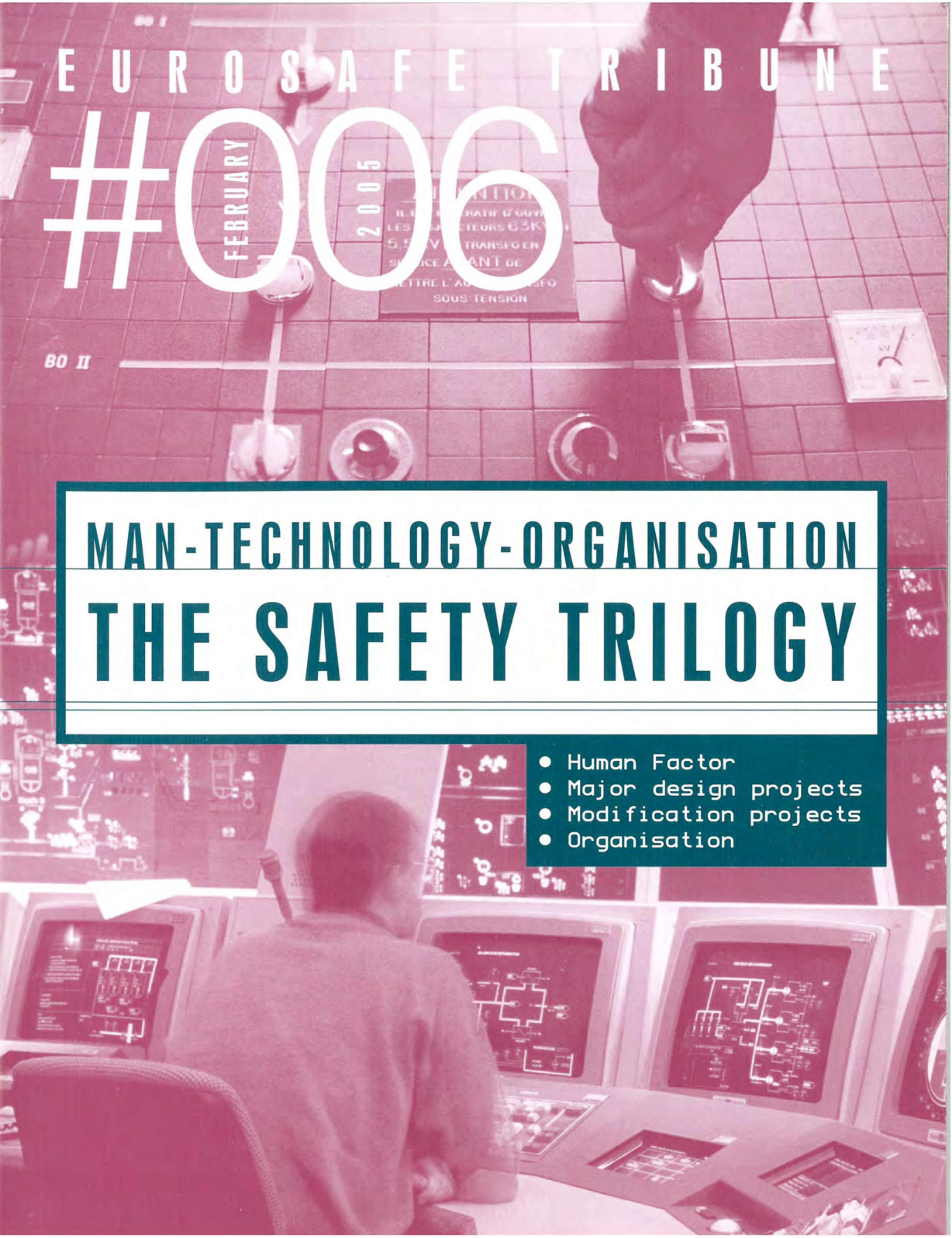
EUROSAFE TRIBUNE

#006 FEBRUARY 2005

MAN-TECHNOLOGY-ORGANISATION
THE SAFETY TRILOGY

- Human Factor
- Major design projects
- Modification projects
- Organisation



TO OUR READERS

CONTENTS

Jacques Repussard and Lothar Hahn

March 28, 1979. It is 4:00 a.m. at the Three-Mile Island NPP when the main feedwater pumps stop running, preventing the steam generators from removing heat. First the turbine, then the reactor automatically shut down, but the confusing information provided by control instruments leads operators to take a series of actions that make conditions worse as the plant experiences a loss-of-coolant accident.

The careful attention paid to the technical optimisation of facilities and equipment thus proved insufficient to prevent one of the two worst accidents in civilian nuclear history. From that day on, a broader picture - the entire system consisting of man + technology + organisation - began to be taken into consideration.

Significant advances have been made in integrating the Human Factor into each step of the life cycle of nuclear reactors, from design through construction, commissioning, operation and modification. The task is nevertheless relentlessly ongoing, for conditions keep changing with the design of new-generation plants such as the European Pressurised Water Reactor (EPR) or the necessity for operation to adapt to market deregulation, but to mention two examples.

Drawing upon lessons learned in various European countries by Human Factor specialists who express the views of safety authorities, technical safety assessment organisations, operators, research organizations and training institutes, the present issue of the Eurosafe Tribune aims at providing stakeholders – scientists, researchers, engineers, operators, managers, regulatory bodies, NGOs, opinion leaders and policy-makers – engaged in the nuclear safety debate with material for assessing requirements and relevant strategies to be applied locally. ●

HUMAN FACTOR, A KEY AREA OF NUCLEAR SAFETY

By Werner Fassmann, Human Factors expert, GRS and François Jeffroy, Head of the Human Factors Study Department, IRSN

Now that plant safety is recognised as being the result of personnel interaction with technical equipment according to the values, goals and rules of an organisational system, the Human Factors (HF) discipline plays a key role, as it provides methods, data and knowledge to understand and improve this interplay between man, technology and organisation. Drawing upon history, this paper provides a brief overview of the ergonomic, organisational, socio-cultural and personal aspects of the HF issue today.

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The expression "Human Factors" (HF) was introduced in 1946 to designate a separate discipline integrating concepts, methods and results of experimental and applied psychology, ergonomics, medicine, operations research and industrial engineering. "Human Factors" refers to the conditions, measures and requirements that influence the abilities, motivation and performance of people who carry out tasks involving both teamwork and technical equipment. It is possible to distinguish between internal and external Human Factors. While the term "internal factors" refers to individual characteristics, such as experience, attitudes and other personal aspects of reliable task performance, "external factors" includes the design aspects of work tools, work environment and task and work organisation.

The HF concept can be viewed in two ways. In a narrow sense, it refers to the field of ergonomics, a scientific discipline that primarily draws on psychology and physiology for the design of man-machine systems, work environments and work tools. In a broader sense, the term HF refers to all human activities and boundary conditions of task performance that influence safety, availability and efficiency of systems. According to this broad definition, HF encompasses a wider range of disciplines, such as organisational science, sociology and cultural anthropology. Evaluating human performance in terms of reliability and error does not mean placing blame on people or assuming a personality trait such as "disposition towards error". Rather, HF experts try to explain relationships between boundary conditions for performance, activities performed and outcomes of human activity so as to develop suitable error prevention and/or mitigation measures in the technical, organisational and HF design field.

› Human Factor development: a historical perspective. The HF speciality at large aims at improving, in an integrated manner, human welfare at work and overall systems efficiency by analysing, designing and evaluating the interaction between humans and the other components of a system using suitable theories, principles, methods and relevant data. In this respect, input from the human and social sciences supports the work of engineering. Efforts to integrate both types of science have a long history, and at least pre-scientific consideration of HF has always been a feature in designing artefacts, tools and machines for efficient use. These efforts to integrate human characteristics and technical systems requirements were also spurred by particular circumstances: accidents, conflicting demands of man and technology, and the massive deployment of often highly sophisticated new technologies. Three periods in time mark this development:

• Before and after World War I, results of experimental psychology and physiology were applied in industry to lower accident rates and increase productivity of primarily physical labour.

• During World War II, HF studies of man's interaction with more complex technical systems were carried out when new military technologies drew increasing attention to factors on which reliable observer and operator behaviour depends.

• More recently, increasing automation and computerisation have been shifting the focus of HF research and development from physical labour to cognitive capabilities. Automation and computerisation can relieve man of many dangerous, stressful and unpleasant tasks and working conditions. But greater automation and the massive use of computer technology can also under- or overload and confuse users if new technologies are not properly designed with respect to human capabilities and needs.

In the nuclear safety field, two major accidents – TMI in the U.S. and Chernobyl in Ukraine – considerably stimulated progress in the use of HF knowledge to design, operate and maintain facilities. In this regard, the Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application, published by the U.S. Nuclear Regulatory Commission in 1983, has been highly influential, because it not only provided a comprehensive and practical HF compendium, it also supported the assessment of human action in probabilistic safety analyses, which have become a very important tool for assessing plant safety.

From a Human Factors perspective, significant progress has been made in several areas, including:

• simulator training;

• management of incidents and accidents by moving from event-based to symptom-based diagnosis;

• organisational support for safe and reliable task performance;

• promotion of a safety culture;

• support for man-machine interaction, particularly in the control room, by providing and facilitating access to relevant information;

• design of maintenance procedures and interfacing of maintenance activities with operation.

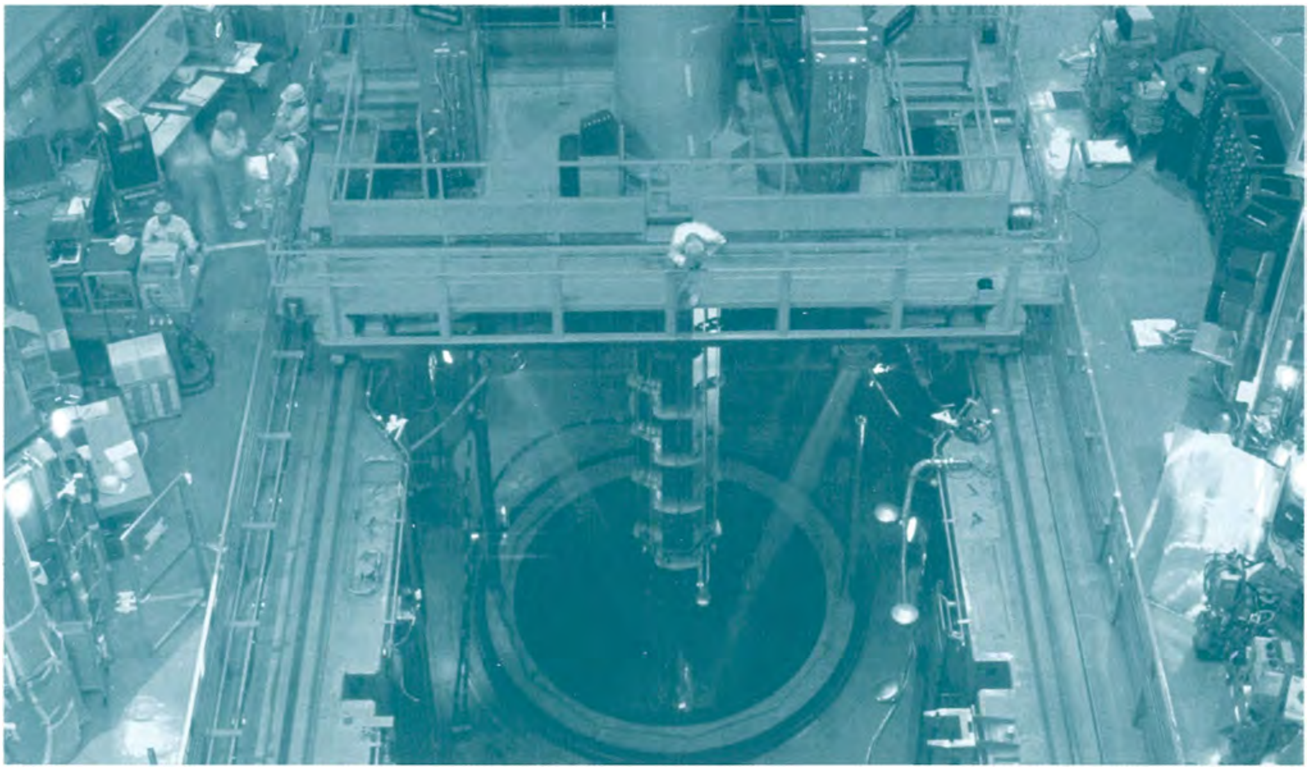
› An urgent need for comprehensive organisational models integrating individual and collective performance. The relationship between HF, organisation and human performance is quite complex: organisational structures and rules define what personnel are required to do. To be effective, →

→ structures and rules have to be put into practice by actual personnel behaviour. Organisations therefore must not only recruit and qualify workforce and managers in a suitable manner, they must motivate people at every level of the organisation to comply with rules through measures such as leadership and control, incentives and sanctions, and HF design to adapt tasks, working conditions and training to personnel needs and capabilities. An organisation must also develop rules for the consistent and continuous application of motivational measures, which have to be observed in daily practice. Motivational measures can influence manifest behaviour and underlying values and attitudes; the effects can thus range from mere opportunism to real commitment. Ideally, organisations should succeed in achieving a high level of commitment, particularly to safe and reliable performance. The success and stability of an organisation depend on actual human performance, which has to be evaluated in terms of required behaviour and results to be achieved. Systematic evaluation provides highly valuable insights for continuously improving organisations, which has become a major topic of organisational learning and development.

Despite considerable work, there is still an urgent need for more comprehensive models to understand and evaluate these factors and their contribution to nuclear safety. In particular, much more sophisticated models for quantitative reliability assessments have to be developed.

Current human reliability models consider only selected aspects of the complex relationships between organisational factors and human performance. Quantitative assessment is largely restricted to rule-based behaviour, whose scope depends on the content and

Fuel loading into the reactor core



amount of training and the written procedures an organisation provides to support task performance. Beyond that, only the omission of oral communications and the effectiveness of recovery from human error by a supervisor can be evaluated so far. There is, therefore, an urgent need for comprehensive models to systematically identify, analyse and assess the organisational, managerial and cultural factors of a company that operates nuclear power plants and their effect on human reliability. The same is true of important aspects of human cognition, in particular the human potential for coping with situations that have not been sufficiently considered in the design of interfaces, procedures and tasks. Last but not least, comprehensive modelling must also show how working groups and entire organisations think and how they make decisions, particularly in risky and stressful situations.

› Human Factors: on-going debate.

Some important HF issues currently being discussed with a view to enhancing safety in the future:

• **regarding NPP control:** How can the man-machine interface be improved? How should the control room of future reactors be designed (the EPR, for instance)? How should information be displayed? What qualifications should a control-room operator have?

• **regarding maintenance:** How can equipment maintainability be factored in at the design stage? How can reliability-centred maintenance contribute to greater safety? What skills must in-house personnel have for effectively checking the results of outsourced maintenance tasks?

• **regarding management:** How to cope with the retirement of about half of the NPP personnel in the next 8 to 10 years (e.g. to start up and commission new plants)? How should young engineers be attracted to nuclear careers? What is the right balance between individual empowerment and supervision?

• **regarding experience feedback:** How to go back systematically to the root-causes of events? (e.g. if an operator misinterprets an ambiguous instruction, the reason why ambiguous instructions are drafted should be analysed). How to perform analyses that lead to a good understanding of events and allow a statistically well-founded assessment not only of particular types of events, but also of the status of the plant as a whole at a given moment?

It is widely recognised that error is integral to human activity. Human Factors studies aim for nuclear safety enhancement and realistic consideration of human strengths and weaknesses by NPP personnel themselves, by designers, by technical support organisations, by the regulatory authorities, and, ultimately, by the public. ■

Human Factors experts' input to safety-oriented design

1. **Identify human capabilities, human needs, task characteristics and conditions of task execution.**
2. **Develop models representing how human performance depends on HF.**
3. **Develop and apply practical methods for analysing and evaluating HF and human performance.**
4. **Recommend measures for designing tasks, workplaces, workplace systems, environmental factors of task performance and training according to human capabilities and needs in such a way that safety, reliability, productivity and personnel satisfaction are best assured.**
5. **Prepare guidelines for systematically considering and implementing HF during the entire design process.**

HUMAN FACTORS ENGINEERING PROGRAMME FOR THE EPR

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The European Pressurised Water Reactor (EPR) is the next generation NPP due to succeed the N4 series in France. EDF's engineering centre CNEN, based in the Paris suburbs, is heading up the company's participation in designing the new reactor. Engineering efforts are not only concerned with designing technical systems but also, more fundamentally, with the situations in which people work. Sources of performance improvement in terms of safety and availability do not depend on the sophistication of such technical systems alone, but also on factoring in the human activity they involve early in the process. This article describes the methodology, organisation and implementation of the Human Factors Engineering (HFE) programme.

▼ The HFE programme helps provide:

- operating personnel with every means of fulfilling their duties to achieve the desired performance in terms of production, quality, reliability, availability, radiological protection, operating safety, maintenance and testing;
- working conditions that are free from physical risks.

Incorporating Human Factors (HF) in the design means taking into account general knowledge of the human operator and specific knowledge of the related work conditions in the design of systems, equipment and documentation, and the organisation and definition of the skills required.

RELYING ON ERGONOMIC DESIGN PRINCIPLES

▼ The method developed to integrate HF is based on ergonomic design principles, such as envisioning the work of future operators in choosing design bases in relation to the work activity to ensure the relevancy of the selected options. Future work activity must be anticipated through an iterative design approach based on successive approximations interfaced with the design process. This is done by taking into account comparable current situations, by simulations performed on simple mock-ups in virtual reality mode or, possibly, on simulators. This method is implemented in four steps.

ANALYSING CURRENT CONDITIONS

▼ Analysis of the work activity in comparison with current conditions allows identification of intrinsic features of the work, i.e. invariable characteristics that will inevitably prevail regardless of the technical tools the protagonists are provided with. Operating feedback is also analysed to sort out adequate and inadequate features of the previous design, and to make necessary changes. Drawing on field interviews and observations, such analysis contributes to the definition of functional specifications for the future system facility or plant.

INVOLVEMENT IN DEFINING SPECIFICATIONS

▼ To integrate HF in the definition of functional specifications, some principles about the operator's role in the facility are defined:

- A clear distribution of tasks between operators and process and control systems. This must be done in a way that it is "clear who or what is in control of operations for a given phase". Beyond assigning repetitive tasks or those exceeding an operator's physiological, psychological and cognitive capabilities to automatic control systems, automation criteria must allow for the acquisition and updating of relevant operating knowledge to enable operators to carry out the most appropriate actions for normal or off-normal situations that may arise.
- Operator confidence in the automatic control systems and in the data supplied by the interface. To achieve this, operators must be provided with adequate and meaningful feedback on the behaviour of automatic systems to understand what they are doing;
- Ultimate control by the operator. Relations between operators, automatic control systems and the process must enable operators to remain in control of facilities for which they are responsible by providing them with the necessary means for intervening in the process and, when required, in the behaviour of automatic control systems.
- Significant feedback to anticipate facility behaviour. The relationship between the operators and the process must provide humans with knowledge of the process' current status to help them predict future conditions.

For this purpose, there must be meaningful feedback from the process so that operators can understand it in real time.

PREDICTING FUTURE CONDITIONS

▼ The forecast of work activity must be prepared in accordance with the specifications adopted for the new social-technical system.

ADAPTING SPECIFICATIONS

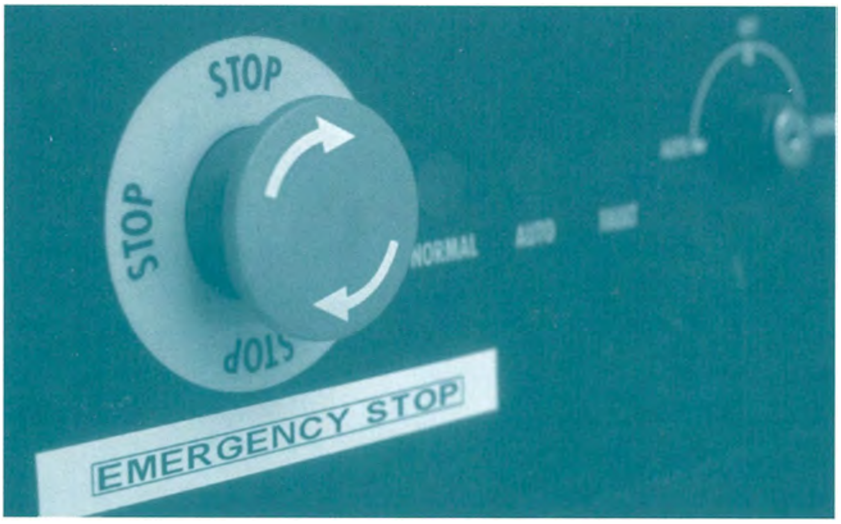
▼ The design options are tested on mock-ups and the test results are analysed to evaluate adaptations required to the design specifications. Proposed changes will be accepted or rejected, based on the objectives to be achieved and technical constraints.

▼ From principles to implementation. The HFE programme encompasses operations, maintenance and testing. It will be implemented in three design areas:

- plant operations: both normal and accidental;
- system design;
- general layout.

Maintenance and testing activities are covered in system design and general layout studies.

Microturbine emergency stop



› Operation: the major role of simulation

▼ The HF contribution at this stage is aimed at ensuring that the characteristics of control room work are taken into account. This involves a variety of activities to be conducted in parallel based on the priorities of a given situation. Studies are thus performed to identify requirements for the man-machine interface (MMI) in terms of information, alarms, component control, communications, cooperation, lock-down locations, shift supervisor room, etc. The resulting specifications will be placed in their practical context through ergonomic testing. The application developed will be assessed on the following basis:

- its usefulness, i.e. whether or not future users are provided with all the functions required to perform their tasks appropriately;
- its simplicity of use in terms of man-machine communications, i.e. information and control should be presented in a meaningful and unambiguous manner, they should be appropriately grouped and sequenced, and should be quickly accessible.

At major stages of the design process, simulations of future situations using MMI mock-ups are planned to assess the feasibility of the underlying control principles. This early testing of design concepts is performed by confronting a representative sample of future users with nominal and emergency scenarios based on sequencing diagrams and analysis of actual conditions.

A full scope simulator will be used at the end of the design process, before starting up the plant, to verify the capability of teams to handle normal and emergency plant operating conditions. The following points will be studied in particular: appropriate control of the reactor under normal and accidental operating conditions, diagnosis and management of incidents and accidents, and management of alarms. Recommendations are drafted accordingly.

Civeaux NPP (France): control room

› System design: complying with construction, operation and maintenance requirements

▼ The integration of HF in the design of basic systems calls for the identification and implementation of appropriate requirements as regards:

- equipment installation;
- system operation: control, continuous monitoring, periodic testing;
- system maintenance, with plant unit in power mode or during an outage.

▼ These requirements are derived from regulations and operating feedback.

› General layout: focusing on applicable rules

▼ General layout studies pertain to civil works on buildings (or engineering structures) and equipment installation in all NPP buildings (nuclear island and conventional island).

A set of rules, directly or indirectly related to HF, derived from regulations, operating feedback, and recognised practices applicable to the EPR project, is applied in layout studies. Such operating feedback has been integrated into the N4 series plants through interviews with operating and maintenance personnel. A comparison of actual situations that involve principles similar to those to be applied to the EPR has identified typical work activities (access, traffic, identification, work environment, communications, etc.) and their corresponding requirements.

This facilitates the definition of basic concepts (work specifications) for the future technical system and layout and, subsequently, detailed specifications.

Radiation protection requirements based on the Alara principle are also integrated early in the design phase. An assessment process is developed for selected activities (on-site operation, maintenance), particularly those considered critical to achieving major objectives such as safety:

- scenarios representative of operation are defined by drawing on operating feedback and analysing current conditions;
- future work situations and activities that are particularly sensitive are designed using virtual reality and, if possible, mock-ups;
- design layout recommendations are drafted.

INTEGRATING MANY KINDS OF SKILLS

▼ HF personnel work together with the design teams to facilitate integration of the forecast future activity in the design basis.

Other resources, such as R&D centres, are involved to provide support in methodological aspects, to carry out specialised studies for specific design bases, to hone assessment testing or to analyse results. HF specialists from utilities also participate by contributing operating experience and future user viewpoints.

Other profiles are also necessary, such as:

- design engineers: in preparation for the HFE programme, design engineer awareness of HF is increased through training. The design team helps integrate the HF perspective in design studies with the support of guidelines or by working with HF specialists;
- specialists in related fields: radiological protection and occupational safety specialists participate in the design and are involved in the HFE programme;
- utility head offices and operating personnel: to integrate the views of the future user, existing NPP teams and technical specialists work with the design engineers and HF specialists by mediating operating feedback, describing user requirements, and participating in design specification assessments on mock-ups and simulators.

▼ The HFE programme for the EPR can be characterised as an interactive process drawing on a combination of highly diverse skills and developed in close association with work on the EPR project. Some key success factors for this programme may be identified, including the availability of HF resources, the integration of the HF perspective into major decisions by project management as well as in the design of technical methods, and a collective effort involving HF specialists, design professionals and experienced utility operators. ●

VALIDATION OF NPP CONTROL ROOMS: NEW HF ASSESSMENT METHODS

By Leena Norros and Paula Savioja,
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The assessment of complex artefacts such as NPP control rooms are claimed to require improved validation approaches. A holistic evaluation may be accomplished by new types of performance assessment criteria that reflect not only the outcome aspects of performance, but also such internal features as culture and habits.

The objective of current research pertaining to the modernisation of the man-machine interface (MMI) in the central control rooms of Finnish nuclear power plants is to develop a method that can be used in integrated system validation of emerging control room solutions. In this process, such issues as the selection of relevant operational situations for the validation, the selection of performance indicators and acceptance criteria, and the amount of testing and assessment needed to validate a system are carefully addressed to provide information about system performance in critical conditions and thus fulfil its purpose of ensuring safe and efficient NPP operations.

› Mediating the relationship between subjects and objects. As shown in *Fig. 1*, an artefact is fit for its use when it promotes meaningful activity in the usage organisation, i.e. activity that derives from the societally-defined purpose for the existence of the organisation. Artefacts play an important part in determining how the users' situational goals develop up as they mediate the relationship between the subjects and their object. Other mediators within the activity system are rules, standards and values, and the division of labour and organisation.

› 1st feature of the proposed method: identifying the core tasks. To describe further what meaningful activity of an organisation and meaningful actions in an organisation are, the concept of the core task, i.e. the core content of work, is used. The process of defining the core task is called core task analysis (CTA). Experts in the field and Human Factors specialists have an active role in the process, as do operators and other plant personnel. CTA begins with the definition of the object and the societal motive for the work. For nuclear power generation, it may, in short, be defined as "producing a maximum amount of electricity from nuclear fission while balancing safety, efficiency, maintainability, quality, and personnel health."

› 2nd feature of the proposed method: assessing system usability. The control room system may be represented as an "information and communication technology (ICT)-based mediating artefact" serving the instrumental, cognitive, and communicational functions of NPP operations; and the concept of system usability may express the generic qualification of the appropriateness of such a tool. In the nuclear field, it should be required that the control room system be able to portray appropriately the critical safety, efficiency and personnel health-related constraints of production. Furthermore, the artefact should provide the user with possibilities to take these constraints into account, and thus develop appropriate work practices. In other words, the operators are able to understand the impact their own actions have on the overall performance of the system. A system with high system usability induces good working practices in the users. It also facilitates the development of shared knowledge and practices within the community. Consequently, high system usability is also experienced by the users as providing possibilities for future work.

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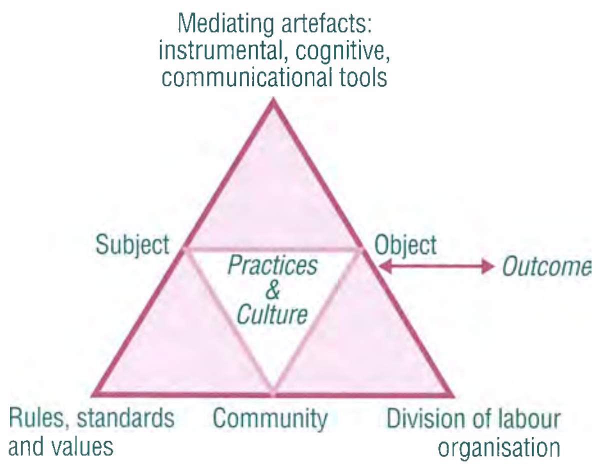
Fig. 1 : **Model of an activity system**



› 3rd feature of the proposed method: incorporating contextual parameters. The primary measurement for the appropriateness of evolving systems is process performance, which is measured by means of parameters such as process status, time, errors, etc. It has been observed, however, that such performance criteria are not necessarily very sensitive to changes in the MMI of instrumentation and control (I&C) systems. Consequently, it is customary to include complementary parameters such as system performance, personnel task performance, cognitive and mental load factors, and anthropometric factors. Whether the results provide information about the generic, but contextually specific ways that operators make sense out of and act on the situation may be questioned. Additional parameters are therefore needed that describe the courses of action as an expression of the 'task-evoked directedness' of the practical interaction with the environment resulting in a continuously developing interpretation of the situation.

› 4th feature of the proposed method: developing the appropriate modelling tool. A special modelling tool called a 'core-task analysis ladder' *(see Fig. 2)* is used to define performance-based indicators and criteria for system usability of artefacts in a work domain. It includes interplay between generic and situational points of view, and involves both →

analysis of user practices and conceptual analysis of the domain and tasks.

› 5th feature of the proposed method: evaluating user practices. In empirical studies, user practices can be evaluated from two points of view:

- first externally, with respect to the outcome of an action, i.e. process performance;
- second internally, to determine the habitual and cultural features that the users' actions express. Drawing on a combination of behavioural and interview data, how (practice or habit) users use available resources and take into account the objectives and constraints of the work domain is assessed.

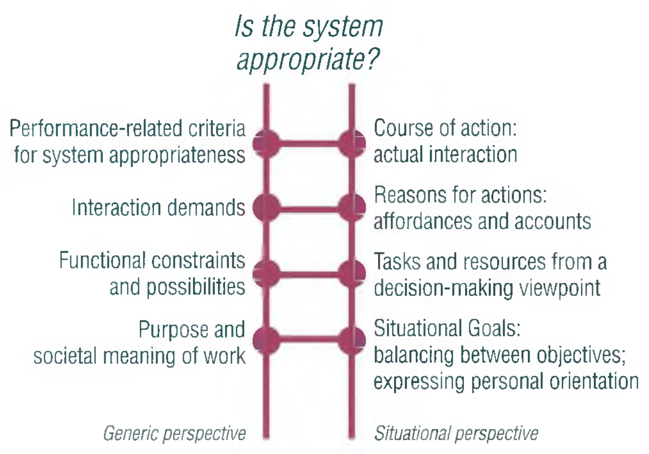
As a result, two types of performance indicators emerge. Both portray the core task demands of control room work.

The final point in the evaluation of practices involves grading the level of the users' orientation to the core task. The criteria are behavioural descriptors of ways of making decisions, ways of collaborating and ways of coping with problem situations. The descriptors are currently classified into six categories that express to what extent the operators have, in action:

- taken into account overall process conditions;
- taken into account the particular nature of off-normal process conditions;
- promoted shared interpretation of the situation;
- promoted unity of collaboration;
- promoted reorientation in problem situations;
- promoted critical assessment of their own resources.

These descriptors demonstrate the adaptability of practices, which is the foundation of good practices. Three (or five) grade scales are constructed to score practices. The logic in these scales is that the medium level expresses an acceptable level of practice and compliance with standards, the lower level indicates risk-prone performance, and the higher level signifies thought processes that ensure good safety and promote development of good practices.

Fig. 2 : **The core task analysis ladder**



The ladder provides a basis for decision-making for the selection of representative test situations, thereby promoting the generalisation of validation results. The ladder also serves to derive performance indicators for user practices that could be utilised in the assessment of the appropriateness of particular systems or artefacts. The indicators may also be used for other purposes, such as operator training.

› System usability: a new focus for assessment. This extension of the analysis makes it possible to understand the logic dictating people's actions. It helps explain, evaluate and predict specific courses of action without, however, necessarily drawing on process performance. In the extended assessment framework, the functioning of the entire activity system serves as an assessment basis of artefacts in situational actions. From this a new focus of assessment emerges: system usability. ■

INTEGRATING THE HUMAN FACTOR IN THE MODERNISATION OF OSKARSHAMN 1

By Thomas Gunnarsson, OKG, Oskarshamn, Sweden
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The Oskarshamn 1 BWR has been in operation since 1972 and is Sweden's oldest operating unit. New requirements for design changes to process systems and instrumentation, as well as existing shortcomings in the control room due to many previously performed modifications, forced an overhaul of the control room. The Human Factors (HF) for modernising the control room, the results, and the lessons learned from this work are explained.

To achieve a high level of safety and efficiency, one must ensure that the operators' working conditions are good, that requirements and resources in the workplace are in balance, and that the ergonomic requirements are fulfilled. In this respect, the extension of the originally compact central control room of the Oskarshamn 1 NPP *(see Fig. 1)*, performed to allow the stepwise installation of new information and control equipment, lead to downgraded working conditions and increased mental work, as operators had to move back and forth between the main and adjacent control room in order to obtain the necessary information to carry out their tasks, often in dynamic and stressful conditions with rapidly changing information. This, among other reasons, prompted the decision to build a modern new screen-based control room located in the same space as the old one, and with the same number of operators.

› A control room based on a unified human-system interface. Based on IFE's HF expertise, the overall integration of information was used as a basis for a conceptual design with optimal and effective interplay between the human (operator) and the system (means for interacting with the plant) in a conceptual design. Briefly stated, the philosophy puts the operator in charge together with automation to perform the plant functions. It was planned that the unified human-system interface (HSI) would be screen-based, with an overview of operation on large screens, and overview information and various manoeuvres on a conventionally equipped safety panel.

› A design management programme involving the end-user. A goal was to have most operators involved in the design and evaluation process, as they are the end-users and have in-depth process and operational knowledge and know the strengths and weaknesses of the current design. IFE was involved in establishing concepts and instructions for all HSI, and assisted in docu- →

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menting design process and results as well as in ensuring that guidelines and standards were followed in the design and evaluation.

› Systematic integration of Human Factor principles in the human-system interface. It was decided that the new control room should be located in the same space as the old one and that the shift team and its composition and responsibilities should remain unchanged. The modernisation included the following design areas: new control room layout with workplaces, new overview information on large screens, a new safety panel, a new display system with a new HSI, a partly new alarm system, new and revised procedures (paper-based), new education and training programmes, and work environment considerations. A simulator was built for the education and training of operators. Virtual Reality (VR) technology was used to design the control room, workplaces and safety panel layout.

As shown in *Fig. 1*, the design process - which was carried out more or less in parallel for each design area - is a continuous and iterative process in which the detailed design is developed based on the verification and validation (V&V) of preliminary designs. Verification involves checking that specifications are met and factored into design. Validation involves testing that the design adequately supports safe and efficient plant operation. Human Factors verification and validation was performed throughout the design and development of the design areas and their integration into a complete control room (see *Fig. 1*).

An important task was to establish a basis for a unified HSI for all design areas, and to integrate HF principles and other design bases in a systematic way in the HSI. But during the work with the HSI concept and specifications, it was discovered that the vendor's system could not meet all of the requirements. The vendor worked on developing general design prerequisites with input from the OKG design team, enabling the involved constructors to solve problems consistently. Moreover, MTO-related (Man-Technology-Organisation) issues identified during the design and documents reviews were tracked for progress reporting and issue resolution.

› Simulation of real situations from the early stages. Three main criteria were assessed for control design: compatibility (that the HSI was in accordance with the operator's abilities and limitations), understanding (that all information presentation, handling, control and response in the HSI should be easy to understand and result in meaningful communication), and effectiveness (that the design supports safe plant operation, that the shift team tasks were safely carried out and supported the fulfilment of team responsibilities). Real situations were simulated.

› Measurement of human performance. The types of human performance measured were plant performance (measurement of the deviations from predefined ideal process values), task performance (measurement of fulfilment and efficiency), cognitive factors (situation awareness, workload, and task complexity), and work process (quality of teamwork). Measurements made before completing operator training indicated that the crew's plant performance was satisfactory in the new control room, and that the workload and task complexity were experienced as being similar. However, there were some concerns about reduced task performance and situation awareness. A follow-up validation was therefore performed after operator training was completed, and the task performance was now better than in the old control room.

› Lessons learned from Oskarshamn 1. The experience gained from control room modernisation shows that:

• The involvement of the end-users (operators) and HF expertise in the overall control room design process ensured human-centred solutions (high usability), and led to a high operator acceptance level.

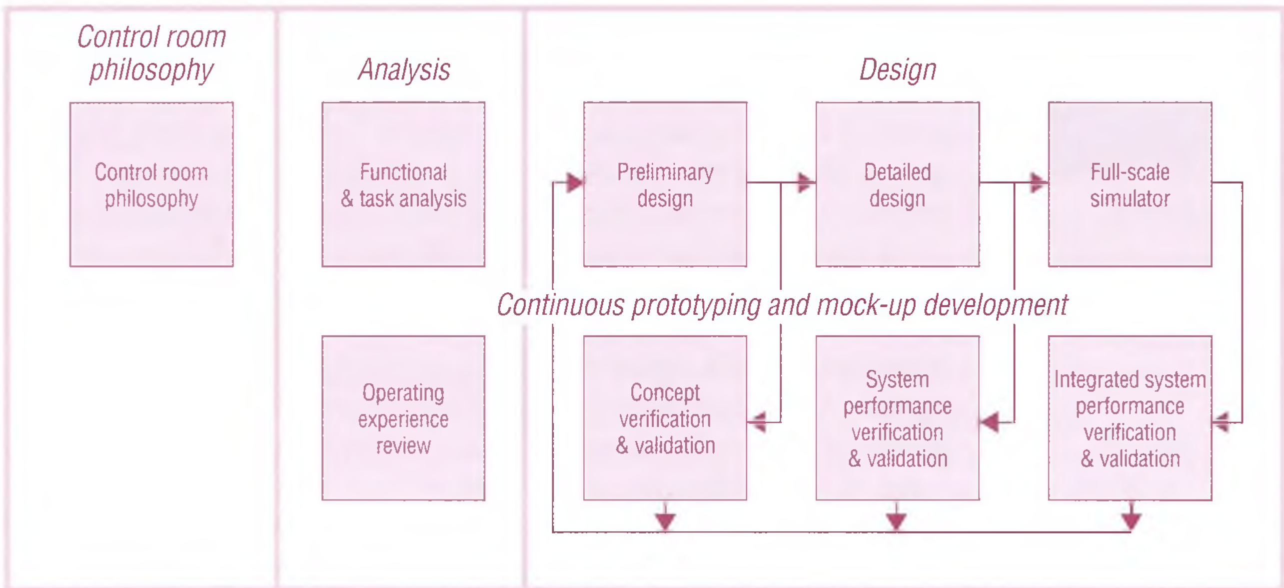
• The integration of V&V activities from the very start ensured a design process in which design flaws are discovered early, reducing the probability of expensive and troublesome issues at later stages in the process, and enhancing quality.

• Close co-operation with the regulatory authorities is considered important. Open dialogue and early information transfer will ensure that the authorities can make a proper evaluation of the project and suggest modifications, and will lessen the time needed in the end for the licensing process. The plant and the authorities have the same goal: to achieve the best possible control room in a structured way.

• VR technology has proven to be a very helpful and flexible tool in the design process. Visualising actual design concepts supports communication and discussion of ideas, and serves as a tool for documenting the design process.

• Vendors should allow some flexibility in their systems and co-operate more with end-users when developing standard products. ■

Fig. 1 : **Simplified design process scheme**



FOCUSING ON MTO INTERACTION
FOR A PROACTIVE AND PREVENTIVE APPROACH TO NUCLEAR SAFETY

A regulator's view by Anne Edland,
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The "Man-Technology-Organisation" concept was introduced in Sweden in the 1990s. To prevent accidents and ensure the smooth operation of nuclear facilities, it was recognised that behavioural competence had to be merged with technical knowledge of design, operations, maintenance and modifications. This interdisciplinary work and a systems approach encompassing human, technical and organisational elements and their interactions proved to be effective tools for the collaborative efforts of engineers and behavioural scientists at the Swedish Nuclear Power Inspectorate (Statens Kärnkraftinspektion, SKI).

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In Sweden, the licensee retains full responsibility for safety, including human, organisational and technical activities. The Swedish Law on Nuclear Activities also establishes the legal authority of SKI to ensure that the licensee assumes this responsibility and that the activities are carried out safely. In this respect, SKI may close plants that do not meet safety requirements. The examples below illustrate regulatory requirements from the MTO perspective.

› Analysing and learning from events. An important safety activity for the licensee is to recognise and analyse events in order to take appropriate measures and learn from experience. To this end, nuclear power plants have assembled teams trained in analysis of the interaction between man, technology and organisation during incidents, including those involving barrier functions. These specialized teams help the licensee develop a system and gain practice in recognising different kinds of events, performing appropriate analyses, discussing solutions, implementing them, and evaluating their effects.

In recent SKI inspections, emphasis was placed on the need for clear, documented and timely decision-making concerning recommendations issued by the incident investigation team, actions to be carried out accordingly, and the assessment of their effects.

› Managing control room modifications. Sweden's NPPs are making major changes to instrumentation and control systems and other modifications that will affect the control room and the human-system interface. The licensee must demonstrate proper control of the entire process, including the human aspects of modifications, particularly with respect to management of the Human Factors programme, review of operating experience, functional and task analyses, the human-system interface, and staffing and training. The development of procedures, the verification of Human Factors and the validation process, and design implementation are also reviewed. SKI assesses how the elements are managed and controlled and performs random verifications to examine the actual process. The outcome may also be reviewed if necessary.

› Working conditions that support safe performance. Human performance, whether for individuals or groups, is affected by working conditions. The licensee must therefore provide proper working conditions so that work can be carried out safely. Factors at work that can negatively affect performance must be identified and appropriate measures taken to prevent errors. What is expected is a system that shows that proactive and systematic action is being taken by the licensee in this respect and that factors such as workload, overtime, motivation, teamwork, and work supervision are considered. Also, it is expected that tasks in need of more frequent or more detailed analysis will have been identified. Most inspections pertaining to organisational processes address the workload of managers and other personnel.

› Managing organisational change. Experience has shown that modifications to an organisation's structure and resources are important factors for risk and safety. In recent years, there has been pressure on the industry to cut costs, which has led to plans to reduce staff, make work processes more efficient, outsource some tasks and self-perform other tasks previously handled ➜

The MTO perspective

The MTO perspective is often used to:

- study instructions given to people on how to work safely;
- ensure individual skills and alertness;
- analyse the management, organisational and safety culture aspects of safe work;
- analyse events to learn "what the event is telling us" so as to prevent its recurrence, i.e. learning from experience.

Examples of areas in which the MTO concept can be applied:

- assessing plant modifications, such as control room modifications, so that operators can simulate a proposed modification from a human and user perspective before it is implemented;
- examining maintenance from an organisational perspective: how is maintenance organised, planned, performed and evaluated?
- education and training: are there enough personnel with the necessary skills and experience to perform the duties assigned to them?
- developing and evaluating procedures for accident management;
- influencing various management and organisational aspects and early recognition of signs of possible declining performance;
- learning from experience.

The MTO perspective is preventive and should therefore be applied to future challenges as well, such as:

- aging facilities;
- modernisation and safety upgrades;
- safe shut-down of operating facilities for decommissioning;
- skills management;
- downsourcing and outsourcing;
- safety culture.

by contractors. Changes such as these can have positive or negative effects of importance to safety, depending to a large extent on how they are prepared, implemented, and monitored. By law, the licensee must have a procedure for managing organisational change.

› Ensuring the availability of skills and personnel. Recent inspections have been devoted to assessing the licensee's system and practices for ensuring that there are adequate personnel with the right mix of skills. The focus has been on the system in place used to determine which skills are required. Factors such as attrition, future plant modifications and maintenance plans also need to be considered by the licensee, with respect to additional analyses for the near future. The focus is also placed on skills that are lacking and on measures needed to bridge the gaps. A related issue was to sort out in-house skills needed at the plants when tasks or functions are outsourced to contractors.

The regulator's position is that the licensee should have sufficient skills within its own organisation to order, manage, and evaluate work performed by the contractor.

› Conclusion: learning from experience is the right way forward. A systems view focused on the interaction between man, technology and organisation is pivotal for a proactive and preventive approach to nuclear safety. To err is human, and though we cannot change human nature, we can change the conditions in which humans work. In order to do this, it is important to have good knowledge of the factors that affect the performance of individuals, groups and organisations.

The system must be able to handle errors and humans must be encouraged to report mistakes, which in turn creates a fair organisational culture in which the reasons for mistakes are investigated and corrected and learning from experience is emphasised. ■

The MTO concept

In Sweden, after initial pioneering work, the MTO concept is well established in industry and with the regulator. At the same time, its scope has grown to include many different issues. Today, seven specialists work at the Department of Man-Technology-Organisation at the Swedish Nuclear Power Inspectorate in areas such as:

- quality assurance, safety management, quality/safety management systems;
- rationalisation;
- organisational change;
- safety culture;
- management and organisation;
- qualifications, fitness for duty, suitability, education and staffing;
- working conditions;
- ergonomics/Human Factors for control room work;
- incident analysis and risk analysis from the MTO perspective;
- maintenance;
- decommissioning.

Together with specialists from other departments, SKI performs inspections and reviews, makes decisions, enforces requirements and recommendations, conducts investigations, spearheads research, and participates in international collaboration in these areas.

SIMULATOR TRAINING: WHERE TECHNOLOGY MEETS SOFT SKILLS

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In German NPPs, incidental situations are fortunately so rare that they cannot be categorised. Nevertheless, in order to keep safety to as high a level as possible, the four major German electricity companies entrusted VGB PowerTech e.V. with surveys on safety management, reporting tools, etc., with a view to taking man-technology-organisation (MTO) issues better into account. These surveys showed the important role of training in decision making: in German NPPs, approximately one third of the few reported incidents are due to – or worsened by – human errors. Despite this fact, attention was mainly focused on technological issues – e.g. automated systems – until about 15 years ago. Then it became obvious that Human Factor and MTO issues had to be given more consideration, though it is more difficult to be confronted with soft skills than with hard science. Today's generation of managers thus regard this issue as a major one.

▼ According to German law, operators must be licensed to operate safety-related systems and components. In the field of training, the rules defined by the safety authorities provide for two types of instructional programmes. First, initial training, required to receive the operator's licence. Carried out in addition to engineering courses, it consists of 3 to 5 years of very stringent and intensive training including 12 weeks of simulator training over the past 2 years. Then, on-going training, which is mandatory to keep a license valid. It consists of an average of 2 weeks of simulator training per year.

▼ As a specialist of simulator training for NPP operators, KSG/GfS [1] organises biannual sessions for about 900 people, 90% of whom are licensed operators. The content of each session is based on guidelines issued by the German authorities and can be described as follows:

- thorough review of the knowledge acquired during the initial training: the complete range of potential operating scenarios is reviewed in 3-year cycles;

- in addition, all the incidents or accidents that have actually occurred in plants worldwide during the previous year are included in the programmes so as to provide "real-world" training;
- trends relevant to operations, such as changes in plant design or operating manuals, are also covered in the training course;
- last but not least, the contents are tailored to individual needs, based on an assessment of the tasks performed by each operator.

MEETING OPERATORS' NEEDS

▼ The trainees' expectations regarding simulator courses can be roughly described as follows:

- keep the average plant availability at about 99% over the year (not including planned outages);
- get acquainted with scenarios they are not used to seeing in their operating file... and life;
- be capable of managing complex incidental situations pertaining, for example, to transient plant behaviour;
- assess their own knowledge: are there gaps to be bridged? Areas to be improved?

▼ The objective of each training course is predefined based on the contents above; an exercise guide is drafted for each scenario and, to assess progress, the actual behaviour of the trainees is compared with the contents predefined in the exercise guide.

ANALYSIS OF THE WORKING SYSTEM OF NPP PERSONNEL

▼ During the sessions, actual situations are simulated, taking into account the entire working system of NPP personnel:

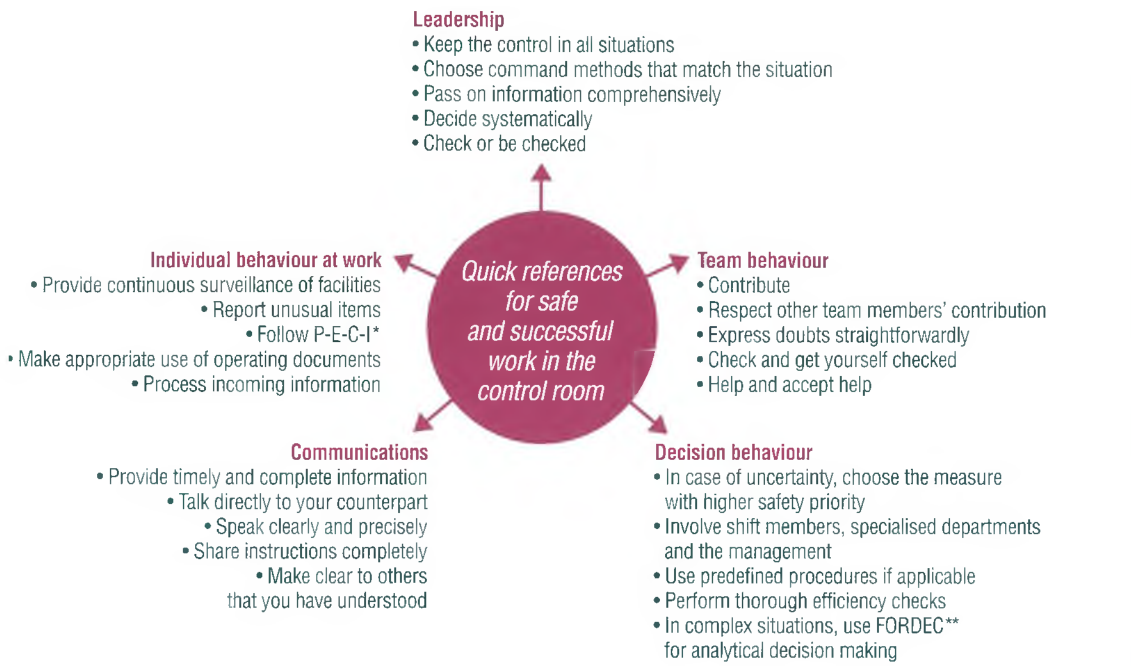
- the control room, where individuals are confronted with the man-machine interface, the panel;
- manuals and other documents: 120 folders, 5 meters of paper for a single plant;
- training and its influence on the operator's knowledge and behaviour;
- the organisation itself: who is the leader, who gives the instructions...

▼ As shown in *Fig. 1*, the working system is analysed according to the PDCA cycle, as it encompasses both system design and safety management through the definition of objectives, the performance of tasks, the analysis of the consequences and, to some extent, the determination of corrective actions.

▼ The training sessions are also an opportunity to review the fields of competencies to be integrated so as to enable man-technology-organisation (MTO) improvements *(see Fig. 2)*. These are based first on the working attitude of the individual, the correct way of operating equipment; secondly on leadership, the way to get each shift leader to make appropriate decisions; thirdly on communications, the way to get the emitter and receptor of a message to understand it in the same way; fourthly on team behaviour, the way to respect other team members' contribution and to check and be checked; lastly on the decision-

Fig. 1 : **The PDCA Cycle of Quality Management**

Fig. 2 : **Quick-reference behaviour for shift personnel in charge**



(*) P – Preparation; E – Execution; C – Check; I – Information

(**) F – Facts; O – Options; R – Risks; D – Decision; E – Execution; C – Check

making process, the way to manage uncertainty or complex situations, for instance.

▼ During the session, trainees are faced with three types of decision situations *(see Fig. 3):*

● Immediate decisions: decisions made to react immediately to emergency situations. Operators are trained for this type of decision, although the technology selected for designing German reactors - based on the 30-minute criterion - prevents them from being confronted with this kind of situation.

● Procedure-based decisions: decisions which can be managed using a decision analysis tree; 90% of all accidents/incidents can be managed in this way.

● Analytical decisions: decisions made to manage situations not immediately recognizable by an operator.

▼ Beyond immediate and procedure-based decisions, emphasis is put on the third category of decision-making, based on Fordec. Designed by Dr. Hörmann for the German Aeronautics and Aerospace Company (Deutsches Zentrum für Luft- und Raumfahrt, DLR) in 1995, Fordec proved effective and well accepted by engineers as a group approach. The method was thus transposed to the nuclear power generation business by adding a set of essential and secondary criteria specific to NPPs.
Fordec allows the selection of the best solution and its implementation in good order, particularly in situations of stress or limited time. As shown in *Fig. 4,* Fordec starts by analysing Facts through to defining as many Options as possible, discussing the Risks and benefits associated with each option, and making a Decision, Executing that decision and finally Checking if all the expected benefits are there.
If not, the process must be revised, beginning with the Facts step.

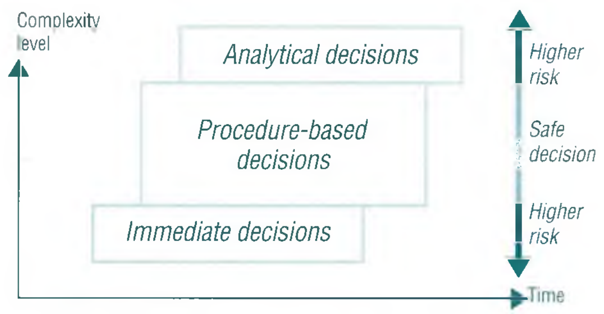
▼ The effectiveness of training is a function of the combination of:

● Team teaching: The sessions are systematically conducted by a team composed of a specialised engineer and a psychologist.

● The use of simulators based on state-of-the-art technology: Being identical to the control room of a real plant, they allow the replication of any real-life scenario likely to occur in a plant, including multiple-cause failures, and allow interactive reactions with the operator. For instance, the simulation is so detailed that it can reproduce a small break on a chip or a major leakage on a main pipe.

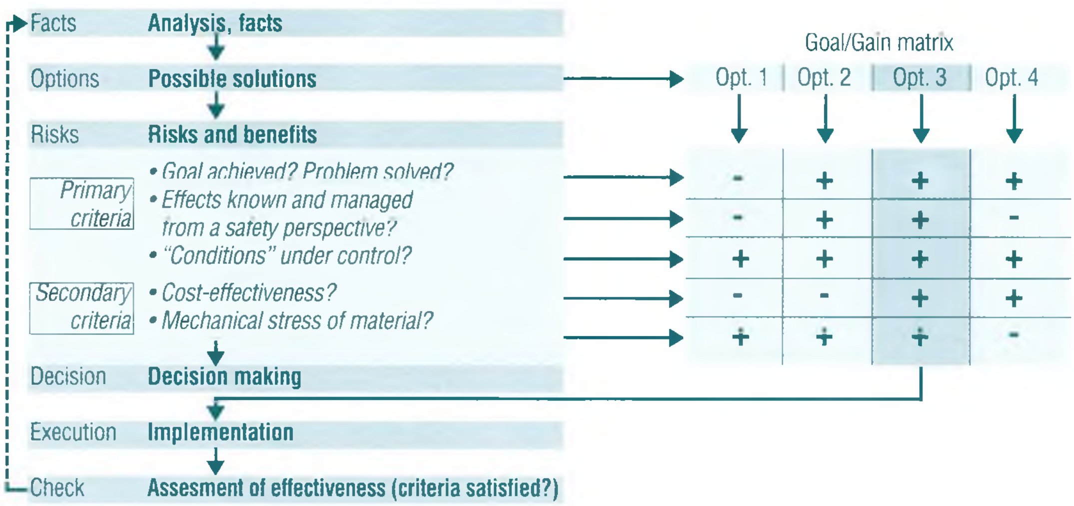
▼ At a time when the phase-out is depressing the entire nuclear industry in Germany and when institutes no longer seem ready to educate nuclear engineers, it is of utmost importance to maintaining suitable safety that operators be provided with high-level training based on continuously improved methods and tools such as simulators. In spite of the costs, this remains a highly profitable investment. ●

Fig. 3 : **Selecting the right decision mode**



(1) KSG Kraftwerks-Simulator-Gesellschaft mbH/GfS Gesellschaft für Simulatorschulung mbH (Essen, Deutschland)
Nuclear Power Plant Simulator Co./Simulator Training Co. (Essen, Germany)

Fig. 4 : **Analytical decision making based on FORDEC**



MORE ON THE WEB

➤ NEA Issue Brief: An analysis of principal nuclear issues

No. 2, January 1988 - The Human Factor in nuclear power plant operation

http://www.nea.fr/html/brief/brief-02.html

➤ Human Factors and Nuclear Safety Presentation

24-26 October, 2000 - Moscow, Russia

http://www.wonuc.org/hrm/hrm_01.htm

➤ Safety Man-Technology-Organisation

Institute for Energy Technology (IFE), Norway

http://www.ife.no/english/hovedomrader/index.jsp?hId=600

➤ Experimental Control vs. Realism: Methodological Solutions for Simulator Studies in Complex Operating Environments

By Gyrd Skraaning Jr, Industrial Psychoglogy division, Institute for Energy Technology (IFE), Norway

http://www.ife.no/english/aktuelt/aktuelt_display.jsp?docId=2500

➤ Useful information is available on the website of the Francophone Ergonomics Society (SELF)

http://www.ergonomie-self.org/

➤ Human Factors in engineering design Technical University of Berlin

http://www.ast.tu-berlin.de/html/arbeitsgruppe/humanfactor/hf_eng.html

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http://www.inmm.org/topics/contents/pdfs/MPC%20A.pdf

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By Kenichi Takano, Senior Research Scientist, Human Factors Research Center, Central Research Institute of Electric Power Industry (CRIEPI), Japan

http://criepi.denken.or.jp/en/e_publication/a2002/02seika31.pdf

➤ EU-Network PRISM (Process Industries Safety Management)

http://www.prism-network.org

UPCOMING MEETINGS & VENUES

➤ *22 March 2005, Paris, France*

Les facteurs humains : prise en compte dans le retour d'expérience (in French)

Organised by Société Française d'Énergie Nucléaire (SFEN) and chaired by Institut de radioprotection et de sûreté nucléaire (IRSN)

➤ *4-22 April 2005, Saclay, France*

Training course on nuclear safety organized within the framework of the NEPTUNO project
(Nuclear European Platform of Training and University Organisations)

Organised by Institut national des sciences et techniques nucléaires (INSTN)

NEPTUNO Project website : www.sckcen.be/neptuno/

➤ *21-26 August 2005, Brussels, Belgium*

ICENES 2005
(12th International Conference on Emerging Nuclear Energy Systems)

Hosted by the Belgian Nuclear Research Centre (SCK-CEN) and sponsored by ENS

e-mail:bverboom@sckcen.be

➤ *31 October-11 November 2005, Trieste, Italy*

Nuclear Power Plant Simulators for Education

Organised by the Abdus Salam International Centre for Theoretical Physics.

e-mail: smr1680@ictp.trieste.it

➤ *30 November-2 December 2005, Vienna, Austria*

Operational Safety Performance in Nuclear Installations

Organised by the International Atomic Energy Agency (IAEA)

The next EUROSAFE Forum will be held in Brussels on 7 and 8 November 2005.

The seventh issue of the EUROSAFE Tribune will contain reports about the lectures and discussions of the EUROSAFE Forum 2004.

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