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NKA/KRU PROJECT ON OPERATOR TRAINING, CONTROL ROOM DESIGN AND HUMAN RELIABILITY

TECHNICAL REPORT ON OPERATOR TRAINING

A Joint Scandinavian Research Project
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1. INTRODUCTION

The Scandinavian project on nuclear power safety has been divided into three branches, Human Engineering in the Control Room, Human Reliability and Operator Training. A number of reports and working papers has been produced within the project related to Operator Training. The aim of this presentation is to summarize this work.

Although all members of the project have taken part in all project activities, Operator Training studies, specifically, have been performed by the Technical Research Centre in Finland and Ergonområd AB and Studsvik Energiteknik AB in Sweden. These studies have been connected with the development of an operator training simulator and a training programme for the Loviisa power plant in Finland. In Sweden the studies, which were ordered by the Nuclear Power Inspectorate, have primarily been connected with the development of competency requirements for nuclear power plant operators. Most of this work on operator competency was actually carried out outside the NKA/KRU project, but it was to a large extent based on ideas and techniques formed in the Scandinavian project.

The results and experiences reported are presented in two ways:

. A technical report of the work
. A user oriented guideline (in Swedish)

The present report is of a technical nature. It is divided into a number of topics, which are all related to each other and can be considered subsections under the subject Operator Training. The work done in the NKA/KRU project within each topic is summarized and reports produced on each topic are given in the reference list in the end of each summary. Furthermore, a complete list of references including all reports and working papers produced on Operator Training in the project is included in a separate report (NKA/KRU-(81)14.

The following topics are covered:

- System and procedure description
- Job analysis for training design
- Training content analysis
- Training system design
- Training simulator use and evaluation
- Training session design
- Instructor tasks in simulator training

The planning of operator training has to start with a definition of the job context. A technique for this is reported in the section "System and Procedure Description", which is a main input to "Job Analysis". The job analysis will result in a job description in terms of typical tasks. The typical tasks are analysed further with regard to their knowledge and skill content and this is reported in the section on "Training Content Analysis". The student operator will acquire the training content through a training system. The work on a "Training System" is reported in the following section. Training simulators are an important means in operator training. Some aspects of these are given in "Training Simulator Use and Evaluation". Some advice is given in the "Training Session Design" and, finally, the "Instructor's Tasks" are described in the last section.

The work of the Scandinavian project NKA/KRU on control room design and related topics has been conducted to meet the special requirements of nuclear power, e.g. concerning operator competency and training. It is quite clear, however, that the results and experiences have a wider applicability than to nuclear power plant operation and operators alone.

2. SYSTEMS AND PROCEDURES DESCRIPTION

A description of a nuclear power plant and its operation from the operator's point of view was produced in order to supply

the project aimed at specifying and designing a program for the training of nuclear power plant operators with input data.

The very basic goal of a nuclear power plant is to produce electric power. A nuclear power plant is usually operated at full power and variations in the demand for energy are usually taken care of by controlling the output of other conventional or hydropower plants. The main goal can be expressed in terms of plant availability. However, because of the radioactive properties of the nuclear process, safety must also be regarded a main goal. The design of the technical systems and the associated procedures has taken place starting from these very basic requirements on availability and safety.

As an overall aid to present the different operational modes of the plant, a state diagram was adopted. In such a diagram the circles represent system states and the arrows between the circles transitions from one state to another. An example of such a state diagram is given in Appendix 1.

From our experience, we found that the state diagram is a useful aid, and it has been tested for systematic planning of operator training in the Swedish nuclear power stations (1) and (2). However, when it comes to representing more detailed information, the state diagram has limitations. The transitions between different states represent overall tasks for the operating crew and constitute one dimension in the operational space of the plant.

A procedure is defined here as a set of rules for controlling the actions of the operator during a planned transition from one state to another.

The main systems with which the operator has to interact when fulfilling his task is another dimension for description. The following main systems were identified:

- Reactor system
- Turbine system
- Electrical system

- Instrumentation and control system
- Other technical systems
- Personnel system
- Documentation system
- Operations management system

The descriptions of technical systems and operational procedures had to be formalised and unified in order to facilitate the work of those who plan for operator training. Protocols were designed with this goal in mind.

The protocol for describing technical systems contained the following headings:

- System boundaries
- The purpose of the system
- Requirements on the system
- Domain of operation
- Restrictions in system operation
- Restrictions in plant operation induced by the system
- Instruments in the central control room belonging to the system.

The protocol for describing procedures contained:

- Initial and target state of the plant
- Necessary initial conditions for the procedure
- Operations necessary to move the plant to the target state
- Time range for performing the state transition
- Actions requiring special attention to time.

The protocol for describing technical systems was applied with success during the planning of the training programme for operators at the Finnish Loviisa I nuclear power plant (3). The protocol for describing procedures has not yet been fully used in a real application but is expected to give as good results as the one for technical systems.

A complete description of the operational environment of the operator should also cover the non-technical systems. However,

since the tasks of the operator are dominated by work with the technical systems, the descriptions of the non-technical systems which were already available in the utility or the power station were deemed sufficient and hence no special protocol was designed for this purpose.

The roles of the different members of the operating crew were described in terms of job profiles. In order to produce a structured aid for this work, a matrix shaped form was designed where the matrix elements represented points of interaction between the systems and the operator during the different procedures. By discussing the process in terms of the state diagram when interviewing the operators, the applicable points of interactions were recorded as notes in the matrix form. Information received during the interviews which fell outside this framework was taken care of separately. The further use of this matrix is described in the task analysis part of this report.

References

1. Sjölin, P.G.: A System and Task Description of a Swedish Nuclear Power Plant - Systems, States and Procedures (in Swedish). Studsvik Energiteknik AB, Report Studsvik/RR-78-/12, June 1978. NKA/KRU-P1(78)306.
2. Andersson, H., Sjölin, P.G., and Wirstad, J.: A System and Task Description of a Swedish Nuclear Power Plant - Summary Report (in Swedish). Studsvik Energiteknik AB, Report Studsvik/RR-78/11, June 1978. NKA/KRU-P1(78) 305.
3. Tuominen, L., Wahlström, B., and Timonen J.: A System and Task Description of Operating Personnel of Loviisa Nuclear Power Plant. Technical Research Centre of Finland, Electrical Engineering Laboratory, Report 39, Espoo, September 1978. NKA/KRU-P1(78)201.

3. JOB ANALYSIS FOR TRAINING DESIGN

Basic information about operator jobs was collected in a pilot study. Job descriptions in terms of typical tasks were made for all states of plant operation. These job descriptions were prepared with the objective of deriving competency requirements and training content for the operators' jobs.

A special job analysis method was developed and used for operator jobs (e.g., shift supervisor, reactor operator and for turbine operator) at the PWR plant Loviisa 1 in Finland and at the BWR plant Oskarshamn 2 in Sweden ((1) and (2)). In the job analysis method, the job structure found in Figure 3.1 was used. It indicates that the job can be divided into a number of functions which, in turn, can be further divided into subfunctions and tasks. Some of these tasks were called typical tasks. What defines a typical task is described later.

Each job was described with a set of typical tasks. The number of tasks needed to describe the jobs varied from 150 to 300. For both plants the reactor operator and the turbine operator tasks were subsets of the tasks of the shift supervisor. There were also some overlap between the tasks of the reactor operator and the turbine operator. The overlap seemed to be greater at the BWR plant.

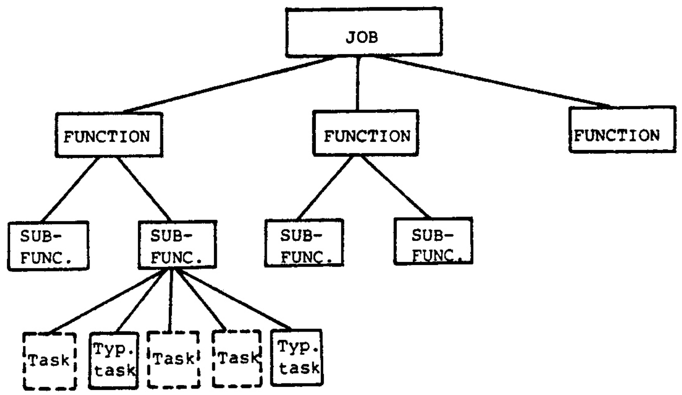

Figure 3.1 Principle job structure for the analysed operator jobs.

For the BWR study, tasks were found under the main functions: Monitoring, Testing, Diagnosing and Evaluating, Manoeuvring, Taking information, Giving information, Collecting information and Planning resulting in a total of eight. The PWR study was structured under the functions: Evaluating, Manoeuvring, Monitoring, Planning and Other tasks or five in all. Comparisons between the typical tasks in the two descriptions showed that typical tasks under the function "Other tasks" in the PWR study were fairly similar to those under the Testing, Taking, Giving and Collecting information functions in the BWR study.

Typical tasks belonging to all the main functions mentioned above were collected for all major states and state transitions in plant operation. A simplified state diagram is shown in Figure 3.2. The detailed state diagram which was used for the job description at the Oskarshamn BWR power station is found in Appendix 1.

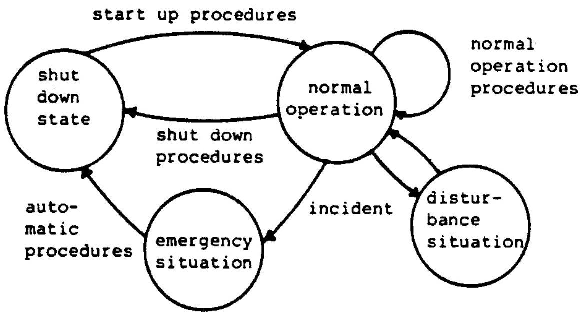

Figure 3.2 A simplified state diagram for a nuclear power station showing major states and procedures i.e. the mission profile.

Thus the final set of typical tasks covered all important modes of plant operation. The resulting job descriptions were considered to be sufficiently representative to allow valid conclusions about the competency requirements for the jobs to be made.

Typical tasks are, however, not equally difficult to learn, nor are they equally difficult to perform or equally important. An easy task may be important and vice versa. Each typical task was rated on these aspects. In the BWR study, the performance requirement was rated on a 3-level scale. For the PWR study, complexity and importance were rated, also on 3-level scales.

<u>Application of the results</u>

The results of the studies were not only the job descriptions as such. Experience was also gained in applying the methods which, among other things, led to improvements in carrying out the job analysis. The methodological results are reported separately ((3) and (4)).

In Finland, the job descriptions have been used for deriving training objectives for the Loviisa training simulator. In Sweden, the job descriptions have been used to derive knowledge requirements for operator jobs at Oskarshamn 2.

In addition, the improved job analysis method has been applied on other nuclear power plants in Sweden and all the resulting job descriptions have in turn been used to derive demands on skills and knowledge for operators in Swedish nuclear power plants.

References

1. Tuominen, L., Wahlström, B., and Timonen, J.: A System and Task Description for the Operating Personnel of the Loviisa Nuclear Power Station. Technical Research Centre of Finland, Electrical Engineering Laboratory, Report No. 39, Espoo, September 1978. NKA/KRU-P1(78)201.
2. Andersson, H., Bäck, P., and Wirstad, J.: Job Analysis for Training Design and Evaluation. Description of a Job Analysis Method for Process Industries. Ergonområd AB, Report No. 6, January 1979.
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4. Timonen, J.: Job Analysis for Training Planning and Evaluation. NKA/KRU working paper, NKA/KRU-P1(79)204.

4. TRAINING CONTENT ANALYSIS

The knowledge content of the operator job has to be defined. The operator job has been analysed according to the job analysis technique described in the previous section. It means that the job is defined by a large number of operator tasks which are spread over all working areas of the job. This set of so called typical tasks - between 150 and 250 for the three operator jobs, shift supervisor, reactor operator and turbine operator - defines the knowledge and skills needed to perform the job successfully. The principle relationship between typical tasks and the body of knowledge and skills is found in Figure 4.1.

The knowledge and skills can be expressed in a number of ways. Within the Swedish work concerning operator competency and training, a knowledge and skill terminology which is plant oriented was generated (1). The reason for plant oriented terms is usability; i.e., the terms must be understood and accepted by operators, supervisors and instructors of the plant, the utility or other officers involved in operator training. There are three main sets of terms used.

I. Knowledge categories.

II. Knowledge objects which represent distinctive units about which one has knowledge.

III. Knowledge levels which express the depth of the knowledge.

1. Plant layout knowledge which is defined through two features, (a) the name of the plant and its different parts according to the system list and (b) the localities of the plant.

2. Component knowledge. There are some components which are found in a large number over the plant; e.g., pumps and valves. The knowledge of components are defined through

three features, (a) the function of the component, (b) its construction and (c) its capacity and its limitations.

3. Manoeuvring knowledge. This is defined through the "superficial" knowledge of the control room; i.e., the displays and controls. The knowledge related to controlling the process will be found in category 4. Static System Knowledge and 5. Dynamic Process Knowledge. Manoeuvring knowledge is defined through (a) localization of displays or controls in the control room, (b) its operations and (c) tests carried out on the control room equipment.

4. System knowledge is the theoretical knowledge about each system of the plant with regard to (a) function, (b) construction, and (c) flows and supplies.

5. Process knowledge is the theoretical and practical knowledge defined through (a) co-functions of systems and (b) control functions related to the functions and (c) critical parameters related to different states and transitions.

6. Reactor core knowledge is actually a static and dynamic system knowledge which has been separated out because of its importance. The static aspect is defined through reactor physics and the dynamic through core kinetics.

7. Knowledge in localizing and identifying disturbances. For each plant, a large number of individual and combined disturbances which can take place in the plant have been described and analysed. This knowledge category, which is both theoretical and practical, concerns (a) the identification of the disturbance and (b) the ability to predict its consequences.

8. Knowledge on measures at disturbances. It is a practical knowledge defined through (a) the use of checking procedures when a disturbance has happened, (b) how to organize actions against the disturbance and (c) how actions are carried out.

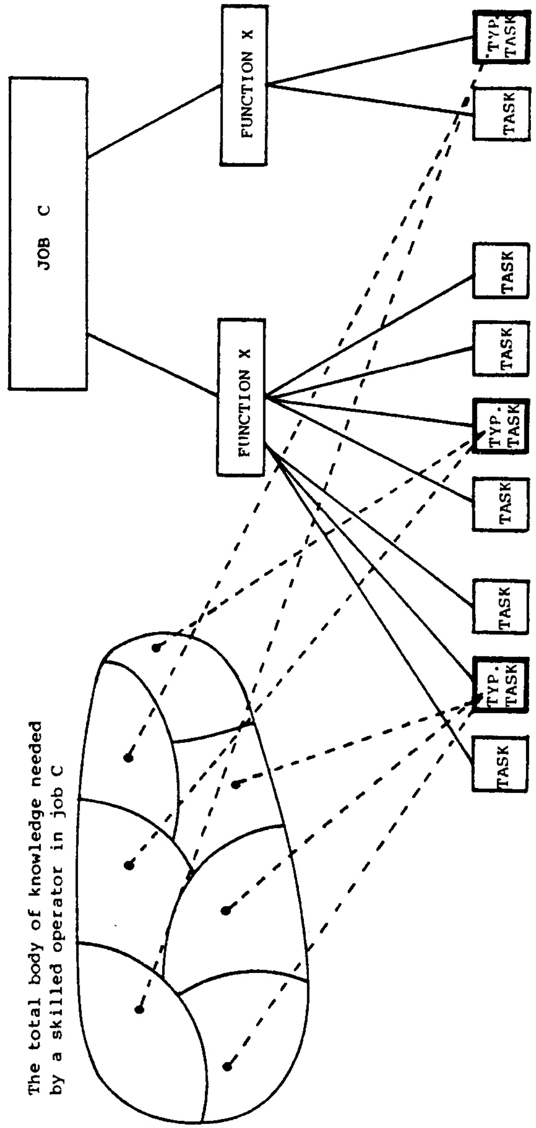

Figure 4.1 Principle for relations between typical tasks of a job and the body of knowledge and skills needed for the job.

9. Knowledge on measures at fire, serious accidents and sabotage. This is also a practical knowledge as the previous knowledge category. It is also defined through (a) checking, (b) organizing actions and (c) action taking.

10. Organizational knowledge. It is knowledge about the plant organization concerning (a) plant units, jobs and personnel and (b) competency and responsibility related to units and personnel.

11. Administrative knowledge concerns the documents used in the plant. These can be divided into those documents which the operator has to fill in and those which are steering or guiding his work. The category is defined through knowledge on (a) content of the document, (b) its placement and (c) its use.

12. Knowledge on safety regulations is actually a subcategory to 11. Administrative knowledge. It is divided into (a) content of safety regulations and (b) knowledge about when a regulation should be applied.

13. Knowledge on supervision. This knowledge category has been divided into four parts, (a) initiation, (b) instruction, (c) motivation and (d) control and feedback.

There are five categories of knowledge objects. Two of these categories do not represent objects in a physical sense. But they are all distinctive entities of the plant which are available in design or operation of the plant.

1. Technical systems

2. Organizational units or persons

3. Documents

4. Disturbances

5. Actions

The depth of the knowledge or skill is defined in three levels

3. Thorough knowledge or skill means learning to the extent that the material can be activated without use of instruction, advice or any other aid.

2. Knowledge or skill means that the material can be activated with use of instruction, advice, etc.

1. Orientation means familiarity with the material normally without demand on performance.

A procedure has been developed to transfer a typical task into knowledge content using these terms. The transfer is very much based on expert judgement. Thus, it has to be carried out by experienced operators or someone else who is familiar with the operation and the technical, organizational and regulatory aspects of the plant.

Operator knowledge and human information processing

It is obvious that there are interesting functional relations between operator-process interaction on one side and operator training on the other. This relationship can be expressed in the following way. The operator will be prepared through a combination of basic education, job training and previous work experiences to be able to steer and monitor the process. The means for the operator to "look into" the process is the operator process interface, i.e. the presentation of static and dynamic process data on instruments, recorders, VDU-pictures etc., the presentation of alarms, "historical" data etc. as well as the controls in the control room provided to influence process parameters and states. The problem of finding good solutions in the exchange of information between the operator and the process is complicated. It requires among other things a thorough understanding of human information processing. As human information processing is dependent on previous operator training and experience, there is a definite need to consider human information processing, its control room design consequences and operator training interactively.

This relationship between operator process interaction and operator training could probably be understood better if a common terminology for operator-process interaction and operator training was available.

Operator training is normally considered within a framework of so called training technology. Operator Training in the Scandinavian project, especially the Swedish work on operator competency, represents a modified training technological approach.

A Danish contribution to the NKA/KRU project concerns primarily man-process interaction and a terminology or conceptual structure which is oriented towards human information processing or cognitive psychology has been developed (2) for control room purposes. It has also been utilized in the NKA/KRU project in connection with experimentation on man-process interaction.

A first step has been taken in the KRU-project to related the knowledge terminology to the Risø concepts on human information processing (3). It indicates that there are understandable relations between the knowledge terms on one side and human information processing models and related human performance concepts on the other. Interesting patterns are detected when Plant layout knowledge, Component knowledge, Manoeuvring knowledge, System knowledge, Process knowledge, Reactor Core knowledge, Knowledge on localizing and identifying disturbances, Knowledge on measures at disturbances and Knowledge on measures at fire, accidents and sabotage are related within a matrix to models of Physical form, Physical function, Functional structure, Abstract function, Functional meaning, Skill-based behaviour, Rule-based behaviour and Knowledge-based behaviour.

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1. Wirstad, J. and Andersson, H.: Competency for Nuclear Power Operators. A System for the Acquisition and maintenance of operator competence in Nuclear Power Plants. Ergonområd AB, Report No. 16, October 1980.
2. Rasmussen, J.: On the Structure of Knowledge - A Morphology of Mental Models in Man-Machine System Context. Risø, Report Risø-M-2192. November 1979.
3. Wirstad, J.: On Knowledge Structures for Process Operators. Ergonområd AB, Working paper. January 1981.

5. TRAINING SYSTEM DESIGN

A system concerning operator competency and training has been defined for control room operators (1) and includes the following parts:

- Recruitment requirements on the operators
- Requirements concerning operator knowledge and skills
- Requirements concerning job training programme with associated courses for basic job training, retraining and continued job training
- Training organization requirements
- Follow-up requirements

The requirements are met at each power station via recruitment procedures, operator training arrangements and follow-up procedures which also take the local conditions into consideration.

The basis for the training system are the job analyses and descriptions of the control room operator jobs mentioned in an earlier section of this report. The job description divides the job into a number of subactivities or functions. Under each subunit there are a number of typical tasks. A set of 150-250 typical tasks defines the job. If the operator knows these tasks he knows practically all tasks of the job.

The typical tasks have been analysed for their knowledge and skill content. This has been described in the previous section of this report. With a special procedure, the typical tasks have been transferred into knowledge and skill terms and accumulated into a description of the knowledge and skill content of the job.

The typical tasks and the description of their knowledge and skill content were analysed in order to define recruitment requirements for operator students. The recruitment requirements were expressed in terms of an educational speciality and/or educational level which are found in the public school system. There may be recruitment requirements on practical experiences as well.

<u>Job training programme and courses</u>

The knowledge and skill content required in the operator job will be met by a job training programme. This is divided into three parts:

- Basic job training
- Operator retraining
- Continued job training

The basic operator training consists of a number of courses which will lead to a competent control room operator. High degree of process control automation and a relatively low frequency of disturbances in operator jobs means that on-the-job activities alone are not enough for the operator to maintain knowledge and skills. The operator must, therefore, annually go through special retraining courses and courses on continued job training. The latter concerns new things in the plant, i.e. technical, organizational, regulatory changes and last but not least operational experiences which the operator must know about in order to be as competent as possible. The need for rehearsal of previously learned material and a need for wider and deeper operator knowledge and skills is something typical for jobs in relation to complex processes. This need should be considered carefully when planning operator job training.

The goal of each course of the operator job training programme is expressed in typical tasks, if possible, and is specified in knowledge and skill terms. There must be harmony between the list of accumulated knowledge and skills which resulted from the analysis of the typical tasks on one side and the goal specifications for all courses on the other.

All courses in the basic job training programme including theory and practice are described in the following terms:

. To whom the course is given

. Course time, i.e. number of days or weeks when the course is given and effective course time

. Type of course, teacher led or self studies

. Who gives the course, internal course or external

. Training aids, e.g. written material, AV-aids or simulator

. Individual measurements to follow-up the performance of the student

. Knowledge categories included in the course

The most suitable order for the different courses is presented in Figure 5.1.

For each course there is a course description according to a common form. These course descriptions are somewhat more detailed than the summary of the training programme mentioned above. But they still represent a brief description of goals, knowledge and skill content, learning media and follow-up measures.

The course description contains the following headings:

. The name of the course:	(a short name which indicates its content)
. Goals of the course:	(if possible in terms of typical tasks with associated performance requirements)

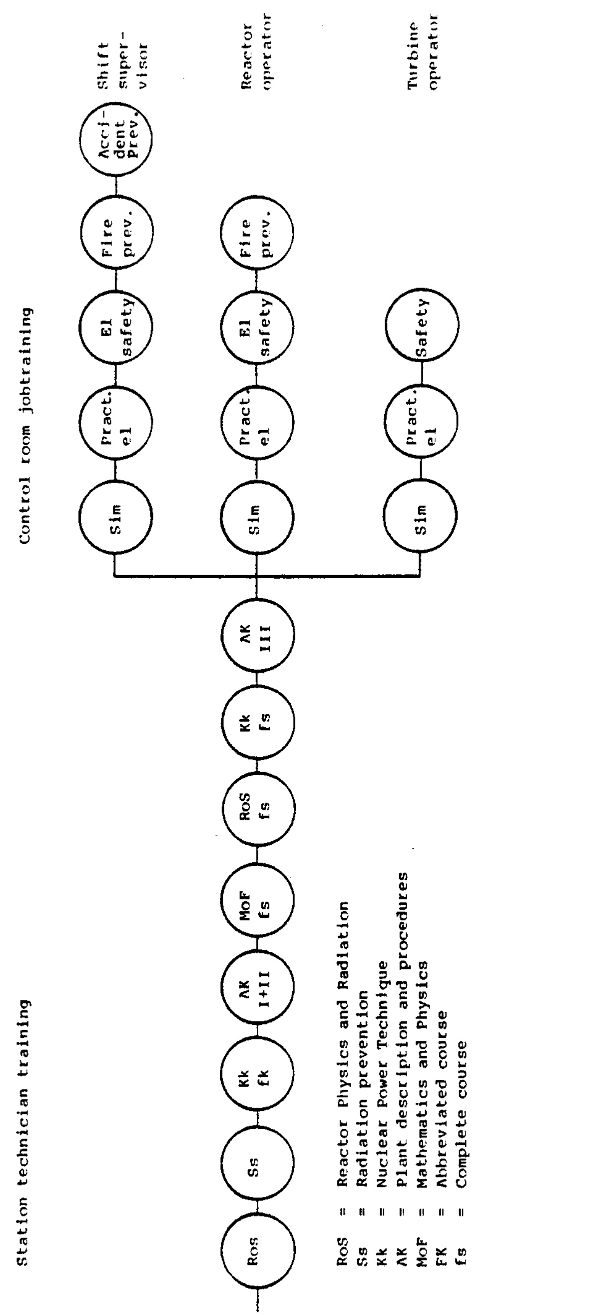

Figure 5.1 Example of order between courses being used for a combined station technician control room job training.

. Goal specification:	(in terms of knowledge categories and important knowledge objects with associated knowledge levels)
. Previous knowledge needed:	(other courses in the control room job training programme or in terms of basic knowledge used in recruitment for control room jobs)
. How the course is carried out:	(e.g. led by teacher, self studies, practical training with instructor, etc.)
. Course time:	(number of weeks for the course and number of hours effective time)
. Training aids:	(course material as written material. AV-aids, and simulators)
. Individual measurements:	(written tests, practical performance test, checklists etc.)

The size of a course can vary from part of a day up to several weeks. The description of a large course can preferably be divided into subunits. Each subunit can then be described in terms of goals, content specifications, course time, how the subunit is carried out, training aids being used and in terms of individual measurements.

Training organization

A job training programme requires resources. It is very important that there is an adequate organization which can carry out the intention of the operator training programme.

The training organization of the plant is expressed in terms of subfunctions needed together with their associated requirements. There are four different subfunctions which should be resolved within the training organization:

1. Allocation of resources of the plant so demands for resources for training are satisfied.

2. Training programme planning including planning and supervision of development and administration of the control room operator job training programme.

3. Course planning and development in accordance with the training programme for the control room operators including development of training aids, individual measurements and methods for the inventory of training demands.

4. The giving of courses including teaching, instruction, individual measurements and competency follow-up and course evaluation.

There are some requirements for the people who carry out subfunctions 1 and 2 above:

- Suitable background with process operation and/or training technology

- Authority for planning

- Placement within the plant organization which makes it possible to coordinate training planning with operational planning of the plant

There are the following requirements for those who see to subfunctions 3 and 4:

- Operational experiences from control room jobs

- Experiences from and interest for training and instructional work

- Ability to express oneself written and orally.

An important requirement for the training organization is efficient and vital communication within the organization.

Individual follow-up

The individual follow-up is carried out on several occasions; in connection with recruitment for control room job training, during and after control room training, in connection with actual control room work, after annual job retraining and continued job training and, finally, after an absence from an active control room job. The follow-up is conducted by the utilities with support from other training units such as the Nuclear Power Training Center which in a substantial way contribute to operator job training. What is followed up is defined through the typical tasks and the knowledge and skills given in the goals and goal specification of a course.

There are different measures or registrations which can be used for individual follow-up; e.g., written knowledge tests, practical performance tests, practical simulator tests and checklists which the instructor and the student operator both sign when a certain activity or part has been trained or demonstrated.

Reference

1. Wirstad, J. and Andersson, H.: Competency for Nuclear Power Operators. A System for the Acquisition and Maintenance of Operator Competence in Nuclear Power Plants. Ergonområd AB, Report No. 16, October 1980.

6. TRAINING SIMULATOR USE AND EVALUATION

Within the Scandinavian project, the work on training simulators has been conducted through reviews of the literature in the field, through working papers and also through some limited experimentation.

Literature reviews

The first report was a brief overview of various fields of application of training simulators including - aviation, nuclear power plants, process industry, driving and navigation - and how simulators are used in these fields. Other topics were types of simulators and simulator trade-offs. The report also includes an extensive bibliography (1).

In the second report, the need for simulation was reviewed and the use of simulators justified on the basis of a number of criteria. The role of simulators was discussed against the background of training media that are or could be used. The question of degree of realism or fidelity of simulation was tackled with comparisons being made between views from the industry and views from the area of process control. Emphasis was also placed on the importance of instructional control. Finally some future directions for study were sketched. There is also an extensive list of references (2).

Structures for describing simulators

Structures for describing simulators have been developed in two working papers ((3) and (4)). The first concerns, mainly, the technical features of simulators. The second puts more emphasis on pedagogical aspects.

Evaluation of training in simulators

Finally a practical model for evaluating training effects in simulators has been developed and tried experimentally (5). In a study comprising both a full-scale simulator and a compact

simulator, subjects were trained on the compact simulator and were also given courses on reactor control and the effects of xenonpoisoning on the reactivity. They were later given a task on the full-scale simulator where a number of variables were collected as potential indications of performance. Instructors' judgements were also included.

The experience from the study showed that it is possible to develope valid performance measurements on the simulator. It is, however, not a simple and straightforward task to do so. It is necessary to make a thorough analysis of the task and the criteria that should be used for evaluating the performance. The result also showed that it was not sufficient to rely on automatically recorded variables in finding the relevant variables for performance measurement. It seems to be necessary to use skilled judges to take into account important variables about the subjects' behaviour that cannot be recorded in other ways.

During the project two areas of interest have grown in importance. They are:

1. The concept of fidelity.

2. The importance of a systematic approach in defining the function of the simulator in each training context.

Fidelity means different things to different people. This has become apparent from the literature reviews and from the study of evaluation of training in a simulator.

It seems as if the fidelity of a training simulator can be divided into three different areas where the level of fidelity in one area can be varied relatively independently of the fidelity in the others. The first area is physical fidelity. Here a high level of fidelity means that the form, the number and the location of instruments and controls in the simulator are very similar to the control room for the real process.

The second area is information and control fidelity which means that the variables which are presented in the control room and could be controlled from there also can be presented and controlled in the simulator.

The third area finally is process dynamics. High fidelity here means that the variables in the simulated process vary in the same way as they do in the real process.

The question as to how much fidelity is needed for different purposes can be exemplified.

A mock-up obviously has a high degree of physical fidelity and zero fidelity in the other areas. For familiarization training in new control rooms, a mock-up could, however, be very effective despite the short-comings in the second and third areas.

A CRT-based simulator could on the other hand have almost zero physical fidelity but still have a high degree fidelity in the second and the third areas.

Such a device could be very effective in learning about process dynamics and also about the effects of possible operator actions on the process. Simulators with combinations of CRT's and conventional equipment can also serve similar purposes.

By a full-scale simulator is meant a simulator that is aiming at the highest possible fidelity in all three areas. The degree of fidelity that can be obtained is usually restricted due to costs when physical fidelity is concerned and both costs and technical reasons when process dynamics is concerned.

The examples given above bring us to the next question which deals with the role of the simulator within the training context. As the examples indicate, the value of the simulator as a training device varies not only as a function of the features of the simulator but also as a function of the training objectives. This means the question "is the degree of

fidelity high enough" can not be answered without knowing what training should be carried out with the simulator. As the examples show, a thorough analysis of the training objectives does not necessarily result in demands for high fidelity in all areas. On the contrary, deviations from high fidelity are often introduced deliberately in order to improve the training effects. Examples are freezing, speeding and backtracking facilities. It is also possible to display information which normally is not present in the control room just in order to improve the understanding of the process. Combinations of simulators with restrictions in fidelity may then have a greater potential than might be expected at a first glance, provided, however, that they are included in a systematically developed training programme.

When the simulator on the other hand is used as a device for performance measurement, the need for high fidelity in all areas increases drastically since the performance test must be done under "fair" conditions if there is to be any predictive validity in the results.

The question "how much fidelity do I need" can therefore not be given a simple answer unless the objectives of the user are known.

Because simulators can be valuable devices used in an optimal way and because they are too expensive to be used in other ways, it seems to be important to include principles of training system design already when the degree of fidelity is specified.

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7. TRAINING SESSION DESIGN

The simulator training of the Loviisa nuclear power plant is based on training modules called sessions. A session is an entity with content and goal defined. The time needed for one session can vary. The whole simulator training program is composed of these sessions ((1) and (2)).

In the planning of the simulator training program, the task analysis of the operators has been of great importance. In connection with the task analysis, the importance and exacting nature of the tasks were studied. Results of the task analysis give information on the order things should be taught to the trainees ((3) and (4)).

The operators must be able to operate the plant economically, safely and follow the administrative orders given to them.

Two training goals can be seen:

- to be able to operate the plant as economically as possible
- to be able to predict and identify disturbances and be able to cope with a disturbance so that production can go on without any safety risks.

To the first category belong preplanned start-up and shut-down procedures. To the second category belong the predicting and identifying of disturbances; the operators must know the plant so well that they know the meaning and effects of changes in process parameters.

In the planning of a training session there are two important aspects to consider; the part a session plays in the whole training program and the pedagogical side of training.

In the planning of the simulator training program the following should be considered:

- The operation of different subsystems should be taught in connection with meaningful maneuvers of the plant.

- Individualization of training.

- Sequencing of instruction: the trainees must first be taught and master the tasks required as basic knowledge in the later sessions considered.

- Objective performance measurement.

In order to define the content of a simulator training program, the process and the operator's tasks must be described in different procedures.

For the task analysis of the operators, the plant was divided into functional subsystems and for each subsystem a system description was written. In order to describe the procedures of the plant a state diagram was done (see Appendix 1). All this work was necessary for the task analysis work.

The task analyses were made as interviews with the help of the state diagram. The results were structured in the form of questionnaires. With the help of the questionnaires the importance and exacting nature of the tasks were asked.

The task analyses gave information about the content of the training program. Notice that simulator training does not only aim at operational skills, but also planning and analyzing of procedures and disturbances.

A part of the Scandinavian project was the planning of simulator training program for the Loviisa simulator. For the training program about 60 sessions were planned. The content of a session is:

1. general advice of how to make a session
2. a short description of its content and goal
3. initial state
4. malfunctions
5. monitored variables
6. session's course of events
7. advice to the instructor

Figure 7.1 shows that a training program needs revision at least in the beginning. A training program changes all the time. One should also notice that there is not just one way to plan a training program or a session and the results of training in practice pinpoint both the benefits and deficiencies.

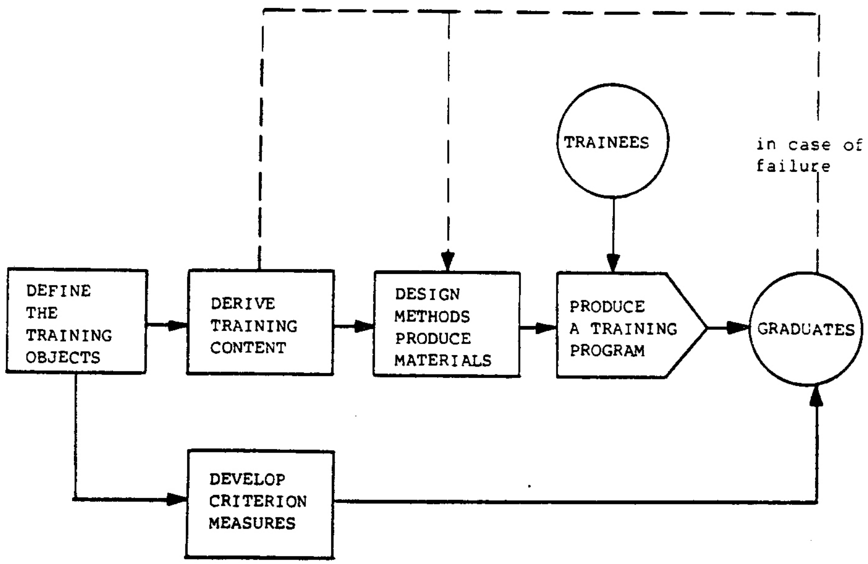

Figure 7.1 Training session planning as a flow.

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8. INSTRUCTOR TASKS IN SIMULATOR TRAINING

The reason for the use of simulators in operator training has been the effectiveness of simulator training compared with e.g. on-the-job-training. However, the usefulness and value of the simulator in training depends essentially on how the simulator is used. One can say that the simulator itself does not train, but only the manner ín which it is used ((1) and (2)).

A part of the Scandinavian control room design project is the simulator training of operators, and an important part of the training are the instructor's tasks.

A description of instructor tasks

The instructor has certain tasks in his training work, but he may have other duties, too. The instructor's tasks are divided into several activities and he has to consider how to emphasize different areas of his tasks ((3), (4) and (5)).

This section is meant to give a picture of the tasks of the instructor. These are presented in the structure shown in Figure 8.1. The main reason to structure the instructor's tasks is to clarify the general picture of the job and to help the instructor to plan his work.

Instructor's tasks are divided into two groups; those associated with training and those supporting the training area.

1. The most important tasks of the instructor during the training are the conducting of a session with necessary flexibility and the bringing of pedagogical aspects to training like motivating the trainees, making the aims of the training clear, giving feed-back to the trainees. During the initial courses he is in the simulator control room instructing the training. On the other hand, at the end of re-training, the instructor may just observe the trainees' activities.

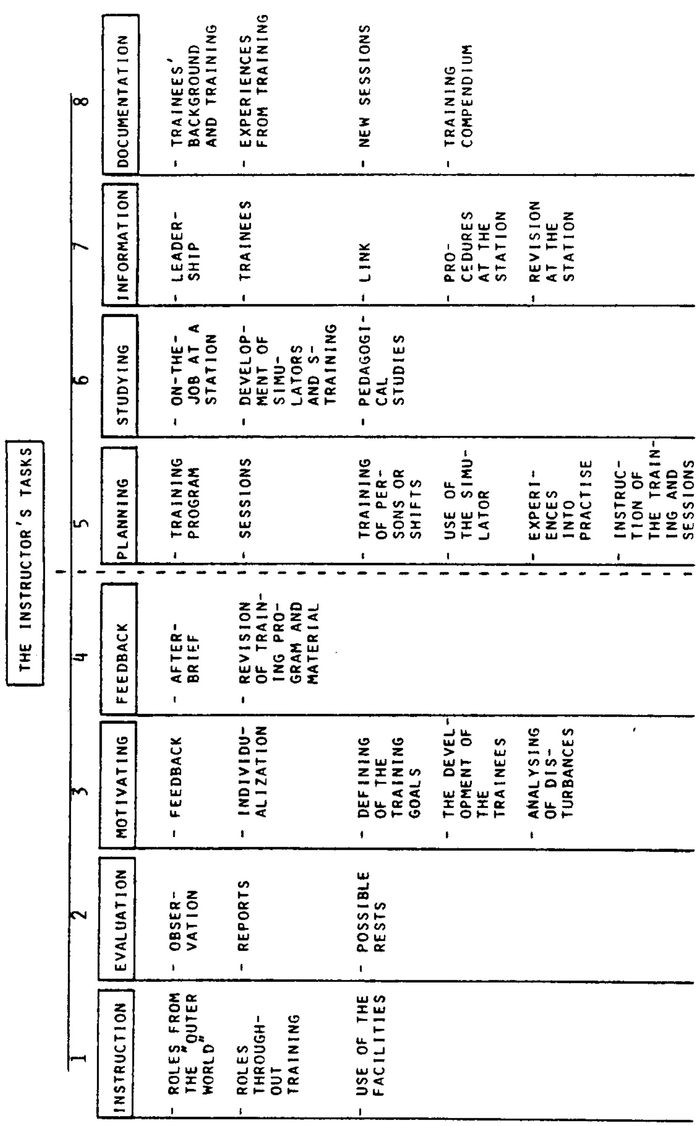

Figure 8.1 The instructor's tasks

The instructor has also other tasks; e.g., he may represent the "outer" world, the station personnel etc. through telephone communication.

2. Evaluation is one of the most important tasks in training. Evaluation can be verbal. Reports are available in the simulator for instructional and evaluation purposes. Also literal examination could be considered. Notice that evaluation is objective, i.e. in relation with the aims of training. The evaluation must be a part of every session, not tests made at random.

The simulator is provided with a console for the instructor to be able to conduct training. The console is provided with certain facilities. A typical instructor's console is provided with

- function buttons
- an alphanumeric keyboard
- a telephone
- alphanumeric CRT display units
- full graphic CRT display unit

The instructor communicates with the simulator with the help of function buttons and the keyboard. Reports are taken after the session to help with the analysis of the procedures or disturbances. The simulator has certain features developed for training purposes. These are

- opening of the training session
- controlling the initial states
- controlling the simulator mode
- backtrack
- snapshot
- activating malfunctions
- controlling the instructor set parameters
- taking the reports
- closing of the training sessions

The start/freeze features of the simulator can be used if analysis of the situation is needed.

Backtrack is used if a certain situation is to be repeated.

3. Motivation is one of the most important factors in learning. The personality of the instructor is of great importance but there are certain methods or means to motivate trainees. Feed-back is one way to motivate, also individualizing of the training. The aims of each session must be defined so that the trainees know when they have reached knowledge and skills demanded. Training with malfunctions must not be so difficult that the trainees are unable to solve the problems. Analyzing of problems is also motivating - at least when the trainee has the experience that he has learned a new thing.

4. Feed-back has two main goals; to give the trainees knowledge about their progressing in their studies; the other goals of feed-back is to be able to revise the training program or sessions.

5. Planning is important for the instructor in order to be able to emphasize his different activities correctly. Planning can be seen on two different levels. First, the planning of the instructor's work, his dividing of his time for the different areas of activities. Second, the training program must also be planned and revised; the training program as a whole, the sessions, training of persons or shifts, the use of the simulator etc. The instructor puts into practice the knowledge, experiences and ideas he gets from his work and develops both the training program and separate sessions.

6. The instructor himself must study also. He has a certain basic education, usually that of a shift supervisor, and depending on his earlier studies he has certain skills for training. The instructor must be in close contact with the station so that he is aware of the procedures and incidents of educational value at the station.

The instructor must follow the general development of simulator training and simulators. One of the important areas of his studies are pedagogical studies.

7. The management of the station must receive information about the development of the training. The simulator training must have a defined part in the operator training so that the training organization of the station knows the role of the simulator training in the total training program. The trainees must get information about the training that concerns themselves. The instructor is a link between the station and the simulator. He should be aware of intended procedures at the station but he should also get information about incidents which already have occurred. He should also pay regard to transient analyses made at the station.

Information about revisions at the station is important; the instructor must be aware of the need of updating the simulator.

8. The instructor must follow up the experiences of the operators at the station and the training they receive at the simulator. This is important in order to make the operator's knowledge about the station as wide as possible.

Documentation of interesting training situations, revisions and new sessions are also necessary. A part of the instructor's work could be to participate in writing training compendiums.

<u>Comments</u>

The simulator training sets great demands both on the training program and on the instructor. There is not only one correct way of carrying through the training and that is why only advice is given. The final decisions are the instructor's.

Revision of the training program and the personal development of the instructor guarantee the best possible result.

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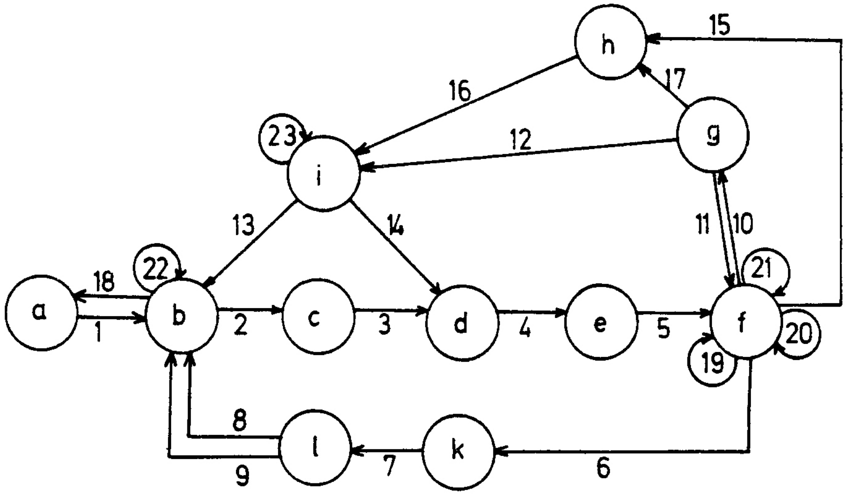
APPENDIX



States and transitions for a BWR nuclear power plant (O2)

States

a Reactor after refuelling
b Cold subcritical plant
c Heated subcritical plant
d Hot critical, reactor power 5% turbine not running
e Turbine at nominal speed
f Normal operation
g Disturbed operation
h Emergency operation
i Hot, tripped, subcritical reactor
k Hot, critical reactor, power 5%
l Hot, subcritical reactor

Transitions and procedures

Transition	Procedure
1.	General plant preparation
2.	Preparation for start up (heating of reactor using residue heat)
3.	Start nuclear heating and increase power to 5% Start aux. feedwatersystem to control waterlevel in reactor tank Heat steam pipes and continue nuclear heating using control rods Dump steam to condenser
4.	At 5% power, switch from aux. feedwater system to feedwater system Bring turbine to nominal speed
5.	Syncronization and loading of generator Increase generator power to 20%
6.	Decrease power to 5%
7.	Shut down to hot subcritical reactor
8.	Cooling by dumping steam to condenser
9.	Cooling by dumping into containment
10.	Incident causing disturbed operation
11.	Return to normal operation after disturbed situation
13.	Cooling of subcritical reactor
14.	Start up of hot reactor
15. or 10-17	Incident causing emergency situation
16. or 12	SCRAM or manual shutdown
18.	Refuelling
19.	Change of control rod pattern
20.	Increase or decrease of power level
21.	Change of shift
22.	Maintaining state b (residue heat cooling)
23.	Maintaining state i to be able to perform transition 14 later