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FOREWORD

The CSNI Working Group on Human and Organisational Factors (WGHOF) is tasked to improve the current understanding of human and organisational factors and the way in which they impact upon nuclear safety.

The nuclear sector is currently in a phase where new reactors are being built, advanced reactors are being planned and existing reactor control rooms are being modernised. These changes are likely to result in designs, tools and operating concepts for new reactors that differ from those currently in place.

In order to explore these issues, the CSNI Special Expert Group on Human and Organisational Factors (SEGHOF, the predecessor of WGHOF) and the Halden Reactor Project (HRP) hosted a joint workshop on "Future Control Station Designs and Human Performance Issues in Nuclear Power Plants" in Halden, Norway in May 2006. The workshop discussed a number of research issues and activities that were underway in both the nuclear and related high-hazard sectors, and identified a need to draw these activities together to provide an integrated perspective.

This technical opinion paper represents the consensus of the CSNI/WGHOF on the state of research topics on human performance in new nuclear plant control room technology. It seeks to provide an overview of safety-significant human and organisational factors associated with developing reactor control room designs and to identify the types of research needed to address them. It takes into account the findings of the workshop as well as those from related work being carried out by other international regulatory and scientific organisations. The paper identifies eight broad topic areas which may warrant further research.

This paper has been prepared by a small task force. Dr. Julius Persensky, to whom the NEA wishes to express its particular gratitude, is the key author, assisted by Dr. Thomas Sanquist of Pacific Northwest National Laboratory and Dr. John O'Hara of Brookhaven National Laboratory. Ms. Magnhild Kaarstad (Halden Reactor Project), Dr. Valerie Barnes (US Nuclear Regulatory Commission), Dr. Leena Norros (VTT Technical Research Centre of Finland) and Dr. Craig Reiersen (UK Nuclear Installation Inspectorate) contributed significantly to the final editing of the work.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The nuclear community is currently at a stage where existing reactor control stations are undergoing various forms of modernisation; new reactors are being built in many countries; and advanced reactors are being designed through international cooperation to support power generation for decades to come. A range of new technologies and concepts are being considered to support and enable the operation of these facilities. These have the potential to impact upon the roles of the plant operators and the ways in which these roles are discharged. It is important, therefore, that the potential impact – both positive and negative – is evaluated and understood.

The purpose of this technical opinion paper (TOP) is to identify a set of research topics that will enhance the state of knowledge related to the human and organisational factors (HOF) aspects of control station modernisations in existing plants, new nuclear power plants (NPPs) and advanced reactors. Research to address the topics described in this paper will provide the technical basis to help ensure that the benefits of new technology are realised and that the potential negative effects are minimised.

The original impetus for this paper was to advance the research topics identified in the workshop organised in 2006 by the CSNI Special Experts' Group on Human and Organisational Factors (SEGHOF, the predecessor of WGHOF, Working Group on Human and Organisational Factors) and the Halden Reactor Project (HRP) on "Future Control Station Designs and Human Performance Issues in Nuclear Power Plants". However, it has become apparent that there are several recent and ongoing efforts to develop plans for HOF research among WGHOF associated parties as well as other international regulatory and scientific organisations. These organisations have identified similar and related research questions and developed plans and proposals to address them. Thus, WGHOF prepared this TOP as a means of generating an integrated perspective on safety significant HOF issues and to identify the types of research needed to address them. The TOP identifies eight broad topic areas which may warrant further research. These areas are as follows:

- Human Factors Engineering (HFE) Methods and Tools.

- Operating Experience from New and Modernised Plants.
- Evolving Concepts for the Operation of Nuclear Power Plants.
- The Role of Automation and Personnel: New Concepts of Teamwork in Advanced Systems.
- Management of Unplanned, Unanticipated Events.
- Human System Interface Design Principles for Supporting Operator Cognitive Functions.
- Complexity Issues in Advanced Systems.
- Organisational Factors – Safety Culture/Safety Management

For each topic, the fundamental research questions are identified, as well as a summary of the human performance issues involved, candidate research objectives, major methodological considerations, and expected results. This TOP is intended for a broad spectrum of international stakeholders. The principal interest will be to research organisations that are capable of, and have the facilities to implement, the proposed research, e.g. the OECD Halden Reactor Project. Other stakeholders include regulatory agencies, international organisations (e.g., NEA and IAEA) and industry organisations that could support the research and would benefit from the results of the research.

1. PURPOSE

The purpose of this technical opinion paper (TOP) is to identify a set of research topics that will enhance the state of knowledge related to the HOF aspects of new and advanced nuclear power plants (NPPs) and control station modernisations in existing plants. The results of this research will help assure reliable human performance when using new technologies. To develop this TOP, the Working Group on Human and Organisational Factors (WGHOF) has reviewed several reports that identified research questions in HOF areas and combined the recommendations from those reports with the findings from a 2006 workshop organised by the CSNI Special Experts' Group on Human and Organisational Factors (SEGHOF) and the Halden Reactor Project (HRP). This TOP is intended to promote the co-ordination of international research activities in HOF and aid in identifying research programs that can be supported by international agreements on topics of common interest.

2. INTRODUCTION

The nuclear community is currently at a stage where existing reactor control stations are undergoing various forms of modernisation, new reactors are being built in many countries with computer-based control rooms, and advanced reactors are being designed through international cooperation to support power generation for decades to come. With the introduction of advanced plants, we will see new reactor and system designs, new tools to support plant personnel, and changes to NPP staffing configurations. The concepts of operation and maintenance for this new generation of plants are likely to be quite different from those employed in today's plants. It is important that the potential impact on these developments is evaluated and understood by prospective operators and regulators responsible for determining the acceptability of new designs to support human performance in maintaining plant safety.

Research and development for advanced plants is having an impact on existing plants as well. For example, the technology developed to provide advanced plants with state-of-the-art digital instrumentation and control (I&C) systems and computer-based control rooms is also becoming prominent in the modernisation of existing plants and in new builds. One difference between plant modernisations and new builds is that building a new plant creates an opportunity for a totally new design, while modernising an operating plant has constraints imposed by the existing facilities and concepts of operation. In addition, modernisation projects often require implementation of new systems over the course of several outages, thus creating interim states between the old and new design that may themselves pose human performance challenges.

The introduction of new technology is viewed as having great promise to improve the safe operation of nuclear plants. In order to ensure the appropriate application of technology to support human performance and plant safety, it is important to evaluate the technological advances in terms of their potential negative as well as positive effects. Research to address the topics described in this paper will provide the technical basis to help ensure that the benefits of new technology are realised and that the potential negative effects are minimised.

3. SCOPE

The original impetus for this paper was to advance the research topics identified in the workshop organised by the CSNI/SEGHOF and the HRP on: "Future Control Station Designs and Human Performance Issues in Nuclear Power Plants". However, it has become apparent that there are several recent and ongoing efforts to develop plans for HOF research among WGHOF associated parties as well as other international regulatory and scientific organisations. These organisations have identified similar and related research questions and developed plans and proposals to address them. Thus, WGHOF has prepared this TOP as a means to generate an integrated perspective on safety significant HOF issues and to identify the types of research needed to address them. This paper can serve as a basis for further international cooperation and co-ordination among interested parties and to assist in focusing the research programme at the HRP as well as other research organisations.

4. APPROACH

The TOP was prepared by a sub-group of WGHOF, staff of the US Nuclear Regulatory Commission (NRC), and consultants from the US Department of Energy National Laboratories with relevant expertise. The participants who prepared this TOP reviewed nine HOF issue surveys and planning documents to identify key research needs related to advanced technology. A brief description of each of these documents can be found in the Appendix.

The research needs identified in the proceedings of the CSNI/SEGHOF/HRP workshop formed the basis for this analysis. The additional documents were used to provide more detailed insights into key issues.

The research issues identified in these nine documents were integrated to form broader research programme topics. The eight research areas are:

- Human Factors Engineering (HFE) Methods and Tools.
- Operating Experience from New and Modernised Plants.
- Evolving Concepts for the Operation of Nuclear Power Plants.
- The Role of Automation and Personnel: New Concepts of Teamwork in Advanced Systems.
- Management of Unplanned, Unanticipated Events.
- Human System Interface Design Principles for Supporting Operator Cognitive Functions.
- Complexity Issues in Advanced Systems.
- Organisational Factors – Safety Culture/Safety Management.

5. RESEARCH PROGRAMME TOPICS

This section describes the research programme topics that were identified in the document review. For each topic, the fundamental research questions are identified, as well as a summary of the human performance issues involved, the research objective, major methodological considerations, and expected results. Note that the objective, methodological considerations, and expected results are presented at a level to support planning only. Each research programme topic should be formulated in detail to identify specific research projects.

HFE methods and tools

Questions

What are the strengths and limitations of new HFE methods and tools and what criteria should be applied in evaluating their acceptability for use in advanced reactor and control station designs?

Basis

Just as the technologies available for new reactors are changing, so are the methods and tools used to analyse, design, and evaluate the HFE aspects of NPPs. Advances in the methods and tools used by HFE professionals are revolutionising the ways in which their tasks are accomplished. For example, emerging HFE methods and tools include computerised applications for performing traditional HFE analyses, rapid development engineering, cognitive task analysis methods, use of virtual environments and visualisations, and application of human performance modelling.

These changes are impacting the commercial nuclear industry, and regulatory authorities will be faced with evaluating the methods and tools used for new designs as an important aspect of safety reviews. The documents reviewed for this paper consistently emphasised the importance of research issues related to HFE methods and tools in the safety review process. This is consistent with the findings of a recent US National Research Council study. This study identified the major reasons systems fail. Of the 15 reasons noted, most have to do with various aspects of the design process and the methods and tools used by HFE practitioners.

Thus research is needed to address advances in HFE methods and tools that are being and will be used to analyse, design, and evaluate new reactor designs to ensure that NPP personnel have the knowledge, information, capabilities, work processes, and working environment (physical and organisational) to safely and efficiently perform their tasks. The research programme should build upon the work already performed and documented in sources such as those identified above.

Objectives

The objective of the HFE methods and tools programme is twofold:

- To develop review guidance and acceptance criteria to ensure that new HFE methods and tools are being appropriately applied to NPP design.
- To identify and/or develop tools for use by regulatory authorities to support reviews of the HFE aspects of NPP design, operations, and maintenance (examples include tools to assess plant staffing profiles and tools to examine changes to risk-important human actions).

Research activities

Major research activities in support of these objectives could include:

- Review past surveys of HFE methods and tools and update them based on recent international experience.
- Identify trends that are significantly impacting the nuclear industry.
- Conduct research to identify principles for the validation of methods and tools and for determining their appropriate use.
- Identify method and tool needs of regulatory personnel.
- Develop tools for use by regulators by adapting/modifying promising HFE methods and tools for use in safety reviews.

Expected results

The expected results of this programme will further expand the international community's knowledge of state-of-the-art HFE methods and tools and their strengths and limitations. This knowledge can be used to provide the technical basis for review guidance and tools for regulatory authorities to evaluate the use of new HFE methods and tools in NPP design and for conducting regulatory assessments.

Operating experience from new and modernised plants

Question

What can be learned to improve HOF from collecting and analysing detailed operating experience from current Generation III and III+ plants, as well as plants that have undergone extensive modernisations?

Basis

Although a number of Generation III and III+ plants have been operating for many years (e.g., ABWRs in Japan, the N4 in France), very little information is generally available pertaining to their actual operating experience. The same can be said for the many NPPs around the world that have undergone extensive modernisation programs using many of the technologies that have been developed for new plants. This information is very important to the development of future research and as an input to the development of regulatory approaches to the safety review of new technology.

Objective

Co-ordinated with WGOE, the objective of this programme area will be to collect the operating experience of current Generation III and III+ plants in areas pertaining to HFE.

Research activities

The major research activities to accomplish this objective could include the following.

- Develop a structured methodology for information collection, organisation, analysis, and lessons learned.
- Collect and evaluate the documented operating experience that is available.
- Seek additional operating experience through direct contacts with organisations such as vendors, utilities and regulatory authorities, using a combination of data collection methods, including: questionnaires/surveys, phone interviews, and site visits. The scope of information to be sought may include:
  - The types of automation implemented.
  - Characteristics of the user interfaces to automation.
  - User interfaces for plant monitoring and disturbance management.

- Soft control of equipment.
- Computer-based procedures and computerised operator aids.
- Experience related to performance of tasks such as maintenance, equipment tagout, and testing using computer-based interfaces.
- Impacts on human performance of software upgrades and modifications.
- Operator modifiable features such as setpoint adjustment, temporary alarms, and temporary displays.
- Digital safety systems.
- Training technology.
- Approaches to assuring system security.
- Experience with events.
- Identification and treatment of risk-important personnel actions.
- Regulatory strategies for design review.

- Evaluate the information collected to derive lessons learned that may be generally applicable to future new reactor designs and regulatory reviews.

Expected results

The expected results of this programme will be documented in lessons learned reports and made publically available for use by the commercial nuclear industry, researchers, and regulatory bodies. The information collected will also be useful in further refining research questions related to the following six topic areas.

Evolving concepts for the operation of nuclear power plants

Question

What are the most safety-significant human performance implications of new concepts of operation in advanced NPPs?

Basis

The concept of operation for a new or modernised NPP reflects top-down and bottom up considerations. From the top, the concept of operation defines the high-level goals for system operations. From the bottom, the concept of operation rests on the technological infrastructure needed to achieve the system's goals. A concept of operation involves a number of dimensions including:

- Role of personnel and automation.

- Staffing and training.
- Normal operations management.
- Disturbance and emergency management.
- Maintenance and change management.

The operations and technology of NPPs changed very little over the first half-century of commercial nuclear power generation. Although the concept of operation continuously improved over time, such as the advent of symptom-based procedures and improved HSIs following the Three Mile Island accident in 1979, no major changes have occurred. Thus, the current Generation III plants, such as the ABWR and N4, are operated by similar crews performing similar functions to those of early reactors, although with newer technology.

Advances in nuclear plant technology have set the stage for changes to traditional concepts of operation and many human performance challenges identified in the source documents address these changes. Some examples of near-term changes include:

- Operation of a plant by a single operator (many new plants are designed for this capability) and other forms of staffing reductions.
- Operation of multi-modular reactors by a single crew.
- Greater automation, further changing the operator's role to that of a supervisor with little hands-on control responsibilities.
- Passive safety systems.
- Post-core-melt systems and associated actions.

Longer term, even more significant changes can be envisioned, for example:

- Functional decentralisation where a plant is staffed with a very small number of on-site personnel, possibly limited to technicians who oversee the highly automated operation and occasionally perform minor operations and maintenance tasks. Responsibilities for other functions are handled by off-site specialists who either come to the site when needed (such as for maintenance) or perform their tasks remotely, e.g., emergencies may be handled by highly trained crisis management teams.
- Different reactivity effects, e.g., in the lead-cooled fast reactor (LFR) design, the presence of lead in the core area may result in reactivity effects that are different from light water reactors. The LFR will have little neutron thermalisation and lower Doppler effects. Also, the temperature coefficient of reactivity will be less negative and the

neutron lifetime shorter. These factors tend to increase the speed of dynamics related to core power and transient operations. Operators' control of reactor power and safety are dependent on their understanding of these reactivity effects.

- Management of new hazards associated with new reactor technologies, such as liquid sodium, liquid fuel, liquid metal, graphite in the core, and supercritical water.

These are only a few examples of changes foreseen in the near- and longer-terms.

Objective

The objective of this research programme area is to prepare regulators and the industry for evolving concepts of operation and how these concepts of operation can impact human performance and ultimately plant performance.

Research activities

The major research activities needed to achieve this objective could include:

- Review of NPP design trends and trends in operational practices. Consideration should be given to both near- and longer-term designs, such as Generations III, III+, and IV.
- Review operational practices in similar facilities where some related technological changes have already taken place, such as in petrochemical plants and off-shore oil platforms.
- Develop a generic, technology-neutral concept of operation model that can serve as a framework for obtaining information about new designs and identifying the aspects of their concepts of operation that are important to safety. This effort can make use of the concept of operation literature available in guidance documents in the nuclear industry as well as other domains involving complex technologies.
- Conduct simulator studies as necessary to better understand the implications of different concepts of operation for personnel performance.
- Develop a review approach to address safety-important aspects of different concepts of operation. This may involve the use of new methods and tools, in addition to design review guidance.

- Test the review approach and guidance to ensure it is usable, reasonable, and appropriate for NPP applications. Tests should involve several design concepts in addition to light water reactors, such as the PBMR.

__Expected results__

The expected results of this programme will be a validated model of NPP concept of operation that emphasises the safety-important aspects. The results may be used by NPP designers and will provide the technical bases for an approach to conducting safety evaluations of evolving concepts of operation in the nuclear industry.

The role of automation and personnel: new concepts of teamwork in advanced systems

__Questions__

What are the safety-significant HFE implications of automation and new concepts of teamwork in advanced systems?

__Basis__

The operation of an NPP depends on the co-ordinated activities of multi-person teams. Nuclear power plant personnel play a vital role in the productive, efficient, and safe generation of electric power. Operators and other plant personnel work as a team to monitor and control plant systems to ensure their proper functioning. Operators and other personnel share information and perform their tasks in a co-ordinated fashion to maintain safe plant operations as well as to restore the plant to a safe state should a process disturbance arise. Test and maintenance personnel help ensure that plant equipment is functioning properly, and they restore components when malfunctions occur. Behaviours that are typically identified as important elements of teamwork include having common and co-ordinated goals, maintaining shared situation awareness, engaging in open communication, and cooperative planning. Successful teams monitor each other's status, back each other up, and actively identify errors. As new technology has been introduced into control rooms and throughout NPPs, there has been growing recognition that the design of technology needs to consider not only individual performance but also teams.

Further, the technologies available for new and modernised plants offer increases in the automation of process control and decision support to operating teams/crews. Many issues raised in the source documents address the need to consider how automation is designed and implemented with respect to its potential effects on human and team performance. It is well established that poorly designed automation can result in a loss of vigilance, low workload, complacency, and poor operator situation awareness. Poorly designed automation can lead to new forms of human error (such as mode errors, in which controls perform multiple functions but personnel lose awareness of the functions the control is set to perform), and generally reduce the operator's ability to respond to failures.

These concerns take on new meaning when one considers that there is an increase in interaction between operators and automation (such as the use of breakpoint automation for ABWR startup) and that automation is increasingly performing decision tasks that have traditionally been performed by personnel. Thus, in nuclear plants, as well as many other complex systems, humans and automation have essentially become "members" of the same team that monitors and controls the systems.

Research has also shown that advanced systems alter teamwork and team processes. For examples, crews frequently note that peer checks and supervision are negatively impacted when operators work at individual workstations obtaining information and taking actions through VDUs.

Taken together, a new concept of team emerges. The team is composed of personnel, automation, decision aids, and intelligent agents. They interact and share responsibility for performing functions and tasks based on the demands of the situation. Like any team, there is a need to take independent action under some circumstances, share tasks under others, and to back up other team members when necessary. At all times, awareness of each other's activities is important as is trust that all team members will reliably perform their assigned functions and task.

Objective

The objective of this research programme area is to better understand and define this new concept of team and to develop guidance for the review of function allocation and human-automation interaction in human-machine teams. Aspects of human-machine teams that could be addressed include:

- Defining the relative roles of human and automatic resources in static and dynamic situations.
- Identifying the requirements for monitoring and communication between team members including human-to-human and human-to-automation interactions.

- Identifying principles of smooth transitions of control between human and automation agents.
- Developing HSI design principles to support human-automation supervision and interaction.

Research activities

Major research activities could include:

- Review and analyse pertinent literature on teamwork in high-technology systems and its application to nuclear systems.
- Review and analyse the literature on advances in automation, function allocation, and HSI design for interactive systems.
- Identify principles for best supporting human-machine interaction.
- Test the principles using simulator studies and revise, as necessary.

Expected results

The expected results of this research programme topic is enhanced knowledge of the human factors aspects of human-machine teams that may be useful in NPP design as well as in developing guidance for regulatory reviews.

Management of unplanned, unanticipated events

Questions

What are the characteristics of HSIs in new designs that are necessary to ensure personnel are able to manage unplanned and unanticipated events?

Basis

Beyond design basis events have always been a challenge for crews, procedure developers and trainers. The technology associated with new plants may increase these challenges, including the monitoring and management of passive systems, managing or mitigating consequences associated with new hazards, determining the usefulness and applicability of extensive automation and intelligent operator aids in unplanned situations, and the potential need to address novel events under conditions of I&C degradations and failures.

Objective

Research is needed to improve our understanding of how operating crews assess situations, make decisions and take actions so that HSI designs, training, and procedures can support the crews in the face of unplanned, unanticipated events. Understanding and responding to such events involves many aspects of plant design, including alarms systems, information systems, computer-based procedures and new decision aids that are intended to support crews. The goal of this research is to develop a better understanding of how these systems can be brought together to ensure that operators are able to manage novel events.

Research activities

The major research activities to be performed to meet this objective could include:

- Analyse pertinent literature to develop an initial technical basis that addresses:
  - Engineering of resilient systems.
  - Principles for handling unexpected events across industries.
  - Situation assessment and the development of situation awareness.
- Develop and peer-review a set of principles for the design of HSIs, procedures, and training for novel events and transitions.
- Conduct simulator studies to evaluate the principles developed and revise the principles based on the results of these studies.

Expected results

The results of this research programme will provide the technical basis to enhance HFE design decisions, training and procedures and for review guidance for the HFE aspects of managing of unplanned, unanticipated events.

HSI design principles for supporting operator cognitive functions

Questions

What are good practices for implementing and using computer-based procedures (including back-up), and to ensure reliance on and compliance with automated decision aids?

Basis

Computer-based procedures are increasingly used in plants that are modernising and are expected to be a principle design feature of newly built systems. Available research indicates that computer-based procedures fundamentally alter how personnel process and share information, and develop and maintain situational awareness. Additional research is needed to establish standard practices for the design of computer-based procedures, including approaches to information display and sequencing, backtracking capability (breadcrumbs), checks that critical steps have been performed, processes for overriding instructions, and means to communicate procedure sequence to other personnel who are not actively observing displays. The human performance implications of using diverse computer-based paper-based procedures as a back-up to system failure should also be assessed for new generations of operators who will not have years of experience using paper-based procedures.

The design of "intelligent" aids to assist in various aspects of power plant operation should be guided by principles that will allow operators to rely on the systems to reduce workload and help them solve problems, but not "over-reliance" by simply complying with automated system recommendations. This requires a balance between system reliability, providing redundant information about system state to operators, and methods for operators to verify the functioning of automated systems. Human factors research has identified particular types of systems, such as automated flight management systems, that have a level of opacity and complexity of operation which leads to operator distrust, confusion and task performance delay. Research is needed to define appropriate levels of operator aiding that will balance reliance and compliance.

In carrying out their roles and responsibilities, nuclear plant operators perform two types of tasks: primary tasks and secondary tasks. Primary tasks include activities such as monitoring plant parameters, following procedures, responding to alarms, starting pumps, and aligning valves. Secondary tasks are mainly "interface management tasks". Primary tasks have a number of common cognitive elements. These common elements are referred to as generic primary tasks. They are monitoring and detection, situation assessment, response planning, and response implementation. Performing these generic primary tasks well requires a moderate level of workload. If workload is too low, vigilance suffers and the ability of personnel to develop accurate situation assessments diminishes. As the demands of performing the task rise, greater workload is experienced. Ultimately, if workload rises high enough, the ability to perform tasks is reduced. Breakdowns in any of these generic primary tasks can lead to a human error.

To understand human performance, it is also important to consider the other class of tasks mentioned above – secondary tasks. To perform their primary tasks successfully, personnel must also successfully perform secondary tasks or “interface management tasks.” In a computer-based control room, secondary tasks include activities such as navigating or accessing information at workstations and arranging various pieces of information on the screen. In part, these tasks are necessitated by the fact that operators view only a small amount of information at any one time through the workstation displays. Therefore, they must perform interface management tasks to retrieve and arrange the information.

The distinction between primary and secondary tasks is important because of the ways they can interact. For example, secondary tasks create additional workload and may divert attention away from primary tasks and make them difficult to perform. Thus, secondary tasks are important and need to be carefully addressed in control station design.

To perform the primary tasks of monitoring and detection, situation assessment, response planning, and response implementation, operators obtain information and take actions through the HSI. Like all digitally based technologies, the characteristics and functions of HSIs have evolved very rapidly. Some of the general trends are that:

- Information is generally presented at hierarchical levels, e.g., plant overview information at the top and detailed system and component information at the bottom.
- A great deal of decision support is provided, e.g., alarm reduction processing to make the number of important alarms manageable number and computer-based procedures that support information retrieval and action step analysis.
- HSI functions are integrated, e.g., alarm information is presented in information displays and these displays are presented in computerised procedures, and controls can be accessed from procedures and information displays. In a sense, the boundaries between different HSI resources are disappearing.

These trends are made manageable by a great deal of software processing of information.

As the technology rapidly evolves, it is important that HFE considerations in the design of HSIs keep pace. The need for this was recognised in the numerous issues identified in the area of HSI technology in the source documents upon which this report was based.

Objective

The objective of this research programme topic is to develop guidance for designing and evaluating new HSI technologies, including their features and functions, and the implications for human performance of and response to HSI failures. The main focus in this programme will be the role of the principal HSI resources: alarms, displays, controls, procedures, decision support aids, and interface management features.

Research activities

The major research activities in support of this objective could include:

- Review the HSIs currently used in computer-based control rooms to define features and functions.
- Identify trends in HSI design across industries to anticipate the features and functions that will emerge in NPP design in the near-term.
- Using the results of the first two activities, develop overall characterisations of HSIs including trends for functional integration as noted above.
- With respect to the HSI characterisations identified, develop a technical basis of desirable practices for addressing HSI design issues. The basis should include available operating experience, results of vendor studies (and those of related organisations), data gathered from facilities in which advanced HSI concepts are used (including but not limited to nuclear plants), and results found in the general literature.
- As needed, conduct simulator investigations to better understand the impact of design features and functions on crew performance.

Expected results

The expected result of this research programme topic is enhanced knowledge that can be used for NPP designs, as well as for the review of new and advance HSIs with respect to their features and functions and the management of HSI failures.

Complexity issues in advanced systems

Questions

What attributes of a new design contribute to its complexity from the operator's perspective, what is the impact of increased complexity on human performance, and how can complexity be measured?

Basis

One of the recurrent themes identified in the source documents is the issue of *complexity*. Although advanced reactor designers, in some ways, are seeking greater simplicity, the HFE aspects of the plant are likely to be more complex than today's plants. Increases in sensing capabilities, information processing support, intelligent agents, automation, and software-mediated interfaces distance personnel from the functioning of the plant itself. These technologies are potentially beneficial, but crew members report that they also increase the complexity of operations.

Objective

The objective of this research programme will be to identify the underlying factors that make a plant, system(s), the HSIs, scenarios, tasks, or operations complex to plant personnel.

Research activities

The major research activities to meet this objective could include:

- Review and analyse the complexity literature – There has been considerable research in the area of perceived complexity in a number of industrial and academic domains that can be analysed to determine its applicability to NPP design and operations.
- Obtain subject matter expert (SME) input – Contacting SMEs currently studying complexity would ensure the most current approaches and models of complexity are identified.
- Develop models of complexity of nuclear systems – Input from the literature and SMEs can be used as the technical basis to develop models of complexity, including measure(s) of complexity that can be used as part of a safety evaluation. These measure(s) may take several forms depending on the level of design detail available.
- Conduct confirmatory research to validate the models and measures.

Expected results

The expected result of this research programme topic is the technical basis for NPP designs as well as regulatory review guidance for the minimising the perceived complexity of the HFE aspects of plant design and operations.

Organisational factors – Safety culture/safety management

Questions

What are good practices for assuring a shared, strong nuclear safety culture and effective safety management practices across organisational and national boundaries and among new organisations and personnel entering the nuclear industry? Where problems are found to exist, what are the most effective means to assess corrective actions?

Basis

As a result of lessons learned over the past 30 years, the international commercial nuclear power industry has developed a strong safety culture and rigorous safety management practices that are unique among industries. However, the nuclear industry is not unique in facing challenges in assuring that safety culture and safety management expectations are consistently met across organisational and international boundaries. Any large organisation faces challenges in co-ordinating the activities of internal work groups as well as communicating across time zones and, in the case of multi-national corporations, across cultural boundaries. Communication and co-ordination challenges also arise in interactions with external organisations (e.g., vendors, contractors). Assuring that internal work groups and external organisations on which nuclear utilities rely share the nuclear safety culture and meet safety management expectations has sometimes been an issue in the current generation of plants, and regulators have had difficulty in assessing plant safety culture and corrective actions implemented by licensees.

These challenges are likely to increase as a result of three trends in the industry:

- New construction – In many countries it has been many years since a new reactor was constructed such that there is limited experience among designers, suppliers, constructors and regulators. Recent construction experiences in Finland, France and the United States have shown the effects of poor communication and control of contractors and inadequate safety management practices.

- Changing workforce and inexperienced personnel – The workforce in many countries that developed the current nuclear safety culture and safety management practices is nearing retirement and being replaced with personnel who did not live through the many "lessons learned" that form much of the basis for current practices. The United States has noted an upward trend in human errors attributed to inexperience. Further, nations without previous nuclear experience are now seeking to join the nuclear community.
- New concepts of operation – New concepts of operation based on distributed teams, centralised maintenance and operations functions, and greater reliance on multinational suppliers may present challenges in developing and maintaining strong safety cultures between and among members of the evolving organisational structures and inter-organisational networks.

Objective

The objective of this research is to identify effective methods for transmitting and maintaining a shared, strong nuclear safety culture and assuring the implementation of rigorous safety management practices among organisations and individuals who are new to the nuclear industry and will be designing, constructing and operating new and advanced nuclear facilities. In addition, the research will prepare regulators to encourage and assess these new methods and practices.

Research activities

The major research activities to meet this objective could include:

- Review and analyse the research literature addressing principles and methods for successful organisational culture change.
- Collect and evaluate the documented operating experience that is available regarding methods that have been used successfully in the nuclear and other industries to transmit and reinforce safety culture expectations.
- Seek additional operating experience through direct contacts with organisations such as vendors, utilities and regulatory authorities, using a combination of data collection methods, including: questionnaires/ surveys, phone interviews, and site visits.
- Develop a toolkit of methods and techniques for transmitting nuclear safety culture and reinforcing safety management practices.

- Identify and develop better assessment practices and tools for regulators.

Expected results

The expected result of this research programme topic is enhanced knowledge of effective means for inculcating nuclear safety culture values and norms consistently within organisations, across organisational boundaries and among new organisations and personnel who are entering the nuclear community, as well as prepare regulators with assessment practices and tools.

6. CONCLUSIONS AND RECOMMENDATIONS

This paper draws upon the findings of a number of workshops and organisations to identify human and organisational factors research issues that are relevant to the development of new and future nuclear facilities and the modernisation of existing plants. These issues have been combined into eight research programme topics which, if addressed, should contribute to developing a strong technical basis for understanding and managing the contribution of human and organisational factors. These programme topics are inter-related and cut across the various new reactor technologies and control room modifications.

It is recommended that the international community, including regulators, vendors, research institutes and other interested parties, should pursue a collaborative and co-ordinated approach to addressing these important research areas. This should be done by identifying different nations' ongoing and planned research related to these programme topics, and also by identifying topics that are currently not under investigation or that could benefit from greater attention. The means and facilities needed to perform the research should also be considered. This work may help to further inform and prioritise research efforts.

Appendix

DOCUMENTS REVIEWED
TO IDENTIFY RESEARCH PROGRAMME AREAS

1. NEA/CSNI/R(2007)8. Workshop Proceedings – Future Control Station Designs and Human Performance Issues in Nuclear Power Plants

As discussed above, this workshop was organised by the CSNI SEGHOF and the HRP on: "Future Control Station Designs and Human Performance Issues in Nuclear Power Plants". The participants at the workshop represented experience from utilities, vendors, research bodies and regulators working on human and organisational (HOF) issues related to control stations for future nuclear power plant (NPP) designs and for modified control rooms for existing plants. The main objectives of the workshop were to identify human and organisational issues and solutions associated with new control station concepts, to exchange information about approaches and experiences with colleagues from other countries and organisations, and to identify areas where further international research and development activities are needed.

2. Papin, B. (2004), Considering the human factor requirements in the design of advanced reactors. CEA/DEN/CAD/DER/SESI/LCFR/NT DO 37

This document presents the qualitative aspects of the important human factors issues that should be considered during the various phases of the design, focusing on the early design phases, in order to optimise human reliability in operation. In addition, the document proposes a human factors approach to evaluation during the design process that is based on a functional and operational complexity assessment. As an illustration, this approach is used to compare various attributes of pressurised water reactors from the point of view of the relevance of human factors to the design.

3. SAFIR2010 Working Group. (2006). National nuclear power plant safety research 2007 – 2010. Proposal for SAFIR2010 Framework Plan

This document presents a comprehensive research plan for nuclear power safety advocated by the Finnish Ministry of Trade and Industry. The programme includes organisation and human factors, automation and control rooms, and probabilistic safety analysis as elements of concern that directly bear on human factors for advanced control rooms.

4. Dudenhoeffer, D.D., Holcomb, D.E., Hallbert, R.P., Wood, R.T., Bond, L.J., Miller, D.W., O'Hara, J.M., Quinn, E.L., Garcia, H.E., Arndt, S.A., Naser, J. (2007). Technology roadmap on instrumentation, control, and human-machine interface to support DOE advanced nuclear energy programs. INL/EXT-06-11862

This document describes a research and development roadmap developed by a group of research laboratory and industry subject matter experts for the US Department of Energy that focuses on issues associated with the introduction of digital I&C into NPPs. It also includes human-system interaction (HSI) considerations. The focus is on long-term advanced NPP research needs.

5. O'Hara, J.M., Higgins, J.C., Brown, W.S., Fink, R., Persensky, J., Lewis, P., Kramer, J., and Szabo, A. (2008). Human factors considerations with respect to emerging technology in nuclear power plants. NUREG/CR-6947 and a companion BNL Technical report that provides additional information about the considerations identified in the NUREG. BNL Technical Report No. 79947-2008

This study identified human performance research that may be needed to support the review of the implementation of new technology in NPPs. To identify the research issues, current industry developments and trends were evaluated in the areas of reactor technology, I&C technology, human-system integration technology, and human factors engineering (HFE) methods and tools. Subject matter experts from vendors, utilities, research organisations and regulators participated. From an initial list of 67 identified issues, 20 research issues were categorised into the top priority category.

6. NEA/CSNI/R(2005)10. Safety of Modifications at Nuclear Power Plants

This report summarises the proceedings of a workshop that was held to discuss operating experience from modifications to NPP control rooms. The findings were based on events and incidents from around the world and weaknesses experienced during the modification process. The Working Group on Operating Experience (WGOE) and SEGHOF reported and discussed how deficiencies in NPP modifications may introduce safety challenges. The focus areas discussed in the report include minor or non-identified modifications that may impact safety and inadequate consideration of human factors impacts during modification. The proposed common cause was that the potential impacts on human performance of the modifications had not been adequately assessed. The report provides possible improvements on how to better make modifications to NPPs.

7. NEA/CSNI/R(2004)17. Modifications at Nuclear Power Plants – Operating Experience, Safety Significance, and the Role of Human Factors and Organisation

The WGOE and the SEGHOF met to share experience and discuss how minor modifications may introduce safety challenges and affect human and organisational factors in NPPs. The focus areas discussed in the report include modifications at NPPs, operating experience, minor modifications and modifications that are not recognised as such, human factors considerations, structuring the modification process, and regulatory oversight. The report provides recommendations for future work.

8. NEA/CSNI/R(2002)8. Approaches for the Integration of Human Factors into the Upgrading and Refurbishment of Control Rooms

The report describes the results of a workshop/specialists meeting held to identify human factors issues in modernisation projects, the appropriate requirements and specifications to address human factors concerns, and the data to be gathered and analysed. The issues facing utilities, regulators, and vendors were discussed. State of the knowledge and current best practices in human factors for refurbishment and upgrading of control rooms were explored and discussed through focus groups and plenary discussions to shape future work recommendations. The report contains recommendations in five key areas as a result of the discussions: lessons learned, methods and tools, regulatory implications, control room philosophy, and interdisciplinary teams.

9. Halden – Selected research topics from: HP-1233 Draft Proposal for 3-year period 2009-2011, Man, Technology, and Organisation; and HWR-864; Nils T. Fordestrommen and Ann Britt Skjerve (2007). Advanced reactors control centre design and review – Potential research topics and research plan for 2007-2008

These documents represent proposed programmes of research for the HRP for the 2009-2011 agreement period. They are based on input from the Halden staff and management, from programme participants, the Halden Programme Group and Board of Management, as well as from ongoing efforts.

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