Chapter 1: Team work, diagnostic and decision-making

- Spain (TECNATOM s.a.): “Team work, diagnostic and decision-making”
- Finland (VTT): “A method for analysis of NPP operators’ decision making in simulated disturbance situations”
- Finland (VTT): “Contextual analysis of the operators’ on-line interpretations of process dynamics”
- Finland (VTT): “A contextual approach to systems safety-analysis of decision making in an accident situation”
- Japan (CRIEPI): “Modeling and simulation of operator team behavior in nuclear power plants”
- Japan (NUPEC): “Development of team performance evaluation method and its application for team performance improvement”

Chapter 2: Stress

- Spain (TECNATOM s.a.): “Stress”
- USA (US NRC): “Stress”

Chapter 3: Fidelity

- France (IPSN): “Comparison methods of simulator fidelity models and impact on operation”
- USA (US NRC): “Simulator fidelity issues”
CHAPTER 1: TEAMWORK, DIAGNOSTIC AND DECISION-MAKING

SECTION A. DEFINITION OF ISSUES

TEAMWORK

Teamwork is the work being accomplished by a group of people with assigned individual roles and responsibilities whose priority is accomplishing a common goal, in such a way that:

- The goals of the team are clearly understood by its members.
- The members of the team communicate their ideas and feelings with accuracy and clarity.
- Participation and leadership are shared by the members of the team.
- The procedures for decision taking are used with flexibility and the input of all the members is taken into account.
- Power and influence is equally shared by all members.
- The conflicts arising through the opposition to certain ideas are absorbed. Discussions lead to compromises, quality and creativity in work. Minority opinions are listened to and understood.
- The ability to resolve problems by the team is effective.

DIAGNOSTIC AND DECISION-MAKING

Diagnostic and decision-making is a logical mental process developed in the following stages:

- Supervision: to know the state of the plant at all times, differentiating between normal and problematic situations, being able to forecast abnormal evolution.
SECTION B. CURRENT PRACTICES

Teamwork, diagnostic and decision-making are subjects included into a specific training programme ("Human Factors" course), before starting simulator training.

The Human Factors course is delivered in classroom setting using lectures and practices. The skills acquired during this training are implemented during simulator training programme.

FINAL OBJECTIVE

On completion of this course, the trainee will possess the bases required to understand efficient teamwork and previous diagnostic techniques, necessary for decision making in the operation of a nuclear power plant.

CONTENT SUMMARY

Leadership

All organizations, teams or groups need a person to plan the objectives to be achieved, to organize the tasks to be carried out, to organize the members of the team, to coordinate the work within the team and to ensure there is a relationship between the members of the team.

In turn, this task should be carried out with the greatest quality possible, and it should be accepted by the majority of the team members.
The person responsible for these tasks is the leader.

This chapter analyses the aspects related to the characteristics of a leader, different styles of leadership and the functions of the leader, together with the role of the leader in the control room.

Teamwork

Whereas a small percentage of incidents caused by human error can be attributed to a lack of knowledge of the persons involved, it has been shown that the majority are due to failures in the activity of the team due to lack of effective interaction amongst the members.

Therefore, it is crucial an effective teamwork for the adequate solving of the numerous problems arising in the control room.

The building of a team, working effectively, is a long term process which requires different learning steps, in such a way that the team members acquire and put in practice a series of skills increasing in difficulty.

Motivation

A person must have ability and the will to work if he is to carry out a job correctly. Intellectual capacity, dominion over the task, experience and skill. Will comes with confidence, the level of commitment and motivation.

Therefore, motivation is an important element which governs the reasons why a person carries out a certain task or action.

Motivation is determined by the necessity a person has to cover his own requirements.

In this respect, different motivation strategies, focused on intrinsic factors to the task ("job enrichment"), are depicted.

Communication

A system communication is required in all cases requiring an exchange of information or instructions. Regardless of the type of communication, the information must be
transmitted and received and it must be complete and accurate. However, the most important thing is that the information must be understood.

Problems involved with verbal communications have caused numerous human errors in nuclear power plants, giving rise to a broad spectrum of events and incidents, and, in some cases, they have brought about serious situations. Power plants may reduce the contribution of human error to these events by ensuring that verbal communication is made correctly.

Inadequate communication has been identified as a causal and contributing factor to 15% of all events related to human activity. Within this group, two thirds of problems arose from verbal communication. In this sense, the principle areas are the changing of shifts, explanations given prior to carrying out a particular task, and communication during the carrying out of jobs.

**Diagnosis**

The complexity of the running of a nuclear power plant, which is closely linked to the economic and safety repercussions involved, means that the exhaustive training and know-how of the members of the control room is absolutely necessary if we are to forecast, on the one hand, and to counteract, on the other hand, any problem which might arise.

We could say that the team has, not only the responsibility of guaranteeing the correct running of the plant, within certain fixed limits, but also of optimizing all its parameters.

The team as such and its members, should have the preventive know-how and training to enable, them to develop the parameters of the plant which deviate from their normal values and to pay special attention to any detail which might lead to an abnormal condition in the plant, and, in any event, to be prepared to solve the problem.

In this context, special emphasis must be laid on the strict following of the established procedures for the equipment so as to guarantee the correct development of the plant, with special attention being paid to the security and reliability of each task.

Success depends above all on the attitude the team has to its work.
The members of the control room team should have sufficient abilities and willingness to diagnose the problems in the plant and to determine effective solutions. This means they must learn logical mental processes for identifying problems, determining possible and probable causes and for knowing how to order and give priority to corrective actions and for evaluating the results.

Annex-I includes the Human Factors Training Programme

MODELS OF HUMAN BEHAVIOUR

The following is a description of the models of the human behaviour being used within simulator training programmes.

**Leadership**

- Leadership style: the basic qualities of a shift supervisor who is a true leader who will act effectively in the control room.

- The six principles for achieving effective supervision.

**Teamwork**

- Shift roles and responsibilities: for good teamwork the roles and responsibilities of each team member must be clearly defined. This avoids the individual responsibility of each member becoming diluted in the responsibility of the team.

- Teamwork model: basic task which the control room team should perform in order to establish their teamwork, such as the strategic development of activities, assigning tasks, solving problems and coordination.

- Assertive behaviour: assertiveness has been defined as the desire to interrelate with others.

**Motivation**

- "Job enrichment": tasks intrinsic motivating factors.
Communication

- Techniques of communication: to ensure correct verbal communication requires the knowledge and putting into practice of a series of communication techniques which have been seen to be successful in industry in general, including the use of the phonetic alphabet and communication feedback among others.

- Writer's practical guide: aimed at providing a series of general recommendations which should be useful when having to make any kind of written communication.

- Shift turnover: the relieving of operation shifts in the control room is an important moment when the process of oral and written communication plays a principle role.

Diagnosis

- Attention to details: an alert and attentive attitude to detect minimum subtle changes which might cause a failure.

- Logical process of diagnosis: the stages which must basically be developed for effective diagnosis.

- Areas in which the models of human behaviour are being applied:

- Directing shift operations.

- Crew interaction.

- Communications:
  . Shift communications during operation
  . Communications with other sections
  . Shift turnover
  . Written communications

- Control board operation.
- Alarms interpretation and events diagnosis.
- Emergencies response.

All of them are areas of trainees assessment during the simulator evaluation.

METHODOLOGY

Formal instruction, discussions and case studies, role playing, diagnosis practical exercises and quizzes.

LENGTH

Four days. 24 hours of instruction.

SECTION C. FURTHER DEVELOPMENTS

Migrate the human factor course on CD-ROM using multimedia techniques, text, graphics, sound and video images, for self study and retraining.
ANNEX I  HUMAN FACTORS TRAINING PROGRAMME:

1st day  INTRODUCTION

- LEADERSHIP
  - The boss and leadership
  - Reactions before a new boss
  - The leader
  - The skills of the leader
  - Styles of leadership
  - Strategies of leadership (Situational leadership)
  - The functions of the leader
  - Leadership in the control room
  - The six principles for achieving effective supervision
  - Tests
  - Business games

2nd day  TEAMWORK

- The characteristics of a team
- The building of a team
- Teamwork
- Resolving conflicts
- Tests
- Videos and case studies

- MOTIVATION
  - Motivation and behaviour
  - Hierarchy of necessities
  - Motivating Factors
  - Guidance and support

3rd day  COMMUNICATION

- Verbal communication
- Written communication
- Relieving
- A writer's practical guide
- Non-verbal communication
- Videos and case studies
Communication exercises

4th day
- Diagnostic
- Syntonising the control room team with the plant
- Diagnosis and resolving problems
- Videos and case studies
- Diagnostic exercises
FIGURES
DETECTION OF THE PROBLEM

TO RECOGNIZE THE SYMPTOMS

DEFINITION OF THE PROBLEM

ESTABLISH CAUSES

CHOOSING THE POSSIBLE SOLUTIONS

POSITIVE EXPERIENCES

CONSEQUENCES OF THE PROBLEM

ACCEPTABLE SOLUTIONS

RESOLUTION OF THE PROBLEM

'\*THE NECESSARY KNOWLEDGE, PERSONS, EQUIPMENT AND TIME SHOULD BE USED\*'
CONFLICTS WITHIN THE TEAM

- KNOWLEDGE OF VALUES
- THE INTERNAL SOCIAL STABILITY OF THE TEAM
- RECOGNITION OF THE BOSS AS LEADER
- AWARENESS OF INDEPENDENCE
INTRA-PERSONAL CONFLICTS

SITUATIONAL FRUSTRATION

CONFLICTING NEEDS
THE BUILDING OF A TEAM

FUNCTIONAL TEAM

MANAGEMENT

TEAM MEMBERS

ACTUATION GUIDES

IMPLEMENTATION

DECISION TAKING

ROLES

AND

RESPONSIBILITIES

EXPERIENCE

PERSONALITY
<table>
<thead>
<tr>
<th>GROUP</th>
<th>HOMOGENOUS</th>
<th>HETEROGENOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADVANTAGES</td>
<td>Improves the carrying out of the task</td>
<td>Common beliefs</td>
</tr>
<tr>
<td></td>
<td>Common weak points</td>
<td>Less potential for growth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Boredom</td>
</tr>
</tbody>
</table>
TEAM C.R.

GOAL
100%

PROCEDURES T.E

QUALIFICATIONS + TRAINING

STANDARDS BEHAVIOUR C.R.

RESPONSABILIDAD
ST. AST.
RO. TO.

ST
RO
TO
AST
THE BEHAVIOUR OF A MEMBER OF A TEAM

ACHIEVEMENT

- He values his time
- He likes to analyse his work
- He establishes goals, stages, objectives
- He controls them himself
- He communicates well
- He is autonomous, responsible
- He fulfills and plans his work

POWER

- He is dogmatic and superior
- He imposes his criteria
- He acts in a brusque and critical way
- He wants to win

AFFILIATION

- Good for public relations
- He will be the joker of the group when things are going well
- He will feel himself the victim if things are going badly
- Servicial
THE BEHAVIOUR OF LEADERS

ACHIEVEMENT

HE ESTABLISHES OBJECTIVES FOR HIS COLLEAGUES AND HE CONTROLS THEM
HE PLANS ADEQUATELY TO ACHIEVE THE OBJECTIVES WITH THE PARTICIPATION OF ALL THE TEAM
HE CONTROLS HIS TIME
HE ALWAYS EMPHASIZES POSITIVE RESULTS IN PEOPLE.
HE IS INFORMED AND GIVES CLEAR INFORMATION TO OTHERS

POWER

HE WANTS TO IMPOSE HIS OWN CRITERIA
HE IS CRITICAL AND HARD
HE FINDS FAULT AND DEFECTS
HE IS NOT INTERESTED IN INFORMING OTHERS
HE OVERESTIMATES HIS OWN WORTH
HE HAS AN ATTITUDE OF CONSTANT STRUGGLE
HE CONSIDERS THAT HIS TEAM MEMBERS ONLY WORK WELL IF THEY ARE CLOSELY SUPERVISED

AFFILIATION

HE IS KIND AND RESPECTFUL
HE HAS LITTLE AUTHORITY OVER HIS TEAM
HE IS MORE CONCERNED WITH PEOPLE THAN OBJECTIVES
HE DOES NOT COMMIT HIMSELF, BUT TENDS TO BE RETIRING
IF HE HAS PROBLEMS WITH HIS COLLABORATORS HE WILL REFER THE PROBLEM TO HIS SUPERIORS
THE BEHAVIOUR OF PERSONS WITHIN A TEAM

ACHIEVEMENT

HE DEVELOPS INITIATIVES
HE LISTENS TO OTHERS
HE INVITES HIS COLLEAGUES TO PARTICIPATE AND GIVE OPINIONS
HE VALUES THE IDEAS OF OTHERS
HE CONTROLS AND VALUES HIS TIME

POWER

HE IMPOSES HIS IDEAS
HE ORDERS AND TELLS OTHERS WHAT TO DO
HE NOTICES OTHER PEOPLE'S MISTAKES AND LIKES TO POINT THEM OUT FREQUENTLY
HE NEVER WANTS TO LOSE AN ARGUMENT

AFFILIATION

HE IS INTERESTED IN MAKING FRIENDS AND BEING LIKED
HE DOES NOT LIKE ARGUMENTS AND AVOIDS THEM
HE DOES NOT CONFRONT THE CRITERIA OF OTHERS AND CHANGES HIS OWN CRITERIA EASILY SO AS NOT TO CONTRADICT
HE IS ATTENTION IS CENTERED MORE ON PROTOCOL THAN A CONCRETE OBJECTIVE OF THE GROUP
MORE TIME IS SPENT ON UNPRODUCTIVE MOVEMENTS THAN ON THE GOALS AND OBJECTIVES OF HIS WORK
A METHOD FOR ANALYSIS OF NUCLEAR POWER PLANT OPERATORS' DECISION MAKING IN SIMULATED DISTURBANCE SITUATIONS

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Abstract

An analysis method has been developed for analysis of nuclear power plant operators' decision making in simulated disturbance situations. The aim of the analysis is to investigate operators' orientation which is expected to manifest itself as collective strategies in utilization of resources of decision making. Resources analysed here are different information sources and, in addition, collaborative resources like communication and participation. The cognitive approach on the basis of the method considers decision making as collective construction of common interpretation of available information. Utilization of information is evaluated with respect to operative context. This is made with help of conceptualization of the disturbance situation from the decision making point of view and by construction of operative reference for activity. The latter means conceptualization of the situation from the safety point of view and also consideration of other boundary constraints of decision making, i.e. economical and technical aspects.

The analysis method is intended to be used in routine simulator training in nuclear power plants. By virtue of it's contextual and dynamical approach it makes the developing nature of activity visible. Cumulation and distribution of knowledge of decision making as developing activity, controlled by orientation and boundary constraints of process control, is expected to improve operational culture of a plant organization.
1 INTRODUCTION

Decision making in highly automated work like process control in a nuclear power plant requires intellective skills because the production process is represented in informed form, i.e. as converted into information (cf. Zuboff 1988). The function of these skills is to give meaning to the mediated information automation produces.

Our research group, composed of man-machine psychologists, has a contextual and dynamic approach to analysis of these skills in process control (Norros, in press). This approach has been developed in our research program concerning decision making in informed work, especially on safety critical areas.

According to our view, activity is dependent on it's context and therefore activities are dynamically constructed in concrete performance situations. Consequently, process control operators' decision making should be analysed by taking it's operative and social context as reference of analysis. It is important to clarify how operators take these contexts into account in their collective decision making. We have used the concept of orientation to describe this subjective relationship to the object of activity.

Our approach is also historical in the sense that developmental aspects of activity have been taken into account. Decision making is viewed as developing according to personal development of operators and changes in operational culture.

On the basis of these concepts we have developed a method for analysis of nuclear power plant operators' decision making in simulated disturbance situations. The method has been developed in collaboration with nuclear
power plant operators, trainers and other nuclear power plant experts. Chapter 2 introduces the current phase of our theoretical approach. The method itself will be presented in chapter 3. In the last chapter some aspects concerning it's development and it's usefulness with respect to simulator training will be discussed.

2 CONCEPTUAL MODELLING OF DECISION MAKING IN PROCESS CONTROL

2.1 The model

Our research program was based on need of conceptual tools for analysis and evaluation of process control operators' decision making in a nuclear power plant. A model was developed for decision making in a disturbance situation. It was used as a conceptual tool and developed further in a study concerning nuclear power plant operators' diagnostic decision making in a simulated disturbance situation (Hukki & Norros 1993). Evaluation of decision making with help of the model was made in collaboration with a nuclear power plant expert.

The model is a conceptual description of operators' collective diagnostic and operative decision making in a particular disturbance situation. In the next paragraphs the basic concepts of the model will be described.

According to our view, diagnosis in the traditional sense means recognition and localization of a disturbance. In this sense it has often been comprehended as fault finding. Diagnosis can, however, be considered in a wider sense, as interpretation of a whole situation. That means recognition of a disturbance with respect to the plant process, i.e. recognition of the degree of disturbedness of the whole process. This wider diagnosis requires
coherent conceptual representation of process dynamics.

The coherence of representation of process dynamics is supposed to depend on a subject’s orientation. This concept which we consider as central in evaluation of operators’ expertise can be defined, in general, as subjective relationship to the object of activity. Our view is that in a disturbance situation it is a process of framing the situation and therefore it controls the dynamic construction of decision making. Individual orientations of the members of the crew control the dynamics of the construction. This dynamics, i.e. cooperation, can be considered as manifesting something like collective orientation. It’s dynamics is dependent on crews’ utilization of cooperative abilities of it’s members, i.e. of communication and participation.

In evaluation of operators’ comprehension of process dynamics a more extensive operative reference is needed than description of ideal task performance. For evaluation of adequacy and dynamics of disturbance handling the disturbance situation must be conceptualized in order to define relevant criteria for evaluation. Safety is the ultimate criteria for decision making in process control in nuclear power plants. Therefore criteria of decision making have to be defined primarily with respect to safety aspects. A feasible reference for evaluation can be created by utilizing the concept of critical safety functions (see e.g. Corcoran et al. 1981). These global functions of the plant process, e.g. mass inventory of the coolant and heat transfer from the reactor core are essential from the safety point of view. Recognition of those functions which have been threatened during the disturbance situation and maintenance of them with help of adequate operative methods can be used as operative reference.

Diagnostic and operative interpretations are constructed on the basis of available process information (on-line information indicating the physical
state of the process) and procedures. On the basis of the arguments mentioned above we supposed that coherence of operators' comprehension can be inferred on the basis of type of their utilization of process information and procedures. The aim of the above mentioned study (Hukki & Norros 1993) was to find out possible differences in utilization of process information in diagnostic decision making. On grounds of the results the model seemed to work. Utilization of process information differed between the crews. There was two types of utilization. Part of the crews made diagnostic inferences directly on the basis of process dynamically informative information, i.e. information which can be used as evidence of the functional state of the whole process or of a functionally essential part of it. Part of them proceeded by using information locationally, by excluding alternative locations of a disturbance. In conclusion, there seemed to be two types of orientation controlling the crews' decision making.

Moreover, orientation seemed to be related to adequacy of diagnostic and operative task performance. Those crews which proceeded by excluding diagnostic alternatives underestimated size of the disturbance which lead to unoptimal operations.

Cooperative aspects of utilization could not be analysed in the study due to deficiencies of the data.

2.2 The extended model

After the before mentioned study our conceptual model for analysis has been constantly developing. The concepts concerning contextual and dynamical aspects of decision making have been elaborated further. Moreover, the historical aspect of decision making has been considered.
The concepts of operative and social context have developed. As to the operative context, it has been widened. According to our current view, in addition to understanding of process dynamics also comprehension of action of technical systems and components with respect to process is essential in disturbance handling. Therefore it is not sufficient to analyse utilization of only on-line process information and procedures. Information sources are also considered more comprehensively, by taking into account also information in the form of administrative directions and technical plant documents. This information concerns aspects like safety restrictions, technical and economical constraints etc. that the operators should take into account in their diagnostic and operative decision making. These aspects affect usability of different operative methods in process control. Considering of this other type of information makes necessary to define respectively it’s informativeness with respect.

Consideration of social context of operators’ decision making has been widened from a crew to other individuals and groups in the work organization. Decision making will be comprehended, on a more global level, as network of interactions between control room, maintenance, management etc. Requirements and decisions on other organizational levels create constraints for the crew’s control room activities.

Evaluation of orientation has been under elaboration, too. On the basis of the results of the before mentioned study it was supposed that there are two different aspects of orientation controlling construction of decision making. They are tendencies to coherence and reflectivity. By coherence we mean coherence of comprehension of the object of decision making activity which in the case of process control is the plant process. Reflectivity is defined as taking into account the context of activity. In the current phase of our approach evaluations of these (and possibly other) aspects of orientation are made in two independent ways, by evaluating operators’ activity in decision
making and by evaluating, through interviews, their comprehensions of their activity.

These tendencies are supposed to manifest themselves in operators' action strategies in their decision making. Analysis of these strategies can be made with respect to different types of utilization of resources of decision making. These resources are information sources and collaborative resources.

In the case of the information sources evaluation is based on operators' action strategies in setting their operative goals. The aim is to consider two dimensions of these strategies, constructiveness and situativity. Utilization of information is constructive if activity is directed towards making coherent conception of the state of the plant process on the basis of process dynamically informative high level indicators, i.e. with respect to mass and energy balance. Utilization of information is situative if e.g. diagnostic counter evidence and if usability aspects (e.g. technical or economical constraints) are taken into account in their choice of alternative operative methods.

In the case of collaborative resources tendency to coherence is evaluated as tendency to a common interpretation in construction of decision making and reflectivity as tendency to utilize situatively communicative and participational abilities of one's own and of the other members of the crew.

Taking the historical aspect into analysis of decision making combines the contextual and dynamic aspects of our approach. Decision making is viewed as dynamic construction also on more global level, with respect to orientational changes of operators', training department and other levels of the work organization.

On the basis of this elaborated version of our conceptual model we have
developed an analysis method. The method which will be introduced in the next chapter has been developing during its preliminary use. Some aspects with respect to this development will be discussed in chapter 4.

3 AN ANALYSIS METHOD FOR DECISION MAKING

The analysis method makes possible to test our theoretical concepts in concrete disturbance situations during simulator training. The aim of the analysis is to have support to our concept of orientation as controller of construction of activity in decision making.

The method offers a tool for systematical conceptualization of crews' task performance as collective construction of diagnostic and operative interpretations on the basis of available information in this specific situation. The crews' task is to stabilize the disturbed plant process during the simulator run.

The method consists of two main parts. The first is creation of operative reference for analysis of decision making and the second is analysis of decision making with respect to this reference.

3.1 Creation of operative reference

In this preparatory phase the operative context of operators' decision making will be conceptualized. An essential feature of the method is that operative reference will be constructed for a specific disturbance situation. Therefore, when applied to a new disturbance situation a new reference must be made.

Creation of reference includes two phases. The first is design and conceptu-
alization of the disturbance situation on a general level and the second is creation of operative criteria for decision making. It is necessary to carry out these phases in collaboration with trainers and other nuclear power plant experts.

3.1.1 Design and conceptualization of the disturbance situation

In the design of the disturbance situation some aspects in addition to normal educational demands should be taken into account. In order to make the degree of operators' professional competence visible disturbedness of the plant process should be serious enough and adequate decision making should require operative choices.

An example of conceptualization of a disturbance situation from the decision making point of view is depicted as a flow model in figure 1. The course of decision making is roughly as follows. In the beginning of the simulator run the trainer gives the crew the necessary information concerning the baseline state of the plant. The disturbance situation begins when the first plant alarms indicate of some kind of a disturbance. The crew makes a diagnosis on the basis of available information. This information includes, on one hand, on-line process information an, on the other, documents like procedures, administrative directions and technical restrictions. On the basis of their diagnosis operators set operative goals in order to stabilize the plant process. These goals can be reached by alternative operative methods. If no method has been chosen the automatic plant protection systems will be activated during a predefined time. The amount of operative goals and therefore of operative choices depends on the situation. A new goal is again based on utilization of current available information.
Figure 1. Decision making in a disturbance situation.
It is important to note that this kind of conceptualization of a disturbance situation is an oversimplification because in reality a diagnosis can change and there can be parallel diagnoses and operative goals.

The general flow model will be used as a conceptual tool for evaluation of crews’ task performance.

3.1.2 Creation of reference tables

Two reference tables are created and used as operative criteria of decision making.

The first one is conceptualization of the disturbance situation from the safety point of view. The situation is conceptualized with respect to the physical state of the plant process according to the concept of critical safety functions. The table is a description of those critical safety functions which will be threatened during the situation and of adequate maintenance of them. It includes those critical symptoms on the basis of which the threatened critical safety functions can be recognized. These symptoms are high level indicators of the functional state of the process. They can be process parameters or indicators of (in)activation of technical systems. Stabilization of the process means maintenance of the threatened critical functions. Maintenance of a critical function can be considered as a high level goal. In the table the adequate operative methods for reaching each goal are presented. These goals and methods are respective to the ones in the flow model in figure 1.

Because the disturbance situation can be handled in different operative way the second table is designed for comparison of alternative operative methods from the usability point of view. This table includes all alternative
operative methods. The comparison will be made with respect to different aspects of usability. From the safety point of view the methods can differ by e.g. their capacity with respect to the critical functions to be maintained and possible risks. Other aspects affect the mutual priority of the alternatives, too. These can be general constraints like economical aspects and technical constraints (complexity of use, dependences on other systems or components etc.). They can also be constraints set by the specific situation, e.g. availability of technical components and systems.

The two reference tables are used as conceptual tools in evaluation of crews' task performance.

3.2 Analysis of crews' decision making

In this phase operators' strategies in decision making are evaluated in order to find out their orientational tendencies. Inferences are made on the basis of their comprehensions of decision making in process control and their strategies in utilization of informational and collaborative resources of decision making.

The method offers different mutually supportive means for clarification of the role of orientation in operators' decision making. One way is evaluation with help of interviews, on the basis of operators' verbalized comprehensions concerning process control. Another is evaluation on the basis of differences in their utilization of resources of decision making. This type of evaluation is made during the simulator run and after it, during a debriefing session. It is necessary to make it in collaboration with a trainer.
3.2.1 Operators' comprehensions of activity

The developed interview is diagnostic with respect to supposed manifestations of types of orientation. It is composed of questions concerning operators' comprehensions of the object of their work (the plant process), of process control activity in general and of their own ways of action. These themes include questions of the plant process as a technical system and as an object of decision making, of available resources of decision making, of professional requirements etc.

Evaluations of operators' comprehensions are made by categorization of them with respect to coherence and reflectivity tendencies and to operative reference tables and by comparing these evaluations with each other.

The operators are interviewed one at a time. The interviews are made before observation of the task performance because they enable getting acquainted with the operators and facilitate the observation. During observation they make possible to understand better the operators' ways of action and to make comparisons between the verbalized comprehensions and the real process control activities in a (simulated) disturbance situation.

3.2.2 Operators' action strategies during decision making

The object of observation is operators' decision making as construction of interpretation of the disturbance situation and at the same time, as collective construction of common interpretation. Use of different information sources and collaborative resources are in construction of diagnostic hypotheses and operative goals and in choice of operative methods are observed.
Besides during the simulator run observation can be made also afterwards, on the basis of registrations of the operators' activities and of the physical state of the plant process. These include on-line registrations of operators' verbalizations and movements (in form of video tapes) and operative activities, plant alarms and other indicators of the process state (in form of computer registrations).

Evaluation of decision making is made preliminarily during the simulator run and it is possible to deepen it during a de-briefing session which is carried out collectively with operators. The session is arranged as immediately after the simulator run as possible in order to make sure that they remember details of their decision making. Operators explain their motives and arguments for their diagnostic and operative inferences. The general flow model and the two reference tables are used as conceptual tools. The operators consider their decision making as a route composed of diagnostic phases and setting of operative goals. Their choices of operative methods are considered as alternatives among other possibilities. Handling of these alternatives with respect to safety and other boundary constraints of process control possibly deepen evaluation of their orientation.

Evaluation of utilization of resources of decision making is made with respect to evaluation of adequacy of their process control activities.

Adequacy of disturbance handling, i.e. adequacy of operators' diagnostic and operative inferences is made on the basis of the operative reference tables. Operative goals and diagnostic interpretations as the basis of these goals are considered with respect to reference table 1 from the mass and energy balance point of view.

The crew's choices of operative methods are evaluated with respect to reference table 2 from the view point of consideration of usability aspects.
Chosen methods are marked on the general flow model as a route of decisions.

Utilization of information resources is evaluated with respect to the same operative reference tables. Constructiveness of operators' strategy is inferred by utilization of process dynamically informative informativeness for making coherent conception of the state of the plant process. Situativity of strategy is inferred by consideration of diagnostic counter evidence and usability aspects of alternative operative methods. Inferences from aspects of operators' orientation in decision making are made on grounds of these evaluations.

In evaluation of utilization of collaborative resources operators' tendency to coherence is inferred by considering how individual members of the crew contribute to construction of a common interpretation of the situation. Their tendency to reflectivity is evaluated by analysing how situatively they utilize their own and others' communicational and participational possibilities in use of common information resources.

By comparing different ways of analysis it is possible to clarify the role of orientation as controller of construction of activity in decision making. Investigation of operators' strategies in utilization of information increases knowledge of qualitative differences in operators' disturbance handling. It also enables consideration of possible relationships between these differences and deficiencies in disturbance handling.

4 DISCUSSION

The analysis method described in this paper offers a conceptual tool for systematical evaluation of nuclear power plant operators' decision making
in simulated disturbance situations.

The expected strength of the method lies in its contextual and developmental nature. It makes possible to design a disturbance situation according to educational needs and to evaluate decision making with respect to its operative context. In addition to this, it enables consideration of decision making as collective construction of interpretations controlled by orientation.

The method is aimed to be used in simulator training in nuclear power plants. Collective creation of the operative reference tables during a debriefing session is expected to enhance feedback to the trainees. Due to conceptualization of the disturbance situation with help of operative reference they become more conscious of their strategies in decision making and in cooperation.

Feedback to trainers is expected to increase, too. They become more conscious of their criteria and strategies in their training activity and this will be reflected later in the quality of training.

Along to the development of simulator training, due to the accumulation and distribution of knowledge of decision making considered with respect to its boundary constraints, the operational culture is supposed to develop.

Accumulation of knowledge of qualitative differences in operators' decision making and also comprehension of importance of orientation in decision making will become more clear. Orientation expectedly influences learning. Tendency to coherence and reflectivity towards own and others' activity enhances professional competence. Learning can be improved also by deliberately developing operators' orientation during simulator training.

Next some aspects concerning the development of our analysis method
during it's preliminary use. It, too, seems to reflect our concept of contextual and developing nature of activity. The conceptual integration of the method increased all the time through mutual interaction between it's submethods and phases.

E.g. the interview became more concentrated and the importance of the de-briefing increased. Creation of the operative reference became more elaborated and the structure of the de-briefing session better organized by mutual interaction between the developers of the method (researchers, trainees, trainers and other experts). These experiences will be utilized in our future studies.

Analysis of the preliminary use of our method is under investigation. The method will be applied to other process control areas, too. The operative context will be extended to comprise not only decision making in disturbance situations but also normal routine work in process control. According to our current expectations, differences in operators' orientation are reflected in their action strategies during normal work.

5 REFERENCES


CONTEXTUAL ANALYSIS OF THE OPERATORS' ON-LINE INTERPRETATIONS OF PROCESS DYNAMICS

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Abstract

The aim of the study was to identify qualitatively different modes of interpretation of process situation based on an analysis of the operators' ways of utilizing available information and cooperative resources of activity. The study was carried out in a nuclear power plant full-scope training simulator and an analysis method was developed during the study. The experiments comprised of 11 crews' performance in a complicated disturbance situation. The research material included pre-interviews with the operators, detailed registrations of process data, observations and videotaped recordings of the operators' performance, and debriefing discussions with each crew.

As a result of the analysis of the operators' task performance structured descriptions of each crews' conceptions of the disturbance and choice of operative methods were prepared. Based on these, behavioral anchors were defined for ratings regarding the modes of the crews' interpretations. The dimensions of evaluation were derived assuming that the dynamics of construction of an interpretation of the situation is related to typical features of a person's relationship with the environment, tendency to coherent explanation and account for the specificity of the situation. As a result of the analysis three different modes of interpretation of process situation were identified, constructive, schematic and implicit modes. These modes could be distinguished from each other regarding the use of information and cooperative resources, criteria being attention to process situation, basis of interpretation and explication of interpretation. Analysis of the relationship of these modes with the operators' conceptions of the plant process is currently going on in order to make inferences concerning the crews' orientations.

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1 This study has been carried out in collaboration with the Toellisuvuden Voima Oltkluoto Nuclear Power Plant. The chief simulator trainer Markku Malinen and his colleagues have in essential way contributed to the study through providing process technical experience in all phases of the study.
1. INTRODUCTION

The essential task of the operating personnel of complex highly automated systems is to cope with the more or less unpredictable problems and failures of the system. In order to be able to interfere with the process the operators must be able to interpret the process information on the basis of their previous experience and knowledge. In our research we have investigated how the operators of nuclear power plants and other complex environments construct their on-line interpretations of the process situation and make decisions for action.

This problem has made us conscious of the restrictions of the traditional approaches of cognitive psychology in understanding the essential nature of practical activity. According to Suchman (1987) the well established planning metaphor of activity assumes that human actions are governed by plans because they retrospectively can be described as following such. In essence, however, activity is embedded in its practical and social context, plans being resources of the situative construction of the course of actions (Suchman 1987, Collins 1990, Hollnagel 1993).

The interaction with the operators has, furthermore, taught us that determination of regularities between abstracted variables of behaviour, which is the typical research paradigm in psychology, produces only a general explanation of the actor's decision-making. The fact that such explanations are often experienced inadequate and strange by the subjects themselves has been interpreted by us to reflect an implicite critique of the used research paradigm. We see that for understanding the operators' behaviour in a situation it would be necessary to find out the significance of the constraints of the situation to the subject, and take this as a starting point for the analysis (Harre & Gillet 1994, Eskola 1993). We have used the subject's orientation towards the object of activity (Norros 1995) as a means to define the logic according to which the situative constraints are taken into account by the actor in a situation demanding action.

In our previous study (Hukki & Norros 1993) differences between NPP operator crews could be found in the utilization of process information. The use of the so-called process dynamically informative information that reflects effectively the essential functions of the process, was interpreted to indicate a functional orientation. Whereas the lack of utilization of process dynamically informative information was thought to reflect non-functional orientation. Those crews with functional orientation seemed to be more efficient in their diagnostic activity.
In the present study the results regarding the utilization of informativeness were taken into account in the development of the analysis method (Hukki & Norros 1994). Being convinced of the necessity to create a contextual methodology for analysis of decision-making much effort was devoted to the description of the context which provides the situation for the actors. In our method the context is defined through certain reference models (see below).

The focus in the study was the dynamics of construction of interpretation of a disturbance situation, a phenomenon which has recently been approached also in studies of “situation awareness.” Our theoretical assumption was that differences in the crews’ orientations become manifest in action as differences in modes of utilization of resources. The aim was, then, to identify qualitative differences in the operators’ modes of using available information and, as a new aspect, utilization of cooperative resources of activity. The relevance of the latter, collective aspect, for the construction of interpretations has recently been widely acknowledged. The formulations of such authors as Hutchins (1990), Engeström (1990) and Lave & Wenger (1991) regarding the nature and role of cooperative activity have contributed to our methodical decisions regarding cooperation.

The dimensions of evaluation of the mode of decision making were derived on the basis of own earlier results of NPP operators’ disturbance handling (Hukki & Norros 1993) and on the basis of a parallel study on anaesthetists’ expertise (Klemola & Norros 1995). They also find support from recent theoretical considerations regarding a subject’s formation of functional relationships with environment (Harré & Gillet 1994, Järvelä 1994). Based on these sources we assumed that construction of an adequate and adaptive interpretation of the situation would require two kinds of relations between the subject and environment, the tendency to coherent explanation of the situation referring to the necessity to conceptualize the environment in general terms, and the tendency to take account of the specificity of the situation. We expected that these tendencies would become manifest through differences in the operators’ utilization of process information and cooperative resources, and that their role in the construction of interpretations of the situation would signify differences in the operators’ orientations.

2. METHODS

2.1 DESIGN OF THE EXPERIMENT AND THE MATERIAL

The study was carried out at the TVO Nuclear Power Plant. It comprised of simulator experiments, including pre-experiments, and it was implemented as
a part of a yearly simulator refresher training. All crews of the plant participated in the study, and 11 crews, each including 4 operators (chief supervisor, and reactor, turbine and field operator) performed the experimental run, which was the same for each one. The experimental session lasted half a day, including three phases (see Hukki & Norros 1994 for details):

Orientation interview. Before the experimental run each member of the crew was interviewed concerning his conceptions of the plant process, process control activity in general and his own ways of action. The interview was tape-recorded. This data is under analysis and not included in this paper.

Task performance in the simulator. The crew was given a short introduction of the plant's current state and the operators were instructed to run the process as they normally do in simulator training sessions. The task performance lasted 1-2 hours. During the run following data was registered:

- simulator logs of process events
- simulator logs of operations carried out by the operators
- videotaped performance including operators' communications (later transformed into written protocols)
- expert observations of the crew's disturbance handling during the run (with the help of prepared note sheets)

Debriefing. After the run the operators had a chance to comment on their performance and give arguments concerning their decisions. A flow-model of the disturbance was used to guide the discussion which was also tape-recorded.

The task of the crew was to identify the state of the process after an evident process disturbance - loss of feed water and the reactor level with the possible consequence of overheating the reactor - the origin of which was not clear. Simultaneously, the operators were required to choose methods to stabilize the process and prepare it for maintenance.

In the design of the disturbance situation two requirements were considered important. First, identification of the state of the process should not be trivial. In this case the symptoms of the actual disturbance could easily be mixed up with those of some other problems. Therefore, an adequate diagnosis dealt with identification of the process dynamic nature of the instability of the process, but it was not necessary to specify the initiating event. According to the second requirement there should be several alternative methods to manage the situation. Consequently, the crews would have the possibility to choose operative methods according to their preferences.
2.2 ANALYSIS OF THE MATERIAL

The material used for the analysis of operators' on-line interpretations of process dynamics was gathered during the performance and the debriefing session. In the analysis we used our own method (Hukki & Norros 1993, Hukki & Norros 1994). The method consists of two main parts, the creation of operational reference for analysis of decision making, and the analysis of decision making with respect to this model.

(a) Creation of operational reference

By operational reference we mean description of the disturbance situation from the operators' decision-making point of view. It comprises of aspects that can be inferred to be relevant for the successful performance in a particular situation. The reference will have to be constructed for each specific disturbance situation to serve its function to contextualize the analysis of decision making. Close cooperation with domain experts is necessary for the definition of the references.

Two types of reference were created, a general flow-model of the disturbance situation and detailed reference tables. The flow-model (see Hukki and Norros 1994) included the main phases of the decision-making, diagnosis, goal setting and choice of operative methods. Also failures or unavailabilities of subsystems which were designed in the disturbance in order to increase its complexity were indicated in the model. The model was not a description of the sequence of expected actions, instead it defined the known action possibilities in the situation. During debriefing discussions with the crews more possibilities were found.

In addition to the flow-model, reference tables were constructed: a diagnostic reference table defined critical diagnostic symptoms of the disturbance and their interactions, and an operational reference table identified the feasibility of each operational method from the point of view of general boundary conditions of the situation. These conditions included process dynamic safety constraints, technical constraints (e.g. safety-technical prescriptions, complexity of use, interaction with other systems, technical wearing of the systems) or general economic constraints (e.g. expected length of shut-down may depend on the choice of methods in the stabilization of the process). Also specific constraints of the situation, such as availability of technical components and systems were defined.
(b) Analysis of decision-making

The operators' on-line decision-making was then analyzed with the help of the above described reference models. The sources of data were the pre-interviews and the performance data. This paper includes only the results of the latter.

In the analysis of the performance data there were three phases which represent different levels of analysis.

*Description of task performance.* The aim was to describe, with the help of the reference models, the diagnostic and operational actions of the crews. A well structured description was then written of each crew's process control performance.

*Analysis of the modes of utilization of resources.* In this phase the aim was to describe operators' decision making based on analysis of the operators' ways of using available information and cooperative resources of activity. In the evaluation the point of view of the chief supervisor was selected because he leads and coordinates the crew's activity. The activity of other crew members was thus viewed from a more restricted perspective, as a resource of the chief supervisor. If necessary, the method allows analysis from other crew members' points of view, too.

The main objects of evaluation were two, the chief supervisor's mode of interpretation of the situation and mode of cooperation. These objects of evaluation are indicted in the table 1. They were evaluated in regard with two theoretically defined criteria, intensity of tendency to coherent explanation of the situation (active/intermediate/passive) and intensity of taking account of the specific features of the situation (active/intermediate/passive) (table 1). Taking the point of view of utilization of resources several subitems of evaluation were then defined through applying these criteria to the objects of evaluation. Operational criteria for them were created with the help of the reference models, and the descriptions of the performance served as behavioral evidence for the ratings. As a summary of the ratings, a final verbal evaluation of each crew's decision-making was formulated.

*Determination of modes of decision-making.* In the final phase of our analysis a summary of the crews' decision-making was prepared through identifying the relationships between the utilization of information and cooperation as expressions of the assumed subject-environment relationship. The aim was to see whether patterns of relations regarding the role of utilization of resources could be found within the crews.
Objects of evaluation

* Mode of interpretation of the situation
  - explaining the nature of disturbance
  - evaluation and choice of the optional operational methods

* Mode of cooperation
  - coordination of cooperation within the crew
  - communication

Criteria of evaluation

* Intensity of the tendency to coherent explanation of the situation (active/intermediate/passive)

* Intensity of taking account of the specific features of the situation (active/intermediate/passive)

Table 1: Objects and criteria of evaluation of the utilization of resources.

3. RESULTS

The results of the ratings and the final verbal evaluations written on the basis of them, gave, of course, a most comprehensive and concrete picture of each crew’s specific mode of decision-making. These results were presented to the operators themselves, instructors and operative management of the plant. In order, however, to identify common modes of interpretation among the crews a summary of the results became necessary. The result can be seen in the tables 2, 3 and 4.

Table 2 indicates the different crews’ positions regarding the intensity of utilization of available information of the process. The first item of evaluation, attention to process situation, represent the theoretical evaluation criterion “account of the specificity of the situation”. The crews were classified with the help of an active-passive dichotomy. The second item of evaluation in the table 2 is explicit formulation of process dynamic explanations in regard with diagnostic and operative tasks. This item expresses the other theoretical evaluation criterion, “tendency to coherent explanation of the situation”. Again active-passive dichotomy indicates the intensity of the crew’s expression in regard with the evaluation item.
<table>
<thead>
<tr>
<th>Item of evaluation</th>
<th>Intensity expressed by each crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization of process information:</td>
<td>active</td>
</tr>
<tr>
<td>Attention to process situation</td>
<td>passive</td>
</tr>
<tr>
<td>- attention to alarm printer and panels</td>
<td>A B C D E G I K L</td>
</tr>
<tr>
<td>- account of critical safety restrictions of operational methods</td>
<td>A B C I L H</td>
</tr>
<tr>
<td>- anticipation of possible changes</td>
<td>A B C D E I K L</td>
</tr>
<tr>
<td>Process dynamic explanation of the disturbance</td>
<td>H F</td>
</tr>
<tr>
<td>- diagnostic</td>
<td>D F G H K L</td>
</tr>
<tr>
<td>- operative</td>
<td>C C B F E G H K L</td>
</tr>
</tbody>
</table>

Table 2. The crews’ utilization of process information. The letters indicate different crews.

A summary of the crews’ utilization of process information and cooperative resources are indicated in the table 3. It was reasonable to form an intermediate category in summarizing the results regarding the utilization of information. As can be seen from the table the intensity of attention to available information may combine in different ways with explicit process dynamic explanations of the situation. Active attention to information tends to combine with aptitude to make explicit process dynamic explanations (groups CABI) but there is also the crew L which is actively utilizing information without any explicit process dynamic explanations of the situation. Within those crews classified deficient or passive in utilization of information the explicit explanation is perhaps less typical. However, crews E and F gave diagnostic explanations, the crew F even very firmly. This crew’s explanation was however false for a long time. Also crew C within the active utilizes of information formulated first a deficient diagnostic explanation.

Further down in the table 3 we see the crews’ utilization of cooperative resources. Again, there are two items of evaluation, attention to cooperative situation and coordination and distribution of information. (There were
subdimensions also regarding this item. As their internal consistencies were very high, the summary of the evaluations in the table 3 represent well each crews' level of utilization of cooperative resources.)

In addition to dominantly active utilization of process information the crews ABCI also actively utilize available communicative resources in respect to both evaluation items. Characteristic to these crews was a certain cautiousness. While the crew C made checkings regarding own explanations and the situation, more typical to the other three crews was a slight hesitation. The chief supervisor of the crew I was clearly conscious of his insufficient knowledge of certain constraints, and he requested for help in his choice of operative methods.

<table>
<thead>
<tr>
<th>Item of evaluation</th>
<th>Intensity expressed by each crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization of process information</td>
<td>active</td>
</tr>
<tr>
<td>Attention to process situation</td>
<td>ABCI L</td>
</tr>
<tr>
<td>Process dynamic explanations of the disturbance</td>
<td>C</td>
</tr>
<tr>
<td>Utilization of cooperative resources</td>
<td>active</td>
</tr>
<tr>
<td>Attention to cooperative situation</td>
<td>ABCI EDKL</td>
</tr>
<tr>
<td>Coordination and distribution of information</td>
<td>ABCI EDKF</td>
</tr>
</tbody>
</table>

Table 3. Evaluation of the crews’ mode of decision making: Relationship between utilization of information and cooperative resources. The letters indicate different crews.

Also the crews EDK seem to be actively making use of cooperative resources, even though these crews were dominantly passive in their overall utilization of process information. The crews GH who were dominantly
passive in using process information are clearly not utilizing cooperative resources neither.

The two crews F and L deviate from the above patterns. While being active regarding the process and cooperative situation the crew L is typically not constructing explicit explanations. Therefore, in its decision-making this crew seems to approach the pattern found by the crews GH. The crew L can be interpreted to even highlight the typical nature of these crews’ implicit mode of action.

The characteristic that was dominant for the crew F is deficient attention to situational information. This crew’s supervisor relied very much on his preconception of the situation. The crew F joins the crews EDK, who were well coordinated and communicating, seemed to make use of predefined plans but were less active utilizers of situative information. An additional feature of these crews was a certain overconfidence with the chosen methods (DF) or straightforward exclusion of other possibilities (E).

As indicated in the table 3, the crews can seem to form three different groups. On the basis of the previous analysis three criteria of utilization of resources emerge that seem to be informative for distinguishing these groups: attention to process situation, basis of interpretation of the situation and explication of interpretation, the last criterion referring to an essential function of cooperation. Table 4 summarizes the results through defining the three groups of crews with the help of these criteria of utilization of resources of decision-making.

<table>
<thead>
<tr>
<th>Utilization of resources</th>
<th>Crews</th>
<th>EDK</th>
<th>LGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention to process situation</td>
<td>+</td>
<td>0/-</td>
<td>+ 0</td>
</tr>
<tr>
<td>Basis of interpretation of the situation</td>
<td>process dynamics</td>
<td>predefined schemes</td>
<td>?</td>
</tr>
<tr>
<td>Explication of interpretation</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Mode of interpretation</td>
<td>constructive schematic implicit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Identification of the crews’ different modes of interpretation of process situation on the basis of defined criteria of the utilization of resources of decision-making.
4. DISCUSSION

The attempt in the study was to reveal differences among the NPP crews' regarding their modes of making on-line interpretations of difficult disturbance situations. The main objects of evaluation were the mode of interpretation of the situation and cooperation. The assumption was that differences in the crews' orientations become manifest in action as differences in the crews' ways of utilizing information and cooperative resources, within which we expected to reveal variations in expressionss of two basic subject-environment relationship, the tendency to coherent explanation of the situation and taking account of the specificity of the situation.

On the basis of our earlier results (Hukki & Norros 1993) we had reasons to expect that coherency of interpretation of the situation could be achieved through comprehension of process dynamically critical aspects of the disturbance situation. This in view we defined evaluation items and performance criteria through which this tendency could be identifiable. The results indicate that formulation of process dynamical explanations is typical to certain crews and it is combined with an active account of the situational information. A process dynamically based interpretation of the specific situation can thus be reached. Typical to crews manifesting this mode was that the bases of interpretations were explicated and effectively distributed among the crew through communication. This mode of interpretation was named constructive mode of interpretation. In the case of one crew adoption of this mode probably contributed to the rejection of a first false explanation of the situation and creation of an adequate one. This indicates of evident strength of this mode.

The results reveal, however, that the constructive mode is not the only possibility to create coherent interpretations of the situation. There were crews who were less attentive to the situation specific information but who created effectively interpretations about the situation with the help of previously formed own conceptions or procedures. This mode of interpretation was named schematic mode of interpretation. Effective utilization of cooperation as expressed in explicating of interpretations was an important resource in this mode. Earlier experiences and knowledge can be mediated through cooperation which is integrated with the help of procedures. When the explanation of the situation is adequate, activity is fluent and efficient as most of the crews in this group could verify. The possible restriction of this mode of interpretation may be expected to lie in the less sufficient utilization of information for the identification of the specificities of the situation. This may become a problem in non-standard situations or if the explanation is inadequate for some other reasons. Indeed, one of the crews of
this group who was clearly non-sensitive to process situation had difficulties to reject a false explanation until rather late.

Even a third mode of interpretation could be identified. Typical to this mode was that, in particularly, the explanations of the situation were not easily identifiable through the crews' actions or verbalizations. As we based our analysis on such expressions this mode in a sense reflects the specific features of our research methodology. While we, by no means, claim that these crews did not construct interpretations of the situation, it is plausible to say that they did not distribute interpretations in explicite ways among the crew. It can be interpreted as deficiency in the utilization of available cooperative resources, and it may evidently be the major source of vulnerability of this mode of decision making. The implicit mode of interpretation may result in an incoherency of the crews actions and possible misinterpretations of individual member's attempts. Signs of such defects could be identified in the activity of one of our crews, whose performance seemed scattered, and the crew succeeded mainly thanks to the efficiency of an individual operator's operative actions.

Our results seem to indicate that it is possible to describe the dynamic construction of situatively adequate and adaptive activity through the proposed criteria, the tendency to coherent explanation of the situation and account for the specificity of the situation. The modes of interpretation could be distinguished even in regard with the role of these two tendencies. As they were identified in respect to utilization of resources of decision-making, three concrete criteria for identification of modes of interpretation could be formulated: attention to process situation, basis of interpretation and explication of interpretation. Deficiency of utilization of one or the other basic resources, process information or cooperation, seemed to increase aptitude towards a particular mode of decision-making - deficient attention to process situation towards schematic interpretation, deficient use of cooperative resources, i.e. lack of explicit explanations, towards the implicit construction of interpretation. Efficient utilization of both types of resources was characteristic to the constructive mode of interpretation.

Based on the analysis of the different dynamics of constructing interpretations evidence of some of the strengths and weaknesses of each mode was also achieved. Due to the aims of the study no direct evaluations of the adequacy of the crews' performance or the efficiency of the different modes were carried out. It will be an interesting future research problem to try to find a relevant way to acquire such evaluations. Our hypotheses is that clear differences in the efficiency of the modes manifest themselves only in extreme situations, the strengths and weaknesses of the modes being qualitative signs of efficiency in less critical or routine situations.
The results of the study suggest the possibility to teach the crews efficient utilization of resources. However, according to Leontyev (1981) a direct mediation of good practices easily lead to an inflexible activity. Development of orientations may be seen relevant in the creation of adaptive practices. The operators' personal conceptions of the process, their conceptual orientations, should be developed in such a way that conceiving the nature of the process and the constraints regarding the operational methods become personally significant prerequisites for expanding the possibilities of interaction with the process. The results suggest that the crews manifesting the constructive mode of interpretation would have adopted this kind of orientation. Moreover, adaptivity also requires adequate conception of own activity in relation to its object. Relevant in this respect was the tentative result of our analysis, which indicated that cautiousness or overconfidence, clear expressions of operators' conceptions of their own performance in relation to the process, characterized the constructive and schematic modes, respectively. A further analysis of the operators' orientations is in progress.

Based on the described evaluation method we are currently developing a tool to be used in normal simulator training. The work is carried out in cooperation with the instructors of the power plant. The experiences have been promising thusfar. It seems that this kind of a contextual analysis of the crews' activities may create insights within the operators regarding their own decision-making, and increase interest among the crews to reconsider current orientations for opening new possibilities of action.

5. REFERENCES


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A contextual approach to systems safety —
analysis of decision making in an accident
situation

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1 Introduction

Operators controlling hazardous processes work in a dynamic environment
requiring decision making based on interpretation of the situation. Their ability to
manage the situations depends on the state of the process and on the available
resources to handle it, e.g. process information, procedures, co-operative
resources. In brief, the operators’ behaviour is sensitive to the decision making
context. In safety analysis, the contextual nature of activity has been reduced to
assessment of situation specific performance shaping factors.

This paper discusses integration of two complementary approaches for analysing
operators’ decision making and human reliability in accident sequences: (1)
probabilistic modelling, and (2) contextual psychology¹. A probabilistic model
represents decision making as a part in the event sequence depending causally on
the situational factors. The uncertainties in the evolution of the events are expressed
by probabilities. Contextual psychology analyses decision making with respect to its
context, the actual state of the process to be controlled.

The uniting aspect in our collaboration has been decision analytic thinking which
has made possible to find common tools for description of the context. An enhanced
conceptualization of the context, in the future perhaps categorization of situations,
provides possibilities to develop the psychological analysis of decision making.
Results of this analysis contribute to better consideration of human activity in the
stochastic modelling. The current stage of our analysis can be seen as a promising
intermediate phase in the integration of the two approaches. In the continuation,
it is important to carry out the integration in a way that considers decisions as
intentional actions influencing risk, not as components of the risk assessment of the
situation. Such an approach would make visible how operators’ different ways of
decision making contribute to safety.

¹ Integrated analysis methodology is developed on two projects belonging to the Finnish nuclear research
framework programme Reactor Safety (RETU) funded by the Ministry of Trade and Industry. The work is closely
connected to the safety Nordic programme NKS - RAK-I.

Paper presented at EREL ’96 - RSAM III,
Probabilistic Safety Assessment and Management '96,
2 Methodological background

In reliability models, although they may provide feasible human error probability estimates, human activity has mainly been seen as simple basic events. Because operators are not explicitly considered as decision makers many possibilities to identify and improve their prerequisites to make proper decisions in accident situations are excluded. The decision analytic view considers the decision makers as intentional subjects and, therefore, takes their goals into account in the analysis.

The prevailing approach in conventional human factors research has been error analysis which aims to find out how different intrinsic and situational factors contribute to operators' decision making. The interest has been in revealing law-like dependencies between separate factors and performance. The models used in these analyses are causal descriptions of particular cases, not models of the system functionality [1]. Therefore, they do not provide efficient tools for the control of risk. In our analysis we describe the system functionalities and the possibilities and restrictions set by the situation. The objective is to comprehend how the operators contribute to risk by taking into account the boundary conditions in their decision making [2].

We believe that integration of the decision analytic view in PSA and the contextual view in human factors psychology creates possibilities to enhance safety in process control work. This kind of integration leads necessarily to change of the goals of the prevailing human reliability analysis. By now the aim of the analysis has been to produce numerical results which have been used e.g. in the comparison of the reliability of human actions with that of automation. When the objective is to enhance safety of process control it would be more fruitful to consider human errors as consequences of active decision making and, thus, develop human activity on the basis of comprehension of the prerequisites and dynamics of the process control activity.

A new paradigm of human reliability analysis is needed in combination of the different disciplines. With a formal description of the decision making context as a common starting point, our approaches offer an opportunity to combine the operators' and analysts' views. On the basis of the integrated decision analytic view, the operators' decisions in certain context are seen as rational choices between actions aiming to context dependent objectives. Further, it is possible to analyse these decisions taking into account that the operators have different ways to utilize the critical information from the system to be controlled. This leads to a perspective which is more systemic and realistic than that of the conventional approaches.
3 The analysis process

The outline of the integrated analysis process is threefold. First, the decision context is identified and described by creating descriptions of the investigated situation. Secondly, the accident situation is modelled from the risk and reliability point of view using the descriptions as reference. Thirdly, the operators’ decision making is analysed with respect to the reference models.

First a common conceptualization of the situation is carried out in a systematic way. It provides a basis for both reliability and psychological analyses. The decision making context is described on the basis of the identification of the critical functionalities of the physical process. As the reference models are situation specific, they take into account all the relevant boundary conditions and consequences of operators’ activities. These descriptions serve as reference in the psychological analysis of the operators’ activity and provide also tools for the reliability analysis.

The situation is described in a general way, from the point of view of the operators’ task performance. The main idea is not to describe the ideal solution of the task but represent the identified relevant possibilities of activity from the diagnostic and operational point of view. The system structure from the risk and reliability point of view and uncertainty are embedded in the descriptions which make visible the situation specific safety related, technical and economical boundary conditions. They also reflect the prevailing operational culture. These descriptions can be influence diagrams, matrices, inference diagrams etc.

In the next, a probabilistic analysis is carried out. Based on the reference models, the probabilistic analysis is completed by describing the stochastic dynamics of the sequence. Our modelling technique is based on a marked point process framework [3], in which not only stochastic events but also decisions are seen as marked points and the dynamics of the system is modelled by intensities depending on the history of the system, and decision making activity.

We also carry out a psychological analysis of the operators’ decision making in parallel with the probabilistic analysis. The operators’ decision making is evaluated with help of the reference models. The way in which they utilize available process information and co-operational possibilities manifests the coherency of their interpretation of the situation and their ability to take into account the situational demands.

Simulator runs provide useful information for both probabilistic and psychological analyses. This information is mainly qualitative, in the sense that it is not used directly to measure the operators behaviour but to identify the essential features of the crew’s behaviour and the process information, which the operators feel critical.
The question of data is important in modelling decision making and human reliability. In some cases, simulators have been applied in human error analyses, mainly to produce data for human error probability estimation. When a contextual view over human reliability is adopted, the role of simulators becomes different. Thus the observations from simulator experiments can be understood and analysed from a new perspective. Firstly, the simulator runs can be used to validate the description of the situation. Secondly, by observing the operator crew's behaviour during the run the analysts may obtain information on the way which the operators use the information from various sources (measurements, guides, etc.) and how the operators co-operate. Thirdly, operators' decision rationale may be identified by analysing the simulator run.

4 An example

We applied the cross-disciplinary approach to the analysis of operator actions in boiling water reactor (BWR) plant environment. In the beginning, the reactor is shut down for the refuelling outage, and the operators fill the reactor tank in order to open the pressure vessel lid. We consider the risk of causing a cold overpressurization of the vessel. It can be caused either by using high head auxiliary feed water pumps in the filling, and neglecting the observation of the level, or by a spurious start of a high head pump followed by no balancing operator action. Although there is, according to an earlier study [4], no significant increase in core damage risk due to overpressure, the event is interesting in two respects: the event takes place during an outage when circumstances differ significantly from those during the power operation, and the early observation of the related physical processes is not easy due to small amount of instrumentation.

To reach a common view over the scenario, comprehensive reference models were developed first. This required close co-operation between the analysts and the plant personnel. An influence diagram was drawn for each identified unwanted course of events. In addition to that, an operational decision option model was made to present generally the possible operator pump selections. Further, a description of the available relevant diagnostic information was made for psychological analysis of decision making.

On the basis of the reference models a simulator run was planned in co-operation with the plant personnel. It was carried out to check the validity of reference models, and to identify the behaviour of the crew during the accident scenario. During the test run, the operators' on-line process control activities and decision making were observed. The observations confirmed that the water level information is the most important measurement on the process state. To identify the crew's skill to use that information, a measurement error was included in the run. For similar reasons, a spurious start of an auxiliary feedwater pump was included into the scenario.
After the simulator run, the operators were interviewed in a debriefing session. The discussions during the interview concerned the operators' earlier experiences on the scenario, the phases of the realized simulator sequence, and the interpretation of the situation and decision rationale.

In the probabilistic analysis the influence diagram was translated into a dynamic marked point process model, and an expert judgement model was applied in evaluating certain parameters. The accident probability was calculated by Monte Carlo simulation. In this case, decisions on pumping methods are not so important events from safety point of view as the spurious start of an extra high head pump. The fractional contribution of this event is 90% of the accident probability, 8E-10 per shutdown.

Although, in the natural refuelling outage the studied situation includes several factors which make the decision context rather complex, the simulator run represented only the control of water level. Therefore the experiment did not provide enough material for the application of the psychological analysis. From the psychological point of view, the benefit of the case has been especially in the development of the description of the context. We are aiming to include more comprehensive cases in our future studies utilizing the integrated analysis framework.

5 Conclusions

The integration of two complementary disciplines, probability analysis and contextual psychology, as a new paradigm for human reliability analysis provides promising opportunities to comprehend human decision making at risky situations. On the basis of better descriptions of human activity, it is possible to identify the factors having impact on human reliability and thus profoundly enhance the safety critical decision making by influencing the prerequisites of process control activity.

The combination of the two approaches is based on common descriptions of the decision making context, i.e. the reference models. The truly integrating aspect of the analysis is the process beginning from descriptions of the situation and ending with the common formalization of the context. Decision analytic thinking forms the framework for developing the reference models, which represent the flow of decisions and random events and the boundary conditions and objectives of the decision making. In this way the intentional aspect of decision making is reflected properly in reliability models.

For reliability engineering adoption of the decision analysis is relatively easy because it makes possible to formalize human activity in a comprehensive way. The contextual psychological models help validation of decision analytic and reliability
models because they make the operators' bases of inference more visible. They also help mediating the principles and results of human factors psychology into the realm of engineers. By taking the operators' view into account it is possible to achieve a deeper comprehension of the simulated situation which leads to possibility to use new types of evidence in determining human error probabilities.

For human factors psychology, analysis of decision making with respect to its formalized context opens up possibilities to assess the operators' way of action in different types of decision making situations. In the continuation, it is important to carry out the integration in a way that considers decisions as intentional actions influencing risk, not as components of the risk assessment of the situation. Such an approach would make visible how operators' different ways of decision making contribute to safety.

The integrated safety analysis approach was now applied to an accident scenario during refuelling outage. The scenario was analysed through a simulator experiment. As a formalized and comprehensive description of decision making the integrated approach gives possibilities to analyse and interpret the simulator experiments. There are not, however, any obstacles to apply it also to the analysis of other types of operational experience and to maintenance activities.

Acknowledgment

We acknowledge the contribution of Markku Malinen and TVO Olkiluoto power plant personnel.

References:


Modeling and Simulation of Operator Team Behavior in Nuclear Power Plants

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This paper depicts the technique of simulation for plant operators facing abnormal events within the plant. "SYBORG: Simulation System for the Behavior of an Operating Group" is installed in workstations, and simulates the behavior (cognitive action, communication) of a team consisting of 3 operators. This study introduces a "mental model" that describes and illustrates how operators predict plant behavior and make decisions to prevent the deterioration of its conditions. SYBORG simulates decision making processes via communication among operators, considering human relations such as: position, personality, credibility, etc. This paper also shows some interesting results of simulation with SYBORG.

1. Introduction

Safe operation of huge plants is very important for utilities, as they introduce a multi-layered safety system into plants. Well-experienced and well-trained operators also observe plant conditions through the control panels; however, we cannot neglect the possibility of abnormal events occurring in a well-refined system. An abnormal event expected to be easily handled in a small-scale system tends to be confusing for operators in a large-scale system, and thus possibly leading to severe accidents.

In order to develop an operator-friendly environment such as useful interfaces of operator support systems, it is important to know how operators recognize plant conditions, how they process plant information and how they decide on appropriate actions. It is also important to consider the effects of communication (i.e. human relations) among operators because huge and complex systems such as nuclear power plants are operated by teams consisting of several operators, except for one-man operated plants.

Consequently the authors proposed the concept of "SYBORG", which is an acronym for a Simulation System for the Behavior of an Operating Group [1]. It was developed based on cognitive science, group dynamics and also on interviews with nuclear power plant operators.
This SYBORG simulates the thinking processes of operators and decision making processes by a team coping with abnormal plant events.

2. Modeling of operator's behavior & Mental model
2.1 Operator model
Fig. 1 shows the information flow among "SYBORG"[2]. It accounts for 3 operators - one is the leader of the team and the others are followers (each has different role). Based on our assumption that the leader does not observe or touch the control panel, the leader model was designed to contain no action micro model. The leader model accumulates information of the plant via communication. The authors make clear the differences of roles between the leader model and the follower models.

Fig. 1 Information flow among SYBORG

Modeling of the operator focuses on individual behavior such as the process from accumulating information to carrying out some actions including utterances. The operator model consists of the attention, thinking, action and utterance micro models.

The attention micro model simulates functions of eyes or ears. It selects information given to the operator model, considering the operator's arousal level, work load, etc. The thinking micro model simulates functions of human thought processes. It decides upon some actions to stabilize the plant condition. This micro model introduces the "mental model mechanism" which is described in the following section. The action micro model simulates functions of hands and feet. It transfers the intention of the operator model as control actions or observation to the plant model via the MMI model. The utterance micro model simulates functions of the mouth. It transfers the contexts of utterances to the other operator models via the HHI model.

2.2 Mental model mechanism
There are lots of studies on "mental model" and numerous definitions which depend on the standpoint of the researcher(s). The theory of mental model is useful for troubleshooting [3] and for the prediction of system behavior [4]; therefore, the authors define the mental model as
the prediction of the event progress. The discussion with nuclear power plant operators revealed how the operator copes with events occurring in the plants. Consider the SRV (Safety relief valve) being stuck open. Discussion revealed that operators pay attention to a hot well water level and a reactor water level despite of various plant parameters being influenced in this situation. The following explains this more clearly. The SRV being stuck open goes off the reactor pressure to decrease the reactor water level, at which point a feed water control valve that controls the reactor water level automatically opens to supply water. Next, the hot well water level that is the source of the reactor water decreases. All CPs (Condensate water pumps) and FWPs (Feed water pumps) automatically stop if the hot well water level continues to decrease to a certain level. The stops of CPs and FWPs cause the shortage of the reactor water to lead the reactor scram. Operators envision this scenario in instant and pay attention to the water levels of the hot well and the reactor.

Fig. 2 General Structure of a mental model

Thus, the authors introduce the mental model mechanism into the thinking micro model, referring to the mental model envisioned by the operators faced abnormal plant conditions. Fig.2 shows a generalized structure of a mental model. The operator model envisions a mental model and selects a key parameter that is most important for preventing the deterioration of plant condition when operator models accumulate information about the abnormal plant condition. Consider a certain problem happening, triggering the warning of event 1. The effect of event 1 passes to some parameters; parameter #1,#2 and #3. The operator model selects parameter #1 as a key parameter. If the parameter continues to decrease and passes landmark 1, the operator model decides to carry out countermeasure 1. If the deterioration of the parameter #1 is very slow and the operator model recognizes no need to perform a countermeasure, then it starts identifying the cause of event 1.

In order to envision this kind of mental model, each operator model has some knowledge bases (KBs). They store knowledge pertaining to the relations between (1) events and parameters, (2) events and causes, (3) change of parameters and interlock, (4) change of parameter and carrying out countermeasures, etc. The volume of knowledge stored in the KBs can be changed to discuss the effects of lack of knowledge. This means that an operator model that lacks some knowledge behaves incorrectly in some ways.
3. Modeling of team behavior

Modeling of the operator focuses on individual recognition, decision and actions. Of course, the functions simulated in the operator model are not enough for simulating the behavior of the operator. For example, although real operators can guess what the other operators think and what they should do as members of the team, the operator models described above can not. Thus, authors introduced the HHI (Human Human Interface) model that has the task assignment, disagreement and utterance management micro models which consider personality, credibility, position, etc [5]. In this paper, two micro models which are the main function of HHI model are mentioned below.

3.1 Task assignment micro model
The authors assume there are 2 kinds of countermeasures. One is to prevent the deterioration of plant conditions such as countermeasures 1&2 in Fig.2. The other is to solve the root cause of event 1 such as countermeasures 3&4. This means there are 2 types of tasks for problems the operators face. The authors call them emergency tasks and cause identification tasks. Emergency tasks are for preventing the deterioration of plant conditions. Cause identification tasks are for identifying the root cause of the problem.
Moving on, one of the characteristics of team behavior is cooperating with each other to deal with a work that is divided among operators; Thus, the authors assume that each task is dealt with by 2 operator models (the leader model and one of the follower models). The leader model can deal with 2 tasks that are dealt with by the follower models. This task assignment micro model considers several types of the task assignment such as types a follower model follows the leader's instruction for task assignment, types a follower decides itself to help the other follower model, etc. However, a task assignment type is predetermined as one of the team "Characteristics".

3.2 Disagreement solution micro model
Now consider the real operators. They communicate to exchange plant information and their thoughts on plant condition, and then they decide on countermeasures that are thought to be the best ones for the plant. In the communication process, everyone either adopts the same countermeasure or operators select different ones to come up with the best one. There are some cases where a very new countermeasure becomes apparent through communication.
The authors then describe the team's decision making process, assuming that the team's decision making is carried out between 2 operator models that are dealing with the same task assigned by the task assignment micro model. The authors also assume that the team's decision is an alternative to the countermeasures the operator models decided on. The disagreement solution micro model considers 30 kinds of predetermined communication processes. One kind shows that the follower model accepts the leader's countermeasure without counter arguments, despite having a different one himself. Other shows that operators having different countermeasures communicate to select the best one.
The disagreement solution micro model considers several dynamic parameters (arousal level, confidence) and static parameters (expertness, reliability) to describe a variety of communication processes. Although these static parameters are not so important for an organized and trained team, the disagreement solution micro model takes them into consideration.
4. System configuration & Simulation

The authors implemented the results of modeling using computers. The system called SYBORG has 2 workstations (Sun SPARC 10) and 3 personal computers. All computers are connected with each other through a LAN (Local Area Network).

A workstation calculates the behavior of a team consisting of 3 operators. The other workstation calculates the plant behavior [6] when an abnormal event happened in the simplified plant. Both workstations communicate to each other to simulate the relation between the operators and the plant. The personal computers refer to the hard disk of the workstation that temporarily stores the utterances generated by the operator models, and voice-composes them.

<table>
<thead>
<tr>
<th>Contents of simulated behavior</th>
<th>Utterances</th>
<th>Leader Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot well water level Low</td>
<td>Hot well level low alarm</td>
<td></td>
</tr>
<tr>
<td>Recognition of warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report of the warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading of Hot well water level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report of the water level</td>
<td>Level is 109cm.</td>
<td></td>
</tr>
<tr>
<td>Reading of the water level</td>
<td>Level is 107cm.</td>
<td></td>
</tr>
<tr>
<td>Identification of the cause</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report of the cause</td>
<td>Withdrawal valve is open</td>
<td></td>
</tr>
<tr>
<td>Proposal of a countermeasure</td>
<td>Shall I close it ?</td>
<td></td>
</tr>
<tr>
<td>Approval of the countermeasure</td>
<td>Agreed. Do it.</td>
<td></td>
</tr>
<tr>
<td>Implementation of the countermeasure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report of the completion of the countermeasure</td>
<td>Level is 106cm.</td>
<td></td>
</tr>
<tr>
<td>Proposal of a countermeasure</td>
<td>Shall I open makeup valve?</td>
<td></td>
</tr>
<tr>
<td>Approval of the countermeasure</td>
<td>Agreed. Do it.</td>
<td></td>
</tr>
<tr>
<td>Implementation of the countermeasure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report of the completion of the countermeasure</td>
<td>I opened it.</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3 Simulation results

Some simulations with SYBORG were conducted, assuming that all operator models have the same degree of knowledge for plant operations. This means that same countermeasures come to the operator models and no disagreements occur in every situation. Task assignment is also fixed to one of eight types where the reactor model does not help the turbine model, and vice versa.

Fig. 3 shows an example of the simulation results described referring to TADEM [7]. Utterances responding to reports, etc. from other models are left out. In this simulation, it is assumed that a condensate water withdrawal valve closed by accident. If operator models would do nothing against the event, the hot well water level would decrease to the low-low level to trip the CPs. Furthermore, the FWPss automatically trip because of low pressure of the their intake. This leads the plant condition to scram (shutdown).

To counteract this event, fig. 3 shows that operator models recognize the warning, read the hot
well water level, identify the cause of the event, close the condensate water withdrawal valve that opened by accident and open the condensate water make-up valve to recover the hot well water level. The leader and the turbine models deal with the abnormal event occurring in the plant model, based on the precondition of the task assignment in which the turbine operator model is responsible for the operating conditions of the CPs, the condenser, etc. However, the reactor model has nothing to do.

This result shows that SYBORG can simulate the behavior of a team faced abnormal events happening in a simplified plant.

5. Conclusion

This paper describes the technique of simulation for an operating team faced abnormal plant events. "SYBORG: Simulation System for the Behavior of an Operating Group" that is installed in workstations simulates the behavior (cognitive action, communication) of a team consisting of 3 operators. This study introduces the "mental model" that is useful for troubleshooting and prediction of system behavior. The mental model describes and illustrates how operators predict plant behavior and make decisions to prevent the deterioration of plant conditions. This SYBORG simulates decision making processes via communication among operators, considering human relations such as position, personality, credibility, etc. This paper also describes an example of the simulation results, indicating that SYBORG can expectedly simulate the behavior of the operating team faced abnormal events happening in a simplified plant.

The authors will improve on SYBORG through verification experiments with subjects. Learning mechanisms and error mechanisms will be added to SYBORG in the future.

References

Development of Team Performance Evaluation Method and its Application for Team Performance Improvement

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Abstract

The performance of an operating team in the control room of a nuclear power plant depends on the abilities of its members and their circumstances. The definition of team reliability that each member gives and receives information without error and acts as a team member correctly, would be an index which is used for an evaluation of the performance of an operating team. In this report, the evaluation model of the team reliability and the results of our quantitative evaluation, in that, contribution of the operating team formation, communication in the team and other factors relating to the team reliability are analyzed, are shown. Measures for team reliability improvement, which are derived from this analysis applying the Analytical Hierarchy Process, are also shown.
1. Introduction

Among the tasks requiring cooperation in nuclear power plants, are team tasks such as operating shifts and organizational tasks. For example, operational tasks are team tasks in almost all ordinary operating modes, whereas in the case of an emergency they are organizational, combining central control room staff and emergency operation room staff. On the other hand, maintenance tasks are nearly organizational because they are conducted usually in the form of joint organization between the main contractor and its subsidiaries. In order to carry out these tasks reliably and smoothly, there is instrumentation such as monitoring panels and controls and communication facilities such as the telephone and paging systems.

The purpose of this study is to evaluate the performance of the cooperative tasks in nuclear power plants and to develop measures to improve the performance of the operating team.

2. Evaluation Method

(1) Study Process

The performance of an operating team in the central control room of a nuclear power plant depends on the abilities of its members and the circumstances surrounding the team. As an index to evaluate the performance of the operating team, team reliability, which is defined as each member giving and receiving information without error and acting as a team member correctly, is adopted in this study. The evaluation models for this team reliability are prepared for the man system and the man–machine system. Applying those models, factors affecting team reliability are derived and measures for improvement in team coordination and communication are deduced. In order to do these studies systematically, a process such as that illustrated in Figure 1 is prepared.

(2) Team Performance Evaluation Models

<Evaluation Model for Man System>

Team performance is evaluated on the standpoint of reliability of team activity. The following items are chosen as evaluation factors,
Figure 1 Study Process
information among team members : $\omega_{ij}$,
ability of team member : $\beta_i$,
external information : $Wi$.

The probability $P_i$ that each member $i$ makes his decision correctly is expressed as

$$P_i = \frac{1}{1+\exp\{-\omega_{ij}+Wi+\beta_i\}}$$

... (1)

This $P_i$ is a monotony increasing function, such as the function value is minimum:0.5 where all factors are zero and an asymptotic value is 1.0 where any factor is infinite.

The probability $P$ that the team makes correct decision is expressed based on the model of the group decision \(^2\) as follows.

$$(P, P') = (\pi_1, \pi_2, \ldots, \pi_m)*$$

\[
\begin{bmatrix}
  d_{11} & d_{21} \\
  d_{12} & d_{22} \\
  \vdots & \vdots \\
  d_{1m} & d_{2m}
\end{bmatrix}
\]

... (2)

where,

$P$ : probability that team makes correct decision,

$P'$ : probability that team makes incorrect decision,

$\pi_i$ (i=1,2,..,m) : probability that team is in state $i$ and derivative of $P_i$,

example: all members make correct decisions, $\pi_1=P_1*P_2*\ldots*P_n$;

member 1 is incorrect and the others are correct, $\pi_2=(1-P_1)*P_2*\ldots*P_n$.

dij(i=1,2; j=1,2,..,m): probability that team makes correct or incorrect decision when team is in state $i$.

The team performance evaluation model expressed by equations (1) and (2) is applied for the deduction of improvement measures for the man system.
<Evaluation Model for Man–Machine System>

Adding two factors, such as machine system reliability and correction of wrong information from machine system, to the model for machine system, the evaluation model for the man–machine system is drawn up. That is, in addition to the equations (1) and (2), the probability $P_i$ that each member $i$ makes the correct decision in the man–machine system is expressed by equation (3) applying the correction factor $\mu$ to the wrong information probability $(1-P_m)$.

$$P_i = P_i^*P_m + P_i^*(1-P_m)^*\mu$$

...(3)

where,

$P_m$ : probability that machine system transmits correct information

$\mu$ : probability that man corrects wrong information transmitted from machine system

(3) Evaluation Method of the Improvement Measures

Applying the team performance evaluation models, contributions of each factor to the team decision reliability are examined parametrically. This examination identifies several types of team performance improvements. The advisable improvement measures are derived from among these improvement types applying the Analytical Hierarchy Process (AHP) which is one of the quantitative decision making methods. The evaluation flow of improvement measures is shown in Figure 2.

3. Application

Applying these evaluation models to the operation team in the central control room of a nuclear power plant, improvement measures for team reliability are investigated based on the following conditions.

**Conditions**

1) Formation of operation team : 5 persons (shift supervisor, chief operator, reactor operator, turbine operator, auxiliary component operator)

2) Surrounding conditions : 4 cases (human improvement: easy or not ; hard ware improvement: easy or not ; Table 1)
Weighting Evaluation Factors
(Paired Comparisons)

Weighting Improvement Types
(Paired Comparisons)

Comprehensive Scoring
and Ranking

Figure 2 Analytical Hierarchy Process
### Table 1: Surrounding Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Human Improvements</th>
<th>Hard Ware Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>easy: it is easy for a utility to improve its human resources</td>
<td>easy: it is easy for a utility to improve its hard wares</td>
</tr>
<tr>
<td></td>
<td>not easy: it is not easy to improve its human resources</td>
<td>not easy: it is not easy to improve its hard wares</td>
</tr>
<tr>
<td>1</td>
<td>easy</td>
<td>easy</td>
</tr>
<tr>
<td>2</td>
<td>easy</td>
<td>not easy</td>
</tr>
<tr>
<td>3</td>
<td>not easy</td>
<td>easy</td>
</tr>
<tr>
<td>4</td>
<td>not easy</td>
<td>not easy</td>
</tr>
</tbody>
</table>
3) Evaluation factors: (1) man system

- information among team members (ωij), external information (Wi),
- ability of team member (βi)

(2) man–machine system

- compensational factor among team members (dij), reliability of machine system (Pm), correction factor for wrong machine system information (µ)

3.1 Applicational Evaluation of Man System

(1) Improvement Types

Based on the evaluation model and the conditions, each evaluation factor is parametrically examined, and the improvement types and measures are derived as follows.

- Human Improvement Type

  ① [improve member ability (βi)] + [enhance amount of information (ωij)]

  note: Amount of information is that of information which is communicated between the operators. In order to enhance the amount of information, concentration of information to the shift supervisor under his strong leadership is effective for team reliability improvement.

- Hardware Improvement Type

  ② [improve display systems (arrangement and number of systems; W1)] + [improve instrumentation in a control room (indicator and recorder; W2)]

- Combination Type

  ③-1 [improve member ability (βi)] + [enhance amount of information (ωij)]
  + [improve display systems (arrangement and number of systems; W1)]

  ③-2 [improve member ability (βi)] + [enhance amount of information (ωij)]
  + [improve instrumentation in a control room (indicator and recorder; W2)]

  ③-3 [improve member ability (βi)] + [improve display systems (arrangement and number of systems; W1)] + [improve instrumentation in a control room (indicator and recorder; W2)]
③-4 [enhance amount of information (ω ij)]+[improve display systems (arrangement and number of systems; W1)]+[improve instrumentation in a control room (indicator and recorder; W2)]

(2) Evaluation Results

As for the surrounding conditions 1-4, derived improvement types and measures are evaluated using AHP and the results are shown in Table 2.

In the surrounding conditions 1, 3 and 4, the combination type ③-1 scores the highest and this is to be an appropriate derivative.

That is, the derived measures corresponding to the combination type ③-1 are as follows,

- human improvements;
  - improvement of member ability (schooling and training on mock-ups)
  - enhancement of amount of information (concentration information to the shift supervisor with strong leadership)

- hardware improvements;
  - improvement of display systems (installation of large display screen or individual display terminals for each operator to obtain common occasional plant information)

In the surrounding condition 2, the combination type ③-3 scores the highest and this is to be an appropriate derivative.

That is, the derived measures corresponding to the combination type ③-3 are as follows,

- human improvements;
  - improvement of member ability (schooling and training on mock-ups)

- hardware improvements;
  - improvement of display systems (installation of large display screen or individual display terminals for each operator to obtain common occasional plant information)
  - improvement of indicators on instrument panels (addition of indicating function to recorders and limit marks to indicators)
<table>
<thead>
<tr>
<th>Surrounding Condition</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement Type</td>
<td>Human: easy</td>
<td>Human: easy</td>
<td>Human: not easy</td>
<td>Human: not easy</td>
</tr>
<tr>
<td></td>
<td>Hard : easy</td>
<td>Hard : not easy</td>
<td>Hard : easy</td>
<td>Hard : not easy</td>
</tr>
<tr>
<td>Human Improvement Type ①</td>
<td>0.150</td>
<td>0.070</td>
<td>0.236</td>
<td>0.155</td>
</tr>
<tr>
<td>Hard Ware Imprvmt Type ②</td>
<td>0.109</td>
<td>0.208</td>
<td>0.054</td>
<td>0.119</td>
</tr>
<tr>
<td>Combination Type ③-1(β, ω, W1)</td>
<td>0.214</td>
<td>0.105</td>
<td>0.272</td>
<td>0.209</td>
</tr>
<tr>
<td>Combination Type ③-2(β, ω, W2)</td>
<td>0.170</td>
<td>0.097</td>
<td>0.254</td>
<td>0.173</td>
</tr>
<tr>
<td>Combination Type ③-3(β, W1, W2)</td>
<td>0.169</td>
<td>0.260</td>
<td>0.090</td>
<td>0.173</td>
</tr>
<tr>
<td>Combination Type ③-4(ω, W1, W2)</td>
<td>0.174</td>
<td>0.251</td>
<td>0.090</td>
<td>0.173</td>
</tr>
</tbody>
</table>
3.2 Applicational Evaluation of Man–Machine System

(1) Improvement Types

Based on the evaluation model and the conditions, each evaluation factor is parametrically examined, and the improvement types and measures are derived as follows.

-Human Improvement Type

① [improve ability to correct wrong machine system information (training of emergency correspondence ; \( \mu \))]+[improve compensation among team members (preparation of communication and action manuals ; dij)]

-Hard Ware Improvement Type

② [improve reliability of instrumentation (dual or diverse system ; Pm)]

-Combination Type

③-1[improve ability to correct wrong machine system information (training of emergency correspondence ; \( \mu \))]+[improve reliability of instrumentation (dual or diverse system ; Pm)]

③-2[improve compensation among team members (preparation of communication and action manuals ; dij)]+[improve reliability of instrumentation (dual or redundant system ; Pm)]

(2) Evaluation Results

As for the surrounding conditions 1–4, derived improvement types and measures are evaluated using AHP and results are shown in Table 3.

In the surrounding conditions 1 and 3, the human improvement type ① scores the highest and this is to be an appropriate derivative.

That is, the derived measures corresponding to the human improvement type ① are as follows,

- improvement of ability to correct wrong machine system information (training of emergency correspondence on mock-ups)
- improvement of compensation among team members (preparation of communication and action manuals)
<table>
<thead>
<tr>
<th>Improvement Type</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Improvement Type ①</td>
<td>Human: easy</td>
<td>Human: easy</td>
<td>Human: not easy</td>
<td>Human: not easy</td>
</tr>
<tr>
<td></td>
<td>0.354</td>
<td>0.206</td>
<td>0.405</td>
<td>0.318</td>
</tr>
<tr>
<td>Hard Ware Improvment Type ②</td>
<td>Hard: easy</td>
<td>Hard: not easy</td>
<td>Hard: easy</td>
<td>Hard: not easy</td>
</tr>
<tr>
<td></td>
<td>0.125</td>
<td>0.221</td>
<td>0.085</td>
<td>0.147</td>
</tr>
<tr>
<td>Combination Type ③-1(dij,Pm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.305</td>
<td>0.321</td>
<td>0.336</td>
<td>0.343</td>
</tr>
<tr>
<td>Combination Type ③-2(μ,Pm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.174</td>
<td>0.252</td>
<td>0.176</td>
<td>0.192</td>
</tr>
</tbody>
</table>
In the surrounding conditions 2 and 4, the combination type 3-1 scores the highest and this is to be an appropriate derivative. That is, the derived measures corresponding to the combination type 3-1 are as follows,

- human improvement
  - improvement of ability to correct wrong machine system information (training of emergency correspondence)
- hardware improvement
  - improvement of reliability of instrumentation (dual or redundant system)

4. Summary of Evaluation Results

Measures to improve the reliability of the operation team are derived through the evaluation of the man and man-machine systems. These are summarized in Table 4.

5. Conclusion

Team performance evaluation models which include operators in a central control room as the man system and instrumentation as the machine system are developed to assess the reliability of an operation team in a nuclear power plant. The improvement measures for the operation team formation and team communication are derived by applying these models. That is;

a. Performance evaluation models of team members and the team as an organization are developed.

b. Applying these evaluation models and setting, as evaluation factors, ability of individual team member, information among team members, external information, compensation among team members, reliability of machine system (instrumentation) and correction of wrong information, team performance is examined parametrically. This examination identifies several types of team performance improvement.

c. The advisable improvement measures are derived corresponding to the surrounding management condition of the electric utility.
<table>
<thead>
<tr>
<th>Srd. Cond.</th>
<th>Improvement Type</th>
<th>Evaluation Factors</th>
<th>Improvement Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 3</td>
<td>Man System Combination Type 3-1</td>
<td>*ability of member (β_i)</td>
<td>*schooling &amp; training on mock-ups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*amount of information (ω_ij)</td>
<td>*concentration information to shift supervisor with strong leadership</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*ext. information from display (W1)</td>
<td>*large screen, individual terminals</td>
</tr>
<tr>
<td></td>
<td>Man-Machine System Human Improvement Type 1</td>
<td>*correction factor for wrong information (μ)</td>
<td>*training of emergency correspondence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*compensation among team (dij)</td>
<td>*communication &amp; action manuals</td>
</tr>
<tr>
<td>2</td>
<td>Man System Combination Type 3-3</td>
<td>*ability of member (β_i)</td>
<td>*schooling &amp; training on mock-ups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*ext. information from indicator (W2)</td>
<td>*improved instrumentation panel</td>
</tr>
<tr>
<td></td>
<td>Man-Machine System Combination Type 3-1</td>
<td>*correction factor for wrong information (μ)</td>
<td>*training of emergency correspondence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*reliability of instrumentation(Pm)</td>
<td>*dual or redundant instrumentation system</td>
</tr>
<tr>
<td>4</td>
<td>Man System Combination Type 3-1</td>
<td>*ability of member (β_i)</td>
<td>*schooling &amp; training on mock-ups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*amount of information (ω_ij)</td>
<td>*concentration information to shift supervisor with strong leadership</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*ext. information from display (W1)</td>
<td>*large screen, individual terminals</td>
</tr>
<tr>
<td></td>
<td>Man-Machine System Combination Type 3-1</td>
<td>*correction factor for wrong information (μ)</td>
<td>*training of emergency correspondence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*reliability of instrumentation(Pm)</td>
<td>*dual or redundant instrumentation system</td>
</tr>
</tbody>
</table>
d. The derived improvement measures common to each surrounding condition are,
   - concentrate information to a shift supervisor with strong leadership,
   - improve ability to correct wrong information by training of emergency
correspondence on mock-ups,
   - improve display systems by installing a large display screen or individual
display terminals for operators to obtain common occasional plant information.

Reference
CHAPTER 2: STRESS

SECTION A. DEFINITION OF ISSUES

To begin to clarify terms, the best place to start to define the word "stress". It has always been difficult to define both in the language of the street (where we all know what is understood by stress but nobody can describe it exactly) and in the scientific field, where different specialist areas are concerned independently with the same subject, and where each expert has his own special suppositions based on his own specialist field.

It is difficult to make an exact definition of the concept of stress. Psychologists, sociologists, doctors... all have different points of view on the subject.

All branches of science agree on the fact that the word stress has its origin in physics, as a "constructed" term, in other words, as a technical or abstract concept.

In Physics, the word stress refers to a force which acts on an object and which, when a certain measurement has been passed, leads to the deformation or the destruction of the object or system.

It is easy to transfer this definition to the human being:

• In this sense, stress can be defined as "any internal or external force which generates physical or mental tension".

• In all living beings, stress is the danger which threatens wellbeing and, as a result, even survival.

"It is an innate self-preservation mechanism".

• "A natural biochemical reaction of the organism to any varying situation which obliges it to adapt itself to recover internal equilibrium". As a result of the effect of stress, the living being which is affected endeavour to adjust to the modified
conditions of its surroundings and to either act against the pernicious influence (activity) or to flee from it (passivity).

Stress control means to learn the psycho-motor ability to control our physiological activation in response to endless stress producing factors found in daily life.

SECTION B. CURRENT PRACTICES

There is a specific stress management training programme, before starting simulator training.

This stress management course is implemented in classroom setting using lectures and practices.

Although it is not intentionally foreseen. Stress are induced during simulator training session by implementing, transients and emergencies scenarios as close to reality as possible.

FINAL OBJECTIVE

On completion of this course, the trainee will be able to identify stress-related behaviour and stress inducing conditions and implement techniques that minimize the impact of stress on people performance.

CONTENT SUMMARY

What is stress

You can not control what you do not know.

Doctor Hans Selye defined stress in 1956 as: "a joint of specific symptoms (syndrome),
of our organism in response to certain stimulus (stressors)

**Stressors**

To identify stressors which induce to stress, is other important step in order to control stress. To know stressors in advance and be prepared to face then.

Any internal or external stimulus can induce to stress. Intensity and newness of the stimulus and the way you have leaned the stimulus are the main factors to consider.

There are many types of stressors. Inside the individual (psychological and inheritance stressors) and outside the individual (biochemical stressors, as alcohol, tobacco, drugs, bad nutrition, pollution...). And also are considered as stressful those situation that produce to the individual important changes in his way of life (for instance: divorce).

**Effects of stress. Symptoms**

The general excitation reaction to an stressor is initiated as the consequence of the excitation of a gland (hypophysis) and the action of one hormone (ACTH) that release adrenaline and the chain of symptoms of stress.

In summary, under stress, heart rate increases, blood is diverted from intestine and skin to large muscle groups and brain (survival regions), blood flow decreases in areas used for high level cognitive thinking, breathing is stimulated and coagulation capability is increased.

Muscular response is the most representative of stress, some muscles are tensed and prepared for confrontation (back muscles, legs, abdomen), while some other are relaxed so as not to rob energy from the "survival" muscles (bowel, bladder, manual dexterity is reduced).

The result of the short-term body's response to stress is to prepare it to "fight or flight".

Long-term effects of stress are associated to other kind of diseases as anxiety, depression,
insomnia, heart diseases, ulcers and other immunological and sexual troubles.

**Coping strategies**

Stress management requires a life style respectful with our biological, psychological and social needs. Unfortunately most people are very far from this style, nevertheless all of us are able to fix healthy objectives to arrive to the optimum and stay there. The course provides guidance to fix those objectives, it teaches concepts and the current and more effective techniques to achieve a physical, mental and social welfare. The course focuses in:

- Anti-stress food
- Physical exercise
- Deep breathing
- Systematic muscular relaxation
- Music-therapy
- Concentration/Meditation

Training tools used for those practices include video, relaxation tapes and megabrain.

Annex-II includes the Stress Training Programme

**MODELS OF HUMAN BEHAVIOUR**

The models of the human behaviour being used within simulator training programmes are:

- The identification of stress symptoms
Stress coping strategies: actions to accomplish before, during and after an abnormal or emergency situation occurs in the control room.

Strategies to manage stress during simulator training are:

a) Activities carried out prior to a particular event in order to reduce the level of stress:
   - Pay attention to the conditions of the plant.
   - Mentally go over the actions to be taken by the operator for mitigating an imagined event.
   - Determine and practice diagnosis techniques during the shift.
   - Reduce unnecessary noises in the Control Room.

b) Activities carried out at the beginning of an event in order to reduce the level of stress:
   - Follow the procedures.
   - Begin the emergency procedures again from the beginning when the team feels "lost" or when the action of an operator has deviated significantly from the procedure.
   - Continually apply diagnosis techniques and teamwork (good communication and positive participation).
   - Control the activities of the other members of the team to recognize possible stress symptoms.
   - Frequently go over the global situation and control the functioning of critical equipment.
   - Encourage a positive working atmosphere.

c) Activities carried out when stress is felt in order to diminish its effects:
   - Take your hands away from the panel, stand back and try to get a global vision of the situation and the corresponding responsibilities.
Breathe slowly and deeply.
Relax the muscles to reduce tension and to facilitate the circulation of the blood.
Speak quietly to yourself.
Speak to the supervisor or to a colleague about the feelings you are having when under stress or suffering from anxiety.
Look at problems as a team not individually.

Areas in which the model of human behaviour is being applied:

- Control board operation.
- Alarms interpretation and events diagnosis.
- Emergencies response.

All of them are areas of trainees assessment during the simulator evaluation.

METHODOLOGY

Formal instruction, discussions, relaxation practices and quizzes.

LENGTH

Three days. 18 hours of instruction.

SECTION C FURTHER DEVELOPMENTS

- To include relaxation exercises into retraining programmes in order to develop performance patterns.
- Environmental alpha-music in classrooms.
• Advanced instructors training on stress symptoms identification.

• Specific free-time area for students for reeding, leasing music and playing

• Promoting sport into the training centre.
ANNEX II  STRESS CONTROL TRAINING PROGRAMME:

1st day: INTRODUCTION

STRESS
- History
- Definition

STRESSORS
- Stressor characteristics (Intensity/Newness)
- Stressors classification
- Learning theory

QUIZZES AND RELAXATION PRACTICES

2nd day: ACTIVATION UNDER STRESS
- Yerkes-Dodson law
- Activation and individual differences

EFFECTS OF STRESS. SYMPTOMS
- Acute and chronic stress
- Short-term symptoms
- Long-term symptoms
- Stress diseases

QUIZZES AND RELAXATION PRACTICES

3rd day: COPING STRATEGIES
- Life style
- Relaxation techniques
- Therapies

RELAXATION PRACTICES
CONCLUSIONS

FIGURES
75% HAVE EXCESSIVE WORRIES

29% FEEL TIRED WHEN MAKING NORMAL EFFORTS

25% SUFFER FROM UNJUSTIFIED NERVOUSNESS

36% SUFFER FROM SLEEP DISORDERS

25% SUFFER FROM PALPITATIONS

17% HAVE STOMACH OR DUODENAL ULCERS

29% HAVE HIGH OR LOW BLOOD PRESSURE

10% SUFFER FROM LOSS OF MEMORY

NO ONE ADMITTED TO DRUG ADDICTION OF ALCOHOLISM
Stress is:

"A set of specific symptoms, which take place in the organism in response to certain stimuli"

Hans Selye 1956
INTRODUCTION

- THE PARADOX OF STRESS:
  - AN ESSENTIAL FACTOR IN OUR LINES
  - THE SOURCE OF MANY PROBLEMS

- CONTINUAL CHANGES IN MODERN SOCIETY
  ⇒ CONSTANT ADAPTING

- NOT TO ELIMINATE STRESS BUT TO REDUCE IT TO (+) LEVEL

- ADOPT SKILLS WITH A DUAL MENTAL AND PHYSICAL FOCUS. INDIVIDUAL ATTITUDE

- CONVENTIONAL MEDICINE CORRECTS PATHOLOGIES

- THERE ARE FEW DISORDERS WHICH DEPEND SO MUCH ON ONESELF FOR PREVENTION AND TREATMENT

- THE UNDERSTANDING OF:
  - WHAT STRESS IS
  - STRESS INDUCING FACTORS
  - SYMPTOMS

INCREASES THE POSSIBILITY OF CONTROLLING STRESS
RELAXATION EXERCISES. BASIC POSTURE

☐ SEATED

☐ BACK SUPPORTED

☐ SHOULDERS DROPPED

☐ HANDS RESTING ON THIGHS

☐ FEET RESTING FIRMLY AND VERTICALLY ON THE FLOOR

☐ LEGS SLIGHTLY APART

☐ EYES HALF-CLOSED

☐ JAWS AND LIPS SLIGHTLY APART

☐ SOFT AND RHYTHMICAL NOSE-MOUTH BREATHING
PARTIAL OBJECTIVES
FOR CONTROLLING STRESS

1. DEFINE STRESS
2. IDENTIFY THE FACTORS WHICH CAUSE STRESS IN OUR ENVIRONMENT
3. KNOW HOW STRESS INFLUENCES OUR EFFICIENCY
4. RECOGNIZE THE SYMPTOMS OF STRESS
5. KNOW THE LONG TERM EFFECTS OF STRESS
6. KNOW AND PRACTICE THE DIFFERENT RELAXATION AND STRESS CONTROL TECHNIQUES
## TABLE II

**PSYCHICAL FACTORS GENERATED BY STRESS**

### AT WORK:
- Tight time limits, often impossible to fulfill
- Too much or too little work
- Frequent peaks and falling off in workload
- Mistakes detected easily by others, little margin of error
- Frequent conflict with users
- Need to be up to date with a continually changing technology
- Long and irregular time table
- Bad department management
- Job insecurity
- Disagreeable work climate

### AT HOME:
- Communication problems
- Fighting with spouse
- Child leaving home
- Illness of a member of the family
- Separation or divorce
- Sexual problems
- Pregnancy
- Problems with children at school
- Living with in-laws
STRESS IS BASICALLY HEALTHY ONLY AN "EXCESSIVE DOSE HAS PATHOLOGICAL EFFECTS"
CHEMICAL AND BIOCHEMICAL STRESS SYMPTOMS

LARGE CITIES INDUSTRIAL AREAS

LARGE NUMBER OF ADVERSE FACTORS
- EXHAUST GASES
- FUMES (TOXIC)
- SMELLS (BAD)
- TASTES (BAD)
- LACK OF OXYGEN

PHENOMENAL CAUSED BY BIOLOGICAL LACK

- HUNGER
- THIRST
- NUTRITIVE DEFICIENCIES
- WRONG NUTRITION
- OVERWEIGHT/UNDERWEIGHT

DRUGS:
- AMPHETAMINES
- ANTI-DEPRESSANTS
- BENZODIACEPINES
- THYROID HORMONES
- Ephedrine
- NICOTINE
- COCAINE
- TEINE

ABSTINENCE SYNDROMES
- ALCOHOL
- OPIATES
- NICOTINE
- BARBITURATES
HOW TO WORK ON YOURSELF

• LOOK AFTER YOURSELF
  • REST ADEQUATELY
  • "SLOW DOWN"
  • BREATHE SLOWLY AND DEEPLY
  • RELAX
  • BE AWARE OF THE PRESENT
  • TAKE ON A DAILY HABIT
  • TAKE CARE OF YOUR PHYSICAL HEALTH

• ESCAPE FROM ROUTINE
  • CHANGE SURROUNDINGS
  • LIVE INTRINSICALLY SATISFACTORY EXPERIENCES
  • PLAY
  • CREATE EXTERNAL INTERESTS
  • TAKE REGULAR EXERCISE

• REVISE TACIT RULES
• USE ANTIDOTES FOR STRESS
• TOLERATE UNCERTAINTY
• ANTICIPATE CHANGE
• WIDEN ABILITIES
• SATISFY DESIRES
• RESOLVE CONFLICTS
• CLARIFY VALUES
HOW TO

CONFRONT

THE TASK

- REDUCE DEMANDS
  - ESTABLISH PRIORITIES
  - SUPPRESS CERTAIN ACTIVITIES
  - SIMPLIFY ACTIVITIES
  - PROGRAMME DEMANDS
  - REJECT UNREASONABLE DEMANDS
  - REDUCE DEMANDS YOU MAKE ON YOURSELF
  - CAREFULLY CHOOSE THE CAUSES YOU WANT TO DEFEND

- TAKE THE REINS
  - ADOPT AN ATTITUDE OF RESPONSIBILITY
  - DO SOMETHING SPECIFIC
  - SEEK INFORMATION
  - CHOOSE AND DECIDE
  - BE ASSERTIVE

- REDUCE UNCERTAINTY
  - SEEK INFORMATION
  - TAKE ON APPROPRIATE ACTION

- FINISH PENDING AFFAIRS
  - COMPLETE TASK
  - ESTABLISH SHORT TERM OBJECTIVES
  - ESTABLISH A CONSERVATIVE TIMETABLE
  - TAKE DECISIONS
  - EXPRESS EMOTIONS
  - WRITE THINGS DOWN
  - SPECIFY YOUR PERSONAL RELATIONSHIPS

- MINIMIZE CHANGE
Task 5: Role of Simulators in Operator Training

STRESS

1.0 Definition of Issues

A stressful situation occurs when a substantial imbalance exists between the demands imposed on an individual and the individual's ability to successfully handle those demands. Stress can also occur if an individual simply perceives a mismatch between the demands of the situation and his or her abilities to cope with those demands. The causes of stress that have been identified in the research literature are numerous and include environmental factors (e.g., extremes in temperature, noise, and crowding), workload, competing goals, and conditions that are novel or cause uncertainty.

Stress can significantly influence human performance and stress effects can range from facilitation to severe impairment. Interest in the U.S. concerning the effects of stress on the performance of nuclear reactor operators has largely been focused in two areas: the effect of stress on performance during plant operations (e.g., abnormal or emergency operations and plant outages) and the effect of stress on performance during the license examination process. In both of these areas, the emphasis has been on eliminating, minimizing, or coping with sources of stress that can impair operator performance.

1.1 Stress Effects

In 1994, NRC published NUREG/CR-6127, "The Effects of Stress on Nuclear Power Plant Operational Decision Making and Training Approaches to Reduce Stress Effects." The report documented a review of research literature concerning stress and presented an analysis of the effects stress can have on decision making and performance in the context of nuclear power plant operations. Four general types of impairments in cognitive performance were identified:

1. Narrowing and shift in attentional focus
2. Reduced working memory capacity
3. Time pressure effects
4. Impaired crew communication patterns

The following sections discuss each of these impairments and their implications for nuclear power plant operations.

Narrowing and Shift in Attentional Focus

One of the most widely reported effects of stress on performance of cognitive tasks is that in stressful conditions, the performer's attention becomes more narrowly focused on cues central to a task and less sensitive to peripheral cues. As a result, the changes in performance that may be observed under stressful conditions are impaired performance on peripheral tasks and enhanced performance on central tasks. Similarly, performance on tasks that require integration of many cues or decision making that requires consideration of many options may be impaired because of the individual's decreased ability to allocate attention to the peripheral cues or options.
Narrowing and shift in attentional focus could impair operator performance when--
   (1) Multiple tasks need to be performed or monitored simultaneously.
   (2) Multiple sources of information need to be monitored or consulted, some of which are less salient than others.

Reduced Working Memory Capacity

Stress impairs performance when it relies heavily on working memory. Working memory is used for short-term memory tasks, such as remembering a phone number from the time it is read until the time it is dialed. Deductive reasoning, spatial manipulations, and arithmetic computations are all cognitive tasks that rely heavily on working memory and are important components of the tasks performed by nuclear plant operators.

A reduced working memory capacity could impair operator performance when--
   (1) There is a heavy burden on mental simulation of plant systems or control actions.
   (2) There is a significant requirement for mental computation.
   (3) Information from several sources must be integrated mentally.
   (4) Multiple small tasks are being managed simultaneously.

Time Pressure Effects

Various studies have shown that stress can cause decision makers to perform as if they were under time pressure. For example, Janis (1982) found that stress can impair decision making by causing hasty, disorganized, and incomplete processing of information. Decisions under stress may be made more quickly, at the expense of accuracy, and decision makers may omit elements of the decision-making task.

Stress-induced time pressure effects could impair operator performance when--
   (1) A series of simple decisions or judgments can be executed in succession or when speed of execution is not limited by the control room interface.
   (2) Complete and systematic analysis of information is required for effective decision-making.

Impaired Crew Communication Patterns

There have been few studies of the effects of stress on crew performance. Most insights concerning the influence of stress on crew or work team performance are derived from case studies of actual events. In general, the literature suggests that stress can result in a failure of work teams to pool information, thereby jeopardizing effective situation assessment.

Impaired crew communication patterns can have a negative affect on operator performance when--
   (1) Control actions must be coordinated.
   (2) Indications of plant state are subtle or ambiguous.
   (3) Information important to effective decision making must be passed from crew members to the primary decision maker.
2.0 Current Practices

Although there are numerous generic programs and techniques for stress management, most efforts to eliminate stress or minimize its effects on the performance of nuclear power plant operators involve methods that, though perhaps familiar, are not typically thought of as stress management.

Simulator Training

Simulator training is perhaps the most effective tool available to address stress in the context of nuclear plant operations. Repeated training in plant emergency simulations is an important means of mitigating the effects of stress on plant operators by causing effective accident mitigation behaviors to become well-learned, routine behaviors that tend to be less susceptible to, if not facilitated by, stress.

In addition to mitigating the effects of stress on operator performance, simulator training is used to eliminate or reduce a potential source of stress: novelty. Novelty refers to events that have not been experienced before and are perceived to have potential risks. By exposing operators to a wide range of simulated equipment failures, plant transients, and emergencies, the likelihood of operators experiencing a plant event that is truly novel is substantially reduced, as is the potential for the event to induce levels of stress that may cause impairment. Simulator training also reduces stress from uncertainty, the inability to predict outcomes. Research has shown that the ability to predict outcomes, even if the events are aversive and outside the control of the individual, can be less stressful than uncertainty. Providing operators with simulated experiences of the plant responses to specific equipment failures and, consequently, the ability to predict the nature, severity, or duration of the transient is also important to minimizing stress in abnormal plant conditions.

Communications and Team-Building Training

As noted in Section 1.1, stress can impair crew performance by impairing the effective exchange of information among crew members. Training in team-building and communications techniques can mitigate the effects of stress on crew performance. Some utilities in the U.S. have given operators training that has emphasized team-building. Such training generally reinforces the importance of pooling of information for effective decision-making and attempts to address barriers to effective communication, for example, the failure to challenge decisions of another crew member. In general, U.S. utilities provide senior reactor operators with supervisory training that emphasizes the importance of frequent crew briefings to facilitate crew communications and to ensure that decisions and actions are based on complete information.

Examination Process and Methods

In 1991, the NRC staff conducted a study to identify sources of undue stress in the requalification examination process for licensed operators (SECY-91-391, "Results of the Study of Requalification Examination Stress"). Undue stress was defined as stress that
could be practically reduced or eliminated without reducing the validity of the examination. This definition reflected the premise that a valid evaluation of operator ability to perform in emergency conditions, which are inherently stressful, includes an assessment of performance under comparable conditions. Thus, the objective was not to eliminate all stress from the examination process but to remove or reduce to the extent practicable those sources of stress that did not contribute to a valid examination of operator competence.

Through a combination of interviews, observations, and questionnaires, the study found that the three principal causes of undue stress were (1) frequent changes in the requalification process, (2) inconsistency in interpretation of the guidelines provided by NRC for examiners, and (3) specific examination content and grading practices that were perceived to cause unnecessary impediments to demonstrating job competence. These causes of stress in the examination process reflect the well-known causes of stress described in Section 1.1. Changes in the examination process often caused examinations to differ in some way from an operator’s previous examination and, therefore, the requalification examinations continued to be somewhat novel experiences and more stressful than if the process were routine. Inconsistency in interpretation of the examiner guideline also caused unpredictable variations in the implementation of examinations, and thus, operator uncertainty and stress were increased. Specific examination and grading practices were perceived to affect the validity of the examination. Consequently, some operators sensed a loss of control and stress because they believed their true ability would not necessarily determine the pass/fail decision.

As a result of the insights concerning stress in the examination process, NRC has taken several actions that address undue stress in the examination process. These include (1) making changes to the examination process more predictable by defining a schedule for revising the examination guidelines and improving communications concerning these changes and (2) improving consistency in the administration of examinations. The grading method for the simulator portion of the examination was also revised so as to place increased emphasis on the performance of the crew versus individual performance, consequently reducing some of the artificial behaviors that were perceived to affect the validity of the examination. In addition, examiners are given training that discusses (1) test anxiety and sensitizes them to examiner behaviors that could inadvertently cause stress and (2) methods that can be used to put operators at ease during the examination.

Many utilities in the U.S. have also taken measures to reduce stress in the examination process. Some facilities have modified their examination scheduling and security practices to minimize the amount of time that operators are sequestered while waiting for the next phase of their examination. A few utilities have developed programs to assist operators in coping with test anxiety. For example, Sajwaj and Chardos (1988) describe a training program of one U.S. facility that provides instruction in effective study methods and stress management techniques, including postural control to reduce muscle tension, slow deep breathing, and positive self-statements. Another U.S. facility has developed a training program similar to that described by Sajwaj and Chardos and has also incorporated "solo" sessions in their operator simulator training. Solo sessions require a single operator to perform all the actions necessary to respond to a plant transient. The purpose of the exercise is to demonstrate that a single operator can manage many plant transients with
deliberate, un rushed actions. The training has the potential of counteracting the tendency to act as though one is under time pressure when experiencing the stress of an actual event.

3.0 Further Developments

Advanced Control Room Technology

Recent developments in control room technology are likely to have important implications for operator stress and performance during plant events. The digital technologies that are currently being developed and introduced into nuclear plant control rooms have the potential of reducing cognitive workload by presenting information in formats that can facilitate operator assessment of plant state. Similarly, developments in alarm reduction and prioritization have shown a potential for reducing cognitive workload. Computer-based procedures also have the potential of reducing cognitive workload by aiding in place-keeping and the tracking of control actions. The details of the design and implementation of these and other control room technologies, however, will be vital to determining whether the technologies, in fact, reduce working memory requirements and facilitate performance under stress, or simply transform the task without reducing, and even perhaps increasing, workload.

Severe Accident Management

Severe accident management has been an area of considerable focus at U.S. facilities during the past several years and utilities are currently implementing programs to enhance their severe accident management capabilities. The potential effects of severe accident conditions on operator stress and performance are important considerations in the development of severe accident management programs and, consequently, they were a primary focus of NUREG/CR-6127. Severe accident conditions can be expected to be highly stressful because of current limitations in the understanding of severe accident phenomenology, difficulties in predicting accident progression, the potential for instrumentation and equipment to be exposed to conditions beyond their qualification, and the likelihood that multiple systems normally available to an operator for event mitigation will have failed or will be unavailable for other reasons. As a result, operators will likely be challenged by a heavy workload while coping with novel and uncertain conditions. NUREG/CR-6127 identified several training approaches for mitigating the effects of stress on the operator’s cognitive skills. These approaches include (1) training techniques that make personnel more efficient information processors and reduce the demands on attention and working memory, (2) training to enhance crew coordination and communications skills, and (3) training using realistic severe accident simulations to reduce the novelty of severe accident conditions. The last recommendation was made recognizing that current simulation models generally do not support the simulation of severe accident conditions and NRC does not require such capabilities at U.S. facilities. Nevertheless, non-real-time simulations could be used to expose crews to the data unreliability, conflicting goals, and less prescriptive guidance that they would likely encounter during a severe accident.
References


I Introduction

The group ETF has set itself the task of studying the reliability of the simulators used to train operators. This presentation deals with certain aspects of this topic: more specifically, after a general introduction concerning the diversification of requirements and a reminder of the historical development of simulator evaluation methodologies, there follows a description and then an example of a proposed evaluation which can be used directly and which is based on control concerns.

II Diversification of simulator requirements

The question of the representativeness of simulators has been coming increasingly to the fore, in view of their increased use in France over the last ten years. This change is due as much to the spectacular progress made in computer calculation equipment as to the diversification of real simulator requirements in the field of nuclear safety. These concern, for example:

- the drafting and evaluation of operating documents,
- physical and theoretical training for operators in normal situations, incidents and accidents,
- the performance of emergency drills,
- the evaluation and validation of the Man-Machine Interface (S3C simulator reproducing the computerised control room in the N4 series of reactors).

Not to mention requirements associated with improvements in design and safety which necessitate greater accuracy in thermohydraulic modelling:

- studies of new systems for the European reactor and the design of the new N4 series of reactor (DMAX core control system),
- the development of transients as part of safety studies in addition to the use of reference codes,

With regard to the quality of thermohydraulic modelling for simulators, the member countries today refer to the evaluation methodology set out in ANSI 3.5 in 1985, [1] and [2]. In France, the progression of the simulator performance acceptability tests is not as systematic as it is not officially subjected to the Safety Authority unlike in the USA (the Federal Regulations of the NRC lay down the accreditation criteria for simulators which operators can practice on to obtain their licence). Faced with the diversification of possible uses which has also been accompanied by the appearance of an increased number of simulator types, the 1985 frame of reference for requirements has changed. The methodology used for evaluating these tools can then be reconsidered.
II Methodology used for evaluating control simulators.

It is important for the ETF group to have some reminder of past and present methods used for evaluating simulators. In the first methods, the preferred evaluation paths were those marked (1) and (2) on the diagram below. These methods were primarily concerned with obtaining quality retrieval. The consistency of the calculated responses with those observed at the unit must today still be considered as the best way of evaluating capacities in normal operation. Then, a spectrum of transients far more serious than those which can be found in data available on the units, was taken into consideration in light of the TMI accident: the simulator, until then considered as a mere tool used to provide theoretical training in normal or incident operation, must now also represent deteriorated situations, or even severe accidents. Consequently, the preferred evaluation method is now Path (5) where the reference code plays a key role: one of the dominant features of the current validation method is the stress it places on quality forecasting.

The scale of the area covered by this process has necessitated the construction, throughout the world, of 160 test installations for different purposes, listed in [3], of some twenty system loops reproducing the entire reactor coolant and secondary systems at a scale of between 1:700 and 1:48, to promote selective observation of 67 physical phenomena [3]. Many thermohydraulic codes, with different levels of performance depending on the number of equations they contain (between 3 and 6), can be adopted as "baselines" to evaluate simulator responses, the only constraint being that they are "realistic". The process of qualifying and verifying the reference code itself is outside the scope of this presentation (Paths (2), (3) and (4)): assuming that the answers provided by the baseline code are relevant.

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Figure n°1 : organigramme d'intervention des calculs de transitoires REP
As long as computer limitations prohibit real-time calculations which make direct use of the reference code, Path (5) will have to be used and the methodology set out in [1] will be the first step towards this goal. An additional solution which makes it possible to evaluate the quality of the responses provided by the simulators in a way that can be processed directly by persons involved in control operations, uses this as its basis.

The conventional side of the methodology consists, firstly, in selecting a set of transients such that all the system states are simulated at least once. The term "system state" is taken to mean the different dynamic phenomena encountered in transient situations (natural convection, dewatering etc.); they comprise a sub-set of 67 physical phenomena listed for the reference code, because certain situations cannot at present be modelled on simulators (large breaks for instance). No attempt is therefore made to produce the associated states (example of the progression of the hardening front) as observable phenomena. The fifty or so transients selected in this way are divided into five or six broad families (loss of head, excessive heat to be removed, LOCAs etc.); these families in an array, where the lines are represented by the states of a system (about forty of them): as some of the states are specific to a particular component in the nuclear steam supply system (steam generators, pressuriser etc.), sub-units are formed in this first overall array as shown below:

<table>
<thead>
<tr>
<th>System states</th>
<th>Transient family 1: Loss of head etc.</th>
<th>Transient family 2: LOCAs</th>
<th>...</th>
<th>Transient family j</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural convection</td>
<td>component 1: reactor</td>
<td>component 1: reactor</td>
<td></td>
<td>component 1: reactor</td>
</tr>
<tr>
<td>Dewatering</td>
<td>Component 2: Steam generator</td>
<td>Component 2: Steam generator</td>
<td></td>
<td>Component 2: Steam generator</td>
</tr>
<tr>
<td>lth state</td>
<td>component n</td>
<td>component n</td>
<td></td>
<td>component n</td>
</tr>
</tbody>
</table>

Crosses are entered in the column/line reference when the simulator provides a response with an acceptable deviation or zero deviation from the baseline code.

Secondly, each sub-unit in the array (nuclear steam supply system component) is observed for each family of transients: the difference in amplitude, delays in changes of the physical parameters calculated and the action or failure of automatic control devices are compared with those for the baseline code. For example, for the set of transients which belong to the family of LOCAs, X% of the simulated responses show a satisfactory amplitude, with regard to the pressuriser component, and on average for all the transients in this family.

Observation of the arrays obtained using this evaluation method leads us to a statistical representation of these responses and one which is typically focused on simulator
thermohydraulics: however, the operator has no means in the control room of observing the phenomenology in the reactor building and nuclear steam supply system in as much detail. Furthermore, the return of condensed water in the steam generator tubes for instance, or the transition into dual operating state in the reactor coolant system, does not directly concern him according to his operating documents: in the operator's eyes, the system state can only ascertained from indicators in the Control Room, and it is the values of these indicators that he consults in accordance with the operating documents and which determine the course of action he takes. This is why it appears important for any new simulator response array lines to include not the system states but the parameters monitored by the operator. Furthermore, the spectrum of transients must be that covered in the operating documents: it must in particular be extended to include shutdown states and deteriorator states of the installation. These extended transients can be classified into different families according to the area covered by a particular procedure designed as a countermeasure for the postulated transients: for instance, not all of the LOCAs are covered by the same procedures because, depending on the size of the break or the state of the unit, the state parameters do not develop in the same way as the control actions; this family must therefore be subdivided. This additional array is given below for reference purposes, in keeping with the state-oriented approach method of control:

<table>
<thead>
<tr>
<th>Operating state parameters</th>
<th>Transients covered by Procedure 1</th>
<th>Transients covered by Procedure 2</th>
<th>etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCS states</td>
<td>Amplitude of the response and action of automatic control devices</td>
<td>Id.</td>
<td>Amplitude of the response and action of automatic control devices</td>
</tr>
<tr>
<td>Vessel water level</td>
<td>Id.</td>
<td>Id.</td>
<td>Id.</td>
</tr>
<tr>
<td>TPSC</td>
<td>Id.</td>
<td>Id.</td>
<td>Id.</td>
</tr>
<tr>
<td>Secondary system states</td>
<td>Id.</td>
<td>Id.</td>
<td>Id.</td>
</tr>
<tr>
<td>Steam water level</td>
<td>Id.</td>
<td>Id.</td>
<td>Id.</td>
</tr>
<tr>
<td>Generator water level</td>
<td>Id.</td>
<td>Id.</td>
<td>Id.</td>
</tr>
</tbody>
</table>

When the difference between the simulated and the baseline responses is less than or equal to a threshold value (say 5%), a cross is placed at the intersection between the state parameter and the transient being controlled. By moving this threshold, it is possible to perform sensitivity studies on the methodology used to evaluate the simulators and to observe the consequences this has on the effect of the operating documents. This solution is all the more useful since the type of simulator used to draw up operating rules is often not the same as that used for training or for validating procedures: by filling in the additional array above, it is fairly simple to perform a comparative study of these two types of simulators. Completing the state arrays to varying degrees may be an indicator for reviews to determine the best simulator for a particular purpose.

In the case of a loss of feedwater transient, this method is illustrated for a state parameter where any overstepping of the S1, S2, S3 and S4 parameters is entered in the Control Room and is then used in the orientation tests for control procedures in the state-oriented approach mode:
Time (x-axis) that parameters are overstepped for 3 simulators of 2 different types.

Comparison of amplitudes as a %age of the amplitude of the state parameter (y-axis), against time (x-axis).
The differences between study simulation and the reference code, shown by these samples, can be detailed:

1) The first picture shows large differences in time taken by state parameter evolution, predicted by the reference code and by the simulator studies (for example, with the code reference, S1 is reached 2000 s before that it is reached in the study A).
2) The second picture shows different types of parameter evolutions in time but also important discrepancies between the values predicted for the same hour (for example, when time reaches 5550 s, full scope predicted a little amplitude for the parameter, the reference code an highest).

The consequences for operators training can be the following:
- if the state parameter value is a reference to change procedure, the orientation in the procedures will occur not in the same hour during the simulation and during the true situation, if it looks like reference code, or will be not the same,
- the time references learned with the simulation experience can be wrong, operators can imagine to have a lot of time and in true situation, they will have less to do procedure actions. The learnt rythme may be wrong.

**III Conclusion**

A solution which is different to the conventional method of evaluating simulators is one means of directly determining their degree of representativeness according to concerns which are akin to those used in operations. It is a means of allowing for a broadening of the areas covered by the procedures by writing an adequate set of procedures. In all cases, the initial conditions and the limits must be identical for the simulated scenario and for the scenario calculated by the reference code, for a reasonable comparison of the results. The simulator responses to this set of transients can give rise to sensitivity studies of the method of evaluation itself: in this way, the effects of a maximum permissible difference between the simulated response and the baseline code can be measured in terms of difference of orientation in the operating documents.
BIBLIOGRAPHIC REFERENCE


Légendes:

Figure 1

1 TESTS AT THE UNIT, MAJOR OPERATING TRANSIENTS
2 EXPERIMENTAL TESTS FOR DIFFERENT PURPOSES (ANALYTICAL TESTS)
3 PWR MOCK-UP TESTS (system loops)
4 THERMOHYDRAULIC CODES STUDIES (REFERENCE CODES)
5 SIMULATORS
6 VALIDATION OF CONTROL OPERATIONS
7 VERIFICATION
8 QUALIFICATION
9 Figure 1: Logic chart showing how PWR transient calculations are mutually validated.
THE RELIABILITY OF THE SIMULATORS: evaluation paths

1. TEST AT THE UNIT
   MAJOR OPERATING TRANSIENTS
   (2)
   (5) SIMULATORS real-time calculations

2. ANALYTICAL TEST
   THERMOHYDRAULIC REFERENCE CODES
   (3)

3. PWR MOCK-UP TEST
   (system loops)
   (4)

Verification
Qualification

CSNI / PWG1 / Task n°5
IPSN/DES - 18th Sept 1995
THE RELIABILITY OF THE SIMULATORS: transients selection matrix

<table>
<thead>
<tr>
<th>SYSTEM STATES</th>
<th>TRANSIENTS family 1</th>
<th>P</th>
<th>TRANSIENTS family 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Distorsion in flux</td>
<td>core</td>
<td>X</td>
<td>core</td>
</tr>
<tr>
<td>- Natural convection</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>etc..</td>
<td>...</td>
<td></td>
<td>...</td>
</tr>
<tr>
<td>Dewatering</td>
<td>SG</td>
<td></td>
<td>SG</td>
</tr>
</tbody>
</table>

NEW MATRIX TACKING INTO ACCOUNT COUPLING SIMULATED CONTROL OPERATION AND THERMOHYDRAULIC MODELLING
# TABLE III
PWR Transient State Matrix Summary

<table>
<thead>
<tr>
<th>Transient States</th>
<th>3.2 Loss of Load</th>
<th>3.3 Excess Heat Removal</th>
<th>3.4 Loss of Feedwater</th>
<th>3.5 Loss of Flow</th>
<th>3.6 Loss of Coolant</th>
<th>3.7 Miscellaneous Transients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactor States</strong></td>
<td></td>
<td></td>
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<tr>
<td>Natural circulation</td>
<td>X</td>
<td>X</td>
<td>4X</td>
<td>2X</td>
<td>2X</td>
<td></td>
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<tr>
<td>Loss of natural circulation</td>
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<tr>
<td>Two-phase flow</td>
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<tr>
<td>Imperfect mixing in plenum</td>
<td>X</td>
<td></td>
<td></td>
<td>11X</td>
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<td>Upper head steam void</td>
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<td>Occurrence of departure from nucleate boiling</td>
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<tr>
<td>Inadequate core cooling</td>
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<tr>
<td>Reestablish core cooling</td>
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<tr>
<td>Cladding-water reaction</td>
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<td>Power-operated relief valve open</td>
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<td>X</td>
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<tr>
<td>Safety valve open</td>
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<tr>
<td>Two-phase flow through valve</td>
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<tr>
<td>High pressure</td>
<td>5X</td>
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<td>2X</td>
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<td>Low pressure</td>
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<td>9X</td>
<td>X</td>
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<tr>
<td>High level</td>
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<td>X</td>
<td>4X</td>
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<tr>
<td>Low level</td>
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<td>8X</td>
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<tr>
<td>Dry</td>
<td>5X</td>
<td>X</td>
<td>2X</td>
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<tr>
<td>Solid</td>
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<td>Nonequilibrium conditions</td>
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<td>4X</td>
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<tr>
<td>Primary side natural circulation</td>
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<td>X</td>
<td>4X</td>
<td>3X</td>
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<td>Primary side two phase</td>
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<tr>
<td>Primary side reflux condensation (UTSG)</td>
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<td>Boiling/condensing once-through steam generator</td>
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<td>Secondary side excess inventory</td>
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<tr>
<td>Partial U-tube uncover</td>
<td></td>
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<tr>
<td>Dry secondary side</td>
<td></td>
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<tr>
<td>Change in heat transfer regime</td>
<td>3X</td>
<td>3X</td>
<td>3X</td>
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<td>Use of auxiliary feedwater</td>
<td>5X</td>
<td>5X</td>
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<td>Atmosphere dump or turbine bypass</td>
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<td>Safety valves open</td>
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<td>SG tube rupture</td>
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<td>Oscillatory mode (UTSG)</td>
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<td>Dry primary side</td>
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<td><strong>Reactor Coolant Pump States</strong></td>
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<td></td>
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<tr>
<td>Cavitation or two-phase flow</td>
<td>3X</td>
<td>X</td>
<td>4X</td>
<td>11X</td>
<td>4X</td>
<td>2X</td>
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<td>Pump trip and coastdown</td>
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<tr>
<td>Rotor seizure</td>
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<tr>
<td>Reverse flow</td>
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<td><strong>Reactor Coolant Piping States</strong></td>
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<td>Two-phase flow</td>
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<td>Flow regime changes</td>
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<td>Flow-through break</td>
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<tr>
<td>Reverse flow</td>
<td></td>
<td>X</td>
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</tbody>
</table>

(Continued)
OPERATOR'S CHOICES OF PROCEDURE AND PARTS IN THE OPERATING DOCUMENTS, DEPENDING ON THE FIDELITY AND SIMULATOR TYPE
OPERATOR'S MENTAL REPRESENTATION OF DYNAMICS MODES DEPENDING ON THE SIMULATOR TYPE

COHERENCE OF THE DRAFTING OF OPERATING DOCUMENTS WHICH ARE CONCEIVED WITH STUDY SIMULATORS AND OPERATOR'S TRAINING WITH FULL SCOPE SIMULATOR
Task 5: Role of Simulators in Operator Training

SIMULATOR FIDELITY ISSUES

1.0 Definition of Issues

Fidelity Requirement

In 1982, through Section 306 of the Nuclear Waste Policy Act, the U.S. Congress directed the U.S. Nuclear Regulatory Commission (NRC) to establish, among other things, "simulator training requirements for applicants for operator licenses and for requalification programs." In 1987, NRC published final amendments to Part 55 of Title 10, Code of Federal Regulations (10 CFR Part 55), entitled "Operators' Licenses." The simulation facility has been considered to be the traditional "full-scope" control room, although limited-scope and part-task simulation devices may be incorporated in the simulation facility. The regulations assume simulator fidelity and encompass simulator design, testing, and usage for initial and requalification examinations and on-the-job requalification training.

Simulator fidelity is perhaps the most abstract "component" in the matrix of simulator requirements. American National Standard Institute/American Nuclear Society ANSI/ANS 3.5, "Nuclear Power Plant Simulators for Use in Operator Training and Examination," has not previously defined fidelity. The 1993 revision of ANSI/ANS 3.5 offers a definition of "physical fidelity" as a measure of the degree of similarity between the simulator and the reference unit with respect to the replica hardware. Fidelity, however, is naturally the goal of the software simulator development process, thus, the redundant and often exhausting efforts required by software scope, verification to software design, validation of program performance to actual plant response or best estimate performance, and periodic testing to confirm sustained fidelity in a changing environment. Fidelity is essential for effective and valid simulator training and examination programs.

2.0 Current Practices

References to simulator fidelity can be found in the Code of Federal Regulations, the regulatory Guides, the ANSI/ANS standards, the NUREGs, the Examiner Standards, and NRC inspection procedures. Figure 1 depicts the relationship between these documents and ties them to the processes of initially designing and subsequently maintaining a simulation facility. It may be noted that "Simulator Fidelity" appears along the critical path to the examination and training application.

In 10 CFR Part 55, the bases are given for the regulatory environment surrounding simulators. Specifically, the requirements of 10 CFR §55.45, "Operating Tests," describe the type of operations that the simulation facility must be able to support. If fidelity discrepancies exist that would greatly hinder or limit the ability of the licensee to conduct an examination on the simulation facility such that the requirements of 10 CFR 55.45 cannot be met, operating examinations shall not be conducted until the facility licensee has corrected the discrepancies and recertified the simulator.
ANSI/ANS 3.5 provides methods acceptable to the NRC staff for a facility licensee (1) to certify a simulation facility consisting solely of a plant-referenced simulator or (2) to obtain approval of a simulation facility for use in portions of reactor operator and senior operator license examinations.

Regulatory Guide 1.149 endorses ANSI/ANS 3.5 and describes methods acceptable to the NRC staff for complying with those portions of 10 CFR Part 55 regarding (1) certification of a simulation facility and (2) application for prior approval of a simulation facility for testing. Regulatory Guide 1.149 specifically describes the Commission's exceptions to ANSI/ANS 3.5.

The simulator scope and design and the verification and validation processes are closely related to the acceptability of the simulation facility for training and examination. NRC has two significant concerns in this area: (1) to validate features initially and (2) to periodically test features that are used in the training and examination program. Validation and periodic testing requirements entail related documentation requirements that are a function of the purpose of the test. Validation tests during initial construction and following significant software changes involve larger quantities of procedural data than periodic tests that are intended to demonstrate general operability. ANSI/ANS 3.5 and Regulatory Guide 1.149 do not impose minimum procedural documentation requirements for validation testing.

NRC Form 474, "Simulation Facility Certification," recognizes either ANSI/ANS 3.5-1985 or ANSI/ANS 3.5-1993 as an option for certification. NRC Form 474, which was used to initially certify simulation facilities, can be used to update testing schedules and to submit the quadrennial test reports required by 10 CFR 55.45. More importantly, NRC Form 474 is used to describe exceptions to or deviations from ANSI/ANS 3.5.
NUREG-1262, "Answers to Questions at Public Meetings Regarding Implementation of Title 10, Code of Federal Regulations, Part 55 on Operators Licenses," supplements the guidance in Regulatory Guide 1.149. Many of the relationships between the simulator development process and the regulatory requirements discussed in this paper are addressed in a practical question-and-answer format in NUREG-1262.

NUREG-1258, "Evaluation Procedure for Simulation Facilities Certified Under 10 CFR 55," serves as a guideline for the NRC staff's evaluation of a simulation facility. NUREG-1258 comprises a four-part, multi-discipline inspection of a simulation facility using the criteria of ANSI/ANS 3.5 as endorsed by Regulatory Guide 1.149. The purpose of the inspection is to verify the adequacy of the simulation facility to meet and support the requirements of 10 CFR Part 55. The four parts of the NUREG-1258 procedure are as follows:

- Performance Testing
- Physical Fidelity/Human Factors
- Control Capabilities
- Design, Updating, Modification, and Testing

Normally, a NUREG-1258 review is conducted in two phases, offsite and onsite. The offsite review is used as a prelude to and a screening for the onsite review. Time constraints or limited concerns may obviate the separate offsite review or the onsite option.

Since implementation of 10 CFR Part 55 in 1987, the Commission has maintained that simulation facilities must meet more than the requirements of the operating test as outlined in 10 CFR 55.44. Simulators must also avoid misleading or negative training, which could result from the use of a simulation facility that does not correctly portray plant response to malfunctions. Although they follow ANSI/ANS 3.5, individual periodic testing programs vary greatly.

NRC does not have specific expectations as to the extent of testing and documentation associated with validation and periodic testing. The scope of test procedures and associated test documentation is guided by ANSI/ANS 3.5 and facility administrative procedures and is under the control of the facility program.

NRC examiners routinely observe simulator performance as part of the operator licensing program. Their comments are included as an attachment to individual examination reports, which are placed in the public document room. Table 1 summarizes approximately 1,100 comments from examiners during 1989-1994.

Simulator performance discrepancies persist in the areas of the nuclear steam supply system (NSSS) and major balance-of-plant (BOP) design. More importantly, the rate of occurrence of these discrepancies has remained constant over the monitored period in spite of substantial improvements in simulator computing capacity, software development
tools, and model sophistication. In many cases, NSSS and major BOP discrepancies can be noted following significant software modifications, thereby indicating a need to ensure effective implementation of the verification and validation portions of software management, even if newer and better models using better tools are being introduced.

Table 1  Simulator observations by NRC examiners, 1989-1994

<table>
<thead>
<tr>
<th>Type of observation</th>
<th>Number of comments</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NSSS) dynamic response discrepancies in normal operations</td>
<td>98</td>
<td>9</td>
</tr>
<tr>
<td>NSSS dynamic response discrepancies in normal operations</td>
<td>91</td>
<td>8</td>
</tr>
<tr>
<td>NSSS logic response discrepancies</td>
<td>96</td>
<td>9</td>
</tr>
<tr>
<td>Balance of plant (BOP) dynamic response discrepancies</td>
<td>78</td>
<td>7</td>
</tr>
<tr>
<td>BOP logic response discrepancies</td>
<td>69</td>
<td>6</td>
</tr>
<tr>
<td>Display systems (plant process computer, etc.) discrepancies</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>Radiation monitor program discrepancies</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>Instructor station errors</td>
<td>42</td>
<td>4</td>
</tr>
<tr>
<td>Hardware/computer problems</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Software/ executive program problems</td>
<td>58</td>
<td>5</td>
</tr>
<tr>
<td>Hardware/panel components problems</td>
<td>54</td>
<td>5</td>
</tr>
<tr>
<td>Physical fidelity discrepancies</td>
<td>95</td>
<td>9</td>
</tr>
<tr>
<td>Miscellaneous problems</td>
<td>96</td>
<td>8</td>
</tr>
<tr>
<td>Documentation discrepancies</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Lack of repeatability</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>No problems reported</td>
<td>93</td>
<td>8</td>
</tr>
<tr>
<td>Lack of capability - American Nuclear Society (ANS) 3.5 required</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Lack of capability - examiner preferred</td>
<td>75</td>
<td>7</td>
</tr>
</tbody>
</table>

The NRC staff does not quantitatively assess discrepancy counts as a measure of simulator fidelity or of the ability to meet 10 CFR Part 55 requirements, although persistently high discrepancy counts do sometimes attract attention. In such cases, the staff usually contacts the facility simulator supervisor and reviews the nature of the
outstanding discrepancies to discern fundamental problems that could hinder an examination. In some cases, NRC representatives from Headquarters might visit a simulation facility to evaluate specific concerns in more depth with the simulator support staff. Typically, an NRC simulator evaluation involves a review of the following items:

- Documentation of training value assessments used to define required software changes.
- System performance tests performed after resolution of the discrepancy.
- Integrated plant performance tests performed after resolution of the discrepancy.
- Comparison of system performance test results before and after resolution of the discrepancy.
- Selected system discrepancy report history and disposition
- Related system discrepancy report history and disposition
- Changes or adjustments to the facility’s periodic performance test schedule
- Software documentation changes

3.0 Further Developments

A simulation facility is not limited to the control room replica. The regulatory definition provides for other simulation devices. Part-task or limited-scope simulators, as well as other devices, may be included in the training and examinations programs and may be used for examination and on-the-job requalification training if they are defined on NRC Form 474. In most cases this definition would entail two exceptions to the certification statements of the NRC Form 474: (1) the simulation facility might no longer consist solely (emphasis added) of a plant-referenced simulator and 2) the simulation facility would not, at least in part, meet the guidance of ANSI/ANS 3.5 because ANSI/ANS 3.5 specifically excludes limited-scope and part-task simulators from its scope. NRC does not consider exceptions such as these to be problems but does expect fidelity to be comparable to that addressed by ANSI/ANS 3.5.
Paks Nuclear Power Plant
Simulator Centre

DEVELOPMENT AND USAGE OF A
COMPUTER BASED ASSESSMENT TECHNIQUE
FOR SIMULATOR TRAINING

Contents:

Introduction
Functional Description
An example
Computer environment
Experience
DEVELOPMENT AND USAGE OF A
COMPUTER BASED ASSESSMENT TECHNIQUE
FOR SIMULATOR TRAINING

Introduction

A demand concerning the usage of simulator for operator assessment has come up since we started the operator training on it. In the beginning we had the following tools for evaluation:

- event lists and parameter lists generated by the simulator instructor's system
- observations by the instructor and the overseer shift supervisor

Owing to the fact that handling of the event and parameter lists (in different form, with different time scale) was quite difficult and the observations were usually subjective, the method did not satisfy all the requirements. The documentation of evaluation was also not satisfactory. After considering all the demands concerning the correct evaluation we started the elaboration of a monitoring system which is aimed to avoid the disadvantages experienced before.

FUNCTIONAL DESCRIPTION OF COPAS
(Computerised OPerator Assessment System)

The source material of the development was the Emergency Operating Procedures (EOP), because these are in a quite accurate form, suitable for computer processing.

An EOP is handled like a logical network of the statuses and events. In fact, the system in real-time mode follows the event-flow on the simulator during a transient, and compares it with the pre-definite events. The start of the program is triggered by an instructor's action, which causes the transient/accident, giving the zero time. In brief, we can get the following services:

- It demonstrates each key step which has to be taken by the operators during a transient. These steps are in logical sequence and in AND/OR connection, which is determined by the EOPs. A key step can be operating one piece of equipment (e.g. stopping a pump, or try to close a valve) or operating all of the elements belonging to an equipment group (e.g. full isolation of a loop - including the auxiliary systems too -, which involves the closing of 7 valves one by one).
During the scenario:

- Besides the name of the given operation the time of execution also appears on the logical diagram. It can be the starting time or the completion time of the operation.
- If the sequence of execution is not correct, the time appears in a different colour.
- There will be a warning sign next to the names of the operations which have not been executed by the time then the scenario is over.
- It demonstrates the change in the time of the most important parameters during the transient.
- It indicates if the essential parameter limits are exceeded.
- If required it gives a message if limitations or instructions are violated.

After each session the instructors with the overseer shift supervisor fill in a questionnaire by the logical diagram and their observations (encl. 1). This questionnaire and the hard-copy of the logical diagram are the documentation of the session.

AN EXAMPLE SCENARIO

The example shows the main functions of the system. The triggering event was a steam generator tube rupture on the second loop, with an additional malfunction, leakage of a main gate valve, of course on the same loop.

See the static part of the display on the encl. 2., and the results of two different executions on the encl. 3, 4.

The required events are:

- start of an additional make-up water pump (OR connection !)
- stop of the primary coolant pump (on the second loop)
- manual reactor trip (at both channel)
- isolation of the affected loop (closing seven valves)
- disconnection of the 7 bar (auxiliary) steam consumers from the main steam header (closing two valves)
- dividing of the main steam collector (closing three sectioning valves)
- reduction of the primary circuit pressure (opening a valve and a control valve, switching off the heating elements of the pressurizer)
- reduction of the steam to the condenser (opening two control valves) (OR connection!)
- disconnection of the hydroaccumulators from the primary coolant system (closing four valves)
- separation of the damaged steam generator (closing a valve at the steam side)

The displayed measurements are:
- X0YP1OL101 water level in the pressurizer
- X0YP1OL101 pressure of the primary circuit
- X0HUR_ATM average of the inlet and outlet temperature of the six loops

Levels, time markers and messages which are used:
- on the first diagram:
  * I = 470 mm; protection level for the emergency core cooling system
- under the first diagram:
  * The coloured bar graphs show the operating periods of the make-up water pumps. (X0TK42D001,2,3)
- on the second diagram:
  * p = 100 bar; pressure level according to the operating procedure. The protection level for the emergency core cooling system is on 92 bar (p<92)
  * The first red time marker belongs to the message; "T<255 sönt". It means, that the temperature of the primary circuit lower then 255 centigrade, and the p<92 bar protection signal is inhibited. The operator can continue the reduction of the pressure.
  * p = 70 bar; when the pressure less then 70 bar, the operator may disconnect the hydroaccumulators.
  * The first green time marker shows the disconnection of the hydroaccumulators.
  * p = 50 bar; when the pressure is less then 50 bar, the operator may to separate the steam generator.
  * The second green time marker shows the separation of the steam generator.
  * The second red time marker belongs to the message; "GF bizt. szel.". If they are existing, it means that the separation of the steam generator was a bit early because there is a protection level on 52 bar to open the safety valve of the steam generator.
- on the third diagram:

* T = 245 centigrade; temperature level according to the operating procedure. The operators may overcool the primary circuit, when the boron concentration is greater or equal to a value, which is determined by the reactor physics.

* The red time marker belongs to the message; "bór:". They appear when the average temperature overcrosses the 245 centigrade boundary, including the numeric value of the boron concentration.

COMPUTER ENVIRONMENT

The COPAS is installed on the simulator computer system (2 * VAX 11/782), allowing the direct access to the whole surface of information (e.g. to read the common memory and the event log of the operator's and instructor's actions), and to make possible the usage of the original Finnish (NOKIA/AFORA) simulator program development system (SPDS).

A few specific details are:

- operating system: VAX/VMS 4.7
- language: Fortran, with SPDS precompiler
- output device: DEC VT340 terminal with DEC LJ250 printer, using ReGIS protocol
- Fortran --> ReGIS graphics library and graphics editor are own developments.

EXPERIENCE AND THE STATE OF IMPROVEMENT

The development of the tool was started in the middle of 1990. We have been using it building in the refreshment training since the beginning of 1991. Actually the monitoring system is elaborated for 25 different transients chosen from the EOPs (See encl.5).

From this set 5-6 transients are selected by a random-based computer program for each shift on the training course. This way after the third training cycle we have the experience of about 400 runs to summarise. (May 1992)
According to the experience gained till now the system provides a faster, more exact and more objective evaluation than the method used before.
<table>
<thead>
<tr>
<th>Transient code:</th>
<th>Date:</th>
<th>Shift:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition of transient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in time</td>
<td>late</td>
<td>no recognition</td>
</tr>
<tr>
<td>Errors in the sequence of the execution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>number:</td>
<td>serious:</td>
<td></td>
</tr>
<tr>
<td>Missing operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>number:</td>
<td>serious:</td>
<td></td>
</tr>
<tr>
<td>Exceeding limits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>number:</td>
<td>serious:</td>
<td></td>
</tr>
<tr>
<td>Co-operation of the control room personnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>good:</td>
<td>unsatisfactory:</td>
<td></td>
</tr>
<tr>
<td>Co-operation between control room personnel and field operators (instructor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>good:</td>
<td>unsatisfactory:</td>
<td></td>
</tr>
<tr>
<td>Using of adequate information tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>good:</td>
<td>unsatisfactory:</td>
<td></td>
</tr>
<tr>
<td>Assessment of whole scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>good</td>
<td>satisfactory</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructor:</td>
<td>Shift supervisor:</td>
<td></td>
</tr>
</tbody>
</table>
NPP Paks Simulator Center
Eop code: PR42-3-04

SG tube rupture without isol 00:00

Stop of PCP 01:44
Manual reactor scram 01:55

Isolation of the loop
Closing of the 7 bar steam sys 09:44

Reducing of the primary press
Reducing to the condenser

Sect. of the main steam coil

T < 255 °C

X0TK42D001, D002, D003

Sectioning of the SG 22:35

Sect. of the hydroaccum.-s 17:16

encl.3.
NPP Paks Simulator Center
Eop code: PR42-3-04

SG tube rupture without isol 00:00

Stop of PCP 02:03
Manual reactor scram 02:09

Isolation of the loop 03:40
Closing of the 7 bar steam sys 03:10

Reduction of the primary press 05:57
Reducing to the condenser 05:48

Sect. of the main steam coll 02:54

T < 255 °C

X0TK42D001,D002,D003

Sect. of the hydroaccum.-s 25:18
Sectioning of the SG 29:56

encl.4.
List of transients

1) Control rod drop
2) Loss of 3 PCPs
3) Loss of 4 PCPs
4) Loss of voltage
5) Trip of last turbine
6) Trip of one turbine
7) One generator trip when the turbine stays in nominal speed
8) Loss of load
9) Main transformer trip
10) Trip of one main feedwater pump without starting of the reserved one
11) Trip of all the main feedwater pumps
12) Loss of PCP intermediate cooling system
13) Loss of control rod intermediate cooling system
14) Small leakage of primary circuit
15) Large leakage of primary circuit (HPIS start up)
16) Spurious opening of the pressurizer safety valve
17) Steam generator tube rupture
18) Steam generator tube rupture without possibility of isolation. (The main gate valve sticks in intermediate position.)
19) Rupture of the steam generator steam line outside the containment
20) Rupture of the main steam collector
21) Spurious opening of the steam generator safety valve
22) Rupture of the main feedwater collector
23) Rupture of the feedwater line inside the containment
24) Spurious start of the emergency core cooling system ($p_{cont.} > 1.1$ bar)
25) Spurious start of the emergency core cooling system ($p_{primary circ.} < 92$ bar)