NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Principal Working Group 1 on Operating Experience and Human Factors

APPROACHES TO THE INTEGRATION OF HUMAN FACTORS INTO THE UPGRADING AND REFURBISHMENT OF CONTROL ROOMS

WORKSHOP PROCEEDINGS

Halden, Norway, 23-25 August 1999

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1. BACKGROUND

During the 23rd-25th August, 1999, under the auspices of Principal Working Group 1 (PWG1) on Operating Experience and Human Factors, the Committee on the Safety of the Nuclear Installations (CNSI), and the OECD Nuclear Energy Agency (NEA), a Workshop/Specialists meeting was held dealing with “Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms.” The meeting was organised in co-operation with IAEA, and was hosted by the Halden Reactor Project, Norway.
2. INTRODUCTION

A modern approach to control room design, be it for upgrading or complete refurbishment, requires the integration of many disciplines and approaches. The integration of human factors into such a process continues to present challenges. How such a process should be conceived, planned, and carried out is of considerable interest to designers, operators and regulators.

Many NPPs around the world have been, or will be faced with decisions concerning modernisation of their control rooms. Such changes can be driven by a range of issues including; the need to replace outdated control and instrumentation systems; increasing regulatory concern about human performance; or the need to provide a better process control environment for NPPs whose life cycles extend beyond that originally intended. Considering the importance of operator performance for safe and profitable operations, a process for ensuring that human factors issues are properly addressed could be central to the success or failure of such a project. Human factors is of particular importance when a combination of existing and new systems are to be used, resulting in a so-called ‘hybrid’ control room.

The workshop addressed this topical area by providing a forum where a number of important areas could be discussed and experiences and lessons shared. Topics identified before hand as important and worthy of discussion included:

- Exploration of how human factors issues can be identified.
- Consideration of those processes and techniques necessary to ensure that appropriate requirements are specified, and that suitable data is gathered and analysed.
- Identification and discussion of issues related to the above topics together with lessons from utilities, vendors and regulators which have faced, or are currently facing, these challenges.

The meeting itself focused on the state of knowledge and current best practices within these areas and provided a forum for the open discussion of the human factors issues, as seen by a broad range of interested parties, in relation to the upgrading and refurbishing of control rooms. The workshop attracted 16 contributions from 13 different countries and provided a range of insights and lessons based on design experience, practical experience, research and regulatory needs, and an opportunity for the exchange of experiences and approaches on a range of important topics. The workshop also sought to identify and prioritise areas meriting further consideration and research.
The 34 participants shared their experiences and perceptions on a broad number of aspects including:

- The identification of human factors issues from the utility, vendor, and regulatory perspectives.
- Ensuring the inclusion and implementation of human factors issues within the upgrade or refurbishment process.
- How this change process should be managed.
- Feedback from practical experience and real concerns.
- Meeting modern human factors requirements.

These proceedings document the papers presented at the workshop, the result of the group work conducted during the meeting, and concludes with a summary of the conclusions and recommendations from the workshop.

The members of the Programme Committee were: Mr. R. Montmayeul (EdF), Mr. J. Wachtel (US NRC), Mr. M. Green (HRP), Mr. D. Tasset (IPSN), Dr. W. Fassmann (GRS), Mr. B. Fitzpatrick (WANO), Dr. M. Dusic (IAEA) and Mr. L. Carlsson (NEA). The committee would like to express its thanks for the valuable support provided both before and during the workshop by Elisabeth Mauny from the NEA and to Marit Larson from the Halden Reactor Project.
3. SUMMARY OF GROUP DISCUSSIONS

The Basic issues, themes and questions to be discussed in the group work were as follows:

- What has been achieved so far, e.g., experiences, design principles, lessons, and findings, that we can rely on and apply successfully?
  - What issues were they trying to address?
  - What problems were they trying to solve?
  - What difficulties were identified, or were overcome?
  - What lessons have been learned from the project that might be useful to others?
  - What knowledge/information have they gained that means certain research need not be repeated by others?
  - How might the human factors aspects differ for existing plants/upgrades as opposed to new designs?

- What aspects are missing?
  - What do they still not know that requires more research, discussion, assessment, or better tools?

- Which aspects should be investigated in future research, to efficiently support regulatory authorities, utilities, designers and expert organisations?
  - What are the most important human factors issues in this area facing your plant(s) in your country over the next several years?

- How can we structure future practically orientated activities in the area? Indicate a priority.
  - What unique issues are faced in conducting such human factors studies within the nuclear environment?
  - Where should human factors research and testing be focused in the foreseeable future?

- What conclusions do you draw from the papers presented in this area?

3.1 Discussions presented by Group 1

- The main areas for discussion in group 1, were:
  - Need for human factors programme from the start.
  - Use of operator and other input.
  - Test and evaluation important.
While common human factors programme activities have been identified, tools to support designers and evaluators to perform activities are needed. Tools should help tailor available information to projects. Example presented at the workshop include,

- HIBISCUS
- DIMS (design issue management system)
- NREAL

One cannot consider one human system interaction resource or system as independent from the total human system interaction, the procedures and training. It is important that design changes are considered in relation to each other.

Upgrades can enhance or detract from human performance. The impact of changes on crews and crew performance need to be carefully assessed and addressed in upgrade projects.

- Use operational experience and knowledge about technology.
- Look for broader impact of the technology itself.
- Good human factors can help realise the benefits.

We tend to take a “top-down” view, but we also need the “bottom-up” view. The ‘bottom-up’ approach has many merits and should not be neglected.

The benefits and drawbacks for digital verses conventional systems should be carefully considered. Conventional systems have served well and have benefits which should not be overlooked. Benefits include: considerable operating experience; meet needs of the operators; match the characteristics of the plant, age; cost; maintainability.

Plants change continuously. The upgrade must include design for change and maintainability – as change will occur so must the design. Maintain configuration management. Computers are replaced, e.g. we don’t want a new system depending on a computer system that may be replaced in 3-4 years.

It is important to have the ability to monitor the health of new support systems. Is the computerised process system doing what it is supposed to do? There is a need for health and performance monitoring of the system itself.

What has been achieved so far?

- There has been a convergence of human factors methods in recent years leading to roughly similar processes which consider similar analyses as important.
- It is important that the human factors programme must be adapted to the size and scope of the upgrade project.
- The human factors programme should be part of the design process from the early stages of the design to be most effective.
- It is important that the justification for the change should be clearly understood, i.e., why is the modernisation being performed.
- Plant changes are often continuous and can result in diverse control room systems if not attended to.
- A clear concept of operations is needed to structure the upgrade processes and ensure continuity of operations as changes are introduced into the control room.
• The upgrade should be analysed for impact on test and maintenance as well as operations (especially software).
• Obtaining operations input is an important aspect of design and should be obtained from the start.
• Analysis of operating experience is important in designing upgrades - fix what is bad, not what is good.
• Test, evaluation, and V&V are essential and are best when performed throughout the design process to detect and resolve issues as early as possible.

➤ Validation considerations.

• Greater standardisation has been observed.
• Validation methods need to be tailored by the scope of the upgrade.
• Validation methodology is an issue needing careful consideration.
• Validation is different from verification and can be a large effort.
• Validation needs to consider realistic operation conditions.

➤ What needs to be done/missing

• While the importance of operator input is recognised, how and where to best incorporate operator input needs to be explored.
• Methods to account in design for varying psychological states known to be associated with human error, such as stress, are needed.
• Methods to justify human factors activities as cost effective are needed.
• Methods to link control room upgrades with PSA/human error for safety impact analysis are needed.

3.2 Discussions presented by Group 2

➤ What has been achieved so far?

Methods for H.F. input in design / upgrades:
• Guidelines (all sorts of them!)
• Including operators in design process
  • Lego control room mock-ups
  • Discussion
  • SW techniques, VR methods
• Realise the subjective nature of individual operator input + attempt to gather diverse data
• Validation techniques
Recognition of common issues
- Difference between upgrades + new designs
- Need for diverse, broad-spectrum approach
- Need to determine priorities – where do we devote our efforts
- Need for cost / benefit – bottom line value
- Need for V&V throughout the process rather than at the end (early, while you can do something)

Advanced technology – issues:
- Affects teams
- Navigation – keyhole effect (hiding info)
- Advantages for human performance
  - identify if there are
  - what they are
  - what would need improving?
- Configuration control

In the nuclear industry there is a trend towards more upgrades, fewer new designs, going towards computerised control rooms
- alarm reduction
- info hierarchies, graphic displays
- computerised displays (rather than tiles)
- soft controls
- computerised procedures
- COSSs
- crew sizes
- cockpit workstations
- large screen overview

Potential benefits
- ↓ WL
- ↑ Integrated info (not data)
- ↑ Configuration control
- ↑ Flexibility
- ↑ Integration of systems (unified interface)
Potential problems to investigate

- Measures of effectiveness / complexity
- Information overload
- Keyhole effect / secondary tasks
- Time delay + “fly by wire” issues
- Sufficient display area
- Effects on team performance / co-ordination, communication
- Poor integration

What is missing/ what needs to be done?

- “State of the art” appears to vary in countries with respect to advanced vs. conventional upgrades, use of guidelines and recognising the value of human factors. A standardisation process would be of great value.
- There is a need to share information on common issues regarding:
  - quantifying human factor value
  - showing cost benefits
  - need for clear criteria to evaluate upgrades

Help on using the guidelines

Guidance needed on /for:

- making trade-offs (in design, in H.F. input)
- applying guidelines
- designers
  - to make usable interfaces, control rooms, procedures, alarm systems
- regulators
  - so they can evaluate designs / upgrades using consistent, objective criteria

Need criteria

- to determine if a design / upgrade is “good enough”
- benchmarking
- identifying relevant performance criteria
- establishing standards of acceptability

Need more consideration of team performance

- operators work in teams
- experience shows that advanced plants change the ways team interact
- need to evaluate / characterise team interaction
3.3 Discussions presented by Group 3

- **What have been achieved so far?**
  - **Guidelines**
    - There are many guidelines, standards, references which are useful for design and for safety review. It is possible to consider this kind of document as a minimal set of requirement, some kind of frame used by the safety authority to examine the design process. For example, such a document (NUREG-711) has been used by IPSN for analysing the design of the MMI of the European Pressurized Reactor (EPR).
  - **Economical aspects**
    - Presentation of Borselee plant upgrade include some way to quantify aspects of costs and benefits of human factors integration in the process. It is a promising issue, which should be important to develop in further research.
  - **Share experience**
    - V&V process: discussion about research versus practical aspects of this process. Experience of Borssele plant upgrade seems very practical. In industrial programs, there are very much constraints (schedule, cost, availability of people, simulators, etc.) that are not so strong in research programs.

- **What aspects are missing?**
  - **Guidelines**
    - Application of NUREG needs some adaptation. It is impossible to follow every detail. It is only some general frame to help the design.
    - Design and review guidelines should have to be distinguished.
    - Need more requirements for designers.
    - How to use the kind of tools provided (standards, validation tools, handbooks, etc.) in the design process. Standardisation can provide some more consistency between plants.
  - **Economical aspects**
    - The economical factors related to HFE: can we better show cost-benefit when integrating human factors into the design process - both for hybrid CRs and total modernisation’s.
    - In quantification of costs/benefits: to take into account the entire system and plant, not only the control room.
  - **Share experience**
    - Need to share experience on difficulties we have in human factor projects.
    - Need more practical and experimental data.
    - Need good examples of success stories and things we could learn. We spend a lot of money and resources developing things, but not enough on post-hoc evaluation.
    - Continue the discussion/share more applied experiences – go into more detail. How to apply experience/information we all have in future work. Possibility of a future internet connection between people at this workshop and others interested.
Holistic perspective
• Important to consider the entire environment - not only the installation but also the operational area in the control room, training, maintenance, local stations, etc.
• What also is missing is studying the interaction and communication aspects in the control room, and the role of team members in them.

Discussions presented by Group 4

Two main areas were discussed:
• The design process with the question of the integration of Human Factors (HF) in this process, and,
• The design product with the question on how to provide a good design and what kind of information we need.

The design process

• The methods for the integration of HF in the design process are based on a structured approach; they are now well known. They need to mix top down and bottom up approaches.

• Major changes such as change in alarm systems did not come from operators needs but were imposed by technology changes. This led to HF problems due to late implication of operation personnel, maintenance personnel, HF specialists, regulatory bodies, and other interested parties.

• The group came to the conclusion that it is needed to emphasise the as early as possible participation of all the end users in the design process in order to base requirements on real users’ needs. Also the design team should be interdisciplinary and the development team should have sufficient experience.

• Managers should be made aware of the proper approaches, and rules for applying them should be established clearly at the beginning of the project.

• Everybody speaks of HF but it is difficult to understand what it includes. It is also difficult to talk with HF specialists who have their own language. If application progress is to be made, HF should be made easier to understand by plant personnel and managers. In addition HF specialist should also have operational experience.

• There is not a unique HF approach and HF approaches have to be considered broadly since there is not a unique solution to a design problem. Anyway new designs should always be assessed and operation feedback collected to serve as a basis for improvements.

The design product

• The question here is more on how to do the job of designing, how to make a good design. There is a lot of knowledge you need to get in order to design; among them standards, bad stories of designs that failed, experience return of previous designs, guidelines, and other more dedicated data as operators population profile, company operation and cultural habits, etc.

• A certain guidance is needed there on issues, questions to ask, what you should do and not do.
• A lot is known but information is scattered among various guidelines or other information sources. An effort should be made to put information together in a systematic way and to guide on how to use it (information can be context dependant). Exchange of experience is also deeply needed, as control room upgrade or refurbishment experience is still rare.

• An important point is to be able to measure and if possible quantify the benefit of implementing a change in terms of cost and benefit.

• Upgrading is not replacing but there can be overlapping. It is a complex process as it can be done in many different ways. Major HF problems or factors influencing the process have to be taken into account. The operating philosophy should be kept consistent particularly as the level of information and automation are concerned but you have also to take advantage of the potential of the computer system to provide new information.

• There are two ways to consider the design: either to start from technology, or to start from the cognitive and social aspects. Unfortunately upgrading is more often technology driven than HF driven and this leads to problems. One of the problems is that computerised new systems tend to cover normal operation which operators know well already, and much less disturbed operation where operators would like to have support. Side effects of a new system are often overlooked by designers and the impact of the new system on the whole work system has to be considered (not only for operation tasks but also maintenance tasks, testing tasks, etc.).

• The main issue is that operators can rely on the system; it can be able to detect malfunctions and have back up. Technology is mature enough to provide good systems.

• How to license a computerised system is still an issue. There are too many standards. The regulator has his own view and the industry (which progresses) has another one. Discussions of both parties are strongly needed to define a licensing process. It is really needed to consider the regulatory issues at the beginning of a project.

➢ Future research areas:

The Group identified key areas for R&D in order to know better how to support the following points:

• Team co-operation and team work (groupware)
• Information processing (diagnosis and decision making at high cognitive level)
• Measurement of the performance of the work system (preferably quantitatively)
• Overall consistency of the work system (and look at side effects).
4. PLENARY DISCUSSION

The plenary discussion agreed that there are generally three main areas to follow regarding control room upgrades:

1. **Follow up lessons learnt on control room upgrades and licensing issues.**

   We need a philosophy of design to ensure consistency. Training for operators (teamwork) involves shared cognition. The same is true for the design team and the design process. We need a shared understanding of the design process. H.F. people need process knowledge, operations people need H.F. knowledge.

   There should be a systematic follow-up of lessons learnt including how regulators treat upgraded control rooms. Different approaches, good practices, success stories, and failures should be collected. This systematic knowledge acquisition should focus on good practices.

   It is important to know why certain designs fail so that we don’t make the same mistakes again. When it has been established what is wrong, this can be compared with what you are doing. If the system is a success, the pitfalls should be avoided in other systems. Some plants involve operators at an early stage. One should be careful involving too many participants in developing a new system.

   Also, one should be careful when taking lessons from other design experience. It is not sure that the experience acquired in one project can be generalised to other projects, because the context is different, the situation, objectives, people involved, history, culture, and the socio-economical aspects, will probably vary.

   Lessons learnt from plant upgrades should not simply focus on operating experience. It should also include licensing issues. At Beznau the big upgrade came very late in the process. This knowledge can help researchers and other plants to get a sense of costs, etc. The utilities have difficulties to know what the regulatory shall request; they have no knowledge what the regulatory shall require as validation. In the example of the Beznau NPP, the V&V arrived late in the design process.

2. **Develop and co-ordinate methods and tools to support evaluations and comparisons**

   Human factors basis are not well known. There was an expressed hope by the participants in the workshop that human factors will be more involved in CR upgrades in the future. Human factors should be independent on technology, and try to stay on the same system basis. The human function in a control room is always the same.

   Purchasing computers is a tough issue which lasts for a while. And it would be difficult to purchase a similar computer after three years. Therefore hybrid control rooms are being developed - we have no choice. More technology is brought into the control room because we can do it, not necessarily because it
represent the best solutions. There should exist guidelines for utilities on how to change, they should know the context and specify any change with consistency.

There is a need for more detailed guidelines or solutions. E.g. shall a new alarm display be organised on the basis of a functional or an organic structure. Consistency, i.e. impacts on existing design, should be assessed in such a situation. Suitable guidance is needed. A broad approach should be followed to ensure consistency, i.e. the philosophy behind design and change should be clear. Guidance, i.e. questions to be asked, should be provided on how to detect the philosophy behind design and change.

Methods and tools for upgrading and for tailoring human factors programmes should be better coordinated. This is the weakest area of knowledge. One should focus the efforts on "how to do an upgrade". Perhaps we need clearer "requirements," but many different designs can come out of the same set of requirements. Development and application of suitable criteria are needed.

Performance measures are needed. People’s needs & uses should be considered, and design should improve performance. One should evaluate the changed design and provide and use information about lessons learnt also in licensing. Criteria and coherent, easy-to-apply guidance supporting design, assessments, and evaluations should be developed.

There was a consensus among the workshop participants that one of the largest challenges in this area is co-ordination of methods and guidelines to make it easier. Tools on functional analysis need to be developed. Also, there is a need to co-ordinate efforts to put human factors into effect, and how to use tools in a cost effective way and include human factors. An interdisciplinary design team with a shared understanding of what, why and how to change should be used in upgrades. This interdisciplinary design team will develop a shared understanding of what to do and how to proceed.

3. Ways of analysing progress of cost benefits and risks.

It is important to analyse upgrade programs in terms of costs/benefits and also in terms of risks. In this respect risk should not bee seen as a negative impact. How do you show that upgrades don’t increase risk? In order to assess cost and benefit appropriately, there is a need for a clear baseline. What is important is to find see where you start from and what to change. Aspects of operation and maintenance as well as functions allocated to automation and personnel should be considered.

In Sweden, work has started with regard to develop a baseline. This should be finished by spring in 2000. Halden has collected data to prepare a baseline situation for Ringhals. ISO and different IAEA documents can also serve in this task. It would be useful to gather and compare all available baseline documents.

Upgrades must be based on the status of existing designs. In this way it is possible to link upgrades to risk and to cost-benefit. It is not improvement, if what we have is already "good enough." Upgrades should thus assess the usefulness, costs, benefits, risks, side effects, and consistency of changes with respect to the previous design and design concepts. This needs to be done, as far as possible, prior to and during the design process.
5. WORKSHOP CONCLUSION - AREAS FOR FUTURE WORK

The workshop was adjourned and concluded by the Chairman in that he summarised five main points considered by the participants in the workshop as important areas for future work or research:

- **Lessons learnt.** There is a need to collate a ‘lessons learnt’ database relating to human factors and control room upgrades. This should include results or lessons from upgrade projects relating to: effect on the plant; implications of the change; costs and justifications; regulatory aspects; etc. Such a resource would help to:
  - Identify pitfalls in order for designers/utilities/regulators to avoid mistakes made by others.
  - Help to identify significant issues for research.
  - Help other plants to assess costs/implications of upgrade programmes.
  - Help to collect success stories, examples and case studies demonstrating the use of human factors principles.

- **Methods & Tools.** There is a need to co-ordinate the method/tool development and use in order to better support evaluations and comparisons.
  - What methods should be used and how they should be applied.
  - How to tailor the tools to the scope of the project.
  - What performance measures to use, how to adapt and apply the guidelines themselves.

- **Need to consider regulatory implications.** What are the regulatory implications – there is a need to show how to establish a performance baseline before change in order to demonstrate that performance is at least as good, or better, that prior to the change.

- **Control room philosophy.** It is important to support the use of a ‘control room philosophy’ prior to, during, and after the upgrade. This will help maintain the integrity of the control room across numerous changes, for example, the requirements for a unified MMI throughout the control room.

- **Interdisciplinary appreciation.** There is a need to have a better-shared understanding of the design process and how the different disciplines involved contribute to it. One should also appreciate what, and how each of the disciplines can contribute to improving the final product.
6. APPENDICES

APPENDIX 1: LIST OF PARTICIPANTS

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# APPENDIX 2: PROGRAMME FOR NEA/IAEA WORKSHOP

Park Hotel, Halden,
Monday 23rd – Wednesday 25th August 1999

## Day 1

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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<tbody>
<tr>
<td>9:00-9:45</td>
<td>Welcome from Halden Reactor Project (F. Øwre)</td>
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<tr>
<td></td>
<td>Introduction from Chair (J. Wachtel)</td>
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<tr>
<td></td>
<td>Participants introduction</td>
</tr>
<tr>
<td>9:45-11:45</td>
<td><strong>Session 1: Lessons from current control room development and evaluations</strong></td>
</tr>
<tr>
<td>9:45-10:10</td>
<td>Mark Feher (AECL) <em>Application of Human Factors to the CANDU 6 Control Room Upgrade</em></td>
</tr>
<tr>
<td>10:10-10:35</td>
<td>Dezsö Sarkadi (HAEC) <em>Human Side Preparedness before the Refurbishing Reactor Protection System in Paks-NPP</em></td>
</tr>
<tr>
<td>10:35-10:55</td>
<td>Coffee</td>
</tr>
<tr>
<td>10:55-11:20</td>
<td>J.W. de Vries (Borssele NPP) <em>The Borssele NPP New Control Room Based on a Human-Factored Operational Concept</em></td>
</tr>
<tr>
<td>11:20-11:45</td>
<td>Alfonso Jiménez (Tecnatom, s.a.), H: Deutschmann (HSK), &amp; L. Lot (NOK) <em>Verification and Validation of New Operation Support Systems for Beznau NPP</em></td>
</tr>
<tr>
<td>11:45-12:30</td>
<td>Group Discussions</td>
</tr>
<tr>
<td>12:30-12:45</td>
<td>Group Preparation for Presentations</td>
</tr>
<tr>
<td>12:45 – 13:30</td>
<td>Lunch</td>
</tr>
<tr>
<td></td>
<td><strong>Session 2: Approaches to and lessons from assessment</strong></td>
</tr>
<tr>
<td>13:30-14:10</td>
<td>John O’Hara, William Stubler, James Higgins and William Brown (BNL), Jerry Wachtel and J.J.Persensky (USNRC) <em>Human-Factors Guidance Development for Control Room Modernisation</em></td>
</tr>
<tr>
<td>14:10-14:35</td>
<td>Angelia Sebok, Steven Collier and Per Øivind Braarud (Institutt fur Energiteknik) <em>Incorporating Human Factors in Control Room Upgrades: Theory and Practical Experience</em></td>
</tr>
<tr>
<td>14:35-14:55</td>
<td>Coffee</td>
</tr>
</tbody>
</table>
14:55-15:20  Daniel Tasset (IPSN)  *Human Factors and Operation Aspects in Computerisation of the Control Room: a French Safety View based on N4 experience*

15:20-15:45  Kent Bladh (SwedPower)  *Validation of Control Room Upgrades*

15:45 – 16:30  Group Discussions

16:30 – 16:45  Group Preparation for Presentations

16:45  Close of day

*Cruise on the fjord (Bus from Park Hotel at 17:45 - return 23:00)*

### Day 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</thead>
</table>
| 9:00-9:45  | Opening from Chair (J. Wachtel)  
Plans for the day  
Individual Group Presentations of Day 1 Summaries  

**Session 3: Lessons from COSS’s & specific issues**  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</table>
| 9:45-10:10 | John O’Hara, William Stubler and James Higgins (BNL), Joel Kramer (USNRC)  *Human Performance Issues in Control Room Modernisation*  

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<tr>
<th>Time</th>
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</table>
| 10:35-10:55 | Coffee  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</table>
| 10:55-11:20 | Yong H. Lee (KAERI)  *An Experience on Human Factors Evaluation of a Safety Parameter Display System in Korea*  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</table>
| 11:20-11:45 | Øivind Berg, Thorbjørn Bjørlo (Institutt fur Energiteknik)  *Experience from Integration of Operator Support Systems to Enhance Human Performance*  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</table>
| 11:45-12:30 | Group Discussions  

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<tr>
<th>Time</th>
<th>Item</th>
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</thead>
</table>
| 12:30-12:45 | Group Presentation Preparations  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</table>
| 12:45 – 13:30 | Lunch  

**Session 4: Lessons from training, test and research facilities**  

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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</thead>
</table>
| 13:30 – 14:10 | Eberhard Hoffman (KSG/Gfs)  *Control Rooms in German Nuclear Power Plants*  

28
<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:10-14:35</td>
<td>Jean-Marc Fourneron, B. Papin, C. Germain (CEA) Integration of Human Factor and Experience Feedback in the Design of the Future French Irradiation Reactor</td>
</tr>
<tr>
<td>14:35-14:55</td>
<td>Coffee</td>
</tr>
<tr>
<td>14:55 – 15:20</td>
<td>Carlos Chávez-Mercado (Universidad Nacional Autonoma de Mexico) Human Factors and the Nuclear Reactor Engineering Analysis Laboratory</td>
</tr>
<tr>
<td>15:20 – 15:45</td>
<td>Gregor Eberle (Philippsburg NPP) Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms</td>
</tr>
<tr>
<td>15:45-16:30</td>
<td>Group Discussions</td>
</tr>
<tr>
<td>16:30-16:45</td>
<td>Group Presentation Preparations</td>
</tr>
<tr>
<td>16:45-17:00</td>
<td>Presentation from Joaquin Martin-Bermejo CEC. European Research Programme</td>
</tr>
<tr>
<td>17:00</td>
<td>Close of day</td>
</tr>
</tbody>
</table>

*Guide tour to Halden Fortress (Bus from Park Hotel at 17:45 return 19:00)*

**Day 3: Recommendations/Future work**

<table>
<thead>
<tr>
<th>Time</th>
<th>Item</th>
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<tbody>
<tr>
<td>9:00-9:45</td>
<td>Opening from Chair (J. Wachtel) Plan for the day Individual Group Summary Presentations from Day 2</td>
</tr>
<tr>
<td>9:45 – 10:00</td>
<td>Coffee</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>Group discussions; prepare charge to committee</td>
</tr>
<tr>
<td>11:00-12:00</td>
<td>Group presentations; charge to committee Closing Remarks: Chair (J. Wachtel) Invitation to demonstrations – Mark Green</td>
</tr>
<tr>
<td>12:00 – 13:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:00 – 16:00</td>
<td>Visit to Halden Reactor Project: HAMMLAB, Virtual Reality Centre, demonstrations of operator support systems</td>
</tr>
</tbody>
</table>
APPENDIX 3: THE WORKING GROUPS

Group 1
Mr. Mark GREEN (Secretary)
Mr. Mark FEHER
Dr. John O'HARA
Dr. Eberhard HOFFMAN
Mr. S. SMEATON
Mr. Jung Chang Na
Mr. Steve COLLIER

Group 2
Mr. Jerry WACHTEL (Secretary)
Mr. Dezso SARKADI
Mrs. Angie SEBOK
Mr. Jun-ichi TANJI
Mr. Jean-Marc FOURNERON
Mr. Dietmar ASSE
Ms. Anna Maria OLSSON
Mr. Anders JOHANSSON
Mr Seong-Nam CHOI

Group 3
Mr. Daniel TASSET (Secretary)
Mr. J.W. DE VRIES
Mr. Yong H. LEE
Dr. Carlos CHAVEZ MERCADO
Mr. Thorbjorn BJÖRLO
Mr. Conny HOLMSTROM
Mr. Lars-Göran SJÖSTRÖM
Mr. Hans EDVINSSON

Group 4
Mr. René MONTMAYEUL (Secretary)
Mr. Alfonso JIMENEZ
Dr. Kent BLADH
Mr. Øivind BERG
Mr. Gregor EBERLE
Dr. FASSMAN
Mr. Joaquin MARTIN-BERMEJO
Mr. Lennart CARLSSON
Mr. Kjell HAUGSET
APPENDIX 4: CALL FOR PAPERS

OECD NUCLEAR ENERGY AGENCY
AGENCE DE L’OCDE POUR L’ENERGIE NUCLEAIRE

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

PRINCIPAL WORKING GROUP No. 1

ORGANISED IN CO-OPERATION WITH

INTERNATIONAL ATOMIC ENERGY AGENCY
WORL ASSOCIATION OF NUCLEAR OPERATORS

CALL FOR PAPERS

FOR A

WORKSHOP/SPECIALISTS MEETING

ON

APPROACHES FOR THE INTEGRATION OF HUMAN FACTORS INTO THE UPGRADING AND REFURBISHMENT OF CONTROL ROOMS

HOSTED BY
The OECD Halden Reactor Project

Halden, Norway

23rd – 25th August, 1999
ORGANISATION

An OECD/NEA Workshop/Specialists meeting is to be held on “Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms.” It will be organised by the Principal Working Group 1 (PWG1) on Operating Experience and Human Factors, of the Committee on the Safety of the Nuclear Installations (CSNI), of the OECD Nuclear Energy Agency (NEA). The meeting will be organised in co-operation with the IAEA, and will be hosted by the Halden Reactor Project, Halden, Norway on the 23rd-25th August, 1999.

BACKGROUND

A modern approach to control room design, be it for upgrading or complete refurbishment, requires the integration of many disciplines and approaches. The integration of human factors into such a process continues to present challenges. How this process should be conceived, planned, and carried out will be of considerable interest to designers, operators and regulators.

Many NPPs around the world have been, or will be faced with decisions concerning modernisation of their control rooms. Such changes can be driven by a range of issues including; the need to replace outdated control and instrumentation systems; increasing regulatory concern about human performance; or the need to provide a better process control environment for NPPs whose life cycles extend beyond what was originally intended. Considering the importance of operator performance for safe and profitable operations, a process for ensuring that human factors issues are properly addressed could be central to the success or failure of such a project. Human factors is of particular importance when a combination of existing and new systems are to be used, resulting in a so-called ‘hybrid’ control room.

The workshop/specialist meeting will:

- Explore how human factors issues can be identified.
- Consider what processes and techniques are necessary to ensure that appropriate requirements are specified, and that suitable data is gathered and analysed.
- Identify and discuss issues related to these questions together with lessons from utilities, vendors and regulators which have faced, or are currently facing, these challenges.

SCOPE OF THE MEETING

The agenda for the meeting will focus on the state of knowledge and current best practices within this area. The purpose of the meeting is to provide a forum for the open discussion of the human factors issues, as seen by a broad range of interested parties, in relation to the upgrading and refurbishing of control rooms. Contributions will be sought based on design experience, practical experience, research and regulatory needs, and the meeting will provide for the exchange of experiences and approaches on a range of important topics. This will enable the identification and prioritisation of areas merit further consideration and research. It is proposed that the format of the meeting should include presentations on current knowledge and concerns, and small group workshops to identify important issues for designers, utilities and regulators, as well as future research needs.
TOPICS FOR CONTRIBUTIONS

Among topics to be discussed participants are invited to share their experiences and perceptions on a broad number of aspects, including:

- Identification of human factors issues from the utility, vendor, and regulatory perspective.
- Ensuring the inclusion and implementation of human factors issues within the upgrade or refurbishment process.
- How this change process should be managed.
- Feedback from practical experience and real concerns.
- Meeting modern human factors requirements.

PROGRAMME COMMITTEE

The Workshop/Specialists meeting will be organised under the direction of the Programme Committee, whose Members are:

- Mr. R. Montmayeul (EdF)
- Mr. J. Wachtel (US NRC)
- Mr. M. Green (HRP)
- Mr. D. Tasset (IPSN)
- Dr. W. Fassmann (GRS)
- Mr. B. Fitzpatrick (WANO)
- Dr. M. Dusic (IAEA)
- NEA/PWG1 secretariat

MEETING ARRANGEMENTS

Meeting Participation

Participation in the Workshop/Specialist meeting is expected from persons knowledgeable in the technical issues above mentioned. Nominations should be made through national delegates to the CSNI and official government representatives using the attached registration form. The registration form should be sent to the secretariat by 7th May for the authors, together with the abstract, and by 10th June 1999 for the other participants.

Abstract Form

The abstract should indicate the relationship to the scope of the meeting (parts 3 and 4, above). It should be between 200 and 400 words in length. It should submitted to the NEA secretariat whose address is in the registration form.
Schedule

The abstract should reach the secretariat by 7th May 1999. The Programme Committee will meet to select the papers and prepare the provisional programme. The authors of the selected papers will be notified at the latest 10th June 1999.

Authors should send the final version of the paper to the secretariat no later than 6th August 1999.

Working Language

The working language for the meeting will be English. No translation service will be available.

Meeting Proceedings

The proceedings will be published and will include all accepted papers together with a summary of the overall conclusions of the meeting.

Local Arrangements

Details of local arrangements are being developed and will be sent to authors and participants together with the provisional programme. For questions you may contact the Secretariat:

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(from 1.2.2002 pekka.pyy@oecd.org)
OECD NUCLEAR ENERGY AGENCY
AGENCE DE L’OCDE POUR L’ENERGIE NUCLEAIRE
Committee on The Safety of Nuclear Installations
Principal Working Group No.1

Registration Form
to the Workshop Meeting on
Approaches for the integration of human factors
into the upgrading and refurbishment
of control rooms

In response to the announcement and call for papers
we inform you of the nomination of

Name:_____________________________________________________________
Ms. ( ), Mr. ( ), Dr. ( ) Prof. ( )

Position:__________________________________________________________

Organisation:_____________________________________________________

Address:________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Tel:_________________________      fax:_______________________________

E-mail:_______________________________________________

Title of my presentation:

Please return the form by 7th May, 1999 at the latest to:

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OECD Nuclear Energy Agency
Le Seine St Germain
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APPENDIX 5: PAPERS OF THE WORKSHOP
Application of Human Factors to the CANDU 6 Control Room Upgrade

M.P. Feher
Atomic Energy of Canada Ltd. (AECL),
2251 Speakman Dr.,
Mississauga, Ontario, Canada.
L5K 1B2

Abstract
This paper will present the background and approach to the AECL CANDU 6 Generic Human Factors Program and describe the application of the program to the control centre improvements in progress for an installation in the CANDU 6 plant being constructed at Qinshan, China.

The current CANDU 6 plant design has evolved over the past two decades based on the design developed in the 1970's for the original CANDU 6 plants at Point Lepreau and Gentilly in Canada, Wolsong in Korea and Embalse in Argentina. Changes and additions to the CANDU 6 design have been made over time to reflect experiences in Canada and overseas. This design evolution is expected to continue for the foreseeable future with potential inputs from all existing CANDU plants. This paper describes the generic human factors engineering program and process that apply to the evolution of the design of the CANDU 6. The paper will summarize the activities and processes used to address the analysis, development, evaluation and implementation of a design change. These activities ensure that the human performance requirements of the plant operational and maintenance staff are systematically integrated into the CANDU 6 design process.

The paper summarizes the current application and lessons learned in the upgrade of the design of the CANDU 6 control centre for the current project being constructed in China.
Approach to Applying Human Factors to Design Evolution

An integrated design effort is being proposed by the CANDU 6 development program to ensure that human factors engineering design principles and criteria are implemented as required by project needs, and are documented in specific Human Factors Program Plans. The process is in review both internally and by Canadian regulators. The approach described in this paper is expected to be adopted for future programs once regulatory and corporate reviews are completed. This paper describes the program as it is currently drafted.

Three design goals have been identified to ensure that the system designs meet the CANDU 6 needs in the areas of licensability, and capital and operating, maintenance and administrative (OM&A) costs, in addition to meeting the functional requirements.

1) Safety - The design should support safe and reliable operation in all operational states in order to maintain safety of the public and the plant staff. The plant must be licensable and be able to maintain licensability over its intended life.

2) Operability/Maintainability - The design of the plant and the design process should:
   - provide an assignment of functions that effectively utilizes operator and system capabilities to achieve operational objectives,
   - ensure the availability of plant functions when they are needed,
   - provide for the planning and scheduling of maintenance and testing based on plant performance, and permit necessary system/equipment maintenance safely, quickly and cost effectively, and
   - minimize the cost of operating and maintaining the plant.

3) Capital Cost - The plant should be designed to minimize the cost of design, procurement, construction, and commissioning.

The first and third design goals are effectively addressed by the existing AECL design process. The second goal has resulted in a number of enhancements to the design process and is the focus of human factors related activities. The incorporation of human factors design principles and criteria into the design of CANDU 6 enhancements, based on the above three design goals, is achieved through the provision of human performance information, the application of human factors design guides, standards and procedures, reviews, evaluations and analyses.

HFE criteria, considerations and issues are documented in a structured and controlled fashion throughout all steps of any particular CANDU 6 design enhancement. Documentation of the human factors engineering input to the design:
   - enables tracking of the design issues and concerns to ensure they are appropriately assessed and dispositioned,
   - enables both project and outside organizations to evaluate the degree to which human factors has been integrated into the design, and
   - provides a summary list of all resultant human factors issues.

The actual input to the design is documented within the existing and/or planned project documentation structure. This is part of the process of treating human factors like any other engineering discipline in the design process and supports on-going efforts to improve buy-in to human factors programs.

Any enhancement to the CANDU 6 design must maintain the philosophy that the human operators are ultimately responsible for the safe and efficient operation of the facility. This requires that operators be supported in their roles as system supervisors, intervenors, and manual controllers, where appropriate. In recognition of this important role for humans in overall plant operation, design principles have been established to address their needs. Principles are statements that establish the need to define requirements and design features, and to guide designers throughout the
Figure 3: CANDU 6 Development Approach to Human Factors Impact Analysis

The following detailed design activities are carried out as deemed necessary by the nature of a specific proposed CANDU 6 design enhancement. Details regarding the methods, tools and techniques to be used in these activities are specified in the project-specific human factors engineering plans, design guides, or procedures. The possible activities include, but are not necessarily limited to:

- Task And Human Error Analysis
- Human Reliability Analysis
- Control Centres (Interface) Design
- Maintainability and Commissioning Assessments
- Function Analysis Review
- Workload Analysis
- Workplace and Workstation Layout Assessment
- Physical Working Environment Assessment
- Input to Operating, Maintenance and Emergency Response Procedures

Specific Application for Qinshan MCR Upgrade

The Qinshan plant in China is based on an existing CANDU 6 design that is a proven successful product. Changes to the design are controlled and scrutinized to maintain the proven concept, keep customer risk to a minimum, and minimize costs. Following the signed contractual agreement, AECL entered into discussions with the Chinese client to offer an upgrade to the control centre portion of the product. This upgrade serves to enhance the CANDU 6 design in an area where significant development has been accomplished and risks have been mitigated.
Human factors impact analyses:
- Assessing Operating Experience With the Reference Design
- Operational Impact Assessment
- Functional Impact Assessment
- Maintenance Impact Assessment
- Design Evaluation
- Review of design documentation (including supplied commissioning, operating, and maintenance manuals) for human factors considerations

The most interesting and unique part of this work is the human factors impact analysis. These are explained in more detail in the following Section.

Human Factors Impact Analyses

The human factors impact analyses are founded on the following basic policy statement defined in AECL procedures:
- the design of a CANDU 6 plant and the design process used to create it should:
  - provide an assignment of functions that effectively utilizes operator and system capabilities to achieve operational objectives,
  - ensure the availability of plant functions when they are needed,
  - provide for the planning and scheduling of maintenance and testing based on plant performance,
  - permit necessary system/equipment maintenance safely, quickly, and cost-effectively,
  - minimize the cost of operating and maintaining the plant, and
  - support operators in their need to know and understand:
    - the plant functions to be monitored and controlled, and their performance goals,
    - the relationship of each function to the primary safety and availability targets,
    - the relationship(s) of each function to other functions,
    - the applicable state(s) for each function for each operating region of the plant,
    - the initiating, on-going, and terminating conditions that define the bounds of operation for each function,
    - the performance measures and criteria to be used in judging function performance, and
    - the control and information needs for operators and automation to jointly perform tasks for each function in all operational situations.

Assessing Operating Experience With the Reference Design

Operating Experience Review (OER) for systems impacted by the proposed design change is performed to draw on the evolving CANDU and international experience base to identify relevant operational and design issues that need to be addressed. Operational and design improvement issues can include areas such as:
- operational requirements,
- operational strategies and practices,
- cognition,
- support for decision-making and control actions,
- equipment, facilities, and layout,
- design philosophies, and
- design approaches and processes.

The following questions should be used to assess how well operating experience has been applied into the design:
- Was a reference design identified?
- Were system design changes identified for the related CANDU 6 system from the design reference? Should they have been?
• tasks to be performed by operations, both generic (described in the CANDU 6 Operational Basis) and specific to the systems and components.

The output of the review is integrated into the design process with the objective of contributing to reduced life cycle costs associated with commissioning, ongoing operation and future modifications of the plant.

Functional Impact Assessment

As for the other impact assessments, a procedure used by a human factors specialist provides a policy statement and guidance to complete this activity. Design documentation is reviewed by the human factors team to assess the adequacy of defined functions against operational and human needs. The results of the assessments are discussed with process and control system designers to establish changes to the process or control designs, and/or to the operational, functional and maintenance bases as required. The key areas of assessment include design compatibility with:

• operating experience with the reference design
• the suitability of allocations of the control and supervision of plant functions between humans and machines, and
• the impact of the design on integrated operation of the plant.

The assessments are designed to highlight negative impacts on:

• overall plant safety,
• regulatory compliance,
• protection of plant investment,
• operations, maintenance and administration (OM&A) costs,
• preferred operational practice, and
• the ability of operating or maintenance staff to successfully perform their assigned duties including the availability of required controls and display information.

The primary outcome of this activity is recommendations for changes to the design or operation to improve overall design effectiveness. This activity is performed using a review of the system design documentation and drawings as well as discussions with the system designers themselves. In some cases previous design evaluations and prototypes are used to support the assessment.

Maintenance Impact Assessment

Also supported by procedure, design documentation is reviewed by the human factors team to assess the adequacy of the design to meet human maintenance needs. The results of the assessments are discussed with process and control system designers to establish changes to the process or control designs, and/or to the operational, functional and maintenance bases as required. The key areas of assessment include design compatibility with or support for:

- maintenance planning/scheduling,
- historical process analysis,
  • data access and collection,
  • data visualization, performance analysis and diagnosis,
  • reporting and documentation,
- historical event analysis,
- operational/on-line monitoring and analysis,
- system testing,
- maintenance implementation,
  • work package definition,
  • work control,
- Reduced maintenance costs through the use of information now available for process surveillance and condition-based maintenance programs.
- Reduced outage times and faster restoration to power generation
- Equipment obsolescence protection and high performance for the Plant display system
  - Off-the-shelf hardware components in a modular design.
  - Platform independent software design techniques.
  - Advanced computer system health monitoring.
  - High speed data distribution inside and outside the MCR.
  - High level of Software Quality Assurance.
- Full historical data recording and distribution in support of event analysis and maintenance monitoring and planning.
- Improved control room aesthetics presents a modern and technologically advanced image.
- Improved control room ergonomics improve operating staff vigilance, performance and pride in the environment, support for operator shiftwork though lighting technology and enhanced administrative task support.

The success of this program will be, in part, due to the application of the human factors program from the initiation of the upgrade proposal through to the end of the in service hand-over. The approach to human factors for the evolution of existing designs maintains the philosophy that the CANDU 6 design be founded on proven systems, components and technology while maintaining an ability to evolve and upgrade the design. In this way CANDU design can both take advantage of appropriate new technology and address the inevitable obsolescence of older equipment and systems.

References


Control Centres and Human Factors Related Publications List


Human Side Preparedness in the Refurbishing of Reactor Protection System in PAKS NPP, Hungary

Presented by DzsőS SARKADI
Hungarian Atomic Energy Authority
Nuclear Safety Directorate

Halden, Norway, 23-25 August, 1999

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1. Nuclear facilities in Hungary
2. Regulatory system related to the
   Application of atomic energy, legal basis
3. Refurbishment of the reactor protection
   System in unit 1. PAKS NPP, Hungary
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4. Human factors in licensing period
5. Human factors in the construction period
6. Human factors in the commissioning and operation phase
7. Summary

1. Nuclear Facilities in Hungary

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<th>Nuclear Power Plant</th>
<th>Nuclear Training Reactor</th>
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<td>Institute for Nuclear Techniques Technical University of Budapest</td>
<td>KFKI - Atomic Energy Research Institute</td>
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<td>Pool</td>
<td>Task (WWER-SzM)</td>
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<tr>
<td>Capacity</td>
<td>4x460 MW</td>
<td>1001 Wth</td>
<td>10 MWh</td>
</tr>
</tbody>
</table>
2.1. Legal Basis

- Govn't decree nr. 87/1997 (28 May) defines the legal status of the Hungarian Atomic Energy Authority (HAEA)

- Govn't decree nr. 108/1997 (25. April) provides the general procedures for the Hungarian Atomic Energy Authority in regulatory processes related to nuclear safety

2.2. Structure of Regulation

- Atomic Energy act
- Govern't & min. Decrees
- Regulations
- Regulatory guides
- Procedures, standards, etc.
2.3. Regulatory system related to the application of atomic energy

2.4. Hungarian Atomic Energy Commission (HAEA)

Main responsibilities of HAEA:

- Regulation, licensing, inspection on Hungarian nuclear facilities
- Enforcement of nuclear safety
- Public relation and hearings
- Safeguards activity on nuclear materials
- Risk analysis on the environment and society
2.4. Hungarian Atomic Energy Commission (HAEA)

- International relations regarding to nuclear safety, promotion of international standards and recommendations
- Research & development related to nuclear safety, support of new safety ideas
- Control of QA activities in nuclear facilities
- Periodical reports to the Hungarian government and parliament

2.5. Hungarian Atomic Energy Commission (HAEA)

Co-operation in other activities:

- Physical protection
- Emergency preparedness and civil protection
- Fire protection
3. Refurbishment of the Reactor Protection System in Unit 1. PAKS NPP, Hungary

3.1. After a long term (about 2 years) competition of the tender reactor protection system refurbishment (RRP) the winner has been the German firm SIEMENS with his newly developed computerised intelligent (programmable) system TELEPERM-XS. The basic requirements and technical specification was worked out by the management of NPP PAKS but the Hungarian authority (HAEA) has added more additional requirements and conditions in the tender specification.

3. Refurbishment of the Reactor Protection System in Unit 1. PAKS NPP, Hungary

3.2. The first début of this new SIEMENS system was planned in PAKS NPP, so from this exceptionally reason a very important agreement has been realised between our utility and the firm SIEMENS. For many years on the site of our NPP there is a full-scope training simulator for the type WWER-213 former Soviet designed nuclear power reactor. In the first step in 1998 we have applied the new reactor protection system to our simulator in parallel with the former reactor protection system. From this big refurbishment of our training simulator we have obtained a lot of technical, operational and human experiences.
3. Refurbishment of the Reactor Protection System in Unit 1. PAKS NPP, Hungary

3.3. In our periodical simulator training we have tested our operator personal how quickly they can get the necessary abilities and skills to work with this new system. From the beginning the experiences were very positive.

3.4. In this period we performed prudent training for the maintenance personal too, mainly for the handling of a special test-machine developed by SIEMENS for the testing of the new RRP system for the operation and of course for the shut-down and outage states.

3.5. We have generated artificial errors in this new system and tested the reactions of the personal.

4. Human Factors in Licensing Period

4.1. From the beginning HAEA has been the statement, the human factors have significant to the nuclear safety, therefore HAEA pays wide attention to the human factors, ergonomic aspects and mainly to the personal skills:

- Education, training, qualifications
- Graduation level, computer knowledge
- Knowledge of languages (English and/or German)
- Practice in the NPP PAKS, or related fields
- Connecting certificates (operation, maintenance, physical and mental healthy, etc.)
4. Human Factors in Licensing Period

4.2. HAEA prescribed preliminary education programs which were taken place in the site of the NPP PAKS:

- High level education programs were realised for the related engineers and leaders of operational and maintenance personal on the computerised I&C technical methods.
- Practical education programs were performed for the operational and maintenance personal.
- NPP PAKS and HAEA organised special visits to the factory sites of SIEMENS for the management, operational and maintenance personal.

5. Human Factors in the Construction Period

5.1. Education and training programs started on site PAKS NPP focused on the practical aspects.

- Practical education programs have been taken for the related engineers and leaders of the operational personal.
- Practical education programs were performed for the operational and maintenance personal combined with rigorous training programs on the extended simulator.
- Specific education for all HAEA inspectors in Budapest.

5.2. Examination and licensing of the related personal in all levels in the presence of HAEA representative.
5. Human Factors in the Construction Period

5.3. Active manual participation of the maintenance personal in the montage works.

5.4. Active participation of the operational and maintenance personal in the immediate tests of the new RRP system.

5.5. Modifications in construction period:
- On some ergonomic aspects (colouring, furniture and panel arrangement, loudness of audio signals, etc.)
- On positions of computer monitors
- On the control panels, geometry and position arrangement of signal instruments by the request of the personal

5. Human Factors in the Construction Period

- On the co-operation and graphic harmonisation of the new RRP system monitors and process computer monitors
- On the operational manuals and instructions
- On the lighting of the control room

5.6. Utilisation of the human experience from the extended training simulator.
6. Human Factors in the Commissioning and Operation Phase

6.1. Participation of the related engineers and technical management in the final test of RRP.
6.2. Detailed investigation of the explored and fixed errors, modifications and their conditionally expected side effects.
6.3. Revision of the final technical (real) documentation and commissioning protocols.
6.4. Continuously technical inspection in the restart period of the reactor.
6.4. In operational phase there is a permanent data collection on the technical and personal errors or malfunctions.

7. SUMMARY

- We are after a successful reactor protection system refurbishment in our NPP PAKS Unit 1., the obtained results were really similar as we have expected before.
- We are sure that the upgraded nuclear safety relates not only to the modern technical solutions but also to the high level of the ergonomic performance, the good man-machine interface and the intensive education and training.
- In our NPP-s unfortunately they are still more unsolved problems in the fields of ergonomic factors, man-machine relations but we force permanent development to eliminate them.
Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms

OECD Halden Reactor Project 23-25 August 1999 - Halden, Norway

The Borssele NPP new Control Room, based on a Human-Factored Operational Concept.

Jan Willem de Vries
Nuclear Power Station Borssele
The Netherlands
1. Introduction

The Borsselle Nuclear Power Plant in the Netherlands (KCB), commissioned in 1973, is located near Flushing on the Schelde estuary. It is owned and operated by EPZ, the Electricity Generating Company Ltd. for the Southern Netherlands. After 8 years of preparation, in 1997 an extensive backfitting programme was carried out at this twin-loop 480 MWe PWR in order to raise nuclear safety to a level comparable with that of a modern plant.

After assessing KCB in the light of recent regulations, studies on special aspects such as earthquake and leak-before-break qualification as well as a detailed probabilistic safety assessment (PSA) were carried out. Then a comprehensive safety concept was developed by EPZ in co-operation with Siemens/KWU. In this concept a new design basis, founded on deterministic regulations combined with the findings of the PSA, was defined. All today’s requirements as earthquake, gas cloud explosion, plane crash, single failure criterion, HELB (high energy line break), ATWS, 30 minute criterion, internal fire and flooding etc. had to be fulfilled. In order to cover the new design basis 18 major sub-projects were defined, among them measures as a completely new emergency diesel generator system including new batteries and inverters for the UPS, a new reactor protection system (RPS) in order to meet the 30 minute criterion and new Sebim primary safety/relief valves mounted directly on the pressuriser “dome”, suitable for primary feed and bleed and able to cope with ATWS.

The external events requirements are met by the upgraded and extended ‘protected zone’. This zone includes the reactor containment and the bunkered building, housing the alternative cooling system, the RPS and a new back-up control room. The primary and secondary feedwater systems in this zone have their own diesel generator sets, instrumentation and independent water storage to which a deep well system for long term cooling was added. They are able to withstand external events as earthquake, airplane crash, gas-cloud explosion and flooding. Of course internal events are taken in account too.

The protected zone was expanded to include an additional bunkered building to accommodate for the new RPS and back-up Control Room. From here it is possible to bring the reactor to a safe and stable cold sub-critical state.

A major part of the Backfitting Project focused on electrical systems, instrumentation and control and Human-Machine Interaction (HMI). The design objectives for the new and upgraded E, I&C, derived from the new design basis, led in its own way to a whole range of sub-projects. From the Human Factor point of view two of them are of special interest, namely the renewal of the Main Control Room and the revamp of the Process Computer.

In the course of the project a lot of experience was gathered on how to implement the Borsselle Human Factored Operational Concept in the design of the new HMI / MMI, and in getting technology and layout in the new Control Room accepted by the users.
2. Human-Factored Operational Concept, NPP Borssele:

In order to get a better insight in the sub-projects renewal of the main control room and revamp of the process computer, first some words on the operational concept of the plant.

In the operational concept at Borssele NPP the human being is regarded as the most important factor. The operational staff have the competence to identify and correct omissions and errors in the plants' design and procedures. However, the human as decision maker is heavily supported by high degree automated systems which prevent human error.

A design principle of the Borssele reactor protection system (RPS) is that within 30 minutes after initiation of a RPS safety action no manual operator intervention is required in order to satisfy the critical safety functions of the process. This so called '30 minutes criterion' allows operators to diagnose the NPP's status, and prepare proper action required by the plant situation. For a subset of postulated accidents similar '2 hour' and '10 hour' criteria apply.

For the sub-tasks of diagnosis and selection of priorities a set of "symptom-based" Emergency Operating Procedures are available. These EOP's have been developed from the generic guidelines of the "Westinghouse Owners Group". The "status trees" of the procedures are as pop-up mimic available too on the process computer workstations. The procedures are divided in:

+ **event-related procedures** (20 modules, called optimal recovery procedures)

+ **event-independent procedures** (20 modules, called function restoration procedures having the highest priority)

Further, operations personell behaviour can be characterized by a disciplined, open and self-critical attitude and being aware of the need for a "safety culture".

All deviations from the most safe plant conditions are evaluated in a structural way, its root cause defined and eliminated. These surveillance tasks are aided by the existence of the in 1996 implemented new Technical Specifications following the NUREG-1431 model.

Finally, in the Borssele operational concept safety goes before economics. To maintain and improve operational nuclear safety has a higher priority as the generation of electrical energy. The economic task is carried out only if all safety conditions are met.

3. Renewal of the Main Control Room:
Originally the project scope did not define a complete revamp of the main control room. However, given the large extent of the modifications, during the engineering stage it became clear that it would not be possible to accommodate the extended HMI demands in the existing main control room (MCR). Gradual upgrading during the past 20 years had used up any available space on the main control desk and the wall-panels. In the course of the project it was therefore decided to build a completely new one.

In order to ensure that all design-aspects would be covered, a HMI-Working Group was established with participants from relevant departments in the NPP's organization as well as external ergonomic advisers. Its goal was (and is) to have a consultative body where departments as operations, training, process-technology and maintenance can - from their own field of expertise- with respect to the HMI, give input and participate in the design of the systems which are modified or newly built.

Modern design pays a lot of attention to those engineering design aspects, such as the "30 minutes criterion", which allow tolerance for delayed human interaction during the course of automatic actions of safety systems. This approach gives breathing space to the operator after initiation of the protection system and leads to a more level-headed reaction on disturbances and a composed entering of the Emergency Operating Procedures and the Function Restoration Procedures.

After analyzing the shortcomings of the old MCR by walk-tough/talk-tough of problems and interviews of the operators, a complete operations shift was made available to design the lay-out of control-desks and panels for both the existing Main Control Room and a new back-up CR.

This was done using wooden mock-ups, observing a set of rigorous ergonomic limiting conditions and the operational concept of the NPP. This process took five people working for three months. The Human Machine Interaction Working Group conducted this process. In essence the MCR is now divided into four quadrants, each operator having his controls and instrumentation within his own domain.

After review by all end-users (shifts) a high degree of acceptance was achieved and two control rooms were ordered. One for the full-scale replica simulator - also part of the back-fitting program- and one for the real NPP. Experiences from test-runs with the first delivered simulator CR were incorporated in the MCR design for the NPP.

During the outage in which the MCR was renewed, a temporary small control room was provided, equipped with all systems to operate the spent fuel pool and all necessary auxiliary systems to keep the plant safe.

4. Revamp Process Computer:
Another back-fitting sub-project was the revamp of the process computer. The main reason to do this was the extended number of analog and binary point ID's required by the back-fitting project. A sub-project was started with an ABB subsidiary, ABB Combustion Engineering Nuclear Power. The old process computer MMI, requiring a lot of key-board input for information retrieval, was replaced by a modern graphic user-interface with X-Windows for multi-window applications. The SUN-operator workstations have a wide variety of displays with modern intuitive user interface. All process displays are based on extensive human factors research conducted in the 1980's by Combustion Engineering in cooperation with the Halden project. User interaction has been updated to use modern techniques unavailable at the time of the original studies.

An SPDS (safety parameter display system) is included in the bunkerized part of the process computer.

NPP Borssle were in fact the first in the world (1989) to implement a large screen Integrated Process Status Overview (IPSO) in a nuclear power station. At that time a hard-wired panel (1.35 by 2.25 m) with LED displays controlled by a customized computer was installed, receiving real-time data from the process computer (PPS). In addition, a bank of four CRT's below the panel presented critical plant data and alarms. The revamp of the process computer included the replacement of the old IPSO with a large format high resolution LCD back projection display from Dr.Seufert GmbH, Germany, animated with real-time data from the PPS by a SUN-SPARCstation over the network. This configuration enabled the ability to customize the display for changes in the plant and gives the operator the same "look and feel" as the PPS operator workstations.
For the IPSO three special "IPSO plant Modes" are defined, each showing a different mimic:

A. Power Operation
B. Residual Heat Removal
C. Emergency Core Cooling

The design of the new IPSO includes work of international research groups like the Halden Reactor Project who has researched the human machine interface aspects in control room design and alarm status presentation.

For both, process computer and IPSO the new technology replaced the existing key-boards with a trackball or mouse as pointing device and was with its improved operator interface easily accepted by the control room crew after some training sessions on the simulator. Here again from the start on operational staff was involved in the selection, design and review of the new system displays.

5. References:


Ing. J.W. de Vries
N.V. EPZ NPP Borssele
Dept. of Nuclear Technology

Presenta\HumFactors\OECDHaiden\PaperWkshp.Vrs.doc 6-8-99
Workshop Meeting on Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms  
Halden 23 – 25 August, 1999

Verification and Validation of new Operation Support Systems for Beznau NPP  
Alfonso Jiménez (Tecnatom, S.A.), Herbert Deutschmann (HSK) and Lucio Lot (NOK).

ABSTRACT

Foreword

This presentation describes the activities associated with the Verification and Validation works performed by Tecnatom on a computerised Advanced Alarm System (AAS) and a Computer Based Procedure System (CBP), for the licensing of these systems to be used in the control rooms of Beznau NPP (property of NOK).

In this process Tecnatom has acted as an independent company in the evaluation of the new systems, supporting Beznau NPP to obtain the approval from the HSK (Swiss Federal Nuclear Safety Inspectorate) for the implementation of these systems into the training and operating concepts of the plant.

Verification and Validation Process

The first activity of this process was the development of the applicable methodology, being based on international standards such as: NUREG 0700 rev.1, EPRI TR-101814, NUREG 0711 and NUREG/CR6393. Verification and Validation procedures were developed for conducting the activities.

The verification activities have been focused on an independent evaluation of the following subjects:

- Interconnection between the Plant Information System and the new systems.
- Detailed check of the system databases and the correspondent plant data.
- Human System Interface verification.

The verification activities have been documented using special formats. The verification process consisted in the detailed evaluation of each element included in the databases that are needed to define the Emergency Operating Procedures (EOP's) and the alarm messages.
The verification process has reached the following objectives:

- Consistency of the data structures
- Completeness
- Unambiguity
- Correctness of the data values against the emergency operating procedures and the alarm logic’s of the plant (logic/sequence/priority).
- Readability
- Protection against unauthorised changes

The validation activities have been performed to demonstrate that the systems are operational and that they comply with functional and HFE requirements included in the methodology.

These activities have consisted in the execution and analysis of several test cases or scenarios in a simulator with actual Beznau crews. The evaluation has been achieved by assessing the use of the CBP system in relation to the operator interactions with the system, taking into account an operator/human performance model of activities when responding to abnormal or emergency conditions. The major activities represented in this model are:

- Monitoring/detection
- Situation assessment
- Response planning
- Response implementation
- Feedback

Special emphasis was placed on the following topics when evaluating the operator’s actions:

- Situation awareness
- Workload
- Communications
EVOLUTION OF THE OPERATIONAL CONCEPT IN BEZNAU NPP CONTROL ROOM

This section discusses the control room operating philosophy in the current situation and how the operational concept evolve after the V&V process implementation with the introduction of AAS and CBP.

Current operational concept

The current operational concept can be explained as the “operating triangle” shown in Figure 1.

![Figure. Current Operational concept](#)

If an upset is caused by a system or component, the current GMA alarm system and the conventional instrumentation provide the panel operators with enough information to identify the plant disturbance.

After a reactor trip or a safety injection, the emergency procedure E-0 were executed, using the above mentioned information and the paper EOPs. During this time, the shift supervisor and the panel operators have split duties. The shift supervisor use the paper EOPs and communicate the major procedural steps to the
Within ten minutes, the pikett engineer is expected to enter the control room to assist in monitoring the critical safety functions. He assess the plant status with the shift supervisor.

**Proposed operational concept**

Figure 2 shows how the AAS and CBP systems were integrated into the operational concept of Beznau NPP after the V&V process completion.

If an upset is caused by a system or component, AAS and the conventional instrumentation provide the control room personnel with enough information to identify the plant disturbance. The current GMA alarm system remain as a redundancy.

*Figure: Proposed operational concept*

After a reactor trip or a safety injection, the emergency procedure E-0 were executed by using both AAS and CBP. During this time, the shift supervisor use CBP
to monitor proper execution of procedures and communicate the major procedural steps to the panel operators.

Once the pikett engineer enters the control room, he use the conventional instrumentation to support the crew, monitoring the critical parameters.

These changes in the operational concept were congruent with the training that is being carried out.

FUNCTIONAL CRITERIA FOR CBP V&V PROCEDURES DEFINITION

There are some specific requirements that have to be considered when selecting the tests to be performed in the CBP V&V process.

The Westinghouse Owner Group establishes in their Emergency Response Guidelines the action steps for the development of plant specific emergency operating procedures.

The CBP V&V process include a set of verification formats and validation scenarios so that all critical safety functions and the mayor paths of E-0, E-1, E-2, and E-3 series were checked.

These are two different and complementary approaches to face the plant operation under emergency conditions.

HUMAN FACTORS CRITERIA FOR AAS AND CBP SCENARIOS DEFINITION

Besides the functional requirements above stated, the human factors engineering also imposes constraints on the AAS and CBP validation tests: a set of realistic and feasible scenarios should be selected.

- Scenarios should be realistic in the sense that they should represent what could actually happen and should require subjects to produce responses typical of what would actually be required in such situations. In general, if subjects are asked to deal with situations they do not believe could happen, or to produce responses that they would be unwilling to make in reality, there is significant risk
that the scenario will not be useful for the evaluation. Further, even if subjects do comply with unrealistic requirements, the results will not be representative of eventual system performance in an operational environment. The selected scenarios should include environmental conditions such as noise and distractions that may affect human performance in an actual NPP.

- Scenarios should be feasible in the sense that they should not impose requirements that exceed the capabilities of the simulator facility being employed.

**AAS AND CBP VALIDATION**

The purpose of the AAS and CBP validation were to demonstrate that the systems perform the functions expected, and that operators and systems interact properly to perform the required functions and to support safe operation of the plant.

The validation tests cover the system functions in a fully representative manner. The validation tests were performed through dynamic task performance evaluation using evaluations tools which are appropriate to the accomplishment of this objective under a range of operational conditions, including normal and upset conditions.

**PREPARATION FOR THE EVALUATION**

This phase includes:

- Selection of scenarios
- Task evaluation
- Data collection methods

**Selection of scenarios**

The scenario selection began with the determination of the operational events that were used to develop the validation tests. Special emphasis were placed on abnormal and emergency conditions to better test AAS and CBP. The operational
events should address the main plant systems and safety functions (the actions to maintain plant safety). Each safety function is associated with plant processes (plant system configurations or success paths) which are responsible for or capable of carrying out the function.

The scenarios contain critical tasks, as identified in the task evaluation. They describe the initial conditions, the proper sequence of plant responses and applicable symptoms.

Task evaluation

The task evaluation must adequately define the personnel task requirements that were used during the validation phase to evaluate the adequacy of the systems HSI, to guide the application of HFE guidelines and support the development of safety performance criteria for the system validation. The information that constitutes the basis for the task evaluation includes documentation of procedures, training, existing task allocations, system design objectives, and often, interviews with operators.

Data collection

The data collection methods that were employed during the test sessions include both online and offline methods. While the online methods assess the variables of interest during the course of a trial, the offline methods involve assessment after the trial is completed. In general, online methods tend to provide finer grained data and, hence, are more useful. However, there is usually a limit to how much online assessment can be performed before measurement becomes obtrusive in the sense of distracting operators from their tasks. That is the reason to employ a mixture of online and offline methods. The nature of this mixture depend on the evaluation objectives.

Online methods that were used during the tests are, for instance, the recording of the event logs from the simulator, the recording of the interactions of the operators with the systems, and the evaluations of the observers. The sequence of crew’s
thoughts and actions, and the key steps in the reasoning process should be observed: the diagnoses, the various identified phases, and the resulting actions.

- Test sessions

A preliminary talk to explain the experiments to the crew take place before the test sessions.

Tests were executed on simulators. During these tests, each operator play his usual part while the evaluation team observe the exercise and document the crew/systems performance.

- Debriefing sessions

A debrief session were carried out after each test session, containing interviews and questionnaires, that allow to go through the problems experienced by the crew and to supplement the real time observations.

In these sessions, the data collection were performed by using offline methods. While the HFE specialist should attempt to collect objective data whenever possible, in some aspects of the evaluation the objective data are not sufficient to enable a complete analysis of a system or test item.

The offline methods that were used in the debrief sessions are questionnaires and interviews:

Structured questionnaires (debriefing questionnaires) administered to the test participants. The test subject questionnaires were examined and tabulated to determine the range of test subject opinions regarding the experiment.

Debriefing interviews with the participants to obtain comments in a less structured, more interactive manner. An interview at the end of the test to note down the crew's comments, to go through the problems experienced and to supplement the real time observations.
Data analysis and results evaluation

The data analysis and results evaluation process consist of four basic phases or steps: transformation, organisation, identification and interpretation.

The first step involves transformation of the raw data into dependent measures of interest. The second step is the organisation of these measures into a form suitable for further analysis. (These steps of transformation and organisation can be expedited by having all raw data in computer-readable files). The third step involves identification of significant main effects and interactions, and if the systems do or not meet the objective criteria defined during the evaluation process. The final step is interpretation of results. This step must be performed by someone with knowledge of the context and situations to which the evaluation is relevant.

The test results were evaluated against the acceptance criteria defined in the validation procedures.

OPERATION PHILOSOPHY AND USER CONCEPT OF ADVANCED HSI SYSTEMS

The introduction of computer-based HSI systems into the control room changes the amount of plant state information available to operators. It also changes the accessibility of the information to different members of the crew. In particular, CBP provides the shift supervisor with the plant state information required to work through the procedural steps. It is no longer necessary for the shift supervisor to ask the board operators to read plant parameter indications off the control board and talk them loud in order for the shift supervisor to determine whether a procedural step is satisfied or not. The CBP provides that information directly.

This change in technology introduces the opportunity to change the traditional roles assigned to crew members in responding to emergencies. A user concept has to be developed which allows the necessary flexibility but assure the minimum forced communication for safety awareness.

A study, based on observations and questionnaires in the early stage of simulator training sessions, has shown large dependency in crew performance on effective crew communication (no specific communication rule was in force at that time).
The new systems allow different levels of use by the operators (large variation from forced rule for communication like as paper procedures to situations with no specific rule for communication as in the NRC study), it has large impact on crew performance. With other words: CBP could shift the content of communication to a higher level that more directly addresses the status of the plant relative to the goals of the procedures and achievement and maintenance of safety functions. It is also possible that by removing the forcing function to communicate, the CBP results in reduced communication and as a consequence the situation awareness among crew members might also be reduced.
Human Factors Guidance Development for Control Room Modernization

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OECD/NEA Workshop on Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms

Halden, Norway

August 23-25, 1999
Outline

- Background
- Description of NUREG-0700, Rev 1
- Development of NUREG-0700, Rev. 2
- Current Status
Background

- Personnel performance is important to NPP safety
  - Supervisory control
  - Component and system maintenance and availability
  - Defense-in-depth safety philosophy

- Events have illustrated the importance of human-system interface (HSI) design to personnel performance and plant risk

- NRC conducts reviews of HSI design to protect public health and safety

- NRC HSI Review Resources
  - Standard Review Plan (NUREG-0800), Revised 1994
  - HFE Program Review Model (NUREG-0711), 1994
  - HSI Design Review Guideline (NUREG-0700, Rev. 1), 1996
  - Numerous supporting documents, such as Regulatory Guides, Information Notices, and NUREG/CRs
Background
NUREG-0700, Rev. 1

- Primary guidance for HSI review

- Originally published in early 1980s to support post TMI control room reviews

- Updated in 1996
  - Review procedures
  - Guidance for general human-computer interface aspects of NPPs
  - Address some of the usability issues

- Update was largely based on available guidance

- NRC planned future revisions to address aspects of HSI technology for which guidance was not available
Background
• Basis for NUREG-0700, Rev 1

NUREG-0711: General HFE Review Criteria

NUREG-0700: Guidelines for Control Room Design Reviews

NUREG/CRs: Guidance Development & Technical Basis

- NUREG/CR-5908: Advanced HSI Guidelines
- NUREG/CR-6105: Advanced Alarm Systems
- NUREG/CR-6146: Local Control Stations

NUREG-0700 Revision 1
• HSI Design Review Guideline
Description of NUREG-0700, Rev. 1
Components

- Review Procedures
- HFE Guidelines
- Design Review Guideline (DRG)
  Software Application

Human-System Interface
Design Review Guideline

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Human Factors Guidance
Review Procedure Overview

- Review objectives
  - Ensure HSI support safe and reliable performance
  - Achieved by ensuring the HSI design deficiencies are identified and resolved

- Scope
  - Interface resources such as alarms, displays, and controls
  - Workstations
  - Workplace layout and environmental factors
Description of NUREG-0700, Rev. 1
Review Phases and Analyses

• Planning

• Prepatory Analyses
  - Operating Experience Review: Identify HSI-related performance issues
  - Function and Task Analysis: Identify HSI requirements and performance criteria for personnel tasks
  - HSI Inventory and Characterization: Identify HSI characteristics, functions, and performance features

• HSI Design Evaluation (see next slide)
  - HSI Task Support Verification
  - HFE Design Verification
  - Integrated System Validation

• Human Engineering Discrepancy (HED) Resolution
  - HED Evaluation: Reviews process for prioritizing and analyzing HEDs
  - Design Improvement Identification: Reviews process for developing design solutions
  - Design Improvement Verification: Verifies that solutions are implemented
Description of NUREG-0700, Rev. 1
HSI Design Evaluation Phase

- HSI Task Support Verification
  - Verifies that the HSI supports task requirements
  - Method is to compare HSI inventory to the criteria derived from task analysis
  - HEDs identified for unsupported task requirements and unnecessary HSIs

- HFE Design Verification
  - Verifies that the HSI design considers human capabilities and limitations
  - Method is to compare detailed HSI design to the criteria derived from HFE guidelines
  - HEDs identified if the design is inconsistent with HFE guidelines

- Integrated System Validation
  - Validates that integrated design meets dynamic performance requirements
  - Criteria derived from task, risk, and system engineering analyses
  - HEDs are identified if dynamic performance criteria are not achieved
Description of NUREG-0700, Rev. 1
Detailed Guideline Topic Areas

1. INFORMATION DISPLAY
   1.1 General Display Guidelines
   1.2 Display Formats
   1.3 Display Elements
   1.4 Data Quality and Update Rate
   1.5 Display Devices

2. USER-SYSTEM INTERACTION
   2.1 General User Input Guidelines
   2.2 User Input Formats
   2.3 Cursors
   2.4 System Response
   2.5 Managing Displays
   2.6 Managing Information
   2.7 Prevention/Detection/Correction of Errors
   2.8 System Security

3. PROCESS CONTROL AND INPUT DEVICES
   3.1 General Control Guidelines
   3.2 Input Devices
   3.3 Conventional Control Devices
   3.4 Control-Display Integration

4. ALARM SYSTEMS
   4.1 General Guidelines
   4.2 Alarm Definition
   4.3 Alarm Processing and Reduction
   4.4 Alarm Prioritization and Availability
   4.5 Display

4. ALARM SYSTEMS (Continued)
   4.6 Control
   4.7 Automated, Dynamic, and Modifiable Characteristics
   4.8 Reliability, Test, Maintenance, and Failure Indication
   4.9 Alarm Response Procedures
   4.10 Control-Display Integration and Layout

5. ANALYSIS AND DECISION AIDS
   5.1 Knowledge-Based Systems

6. INTER-PERSONNEL COMMUNICATION
   6.1 General Communication Guidelines
   6.2 Speech-Based Communication
   6.3 Computer-Based Communication

7. WORKPLACE DESIGN
   7.1 Workstation Configuration
   7.2 Control Room Configuration
   7.3 Environment
   7.4 Panel Layout
   7.5 Panel Labeling

8. LOCAL CONTROL STATIONS
   8.1 Labeling
   8.2 Indication
   8.3 Control
   8.4 Communication
   8.5 Environment
1.1-1 Display Screen Partitioning for HSI Functions
A standard organization should be adopted for the location of HSI functions (such as a data display zone, control zone, message zone) from one display to another. ADDITIONAL INFORMATION: Consistent display formats will help establish and preserve user orientation. Reserved screen areas, for example, might be used for a display title, data output by the computer, display control options, instructions, error messages, and user input and command entry. Display formats should be consistent with accepted usage and existing user habits. NUREG/CR-5908
Description of NUREG-0700, Rev. 1
DRG Software Application

• Review planning
  - Supports compilation of individual guidelines for a specific review

• HSI review
  - Enhances guideline search, access, and navigation
  - Provides electronic checklist and notetaking capabilities
  - Supports field and desktop use

• Analysis and report generation
  - Provides automatic data analysis and report preparation
  - Provides database for subsequent analysis

• Maintenance
  - Supports guideline editing
  - Supports incorporation of new guidelines

• Runs on standard windows-based PC
Description of NUREG-0700, Rev. 1
Lessons Learned

- Guidance was widely adopted both within the nuclear and other industries

- User feedback
  - Generally positive
  - Areas needing improvement have been noted

- Gaps exist
  - Aspects of HSIs for which guidance is limited
Development of NUREG-0700, Rev. 2
Objectives

• Maintain the document as a state-of-the-art design review guide

• Use feedback and lessons learned to improve the technical merit and usability of the guidance

• Address plant modernization and "hybrid" HSIs

• Address gap in important HSI technologies

• Improve review procedures

• Improve DRG software
Development of NUREG-0700, Rev. 2
Guidance Development Methodology Objectives

- Produce valid guidance
- Applicable to any aspect of HSI technology
- Cost conscious (use best available resources)
Development of NUREG-0700, Rev. 2
Validity Considerations

- Internal validity is the degree to which the individual guidelines have a documented technical basis
  - Information upon which the guideline is established and justified
  - Technical bases vary for individual guidelines
  - Audit trail allows
    - The technical merit of the guideline to be evaluated by others
    - A more informed application of the guideline
    - Deviations or exceptions to the guideline to be evaluated

- External validity is the degree to which the guidelines is consistent with nuclear industry human engineering practices
  - Independent peer review
  - Comparison of guidelines to practical operational experience in actual systems by independent field testing

- Both are examined in source material and established as part of the guidance development process
Development of NUREG-0700, Rev. 2
Methodology Overview

HSI Characterization and Analysis of Guidance Needs → Technical Basis Development

Guidance and Internal Validity Development

Unresolved Issues Identification → External Validity Development

External Validity Development

Guidance Integration into NUREG-0700

Technical Basis and Validation in NUREG/CRs
Development of NUREG-0700, Rev. 2
Technical Basis Development

Technical Basis Development

Existing HFE Standards and Guidance Sufficient

Yes

No

HFE Handbooks and Texts Sufficient

Yes

No

Basic Literature Sufficient
Scientific, technical and trade journals

Yes

No

Industry Experience Sufficient
Surveys and interviews with designers and researchers in industry

Yes

No

Original Research Sufficient
Studies conducted specifically to develop review guidance

Yes

No

Guidance Development
• HFE guidelines
• HSI process guidelines
• Review procedures

Internal Validity Development
• Technical basis
• Guidance development methodology

External Validity Development
• Peer review
• Field test and evaluation
• Confirmatory research

Identification of Unresolved Issues
Development of NUREG-0700, Rev. 2
Planned Guidance Enhancements

• Design Review Procedures
  - HFE Program Review Model (NUREG-0711, Rev 1)
  - Integrated system validation (NUREG/CR-6393)
  - Plant modernization process (NUREG/CR-6637)

• HFE Guidelines
  - HSI Characterizations
  - New guidelines for selected topics (gaps), such as computer-based procedures
  - HSI specific design process guidance (for selected topics)

• DRG software
  - General HFE (improved screen design and function operation)
  - Support multiple reviews
  - Enhanced analysis and reporting capabilities
Development of NUREG-0700, Rev. 2
Additional Planned Enhancements

• Guidance generation database
  - One database produces all formats of guidance: hardcopy, checklist, and computer-based

• Guidance tracking database
  - Complete audit history
  - Searchable

• NUREG-0700 suite (CD and/or web-based)
  - Review procedures (NUREG-0700, Vol. 1, Part 1)
  - Evaluation support (DRG)
  - Guidance generation database
  - Guidance tracking database
  - Guidance technical bases (Supporting NUREG/CRs)
Current Status of NUREG-0700 Revision 2

- Most of the new guidance has been developed and the NUREG/CRs will be published shortly.
- Assembling of the draft revision will begin this winter.
- Software revisions have just begun to be investigated.
- Field tests are planned.
- Rev 2 is expected to be completed next fall.
INCORPORATING HUMAN FACTORS IN CONTROL ROOM UPGRADES: THEORY AND PRACTICAL EXPERIENCE

by

Angelia Sebok, Stephen Collier, and Mark Green

Keywords: verification and validation, human factors, control room, interface design

HALDEN PROJECT PARTICIPANTS ONLY

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INCORPORATING HUMAN FACTORS IN CONTROL ROOM UPGRADES: THEORY AND PRACTICAL EXPERIENCE

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ABSTRACT

Human factors issues exist in nearly all aspects of control room design. To optimally integrate human factors in control room upgrades, a systematic, comprehensive, and thorough approach must be taken.

Control room upgrade projects consist of several phases, from conceptual design to implementation. The human factors issues in these projects cover a wide variety of concerns, e.g., control room layout, interface design, procedures, training. Various human factors issues exist in all phases of control room design and upgrades. While human factors input ideally should be incorporated in all of these phases, practical experience often differs. In real control rooms, constraints such as money, time, and conflicting demands limit human factors input.

Experiences at the OECD Halden Reactor Project address these issues. A Verification and Validation plan has been developed to help both regulators and utilities to plan, carry out, and inspect the human factors work in any upgrade. Experimental research addresses the issues in various aspects of control room upgrades (e.g., staffing, interface design, task allocation, automation). Control room upgrade projects provide practical experience and insights into how industry views the potential benefits of human factors input.

Our experiences in control room upgrades in various industries provide lessons learned in terms of technical expertise, an understanding of the issues and the practical constraints, as well as the problems inherent in not addressing these issues. These projects have been performed in a variety of process control industries (e.g., nuclear, petroleum, electrical distribution) and offer a set of diverse perspectives on how human factors is actually included in control room upgrades.

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1. INTRODUCTION

Control rooms are dynamic and changing environments. Due to operational experience, regulatory demands, new technology, ageing of existing systems and other factors, the control room will undergo minor as well as substantial changes in its lifetime (International Atomic Energy Agency, 1995). Typical control room evolutionary projects include the replacement or upgrade of process monitoring systems, re-organisation of hard-wired panels and desks, re-allocation of functions and tasks. The human factors work required to design, test and evaluate a smaller evolutionary change will be considerably different from that for the introduction of a new advanced control room. Evolutionary changes are acknowledged in the literature as an area where the human factors work is both important and needs to be tailored to individual projects. However, very little practical guidance is available.

For a new control room, the full range human factors activities covered by textbooks and international standards may be applicable. However, this type of project is increasingly rare, and so we find that existing guidance becomes ever more in danger of missing the point. If refurbishment changes take place without the necessary human factors work, there is a danger of problems being introduced, even assuming upgraded systems are acceptable when considered in isolation. Problems IFE has found (see, for example, Collier, 1996) relate to integration and the absence of an integrated control room concept. Examples include interface inconsistencies, functional overlaps or gaps, lack of integration between different systems, lack of support for changed ways of working, even duplicated alarms on systems of different vintage. IFE has found such problems both in its own research simulators (see, for example, Sebok et al, 1999) and testing of prototypes, and in the 'real world' of consultancy regarding the upgrading of control rooms.

2. EVOLUTION NOT REVOLUTION

While a comprehensive approach to human factors will ensure integration of systems, such an extensive approach may not be appropriate for all projects. It would be a considerable burden on utilities if they were required to provide evidence on the suitability of refurbishments to the same level of detail as is required for a completely new control room. It would also be a burden on the inspection process. One possibility for a way forward for both a regulator and a licensee is to find a way for previous work to be reused under certain conditions, and to concentrate valuable resources on changes. Both the licensee and regulator would in this method need audit and evaluation tools for assessing what has been done and for directing the course of refurbishments being considered.

For evolutionary changes, information often exists already, such as analyses from previous design documents, procedures, and operation experience. Together, as IEC 1771 (1995) points out, these can constitute an important pre-validated data set. This data set can be
used to meet some of the requirements of the human factors design and evaluation process, although issues such as the degree of change and the quality of existing material must obviously also be taken into account. Consequently, IEC 1771 (1995) notes that the activities need to be tailored to the particular needs and circumstances of individual projects.

How can one discover the areas where work needs to be concentrated, or to show where a proposed solution is deficient? The IEC 1771 standard draws attention to two important principles when deciding the requirements for projects of this nature. These are the 'degree of innovation' and the possibility of 'qualification by similarity'.

The degree of innovation relates to those areas of innovation in the change and concentrates activities on them. The degree of innovation varies along a continuum from a replica of an existing design, which would require very little new work to make it licensable, to an evolutionary design requiring selected activities, to an advanced and relatively distantly related design requiring the full scope of activities. For evolutionary changes, activities can be concentrated on the areas of change and their integration with existing, proven features of the design (IEC 1771, 1995).

Qualification by similarity relates to the extent to which a new design or modification contains features that are already proven. IEC 1771 suggests that qualification by similarity is applicable if it can be shown that "the differences between the old and the new systems or equipment do not affect performance or that performance is superior" (IEC, 1995, p. 53). IFE has begun to consider how both of these principles can be applied to human factors work.

The open literature gives little concrete guidance on how the human factors work necessary for these sorts of changes should be determined. Recent research work at Halden (e.g., Collier and Green, 1999) and bilateral work for several of our clients have begun to address these problems. IFE has repeatedly met these issues in a variety of upgrade projects. Before learning some practical lessons from these projects, we briefly summarise our recent, more theoretical work on the verification and validation of human factors work.

3. VERIFICATION AND VALIDATION OF HUMAN FACTORS

As we have noted, systems, facilities and equipment are periodically updated during a power plant's lifetime. This has human factors implications, especially if the central control room is involved. Human factors work may therefore be required. There is extensive literature on human factors itself, but not so much on how it is verified and validated. Therefore, HRP performed a study to review the literature and establish a knowledge base on verification and validation of human factors issues (Collier and Green, 1999). The report first discusses verification and validation (V&V) as applied to human factors work. It describes a design process and the typical human factors topics involved. It then presents a generic method for V&V of human factors. This is built on a review of standards, guidelines, and other references.

Presented at the NEA/IAEA Workshop Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms, Halden, Norway, 23–25 August, 1999
The V & V model given in IEC (1995) and generalised in Collier and Green (1999) offers an overall plan for how human factors should ideally be implemented in a design process. Essentially, verification and validation are included throughout the design process, not merely as a step at the end. In reality, work is often necessarily carried out differently from such an idealised plan. Or experience is that in safety-critical industries (or rather, industries where the perceived risk is high), human factors as an engineering subject is recognised as having value. However, in many other industries, the approach is on an issue-by-issue basis. There is much interest in control room layout, interface design, alarm systems: issues where the human factors contribution is readily apparent. However, the scope of these projects is often restricted to the design phase. Different techniques are used in these limited-scope projects to ensure, to the extent possible, V&V throughout the design phase.

4. PRESENT STATE OF THE INDUSTRY: DIVERSE PERSPECTIVES

We now describe our experiences with control room upgrade projects in a diverse set of industries. These experiences vary across high-risk industries, such as nuclear and petroleum, to perceived-lower-risk industries including electrical distribution and steel manufacturing.

4.1 Nuclear Industry

In the nuclear industry, where safety is a primary concern, the need for human factors input has long been recognised. Human factors input into nuclear power plant control room design is sought at initial design phases as well as in modifications.

4.1.1 Philosophy Development

In one project, a client was interested in a philosophy for a series of upgrades in the future. Such foresightedness itself was promising, but on the other hand it was difficult to predict the course of the future for the next 5 to 10 years. A general design philosophy was developed to guide the future upgrades.

General findings in the present-day control room revealed the need for a comprehensive approach. Control room layout and workstation layout were both found to be less than optimal due to compounding minor changes over years of usage. A lack of an integrated plan or vision for the control room resulted in systems being added without being integrated. Tasks and responsibilities changed over time, without the corresponding necessary changes being made in the control room. This resulted in conflicting systems and insufficient support at the workstation for operator tasks. Similarly, the interfaces with which operators work were found to vary. Operators had several different types of interfaces at their workstations, and these differed in terms of displays, controls, and functionality. Similarly, alarm systems were not fully integrated and individual systems were not fully exploited. Newer systems
were not necessarily improvements on old ones, and there were occasions of overlapping functionality.

The design philosophy produced for this client included guidance for a series of upgrading steps. We determined the human factors implications for each of these steps. To reduce the burden on the customer, we indicated where existing work could be used as part of the case for verification, validation and licensing, and where new work might be needed.

4.1.2 Control Room Modernisation

HRP is currently performing a long-term project at another nuclear plant. The utility is modernising one of their three control rooms, and has been working with IFE since 1995 to ensure that human factors issues are addressed in a systematic and comprehensive manner. The project includes human factors input in developing a design philosophy, control room design, specific interface component design, and experimental validation studies.

The philosophy describes how the control room and interface design should support users in performing their tasks. It provides the framework by which the design will later be evaluated.

The control room design addressed layout issues, crew workstation design, usability, visibility, and accessibility. This project was performed with the help of Virtual Reality (VR) technology. Potential designs were modelled in VR and discussed with operators and human factors specialists. Using such a visualisation tool, potential problems become apparent and are easily remedied early in the design process.

Another aspect of this project concerns interface design. The hard-panel instrumentation and control systems are being replaced with advanced technology. Thus, the human machine interface must be designed and evaluated for individual computerised displays, large screen overview displays, and alarm systems. For this phase of the project, V&V is performed as an integral part of the design process. Potential designs are developed, based on task requirements and the design philosophy, and are evaluated against guidelines, human factors expertise, and operator expertise. The large screen overview is also evaluated through the use of VR models.

At the end of the design phase, a set of experimental studies are planned to ensure that operator performance in the new plant design is at least equivalent to operator performance in the current plants. Performance measures such as situation awareness, operator performance, workload will be used for these assessments. The continual V&V steps throughout the project will hopefully eliminate major surprises (i.e., identification of major problems in the design) at this point. However, an entire control room is not simply the sum of its parts, and this study is being conducted to identify potential problems with the integration of these components.
4.1.3 Experimental Validation Studies

Another series of HRP projects in the nuclear industry include experimental validations; identifying and comparing human performance in different plant and interface conditions. Several experiments have been performed (Hallbert et al, 1996; O'Hara et al, 1997; Hollnagel and Miberg, 1999), and others are being planned, whereby these different plant types or interface conditions are being evaluated.

4.1.4 Summary

In general, the approach to human factors in the nuclear industry is comprehensive, addressing human factors aspects in control room design, interface design, alarm system design, as well as developing and specifying the philosophy guiding the design. Verification and validation checks, using guidelines and experimental studies, are planned and performed.

4.2 Petroleum Industry

In the petroleum industry, like the nuclear industry, safety is a major concern. Human factors input, in recent years, has been limited to control room designs and interface evaluations. More recently, a project was performed in which incident reports were analysed with the goal of improving safety on the oil platforms. The result of this project was a new system for reporting incidents, training on this system, and a closed feedback loop, whereby lessons learned from the incidents can be applied to future system designs, training, and work practices.

A project has just been initiated to take a comprehensive approach to human factors input: developing a methodology for evaluating and ensuring that human factors has been appropriately accounted for in oil platform control rooms. This methodology will refer evaluators to relevant guidelines, and guide them in evaluating if human factors issues have been appropriately accounted for in a wide variety of circumstances. The topics to be addressed by this methodology cover a wide range of human factors issues (e.g., control room layout, interface design, procedures). A feedback loop will be developed to ensure that deficiencies identified can be remedied and re-evaluated.

4.3 Electrical Distribution Industry

In contrast to the nuclear and petroleum industries, the electrical distribution industry is not perceived as safety critical. Blackouts may occur, but are minor compared to accidents like Chernobyl or Piper Alpha. The electrical distribution industry, to a limited extent, recognises the value of human factors input, particularly related to control room and interface design. HRP has performed projects in these areas for the electrical distribution industry. Control room projects involve analysing work practices, identifying layouts, developing and proposing design solutions, and using VR models for a talk-through
validation. The interface design projects vary from piecemeal evaluations (e.g., looking at a few displays and offering comments) to the development of general HMI guidelines and detailed design specifications.

Based on our experience, general findings in this industry are that interfaces are diverse rather than unified and offer conflicting functionality. At times, operators must take a print out from one computer system to manually type in the same data to another computer system. Alarm systems are not integrated. This lack of integration leads to increased potential for human error; potential for suboptimal choices of generation sites, network connections, and electricity trading; and a less than optimal working environment.

While attempts have been made to suggest a more comprehensive approach, the industry presently does not appear to perceive the value. Based on our experiences, the industry’s approach to V&V is “trial and error.” Presently, no benefit is seen in reviewing previous incidents and accidents because they are considered too infrequent and not controllable. However, within specific areas, such as information presentation on computer interfaces, the need for human factors input is clearly recognised.

4.4 Other Process Control Industries

In addition to nuclear, petroleum, electrical distribution, HRP has experiences in other process control industries. A general finding from these industries is that a lack of a clearly-defined approach regarding the control room has led to diverse and conflicting systems being installed and equipment and work areas being inadequate to meet changing task demands. Different types of projects have been performed, based on the customer’s request. In one industry, the project included developing guidelines for interface design and then ensuring, through a series of validations, that the new design sufficiently met these requirements.

Another project included a control room consolidation: three control rooms were being merged into one. A severe restriction on this project was that no equipment was to be changed. In each of the control rooms, operators worked with diverse and conflicting interfaces. When the three rooms were placed together, these inconsistencies would be intensified. Since the customer was not interested in developing a philosophy or evaluating the design, HPR took an alternative approach. In addition to recommendations for the combined control room, a more ideal and integrated design approach was presented. This may not be implemented by the customer in the near future, but they have the information available to make such decisions when the need becomes apparent.

5. CONCLUSIONS

We have seen considerable evidence that industrial clients see the value of a human factors programme. Those that are highly regulated are willing to invest in a far-sighted programme. Even so, these and other, less-regulated industries face the continual problems of piecemeal upgrading and its consequent problems of lack of integration, inadequately planned functionality, and their impact on operations and even licensability.

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A standard approach can be used for the planning of V&V and human factors work in an upgrade project. This approach should be applied throughout an upgrade project. The amount of new work needed in a project is related to the degree of change. Some time spent with this type of planning should be repaid in the long term by a better integrated and more functional control room. If licensing is an issue for a particular industry, the adoption of an upgrade process will make it easier to collect and present the type of evidence that a regulator will need to license the upgrade. We hope that our emphasis on the process as well as the products of human factors work in upgrades will find broad applicability.

REFERENCES


Human factors and operation aspects in computerisation of the control room: a French safety view based on N4 experience

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1. The new N4 series

The N4 reactor series is part of a continuation of the French nuclear programme. It is an innovative series, both in terms of technology and in terms of the integration of human performance into the design.

While the new series is in some respects a continuation of the P'4 series [3.], it includes several innovations (steam generators, turbine, reactor vessel, and primary pumps), especially as regards the instrumentation and control system which is computerised. Indeed, the French operator Electricité de France (EDF) decided to "build a wholly computerised control room, capable not only of receiving operator commands but also of diagnosing problems, prioritising alarms and displaying the appropriate operating procedures to operators" [2.], in particular with the new state-oriented approach emergency operating procedures. The decision was strongly motivated by the Three Mile Island accident when the importance of the information displayed for operators in the control room and the way it was processed by them was realised.

Computerisation of the control room was a major innovation, because no other control rooms of this type had been built in nuclear power plants [3.]. Moreover, EDF decided to develop a study simulator (S3C) to support the design of the computerised control system and validate use of the control room, particularly the operator workstations. It was an innovative aspect of the N4 series to take into account human factor aspects in the design approach of the new computerised control room. To do this, EDF devoted a considerable effort to ergonomic assessment carried out on the S3C simulator: from 1986 to 1996, several successive ergonomic validation trials have been realized with operating teams on simulator.

The objective of this paper is to present the contribution of the Institute for Protection and Nuclear Safety (IPSN), the technical support of the French safety regulatory authority (DSIN), and the lessons learned from the experience gained, as regards safety in the design and evaluation of a computerized control room.

During the design, the IPSN assessment concerned topics such as: operation with the computerized control system, operation with the auxiliary control panel, management of the computerized control system failures, organization of the operating team, operation team training. This assessment was mostly based on results from trials on simulator, and allowed to identify positive aspects but also difficulties to operate with the new control room.
2. Ergonomic evaluation in the design of the N4 control room

In this chapter, we provide a short description of the ergonomic evaluation performed by EDF during the design of the N4 control room.

2.1 First test series (1987-1994)\(^1\)

2.1.1 Evaluation methodology

Main features of the methodology for the evaluation are:

- a multidisciplinary team, including operations specialists, designers of computerised stations, instructors, ergonomists, occupational doctors (for the first test series) and data analysis experts.

- evaluation themes as follows:
  - physical and environmental aspects of the control room: it concerns the design and physical environment (temperature, noise, light) of the workstation as well as the visual aspects (legibility of the information, evaluation of the influence of screen-based operations on visual fatigue, etc.).
  - man-machine interface. This theme concerns consistency of interaction and presentation modes. Particular attention is paid to work station management aspects.
  - cognitive aspects. It refers to the study of the functions which play a part in information processing by the operator (perception, memory, reasoning, etc.). This topic seeks to deal with everything connected with the operator's knowledge and the role of this knowledge in processing information and carrying out actions.
  - organisational aspects. It concerns the suitability of the computerised control room for the operating crew (interaction, coordination of actions, tasks allocation, ...).

Each theme gave rise to the definition of hypotheses concerning the points to be analysed, in particular to ensure that the computerised control room is suitable for operating.

- list of observables developed for each hypothesis. Observables are elements of operator activity (use of the panel, means of interaction, verbal communication, direction of looks, etc.) or of the process condition (appearance of an alarm, change in the process state, etc.) which are collected during tests on simulator.

- post-test interviews. Main objectives are to obtain explanations from the operations team on the particular problems encountered during tests, and to get a general opinion on the control room. These interviews were carefully prepared, based on interview guides according to the themes, and data observed during the test.

2.1.2 Test series and results

From 1987 to 1994, three series of tests were carried out by EDF on the S3C simulator for the ergonomic evaluation of the N4 control room:

- first one took place in 1987. The control room then consisted of two operator stations and the wall mimic panel. This series consisted of 200 tests in which eight different crews took part, made up of two

\(^1\) The description of the first test series is partly based on an EDF article in RGN review (cf. [4.]).
operators and a shift supervisor. Eighteen scenarios were devised, including ten lasting 8 hours during which there was a shift turnover.

- second series took place in 1989. It consisted of about 50 tests with about 15 scenarios. It involved 6 teams all made up of two operators to which were added, in four cases, a shift supervisor and an engineer playing the role of a safety engineer. The S3C simulator has been modified: addition of a third station, introduction of computerised procedures, and modification resulting from the first series (alarm dialogue, setting up of the operator workstations, etc.).

- third series of tests took place in 1994, and consisted of 48 tests with some ten-scenarios. Four complete teams participated in the tests. With respect to previous series, major changes in the S3C simulator were the setting up of an auxiliary panel (conventional panel for use in case of breakdown of the computerised control system), the addition of a fourth station, and the introduction of accident procedures. Then, this series of tests focused mainly on operation in incidental and accidental situation, and on operation with the auxiliary panel.

From the point of view of EDF [4.], these series of tests allowed to validate the concept of computerised control room, and some design choices as the wall mimic panel, the computerised procedures for incident and accident situations, etc. They also allowed to identify problems posed by certain design choices, and showed the need for considering changes in the role of the operator resulting from computerised procedures, as well as shift supervisor's role and resources in an incident situation. From a general point of view, EDF considers that the three series of tests allowed a large number of problems to be anticipated and to bring in modifications during design.

2.2 A fourth series of tests on S3C simulator (1996)

The latest series of tests for the ergonomic evaluation took place in 1996. It concerned 15 tests with 5 different scenarios, involving three complete teams. The tests focused on operating in incident and accidental situations.

The main changes regarding previous tests concerned the methodology. Indeed, in this fourth series, the objective was no more to check hypotheses associated to quantitative analysis, but to investigate some themes on the basis of facts, observed during the tests, which are considered as important for operation, and the results of a qualitative analysis of these facts.

3. Main aspects of IPSN's contribution to N4 safety assessment

This chapter is partly based on the IPSN article in RGN review (cf. [5.]), which contains a presentation of the safety assessment of human factors aspects in N4 series.

3.1 Initial preoccupations as regards safety

In 1984, the two major questions relating to safety were as follows:
- can the unit be operated acceptably with a computer system?
- can the unit be operated acceptably if the computer system fails?
There was no clear-cut answer to these questions due to lack of experience in the matter, for although the eighties saw the arrival on the industrial scene of an ever-increasing number of computer systems and alphanumeric display screens (digital instrumentation and control systems) replacing analogue panels, no computerised control room of the N4 type had ever been built in a nuclear plant.

In 1984, first IPSN's questions on human factors aspects focused on basic issues which can be summed up as follows:

- Influence of computerisation on operating activities, particularly in incident or accident situations:
  - Influence on how data was collected and processed,
  - Influence on coordination within the team (organisational aspects),
  - Influence of on-screen alarm displays,
  - Influence on how orientation errors were retrieved by operators,
  - Operating imagery management,
  - Extent to which operating procedures were suited to operator objectives as regards operation.

- Instrumentation and control failures.

- Extent to which S3C simulator was representative.

EDF was also questioned about the influence of alarm management on operation, and about the interaction between operation and other departments (maintenance, periodic tests, monitoring and availability of safety-related equipment).

3.2 Methodological aspects: simulator assessments and experience feedback

The IPSN stated its position on the methodological aspects very early on. Indeed, although it left EDF responsible for selecting the solutions for carrying out assessments from a human factor point of view, the IPSN asked to be allowed to assess not only the results of the validations but also to give its opinion on the specifications, the methods envisaged and the resources used by the nuclear operator to put forward its safety demonstration.

In particular, the IPSN made sure that ergonomic assessments were made in conditions which could guarantee the validity of the data collected and the analyses made (choice of issues, observation and data collection methods, operator profiles, choice of scenario etc.) by the teams responsible for making ergonomic observations and analyses. The IPSN also concentrated on the degree to which the S3C simulator was representative of the actual N4 control room.

On the basis of results from the third tests series in 1994, the IPSN recommended EDF to do some more tests, that encouraged the operator to run additional specific tests in 1995, to make ergonomic observations during on-site hot tests and to run a fourth series of tests in 1996 on the S3C simulator.

Furthermore, the IPSN paid special attention to the experience feedback which was likely to be gained from the early operating stages after start-up of the units in the N4 series. In particular, it requested EDF to make an ergonomic assessment of the use of the control room during start-up and the first operating cycle of the Chooz B1 Nuclear Power Plant.
3.3 Main issues dealt with by the IPSN

During the safety assessment, the IPSN dealt with the human factor aspects which seemed to be important for safety, including the following:

1. operation with the Computerised Control System: can the Computerised Control System be operated satisfactorily, particularly in incident and accident situations?

2. auxiliary control panel: when the Computerised Control System fails, can the team switch satisfactorily to the auxiliary control panel, particularly in incident and accident situations?

3. management of Computerised Control System faults by the operating team: how can uninterrupted operation be guaranteed if one of the components of the Computerised Control System, or even the entire system, fails? How can the switch be made from the Computerised Control System to the auxiliary control panel? What strategy should be adopted when the failure cannot be detected by the system?

4. control team organisational structure: can communication and coordination within the control team take place satisfactorily with resources available to the team in the control room?

5. control team training: do the members of the control team have the resources needed to develop and maintain the skills required to operate the unit, particularly in incident and accident situations?

3.3.1 Operation using the Computerised Control System

During the early stages of the safety assessment, the requests made by the DSIN were aimed at encouraging EDF to validate normal and accident operation on the simulator, paying special attention to how operation was organised and to operating procedures. One of the main concerns was that operating interface management activities (dialogues giving access to images and activating commands) would not have to take precedence over process operation.

There were even more requests from 1994 onwards due to the problems encountered during third series of tests. The problems were to do with various aspects of operation (images on screen, information for shift turnover, documentation, etc.).

But they had also to do with the difficulties teams had in understanding the operating logic of the computerised procedures. For example, the Computerised Control System guides the operator; it orients the execution of individual instructions and procedure changes. To do this, the computerised guide system checks the path followed by the operator in his procedure; the underlying mechanisms are not always understood by operators and sometimes they wander off the prescribed path or the team does not completely follow all the rules for using the operating procedure. The IPSN also wondered about the effect of computerised operation on the overall vision operators had of objectives and operating strategies with computerised procedures.

3.3.1.1 Operation and alarm management

During the first series of tests in 1987-88, the IPSN contributed to this subject in an intermediate report which dealt mainly with alarm processing: prioritising of alarms, clearance, most frequent alarms, filtering alarms, etc. The IPSN compared the results obtained with the S3C simulator and the P4 series simulator at Paluel NPP: number of alarms appearing during two scenarios, including steam generator tube rup-
ture. A higher number of alarms was displayed on the conventional P4 panel than on the S3C: "the tests on the Paluel simulator showed that the majority of the alarms, for the most part yellow or white, appearing on the screen were not required to bring the situation back to normal".

EDF upgraded the alarm management dialogue between first and second series of tests. The upgrades gave satisfactory results, particularly by providing a better separation between the display and alarm processing functions. The alarm filtering function, which limits the alarms displayed to those which are deemed necessary for operation, was also seen as a way of facilitating operator action.

3.3.1.2 Operation with « mixed » accident operating procedures

Operation with mixed accident operating procedures is something of a special problem encountered during the transition period where only part of the procedures are computerised: only the orientation and re-orientation modules, along with one of the procedure modules, are computerised. The other modules are still printed on paper: the wholly computerised set of procedures was delivered at mid 1998 and is available only in Civaux 2 plant.

The third series of tests highlighted the problems caused by the switch from computerised procedures to paper procedures when the operator has to adopt a different strategy and change procedures according to the state of the unit.

3.3.2 Operation using the auxiliary control panel

In case of breakdown and loss of the computerised control system, the operation team have to switch to the auxiliary conventional control panel in the control room. This was very soon an important issue for the safety authority. EDF was asked to show that:

- operation using the auxiliary panel was satisfactory, regardless of the state of the unit,
- the “paper” procedures corresponding to incident and accident operation from the auxiliary control panel allowed the auxiliary control panel to be operated satisfactorily,
- the operating teams had the resources required for training and practice in the use of the auxiliary control panel.

During first tests series in 1987 and 1989, the S3C simulator was not equipped with an auxiliary control panel. IPSN assessments and DSIN requests resulted in EDF equipping the simulator with an auxiliary panel for training operating teams and for validation of operation using the auxiliary panel on S3C during further tests series.

The third tests series revealed problems for operating team members with data acquisition (reading parameters, video recorders, etc.), and with the use of paper procedures. EDF improved the paper procedures and the way in which information was presented on the auxiliary control panel.

A mural mimic panel supplemented the information given on the auxiliary control panel and was very much appreciated by the teams. Cooperation within the team was satisfactory and there was a good level of redundancy between the supervisor and the safety engineer on the auxiliary control panel.
3.3.3 Computerised Control System failure

When preparing its safety assessment report, the IPSN highlighted other areas of concern associated with possible failure of the Computerised Control System:

- switch from the Computerised Control System to the auxiliary control panel and back again: procedure to switch from the Computerised System to the auxiliary control panel, return to the Computerised System, criteria for switching from Computerised System to auxiliary control panel, change in man-machine interface, switch from computerised procedures to paper procedures.

The difficulties which occurred during the third tests series in 1994 meant that the procedures had to be improved.

- mixed interface operation, in the event of partial failure of the Computerised Control System: loss of screens or workstations, reconfiguration of workstation or redeployment of team according to equipment still available.

Some problems were encountered during the third tests series in 1994. EDF was asked to take these problems into account in its training actions and operating documents, and to validate the improvements during further tests series.

- faults unknown: these are residual failures which the computer system cannot detect on its own. The operator therefore has to detect this type of fault and take the necessary action.

This problem, already raised by IPSN in 1984, was taken into account later in 1993, leading the DSIN to request EDF that resources be made available to the operator to assist him in identifying and dealing with unknown failures, and that operators be trained in this matter.

3.3.4 Organisational aspects in operation

In 1984, some IPSN questions concerned the consequences of control room computerisation on coordination within the operating team. During the first tests series of the EDF ergonomic evaluation, the organisational aspects were considered as a real issue with specific observations being made during the tests.

From the third series in 1994, the analysis focused on the roles and resources of the supervisor and the safety engineer in incident and accident situations. There did not appear to be much advantage in allocating a computer workstation to the safety engineer; EDF decided to systematically place the safety engineer beside the auxiliary control panel as soon as accident situation operation began.

Many problems appeared concerning the role and resources of the supervisor, some of which persisted during subsequent tests and during training courses. EDF has designed a new set of images for the supervisor workstation in 1998.

Finally, the analysis made by the IPSN also dealt with the new way in which operation was organised at Chooz B1 Nuclear Power Plant (the first in the N4 series): while certain concerns were specific to the unit start-up situation, others echoed the questions already mentioned as to the roles and resources of the supervisor and safety engineer.
3.3.5 Operating team training

Operating team training was dealt with in the early stages of the assessment. EDF had to be encouraged to train operating teams in use of the auxiliary control panel, and for this to be possible, the S3C simulator had to be equipped with one.

From 1994 onwards, the concerns were more varied in nature, covering particular points to be included in training courses, training process validation, maintenance of competence (retraining courses), etc.

4. Integration of Human Factors in design and safety assessment

4.1 Human factors in the safety assessment of N4 control room design

Generally speaking, the position occupied by the human factor in N4 series safety assessment can be divided into three periods:

1. prior to 1983, when assessment began, analysis of the human factor did not appear explicitly in the N4 series safety assessment,

2. between 1983 and 1991, the control room was the focus of attention, and human factor specialists considered issues as varied as control room and workstation layout, the man-machine dialogue, the amount of thinking operators had to do, alarm management, problems relating to eye fatigue and shift work, operator training and how operation was organised.

3. finally, between 1993 and 1997, incident and accident operation using the computerised control room became the most important issue, capturing the attention of human factor specialists who focused on the man-machine interface and operating team training and organisation.

4.1.1 Methodological aspects

At the beginning of the N4 design, in 1983 and 1984, the IPSN analysed the functional specification reports submitted by EDF, including those relating to the S3C simulator. In addition to the specifications, the IPSN took the following elements into account when it was analysing the human factor aspects:

- general data on operator activity in the control room, obtained from previous IPSN studies: several reports were published by the IPSN on safety in computerised control rooms seen from a human factor point of view, on the methods used to analyse operator activity in the process control industry which were also applicable to the nuclear industry and on examples of how work analysis methods could be applied to various sectors of industry.

- the results obtained for certain problems relating to PWR accident operation from a human factor point of view, due mainly to studies carried out in 1982 on the CP1 simulator at Bugey Nuclear Power Plant in the context of a four-party agreement (French Atomic Energy Commission (CEA), EDF, Framatome and Westinghouse).

When EDF began to prepare the ergonomic evaluation, the IPSN’s main objective was to gather important facts and information on the solutions envisaged for the N4 series, which meant working in close collaboration with the EDF teams during the first and second series of tests.
During these tests, IPSN human factors specialists took part in the EDF assessment group: they were involved in all stages of the assessment: test preparation and data collation, processing and analysis. When the results of the second tests series were due to be analysed, analysis of the "role and activity of the safety engineer in the control room" was entrusted to IPSN ergonomics specialists [1].

After the second series of tests, when the main objective was to gather essential facts and information on the computerised control room of the N4 series, the IPSN no more participated directly in EDF’s working groups, and focused on its safety assessment objectives.

From 1993 onwards, the IPSN human factor specialists no more participated to the evaluation team of EDF. However, the IPSN requested to be present at a sample of the tests series in order to get an idea of the context of the tests, the way the data are collected, etc. as well as to better identify the most important aspects of the activities of the operating team and the difficulties encountered by the operators.

For example, during the tests series carried out in 1996, two IPSN people participated in 6 of the 15 tests, but not in the post-test interviews, and the log was not handed over.

4.1.2 Methodology requirements for assessing the safety of human factor aspects

In order to be able to assess the safety of human factor aspects, IPSN human factors specialists requested to have some more information than the one provided in the report submitted by EDF. Information on how individuals and teams operate in different situations can be obtained by observing an actual existing system or by observing tests on a simulator (experiments, training and drills). This was the case when IPSN asked to attend some of the tests on the S3C simulator in order to make their own observations.

In fact, ergonomics specialists rarely possess a priori the information and facts they require to assess such complicated matters as control rooms: ergonomic assessments cannot be made on the basis of specifications alone. But they can perfectly well give their opinion at the beginning of the design stage, based, for example, on experience feedback from plants of the same kind. They can also give their opinion a posteriori after carrying out experiments in real situations or on a simulator.

4.2 Some lessons from the N4 design experience

4.2.1 Approach used for ergonomic evaluation

Because of its scope, the ergonomic assessment of the computerised control of the N4 series is unique in the contribution made by the human factor to the design of a nuclear power plant in France. Regarding previous design in the nuclear field, a lot of effort has been devoted by EDF to the ergonomic evaluation of the control room.

But from the first tests series in 1987 to the latest one in 1996, there has been an important evolution in the methodology used for ergonomic validation: during the first and second tests series (1987 and 1989), the objectives of the tests were mainly to get quantitative data to confirm or not some general principles considered a priori as important for the human factors aspects in the design. The approach was characteristic of a technology driven experimentation, as stated by Vicente in [6].

The third series of tests was something intermediate to the fourth one which can be considered as more « ecological » in the way that « human operator and work environment are reciprocally coupled and can-
not be studied independently of one another» [6]. In this approach, it is not the behaviour of the operators observed on the simulator which determine the validation of a technical solution, it is the qualitative analysis of the most important events observed during the scenarios which provide information for design choices of the system. These important events come from the couple human operator and work environment when performing on the simulator a task like managing an incidental situation.

This approach brings a better understanding and explanation of what is observed during the tests, because the objective is not to check some a priori defined model of behaviour and operation, but to get some information on why some events (negative as well as positive on the operation) have occurred. It has provided some fruitful results when applied during the fourth series of tests on simulator.

4.2.2 Use of the S3C simulator

As the human factors integration is mostly based on the ergonomic evaluation with the S3C simulator, the use of the simulator in the evaluation process can be questionned on following points:

- the first experimentation has been realised on S3C simulator five years after the beginning of the design process. Some important design choices had already been made.
- during the two first series of tests, the simulator was not complete, and then it was not possible to simulate a realistic task environment.
- because the N4 control room was developed in parallel with S3C, there were some important time constraints on the scheduling of the experimentation. There were also some technical and scheduling difficulties for upgrading the S3C simulator according to the evolution in the design and realisation of the N4 control room, in order for the simulator to be as much representative as possible.
- the S3C simulator was used also for the functional verification and validation of the computerised control system, as well as for the training of the operators, that put also some more constraints on the experimentation.
- the S3C simulator is not completely representative of the real N4 design: process simulated (1300 MW series), response times, differences in the man-machine interface, etc.
- with a simulator, it is not possible to take into account issues related to interactions with the environment of the control room (other departments,...), nor to simulate shutdown states.

The use of the S3C simulator during the N4 design process has been very important for the integration of human factors. It has given elements for validating the general concept of a computerised control room, as well as computer-based operating procedures. A lot of modifications have been made on the basis of results from the tests realised on S3C: for example the arrangement and number of workstations in the control room, the number and arrangement of screens for each workstation, the layout of screens (a lot of modifications concerned images, labels, colour coding, information presented, vocabulary and text, etc.).

But the way the S3C has been developed and used in the design process has also put some constraints and limits on the validation process.

This could be a recommendation for future design of new control room and computerised system for operation, to use as soon as possible in the design process some mock-ups (not complete, not reusable), in order to evaluate and validate the main concepts. It seems important not to wait for a full-scale simulator to be ready before to do some ergonomic evaluation, because it is then too late to modify main design
choices, orientations and specifications: this could lead to a situation where the most important results of the tests cannot be taken into account in the design of the real system.

Another comment is that a simulator can never be complete and realistic, it cannot take into account the same work environment as on site, and it cannot be available soon in the design process. Then, a full-scope simulator must be considered, not as the only one tool, but as one tool amongst others for ergonomic evaluation all along the design process. In particular, one very important tool to be used during the first step of design is task analysis from existing situations in other plant still operating or in similar processes and tasks from other industrial domains. This task analysis gives useful information on operation needs for the elaboration of design principles and choices in the specification phase.

That is why it is also important to take carefully into account the operational experience: an ergonomic evaluation has been realised by EDF during normal operation in Chooz B1, and is on the way to be analysed. The analysis of events and incidents is also performed and taken into account.

4.2.3 Computer-based procedures

As regards results from the tests series, the state-oriented approach emergency operating procedures and the computerized control system can be considered as positive and helpful concepts for the safety. In general, the operating teams feel comfortable with them. However, some difficulties arise when the operating strategy provided by these procedures is not completely adapted to the situation perceived by the operators, that is emphasized by the computerization of procedures.

For the moment, there is only few experience feedback to be gained from the N4 plants in operation, but some first lessons could be learnt from it, especially regarding operating procedures.

The analysis of Civaux 1 incident (12 May 1998) shows that the operators have realised three times some actions out of the required procedure, that is not allowed. It shows also that the guidance provided by the computerised control system constitute an effective support for the operator when the strategy proposed is consistent with the current status of the process, but at the opposite it is a constraint when the operator does not follow the orientations provided by the system, or when the system is no more consistent with the current status of the process. This can lead to important delays in realisation of actions important for safety. Moreover, it seems that the members of the operation team, when they have some doubt, accept without question the solution provided by the computerised control system. This ask for question about the level of autonomy given to the operators when applying operating procedures.

Then it seems that this first experience feedback confirm the difficulties observed during the last series of tests on S3C simulator arising from the lack of understanding of the internal logic of the procedures, and of the guidance and check realised by the computerised system.

These first findings can be relied to conclusions from the BNL report [7] on hybrid human-system interfaces, especially following points:

- computer-based systems add to plant complexity: there is the need for operators to have a good mental model or understanding of the computer-based system,
- computer-based systems are not sufficiently observable: that is, they do not make clear their reasoning basis and do not have adequate communication facilities to enable operators to ask questions and otherwise verify system performance.
5. Conclusion

Due to the innovative feature of the N4 series control room, and as regards the experience gained in its design and evaluation, the concept of fully computerized operating systems is now in use on sites. A lot of effort has been made by the nuclear operator EDF and by the safety authority to validate from a human factors point of view the concept of computerized control room and computer-based operation in the control room of N4.

The ergonomic evaluation series of tests have provided useful and positive outcomes based on S3C simulator, but have raised some difficulties which seems to be confirmed by the operational experience feedback. Careful analysis of this experience has to be taken into account from now on.

For design of any new control rooms, in existing plant or in new plant as for instance European Pressurized water Reactor (EPR), some recommendations can be provided about main design choices (partial or full computerization, level of guidance, types of support and tools for operation, ...), which would need further investigation taking into account the N4 series experience and others as well. In particular, and because computerized control system add to plant complexity, human factors in the design process has to be integrated at the initial step of the design in a structured and formalized way, as the one described in NUREG-0711 [8].

6. References


VALIDATION OF
CONTROL ROOM UPGRADES

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- All four Swedish NPPs
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Terminology

- The term "verification" originates from Latin *versus* - truth

- The term "validation" originates from Latin *valere* - strength

In both cases, something is to be confirmed
Verification/Validation

- Verification refers to the technical specifications
- Validation refers to the actual functional requirements
Verification/Validation

- Verification often focuses on components (or parts) of the system
  (cf. system tests)

- Validation often focuses on the complete integrated system including users, control room, control system and process
  (cf. acceptance test)
Definition

ISO 8402 "Quality management and quality assurance - Vocabulary"

2.18 validation
confirmation by examination and provision of objective evidence (2.19) that the particular requirements for a specific intended use are fulfilled
Good practice

- International expertise
- Literature
- Own experience
International expertise

- ABB
- Brookhaven National Laboratory
- EdF
- Halden
- Ohio State University
- University of Toronto
- VTT
- Westinghouse
Considerations

- Validation group
- Test Objectives
- Validation Testbeds
- Plant Personnel
- Operation Conditions
- Performance Measurements
- Test Design
- Data Analysis and Interpretation
- Validation Conclusions
Validation plan

- background
  - safety aspects
  - philosophy

- project goals
  - standards/guidelines
  - requirements

- hypotheses
  - measures

Preconditions

- validation category

Objectives

- hypotheses
  - measures

Preparations

- operator tasks
  - criteria
  - methods

Execution

- data

- validation plan
Validation plan

- Preconditions
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- Analysis and Interpretation
- Results
- Follow-up and information
Methodology

- Objectives
- Hypothesis
- Measures
- Criteria
- Execution
- Analysis
- Results
Objectives

"The operator station of system XXX gives the crew adequate support”

- Satisfactory co-function with other HSI functions
- Clear and simple process presentation
- Information acquisition for diagnosis is supported
- Efficient/simple display navigation
- Supports a correct operator behaviour
Hypotheses

H1  The operators know the state of the process
H2  The operators know how to control the process
H3  Communication and coordination work well
H4  The operators find they have good support
H5  It is easy to find information of relevance
H6  The system is compatible with the existing equipment
H7  Aso
Measures

- Situation awareness
- Workload
- Human erroneous actions
- Controllability
- Error tolerance
- Redundancy

- Time until detection
- Usability
- Compatibility
- Alarm condition
- Operation state
- Process parameters
Human Factors model

Operators

MMI

Support functions
Methods

- Questionnaires
- Interviews
- Think aloud
- Judgement protocol
- Expert evaluation
- Observation
- Video recording
- Logging
# Method selection

<table>
<thead>
<tr>
<th>Measures</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test person</td>
</tr>
<tr>
<td></td>
<td>Quest</td>
</tr>
<tr>
<td>Category</td>
<td>Concept</td>
</tr>
<tr>
<td>Operator</td>
<td>Situation awareness</td>
</tr>
<tr>
<td></td>
<td>Controllability</td>
</tr>
<tr>
<td>MMI</td>
<td>Error tolerance</td>
</tr>
<tr>
<td></td>
<td>Easy to learn</td>
</tr>
<tr>
<td>Support</td>
<td>Understandability</td>
</tr>
<tr>
<td></td>
<td>Usability</td>
</tr>
</tbody>
</table>
Validation activities

- Preparations
- Execution
  - Introduction
  - Observation, video recording
  - Freeze points
  - Interviews after each main activity
  - Questionnaire
  - Final interview
- Data analysis
- Report
Validation report

- validation plan -> Execution -> data

  - data
  - criteria

  -> Analysis

  - results

  -> Follow-up

  - results
  - counter-measures

Kent Bladh, August 1999
Validation of Control Room Upgrades
Validation report

- Preconditions
- Objectives
- Methodology
- Analysis and interpretation
- Results
  - Good practices
  - Deviations (HEDs)
  - Recommendations
- Follow-up and information
Quantitative measurements

1 2 3 4 5 6 7 8 9
Examples of positive results

- It is harder to make mistakes
- The conventional (but modernized) panel give an excellent overview
- The operator interface is adapted to the task
- The system clearly shows what is wrong
- The procedures are well structured and give good support
- The graphical format gives a better overview
Examples of negative results

- The supervisor does not know what the operators do
- Secondary tasks (navigation, etc.) are too time consuming
- Information is missing
- Information is hard to read (fonts, colors, contrast, etc)
- Lack of feedback
- Operator interfaces are inconsistent
- Work roles become different
- Procedures are not always updated
- More training is needed
Some odd comments ...

- Sometimes the pictures are too filled with uninteresting information

- The alarms should be shown at the side so that the whole screen does not disappear

- "Back" is the only button I use, but I never find it
References

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- IEC 1771 Nuclear Power Plants - Main Control Room Verification and validation of design.
- ISO 9241 del 11 Guidance on Usability.
- ISO 11064 del 7 Ergonomic Design of Control Centres: Principles for the evaluation of control centres.
- NUREG-0700 Human-System Interface Design Review Guideline.
- NUREG-0711 Human factors Engineering Program Review Model.
Human Performance Issues in the Upgrading and Refurbishment of Control Rooms

John O'Hara, William Stubler, Jim Higgins
Brookhaven National Laboratory

and

Joel Kramer
Nuclear Regulatory Commission

OECD/NEA Workshop on Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms

Halden, Norway

August 23-25, 1999
Outline

• Background

• Trends in Human-System Interface Technology

• Related Human Performance Considerations

• Addressing Modernization Issues
Background

• Plant modernization programs are increasing
  - Causes include poor reliability of existing equipment, maintenance and spare part issues, and desired performance improvements

• New HSI s often use advanced digital technologies
  - Modernization often results in "hybrid HSI s," containing a mixture of analog and digital technology

• Our objective
  - Define the technology trends in control room modernization
  - Determine the potential effects on personnel performance
Information Basis

• Literature
  - Broad base in complex systems (e.g., process control, aviation, medical)
  - Vendor descriptions of upgrade technology
  - Studies of advanced HSI technology
  - Operational events

• Interviews with subject matter experts
  - Operations personnel
  - Training personnel
  - Maintenance personnel
  - Engineering personnel
  - Vendors
  - Regulators

• Site visits using walk-throughs at nuclear, fossil, and petrochemical plants

• Research
  - Case study of modernization
  - Simulator experiments

• Design reviews at nuclear and other process control facilities
General Trends in Human-System Interface Design

- Human-system interfaces (HSIs) conceptualized on three levels

  - HSI resources, workstations, workplaces

- HSI resources

  - Alarms, displays, user-system interaction, controls, procedures, and support systems

- Workstations

  - Integration of HSI resources into workstations, panels, and consoles

- Workplaces

  - Facility level (e.g. main control room, remote shutdown station, local control stations, technical support center)
  - Equipment layout
  - Environmental design
HSI Resource Trends
Alarm Systems

• Trends
  - Data processing for alarm reduction
  - Great diversity of alarm displays and coding
  - Alarm management facilities (beyond silence, acknowledge, reset, and test)

• Benefits
  - Fewer alarms presented
  - Alarm information more informative
  - Alarm information can be manipulated (e.g., sorted by time or priority)

• Issues
  - Measures of effectiveness
  - Overall complexity
  - Operational experience and research on the effects of new features on operator performance have revealed mixed results
  - Increased workload to interact with and manage alarms
HSI Resource Trends
Displays

• Trends
  - Information hierarchies
  - Graphic displays provide unique representations of plant functions, processes, and systems
  - Information organization
  - Wide variety of display device technology

• Benefits
  - Access to valid data and more information
  - Rapid understanding with little need for interpretation
  - Lower workload processing data into information
  - Clearer understanding of information relationships

• Issues
  - Information overload
  - Correspondence mapping (between plant characteristics and display features)
  - Coherence mapping (between display features and the operator's perceptual processes and mental models)
HSI Resource Trends
User-System Interaction

• Trends
  - Virtual HSIs that are computer-based, soft, and serial HSIs (contrasted with conventional HSI were spatially dedicated and always available)
  - Personnel interface with data management system

• Benefits
  - Common interfaces for plant and HSI interaction
  - Great flexibility

• Issues
  - Keyhole effect (limited viewing area)
  - Secondary task workload associated with interface management, e.g., configuration and navigation, can be large
  - Complex effects have been found (see next slide)
  - Poor training interface management strategies
  - Operators develop their own workarounds, such as constraining HSI flexibility to cope with workload
HSI Resource Trends
Interface Management Effects

Diagram showing the relationship between resources supplied to primary tasks and resources supplied to interface management, with regions for data-limited, divided-attention, and resource-limited.
HSI Resource Trends

Controls

• Trends
  - Soft controls, computer-mediated equipment control using control display

• Benefits
  - Increased control reliability due to richer information
  - More precise control
  - Reduction in hardware (common control interfaces)
  - Flexibility

• Issues
  - Time delays
    - Serial access to controls
    - Increased number of task steps
    - Computer response time under high data processing load
  - Human error
    - Lack of location cues and tactile feedback
    - Coordination of display and control (wrong component control)
    - Mode error
    - Data entry error
HSI Resource Trends
Procedures

• Trends

  - Computer based procedure management systems provide a range of capabilities to guide monitoring and response planning

• Benefits

  - Lower workload acquiring information and processing logical relationships
  - Lower communication load
  - Monitoring of steps of continuous applicability

• Issues

  - Level of automation, control, and over reliance
  - Effects on team performance and communication
  - Loss of awareness of higher-level procedure goals and plant state
  - Underspecification of procedure logic
  - Sufficient display area and handling multiple procedures
  - Transfer to paper procedures on CBP failure in complex situations
# HSI Resource Trends
Automating Procedure Functions

<table>
<thead>
<tr>
<th>Procedure Functions</th>
<th>Level of Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring and Detection</td>
<td>Manual</td>
</tr>
<tr>
<td>Process parameter values</td>
<td></td>
</tr>
<tr>
<td>Operator actions</td>
<td>NA</td>
</tr>
<tr>
<td>Situation Assessment</td>
<td>Manual</td>
</tr>
<tr>
<td>Procedure entry conditions</td>
<td></td>
</tr>
<tr>
<td>Resolution of procedure step logic</td>
<td>NA</td>
</tr>
<tr>
<td>Step status (incomplete or completed)</td>
<td>NA</td>
</tr>
<tr>
<td>Procedure history</td>
<td>NA</td>
</tr>
<tr>
<td>Context sensitive step presentation</td>
<td>NA</td>
</tr>
<tr>
<td>Assessment of continuous, time, and parameter steps</td>
<td>NA</td>
</tr>
<tr>
<td>Assessment of cautions</td>
<td>NA</td>
</tr>
<tr>
<td>High-level goal attainment and procedure exit conditions</td>
<td>NA</td>
</tr>
</tbody>
</table>

| Response Planning                           | Manual  | Advisory | Shared | Automatic |
| Selection of next step or procedure         |         |          |        |           |
| Procedure modification based on current situation |       |          |        |           |

| Response Implementation                     | Manual  | Advisory | Shared | Automatic |
| Transition from one step to the next        |         |          |        |           |
| Transition to other parts of procedure of other procedures |     |          |        |           |
| Control of plant equipment                  |         |          |        |           |

* NA means that the advisory level of automation is not applicable to this procedure function
HSI Resource Trends
Computerized Operator Support Systems

• Trends
  - Computerized operator support systems (COSSs) for diverse activities such as fault diagnosis and maintenance planning

• Benefits
  - Lower workload in analyzing plant data

• Issues
  - Task relevance of the information provided
  - Level of explanatory detail
  - Complexity of information processing
  - Lack of visibility of the decision process
  - Lack of communication functions
  - Poor integration into the rest of the HSIs
Workstation and Workplace Design Trends

• Trends
  - Reduced crew size
  - Operators work at "compact" workstations in seated position
  - Workstations are provided for operators and supervisors
  - Large screen or wall panel displays
  - Support hardware (backup panels, printers, etc.)

• Benefits
  - High degree in HSI resource centralization and integration

• Issues
  - Impacts on crew communication and coordination are significant issues, especially for modernization programs
  - Accommodation of increased crew size in emergency situations
Additional Human Performance Considerations

- Staffing and Crew Coordination
  - New technologies change the ways in which crew members interact, communicate, and coordinate their activities

- Acceptance and Training
  - Resistance to HSI modifications frequently occurs
  - Interim periods can be especially challenging to operators and training often fails to address them
  - Negative transfer between conventional and advanced technology
Additional Human Performance Considerations
(Continued)

• Digital systems maintenance and configuration management
  - Incorrect personnel maintenance actions are a major causes of failures of computer-based systems
  - Inadequate integration into operating practices
  - Inadequate understanding of the intricacies of digital systems

• Design process and implementation considerations:
  - Relationship between the functional design requirements of the new system and the HSI being replaced
  - Assessment of the upgrade's impact on the plant's design basis
  - Many methods of transition from old and new HSI are used
  - Risk associated with temporary configurations
HSI Trends and Human Performance
Conclusions

- Advanced HSI technology can both enhance and degrade performance
- Plant modifications can have a broad impact on personnel performance
  - Personnel role
  - Primary tasks such as process monitoring, situation assessment, response planning, and response execution and control
  - Secondary tasks, methods of interacting with HSIs and their demands
  - Cognitive factors supporting task performance (attention and workload)
  - Personnel factors such as qualifications and training
- Common themes
  - Computer-based systems can add to plant complexity
  - User needs are often inadequately addressed in design of HSI
  - The trend toward virtual work spaces and serial access to information and controls is associated with greater cognitive workload and greater time spent performing secondary interface management tasks
  - Computer-based systems are often not sufficiently observable and have inadequate communication facilities
  - Personnel concerns, such as training and acceptance, are significant considerations in the introduction of new technology
Addressing Human Performance Challenges

- Identify human performance issues:
  - Operating experience and HSI technology experience
  - Look for bigger-picture issues

- Fully understand functional role for operators of equipment to be replaced (beyond design requirements)

- Analyze operator tasks (how new system will be used and how it fits into ongoing operations)

- Analyze new HSIs in terms of interactive effects and compatibility with the:
  - System being replaced
  - Remaining HSIs

- Design HSIs using:
  - Human performance and task requirements
  - Proven technology based
  - HFE standards and guidelines
  - A thorough test program
Addressing Human Performance Challenges
(Continued)

• Obtain user input throughout design and implementation process

• Analyze impacts on staffing and qualifications

• Training for the use of new HSIs, including interface management

• Consider implementation and transition approaches to minimize disruptions of human performance
  - Provide support for temporary configurations (training and procedures)
  - Do not introduce new system prematurely (with too many bugs remaining)
Electronic handbook on human-machine system interface evaluation method for nuclear power plants

Jun-ichi Tanji\textsuperscript{1}, Kazuo Monta\textsuperscript{1}, and Jun Kawai\textsuperscript{2}

1. Introduction

The computer-based advanced control panels have been introduced to the nuclear power plants, the thermal power plants and so on in recent years. It becomes possible to implement the various functions such as intelligent operational support into the interface (Human-machine System Interface: HSI) which enhance the controllability of the total plant, while the interface functions become increasingly complex and diversified. With a background of such HSI development, we have developed HSI evaluation method based on a model of human cognitive processes in order to provide the viewpoint of the evaluation on the operability of interface.

This paper presents a basic model of human cognitive process applied to the electronic handbook HIBISCUS (Human Interface evaluating Biaxial Scheme Under Systematic concept), followed by discussions of the total scheme and construction of the handbook. The applicability of the framework and the contents of HIBISCUS have been achieved by applying to experimental results on NUPEC(Nuclear Power Engineering Corporation)'s plant simulator equipped with one of the latest control panel using CRTs and touch operations.

2. Basic model

2.1 Evaluation scope

The evaluation scope of the human-machine interface is classified according to the axes of interface functions and operating conditions. The interface functions consist of 1) transmission of information, 2) operation support, and 3) plant automatic control. The operating conditions consist of a) normal condition, b) abnormal condition, and c) team organization. Since the "transmission of information at the normal /abnormal conditions" are most essential evaluation parts in this classification, evaluation items in the electronic handbook describe mostly these parts. Moreover, other evaluation parts such as the "support in the team organization" are considered extension of the interface function and the operating condition, and are described as incidental manner in the body of evaluation items.

\textsuperscript{1} Institute of Human Factors, Nuclear Power Engineering Corporation, Fujita kanko Toranomon Building 6F, 17-1, Toranomon 3-chome, Minato-ku, Tokyo 105-0001, Japan, Phone: +81-3-3435-3405, E-mail: tanji@nupec.or.jp

\textsuperscript{2} Mitsubishi Research Institute, Inc., 3-6, Ote-machi, Chiyoda-ku, Tokyo 100-8141, Japan, Phone: 81-3-3277-0769, E-mail: j-kawai@mri.co.jp
2.2 Cognitive process model

In order to clarify items to be considered on the HSI evaluation for the purpose of preventing human errors, the following cognitive process model is introduced. A schematic construction of the model is shown in Fig.1. Whole cognitive processes are divided into a short term memory process, a long term memory process, and an intention forming / execution management process. The short term memory process is composed of a perception activating process, an action program editing process, an operating goal setting process, and a schema program process.

The operator performs smoothly a cognitive process and an action produced by using the schema programs. In the skill base process, an existing schema program is used. In the rule base process, analogous schema programs are chosen according to the circumstances and switched over adequately. In the knowledge base process at the occasion of inexperienced situation, a complicated schema program is temporarily constructed and used. These model processes correspond to the human error categories of GEMS(Generic Error Modeling System) proposed by J. Reason[1].

Based on the foregoing model together with reference to the other published information such as NUREG-0700 Rev.1[2], the evaluation items have embodied and described on the electronic handbook "HIBISCUS".

3. Electronic handbook

3.1 Evaluation items

The interaction between the operator and the interface such as the control panel in the cognitive processes is decomposed into 3-D matrix elements. Each evaluation item is described in the matrix cell element. A 3-D structure table, therefore, has been designed based on the cognitive process model in order to describe evaluation items systematically. The table of evaluation items have three fundamental attributes; "requirements from cognitive processes", "interface functions" and "interface components".

Requirements from cognitive processes are categorized as shown in Table 1 corresponding to each process of the cognition model described in the section 2.2. Contents of the table i.e. evaluation items are arranged with the viewpoint of cognitive process requirements that which point must be considered in designing interfaces so that operators can operate the plant preventing errors.

Interface functions are listed in consideration of what kinds of functions should be used for the cognitive interaction between operators and interfaces. Interface functions are shown in Table 2.

The categorization of interface components as shown in Table 3 is prepared to bridge the gap between specific panel elements and evaluation items.

A schematic construction of the table of evaluation items is shown in Fig.2. In this figure, an example of evaluation table is shown when the alarm element is selected in the
control panel as evaluation object. Contents of each evaluation item consists of following four parts:

- **MAIN TEXT**
  
  The viewpoint of each item is described in general abstract expression. The embodiment of each item is synthesized based on the knowledge of the cognitive process model and the interface function, and gives grounds for the evaluation method.

- **EXPLANATION/EXAMPLE**
  
  An explanation and example design for the MAIN TEXT are shown here to make the text clearly. Designers might see how to implement the requirement of the MAIN TEXT.

- **CORRESPONDING INTERFACE COMPONENTS**
  
  Interface components which could be evaluated by consulting the evaluation item are shown here.

- **REFERENCES**
  
  To make the position of the evaluation item clear, corresponding parts from NUREG-0700 Rev.1 and other guidelines or evaluation methods are referred here.

The description of HSI evaluation items takes the form of the electronic handbook formulated by hyper-text for the practical use. The application procedure using the electronic handbook is described in the next section.

### 3.2 Application procedure

There are two typical ways of use in the procedure of HSI evaluation with the HIBISCUS shown in Fig.3. Outline of ways of use is as follows.

**In basic design**: embody the design elements to satisfy the remarks of evaluation items, which are points to be considered in design process.

**In review process**: apply the evaluation items to objects to be reviewed to check whether the remarks of the evaluation items are satisfied.

The details of the four steps are as follows;

**STEP1: Selection of the objects to be evaluated**

In the design phase, each design object that is the component under designing could be an evaluation object.

In the review process, evaluation objects must be selected in some ways; selection based on tasks, devices and displays.

**STEP2: Selection of the evaluation items to be applied**

Select evaluation items corresponding to the evaluation objects by referring to "MATRIX of evaluation items". An example of selection of the evaluation item is shown in Fig.4. The procedure of selection is as follows.
1) Click the category of interface components which the object belongs to.
2) Evaluation items are indicated on the MATRIX corresponding to the category of the interface components.
3) Click an evaluation item on the MATRIX to see the contents of the item.

**STEP3: Evaluation**

In the design phase, it is important to consider the main point that the evaluation item means and embodies the design elements.

In the review process, the point of the evaluation item is to be checked whether the object satisfies it, and the evaluation sheets for judgement of adequate/not adequate or not applicable, comments on the specific drawbacks and so on, are to be prepared.

**STEP4: Interpretation**

In the design phase, it is required to embody the specification of the design element based on the result of STEP3.

In the review process, it is necessary to make the drawbacks analyzed from different standpoints to the designer.

**4. Applications and discussion**

The applicability of the framework and the contents of interface evaluation items in HIBISCUS have been assessed by the applications to the operator's behavior on NUPEC's simulator equipped with one of the latest control panel using CRTs and touch operations. Three level evaluations have been executed concerning with display and control functions as follows;

- level 1: static evaluation for display contents,
- level 2: limited dynamic evaluation such as navigation controls between several specific displays, and
- level 3: dynamic evaluation of display and control functions along the context of plant operation.

**4.1 Evaluation of display contents**

Static evaluations (level 1) and limited dynamic evaluations (level 2) of specific displays have been executed on the NUPEC's simulator by using the interface evaluation items of HIBISCUS. Level 1 and 2 evaluations have been executed simultaneously as follows;

1) Selection of displays

Typical display and control functions of the simulator were selected. These functions were the summary monitoring display, the trend monitoring display, the system flow diagram display, the control display, the request panel, the sub-cool monitoring display and two guidance displays.

2) Selection of interface evaluation items

In order to evaluate the selected displays, appropriate interface evaluation items
were selected. First of all, associated interface functions were selected according to the characteristics of each evaluating display and panel, then associated evaluation items were selected. The quantities of selected evaluation items were 80 for the information display, 125 for the control displays, 49 for the request panel, 73 for the subcool monitoring and 58 for the guidance display. The interface evaluation items applied to the subcool monitoring and the guidance display have been rearranged and condensed according to the previous evaluation experiences.

(3) Execution of evaluations for the displays

Evaluations have been performed for the actual displays by using associated evaluation items. For limited dynamic evaluations displays have been changed over and controls have been actuated temporally, if necessary for evaluations. The evaluators have marked their comments on the evaluated displays if any related to each evaluation item. When the selected evaluation items are not applicable to the subjected displays, the items have been noted as so.

(4) Analysis of evaluated data

The number of applicable evaluation items for information displays and control displays were approximately 1/2 ~ 3/4 and 2/3 of the total selected items, respectively.

Statistics of the evaluation are shown in Table 4. The results suggest that useful comments have been derived from the analysis by using the interface evaluation items. It is pointed out, however, that there exist some problems which are to be improved such as a larger number of the evaluation items, complexity of the evaluation systems and so on.

4.2 Evaluation along the context

The evaluation items in HIBISCUS are not only able to be applied to the evaluation for static and limited dynamic aspects of the interface, but also have a remarkable feature of application to the dynamic evaluation. The level 3 evaluation has been planned to assess applicability to the evaluation of fully dynamic aspects of interfaces considering operational contexts.

The fully dynamic aspects of interfaces considering operational contexts mean that how operators obtain information, how they make decision and take actions through interfaces within the operational contexts. The operational contexts comprise the variations of system status, purposes and intentions for operations, and display conditions. Therefore, level 3 evaluations should be assessed using the interface evaluation items whether the implemented interface features are suitable for operators so as to make decision properly and to take action smoothly at important operational situations. Level 3 evaluations have been executed as follows;

(1) Selection of operational task scenario

Task scenario of design-based events is selected for level 3 evaluation. NUPEC have several experimental data, then these data have been used for the evaluation. Among the many scenarios, an SGTR(Steam Generator Tube Rupture) task has been selected because
of its proper scenario length, situation variety, and proper variation of monitoring and operational tasks.

(2) Task analysis

Task analysis has been performed by using NUPEC’s experimental data, which are video and audio data of the experimental operation and the story board for the SGTR task. Analytical results have been recorded on the scenario analysis charts in time sequentially. The recorded data are divided into eleven task steps, each of which includes displays, actions taken by the primary operator, and conversations between the secondary and the senior operators.

(3) Extraction of evaluating points

Since it may be actually impossible to evaluate whole task situations, extraction of evaluating points should be necessary for effective evaluation. On the occasion of extracting evaluating points, following conditions have been considered; importance of operating points, executing points or transition points of main task steps in connection with interface functions, inconsistent points between the interface design and operator’s intention or operational sequences. Ten points have been selected for this evaluation.

(4) Selection of interface evaluation items

Corresponding to every extracted evaluating point, associated evaluation items have been selected. The-associated interface functions have been identified according to the nature of each evaluating point, then evaluation items have been selected for each of the associated interface functions.

(5) Execution of evaluations

For each extracted evaluating point, selected evaluation items have been applied to the evaluation of interface functions such as display contents and relation between displays and navigation features. When evaluation are executed, following operator’s view points have been investigated; how decisions are made using what kind of information, what are intended to do, what actions are taken for that purpose, and how the consequences are confirmed with what kind of monitoring information.

Evaluated data have been summarized for each extracted evaluating point with comments and recommendations for each applied evaluation item.

Summary of evaluated data is shown in Table 5, where extracted evaluating points are summarized, i.e. evaluating points of view for these evaluation points, typical general recommendation from evaluations, and number of comments based on these recommendations.

(6) Analysis of evaluated data

Evaluated data have been analyzed and following general recommendations have been introduced for the selected displays. First, some summarized reference displays or addition of navigating information would be helpful for important operational sequences. Second, navigation functions between associated displays should be very important. Third,
automatic displays and automatic annunciation should be carefully applied because of their disturbance for regular operations.

The level 3 evaluation has shown proper applicability of evaluation items to fully dynamic aspects of HSI, considering the operational contexts and using the evaluation procedures described in the foregoing.

5. Conclusions

The electronic handbook HIBISCUS has been developed for evaluation of Human-machine System Interface (HSI) in nuclear power plants. In HIBISCUS, the evaluation items for HSI based on the requirements from the cognitive process model are developed. The table of the evaluation items is composed of three axes: the requirements from cognitive processes, the interface functions, and the interface components.

For applicability test of HIBISCUS, the framework and the contents of interface evaluation item have been assessed applying to experimental results on the latest control panel using CRTs and touch operations. Three level evaluations have been executed for the display characteristics. From the results, the applicability of the handbook has been confirmed.

In order to collect valuable comments from the specialists on the HSI methodology, HIBISCUS has been opened on an internet homepage (http://www.aurora.dti.ne.jp/~hsi/index.html) and distributed to the specialists as CD-ROM. It is expected that HIBISCUS will be useful for evaluation and improvement of HSI in nuclear power plants.

References

<table>
<thead>
<tr>
<th>Cognitive Process</th>
<th>No.</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception Activating Process</td>
<td>1</td>
<td>· <strong>Perceptual Readability</strong>: Perceived information can be produced, memorized, and held easily, so that operators may understand spontaneously the display elements.</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>· <strong>Spontaneous Task Correspondence</strong>: Correspondence of the perceptual images to the goal are consistent with the task sequences, so that tasks are not disturbed.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>· <strong>Consciousness</strong>: From differences between the perceptual image and the goal images, the points to which consciousness are necessary can be detected easily.</td>
</tr>
<tr>
<td>Action Program Editing Process</td>
<td>4</td>
<td>· <strong>Avoid Confusion</strong>: The proper distinctions and coding for same kinds of displays and controls are important, especially in the limit of operator's attentions.</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>· <strong>Consistency with Mental Model</strong>: Consistency with the everyday senses as physical senses, ecology, and stereo types are the important. For natural intelligibility of objects from the perceptual images are necessary to fit the operator's mental models for natural understanding of object meanings.</td>
</tr>
<tr>
<td>Operation Goal Setting Process</td>
<td>6</td>
<td>· <strong>Simplicity</strong>: Tasks are defined so as to need no many operational changeovers or conditional divergences. Also control panels are to be designed simple without complicated tasks.</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>· <strong>Avoid Intrusion</strong>: In order to remember the changeover points of operations, when one sequential operations are executed, other intrusive operations are avoided.</td>
</tr>
<tr>
<td>Schema Program Process</td>
<td>8</td>
<td>· <strong>Situation Assessment, Identification/Diagnosis</strong>: The information and hints are properly represented using variations of perceptual images.</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>· <strong>Action Planning/Correspondence to Strategic Goals</strong>: Candidates of schema programs can be produced easily by using program production conditions. Based on the situation recognition, problem identifications and diagnosis, the action programs are composed to cope with the problem.</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>· <strong>Immediate Response</strong>: The effects of operations and display elements are properly corresponded, so that strategic operations can be executed immediately if necessary.</td>
</tr>
</tbody>
</table>
Table 2  Interface Functions

<table>
<thead>
<tr>
<th>Classification</th>
<th>Index</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>(a)</td>
<td>Plant Status Display</td>
</tr>
<tr>
<td></td>
<td>(\beta)</td>
<td>Plant Alarm Indicators</td>
</tr>
<tr>
<td></td>
<td>(\gamma)</td>
<td>Plant Operation</td>
</tr>
<tr>
<td>Extended</td>
<td>(\delta)</td>
<td>Display of Plant Function and Construction</td>
</tr>
<tr>
<td></td>
<td>(\varepsilon)</td>
<td>Display of Operation and its Results</td>
</tr>
<tr>
<td></td>
<td>(\zeta)</td>
<td>Coordination of Operation and Display</td>
</tr>
<tr>
<td></td>
<td>(\eta)</td>
<td>Operation Guidance</td>
</tr>
<tr>
<td></td>
<td>(\theta)</td>
<td>Operation Navigation</td>
</tr>
</tbody>
</table>

Table 3  Interface Components

<table>
<thead>
<tr>
<th>Category</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Control Panel</td>
<td>Conventional Lights/ Meters/ Recorders</td>
</tr>
<tr>
<td></td>
<td>Alarm Indicators</td>
</tr>
<tr>
<td></td>
<td>Switches / Controllers</td>
</tr>
<tr>
<td></td>
<td>Panel Size/ Shape/ Switches Layout</td>
</tr>
<tr>
<td>CRT/ FD Display Control Panel</td>
<td>Summary Display</td>
</tr>
<tr>
<td></td>
<td>System Components Display</td>
</tr>
<tr>
<td></td>
<td>Trend Display</td>
</tr>
<tr>
<td></td>
<td>Alarm Display</td>
</tr>
<tr>
<td></td>
<td>Operation Input Display</td>
</tr>
<tr>
<td></td>
<td>Request Panel</td>
</tr>
<tr>
<td></td>
<td>Guidance Display</td>
</tr>
<tr>
<td></td>
<td>Menu Display</td>
</tr>
<tr>
<td></td>
<td>Display Organization/ Interactive Relation of Display</td>
</tr>
<tr>
<td>Large Screen Display</td>
<td>Display Elements/ Display Information</td>
</tr>
</tbody>
</table>
Table 4  Numerical summary of level 1 and level 2 evaluations

<table>
<thead>
<tr>
<th>Evaluating Display</th>
<th>Number of evaluation items</th>
<th>Number of recommend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Effective</td>
</tr>
<tr>
<td>Information Display</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary</td>
<td>80</td>
<td>47</td>
</tr>
<tr>
<td>Trend</td>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>Flow diag.</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Control Display</td>
<td>125</td>
<td>74</td>
</tr>
<tr>
<td>Request Panel</td>
<td>49</td>
<td>22</td>
</tr>
<tr>
<td>Sub-cool Display</td>
<td>73</td>
<td>62</td>
</tr>
<tr>
<td>Guidance Display</td>
<td>58</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 5  Summary of evaluated data for level 3 evaluation

<table>
<thead>
<tr>
<th>Evaluating points</th>
<th>Evaluating view point</th>
<th>Typical general recommendation</th>
<th>Number of comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Transition to next step</td>
<td>Smooth transition</td>
<td>Addition of appropriate control elements for transition</td>
<td>12</td>
</tr>
<tr>
<td>2 Automatic display</td>
<td>Appropriateness of display</td>
<td>Avoid unnecessary invasion</td>
<td>4</td>
</tr>
<tr>
<td>3 Selection of necessary displays</td>
<td>Easiness of selection and procedure recognition</td>
<td>Avoid division for request panel selecting displays</td>
<td>12</td>
</tr>
<tr>
<td>4 Confirmation of automatic actuation</td>
<td>Easy confirmation of display</td>
<td>Distinct display for automatic and non-automatic controls</td>
<td>5</td>
</tr>
<tr>
<td>5 Information regarding to automatic display</td>
<td>Relations to associated displays</td>
<td>Residual information of associated displays after automatic display</td>
<td>6</td>
</tr>
<tr>
<td>6 Annunciator</td>
<td>Appropriate annunciation</td>
<td>Distinction between alerts for emergency and feedbacks</td>
<td>4</td>
</tr>
<tr>
<td>7 Confirmation of completion of sequential tasks</td>
<td>Easy confirmation of completion</td>
<td>Systematic displays for specific sequential tasks</td>
<td>6</td>
</tr>
<tr>
<td>8 Selection and operation of necessary controls</td>
<td>Easy selection and operation of controls</td>
<td>Distinction of different control functions</td>
<td>5</td>
</tr>
<tr>
<td>9 Necessary information for specific task</td>
<td>Easy understanding of necessary information</td>
<td>Consideration of display configuration for specific tasks</td>
<td>4</td>
</tr>
<tr>
<td>10 Confirmation and controls for special actions</td>
<td>Easy understanding of sequenced procedure</td>
<td>Smooth transportation capability between associated displays</td>
<td>5</td>
</tr>
</tbody>
</table>
Fig. 1 Cognitive Process Model
FIG.2  Schematic construction of the evaluation table
Fig. 3  The procedure of evaluation with HIBISCUS
Fig. 4  Example of selection of the evaluation item
An Experience on Human Factors Evaluation of a Safety Parameter Display System in Korea

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Man-Machine Interface System Team
Korea Atomic Energy Research Institute (KAERI)

- ABSTRACT

This paper describes an experience of independent evaluations or human factors of a Safety Parameter Display System (SPDS) in Korea. Human factors evaluation on the nuclear power plant and the major systems such as SPDS have been mandatory in the design process of a new plant as well as for the review of the existing plants. In Korea, there have been several HFE (Human Factors Engineering) V&V (Verification and Validation) projects on the SPDSs, which were mainly established with Critical Function Monitoring Concept. Independent evaluations are conducted through a series of pre-planned review activities. Evaluations mainly focused on the assessment of availability, suitability and effectiveness of the system and its interfaces. The information availability is assessed based on the requirements that are extracted through cognitive task analysis of operating procedures. The suitability test utilizes a structured checklist, which is based on a minimal set of human factors evaluation items. Many design issues including HEDs (Human Engineering Deficiencies) are accumulated for tracking in the licensing review, and evaluated by their importance scores for design decision-makings. A computer support system named DIMS (Design Issue Management System) was developed and is now imported on the Web.

1. Introduction

In Korean, we adopt Critical Function Monitoring System (CFMS) as a Computerized Operator Support System (COSS) which satisfies the licensing requirement of Safety Parameter Display System (SDPS) in nuclear power plants. Human factors of CFMS for Ulchin 3&4 and Yeonggwang 3&4 nuclear power units have been assessed during the design verification projects. The project has been performed to support the licensing, with a focus on the matters of SPDS requirements, which is one of major licensing issues for human factors engineering of nuclear power plants in Korea. After TMI incident, human factors evaluation on the nuclear power plant and the major systems has become a mandatory requirement for licensing and reviewing a new design as well as the existing plant upgrades.

The conceptual goal of human factors requirement itself was clear, however, the methods and the practice have not been so clear to indicate progressive improvements. SPDS might be notorious to be such a typical license-wise upgraded feature all over the world including Korea. Almost all NPPs have been equipped with SPDSs or other equivalent systems. The operators’ acceptance and the operational benefit have not yet been reported positively in Korea as well as in U.S. and others.

In Korea, SPDS which is mainly developed by ABB-CE and established with critical function concept, is adopted to Korean Standard Nuclear Power Plant (KS-NPP). This paper describes the experiences of independent evaluations on human factors of the SPDSs as a part of HFE V&V projects. Two independent evaluation projects have been conducted successfully. Evaluations are mainly based on the domestic licensing requirement definition, which is not much different from the US-NRC’s SRP section 18 and other NUREG
documents. A few additional works and implemented processes are identified during the projects. Recently, a more practical method is defined based on the experiences on HFE V&V of SPDSs, and the framework procedures and a support system are now on the way of development not only for licensing but for design improvement.

2. Approach for HFE V&V on SPDS

At first, independent evaluations are conducted through a series of pre-planned activities. By reviewing issues regarding the design process of present CFMS, two generic plans such as human factors engineering program plan (HFEPP) and human factors verification and validation (HFE V&V) plan for CFMS were proposed to satisfy the procedural exhaustiveness of human factor engineering work. These plans are established separately from the main HFEPP and software engineering plan, but the activities are defined in incooperative manner with software design. Although CFMS is not a safety system, regulation requires a through review on human factors such as ; the function, the interface compatibility, the satisfaction to the requirements and current principles as well as the design process. However, Korea donot have a clear evidence to the operators satisfaction, nor the background for the human factor requirements because CFMS had been originally based on and just imported from ABB-CE's concept. The human factor concernsings such as the cognitive compatibility to the operators must be verified whether CFMS would properly support operators to satisfying the safety goal during the tasks in assumed situations in NPPs.

Secondly, the evaluation is focused to the assessment of availability, suitability and effectiveness of the system and its interfaces according to IEEE std-845 and EPRI NP-3701 vol. 2. The availability and suitability were assessed according to human factor criteria and requirements on the CFMS display design, and overall effectiveness was also evaluated by experiments and in parts by introducing an operator performance model. A cognitive task analysis (CTA) method was applied to the definition of information requirements for CFMS. CTA method help to identify the information requirements of tasks which operators supposed to perform during the emergency situation. It emphasizes upon the information organization of a task that is supposed to be the cognitive workload rather than the behavioral workload to the operators. Discrepancies between the requirement information and the information provided in the design are evaluated by studying how those requirements and discrepancies affect the operator's cognitive work during performing the procedural tasks. The result shows that the task support-ness of CFMS would be enhanced and verified in information aspects.

For the HFE V&V of a design, regulatory documents utilize a new word of the task supportness, which means that the design is enough and not excessive to support all tasks operator intended to do during the use of the design. We break down the task supportness requirement into two succeeding requirements with an emphasis on the cognitive aspect of task supportness. They are the availability and the suitability of information items provided to the operator. In other words, we tested what and how the information items are provided by CFMS. Several deficiencies in the information availability and the suitability of CFMS displays including the interaction and navigation aspects were identified. Almost of these deficiencies could be solved easily by introducing human factors engineering principles. Some deficiencies, however, which are not the problems violating directly the regulatory requirements, are still issued to design decision for the better quality of future design and the
maintenance of CFMS.

Finally, a support system named by DIMS (design issue management system), was developed to support the review process by maintaining the requirements, the design issues and their treatments in form of a database. Several review worksheets were also developed from the requirement database of DIMS through holding out the HFE requirements and being specified to CFMS. Recommendations were made to each human factor problem identified in accordance with its estimated importance, and an implementation plan was suggested for the resolution of problems. A multi-criteria and multi-participant decision process is also proposed to support the consistent design decisions on the problems identified by evaluating their relative importance in technical, engineering and managerial aspect.

In the review, most of the methods mentioned in IEEE-std-845 available for man-machine system evaluation had been utilized such as ; documentation review, review by standards, review based on the development facility (a dynamic mockup of CFMS), review by interviewing the operators who are the prospective users or the experienced personnel, review by experiments, review by individual experts and a team of multi-disciplinary experts including licensing staff, and others.

<table>
<thead>
<tr>
<th>Review/Methods</th>
<th>Availability</th>
<th>Suitability</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document - Analysis</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Specialist Opinion - Checklist</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Experiment Review - Simulator</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Operator Opinion - Interview, WT/TT</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Facility Review - PMS-DF</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

☐ : Main Review , ☐ : Supporting Review, ☐ : Assistant Review

3. Availability Assessment

3.1 Assessing the Information Availability of CFMS

CFMS is to support operators during the emergency situation by providing the safety status information as an SPDS in nuclear power plants. CFMS must provide the safety information required by NUREG-0737, Supplement 1, categorizing into 9 critical safety functions (CSFs). Each CSF has its own logic of alerting the operator the challenge to the safety of the plants through basically one CRT page in form of a summary matrix. Several CRT pages can be accessed by a special function key-board and a dedicated CRT in case that operator want to know the details of the CSFs' challenge and their changes according to recovery actions. Since the main indications in main control room are mostly hard-wired conventional, CFMS is assumed to be utilized by Safety Engineer who is responsible to the maintenance of the plant safety, rather than Senior Reactor Operator who is responsible to the management of transients and overall operating process. CFMS is assumed to be utilized in accordance to the emergency operating procedures (EOPs). There is a dedicated set of tasks, named First-02, which consists of not more than 10 steps. However, all of steps must be conducted by Safety Engineer in parallel.
with every step of EOPs in order to mitigate the transients and maintain the safe state of the plant during emergency operation. Although there is only one explicit procedure for CFMS, the procedure itself does not cover every detail tasks for utilizing CFMS. The procedure involves more than the line and the instructions, because operator sometimes needs to identify the specific causes and understand the context of CFS challenge in order to decide whether related prioritized procedures (FRG: functional recovery guideline) should be conducted or not. In order to attain the task goal of procedure by utilizing CFMS, operators should follow the details of alarm logic and information items through the information legs in each CSF, the trends of critical parameters through their temporal plots, and the overall state of the related system through P&ID (pipe and instrumentation diagram) mimic. The information requirements for CFMS can be defined by analyzing the task procedure, including the implicit steps as well as explicit description. Following types of requirement sources are considered for this review such as; Alarm logic of CFSS, procedures related, and operating experience.

The information availability is assessed based on the requirements that are extracted through cognitive task analysis (CTA) of operating procedures. Procedures are usually not finalized for the HFE V&V during NPP design, however, the information requirement items is well defined in, for example, ERGs (Emergency Response Guidelines). CTA is proposed for enumerating the operators' interface requirement items based on the operating procedures. Requirement list (LIST-R) is defined from the analysis of procedures (LIST-P), operating experiences (LIST-O), alarming logics in SPDS (LIST-A), and the thermo-hydraulic analysis of safety functions (LIST-T). Each list adds up and results to a set of requirements for the availability. Another list is defined from the design itself. The inventory list (LIST-I) information items found in the implemented design is extracted for assessing the availability by comparing the two lists. For each information item, the comparisons show whether the partial or complete fulfillment of requirements for SPDS.

3.2 Requirement extraction through Cognitive Task Analysis

The operation in both normal and emergency conditions, are prescribed, and mostly guided by operating procedures. Conducting tasks for operation requires more than merely following operating procedures, reading instruction lines and acting as specified. The operator must frequently abstract for understanding the status of the systems and the goal of tasks, rather than read the indications and raw data as specified in the procedure. Thus, assessing the cognitive processes in conducting the prescribed tasks with a given design is important for a better SPDS that is more compatible to the operators' cognitive process and acceptable to the operators. Therefore, it is desirable that a task analysis identifies such design requirements and assesses them in the light of the underlying organization of tasks with a given design. Task analysis provides data for the human factors design requirements of Human System Interface such as main control room, and other facilities and equipments in NPPs.

It is hard to define the requirements to the cognitive aspect of tasks, however, which become more important in recent NPP designs. An enhanced method for cognitive task analysis proposed by Lee & Yoon based on an information-oriented view on tasks was applied. The method identifies cognitive requirements of operators' tasks by capturing the cognitive aspects of tasks that are supposed to be conducted by operators in emergency situation in nuclear power plants. The method proposed focused to the implicit as well as explicit information for task performance. It identifies the information requirement items for each step of task performance, and then traces their flows in task profiles. Like most TA methods, tasks are decomposed into sub-tasks and further into
elementary actions to enumerate all possible requirements for their specific purposes. The information items should be provided by the CFMS when the tasks are intended to utilize the design. Availability means a question of whether the all information items required are provided by the design or not.

Analysis of the cognitive requirements of tasks, however, is not enough until the requirement items can provide a higher level contextual requirement of the tasks. Task steps are usually organized only through the temporal order or the control flows in physical activities. The flows and usage of task information that will form a kind of cognitive load to the operator can not be easily described in a sequence or aggregating the lower level requirement items. The information items in tasks may often be integrated or abstracted by the operator depending on the condition of his working memory and other cognitive resources as well as task goals. The information flow reveals the cognitive organization of a task, especially given in form of procedure. We introduce some new concepts such as; *cognitive spans of task information*, *working memory relief points*, and *cognitive envelopes* of task procedures. Some of the cognitive characteristics of tasks with a given design of CFMS can be identified in terms of these additional terms that can be obtained by the proposed cognitive task analysis. The congruence of CFMS to the tasks that are required to utilize CMFS can then be assessed.

4. Assessing the Suitability of CFMS

4.1 Integration of Review Criteria

Suitability of CFMS means the quality of the interface and the interaction between operators and CFMS. The assessment utilizes a structured checklist, which is a minimal set of human factors evaluation items found in numerous kinds of licensing documents, industrial standards and human factor references. The main reason why I should make the minimal set is to get the practicality and efficiency in HFE V&V. Many human factors design guidelines and regulations should be considered in the evaluation of a computer-based system in NPPs. Since the necessary review criteria are ubiquitous, an integrated evaluation scope and standardized tool must be identified. It cannot be proven satisfactory without such a predetermined set of criteria. A systematic evaluation checklist in form of a network structure was developed based upon a database of check items and review criteria selected from several mandatory documents for licensing. A systematic evaluation checklist was proved to be useful when it was applied to the evaluation of actual CFMS. It shows that an integrated and standardized checklist is efficient and directly applicable to the human factors evaluation of the CFMS in a new NPP. The development of evaluation checklist went through two phases: integration and standardization.

To develop a systematic checklist, it is necessary to survey and integrate all the relevant information scattered in various documents. They include some regulation documents of Korea, US NRC and others, design requirements generated during the development of the CFMS, and human factors design guidelines such as ANSI/HFS 100-1988 and ISO series in the literature. When integrating the human factors evaluation issues, it is important to exclude the redundant and mutually contradictory statements. Three important regulation documents such as NUREG-0700, NUREG-0800, Supplement 1 to NUREG-0737, and others in the human factors certification, needed to be interpreted into more concrete review criteria and their questions. The basic idea is that since keyword is a core of each review statement, it would be appropriate to integrate review
documents at the level of keywords rather than review statements themselves. Based on the review, an initial set of keywords for checklist items was selected. After eliminating redundant and contradictory items, the remaining items were analyzed by their degree of abstractness. Some of the items were high level design principles, while others were rather detailed guidelines. Also, some of them had a cross-reference to other items. To resolve the different level of abstractness, relationships were established in form of a network structure rather than a hierarchy. The structure mainly has three levels depending upon the degree of abstractness of the items, which are not more than 100 up to now for CFMS.

4.2 Standardization

Although many human factors regulations and guidelines have been provided, few evaluation criteria are available. For example, a statement in a NEUREG-0800 document, that is one of the licensing references, says “It should be easy to compare data from related plant functions”. It has a vague meaning and highly abstract terms without any detailed explanation of the context being evaluated. This arises a chance to be misinterpreted and improperly applied. In other words, it does not provide detailed evaluation criteria. Often, this leads to contradictory and inefficient evaluation results when the evaluations are conducted without detailed criteria. Detailed criteria were developed in form of a hierarchical structure to minimize the variances of the evaluation results. A standardized format was designed to include the evaluation items and their relevant criteria. Table 2 shows an example format.

Table 2. Example of the standardized evaluation format

<table>
<thead>
<tr>
<th>Information</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source document</td>
<td>NUREG 0800, Section 6.2.3.1</td>
</tr>
<tr>
<td>Keyword</td>
<td>Color consistency</td>
</tr>
<tr>
<td>Question</td>
<td>The colors used in CFMS display should be consistent with color codes used elsewhere in the control room.</td>
</tr>
<tr>
<td>Explanation</td>
<td>Check the consistency of the color coding scheme of the CFMS with that of other displays and controls in the MCR</td>
</tr>
<tr>
<td>Information provider</td>
<td>Designers</td>
</tr>
<tr>
<td>Upper and/or lower level item</td>
<td>N-0800-5-2-2-1, N-0800-E-5-2-2-1-c</td>
</tr>
</tbody>
</table>

As shown in Table 2, each item should have an authorized source document name from which it was selected, and may include the upper level and/or lower level statements for the consideration of more careful evaluation.

5. Management of the HFE Issues raised during the design process

It is difficult to systematically consider design requirements and considerations that were raised through various channel as well as regulatory requirements in the design of complex man-machine interface system such as nuclear power plant. A computer support system, named DIMS (Design Issue Management System) is developed for logging and managing the issues, resolutions and opinions to the issues, and for maintaining the consistency of design decision making during the design process. DIMS has an evaluation module for screening the issues raised into a more practical set for engineered resolutions.
Although human factor evaluation deals the assessment of availability, suitability and effectiveness of the system and its interfaces, DIMS is currently focused to the suitability test and issue management. The information availability is manually assessed based on the requirements that are extracted through cognitive task analysis of operating procedures. Suitability test utilizes a structured checklist, which is a minimal set of human factors evaluation items selected from DIMS database of review criteria. Many issues obtained in availability test and any other test as well as suitability test are accumulated for tracking them in licensing, and evaluated for design decision making. Many issues are accumulated into database for tracking them in licensing, and for the design decision making. Main function of issue management is logging the issues from the raised as an HED by the HFE specialists and others to the final resolution phase with consilation among personnels included in SPDS design.

DIMS applied to the human factors review of CFMS to show an example of DIMS application. DIMS has been used to accumulate the human engineering deficiencies (HEDs) of CFMS identified as a result of review, and evaluate their severity of HEDs.

5.1 The objectives of DIMS

The objectives of DIMS are to manage and consider issues that we must consider in the design of man-machine interface system, and to evaluate whether these issues were correctly solved or not. When issues for the design of man-machine interface system were detected, DIMS is a main channel to raise these issues and reflect them on design. DIMS consisted of three modules. The first module is a requirement analysis function to manage and analyze availability requirements extracted from CTA, and suitability requirements from regulatory documents. The second module has the tracking function of the issues raised from various persons. The third module has the evaluation function of importances of the issues in order to support the decision makings in design. Fig. 1, 2, 3, 4 show the structure and screens of DIMS.

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Fig. 1. Logic structure of DIMS
Fig. 2. Initial picture of requirement analysis module

Fig. 3. Initial picture of issue tracking module

Fig. 4. Initial picture of importance evaluation module
5.2 Example results of HFE V&V of CFMS

5.2.1 HEDs raised in HFE V&V

DIMS was applied to the ergonomic review of CFMS screen design. The ergonomic review of CFMS screen design needs the task support verification that reviews the suitability of information displayed in CFMS screen, integrated system validation using real system or simulator, and ergonomic suitability review of design factor. DIMS was utilized to analyze and arrange requirements described in regulatory documents, to review whether a design meets regulatory requirements or not, and to analyze ergonomic problems. The main application of DIMS runs in the suitability test of CFMS. Table 3 shows a part of design issues raised by various disciplines and grouped according to high-level keywords.

<table>
<thead>
<tr>
<th>HED grouping</th>
<th>Keywords of Detailed problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Format (6 items)</td>
<td>Data format (inadequate accuracy) Data format inconsistency Data format understandability Graphic representation inconsistency Enhanced coding (readability) Information coding complexity (shape &amp; color)</td>
</tr>
<tr>
<td>Layout/Grouping (4 items)</td>
<td>Layout (related information) Layout (valve &amp; flow line) Grouping of related information Grouping of navigation information</td>
</tr>
<tr>
<td>Record structure (2 items)</td>
<td>Record structure (semantic format) Record structure (syntactic format, spacing)</td>
</tr>
<tr>
<td>Symbology (2 items)</td>
<td>Symbology (employment of undefined symbol) Symbology (compatibility of symbol employment)</td>
</tr>
<tr>
<td>Identifier/Label (7 items)</td>
<td>Inconsistency of abbreviation employment Inconsistency of label employment Inconsistency of identifier/label position Missing identifier Incomplete identifier Incomplete information Readability of sector number</td>
</tr>
<tr>
<td>Color (4 items)</td>
<td>Type and number of used color Meaning of color coding Color coding conflict Inconsistency of color change employment</td>
</tr>
<tr>
<td>Variable/Function/Navigation (4 items)</td>
<td>Mapping between level 1 &amp; 2 Proximity of related function and information Navigation easiness of scattered information Indication of operating status</td>
</tr>
</tbody>
</table>

5.2.2 HEDs evaluation

DIMS has been used for the accumulation of HEDs and the evaluation of their ergonomic severity for CFMS screen design. Human factors experts, researchers, NPP operators, CFMS designers and managers had participated in this evaluation. HEDs identified through human factors review were classified in groups of severity. When issues raised were not solved, to evaluate the severity of issues is one of the important works in the design and review of CFMS. Issues that can cause severe problem must be solved as quickly as possible. According to this need, importance evaluation function for issues was realized in DIMS. The importance of each
issue according to the ergonomic severity was decided by importance evaluation function.

The criteria to evaluate the severity of HEDs were the potential to cause human errors, workload, resource requirement, training requirement, and the spect of operators’ acceptability.

Table 4. Severity evaluation criteria and their estimated weights

<table>
<thead>
<tr>
<th>Technical Area</th>
<th>Expression</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Error</td>
<td>Confusion, Incomposibility</td>
<td>0.45</td>
</tr>
<tr>
<td>Workload</td>
<td>STM Requirement, Fatigue, Time Load, Integration Requirement</td>
<td>0.20</td>
</tr>
<tr>
<td>Resource Requirement</td>
<td>Identification Requirement, Attention, Perception, Memory Requirement</td>
<td>0.10</td>
</tr>
<tr>
<td>Training Requirement</td>
<td>LTM, Incomposibility</td>
<td>0.10</td>
</tr>
<tr>
<td>Operator Acceptability</td>
<td>Subjective Preference, Operator Acceptance</td>
<td>0.15</td>
</tr>
</tbody>
</table>

In order to obtain the relative weights of these criteria, we used the evaluation function for ergonomic severity of DIMS. In order to obtain importance scores in severity evaluation procedure, the weight of importance criteria to decide the ergonomic severity of issues. We used AHP (analytic hierarchy process) to effectively obtain the weights of criteria in DIMS. The importance score of each issue is obtained by weighted-averaging scores of evaluation criteria for each issue by weights of evaluation criteria. Importance evaluation function was embodied by Visual Basic 3.0.

![Diagram](image)

Figure 5. Structure to obtain importance score using AHP

Then, in order to evaluate the human factors severity of HEDs, we performed rating for criteria. The severity scores of HEDs were obtained by weight-averaging rating values using the weights of criteria. HEDs were classified as three groups by severity scores with cuts of 3 and 7 in case of 9-point scale. Table 5 shows an interim result of severity evaluation of HEDs by human factors specialists.
Table 5. An Interim Results of Severity evaluation of HEDs

<table>
<thead>
<tr>
<th>Rank</th>
<th>HED list</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Information coding complexity</td>
<td>8.56</td>
</tr>
<tr>
<td>2</td>
<td>Color coding conflict</td>
<td>3.05</td>
</tr>
<tr>
<td>3</td>
<td>Meaning of color coding</td>
<td>2.75</td>
</tr>
<tr>
<td>4</td>
<td>Mapping between level 1 &amp; 2</td>
<td>7.20</td>
</tr>
<tr>
<td>5</td>
<td>Proximity of related information</td>
<td>7.10</td>
</tr>
<tr>
<td>6</td>
<td>Layout (valve &amp; flow line)</td>
<td>6.30</td>
</tr>
<tr>
<td>7</td>
<td>Enhanced coing (readability)</td>
<td>6.25</td>
</tr>
<tr>
<td>8</td>
<td>Missing identifier</td>
<td>6.20</td>
</tr>
<tr>
<td>9</td>
<td>Grouping of related information</td>
<td>5.75</td>
</tr>
<tr>
<td>10</td>
<td>Indication of operating status</td>
<td>5.60</td>
</tr>
<tr>
<td>11</td>
<td>Layout (related information)</td>
<td>5.50</td>
</tr>
<tr>
<td>12</td>
<td>Record structure (syntactic format, spacing)</td>
<td>5.35</td>
</tr>
<tr>
<td>13</td>
<td>Navigation easiness of scattered information</td>
<td>5.35</td>
</tr>
<tr>
<td>14</td>
<td>Data format understandability</td>
<td>4.75</td>
</tr>
<tr>
<td>15</td>
<td>Inconsistency of abbreviation employment</td>
<td>4.70</td>
</tr>
<tr>
<td>16</td>
<td>Inconsistency identifier/label position</td>
<td>5.55</td>
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<tr>
<td>17</td>
<td>Readability of sector number</td>
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<tr>
<td>18</td>
<td>Data format (inadequate accuracy)</td>
<td>4.10</td>
</tr>
<tr>
<td>19</td>
<td>Type and number of used color</td>
<td>4.10</td>
</tr>
<tr>
<td>20</td>
<td>Data format inconsistency</td>
<td>4.00</td>
</tr>
<tr>
<td>21</td>
<td>Symbology (compatibility of symbol employment)</td>
<td>4.00</td>
</tr>
<tr>
<td>22</td>
<td>Inconsistency of label employment</td>
<td>3.95</td>
</tr>
<tr>
<td>23</td>
<td>Incomplete information</td>
<td>3.20</td>
</tr>
<tr>
<td>24</td>
<td>Symbology (employment of undefined symbol)</td>
<td>3.10</td>
</tr>
<tr>
<td>25</td>
<td>Incomplete identifier</td>
<td>2.90</td>
</tr>
<tr>
<td>26</td>
<td>Graphic representation inconsistency</td>
<td>2.80</td>
</tr>
<tr>
<td>27</td>
<td>Grouping of navigation information</td>
<td>2.75</td>
</tr>
<tr>
<td>28</td>
<td>Record structure (semantic format)</td>
<td>2.75</td>
</tr>
<tr>
<td>29</td>
<td>Inconsistency of color change employment</td>
<td>1.95</td>
</tr>
</tbody>
</table>

**Result**

Quick resolution (5 items)

Resolution as quick as possible (19 items)

Long-term resolution (5 items)

6. Discussions and future works

In this paper, Korean experiences of HFE V&V on SPDSs in NPPs are described briefly. Additional definitions of HFEV procedures and plans were implemented for assessing the availability, suitability and effectiveness of CFMS as an SPDS for NPPs. The experiences show the necessity of CTA for requirement extraction in availability test, the practicality of a systematic checklist for suitability test, and the usefulness of DIMS for supporting various human factors activities in HFE V&V. Efficiency and effectiveness of the human factors review process was enhanced significantly with these artifacts. Communication among reviewers, system designers, and construction authority became much more specific and constructive. Rapid evaluation and design feedback to design were facilitated. The pseudo-quantified rating results helped the related authorities to approach the CFMS improvement with substantial savings in time and manpower. Since the severity of the problems and the corresponding improvement objectives were expressed as ratings, the remedial action was efficiently evaluated and approved. Multi-disciplinary and multi-criteria evaluations can be conducted by evaluators who have different perspectives from both human factors engineering and NPP operation. A clarified role/responsibility specification between the related departments can support more effective evaluation.

Although various benefits have been found in the evaluation of the CFMS, more researches and works are still required if it will be extended to the evaluation of a computer-based I&C system. For example, the exhaustiveness of the review items for CFMS should be obtained completely. It is also a challenge to continuously update the evaluation system to cope with the new type of display systems following the ever-
changing trends of the computer and communication technology while observing the regulations and design guidelines imposed on the CFMS. More efficient evaluation support functions should be developed and incorporated into the overall design process of CFMS. DIMS was developed by MS-ASSESS and Visual Basic 3.0, now is being converted into Web (url: http://human.kaeri.re.kr/).

References

2. NRC, Guidelines for Control Room Design Reviews, NUREG-0700, 1981.
Experience from Integration of Operator Support Systems to 
Enhance Human Performance

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Abstract

There are many possibilities for improving the support functions assisting the operators in their cognitive tasks when upgrading control rooms. At the Halden Project efforts are made to explore possibilities through design, development and validation of Computer-based Operator Support Systems which can assist the operators in different operational situations, ranging from normal operation to disturbance and accident conditions. Prototypes are evaluated in the HAlden Man-Machine LABoratory, HAMMLAB, and some systems are installed in operating nuclear power plants, thus providing practical experience from integrating new functions as part of plant upgrades.

One of the major problems identified in control rooms are the shortcomings of alarm systems. Over the years the Halden Project has explored different approaches to alarm handling, like alarm filtering techniques, model-based early fault detection and function oriented approaches like critical safety function monitoring. In response to the needs for integrating different alarm processing techniques the alarm system toolbox COAST has been developed. Design features of COAST and experience from different application projects will be included.

Many plants are introducing symptom-based Emergency Operating Procedures. In this connection it is desirable to improve the data validation, information integration and presentation for operators when executing the EOPs. The Computerised Operation MAnual (COPMA) system is a general toolbox developed to implement various kinds of procedures and experience will be reported from applying COPMA in a project for the Paks NPP in Hungary.

Improved core surveillance functions are being introduced in many plants. This is motivated by the advances in computer technology and physics codes which allow more accurate power distribution calculations and determination of margins to operational limits. Also predictive capabilities are available for assisting operators in on-line strategy generation to avoid undesired core states. Experience from integration and use of the core surveillance system SCORPIO at several plants will be discussed.

1. Introduction

A number of weaknesses have been identified in old control rooms in existing nuclear power plants: relevant information may be missing due to limited instrumentation, too much information (alarms) may make it difficult for the operator to diagnose the process state, wrong or inconsistent information may mislead the operator. In addition, the operator could.

benefit from assistance in both diagnosis of problems, in action planning and in implementation of control actions.

Modern computer technology, which increasingly is taken into use in control room upgrades, offers many possibilities for improving operational safety through providing support functions assisting the operators in demanding cognitive tasks. At the Halden Project efforts are made to explore these possibilities through design, development and validation of Computer-based Operator Support Systems (COSSes) which can assist the operators in different operational situations ranging from normal operation to disturbance and accident conditions. These systems are evaluated in the Halden Man-Machine LABoratory, HAMMLAB, and some systems are installed in operating nuclear power plants, thus providing practical experience from integrating new functions as part of plant upgrades.

This paper describes some of these COSSes and presents experiences from integration and evaluation of these systems in the experimental control room of HAMMLAB and in real control rooms of nuclear power plants. The integration aspects are particularly addressed, as these are crucial for obtaining solutions which really improve the working conditions for the operators. In the integration of new functions in a process control environment human factors considerations are very important. The upgraded control room, including the new operator support functions, must be conceived as a balanced entity, which requires a unified human machine interface throughout the control room. Further, proper co-ordination and prioritisation of the different tasks and functions of the operator must be achieved through a top-down design process, defining the information requirements of the operators in the different operational situations to assure proper information structuring and presentation.

2. The Computerised Alarm System Toolbox COAST

Scope

Improvement of the alarm system has been identified as one of the most important requirements in retrofitting and modernisation projects [1][18][27]. Typical problems identified are:
- existing alarm systems are usually optimised for full power operation and should be improved in other plant operating states: during power variation, start-up, low-power, outage periods, and disturbance situations.
- too many alarms presented during large disturbance situations.
- parallel disturbances are difficult to detect.
- acknowledgement of many alarms is sometimes a time consuming task.
- alarms are not presented at the location where the object manoeuvring take place
- etc.

The alarm system should be optimised with respect to these overall requirements and adapted to the capabilities and limitations of humans for information handling, problem solving and decision making. When designing alarm systems, the "dark screen" principle is important for obtaining an alarm system which only calls the operator's attention when something is wrong. No alarms should be presented when a process part is in normal state without failures. During normal changes of the process, a number of parameters are changing. As long as the variations are normal with respect to the state of the process, no alarms should be presented. The main goal is to avoid information overflow in all states of the process.

In order to keep the number of presented alarms at a level where cognitive overload of the operator is avoided in all operational plant states, it is of major importance to structure the alarms. Structuring means better prioritisation, as well as suppression of alarms from the main alarm lists and overview displays.

It is also important to remove false alarms or less important consequence alarms, and to satisfy operator’s need for flexibility, to choose among pre-defined alarm structures and to provide him with the possibility to search for adequate data as additional support during plant state identification. Thus no alarms should be removed from the system. Suppressed alarms should be available for the operator if he wants them in fault diagnosis, etc.

Presentation of alarms should adhere to the following principles:

- alarm- and process information must be integrated. When alarm information is integrated with process information in the same displays, the operator don’t have to extract information from separate sources to obtain a mental model of the process. The data acquisition task is reduced for the operator as well as the required mental processing. The interaction workload with the user-interface is reduced, (e.g. use of keyboard, tracker-ball, exchange of pictures).
- alarms should be presented at several levels. With reference to the “dark screen” principle and principles for filtering and suppression of all irrelevant alarms, the alarm presentation comprises the following levels:
  1. at the top-level, all important alarms are integrated with the continuous overview information for the whole Main Control Room (MCR).
  2. the next level shall present all alarms which are not filtered or suppressed in one or several alarm overview pictures at operator workplaces (e.g. Reactor Operator, Turbine Operator, etc.).
  3. the third level contains alarms in selective lists and process pictures. The selective alarm lists contain all alarms including suppressed alarms, while the process pictures contain alarm information integrated with the detailed mimic diagrams in MCR.

It is required to provide a flexible alarm system which can offer improved functions for alarm generation, alarm structuring, and alarm presentation. The alarm system should be reconfigurable, i.e. it should be easy to make changes, build new alarm structures and alarm logic.

To meet the requirements expressed above for enhancing alarm systems in the process industry, the Halden Project has developed the COmputerised Alarm System Toolbox (COAST) [12][13][20][21][23].

In the past, many systems for intelligent alarm handling have been developed and tested as part of the Halden Project research programme. Examples are alarm filtering [2],[3],[4],[5], model-based fault detection [6],[7],[8],[9] and surveillance of critical safety functions [10],[11]. The methods explored complement each other in different plant operation regimes and provide diversity in plant monitoring systems.

This knowledge is made easier accessible with COAST. COAST enables configuration of intelligent alarm systems which may be adapted to the specific process at hand and it may be integrated into conventional process control systems.

Design features of COAST

COAST is a toolbox for making alarm systems with advanced functionality, see Figure 1. This could be as an add-on module to the process control system (PCS), utilising measurements and binary events from the PCS. Some of these binary events may be alarms which are generated at the distributed PCS level. COAST may then structure these alarms into different types of alarm lists, it may filter and suppress the alarms based on simple or
advanced algorithms, and it may generate new aggregated alarms for better explanation to the operator. Examples of such alarms are function-oriented alarms like critical safety function alarms, or model-based alarms used for early fault detection, or aggregated alarms describing the process state, which in turn are used for suppressing other non-relevant alarms.

![Diagram of a process control system with COAST integration](image)

**Figure 1. COAST as add-on to a process control system.**

The main features of COAST are:

- **Alarm system definition:** A COast LAnguage, COLA, is available to build alarm systems. It is a high level declarative language influenced by natural language, it supports object-orientation and has strong expressive power for arithmetic and logic expressions as well as many time dependent features. It includes first order logic. In addition binary arithmetic is available to reason on bits in a status word. This may be useful in cases where the PCS represents information in every bit in a status byte. The COLA code is compiled by a compiler (Cc), which checks for lexical and syntactical correctness of the code, along with checks for loops in the definitions. This is done off-line.

- **On-line alarm processing:** The COAST kernel is running on-line, utilising the definitions made in COLA. The kernel is event driven and takes care of all processing of alarms when process data are entered to the system by external applications through the COAST Application Programmer’s Interface, CAPI. The CAPI is a function library which is linked into application programs (C++ programs). The communication between the programs is done through the Software Bus, a communication module developed by Institutt for energiteknikk (IFE), Halden [16]. The results from the processing in the kernel are fed to a graphical system through the CAPI.
• **Alarm list extraction:** The external application may ask the COAST kernel for a selection of alarms, which will then be returned in a list. These selections are written using COLA Light, a subset of COLA containing the selection facilities of COLA, offering the possibility to search among existing alarm objects. These selections can be predefined, or new selections can be specified on-line by application programs in order to obtain new lists of alarms. This provides a very powerful and flexible possibility to create selective displays which the operator may use in his investigation of plant anomalies. Whenever new alarms occur which match a selection criterion, they are automatically sent to the application program.

Through COLA Light it is possible to select alarm lists to look at different combinations of alarms. In this way COAST will not remove the alarms completely, but suppress them in some lists, while they at the same time are available in other lists. We believe that such "transparent" structuring will be more and more important, and replace the traditional "filtering" of alarms which is done in some existing systems.

The alarm display system is not a part of COAST, and it is looked upon as an external system. This makes it easier to integrate COAST with existing process control systems. An application program must be written which feeds a graphical system with alarm lists from COAST.

**Examples of Alarm Processing Methods**

- **ALARM GENERATION**

Two main types of alarms may be generated: 1) Basic alarms and 2) aggregated alarms. This distinction says nothing about the priority or importance of the alarms.

**Basic alarms** are generated directly from measurements or binary signals. Thus they may often come from the (distributed) process control system (PCS), or they may of course be generated in COAST. Very often it may be advantageous to take already generated alarms into COAST for structuring there. Especially this is the case for binary alarms where the alarm is triggered by a binary switch, or alarms generated close to the measurement in a distributed control system.

**Aggregated alarms** (in some reports called "high-level alarms") are based upon a processing of more than one measurement and/or basic alarms. They should comprise more knowledge and comply more with the operator’s mental model of the plant than the basic alarms. Below some examples of aggregated alarms are given.

**Group alarms.** These alarms show that there is an alarm in a process part. A group alarm is often made for each major plant system or subsystem. The group alarm itself only tells in which system there is something wrong, not what is wrong.

**Plant system state alarms.** This type of alarms tells about the state of major plant components or plant (sub)systems. An example is "Turbine 1 is tripped". Therefore they are more informative and thus better than the normal group alarms. They should be extensively used in the structuring. Other examples are Process Shutdown alarms and Emergency Shutdown alarms in the oil industry, or "trip alarm" as "SCRAM" in a nuclear power plant. These alarms are given directly from the trip signals, and says that a trip is triggered. This information should then be used to suppress other alarms.

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Plant mode alarms. These are very similar to plant system state alarms, only with our definitions we define the plant modes to be global, as opposed to plant system state alarms. The plant mode alarms usually consist of logical combinations of many basic alarms and process measurements. This is also the difficulty with global plant modes, that a very thorough process analysis is needed in order to find the right definitions of the plant modes. A problem may also occur when trying to define transitions between plant modes and the implications on alarm suppressions. Therefore, a more distributed solution using plant system state alarms instead of plant mode alarms, is often more desirable.

Model based alarms (EFD). The Halden Project has for several years utilised models in the surveillance of the plant state, and a system which utilises model based alarms is EFD, Early Fault Detection [6],[7],[8],[9]. Also a system called MOCOM, Model based Condition Monitoring [24], uses the same concept, even though this system is slightly more directed towards maintenance. In EFD, decoupled, distributed models are calculating the fault-free behaviour of subsystems, and this is compared with actual behaviour of the process. EFD can find faults in components and subsystems as well as in the control system. The implementation of EFD in COAST is extensively described in [13], and for further information you should read this report.

Function-oriented alarms. These alarms are issued if important functions are threatened in the process. A typical example in the nuclear industry is critical safety functions like core cooling, secondary heat removal, etc. At the Halden Project, several systems and studies have been done on this subject. Experiments were conducted in the 80s on systems called Critical Function Monitoring System (CFMS) and Success Path Monitoring System (SPMS) [10]. Later a system called SAS-II [11] was developed. A more recent example including safety function surveillance is the PLASMA project [25]. In [12], the implementation of such an alarm system with COAST is described.

ALARM STRUCTURING

The term alarm structuring includes what is normally referred to as alarm suppressing and alarm filtering. The most important goal with alarm structuring is to reduce the alarm avalanche during plant disturbances. An important goal is also to group and sort alarms in such a way that the presentation can be optimised and adapted to the information needs of the operators at any time.

A major motivation when making COAST was to provide many different alarm suppression methods, while not removing alarms completely from the system. All alarms should still be available in other lists than what the operators normally use. In COAST there is a possibility for generating lists in a flexible way through the COLA Light selections. One can make new lists on-line using selection statements with any kind of boolean expressions inside. This supports selective displays as implemented in CASH [5], where the operators can choose many kinds of combinations of conditions to make new on-line alarm lists. This functionality is thus closely coupled to the alarm presentation, since this structuring, or the selections in COLA Light, decides the conditions for what or which alarms to present. There is also another functionality of the structuring which is implemented in COLA, and this is the grouping of alarms and establishing the basic suppression conditions. Simple group alarms are also a part of alarm structuring.

Different methods for alarm suppression exist. A few methods and how these may be implemented in COAST are described below.

Plant system state suppression. The plant system state alarms describing state or status for (important) parts of the plant, may be used to suppress other alarms. A typical example exists when a part of the plant is bypassed, the alarms within this subsystem are then suppressed. The plant system state suppression may be coupled to simple facts, as e.g. whether a pump is running or not. When a pump is not running, low pressure alarms on the pressure side should be suppressed.

Repeating alarms. Alarms or events when they occur several times in a given length of time should be suppressed and treated in a special way. One may wait to turn them off until they have been off in a period of time. If they go on again within this period, they may be presented again as the same alarm. This would not increase the number of active alarms, but it will reduce the rate with which new alarms are triggered. This requirement is also mentioned in [19]. In COAST there are a number of time reasoning facilities, which may be used for such suppression.

Dynamic alarm limits. Dynamic alarm limits may be defined based on process parameters as pressures or temperatures, or defined on beforehand based on known events in the process. It is simple to define this in COAST, using COLA’s arithmetic and logic capabilities.

Manually blocked or inhibited alarms. An inhibited alarm will typically be a binary signal (e.g. inhibited AlarmX) from the process control system which may be used directly in the suppression logics.

Alarm grouping and sorting. Several standards state that the alarm system should be able to present alarms in different groups according to various criteria, e.g. functional sub-sets, equipment, degrees of seriousness, levels of priority or other characteristics [12]. Also, the proposal for standard in [19] states that one should be able to dynamically sort certain alarms into hierarchies by the degree of seriousness or level of priority. To display different kinds of alarm groups and to present lists sorted by any criterion, is very easy in COAST as this is actually what COAST is made for.

Utilising shutdown logic for suppression. When a shutdown occurs, either a partial process shutdown or a plant shutdown, very many alarms are usually triggered. It is important to suppress many of these alarms, and present only the not expected alarms during this kind of shutdown. This kind of suppression can be done with similar methods as for plant system state suppression. One can define a process shutdown signal as a plant system state. An example is "Turbine A tripped", which causes a shutdown on the turbine A and its connected systems.

Identifying the first out alarm. Identifying the first out alarm in an alarm avalanche is of major importance to be able to find out what did trigger a shutdown. This is very similar to the shutdown alarm suppression above, just a small variation in the use of the logics. It can be seen as a special kind of group alarm, and is easily implemented in COAST by combining the group alarm examples with some other logic about time of when the statuses went on.

Experience with COAST

In HAMMLAB the current alarm system is CASH (Computerised Alarm System for Hammlab) [5]. CASH utilises COAST for the alarm generation and structuring part, while Picasso-3 [14],[15], is used for the alarm presentation.

Several member organisations are currently utilising COAST, either for making alarm systems, or for making other kinds of detection systems. 19 organisations have so far received COAST, and the number is still increasing. This includes both HRP member organisations and companies outside HRP.

One of the companies using COAST more and more extensively is Siemens. A special version of COAST was integrated into one of their process control systems (SICOS LSX), as they wanted to strengthen the process control system with the alarm structuring functionality offered by COAST. Siemens Norway has world wide responsibility to deliver process control systems for offshore installations, and indicates that COAST will still be a part of their future deliveries. Up until now, the process control system including COAST is used on two oil production platforms, owned by SAGA and Philips, in the North Sea.

The application of COAST in the development of the alarm system for HAMMLAB, CASH, as well as the applications on the North Sea oil production platforms have shown that COAST is an efficient and flexible tool for developing advanced alarm systems providing better support for the operators in plant disturbance situations. In HAMMLAB experimental evaluation of CASH also revealed that the structuring and selection features of this alarm system together with its tight integration into the Main Control Room MMI resulted in an alarm system providing very good operator support in transient plant situations.

3. The Plant Safety Monitoring and Assessment System (PLASMA)

Scope

At the Paks NPP in Hungary an extensive plant upgrading programme is taking place. A new Reactor Protection System is being installed, the plant computer system is being exchanged through the so-called Plant Computer System's (PCS) reconstruction project, and new, symptom-based Emergency Operating Procedures (EOPs) are being written. In this connection it was found desirable to improve the data validation, information integration and presentation for operators when executing the EOPs. The entry point to a symptom-based procedure is defined by the occurrence of a well-defined reactor operation status, with all its symptoms. However, the application of the EOP benefits from an operator support system, which performs plant status and symptom identification reliably and accurately.

It was therefore decided that the new PCS will include a PLAnt Safety Monitoring and Assessment system (PLASMA) which will include a Critical Safety Function Monitoring (CSFM) module and provide operator support during the execution of the new EOPs [25]. IFE, Halden and KFKI Atomic Energy Research Institute, Budapest are responsible for the development, testing and installation of PLASMA as a subsystem of the new PCS. The PLASMA project has been initiated and partly funded by the Science and Technology Agency (STA) and JAERI, Japan through the OECD Nuclear Energy Agency (NEA) assistance programme.

The major features of the PLASMA system are to provide operators with the following information:

1. the current safety status of the plant,
2. on-line monitoring of the critical safety function status trees, and
3. displaying the EOPs in a computerised form and those signals which are referenced in them.

Although the system has a modular software structure which can be expanded whenever it becomes necessary in the future, in the first phase the following main functional modules will be developed:

• PLASMA Input/Output Server
  • obtaining all required input signals from the PCS network
  • transferring calculated output signals to the FIX Scada system for further processing

• Plant State Identification
  • determination of reactor operation mode
  • safety systems' status monitoring
  • availability of auxiliary systems
  • determination of missing actuations
  • monitoring of actuations
  • determination of false actuations

• Critical Safety Function Status Tree Monitoring
  • subcriticality
  • core cooling
  • secondary heat removal
  • reactor vessel integrity
  • containment integrity
  • primary circuit inventory

• EOP Selection and Display
  • computerised EOP display
  • displaying the parameters referenced in the EOPs

• Man Machine Interface
  • operator's MMI
  • remote user's MMI
  • system supervisor's MMI

System Design

The demands of having PLASMA as an integrated part of the new Plant Computer System (PCS) for the NPP Paks have an impact on the design of the system.

Since the new PCS is implemented on workstations running in Windows-NT environment and using the Intellution system for realising the Man-Machine Interface, the PLASMA system will be implemented on workstations running in Windows-NT environment with the Intellution FIX DMACS Scada System and duplicated Ethernet communication based on the TCP/IP protocol. The type of platform will be Intel XEON 2x400 MHz Rack server computer. However, the system will be built in such a flexible way that adaptation to other MMI system can be done without much effort.

The system is made configurable as far as possible, in order to allow easy extensions and/or modifications of system parameters. Adding new instruments, for instance, will not require any reprogramming.

A block diagram of the main modules is presented in Figure 2.
The purpose of the different modules are described in the sub-sections below.

**The Input/Output Server**

The “Input/Output Server” (IOS) module will take care of all the input and output signals going into or out of the PLASMA system. SWBus [16] will be used for internal communication between the PLASMA modules, including the IOS module. The IOS will collect the required input data from the PCS through EDA (the FIX Easy Database Access API) calls, and then make them available for the other PLASMA modules through SWBus objects.

The IOS module will take care of writing back the calculated signals to the FIX database for further processing (alarm and event generation, etc.): calculated signals will be put into a circular buffer by using CIR API calls (the CIR API is part of the new PCS software system), and a special FIX CIR driver is applied for transferring them to the FIX database. Thus the calculated signals can be archived, displayed on FIX pictures or on trends, etc., exactly the same way as measured signals.

This arrangement ensures sufficient separation of the PLASMA modules from the rest of the PCS software and provides a clear-cut interface, which facilitates stand-alone testing of the PLASMA software.

**Plant State Identification**

The module “Plant State Identification” (PSI) will take care of the monitoring and evaluation of plant safety status. It will receive periodically, or when necessary, relevant process data to determine the plant safety status. It will also send relevant data to the module monitoring the CSF Status Trees. Process data will be provided for the MMI. Plant State Identification
should be primarily based on simple logic calculations and a number of task-oriented display formats supporting the operator's comprehension of the actual reactor state.

The PSI module performs the calculations necessary to monitor the state of the vital safety and auxiliary systems of the reactor. The PSI functions are the following:

In Normal and Abnormal Operation Conditions:
- determination of the actual reactor operation mode according to the plant's Technical Operational Regulations.
- determination of the actuation state of the vital safety systems.
- determination of the operational state of the vital auxiliary systems.

In Emergency Operation Conditions:
- monitoring the actuation of the reactor protection system (RPS) and other safety systems.
- monitoring the status of the actuated safety systems.
- determination of false safety and protection system actuations.
- determination of missing safety and protection system actuations.

Safety Function Monitoring

The Safety Function Monitoring (SFM) module evaluates those internal variables which are necessary to monitor and display the Critical Safety Function Status Trees. In principle, a status tree is a decision tree with one entry point and with a few possible exit points. The relevant CSF status trees are:

- subcriticality
- core cooling
- heat sink (secondary heat removal)
- reactor vessel integrity (Thermal shock)
- containment integrity
- primary circuit inventory

Information will be provided for the EOP handling module and the MMI. Appropriate CSF alarms will be generated whenever the status of a specific CSF is off-normal. CSF alarms will be interpreted as other process alarms in the plant computer system.

Procedure Selection and Display

The module "Procedure Selection & Display" (PSD) will take care of displaying the requested procedure when selecting it from a CSF status tree display. The PSD module will be based on the COPMA-III system developed at IFE [28][29]. The PSD module will use the ActiveX version of the Microsoft Internet Explorer (MSIEX) web-browser to display the procedures. The module will also initiate the display of the corresponding checklists containing the signals which must be checked by the operator while executing the procedure. The PSD module can also be run independently, not only from the CSF status trees. In this case the operator can select the desired procedure from the Table Of Contents displayed on the left side of the screen. The PSD module has the following functions:

- selection of EOPs from the CSF status trees.
- displaying the selected EOP and its browsing step-by-step.
- presentation of the corresponding Dynamic Reference Lists.
- logging of operator's actions into a log file which can be viewed and analysed later.

*Paper presented at the OECD NEA Workshop on Approaches for the Integration of Human Factors Into the Upgrading and Refurbishment of Control Rooms, Holden 23rd-25th August, 1999.*
The procedure handling will be performed by two different user groups with different privileges:

- internal users with execution or monitoring privilege,
- external users with EOP browsing privilege.

The external users will only have inspection (browsing) access to the procedures while the internal users may have procedure execution access.

**Man-Machine Interface**

The system will have a Man Machine Interface (MMI) which will be fully integrated with the display system of the new Plant Computer System. The MMI will be used for displaying plant safety status, plant safety overview, detailed CSF information and CSF status trees. It will also provide features for EOP handling based on an HTML browser.

There will be three different user groups. These are:

- operators
- remote users (for remote workstations)
- system supervisors

for which different levels of MMI functions will be made.

The group "Remote Users" represents mainly plant safety supervisor officers, engineers or reactor physicists who access the plant computer information from their offices through the network.

The group "System Supervisor" represents the users, which will configure and maintain the PLASMA system. The system will have special displays for configuring the PLASMA system.

A common guideline for organisation of the MMI will be followed concerning picture layout, symbols, text, dialogues, pop-up windows, etc. to support the end-user tasks. Task-oriented pictures will be prepared where appropriate to reduce the demands on the end-user. The most important information for the operators and remote users are

**Operator's MMI**

The MMI for the operator is a unified, integrated MMI for all modules in the system of relevance for the operator. It will contain displays covering:

- displaying of plant safety status
- integration and presentation of alarms from the different PLASMA modules
- fully Integration with the new Plant Computer System (PCS)
- CSF status overview
- CSF status trees and detailed CSF information
- EOP handling (based on HTML browser)

**Remote Users MMI**

The MMI for the Remote Users will basically be the same as for the operator. However, they have limitation with respect to information access. They can view CSF status trees, but they can only use the EOP support module for inspection of the procedures.

*Paper presented at the OECD NEA Workshop on Approaches for the Integration of Human Factors Into the Upgrading and Refurbishment of Control Rooms, Halden 23rd-25th August, 1999.*
System Testing and Validation

The new Plant Computer System including the PLASMA subsystem is developed in a simulator version and nuclear plant unit version. Thus, the PCS system (and PLASMA) will first be installed at the Paks NPP full-scale simulator in September 1999 where testing and validation of the system (and of the new EOPs) will be carried out. Installation of the plant version at unit 1 of Paks NPP will take place during Spring of year 2000.

Experience from the PLASMA Project

In the development of the PLASMA system the close co-operation with the staff of the Paks NPP has been very valuable. Efforts have been made to integrate the PLASMA system with the other modules of the PCS in a seamless way. A unified MMI has been applied throughout the PCS system. The information requirements for proper execution of the EOPs have been carefully analysed, and have been the basis for the structuring and presentation of information in the MMI displays of the PLASMA system.

In the implementation phase early prototyping of MMI functions proved very useful in revealing weaknesses in the first design of the MMI for EOP handling and presentation. A demo package of the EOP display system was installed at Paks NPP and shown to operators and other experts working on the EOP project. Based on their review a new, improved specification of the EOP display system, including the navigation, paging, and step acknowledgement methods to be used was made as an addendum to the previously approved System Specification Document (SDD).

In the development of an integrated control room system as in the case of the PCS/PLASMA system, a final validation in a realistic, full-scale simulator prior to installation in the plant is highly recommended. Thus, the development of PLASMA includes validation of the system (and of the EOPs) in the full scope simulator of the Paks NPP. These validation tests will take place in November – December 1999.

4. The Core Surveillance System SCORPIO

Scope

Core monitoring and physics codes are becoming an integral part of the entire information system at the plants serving the reactor engineering group in core design, safety analyses and operation planning. During plant operation the control room operators rely on key information derived from on-line measurements and calculations for monitoring safety margins. Predictive simulations for planning operational manoeuvres are used for real-time core control optimisation. Core monitoring systems are gradually distributed to new user categories. It is not only the specialists in core physics and simulation codes that are users of the information that is produced from these advanced systems. Information distribution and easy access to core physics calculation tools have been one of the main motivation factors for the utilities installing the SCORPIO system, see references [30], [31], [32], [33].

Considering also the fast development of information technology it is extremely important to design flexible core monitoring systems that can easily be adapted to the different user needs and integrated with other plant information functions. With the increasing number of different computerised support functions, it is important that the core monitoring system is not seen as a stand-alone system, but rather can be seen as a natural part of the entire information system (i.e. a unified MMI). This is of particular importance for the control room operators.

During the recent years there has also been a shift from proprietary hardware and software towards more open off-the-shelf hardware and software solutions. As a consequence of this there is a demand for a flexible framework for integrating the various modules into a core surveillance system. Generic building blocks are used in development to facilitate system integration. The new SCORPIO framework consists of a communication system for interfacing the various modules (e.g. physics codes), an administration system for all the different modules, and a Graphical User Interface (GUI) for generation of MMIs for the different categories of end-users. The Picasso-3 User Interface Management System (UIMS) [34] supports object oriented definition of GUIs in a distributed computer environment. Reuse of interface components and other software modules can make the system development and maintenance more efficient.

The SCORPIO System Development History

The first version of the core surveillance system SCORPIO was installed at the Westinghouse plant, Ringhals Unit 2 in Sweden, in 1984. The main purpose was to provide a practical tool for reactor operators and reactor physicists for on-line monitoring and predictive analysis of core behaviour. It was implemented on Norsk Data mini-computers with a fully graphical user-interface. Due to the technology offered at that time, both the hardware and software solutions were highly vendor specific and not portable to other computer systems without major modifications. However, the system concept and functions provided were appreciated by plant personnel. Especially, the MMI (implemented in Picasso-1) with the strategy generator provided a fast and accurate means for performing predictive core control analyses.

The second version of SCORPIO was developed in 1993-1995 and implemented on Unix workstations. In addition to upgrading the system at Ringhals, the system was installed by Duke Power, USA, on 4 Westinghouse reactors and 3 B&W reactors. SCORPIO was also installed on the Sizewell B reactor. The system could run on all major Unix platforms in a distributed computer network using the TCP/IP communication standard. The Picasso-2 GUI system made it possible to develop the MMI independently from the physics codes and made the MMI portable by utilising the X-Windows standard.

Recently a new framework has been developed which further enhances the flexibility and capabilities for implementing core surveillance systems in different types of nuclear power plants. Modules can be added and replaced in an easy manner. It allows fast and reliable communication of data between modules. Further, the Picasso-3 system supports efficient implementation of different user interfaces. Both Unix and Windows NT platforms are supported.

The new framework has been applied in development and installation of a SCORPIO-VVER version [33] for the Dukovany NPP, Czech Republic. Here it was of particular importance to provide a flexible system for integration of modules originating from different companies. Development of a BWR version is now in progress. This means that SCORPIO will be available for all the major reactor types, and synergy is obtained by application of a common framework both with respect to system implementation and maintenance.

By using the SCORPIO framework, the development time is reduced and the maintenance work is carried out more efficiently, compared to developing systems with lower-level tools. For instance, the MMI can be developed and tested independently of the physics modules.

Integration Framework

The SCORPIO framework for integrating the various modules into a core surveillance system, has the following features:

- the framework is flexible, so that modules can be added or replaced in an easy manner, and so that the system can be developed fast and configured easily.
- fast and reliable communication of data between all modules, including the Graphical User Interface (GUI), is supported.
- the system allows distributed computing and presentation. The different processes may thus be distributed over several computers in a network, with results available at more than one GUI.

The information exchange is based on the Software Bus tool developed at IFE [16]. The Software Bus is an object-oriented communication system, based on the network protocol TCP/IP, and manages a dynamic set of distributed objects. In this context, an object will typically represent a variable, structure or function belonging to a certain module. Applications that use these objects are able to share data and functionality with other processes running on different systems across a network. A Software Bus C library enables communication to be performed through a set of high-level interface routines that are linked with every module. The Software Bus is presently implemented for UNIX workstations and Windows NT computers.

The GUI is built upon Picasso-3, a User Interface Management System also developed at IFE [34]. Picasso-3 is closely related to the Software Bus and is also designed to operate in a network environment. A program referred to as the Module Administrator connects the GUI to the other modules. The general structure of the integration framework is shown in Figure 3.

![Diagram of SCORPIO framework]

*Figure 3. General view of the SCORPIO framework*

Experience from Various SCORPIO Installations

The following examples are typical tasks supported by the SCORPIO system for western PWRs:

*Paper presented at the OECD NEA Workshop on Approaches for the Integration of Human Factors Into the Upgrading and Refurbishment of Control Rooms, Halden 23rd-25th August, 1999.*
- Criticality Calculations

If the power prehistory is complex, it is difficult to calculate critical boron concentration as a function of time. With SCORPIO, this type of calculation is made in minutes, covering up to 72 hours ahead.

- Optimisation of Planned Power Changes

Power reductions, load following and start-up after shutdown are transients which are more efficiently performed if planned hours ahead with SCORPIO's predictive functions. Critical passages can be detected and anticipated.

- Axial Power Distribution Control

Operation outside the delta-flux operating band is only permitted for a limited period. Various control strategies to deal with axial xenon redistribution are efficiently and rapidly evaluated.

- Coast-down Operation Support

Operation at low boron concentration is difficult for a number of reasons. Return to power after a trip might create problems with the delta-flux operating band. The consequences of power manoeuvres at coast-down or low boron concentration can be fully investigated.

- Trend Analysis

Reactivity related parameters are available for trend analysis. The relationship, for example, between temperature variations and impact on the power distribution might be investigated in detail with the monitoring functions.

- Xenon Transients

The general behaviour of transients might also be investigated. SCORPIO output shows xenon transient during load follow operation.

- Power Distribution (Local, Global)

The 3D-power distribution functions make it possible to see how the power distribution varies radially and axially, locally as well as globally, during transients.

- Thermal Margin Limits

The impact of the control rods and the power level on the thermal margins is easily illustrated for a number of transients, and shows that FAH increases with rod insertion.

- VVER Version

In the development of the new core monitoring system for Dukovany NPP, we could utilise experience gained during the development of the SCORPIO core monitoring systems for western type PWRs.

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The major new features of the SCORPIO-VVER system in comparison with the old core monitoring system at Dukovany NPP can be summarised as follows:

- improved limit checking and thermal margin calculation.
- on-line 3D power distribution calculation
- improved validation of plant measurements and identification of sensor failures by utilising the core simulator as an independent means for calculation of 3D power distribution
- optimum combination of measurements and calculations to obtain more precise values of critical parameters
- predictive capabilities and strategy planning, offering the possibility to check the consequences of operational manoeuvres in advance, prediction of critical parameters, etc.
- provide interfaces to off-line analysis codes for core loading pattern design, etc.
- integration of modules for monitoring fuel performance and coolant activity as a means for detection and identification of fuel failures
- improved man-machine interface for operators and reactor physicists
- Improved HW/SW reliability, by introduction of a new computer system.

- Training

Many core related parameters are difficult to simulate on full scale training simulators. SCORPIO provides an efficient way to demonstrate the impact of various strategies and the consequences of inappropriate actions.

**Intranet Coupling**

Intranet solutions are introduced as one way to cope with the increasing demand for improved access and distribution of information in nuclear power plants. The information provided by advanced core monitoring systems is one type of information that may be requested. In the SCORPIO system installed in Ringhals, a module has been implemented which retrieves key data from the core surveillance system and generates HTML code for the WEB browser. In this way every person which has access to the intranet at Ringhals can obtain the status and main parameters of the core.

6. Conclusions

At the Halden Reactor Project research on introduction of computerised operator support systems (COSSes) in NPP control rooms to assist the operators in their cognitive tasks has been an on-going activity for many years. Different COSSes have been developed and integrated in the advanced control room of the Halden Man-Machine Laboratory, HAMMLAB, where they have been evaluated in Human Factors experiments with participation of reactor operators from the Halden Reactor as well as from the Loviisa NPP in Finland. Several of the COSSes developed at Halden have also been installed in commercial NPPs by Institutt for energiteknikk (IFE), the operator of the Halden Project, in connection with control room upgrading projects.

This paper has presented some of these COSSes and experiences from their installation in HAMMLAB and commercial NPPs. Generally, the experience from these projects has been that computerised operator support functions improve plant operation both in terms of operational safety and economy. It is, however, important for successful applications of COSSes that careful evaluation and validation of these systems are performed, in particular the human factors aspects of introducing new functions in the control room. It is important that the COSSes are properly integrated with the rest of the control room setting, in

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particular the man-machine interface of the COSSESes must be perceived as part of a unified MMI-solution comprising the total control room. Further, as new COSSESes also represent new information in the control room, care must be taken to avoid information overflow through a top-down design process taking care of the co-ordination and prioritisation of different tasks and functions to be carried out by the operator, and by structuring information presentation accordingly.

Another experience from control room upgrading projects including introduction of new operator support functions has been that involving plant operation staff in the design process at an early stage is very important for a successful project. This is particularly important with respect to the design of the man-machine interface, and if early prototyping of the MMI-functions are possible, this has proved to be very useful.

A final validation of the systems in full-scale simulators is, if possible, highly recommended to assure that the introduction of the COSS(es) really facilitates the operators' tasks.

References


Control Rooms in German Nuclear Power Plants
Eberhard Hoffman (KSG/Gfs)

Paper missing
INTEGRATION OF HUMAN FACTORS AND EXPERIENCE FEEDBACK IN THE DESIGN OF FUTURE FRENCH IRRADIATION REACTOR

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1. ABSTRACT

The CEA and its industrial partners have launched the project of a new irradiation reactor « Jules Horowitz » which is expected to relay the similar reactors, presently in operation, during the first decade of the 21st century.

The main characteristics of the design of the Instrumentation and Control of this future plant, as compared to those of the presently operating reactors, will result of the synthesis of various kind of requirements:
- operating team demands, as the result of the available operating feedback,
- evolution of the operating requirements (plant availability, operating costs, experiments quality),
- foreseeable evolution of the safety requirements for experimental plants,
- and finally, the evolution in the I&C toward numerical technology generalization.

This presentation will give an overview of the main domains of the plant I&C design which are impacted by this reflection and of the foreseeable directions of evolution which are considered presently.

2. INTRODUCTION

The CEA and his industrial partners are working today on the project of a new irradiation reactor for the first half of the 21st century. The name of this project is « Réacteur Jules Horowitz » : RJH.

This reactor is designed to assume different missions:
- support the power reactors operation,
- allow researches for the new reactor types, and the end of the fuel cycle,
- produce radionuclides for medical purpose,
- provide activation analysis tools to researchers,
- support basic research.

This experimental reactor will be built around a slightly and lowly pressurized primary circuit.

The construction of the reactor could start around 2005.

Our team is presently in charge of the specification of the I&C system.
3. UPGRADING, REFURBISHMENT AND NEW DESIGN OF I&C SYSTEMS

To our point of view, there are many similarities between the approaches involved into upgrading and refurbishment on existing reactors, and the design of a brand new system.

In both case, the goal is to fulfill a set of requirements concerning the operation of the reactors. These requirements are often the same:

- safety of the reactor
- availability
- cost
- flexibility to allow the larger possible panel of experiences
- ...

The experience feedback of the plant operation will be a very important element in both design processes. This experience feedback must be as wide as possible and should ideally benefit from the experience of:

- similar reactors,
- other nuclear plants,
- other industrial non nuclear plants.

Nevertheless, the « external » constraints on the means usable to fulfill those requirements are much smaller in the design of a completely new I&C system than in the case of the upgrading of an existing one.

There is also, when designing a completely new plant, a (small and maybe theoretical) possibility to influence the design of the reactor to allow an easier control room operation. This return on the design of the plant itself is much more difficult in the case of existing plants.

4. EVOLUTION OF REQUIREMENTS

4.1 EVOLUTION OF OPERATING REQUIREMENTS

As explained before, we will try to collect as much as possible experience feedback of existing plants, and mainly experimental reactors, to design the I&C system of the RJH.

But we also have to take into account a new set of requirements expressed by the future manager of the reactor. So, the new system will not be just an improvement of the former systems due to experience feedback.

Due to the much more competitive environment, the main new requirements expressed in the RJH project are:

- high quality of experiments,
- very high availability (250 days of full power operation per year),
- minimization of operation costs.

This will certainly influence the specification of the I&C system, and the organizing of the operating teams. For example, some new tasks could be assigned to control room teams, to be done in background during low activity period. We have also to study if an higher level
of automation on relevant tasks could help to reduce the workload demand on the operation teams.

In the future, the turn over in the operating teams could also be much higher than today (either because of the operators themselves, or because of management needs). This could influence the experience level of the operators. In this case, an higher guidance level could be required for the important operations.

4.2 EVOLUTION OF SAFETY REQUIREMENTS

The design of the RJH will have to take into account the most recent safety requirements.

There has been constant progress around this theme during the last years, and the safety constraints that the RJH will have to take into account are much prescripted than what was asked for previous experimental reactors.

The RJH project will take into account the latest safety rules that apply to this type of reactor.

The evolution of the rules will certainly influence:

- the control room operation. For example, control room operation could have to be much more formal than by the past (extensive use of procedures),
- the architecture and components of the I&C system (classification of the different subsystems, requirements to meet a classification level...).

5. EXPERIENCE FEEDBACK

In order to design our new I&C system, it appeared to us very important to gather the maximum of experience feedback coming from the other experimental reactors (French and European reactors).

The reactors considered are:

- France: OSIRIS, ORPHEE and operators from SILOE (this reactor has been closed recently),
- Norway: HALDEN (HBWR),
- Netherlands: HFR,
- Belgium: MOL (RHF)?

The evaluation of those reactors will range from thorough inquiry (French CEA reactors) to short visits (European reactors).

This process will mainly focus on gathering informations about:

- reciprocal actions between the experience and reactor operation (normal and degraded conditions),
- organization of the teamwork,
- control room operation in the different reactor's situations (normal up to accidental conditions),
- architecture of the I&C system for the reactor and the experiments,
- operating aid systems.
It will capitalize both the current situation and the improvements identified as desirable by the operators, but not possible to realize on existing reactors.

We note however that it seems difficult for basic operators to have an accurate point of view about the system in operation, and to propose evolutions very different from what they use every day. The final design process, to be efficient, will have to take into account:
- the experience feedback,
- the new requirements for the system,
- the last developments about the integration of the human factor in the design of control rooms.

6. MAIN QUESTIONS

6.1 COORDINATION BETWEEN EXPERIMENTS AND REACTOR OPERATION

The main purpose of an experimental reactor is to support the experiments. The reactor will be operated to meet the requirements of all the experiments set up in the reactor. As many as 40 experiments can be running at the same time.

The reactor has also its own operating requirements.

The operators will have to be able to arbitrate the requirements of the different experiments:
- between each others,
- with the reactor,
- with safety.

The gathering of the experience feedback will help us understand those reciprocal actions. This understanding is compulsory to specify an I&C system giving the operators all the means necessary to achieve these arbitrations.

This topic is a key point in the design of the new reactor. Answers to this question will influence:
- the organizing of the reactor and experiments operating teams,
- the architecture of the I&C system (common or separated systems for the reactor and for the experiments),
- the architecture of the building (just one control room for experiences and reactor, or separated rooms).

This could also lead us to propose operating strategies based on clear identification of the objectives of the plant at a precise moment, and of the means available to achieve them, instead of a control room operation based on the display and manipulation of physical systems.

6.2 AUTOMATION AND GUIDANCE LEVEL

Today, the level of automation and guidance in french experimental reactors is fairly low.
The new safety requirements could prescribe an higher level of guidance. The complete study will rely on the analysis of:

- the new safety constraints,
- the complexity of the reactor and experiments operation,
- the experience feedback.

The integration of the human factor is in fact a key point for this subject.

Automation is often seen as a mean to reduce the number of operators needed. We are not sure today, that this is always true. We will try to evaluate this influence of the automation level on the operating crew.

We will have to identify the good criteria to identify the functions to automatize:

- safety actions (human too slow or not reliable enough),
- analog close loop control,
- frequent operations where the operator has no real increase in value (operator's comfort),
- complex tasks taking into account too many parameters to be efficiently managed by a human operator...

6.3 ORGANIZING OF THE OPERATION TEAM

There is a strong willing to optimize the human needs necessary to operate the RJH. A task analysis will have to be done to optimize the part of every operator of the crew.

The final organization will have to optimize:

- the management of incidental and accidental conditions,
- the management of normal situations,
- the number of persons working out of normal hours.

6.4 INTEGRATION OR SEPARATION OF SAFETY FUNCTIONS

Two main options can be considered for the global architecture from the I&C system:

- two separated I&C systems:
  - a classified I&C system in charge of the operation of all safety functions,
  - a "standard" industrial system in charge of the auxiliary functions,
- a unique classified I&C system in charge of all the functions in the plant (safety functions and auxiliary functions).

An important point to choose one of these options will be the accidental conditions management complexity. If this management requires just a small number of informations and operator actions, then the first solution seems to be the more adequate. On the other hand, if this management requires an important proportion of all the informations and actuators, then the second solution seems the best. However, in this case, functions provided to assist the operator decision could be much less powerful, because of the design constraints.
This theme can also lead to interrogations about the best type of man machine interface to control an experimental reactor:

- conventional panels,
- hybrid systems (computerized supervision and conventional hard wired controls),
- fully computerized I&C systems.

Concerning this last point, the experience feedback of the French EDF N4 power plants will also help to identify the improvements and drawbacks of fully computerized I&C systems in the control of nuclear reactors.

7. EVOLUTION OF TECHNOLOGY

This new experimental reactor shall benefit from all the improvements made during the last years in various fields as knowledge about the human factor, or technological breakthroughs. We will have to follow the big industrial trends.

On one side, we do not intend to use systematically the latest technology available just for the sake of innovation.

But on the other side, some experienced technologies used in previous reactors are even not available any more. It would be for exemple very difficult today to build a conventional panel as man machine interface. We will be almost obliged to choose a computerized supervision system, or a computerized I&C system. We will have to take into account the current technological constraints.

8. CONCLUSION

For the design of the RJH I&C system, we decided to have an approach centered on:

- the integration of the experience feedback of similar plants,
- an analysis of the real operator needs,
- the fulfillment of the global design and safety requirements.

We have to choose the more simple way to meet those needs. To achieve this, we will try to use experienced technologies, and to do one step toward a better integration of the human factor in the design of the I&C system.
ABSTRACT

The Nuclear Reactor Engineering Analysis Laboratory (NREAL) is a multi-computer, multiple code-based system with a sophisticated direct manipulation advanced graphical interface. The system embraces a multidisciplinary effort to integrate advanced technology with human factors expertise and techniques. The ultimate goal is to carry out different analysis and studies such as nuclear fuel reloads evaluation, safety operation margins measurement, transient and severe accident analysis, nuclear reactor instability, operator training, normal and emergency procedures optimization, and human factors engineering studies.

Main objective of NREAL is the specification, development and implementation of the classroom analysis simulator (CAS) for nuclear power plant operation training and analysis of severe transient and accident sequences.

The CAS-NREAL has the capability of becoming a highly diverse and sophisticated system for self-study, advanced research kinetics, thermodynamics and flexible modeling. Additional applications include advanced research in ecological displays, decision-making strategies (individual and team concepts), mental model representation, and virtual reality applications as a mean to better define and evaluate operator requirements. As a test-bed for Human Factors Engineering studies, CAS-NREAL has the potential to be used as a new alternative instrument for control console design, system specification, system development, and system verification, facilitating integration of new monitoring and automation technology and the user to the final configuration. The approach uses rapid prototyping for concept development and scenario-based realistic simulations for concept verification. It is shown how both, virtual simulation and rapid prototyping environments are used collectively to rapidly gain insights in concept development and concept verification through an integrated, iterative, user-oriented design, testing and evaluation methodology.
I. INTRODUCTION

A wide variety of computer-based systems are being developed for the nuclear power industry in response to regulatory requirements and advances in computer technology. The objective is straightforward: to aid control room operators in decision making, while enhancing human capabilities and coping with human limitations. The degree to which this objective can be accomplished will be substantially greater if the design of a computer-based system and its interface have a strong methodological basis.

Traditionally, the emphasis in the design of human-machine interfaces has been on the presentation of measured data representing the physical state of components, systems and processes. This data usually is supplemented with information about the underlying functional structure by graphical means such as pictorial and mimic diagrams. Unfortunately, indiscriminate use of this approach frequently leads to the development of interfaces that can be extremely complex in terms of the cognitive effort that needs to be applied for search and integration of information among many informational sources.

One of the biggest problems that confronts the commercial nuclear power industry is the failure to successfully incorporate new technology as illustrated by the requirement to augment the control room with a suitable Safety Parameter Display System (SPDS). This requirement launched the development of a wide variety of dissimilar systems at the cost of millions of dollars to the utilities. Yet, to this date, there is no evidence that any particular SPDS design improves safety or supports more effective plant operation.

The problems experienced by the nuclear industry in integrating SPDS’s demonstrated that this program was launched with an unclear and untested operational concept. Therefore, it is necessary to carry out extensive research using human-machine interface test beds to pretest and validate proposed modifications prior to their implementation.

As pointed out by Rasmussen [1], complexity is not an objective feature of any system. Objective complexity would be justifiable if there would be no other way to convey the proper representation of the internal state of the system. Such situations can and must be avoided.

One way to cope with complexity is to structure the information to a manageable level of information resolution. Paradoxically, this process itself embraces a great deal of complexity since it will affect every single aspect of human-machine interaction; i.e., from how we perceive the information to how it is processed and transformed into meaningful mental models that accurately describe the system and guide human behavior. It follows that any attempt to design a usable human-machine interface must rely on a careful analysis, understanding, and integration of different aspects related to the human information processing system, e.g., visual perception, graphic display formats, and cognitive models among others.
This work describes the development and implementation of an integrated methodology for the prototyping of a control console and information display system. The approach makes extensive use of advanced software graphical tools for virtual representation of task environment and realistic simulations of control processes. It focuses on early and continual involvement of plant operation personnel. The goal is to develop a system to aid the operator in the representation of the internal state of a nuclear power plant while avoiding real or perceived complexity.

II. HISTORICAL OVERVIEW.

Part of the work described in this paper was main component of one of the authors' Ph.D. dissertation back in 1994 [2]. The contents of this paper mainly focuses on how the proposed methodology has been successfully applied since then up to date, with the development of the Nuclear Reactor Engineering Analysis Laboratory (NREAL) concept.

In 1993 the author demonstrated the feasibility and utility of a methodology for the integrated design of control console and information displays system for specific application by the Experimental Breeder Reactor II (EBR-II) of the Argonne National Laboratory-West (ANLW) in Idaho Falls, Idaho [3]. The methodology was used in the design of the control console for the EBR-II plant simulator and Integral Fast Reactor (IFR) projects at ANLW. It spanned from preliminary meetings with EBR-II personnel, to the point where a new control console layout was prototyped and ready for physical development and implementation. Unfortunately, the efforts were cut off by the government decision to definitely shut down the reactor in September 1994.

Nevertheless in 1994, part of the developed work (the EBR-II control room emulation program) was used by Meshkati, Buller, and Azadeh [4] of the University of Southern California as an important tool for the U.S. NRC founded research project "Integration of Workstation, Job, and Team Structure Design in the Control Rooms of Nuclear Power Plants." One of the objectives of this research was to analyze the effect of operators' individual information processing behavior and decision styles on handling plant disturbances plus their performance on, and preference for, Traditional and Ecological user interfaces. The emulation of the central console of the EBR-II control room served as a reference traditional user interface.

From 1995 to 1996, the methodology was applied to develop a Classroom Analysis Simulator Prototype for the Laguna Verde Nuclear Power Plant in Mexico. This prototype with limited functions, was the keystone that attracted international support to build a more sophisticated and multipurpose system.

In 1997-1998, the Institute for Electrical Research (IIE), with International Atomic Energy Agency (IAEA) assistance, developed a Classroom Analysis Simulator able to provide current hard wired simulator capabilities as well as a complete set of visualization and analytical tools for in-depth studies of severe transient and accident sequences. CAS is now the main component of a more ambitious project named the Nuclear Reactor Engineering Analysis Laboratory (NREAL). Seeking ways to develop a broader utilization
of the CAS, the system (and the project) is being transferred to the National Autonomous University of Mexico, the most important university in the country, where CAS and its development will afford a wealth of opportunities in university education and research. The IAEA will continue providing expert services, severe accident computer codes, equipment, and training for the next two years.

III. RAPID PROTOTYPING FOR CONTROL CONSOLE DESIGN

A. Rapid prototyping

The use of prototypes in hardware engineering has had a long and successful history as a way of testing ideas and concepts. Model airplanes in wind tunnels, industrial samples under severe environments, and mock-ups for user testing are familiar examples.

In traditional system engineering, prototyping refers to the construction of a "first of a kind" full scale version of a system for testing and verification purposes, before production of the system begins [5,6].

A related but different concept is that of rapid prototyping as a design and development methodology. Rapid prototyping as a methodology is intended to solve efficiency problems associated with traditional design methods, while increasing effectiveness [7-14].

Current iterative design approaches for nuclear power plant control console use hardware/hardwired interfaces. These interfaces can be complex, expensive, and difficult to construct and modify. For example, any modification usually will require purchasing new equipment, rewiring the system and assessing any potential degradation of the whole system. These problems can be avoided through the use of a rapid software prototyping methodology.

Software prototyping, as defined by Lantz [11] is "an information system development methodology based on building and using a model of a system for designing, implementing, testing, and installing the system" (p.1).

Rapid prototyping is a simple, low-cost alternative to traditional system development because it performs all interface functions without the complexity and expense of hardware purchase and assembly. Since modifications can be accomplished in a matter of minutes, interface development using a rapid prototype provides substantial benefits in design time and cost over typical conventional methods.

Rapid prototyping reduces development costs because it uses fewer resources. This is especially true with currently available inexpensive but powerful software and hardware tools that allow the development of complex experimental computer interfaces. These interfaces can be easily modified and tested, therefore, they facilitate the participation of end-users in an interactive design process. Sometimes the cost using a rapid prototyping methodology is less than 25% of the costs with traditional approaches [15]. Besides, since
users can exercise the system in the early stages of development, unnecessary expensive features can be avoided.

Rapid prototyping possesses the qualities of modularity and plasticity. Modularity allows a segment of the prototype to be added, removed, or modified without affecting severe interactions in the other segments or the system as a whole. The second assertion, plasticity, refers to the ability to change aspects of the prototype with only minor time or cost penalties. It allows testing of modifications before these modifications become part of the production system [8].

The rapid prototyping approach provides advantages for both user and designer. While the user has the opportunity to see his suggestions implemented, the designer can plan and carry out realistic usability tests.

The main assumption of rapid prototyping is that it is not necessary to know the full requirements of a system to build a model. As a matter of fact, system requirement definition is a product of rapid prototyping.

Rapid prototyping allows for flexible development, but it depends on having a specific objective. This does not mean that a formal system proposal is necessary, but simply that a problem or weakness in the existing system has been correctly perceived. Detailed definition and implementation of the system occurs from actual experience with the prototype in a natural way, as a gradual iterative/evolutionary discovery from both user and developer [12].

Rapid prototyping uses a model to perform validation and acceptance testing of the system. Validation is done by operational testing, and since the user is working with the prototype from the beginning, the user is also performing "acceptance testing" of the prototype from the beginning. Users actively participate to insure the functionality and acceptability of the system. The prototype, even though when at the beginning is not more than an electronic mock-up, once finished it is a faithful representation of the system. So, when the prototyping process ends, the prototype becomes the system, a system that accommodates users' decision-making and problem-solving styles.

Traditional design is focused towards the development of the system first and the user interface second. This process is reversed in the rapid prototyping environment. By defining what kind of information is needed and how it will be presented and managed by the graphic interface, the capabilities of the system are being defined at the same time. Another reason for focusing in the graphic interface first is that early user interaction with the system is possible. Working closely with the user during the process of designing the human-machine interface, using the interface itself helps to ensure that the final configuration will satisfy operator expectations, improving usability of the system. Rapid prototyping therefore has been shown to be an effective tool for conceptual development and for usability evaluation [14].
Rapid prototyping can be used to evaluate both user's needs and system feasibility. It allows testing and verification in the laboratory of real world problems of ultimate acceptability, before an extensive commitment of development resources [12].

System testing in the traditional approach usually is carried out at the very end of the project, frequently not leaving enough time for corrections of unforeseen problems. In contrast in rapid prototyping, problems are easily identified and solved quickly. According to Duke et al. [9] rapid prototyping provides a reusable, flexible, general-purpose capability that:

- Separates real from imagined problems, allowing every anomaly to be addressed.
- UnCOVERS the unexpected and the overlooked.
- Forces realistic integration.
- Stimulates development of credible prediction.
- Facilitates timely technology transfer.

Prototyping decreases communication problems between system development people and users in both directions. In one direction, the prototype itself is the main medium of communicating system functions to users. In the other direction users can communicate desired or undesired system features to the designer more easily than they would if the system were being designed on paper.

A problem inherent in rapid prototyping is the lack of a "real system" with which to interface. An alternative solution to this problem is to integrate the prototype with realistic simulations specially built to test specific conditions.

Even though rapid prototyping methodology for information systems provides all above advantages over traditional approaches, the literature about the subject is scarce. This suggests that rapid prototyping is under exploited and is still in the research stage.

Adjacent to the concept of rapid prototyping, in the way it is used in this paper, is the concept of integrated design. Integrated design in this paper denotes that several stand-alone activities have taken place simultaneously. These activities included control console design, information display development and evaluation, iterative testing, and concept implementation and verification. It was the gradual integration of all these activities that accomplished the main objective of determining underlying principles for effective and coordinated control console and information display design. To guarantee the success of this approach, it was necessary to ensure that each activity meet specific objectives before it could be integrated and that once integrated, it did not impede the achievement of the main objective.

Asimow's "Introduction to Design" [5] recognizes two design strategies; design by innovation, and design by evolution. In this work, as part of an integrated design methodology, a concept such as rapid prototyping is adopted and subjected to an evolutionary process of applied design, redesign, testing and evaluation. Integrated design thus, is the synthesis of separate concepts to produce an integrated methodology capable of
dealing with underlying principles and general methods, which are relevant to the design problem of interest. In this work, integrated design and rapid prototyping are applied to nuclear control console and information display design, testing and evaluation.

B. CAS as a Rapid Prototyping Environment for Control Console and Information Graphic Display System Design

Control console design and computer-based display system design are usually different and independent processes. Using CAS as an experimental test-bed, both activities may take place simultaneously. With this approach, a higher level of integration between instrumentation/control operation and display system response is expected, making human-machine interaction more effective and reliable.

CAS as a rapid prototyping environment has been implemented as a multi-computer, reconfigurable modular system. The use of several computers allows multiple simulation models to run in parallel without compromising real-time data acquisition and control. Reconfigurability allows greater flexibility in accessing, displaying and optimizing control console parameters, and modularity allows a component to be added, removed, or modified without affecting other components or the system as a whole.

Four main processes exist: the Control Console Process, the Plant Simulator Process, the Parameter Monitoring Process, and the Visualization Process.

Taking advantage of the UNIX shared memory capability (which is equivalent to a global section in VMS), data from identical shared memory segments (or global sections), that reside on different computers, is sent and received by virtue of two small C applications programs named sender and receiver respectively. There are specific versions of these two programs for communication between UNIX-UNIX, VMS-VMS or UNIX-VMS configurations.

The Control Console Process drives the dynamics for the emulation of diverse control panels. In its normal mode of operation, the Control Console Process provides manual or automatic controller outputs to the Plant Simulation Process via the control console shared memory, while it receives simulated outputs of plant parameters through the plant simulation shared memory.

According to the system operation mode, the Plant Simulator Process is composed of diverse modules: normal operation, transient and severe accident analysis. For the normal operation-training mode, the current hardwired simulator models will be implemented once they are available to the present AlphaStation-based system platform. For transient analysis and severe accident modes, the Plant Simulator Process is driven by the VASIIA [16] and MAAP nuclear codes respectively. Other nuclear codes such as RELAP/SCDAP, MELCOR and CONTAIN are being incorporated with the technical and financial support from the IAEA.
Through their corresponding shared memory segments, both, the Control Console Process and the Plant Simulation Process communicate with the Plant Parameter Monitoring Process and/or the Visualization Process. The Plant Parameter Process and the Visualization Process receive data input through their input shared memory segments. They also have capability for sending control outputs via their output shared memory segments. The Plant Parameter Monitoring Process is used for monitoring and control of plant safety parameters (SPDS module), while the Visualization Process is used for visualization and control of plant components and systems during transient and severe accidents sequences (VASIJA and MAAP modules).

For data recording and analysis, two C language programs are available. These programs are called Datalog and Dataplay. The Datalog program is capable of recording any set of variables and parameters during testing and evaluation sessions, while the Dataplay program is used to playback recorded data.

As a rapid prototyping environment, two graphic interfaces are used. One graphic interface is used for development of control console layouts and graphic displays, while the second interface is for dynamically testing and evaluating the layouts and displays previously created and attached to the Control Console Process. Both interfaces use the DATAVIEWS graphical data base display software on a UNIX computer platform. DATAVIEWS includes DV-Draw and DV-Tools. The DV-Draw graphic-package software allows construction of complex drawings with static and dynamic components that can be easily modified and relocated. The drawing process requires no programming.

DV-Tools is a powerful library of graphics routines in C language that extends DV-Draw's capabilities for manipulating static and dynamic drawings and their components.

The development graphic interface uses the DV-Draw environment and a collection of predetermined drawings that represent control instruments, console components and their dynamics. By direct manipulation of this interface, it is possible to rapidly construct and modify control console layouts. The number of drawings representing console components can easily be increased so as to have a complete library of instruments and controls, which can be accessed at any time. The philosophy behind this developmental tool is that reconfigurability will allow greater flexibility in accessing and displaying the information, providing an adequate framework for the analysis and optimization of console control parameters and displays.

The testing graphic interface is a structured application program written in C language, which makes extensive use of DV-tools functions. This graphic interface was constructed following Shneiderman's three basic principles for direct manipulation [17].

The rapid prototyping environment serves several purposes:

- Provides computer aided design capability of the control console and information display system.
• Provides a favorable environment that an operator can experience for display testing and evaluation, rendering valuable feedback for subsequent iterations.

• The environment can be advantageously used to evaluate and predict operator performance with different control console configurations.

• The environment can be used to determine underlying principles for effective control console design and computer-based display system design.

• The environment can be used for purposes of training that will facilitate the acceptance of the new control console.

As mentioned before, the rapid prototyping environment was applied to the EBR-II Plant Simulator and IFR Projects. At present, the Control Console Process and its graphic interface incorporate a full dynamic simulation of most control console instrumentation and controlling components of panels BB-09, BB10, and BB-11 of the Laguna Verde Nuclear Power Plant. The present configuration reflects proposed modifications to the graphic interface as a result of an iterative, evolutionary, user-oriented design, testing, and evaluation process involving operation and training personnel of the Laguna Verde Nuclear Power Plant. A detailed description of this graphic interface can be found in [18].

C. Case Study: An Operator-based Control Console Layout for EBR-II

In dealing with the definition of a new control console configuration for EBR-II, it was found that there were many approaches to the problem. They ranged from intuition based on experience, to applying an explicit procedure. Between this two extremes there were many sources of information such as guidelines, standards, and handbooks, as well as a myriad of design and evaluation techniques and tools. Task analysis, decision/flow diagrams, computer-based methods and models, cognitive models, and control-theoretic models were some of the alternatives to start with. Regardless of the methodology or techniques to be selected, it was clear that there was a need for a strong specific theoretical foundation or at least some form of analytical skill for them to be carried out effectively. Even if these basic requirements were fulfilled for a limited set of options, they were only aids to design and do not guarantee the success in the highly task dependent assignment of defining a new control console configuration for EBR-II.

Woods and Eastman [19] have pointed out some of the problems usually found during any system design process. They found that traditional human factors and human-computer interaction guidelines and handbooks were of extremely limited use during actual design projects. Shackel [20] states that there is no comprehensive and generally accepted manual on how to design good human factors into computer systems. This opinion is also expressed by Gould [21].

Recognizing the above uncertainties, one is compelled to craft an alternative methodology, instead of selecting an existing one. Such was the case in this work.
Insightful guidance in crafting an alternative methodology was provided by Gould's four behavioral principles of design [21], namely: (1) Early and continual focus on users, (2) Integrated design, (3) Early and continual user testing, and (4) Iterative design. These principles of system design have much in common with the characteristics of the rapid prototyping methodology.

The reminder of this section describes the definition of a new control console configuration for EBR-II using the rapid prototype environment described in the preceding section. The process started with a preliminary survey carried out via written questionnaire [22]. Initial efforts were focused on characteristics of current instrumentation that could lead to operator uncertainty, operator misjudgment, or in general, to operator deficient performance.

The main changes proposed at this level were the replacement of all electro-mechanical chart recorders by computer based color graphic CRT's on the basis that they could provide a more meaningful, flexible, and modifiable way of monitoring plant parameters. Other changes included rearrangement of the key lock system, rearrangement of the alarm panel and replacement or relocation of some instrumentation and controls with potential problems from a human factors perspective.

Nineteen operators participated in the survey. Proposed changes were first presented to the operators. After a brief introduction, the operators were asked about a general assessment of proposed changes and to provide written feedback about which parameters should be displayed on the CRT's. Also, operators were asked which instruments/controls should remain, be removed or changed.

From the survey analysis, a preliminary control console layout was proposed. This layout included the following main changes with respect to the current control console.

- All electro-mechanical chart recorders were replaced by CRT's. Information on CRT's was acquired through the use of mounted track balls.
- Rearrangement of key lock system and alarm panel.
- Re-specification of control console physical dimensions.
- Primary pumps deviation meters removed.
- Secondary pump alternate power controller replaced by a Bailey controller to provide the ability for coarse and fine adjustment.
- A single "Personnel Reactor Airlock" pushbutton, instead of current keyboard used.

The survey provided many important insights for current control console improvement. A general consensus was obtained on the replacement of all chart recorders by CRT's, although several operators were not very sure about what information should be displayed in addition to current chart recorder parameters. Operators were worried about information overload on CRT-based graphic displays, computer/CRT reliability, and
redundant ways of displaying reactor parameters in case of computer/CRT failure. Also, there was no agreement (or not enough information) to definitely decide which instruments to replace, remove or relocate. In fact, some of the operators expressed the desirability of having a full size mock-up of the new control console configuration, or any other way to test out and feel new controls, components or instruments before they were implemented. Another important concern was the grouping of related controls and indicators to make sequential operations more simple and reliable.

The above survey results pointed out three important problems. First, it was clear that much more research was needed before implementing any permanent change to the current control console; second, operator expertise was a valuable, irreplaceable source of information for the needed control console upgrade, and; third, more tools (visual rather than textual) were required.

A rapid prototyping environment was thought to be the best solution to above imperatives. In order to test the concept, a preliminary control console layout that included the initial changes proposed was assembled using the DV-Draw graphic software.

A DV-Tools application program, capable of isolating and enlarging any portion of this control console layout was written and used for purposes of visual analysis. This computer-based graphical tool served as a framework around which the rapid prototyping environment evolved.

The high level of operator incertitude about the control console instrumentation and controls, made clear the necessity of an interactive visual tool for control console layout design. Such a tool was conceived as a view containing all console instruments, console controls and components as individual graphical objects. Using the DV-Draw graphic interface environment, it was possible to select, drag and resize the graphical objects allowing the user to relocate console controls and instruments. The objective was to provide operations personnel with a direct-manipulation tool that would allow them to design customized console layouts. These layouts then could be saved for further analysis and comparison.

An experiment involving 10 EBR-II operators was conducted using the above user-derived approach of control console design. The goal was to obtain useful information about variances related to how the operator perceived the control environment trying to find answers to the following questions: how different an operator-based control console could be from the current control console?, would operator expertise guide the definition of a similar or a completely different new control console configuration?, how real or perceived complexity can be detected and avoided?

The preliminary control console layout used before each experimental session had graphical objects at the bottom representing the control console components which could be individually selected, grouped, resized, deleted, copied, and dragged at the operator's will. A description of the control console component selected was provided at a dedicated help view area. At any time the operator could zoom-in any area of the screen for a closer view.
of the graphical objects. A set of numbered squares could be used to represent any control console component not present as a graphical object at the time of the experimental session.

At the beginning of each session, the operator was instructed on using the graphic interface. Generally no more than 10 minutes were needed for instruction. Each operator had at least 45 minutes to complete the session, but was told to spend as much time as desired or to come back later if preferred. The average time spent per operator was about 1 hour, though one operator spent more than 2 hours. While manipulating the graphic interface, operators were asked to provide verbal rationalization of their actions. Verbal statements were tape recorded for further analysis.

Generally speaking, the operators were cooperative and welcomed the opportunity of participating in the design process. Verbalization allowed the operators to accent small problems in the current control console layout otherwise difficult to detect, providing useful insights for the definition of a new control console configuration. Just as an example, some operators liked the idea of having a guard-ring or raised barrier around pushbuttons instead of toggle switches for controlling control rod movement, arguing the advantage of protection against spurious activation. Others preferred the toggle switches because they mapped better the operator's intention of raising and lowering the control rod, in addition to the fact that operators had already developed a very good feeling of the controlling action without having to look at the switches. They pointed out that safety was not endangered since control rod selectors switches when not used were administratively placed on position 2 which does not have a control rod drive.

Ten different control console layouts were obtained using the above procedure. The ten layouts were compared and used for the definition of a new control console configuration. A gross analysis of the ten configurations obtained showed that the Key lock system and the nuclear instrument control and alarm light panel were the only components that invariably remained in the position where they currently are.

The criteria used to decide on a suitable localization for other control console components was in terms of consistency measurement. That is repeated, independent, and standardized judgments about specific location of controls and instruments were sought. Consistency was expressed as the percentage of trials on which the judgments agreed in both written and verbal reports.

For purposes of consistency measurement, the control console panels were divided into several sections. The location of control console components from the preliminary control console layout and from the 10 experimental sessions conducted with operators were registered in terms of operator incidence responses for relative position of control console instrumentation and controls.

From analysis of the ten operator layouts, verbal statements, and from "judgment calls" on those cases where the rate of occurrence was low, a new control console layout was assembled. Highlights on the new control console layout can be found in [2].
The layout generated was evaluated qualitatively in terms of operator acceptance or attitude by means of an interview and a verbally-administered questionnaire.

Sixteen operators participated in the evaluation in individual sessions of about 1-hour each. At the beginning of the session the operator received instructions on how to use the DV-Draw software. After the instruction period, the operator was asked to carefully analyze each control console panel using the zooming and panning features and to verbalize any positive or negative aspect he could think of. Verbal statements were tape recorded for further analysis. In the second part of the session, the operator was asked about alternatives on the location of some specific instruments or controls, display format (analog or digital readout) and removal or addition of some other instruments. The questions formulated were based on operator judgments and verbal statements compiled during the 10 experimental sessions from which the proposed control console was derived. At the end of the session, the operator was asked to rate the control console layout in terms of acceptance on a 100% rating scale.

Very few modifications to the new control console layout were proposed. Basically changes consisted in the order of some digital displays, order of some items in the control console alarm panels, and the request of modifying the reactor period meter scale. The operators rated the control console layout between 80 and 95 with an average of 89.5.

The resultant control console layout was implemented as the framework for the control console process component of a rapid prototyping environment and dynamically tested in conjunction with preliminary information displays.

The experimental design required operators to manipulate the control console process graphic interface and to monitor reactor parameters using three workstations. A fourth workstation was used for the experimenter to control the dynamic simulation and data recording processes.

Six EBR-II operation crews, each consisting of a reactor console operator and a secondary console operator participated in the dynamic evaluation which embodied three different operational scenarios. The first scenario consisted of power change from 50 to 52 MW, the second scenario involved control rod motion checks and the third scenario included a recovery task from sudden reactivity perturbations. These three scenarios allowed testing of the full capabilities of the rapid prototyping environment and at the same time, provided the experimental framework for testing of the final console layout and CRT-based information displays.

A highly simplified procedure derived from current EBR-II operating instructions was given to each operator at the beginning of the dynamic evaluation session. The procedure described the task to be performed as well as general instructions for manipulating the control console simulation process. Each evaluation session lasted about 90 minutes for all three operational scenarios. During each scenario, the reactor console operator manipulated control rod positions and the secondary operator manipulated secondary flow. Operators interchanged positions as desired at the beginning of each scenario.
For all three scenarios, operators were asked to perform the tasks as they would in the plant. At the end of each simulation session, an 11-item questionnaire was given to each operator as a measurement tool of user satisfaction. Ten of the eleven items consisted of a 7-point semantic regressive differential scale anchored at each end by bipolar adjectives, e.g.:

Very well [7|6|5|4|3|2|1] Poorly

The items covered aspects such as color, display organization, amount and accuracy of information presented as well as usefulness of the displays. Each item was answered for each of the three types of displays used during the dynamic simulation. The last item consisted of an open question encouraging the user to suggest changes leading to improvement of the console layout and displays. After answering the questionnaire, each operator was prompted to verbalize both positive and negative aspects.

All crews completed the assigned tasks in a very similar fashion and in about the same time. Operator feedback about the system and information displays, as well as questionnaire scores were rather positive. Therefore, it is possible to conclude that the rapid prototyping environment, as described in this paper, constitutes a useful tool for system development and is a valid instrument for system and information displays testing and evaluation.

IV. SUMMARY

The demand for decreasing human error and increasing reliability and availability of a nuclear power plant has caused substantial changes to take place, such as physical plant modifications and an increasing level of process automation. These changes directly and indirectly influence safety and lead to reconsideration in the design of the human-machine interface i.e., it could span from instrumentation and control hardwired panels, to sophisticated computer-based graphical interfaces.

The costs of control room modifications can be substantial. In general, any modification will require the purchase of new equipment, the rewiring of the system and the assessment of any potential degradation above the whole plant. For example, relocation of replacement of instrumentation, controls or annunciators may run as high as one million dollars. As the modifications are implemented, there is also the need to change documentation, procedures and training programs that require equivalent changes in the plant simulator. Even when these modifications are in the name of “improving safety”, there is evidence that many control room modifications actually have disruptive effects (at least temporarily) on operator performance. How costly are the negative effects on operator performance and what are the consequences of incorrect performance on plant risk? One conclusion is that it is extremely difficult to assess the real cost of control room modifications.
This work described an integrated approach for control console design and computer-based information graphic display in a rapid prototyping environment. The environment was first applied to the definition of a new control console for EBR-II. The design process considered operation personnel and operation procedures, fundamental sources of information, and involved a methodology that focused on iterative design and evaluation. Evaluation phases ranged from subjective checklists to an initial comprehensive demonstration in a full scope simulator framework. The main results of this work concerned recommendations in terms of integrating user needs and expertise, task environment simulation, and practical experience as an effective approach to achieve usable systems.

Since its conception in 1993, the rapid prototyping environment described here has evolved to become a sophisticated training and research tool, referenced as the Classroom Analysis Simulator, principal component of the Nuclear Reactor Engineering Analysis Laboratory.

The classroom analysis simulator may sensibly reduce the cost and negative consequences of control room modifications by reversing the course of actions i.e., the system can serve as an experimental platform or prototype for testing and validating any modification before its final implementation. Consider the following arguments:

- The classroom analysis simulator is a simple, low-cost alternative because it performs all interface functions without the complexity and expense of hardware purchase and assembling, and because modifications can be accomplished in a matter of minutes.

- Validation is done by operational testing. Since the user is working with a functionally equivalent model of the control room, the user is also performing “acceptance testing.”

- Working closely with the user during the modification process helps to ensure that the final configuration will satisfy operator expectations, thus improving the usability of the system.

- The classroom simulator, used as a system prototype, will help to ensure that any proposed modification is complete, consistent, correct and necessary.

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OECD Workshop on:

"Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms"

Halden 23 - 25 August, 1999

Optimization of the man/machine interface on the KKP 2 control room mock-up

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Philippsburg nuclear power plant
Germany
1. Introduction

The increasing degree and extent of instrumentation in nuclear power plants challenges manufacturers and operators to optimize the control room complex, in particular the man / machine interface.

In this context it is important to take ergonomics into consideration, it is primarily human factors engineering which is relevant here and covered by:

1. Anthropometry - improved design of work places, especially console/panel dimensions just as display devices arrangement.

2. Sensory physiology - reliable recognition of displayed information, structuring by color and shape.

3. Psychology - optimum design of room atmosphere as a whole, e.g. lighting, air-conditioning and acoustics.

For the sake of practice-oriented application of these human factors engineering considerations and for other reasons to be described, a full scale control room mock-up was constructed for unit 2 (1300 MW PWR) of Philippsburg nuclear power plant.

The major aspects for the decision to construct a 1:1 scale KKP2 control room mock-up were:

- More exacting requirements on the instrumentation and control planning team and on the operating personnel as a result of increasingly complex monitoring and control systems and their multitude, with a view to complete centralization of all procederes in the control room.

- Joint actions taken in the modelling of the control room consoles as well as by the planning staff of manufacturer and user as by the designated operating personnel.

- Practice-oriented presentation of planning results for the process engineering of all plant systems in good time to recognize and optimize in-plant correlation affecting operator actions.

- Practice-oriented improvements regarding ergonomic requirements for optimization of the man / machine interface of increasingly stringent requirements placed on the operating personnel.
2. Physical arrangement

The multitude of different tasks to be performed in the control room complex entails of necessity subdivision into 3 functional areas (cf. Fig. 1). The focal point proper, the “process instrumentation and control area”, is supplemented by 2 other functional areas. This avoids interference between the areas. A central view of all systems is ensured as well on the operator main control console as on the shift supervisor desk without having any monitoring devices behind the personnel.

2.1 Entrance area for plant security and controlled access, management of maintenance activities and associated documentation (2).

2.2 Central shift supervisor desk with communications equipment, operating instructions and process displays (8).

2.3 Process instrumentation and control area including master control console and surrounding system control consoles.

Re 2.3 Process instrumentation and control area
The monitoring and control of all systems and of the plant as a whole is performed by means of display and control devices by the shift personnel in the process instrumentation and control area (9-11).
For this purpose this area is subdivided into the master control console - operator main control console (9) with system associated information board (10) and into system control consoles (11).

- Start up and shutdown of the plant to standby conditions (subcritical, hot) and process control in trouble-free load operation is performed from the main control console (9) and its information board. For this purpose the control room devices for operation of the systems directly connected with load operation are located on the main control console. In their essentials these comprise the reactor and turbine generator load control systems, feedwater supply, condensate supply and pressure and volume control loops for the primary system.

- The control devices directly necessary for power generation are concentrated in the central section of the main control console while other functions are accommodated to the left and right thereof.

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Fig. 4: Structuring of instrumentation by different shapes
Organigramme of the EC Services related to Nuclear Fission Energy and Radiation Protection
FIVE R&TD FRAMEWORK PROGRAMMES
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<td>13215</td>
</tr>
<tr>
<td>1987</td>
<td></td>
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</tbody>
</table>

Proposed by the Commission

1st | 2nd | 3rd | 4th | 5th |
----|-----|-----|-----|-----|
5000| 10000| 15000|     |     |
EU ENERGY RTD 4th FRAMEWORK PROGRAMME
1994 - 1998

Nuclear fusion 846 MECU
Nuclear fission 490 MECU
Non-nuclear energy 1,030 MECU
TOTAL 2,366 MECU

Nuclear Fission Safety 170.5 MECU
CCR Joint Res. Centre 319.5 MECU

NUCLEAR FISSION SAFETY PROGRAMME

Area A: Exploring innovative approaches 7.5 MECU
Area B: Reactor safety 51.1 MECU
Area C: Radioactive waste management and disposal and decommissioning 45.8 MECU
Area D: Radiological Impact on man and the environment 53.3 MECU
Area E: Mastering events of the past 12.8 MECU
TOTAL 170.5 MECU
EURATOM in the 5th Framework Programme

OBJECTIVE

to help exploit the full potential of nuclear energy, in a sustainable manner, by making current technologies even safer and more economical, and by exploring promising new concepts

Indirect actions

◆ key action “Controlled Thermonuclear Fusion”
◆ key action “Nuclear Fission”
◆ generic research “Radiological Protection”
◆ support for research infrastructure (large scale facilities, networking, databases and tissue banks)
Road Map for Programme Implementation

Open calls with annual evaluation for generic research

Targeted calls with closing deadlines for key action research

Larger part of contracts early (~ 60% 1999/2000)

Mid-term review in 2000

New targeted calls in 2001

Special calls in 2002
Criteria for selection

Scientific/Technological Quality and Innovation
Community Added Value and Contribution to EU Policies
Contribution to Community Social Objectives
Economic Development and S&T Prospects
Resources, Partnership and Management
<table>
<thead>
<tr>
<th>Programme</th>
<th>Amount (€ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europ Communites 5th Framework Programme</td>
<td>13.700</td>
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<tr>
<td><strong>Thematic programmes:</strong></td>
<td></td>
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<tr>
<td>Quality of life and management of living resources</td>
<td>2,413</td>
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<tr>
<td>User-friendly information society</td>
<td>3,600</td>
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<tr>
<td>Competitive and sustainable growth</td>
<td>2,705</td>
</tr>
<tr>
<td>Energy, environment and sustainable development</td>
<td>2,125</td>
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<tr>
<td><strong>Horizontal actions:</strong></td>
<td></td>
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<tr>
<td>International Cooperation</td>
<td>475</td>
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<tr>
<td>Innovation and participation of SME's</td>
<td>363</td>
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<tr>
<td>Human potential and socio-economic base</td>
<td>1,280</td>
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<td>Direct Actions (JRC)</td>
<td>739</td>
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<tr>
<td><strong>Euratom Framework Programme</strong></td>
<td>1,260</td>
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<tr>
<td>Fusion</td>
<td>788</td>
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<tr>
<td>Fission</td>
<td>191</td>
</tr>
<tr>
<td>Direct Actions (JRC)</td>
<td>281</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>14,960</td>
</tr>
</tbody>
</table>
Key Action Nuclear Fission

Objectives

to enhance the safety of Europe’s nuclear installations and improve the competitiveness of Europe’s industry

Subobjectives

ensure protection of workers and the public from radiation
safe and effective waste management and disposal
explore more innovative concepts that are sustainable
contribute to maintain expertise and competence
Key action: Nuclear Fission

Operational safety of existing installations
Plant life extension and management, Severe accident management, Evolutionary concepts

Safety of the fuel cycle
Waste and spent fuel management and disposal, Partitioning and transmutation, Decommissioning of nuclear installations

Safety and efficiency of future systems
Innovative and revisited reactor, fuel and fuel cycle concepts

Radiation protection
Risk assessment and management, Occupational exposure, Off-site emergency management, Restoration and management of contaminated environments.
Operational Safety of Existing Installations

Priorities

Plant Life Management:
Effects of ageing; On-line monitoring, inspection and maintenance; Organisation and management of safety; Risk based systems approach to modernisation; Qualification of advanced safety and control systems

Severe accident management:
Severe accident management measures; Assessment of severe accident risks (eg. Corium formation and behaviour, melt coolability, hydrogen risks, and source term issues);

Evolutionary concepts:
Evolutionary safety concepts; High burn-up and MOX fuel
“ACCIDENT MANAGEMENT SUPPORT”
(AMS)

♦ INTERACT (NNC Ltd.)
Recommendations for VDU designs and their use in accidents

♦ PASS (ISTEC/GRS)
Fast model-based computational tools for assistance in Accident Management

♦ CRM (ECN)
Decision support system for containment and release management

♦ SIROG (SIEMENS)
Situation Related Operator Guidance

♦ OPA (TRACTEBEL)
Operator Advisor System for use in Severe Accidents
RESEARCH ACTIVITIES

♦ ESCRIME (CEA-Cadarache)
  Optimisation of advanced plant operation

♦ Ergonomy Framework (ISTEC/GRS)
  Ergonomic principles for design of AMS systems

♦ DIAM (ANSALDO)
  Environment tool for development of accident management procedures

♦ SAMARIA (FRAMATOME)
  Design and maintenance of emergency guidelines

♦ TRANSAL (FRAMATOME)
  Transient analyses for accident state assessment
SOAR on "Instrumentation and Signal Validation in Accident Situations" (EUR 16915)

(1) **Scenarios in Accident Situations**: To illustrate the different types of accident progression, estimated size of releases and potential AM measures.

(2) **Instrumentation in Accident Management**: It outlines the different approaches to determine the required information for accident management.

(3) **Signal Validation**: Presents the evolution and improvement of the methods used in the process industry for signal validation, in particular "model-based" and "noise diagnostic".
(1) **General overview** of present practices and recent developments.

(2) Discussion of operator role during AM (review of TMI-2 and Chernobyl), including interface with emergency planning.

(3) Review of the development of AM procedures and related assisting systems in **different countries** (F, D, UK, NL, BE, SE, USA, FI, Japan).

(4) Computerisation of procedures, accident analysis and modelling aids: their use in AM.

(5) Overview, discussion and description of recent developments in **computer-based systems**.

(6) **Conclusions**, recommendations for improvements, and suggestions for future research.
"ACCIDENT MANAGEMENT SUPPORT" (AMS)

TECHNICAL WORK CONTENT

(1) **SOAR ON** "INSTRUMENTATION AND SIGNAL VALIDATION IN ACCIDENT SITUATIONS" (EUR 16915)

(2) **SOAR ON** "OPERATOR ASSISTING SYSTEMS FOR ACCIDENT MANAGEMENT" (EUR 16925)

(3) **SPECIFIC RESEARCH ACTIVITIES ON 2 BASIC TOPICS**:

   - Analysis of operator role and human-machine interface in an advanced control room environment

   - Analysis and development of new tools and computerised systems for operator support in accident situations
GENERAL OBJECTIVES

(1) TO DEFINE, INVESTIGATE AND DEVELOP MEANS AND METHODS PROVIDING RELIABLE INFORMATION AND DIAGNOSTICS AS WELL AS SUPPORT TOOLS FOR ACCIDENT MANAGEMENT.

(2) TO CONDUCT INVESTIGATIONS ABOUT THE DIFFERENT SIGNAL VALIDATION METHODOLOGIES AND SENSOR MODELLING / SIGNAL PROCESSING, WITH EMPHASIS ON THE EXISTING INSTRUMENTATION RATHER THAN NEW INSTRUMENTATION NEEDS.
“ACCIDENT MANAGEMENT SUPPORT”
(AMS)

- COORDINATOR: GRS/ISTEC (D)

- PARTNERS: ANSALDO (I), NNC (GB), CEA (F), FRAMATOME (F), SIEMENS (D), ECN (NL), TRACTEBEL (B)

- CONTRACT TYPE: REINFORCED CONCERTED ACTION


- COMBINATION OF 2 ORIGINALLY ENVISAGED PROJECTS:
  
  (1) "INSTRUMENTATION AND SIGNAL VALIDATION"
  
  (2) "OPERATOR ASSISTANCE"

- FINAL RESULTS PRESENTED AT THE FISA-95 SYMPOSIUM AND OFFICIALLY PUBLISHED BY THE EC (EUR 17126)
Reactor Safety Research at the EC

- Basis for EU research set out in the EURATOM Treaty (1957). Title II of the Treaty assigns the EU to "promote and facilitate nuclear research programmes".

- Main Programmes since 1990:


- Research tasks are carried out:
  - Directly at the Institutes of the JRC,
  - Indirectly through "shared cost" and "concerted" actions coordinated by the EC DG XII.

- Additional research activities through PHARE and TACIS Assistance Programmes.