre-project and implementation planning is typically obtained from the following documentation:

- YVL-guides
- Safety technical specifications
- Statutory decrees and guidelines
- Design basis standards
- The classification document
- Plant database
- Plant documentation
- Operations and maintenance instructions
- Probabilistic safety analysis
- Vendor design basis
- Programmable automation systems
- Cable database
- Area database
- Electrical installation guidelines
- Inspection service manuals

- Welding manual
- Materials specifications
- Modification design instruction

Pre-projecting

The pre-project plan. The pre-projecting aims at clarifying the technical and economic eligibility of the modification and to produce source information for the implementation planning. In the pre-project phase the design basis of the modification is clarified, the technical and economic alternatives are investigated, the need for various analyses established, the environmental impacts are assessed and the time schedule and the profitability calculations are made to a point, where it is possible to decide to continue the project. After a positive investment decision the pre-project planning is continued with the aim to produce the basic designs and enough source information for the implementation planning. Depending on the classification of the modification the next step is to develop the design in principle. After the design in principle has been accepted the pre-projecting is continued with the design on a systems level and the regulatory pre-inspection material is produced. The pre-projecting and the implementation of the modifications at the training simulator are described in separate instructions.

Pre-project inspection. The pre-project inspection is an occasion at which experts from different technical areas assess the implementation alternatives that are described in the pre-project plan. The aim with the pre-project inspection is to get well founded comments on the selected solutions and to give the experts a possibility to give views on issues that have to be observed in the planning up to that point. The pre-project inspection meeting as held once a month on a predetermined time. The modification office is co-ordinating the inspection activities and meetings may be held more frequently when needed. Inspections are made both on plans that have been produced internally at TVO and by an external organisation. At the pre-project inspection meeting the modification co-ordinator presents the modification and all its details. A material describing each modification to be inspected is enclosed to the call for the meeting. The proposer of the modification is together with representatives from the offices of operations, mechanical maintenance, electrical and I&C maintenance, safety, quality and environment, technical support and modification. Each office appoints its representative and the plant meeting confirms the regular members. The head of the modification office acts as the chairman for the inspection and the secretary of the modification office as it secretary. The results of the inspection are written into the modification management system. If there are deficiencies in the pre-project plan the plan is returned to its author. If consensus cannot be reached at the inspection, then the pre-project plan is remitted either to the plant or to the technical meeting for a decision.

Review and approval of the pre-project plan. When necessary an independent review of the pre-project plan is made or the opinion of outside experts is asked for. Observations, needs for changes and suggestions made by the outside expert are assessed by the modification co-ordinator together with the project group. Based on this assessment the pre-project plan is changed or the comments are left without consideration when clear arguments for this can be given. The technical acceptance or rejection is made by the head of the corresponding technical office. In the technical review the modification is assed with regard to its acceptability and influence on the plant as a whole. The decisions are written into the modifications management tool.

Implementation planning

The implementation planning is based on the pre-project planning. In the implementation phase all necessary installation and commissioning documents are produced.

Adjustments in the project plan. When the pre-project plan has been accepted the implementation planning is initiated. The modification project is divided into separate sub-projects, sub-project members are

appointed, necessary construction resources are reserved and the needed installation and commissioning resources are estimated. When the members of the project groups are appointed, a special care is taken to utilise the best knowledge available. The implementation planning is usually done by the modification planning office. If the implementation planning is done by some other body, the modification planning office participates in the monitoring of the work and produces the interface plans to ensure that the modification fits into the modified plant.

Implementation plan. During the implementation phase all documents are produced, which are needed in the procurement, pre-inspections, installation and commissioning to ensure that the modification can be accepted, implemented and taken into operation. In the implementation phase a preliminary work plan is made within the work order system. In the implementation phase the final cost estimates are produced for the modification.

The design basis is gone through in the beginning of the implementation phase and the planning time table is produced. In the time table due account is given to the need for producing procurement documents for equipment with a long delivery time. The needs for spare parts, operations- and maintenance instructions together with other technical information, details of delivery and the persons responsible for the equipment are defined in the procurement documents. The maintenance planning connected to modifications is described in a separate instruction. The time needed for pre-inspections, acceptance inspections and preparations are taken into account in the delivery time schedule. The consideration of environmental requirements is described in a separate instruction.

The procurement of materials, equipment and other resources are made according to the planning documents with due account of the principles and division of work as defined in the pre-project plan. In the procurement valid general and project specific instructions are used.

Modifications that are parts of the same project are described in a standardised way giving background, purpose and a short description. This gives a clear description of the modification and it enhances the alignment of the sub-project to the modification project. This text is later made use of as a description of the modification in various reports and training material.

The correct function of systems and equipment is verified in a trial operation after the installation of the modification. For this purpose necessary test programmes are produced. They are inspected by the operations office and are accepted by the organisation responsible for the plan. When applicable the original test programmes for the plant can be used.

Among other the following documents are produced and accepted before the modification is taken into operation:

- test instructions
- operating instructions
- maintenance plans
- training plans
- final safety analysis report
- safety technical specifications
- probabilistic safety analysis

The documents that are necessary to be updated before the implementation are surveyed preliminary in the modifications proposal phase and the plans are made more specific in the pre-planning and implementation planning phases. The need for updating documents is brought into the modifications management system and is printed out as a form, which is appended to the modification documentation.

The planning documents are assembled in the modification planning office to a *modification package*. A special form stating a *modification order* is used as a flyleaf for the package when it is sent for inspection and acceptance.

Inspection and acceptance of the implementation plan. All inspections and acceptances are signed in the modifications management system and on the flyleaf. The offices participating in the inspections ensure that

- the modifications material is comprehensive and relevant
- the modification is acceptable as seen from all fields of activities
- the modification has been scrutinised sufficiently
- the necessary documentation has been produced

If considered necessary an independent inspection of the planning documents is made or the statement of an outside specialist is asked for.

The organisational unit accepting the modification is given the responsibility

- to assess if the economic precondition for the modification still are valid
- to assess the statement of possible independent inspections and together with the modification responsible decide on its implications
- to assess the sufficiency in the handling of the material
- to ensure that the design basis is valid and that design requirements are fulfilled
- to inspect that the documentation modification monitoring sheet has been duly filled in
- to inspect and accept the technical part of the modification
- to document its decision on the modification order form

The operations director accepts the modifications to be implemented at the plants. An acceptance is required only in the case that the modification has a large impact on the plant safety, power plant process or if it is very large. After this the modifications package is returned to the modifications planning office.

If there within the inspection and acceptance round is a need to make changes or additions to the modification package, it has to be returned to the modifications planning office for these changes to be made. The changes are made by the organisational units, which originally prepared the plans. When the changes have been made the modifications package is returned to the inspections circulation. If necessary the inspections circulation can be started anew.

When the inspection circulation has been completed the documentation modification monitoring sheet is sent to the responsible organisations. When the modification work is ready to be carried out the modification package is sent to the implementing organisation. Accepted modification project can be monitored in the modification management system.

Inspection connected to the implementation of the modification at the plant

The inspection that is connected to the implementation of the modification at the plant is intended to verify the readiness of the installation and to inform concerned organisational units about their upcoming tasks. In the inspection the following issues are considered among others:

- installation time schedules
- planning time schedules
- work permits and the packaging of implementation tasks
- the appointment of the responsible work supervisor

- installation permits
- issues connected to methods of implementation
- handling by the authorities
- plant safety
- labour safety hazards

Monitoring of work and implementation

The modification co-ordinator agrees with the corresponding person on how the monitoring is performed and supervises that the implementation is done in agreed ways. The method of implementation is decided in principle already in the pre-project planning. The installation is usually made by the maintenance department, an outside contractor or vendor. In the case an outside organisation performs the work it is supervised either by the maintenance department or the project responsible for the modification.

Preparations for the implementation. The preparations for the implementation are started already in project planning phase based on advanced information. When the final accepted modification package arrives to the organisation that is responsible for the implementation, a more detailed plan is produced, the procurement of materials and reservations of resources is supplemented, a final implementation schedule is produced and the necessary support services are secured. For the contracted work the installation and building supervisors of TVO secures the corresponding matters with the contractor.

Implementation. The implementation is carried out according to the plan as agreed on in the pre-project planning and the corresponding co-ordination and project meetings. Before the installation is started the co-ordinating work supervisor ensures that all required regulatory approvals have been obtained. The implementation is usually taken care of by the maintenance department or a contractor. The supervision of the implementation is usually carried out by the maintenance department or when agreed by a suitable technical office.

Modifications in the plans during the implementation. If there is a need to deviate from the plan within the modification package, this has to be reported to the sub-project leader and the modification co-ordinator. The modification co-ordinator arranges the handling of the acceptance of the deviations the necessary changes in the modification package. To the appropriate extent this can be handled by issuing a deviation report. The supervisor of the implementation has the right to accept small changes at the installation place. He is responsible that the changes are brought to the installation drawings and that they are recorded in the pages for field changes in the modification package. For the modifications in programmable automation there is a separate instruction.

Inspections and commissioning. During and after the prefabrication and the installation the planned inspections and tests are made. The inspections are made by testing companies and inspectors from the inspection office. After the installation of the modification commissioning inspections and tests of the modified systems, components or structures are made. For programmable equipment a backup copy of the software is made before the tests. This backup copy is archived in the central archive together with its version numbers according to a separate instruction.

Test operation. Test operations for plant modifications are made to the extent necessary. The sub-project leader produces the test programme. The test programme is inspected by the operations department and is accepted by the organisation, which was responsible for it. The actual test operation is co-ordinated by the sub-project leader and it is executed by operations. The sub-project leader produces a result report from the test operation. The modification co-ordinator ensures that the result report gets the necessary regulatory approvals.

Documentation changes after the installation. Immediately after the modification the following documents are updated

- red pen versions of process and instrumentation drawings through operations to the main control room if there have been changes during the installation
- electrical drawings as red pen versions to the document series of the control room and electrical and automation maintenance
- accepted changes in the safety technical specifications to the document series of the control room, mechanical, electrical and automation maintenance, and safety and nuclear offices

When all field installations have been made and the data and information has been collected, the modification package is returned to the modification planning office for the finalisation of the documentation.

Changes in other documentation. A part of the modifications in the documentation have been made already before the commissioning of the modification. Other documents are updated as soon as possible after the commissioning, but at the latest one year after the completion of the modification. When the modification package has been returned to the modification planning office, the original documents are redrawn and updated to reflect the actual installation at the plant. After this the documents are distributed for use and archiving. The inspection of the update of the plant design base is done according to a separate instruction. The maintenance instructions are also updated according to a separate instruction. Updates of the final safety analysis report, probabilistic safety assessment, and the safety technical specifications are made and released by the responsible persons. The safety and the nuclear offices are if necessary updating the safety classification document. When these tasks have been completed they are acknowledged in the modification management system. Pre-project plans and implementation plans are archived in the central archive three years as originals after which they are brought to microfiches that are stored for the plant lifetime. The pre-project plan and the implementation plan are also stored in an electronic format.

Closing of the project and final report

When all tasks in the sub-projects have been closed the sub-projects and the modification project are closed in the modification management system. Before closing the modification co-ordinator produces a report on the modification according to a separate instruction. This report contains for example a comparison between the projected and the actual costs of the modification.

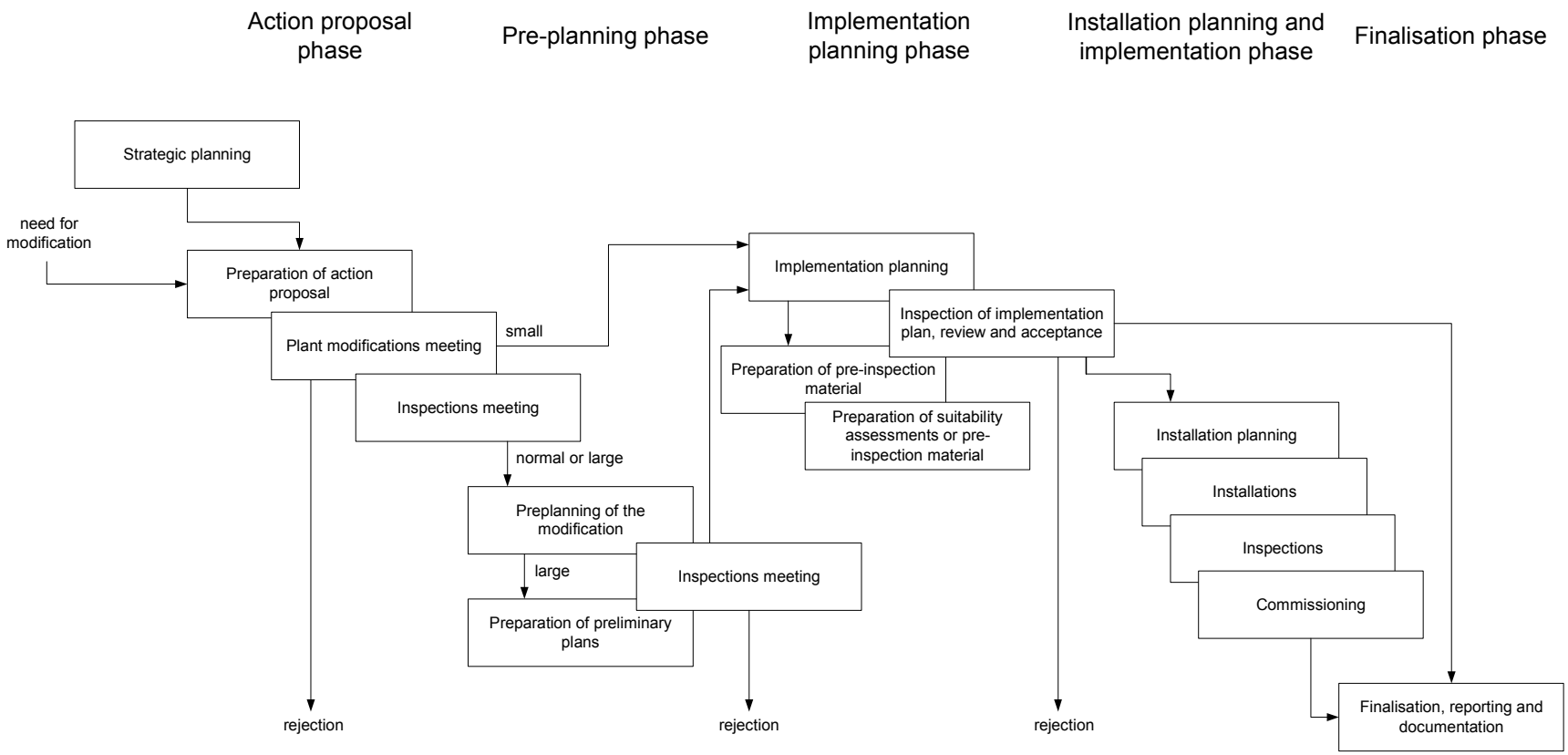
Warranty time follow up

The modification co-ordinator ensures that the tasks specified for the warranty time properly are taken care of. Such tasks are for example warranty inspections, warranty complaints and the release of vendor deposits.

Monitoring the modification process and its development

The development group for plant modifications follows the functioning of the modification process. The group does one yearly assessment of the process, initiates necessary changes and follow their implementation. The performance of the modification process are measured, the results are analysed continuously. Used performance indicators are for example lead-times, quantities, rejection and return percentages, costs and lost production. The modification co-ordination office performs the measurements, analyses them and reports the results.

Enclosure 1. Major phases of the implementation of a plant modification.



APPENDIX 7. ONE EXAMPLE OF INSTRUCTIONS FOR INCORPORATING HUMAN FACTORS IN A MODIFICATION PROCESS

Introduction

This Appendix gives a description of the so called TIGER[8] procedure, which is used by Forsmarks Kraftgrupp AB when modifications are made that influence the human system interfaces (HSI). The procedure is described in an instruction given the number F2-i-300 and the text below is based on the version of the instruction that was ratified at 2002-09-25. The complete instruction consists of 169 pages and it is therefore only summarised to its main parts in this document. The instruction is a handbook, which defines methods that should be used in plant modifications, which influence the working environment of operators in the main or local control rooms. The instruction gives practical advice and support for the analyses, which will form the basis for the design of operator interfaces. The procedure is carried out in six steps comprising of 1) a description of the scope of the modification, 2) a task analysis, 3) a description of the present situation, 4) a suggestion for a new operator interface, 5) verification and assessment of the suggestion, and 6) validation of the plant modification.

To reach cost efficiency it is assumed that the efforts are adapted to the complexity and the HSI influence that the actual modification has. The content of the instruction is based on the application of available norms and standards. The requirements placed on plant modifications are defined in the national Swedish regulation issued by SKI.[9]

The TIGER instruction is divided into the following main chapters:

1. *Procedure for the reviews and development of new ergonomic designs*. The chapter describes the goal of the procedure, quality assurance and acceptance, division of roles and responsibility, the outline of the process, work model, resources and way of working, results, and time schedule and use of time. The chapter includes appendices with one flow chart for the process, one flow chart for criteria to be used, definitions and abbreviations, and ten golden principles.

Ten "golden" principles:
1. Look at the control room to its entirety.
2. Follow a control room philosophy.
3. Think first in functions and only after that in concrete solutions.
4. Use a task analysis.
5. Use ergonomic knowledge.
6. Figure out how others have solved similar problems.
7. Involve operators in the modification work.
8. Do qualitative risk analyses.
9. Be consistent.
10. Pursue simplicity, structure and a logical design.

2. *Initiation of TIGER and definition of scope*. The chapter describes how the scope of the work should be established, how the modification should be described, how the modification should be evaluated, and how the process should be planned including timetable and resources. The chapter includes appendices giving a checklist and a matrix that can be used to support the work carried out.
3. *Identification and selection of tasks*. The chapter is intended to support the identification of tasks that are influenced by the modification and to select those which should be analysed more in detail in later stages of the process.
4. *Description of the present situation*. The chapter is intended to support the creation of written descriptions for how the selected tasks are performed today. It is the goal to create measurable criteria,

[8] TIGER is an acronym formed from the title of the instruction. In the text below TIGER is sometimes used for the instruction and sometimes for the work in carrying out the instruction.

[9] SKI (1998). The Swedish Nuclear Power Inspectorate's Regulations Concerning Safety in Certain Nuclear Facilities, SKIFS 98:1.

which can be used in the verification and validation of the modification. The descriptions will always consist of a task analysis and an error analysis and can, when necessary, contain a link analysis. Necessary forms to support the work are given in three appendices.

5. *Check lists for the HSI design*. In this chapter applicable checklists have been included. The checklists give guidance for the design of operator work stations, computer displays and overview panels.
6. *Verification and evaluation of the suggested HSI design*. This chapter gives guidance for how to verify and evaluate a concrete design suggestion. It goes through the scope, time schedule, goal, methods, criteria, analysis, evaluation, handling of deviations and reporting of this phase of the process. One appendix gives more guidance for the evaluation of new operator tasks and another appendix gives an interview guide with a set of proposed questions to be asked.
7. *Validation of the plant modification*. The chapter gives guidance for the validation of the plant modification in which a more general evaluation is done to ensure that the overall requirements on the main control room, local control rooms, operator stations, work environment, staffing, division of tasks, etc. are fulfilled. This work aims at ensuring that old and new equipment are functioning efficiently tied together. The chapter also give guidance on methods to be used, how the results should be analysed and evaluated, and how possible deviations should be handled. The necessary forms to be used are given in the appendices.
8. *References*. This chapter contains a list of references that have been used in the development of the instruction.

An overview of the procedure

The text below gives an excerpt of the first main chapter of the TIGER instruction. In the general part of the chapter it is noted that the application of the procedure is divided into six steps. These six steps are illustrated in a graphical form in Figure 1. The steps follow closely the general structure of the procedure and are the following:

1. Initiation of the TIGER instruction and determination of the scope.
2. Identification of tasks.
3. The creation of an analysis of the present situation and a task analysis.
4. Analysis and the creation of a HSI suggestion.
5. Verification and evaluation of the HSI suggestion.
6. Validation of the plant modification.

These steps are supposed to be executed in such a way that the steps 1, 2 and 3 are executed before the procurement as a part of the work in developing the specification for the plant modification. The TIGER instruction is basically intended to be carried out when a plant modification has been initiated, but it can as well be used during the pre-project study. The earlier the TIGER process is initiated the easier it is to gain a hearing for the ergonomic principles that is a guarantee that a solution adapted to the operators are found.

The goal for the application of the instruction is to:

- give directions and guidance as to how the phases of a modification process should be carried out;
- ensure that a new or changed operator interface fulfils norms and requirements as well as philosophies that have been approved by FKA;
- ensure that a new or changed operator interface is designed in an optimal way primarily from the users point of view, but also from a safety and maintenance point of view;
- give support to representatives for the purchaser and to the persons in charge in work connected to the modification project;
- co-ordinate the design of the operator interface with training and the development of instructions;
- compile the user requirements on functions and interfaces.

In the quality control and review there are many documents to be produced. Among the documents are the following:

- description of the scope;
- description of the present situation including the task analysis, which includes list of tasks and the information and controls that are used;
- proposal for the new operator interface;
- verification plan;
- verification results;
- validation plan;
- validation results;
- protocols with deviations from the verification and validation;
- meeting records and minutes.

One important condition for a successful application of the instruction is that the TIGER process is initiated in good time. In addition the purchaser of the modification project is responsible for ensuring that competent personnel are available. A third requirement is that there is a good co-operation between the purchaser and the supplier of the modification project, which includes clearly expressed roles and responsibilities. This is arranged through the following principles:

- the TIGER instruction is a tool to be used in the modification process;
- the purchaser is responsible for the execution of the TIGER activities;
- before a formal order can be made to the project it is required that the steps 1, 2 and 3 have been executed and that a report has been enclosed to the specification;
- all reporting initiated through TIGER is made to the purchaser.

Initiation of TIGER and determination of the scope (step 1)

In the preparation of the proposal the purchaser will in consultation with the HSI-group[10] make an assessment whether or not to initiate TIGER. The criteria to be used are described in the Figure 2. If TIGER is initiated the purchaser is responsible for ensuring that the necessary resources are created. The work according to the instruction is managed by one uniting person, who is pushing the work and is responsible for its timely execution. The TIGER-group following the execution of the instruction should include at least the project manager, a representative for the purchaser, at least two operators, a HSI expert, maintenance persons, and system specialists. The composition of the group is resolved on a case by case basis.

At the project start the scope of the application of TIGER should be decided. Guidance for this decision can be found in the instruction. One important part in defining the scope is to perform a functional, a problem and a goal analysis with the aid of checklists. The scope is determined by the scope of the plant modification, its safety influence, the influence on operator tasks, as well as the influences on safety and economy of the plant. In this work resources are allocated for each of the activities within the process. When the time schedule for the work is developed the development of instructions and training programmes are also scheduled.

In the description of the scope resources are allocated for each activity in TIGER together with the establishment of a time schedule for TIGER. In this stage the development of instructions and training is also planned.

[10] A HSI group exists at each of the units. It is a standing group that handles HSI-matters. A TIGER-group is formed when the TIGER is applied on larger modifications.

Identification of tasks (step 2)

The identification of the tasks provides the basis for all subsequent work, i.e. a description of the present situation, development of a new HSI, development of instructions, operator training, verification and validation. The intention is that all tasks that are judged to be influenced are identified. This applies both to existing and new tasks. Then a selection of tasks is made that are assessed with respect to their influence of the new operator interface. A comprehensive analysis of these selected tasks is done when the description of the present situation is created.

The creation of an analysis of the present situation and a task analysis (step 3)

Before the description of the present situation is created an information and control analysis is performed. The analysis establishes the information and the controls that are used in the present HSI and how the information is presented. This analysis should be done when a change of HSI type is planned, such as e.g. when a transfer from control boards to computer screens will be made. This analysis provides the basis when a new HSI is designed. The result is one part of the description of the present situation.

In this phase an analysis is created of the documentation for how, where and when the task is done presently. In this stage a set of criteria should be determined for how the task is performed. These criteria are important when the final validation of the plant modification is done. Examples of such criteria are the difficulty of the task, how near to limit values the task is, the number of errors and mistakes that has been done.

In the description of the present situation a task and error analysis is also carried out. This analysis provides information on operational experience, weaknesses and strengths in the system, barriers that prevent errors, and consequences of errors. The description of the present situation is used for evaluation and verification of a new HSI.

The goal with the analysis is to be able to document the existing HSI and how the task is performed presently. Furthermore it aims at constructing new requirements on functions, HSI and barriers. The results from the analysis of the present situation are used as a basis for the design of a new HSI and it is documented in a report. To ensure the full impact of the review, i.e. to be able to prove that the change has been efficient it is advisable to use the same tasks for the description of the present situation, the verification and the validation.

When the description of the present situation has been created and evaluation of the need for a revision of the scope of TIGER is evaluated. This may e.g. be the case when the scope of the plant modification has changed.

Analysis and the creation of a HSI suggestion (step 4)

The work in TIGER step 4 is supposed to generate one or several proposals for a new HSI (displays/boards/panels). The description of the present situation is used as a basis, but also the information and control analysis when applicable.

Firstly the need for information and control is analysed for each task. If the new HSI is to be realised using displays, this will be done using the checklist for display design. In this phase the main task is to define what kind of information and control the operator will need in order to carry out his task. In addition suggestions are given for how the information should be displayed, e.g. meters, analogue values or digital values.

It may be necessary to go through this phase several times during the design of a new HSI. The work should be carried out in close co-operation with the modification project to ensure that the best possible solutions are reached. One or several comparative task analyses can be used to evaluate the suggestions.

After this the information is compiled using a selected format per display (board/panel). In this phase the first drafts of displays/layout are also made. If the HSI suggestion implies that new displays should be created, these should be incorporated in a display hierarchy. The purpose, the field of application and connections in the display hierarchy is described in a display form. The HSI suggestion is documented according to forms and the basis given in the display checklist.

The goal is to optimise the content of displays and boards to carry out several tasks from the same display/board/panel. One task should be possible to carry out with a maximum of two displays using two display units.

The HSI suggestion is reviewed by the TIGER-group following the execution of the instruction and is then given to the design team. In the case of displays a functional description is prepared, which is used by the project to design the displays.

To evaluate the HSI suggestion the same methods are used as for the description of the present situation and for the verification. To analyse and design a new HSI there is a need for a test environment, e.g. a full scope simulation, the main control room, or an operator station. This evaluation may be carried out several times, especially in connection with large modifications.

The final proposal from a vendor should be evaluated using the same method.

An optimal development process of a new operator interface occurs in close co-operation with the modification project.

Verification and evaluation of the HSI suggestion (step 5)

In the step five the first task is to create a verification plan, which describes how, when and where the verification should be carried out. The plan should contain the following parts, goals, conditions, methodology, realisation, and data analysis. The instruction is used for the compilation of the plan. Here the tasks or scenarios are selected, which will form the basis for the verification. The selection should represent tasks or scenarios that are difficult to carry out, have a large safety influence or can have a large economic influence.

The verification should demonstrate that the operator tasks can be carried out in the expected way and that the intended functionality for the modification is achieved. The verification can give suggestions for changes and can even be used to select the HSI suggestion if there are several (this selection should however normally have been done in the step earlier). In addition the draft instruction should be verified in this connection. The verification of the HSI suggestion should be co-ordinated with the contractually defined tests (FAT) that are carried out.

The TIGER-group is working until the step four and the resources can after that be exchanged depending on the team that has been designing the operator interface. If the design of the interface is done within the TIGER-group, the verification should be carried out by other persons or the verification group should be supplemented by some independent person (e.g. a HSI/MTO expert or an operator previously not involved in the project) who have not been involved in the design. The aim with the verification is to decide if the equipment meets the specified requirements and composition. If the operator interface is designed by a vendor, the verification should be carried out by the operators in the TIGER group.

The verification can be done in a simulator, a testing environment, operator's station or as an expert judgement in small and simple modifications that are assessed to have minor safety influence. The requirement on environment and scope is decided when the scope of TIGER is decided on. The results are documented in a verification report.

One follow up meeting is arranged between the purchaser and the modification project when the verification results have been presented. This meeting takes a stand on possible measures on deficiencies in the plant modification that have been found in the verification. The decisions at the meeting are documented.

Validation of the plant modification (step 6)

The validation can be carried out before or after the installation in the plant. A large modification, which implies a reconstruction of the simulator, should be validated before the operator training is carried out in the simulator.

Large and extensive modifications should be introduced in the full-scope simulator and should thus also be validated in the simulator. This will be done before the installation in the plant. If there are no possibilities for a validation beforehand and in the simulator environment, then a validation may be done in the control room when the installation has been carried out.

A validation plan is developed, which describes how, when and where the validation should be carried out. In the plan goals, conditions, methodology, realisation, data analysis, follow up and reporting are documented. Here additions and changes in the tasks can be done based on experience from the verification.

The validation should clarify that the modification interacts satisfactory with other systems and functions. The validation should always be carried out with other operators than those involved in the earlier work. In addition it is possible to call on external experts to get an optimal evaluation of the plant modification.

The validation should demonstrate that the plant modification fulfils requirements on functions, performance and operator interfaces. More specifically, it is the process to decide on if the physical and organisational design for operation is adapted to support a more efficient handling of functions for the control room personnel. The results are documented in a validation report.

A follow up meeting is arranged between the purchaser and the modification project when the validation results have been presented. This meeting takes a stand on possible measures on deficiencies in the plant modification that have been found in the validation. The decisions at the meeting are presented in a record.

Additional steps

The following steps are not a part of the execution of the instruction, but they should be carried out in close co-operation with the modification project to ensure an optimal implementation.

The operator training can be carried out by the plant or they could be acquired by an external supplier. In the case an external supplier is used, this applies only for the initial training. The basis for the training is the tasks the operators do. If a supplier is supposed to produce and carry out the training it is important to have a specified purchasing process and a close co-operation.

If the plant takes the responsibility for the training, the supplier should train the intended instructors.

The task analysis and the description of the present situation are used to derive tasks, which later on can be used to write instructions. Depending on how the order is laid out, this can either be handled internally or through forwarding a basis material to the supplier, who creates a proposal for an instruction.

The instructions are developed within the plant according to written practices. The task analysis provides the basis.

The present instruction material is given to the supplier together with the task analysis. The draft instructions are used to verify the HSI proposals, which give a verification of the instructions. The instructions are revised when necessary. The operator training is carried out with these instructions. After possible changes the instructions are finally ratified.

Resources and way of working

The TIGER-group should consist of the TIGER co-ordinator, project manager, purchaser representative, and two operators. In addition the croup is when necessary amended with HSI/MTO experts, maintenance persons and systems specialists. The composition of the group is determined when the work is started and the scope of the work is determined. To ensure an efficient realisation of the TIGER instruction a TIGER co-ordinator is appointed with the following tasks:

- co-ordinate the steps in the TIGER instruction;
- ensure that the purchaser and the project manager gets the information and are participating in the work in the extent necessary:
- report to the purchaser and the project manager;
- document the work in the execution of the TIGER instruction;
- train and inform the personnel concerned about the TIGER instruction and how it is used.

The TIGER-group works up to and including step four. After that a change in the resources can be initiated depending on who is responsible for the design of the operator interface. If the verification of the operators interface is carried out within TIGER, the verification should be performed by other persons independent from the initial TIGER-group (e.g. a HSI/MTO expert or a new operators) who has not been involved in the design. This is to ensure an independent verification. The aim with the verification is to decide on if the equipment meets the specified requirements and the composition of the verification group should be optimal from this point of view. If the design of the operator interface is done by the supplier, then the validation is carried out by the operators in the TIGER-group.

The step six in TIGER, the validation should however always be done by other operators than those, who have been involved in the TIGER work. For the verification and validation it is possible to appoint additional resources depending on the scope of the plant modification. If e.g. alarm functions are going to be changed it is important to involve someone with a deep experience in this field. However it is important that the same "experts" are not doing the design and the review of the system.

The work in the TIGER-group is planned when the scope of the application is determined. In this connection tasks are allocated, resources are reserved and the time schedule is established. The work in connection with the TIGER instruction can be divided into working and follow-up meetings. In the working meetings it is not necessary that the whole TIGER-group is present. This may be the case e.g. at the task analysis and the analysis of information needs. At the follow-up meetings it is important that both the purchaser and the project manager are informed on the progress.

Results

The results from the TIGER work are documented in reports and on follow-up meetings where both the purchaser and the project manager are present. All meetings are recorded and the minutes are distributed to all persons concerned. The following reports are produced:

- identification of tasks;
- the scope of the TIGER work;
- the description of the present situation;
- HSI proposal;
- verification plan;
- verification;
- validation plan;
- validation results;
- follow-up meeting.

Time schedule, use of time

The time schedule for the TIGER work should be integrated with the plan for the plant modification project. Major plant modification should be started 2,5 to 3 years before the implementation. The task that determines the time schedule is the HSI design and the training of the operators which takes place about half a year before the implementation of the plant modification.

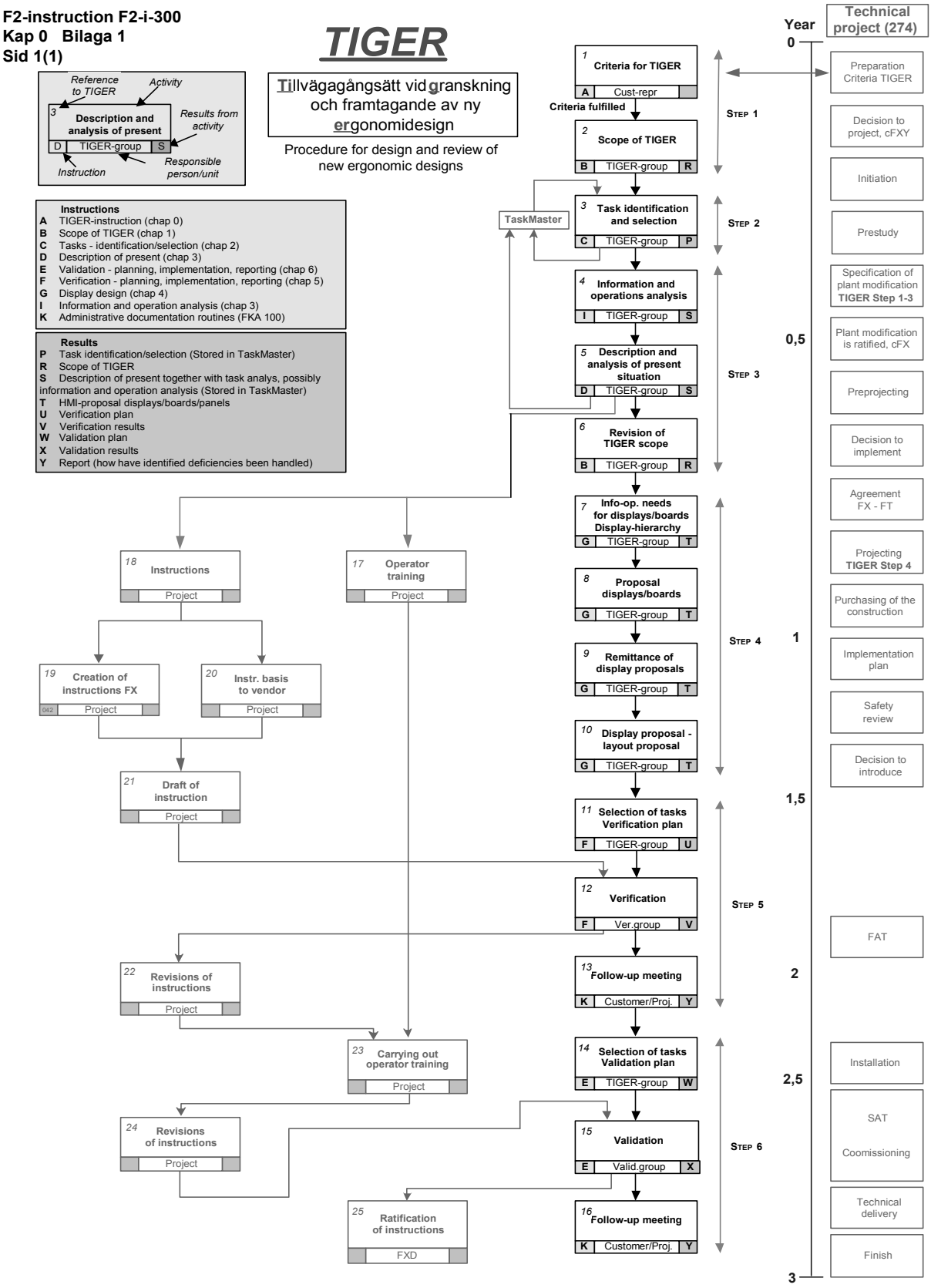


Figure 1. The six steps in the TIGER instruction in a graphical form

APPENDIX 8

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MODIFICATIONS AT NUCLEAR POWER PLANTS - INTERNATIONAL VIEWS ABOUT THE ROLE OF HUMAN FACTORS

H. McRobbie[1], D. Tasset[2], P. Pyy[3], A. Frischknecht[4]

All authors are members of the NEA Committee on the Safety of Nuclear Installations (CSNI)
Special Experts Group on Human and Organisational Factors (SEGHOF)

[1] Canadian Nuclear Safety Commission (CNSC), Canada, mcrobbieh@cnsc-ccsn.gc.ca
[2] Institut de radioprotection et de sûreté nucléaire (IRSN), France, daniel.tasset@irsn.fr
[3] OECD Nuclear Energy Agency (NEA) , France, Pekka.PYY@oecd.org
[4] Swiss Federal Nuclear Safety Inspectorate (HSK), Switzerland, Albert.Frischknecht@hsk.ch

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ABSTRACT

Due to the impact of the human-system interface design on nuclear safety, it is evident that nuclear power plants require a modification process that systematically considers the needs of plant personnel. Although an abundance of information is available about human factors, members of the Nuclear Energy Agency's Special Experts Group on Human and Organisational Factors have observed that designers do not always systematically consider the capabilities and limitations of system users. This paper describes best practices for incorporating human factors into the modification process and concludes by summarizing areas for improvement.

1. INTRODUCTION

During their lifecycle, nuclear power plants (NPPs) undergo engineering modifications that have the potential to impact on safety. These modifications may result from regulatory issues or from internally driven initiatives, such as replacing ageing equipment or improving plant performance. Changes to the plant design that are initiated to resolve technical issues often impact on the operation and maintenance of the station and may present new challenges to plant personnel. Errors resulting from deficiencies in the human-system interface (HSI) design can be a significant contributing factor to NPP incidents and accidents. For this reason, "systematic consideration of the man-machine interface and human factors" in all stages of design is a fundamental principle for ensuring the safety of nuclear installations (IAEA, 1993).

The purpose of this paper is to summarize human factors methods currently in use and best practices for incorporating human factors into the modification process. The paper concludes by providing some recommendations for improvement.

2. SPECIAL EXPERTS GROUP ON HUMAN & ORGANISATIONAL FACTORS

With new information technologies, there is the potential to design powerful HSIs. The Special Expert Group on Human and Organisational Factors (SEGHOF) of the OECD Nuclear Energy Agency (NEA) identified the need to share best practices related to ensuring modifications are designed to accommodate plant personnel. Best practices were shared via a survey in 2002 and a workshop in 2003. Through the survey and workshop, the views of representatives from NPPs, regulators, research facilities, and international organizations from 14 countries were expressed. This paper summarizes the results of the survey and workshop.

3. HUMAN FACTORS METHODS

Humans are both a safety liability and asset, playing a role in the initiation as well as control and mitigation of accidents and incidents. During the design phase, it is possible to make systems less prone to and more tolerant of human errors. The plant design determines the actions and work processes that people must carry out to operate the station. Therefore, the foundation of safe, reliable and meaningful work processes is the design – from the original design of the plant to any design modifications.

Table 1 poses several questions for designers to consider when making modifications that impact on work of operators and maintainers. The design questions need to be answered for each plant state impacted by the modification, whether normal, startup or shutdown, refueling, upset, or emergency. Each design question can be addressed through human factors methods. By following a process that systematically answers the design questions in Table 1, the design should account for the capabilities and limitations of system users.

The human factors methods in Table 1 are described in NUREG 0711, ISO 11064, and IEC 964. Additional information about the human factors methods can be found in the referenced standards and guides. Based on the SEGHOF survey in 2002, these guides and standards are currently in use by human factors professionals.

Table 1: Design questions about system usability and related human factors methods.

Design Questions	Human Factors Methods
With respect to human performance, what has been found with similar designs in this and other stations?	**Operating experience review** identifies lessons learned from past experience. It may include a review of past events, talking to and observing system users, obtaining information about similar designs, and questionnaires to gather feedback systematically.
What functions need to be accomplished and are these best performed by automation or people?	**Function analysis and allocation** systematically identifies functions and allocates them to humans and/or automation, based on the strengths and limitations of each (IEC, 2000; Pulliam, 1983).
What tasks are required to accomplish functions assigned to workers?	**Task analysis** is used to identify task requirements for accomplishing functions allocated to station staff (Kirwan, 1992; Burgy, 1983).
What are potential errors when completing each task and what barriers are required to prevent the errors or improve recovery?	**Human error analysis** and **Human Reliability Analysis** (HRA) identify and evaluate potential human errors that may impact on safe plant operation.
How many people are required to complete these tasks?	**Workload analysis** indicates the impact of the modification on staffing levels (Kirwan, 1992).
What equipment and work environment do people need to complete these tasks?	**Specification of the HSI** required to carry out tasks is based on integrating results from human factors analyses and applying appropriate plant-specific or general human factors design guidance, such as NUREG 0700 (US NRC, 2002).
Can system users successfully use equipment to complete their tasks?	**Human Factors Validation** is testing the usability of the design with system users (O'Hara, 1997; IEC, 1995). Validation tests may include talk-throughs of tasks using drawings or mock-ups, walkdowns in the plant, or running through scenarios using a simulator or virtual reality.
Is equipment available so tasks can be completed? Does the design comply with human factors guidelines?	**Human Factors Verification** ensures the equipment provided allows for completion of tasks, and the design complies with human factors guidelines and is installed as specified (O'Hara, 1997; IEC, 1995).

Each human factors method may result in recommendations to improve the design. It is important that an issue resolution process exists to ensure recommendations are tracked and dispositioned appropriately.

In addition to being an input for HSI design requirements, human factors methods in Table 1 are relevant for procedure and training development. For example, the task and error analyses are important inputs when developing procedures and training. Any critical or error-likely tasks identified in the human reliability analysis can be flagged to receive added emphasis in procedures and training. Validation scenarios may be designed to identify deficiencies in the design as well as in the procedures. In order for NPP staff to perform optimally, the modification process must ensure all impacted procedures are updated and appropriate training is provided.

Research has shown that a causal factor of accidents in complex systems is misconceptions that designers have about operators (Busby, 2002). Human factors professionals and methods act as an information conduit between designers / engineers and system users. Many human factors analysis techniques, such as gathering operating experience from users or running validation scenarios in a simulator, require design team members to interact with system users, as shown in Figure 1. By following a modification process that incorporates human factors methods, the design is more likely to meet the needs of plant personnel.

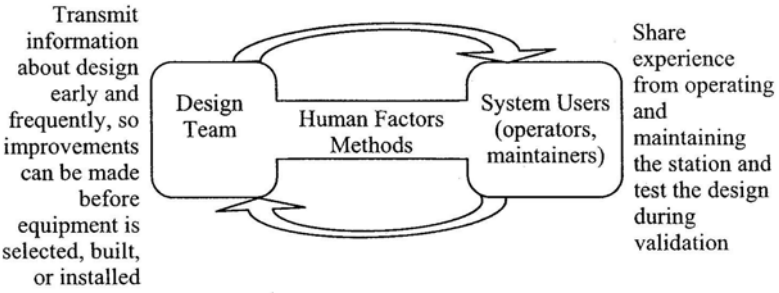

Figure 1: In the model above, design team members transmit information about the proposed design to system users. System users provide input to designers based on their knowledge of the station and through validation testing of the proposed modification. To have the greatest impact, this exchange of information should occur throughout the modification process.

4.0 BEST PRACTICES – HUMAN FACTORS IN THE MODIFICATION PROCESS

Poorly executed modifications of any size may impact on the safe operation of the station. Experience shows that large modifications performed by qualified suppliers lead to fewer events than smaller modifications carried out by plant personnel (Deutschmann, 2003). In the area of human factors, smaller modifications are more likely to be left to designers with limited input from human factors professionals. Regardless of the scope of a design change, NPPs need to have a modification process that ensures user needs are systematically considered when changes impact on tasks to operate, test, or maintain the facility.

4.1 Screening Process

Figure 2 shows a basic screening process that divides modifications into three categories. In order to have different levels of human factors work that are dependent on characteristics of the modification, there must be a clearly defined screening process. Since screening will trigger human factors work, it is important that it is done correctly and early in the modification process.

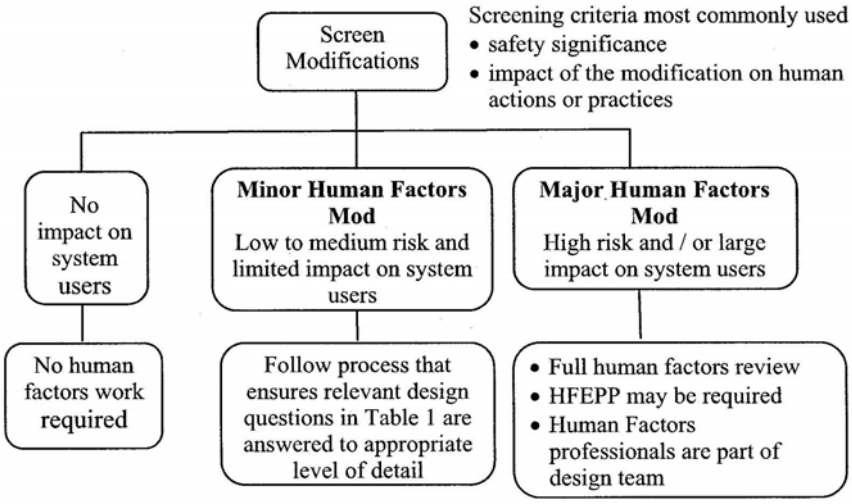

Figure 2: Screening at the outset of the modification process can be used to determine the level of human factors work required to adequately reduce the risk of human error.

To ensure that screening is done correctly, screening team members must be knowledgeable about human error and the safety significance of the modification. In some NPPs, screening to determine the level of human factors effort is done by designers using a checklist that asks questions about important human factors aspects of the modification. In other NPPs, screening is done by multi-disciplinary teams that include staff members knowledgeable about human error and the operation and maintenance of the station. Regardless of who implements the screening process, it is important that clearly defined screening criteria are used.

The criteria most commonly used for screening modifications are safety significance and the impact of the change on tasks required to operate, test, or maintain the station. Examples of factors to consider when determining the impact of the change on tasks are as follows:

- number and complexity of changes to the human-system interface.
- impact of the modification on operator interactions.
- availability of station-specific design guidance that is in a format that engineers can readily apply.

Once the level of human factors effort has been determined, appropriate human factors staff should be involved in the design work early in the project. For example, the potential for human

error should be a consideration when a pre-fabricated or "off-the-shelf" option is selected. Screening to determine the level of human factors effort may be useful for other groups involved with human performance, such as procedure development and training (Kozak, 2003).

Maintenance tasks frequently contribute to events. In order to reduce the risk of error in maintenance, changes impacting on maintainability and testability should be screened and subjected to the same rigour of human factors analysis as changes to operations tasks.

4.2 Major Human Factors Modifications

For safety significant modifications that substantially impact on tasks performed by station staff, it is clear that a full human factors review is required that uses all of the human factors methods in Table 1. Examples of such changes are adding a new trip parameter or a new control panel. Due to the scope of human factors work for major modifications, a Human Factors Engineering Program Plan (HFEPP) is a useful planning tool. Human factors professionals are an important part of the design team for major modifications due to their ability to collect and integrate information from multiple human factors methods.

4.3 Minor Human Factors Modifications

In a NPP that makes many modifications with varying impacts on system users and risk yearly, every modification is unlikely to require a full human factors review. NPPs need to have a process in place to ensure design questions in Table 1 are answered to an appropriate level of detail for minor human factors modifications. Common features of processes used for minor human factors modifications include the following:

- Design teams are smaller and may not include human factors professionals. Therefore, there is more reliance on designers to apply human factors methods.
- Expectations for human factors analysis work for minor modifications must be clearly defined, especially if it will be done by designers with limited expertise in human factors.
- NPPs need to have a training program for design staff about minimizing human error through application of human factors methods. This training program should include the designer's role in applying human factors aspects of the NPP's modification process.
- Some stations have additional criteria for involving a human factors professional, such as availability of station-specific design guidance which is directly applicable to the modification.
- Some NPPs use forms or questionnaires to guide design team members to pertinent issues when minor modifications are made. For example, a form can prompt the designer to carry out the following key reviews:
  - Operating experience review
  - Analysis of tasks and errors which may arise during each task
  - Use of plant-specific design guides
  - Validation of the design

4.4 Performance Monitoring

Once a modification is installed, performance needs to be monitored to track possible impacts of the change on human performance. It is also essential that NPPs have internal audit and self-assessment processes to ensure that the modification process is followed and the modified systems are usable. The cumulative impact of several minor modifications on human performance must also be evaluated periodically.

4.5 Contracting Out Modification Projects

Even when modification work is contracted out, the NPP remains responsible for the safe installation and integration of the modification in the station. When design work is contracted out, NPPs need to ensure that contractors have suitably qualified and experienced human factors staff or provisions for obtaining appropriate human factors expertise. In addition to delivery of the technical system, expectations for incorporating user and human factors input in the modification should be specifically identified as a condition of the modification contract. NPPs also need to verify that the contractor is carrying out the human factors work that was specified in the contract. In order to set expectations and review the work of contractors, NPPs need "intelligent customer capability" in the area of human factors. The human factors capability required to act as an "intelligent customer" must be defined.

5.0 BEST PRACTICES - REGULATOR'S ROLE

Several countries have documented regulatory expectations requiring consideration of human performance when the plant design is modified (UK NII, Finnish STUK, Swedish NPI, German BMU, Canadian NSC). In order to ensure licensee ownership, regulators expect NPPs to set out and follow their own modification process. Most regulators have adopted a process-based approach, in which they ensure that NPPs have an acceptable modification process that systematically considers the needs of system users when engineering changes are planned and executed. Along with ensuring the modification process of NPPs incorporates human factors, regulators must ensure that the process is followed. Implementation of the NPP's modification process is evaluated through approval of individual design changes and audits of the modification process. Audits of human factors aspects of modifications are often part of broader quality management evaluations. Regulators also expect NPPs to have a review process to ensure modifications are adequately reviewed prior to submitting them for regulatory approval.

6.0 BENEFITS AND COSTS

The end result of human factors analysis work is a design that meets the needs of system users; such a design has the following benefits (Kozak, 2003; Miberg Skjerve, 2003; Gregson, 2003):

- Reduced human error by operators and maintainers leading to improved profitability and safety.
- Satisfied users (e.g. operators, maintainers).
- Greater likelihood that the design will meet the needs of users.
- Increased likelihood that the system will be used as was intended by the designer.

A benefit of human factors validation testing is it provides quantitative measurements of aspects of human performance, such as time to complete tasks, goal fulfilment, situation awareness, and trust (Miberg Skjerve, 2003). Human factors validation testing gives confidence to the NPP and regulator that the modification will not have a negative impact on human performance, and thus, safety.

There are many possible costs if a modification does not consider the needs of system users or if human factors is not considered until late in the process. If human factors is an afterthought added into a contract, there will be increased costs to modify the contract. Human factors costs have been found to comprise 1% of the design budget when considered in early design, but escalate as the design progresses (Hendrick, 2003). A major cost associated with inadequate consideration of

human factors is rework to change the design. Rework costs increase as the design progresses. If design requirements do not support human performance, workers may be left working around flaws in the design, leaving the system more prone to human error. These costs would be avoided by setting an objective of maintaining or improving human performance in any modification projects and demonstrating this through human factors validation testing.

7.0 RECOMMENDATIONS FOR IMPROVEMENT

Along with identifying best practices in modification processes, the survey and workshop identified recommendations for improvement.

7.1 Learning from Modification-Related Events

Root cause analyses are often performed when an error by an operator or maintainer has a negative impact on the station. Event investigation systems include causal factors related to deficiencies in the HSI that contribute to events. However, when a poorly designed HSI leads to an event, most investigations do not determine why the design did not support station staff in performing their tasks. The root causes of failures by designers to provide adequate HSIs need to be determined in order to identify appropriate corrective actions.

- When design inadequacies contribute to an operator or maintainer error, the root cause of the design error needs to be investigated. In addition, the modification history of relevant equipment should be reviewed to determine if deficiencies in the HSI are from the original design or a modification. Any deficiencies in the plant modification process that contributed to the event should be corrected.
- Designers should receive training about the impact of design on human error and subsequent events.

7.2 Demonstrating the Value of Human Factors

Regulation is one way to ensure that human factors is adequately incorporated in the modification process. In order for regulation to be effective, it is important for NPPs to "buy-in" to the importance of human factors. "Buy-in" may come about as NPPs understand the safety and financial benefits of systematically considering the needs of system users. All of the benefits and costs in Section 6.0 have an impact on profitability and safety of a NPP.

- Nuclear stations should share qualitative and quantitative experience about the benefits and costs of adequately or inadequately incorporating human factors into modifications.

7.3 Minor Modifications

When large, safety significant modifications are planned, it is clear that a full human factors review is required. Less guidance is available for incorporating human factors into minor modifications.

- International agencies and regulators should provide guidance on incorporating human factors in minor changes. Guidance is also required for addressing the cumulative impact of several minor modifications on human performance.
- NPPs should share operating experience by distributing models/methods used to deal with minor modifications, including screening criteria.

7.4 Developing a Human Factors Culture Among Designers and Regulators

The design of the plant determines the actions and work processes that people must carry out to operate the station. Designers have the safety-critical work of ensuring that the design supports plant personnel in performing their tasks.

- Modification design teams need to develop a human factors culture. A human factors culture is one in which the usability of modified systems is treated equally with other technical issues. In a design team with a strong human factors culture, designers strive to develop user-centred systems and exhibit a questioning attitude when usability issues are not given a high level of priority. A starting point for developing a human factors culture is having leaders of the station and the design team transmit their expectations about human factors through their policies, procedures, and actions. Actions include ensuring there is appropriate human factors expertise in the design team.
- Safety significant modifications may be reviewed by the regulator. In order to ensure human factors issues are appropriately reviewed, the regulator's modification review team must also develop a human factors culture.

7.5 Improved Communication Between Human Factors Professionals and Designers

In order to develop a human factors culture among designers, a common language between human factors professionals and designers is required. Designers/engineers have raised concerns about the usability of human factors standards and guides. Human factors professionals are working towards improving the usability of human factors guidance; in fact, this was the focus of 4 out of 16 paper presentations at the SEGHOF workshop from the United Kingdom, United States, France and Korea (Gregson, 2003; Naser, 2003; Quentin, 2003; Chung, 2003). One of the presentations discussed collating and structuring a large body of human factors guidance in an electronic tool that is intended to make human factors guidance clear and unambiguous and to identify when to seek professional ergonomics support (Gregson, 2003).

- Human factors professionals and designers must continue working together to develop a common language.
- It is also important for designers to know when the scope of work is beyond their expertise and assistance from a human factors professional is required. A clearly defined screening process should assist designers with determining when to seek assistance.

8.0 CONCLUSIONS

With knowledge that is currently available about human factors and causes of human error, modifications should not leave operators and maintainers working around design deficiencies. Although an abundance of information has been available for many years, SEGHOF members have observed that human factors methods are not always systematically applied during design work. This shortcoming may be remedied by applying practices presented in this paper for incorporating human factors into the modification process. In addition, NPPs and regulators are challenged to develop a human factors culture in NPP design teams and regulatory review teams. Systematic consideration of the tasks of operators and maintainers throughout the design process will lead to improved human performance and reduced error rates.

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REFERENCES

Burgy, D., Lempges, C., Miller, A., Schroeder, L., Van Cott, H., Paramore, B., 1983. Task Analysis of Nuclear Power Plant Control Room Crews, NUREG/CR 3371.

Busby, J. and Hibberd, R., 2002. Mutual misconceptions between designers and operators of hazardous systems. Research in Engineering Design, 13, 132-138.

Canadian Nuclear Safety Commission, 2003. Human Factors Engineering Program Plans, G-276.

Chung, Y., Goo, C. and Cha, W., 2003. Regulatory experience of human factors for operating nuclear power plants, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Deutschmann, H., 2003. The Swiss modification process in nuclear power plants regulatory regime – Regulator/Operator process and experience related to events with safety impact, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Finnish STUK, 1991. General regulations for the safety of nuclear power plants, Feb. 14, 1991/395.

Gesellschaft fuer Reaktorsicherheit (GRS), 1988. Control Room, Emergency Control Room and Local Control Stations in Nuclear Power Plants, KTA 3904.

Gregson, D., Marshall, E., Gait, A. and Hickling, N., 2003. Providing ergonomics guidance to engineers when designing human-machine interfaces for nuclear plant installations, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Hendrick, H., 2003. Determining the cost-benefits of ergonomics projects and factors that lead to their success, Applied Ergonomics, 34, 419-427.

International Atomic Energy Agency, 1993, Safety Fundamentals – The Safety of Nuclear Installations, Safety Series No. 110.

International Electrotechnical Commission (IEC), 1989. Design for Control Rooms of Nuclear Power Plants, IEC 60964.

IEC, 1995. Nuclear Power Plants – Main Control Room – Verification and Validation of Design, IEC 60964.

IEC, 2000. Nuclear Power Plants – Design of Control Rooms – Functional Analysis and Assignment, IEC 61839.

International Standards Organization (ISO), 2000. Ergonomic design of control centres, ISO 11064.

Kirwan, B., Ainsworth, L., 1992. Guide to Task Analysis, Taylor and Francis, London.

Kozak, A. and Malcolm, J.S., 2003. Integration of human factors engineering into the refurbishment of a multi-unit CANDU station, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Miberg Skjerve, A. and Skraaning, G., 2003. A classification of validation criteria for new operational design concepts in nuclear process control, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Naser, J., Hanes, L., O'Hara, J., Fink, R., Hill, D. and Morris, G., 2003. Guidelines for control room modernization as part of instrument and control modernization programs, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

O'Hara, J., Higgins, J., Persensky, J., Bongarra, J., 2002. Human Factors Engineering Program Review Model, United States Nuclear Regulatory Commission Report, NUREG 0711.

O'Hara, J., Stubler, W., Higgins, J. and Brown, W., 1997. Integrated System Validation: Methodology and Review Criteria, NUREG/CR-6393.

Pulliam, R., Price, H., Bongarra, J., Sawyer, C., Kisner, R., 1983. A Methodology for Allocation of Nuclear Power Plant Control Functions of Human and Automated Control, NUREG/CR 3331.

Quentin, L. and Niger, D., 2003. Taking into account of socio-organisational and human aspects into upgrade packages, NEA/CSNI Workshop on Modifications at Nuclear Power Plants, October 6-8, 2003, Proceedings to be published.

Swedish Nuclear Power Inspectorate, 1998. Regulations concerning safety in certain nuclear facilities with General Recommendations concerning the application of the Swedish Nuclear Power Inspectorate's Regulations, SKIFS 1998:1.

United Kingdom Nuclear Installations Inspectorate, 1992. Safety Assessment Principles.

US Nuclear Regulatory Commission, 2002. Human-System Interface Design Review Guideline, NUREG 0700.