NKA NORDIC LIAISON COMMITTEE FOR ATOMIC ENERGY

NKA/KRU-(81) 16
November 1981

ENLARGED NORDIC COOPERATIVE PROGRAM ON NUCLEAR SAFETY

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

SUMMARY GUIDELINES FOR MAN-MACHINE INTERFACE DESIGN WITH ANNOTATED REFERENCES

A Joint Scandinavian Research Project
Sponsored by

The Nordic Council of Ministers

VTT OFFSETPAINO ESPOO 1981

INTRODUCTION

Trends toward higher levels of automation combined with a wider utilization of process computers open up a wide spectrum of possibilities as well as perils for the designer. Well-proven practises, traditions, etc. may have to be forsaken and new solutions found for maintaining plant productivity while minimizing the risk for serious consequences of disturbances. At the same time, it will be necessary to take a fresh look at operator roles and responsibilities and the requirements these will place on selection, staffing, training and support. In particular, it seems also clear that increased attention will be required to closing the loop, so to speak, in the design process by adding more emphasis on an evaluation of man-machine interface design through the use of appropriate methods for analyzing actual operator performance in realistic operating situations. Some of these problems have been treated in the NKA/KRU project on control room design, human reliability and training and the results of the work have been published in the following series of reports:

NKA/KRU-(81)11 Summary Report

NKA/KRU-(81)12 Technical Summary Report on Operator Training

NKA/KRU-(81)13 Technical Summary Report on Control Room Design and Human Reliability

NKA/KRU-(81)14 Publications List

This particular document attempts to relate the same information to the total man-machine interface design process and thus give an alternate means for accessing the results of the project. For a similar approach with respect to training, see ref. (57).

MAN-MACHINE INTERFACE DESIGN

The advent of the new technology will have strong repercussions for control room design. The use of computers will make everything possible but not necessarily better - and that is the danger.

In the conventional approach, fixed arrangements of meters, recorders, indicators, etc. were arrived at with little specific attention being paid to the compatibility of the result with situation and/or task-related factors. Thus the operator - via his "on-the-job" training and experience - was expected to "adapt to" the resultant control board layout. However, this traditional one indicator/sensor approach will ultimately give way to a facility with an almost unlimited capability for selecting, combining, transforming, accessing, and displaying measured, stored and/or inferred plant data. Thus, in order to obtain maximum benefit from this technology, the designer will have to have explicit and detailed knowledge about the task spectrum involved as well as the associated needs for information which have to be satisfied. In addition, a well-founded conception of the operator as a system element must be available so that the information content, form, timing, integration can be made compatible with human capabilities and limitations.

This influences the design process greatly - especially when the generation change in technology is implemented for the first time. Special problems will arise also when an incremental change is planned as a "backfit" or "update" to an existing control room where one hopes that the combination of old and new approaches will improve the operators' abilities to cope.

In general, practical design work is carried out within a project organization. A new project involves "top-down" planning, which proceeds through several decision-making phases from general concepts - for example concerning the MMIF system - to the detailed design of the various parts of the system. Thus, in a way, the system is designed several times, but

always on a different level of detail. As a decision-making process, the design work forms a tree structure in which each design decision corresponds to a point that in general cannot be returned to as the work progresses. In practice then, this means that an earlier chosen high level concept cannot normally be changed at a subsequent design level; thus the concept serves as a design constraint. A result of this is that, at each decision-making level, the project should preferably be "foreseen" sufficiently far downwards; i.e., a sort of design "simulation" should be carried out, on the one hand for avoiding decisions and concepts that would mean unnecessary design constraints and might lead to an ineffective practical implementation and, on the other hand, for providing sufficient and necessary guidance for the continued design. This simulation would thus include the relevant "bottom up" checks to assure realizability.

If the discussion is now restricted to the man-machine interface, then such a process should insure that the ultimate realisation of the control room is not restricted to the selection and location of an indicator for each sensor but rather is the implementation of a host of decisions made at all phases of the design which relate to the total control room complex, and thus include the dimensions of automation, control task spectrum, interface philosophy, manning, training, organisation, physical work environment, etc. Fig. 1 illustrates some of the key decision points - particular those related to the design of the man-machine system. For the sake of completeness and also to reflect actual practise, a distinction should be made again between a <u>new</u> design and a <u>re</u>-design. As discussed above, the former would follow the "top-down" intentional flow direction with occasional "bottom-up" realisability checks. However, a re-design normally occurs in a parallel fashion via incremental modifications at <u>all</u> relevant levels in response to the need or desire for a change to an existing design.

MAN-MACHINE SYSTEM DESIGN AIDS

Thus the design of modern man-machine interfaces for industrial control systems is a complex task and must take a great number of technological and human factors into account. In reality, more than just the interface is involved - since issues such as organisation, environment, job-aids and many others are closely related. Unfortunately, there is at present not established theory nor proven practise for carrying out such a design. On the other hand, the aim is not to achieve a (non-existent) optimal solution but to avoid pitfalls and seek "good" designs. It is also true that many of the points which must be considered during design are "application independent". Thus, a guideline which in some systematic way could alert designers to the important questions to be asked and ultimately resolved would at any rate help to assure a higher degree of completeness in the coverage of the vital issues as well as do it at the appropriate point in the design process. Several attempts have been made to generate such a guideline. In particular, the Finnish team has as part of their contribution to the KRU-project produced a "Guidelines for MMIF Design" (ref. (59)) which is based in part on similar work being done in international circles under the auspices of the European Workshop on Industrial Computer Systems (EWICS).

It is of course clear that "application independent" questions do not (necessarily) have "application independent" answers. Thus, since the guideline is more of a "flag waver" or "attention getter" than a solution generator, it needs to be complemented by other aids such as "hard" data where they exist, proven methods and/or well-founded design criteria. As a modest step in this direction, this report attempts to relate the work of the KRU-project to relevant parts of the design guideline structure shown in Fig. 1 (and in much more detail in ref. (59)) in the hopes that this alternative way of accessing the results will be a useful aid. It should be quite clear that the project was restricted in its scope - indeed problems sufficient for a new project were uncovered. Therefore KRU-project based support of the design areas shown on Fig. 1 is incomplete. Fig. 2 lists by design area (decision point)

appropriate references (by number) to the enclosed annotated publication list. This permits a "jump in - jump out" usage of the material without necessitating a formal top-down approach.

In concluding, particular mention would be made of the area of performance analysis, which normally is not part of a design activity. Considerable work has been done - particularly in Denmark - on methods for gathering and analyzing data on operator performance. This was done out of the conviction that, among other things, new methods were required for giving designers a qualitative understanding of the functioning/appropriateness of new computer-based aids such as displays, etc. These of necessity have to be evaluated as integrated sets in realistic situations - including the category of "rare events" which by definition can not give a basis for quantitative "hard" data. The KRU-project has made it possible to test and evaluate such methods and these are referenced in this report.

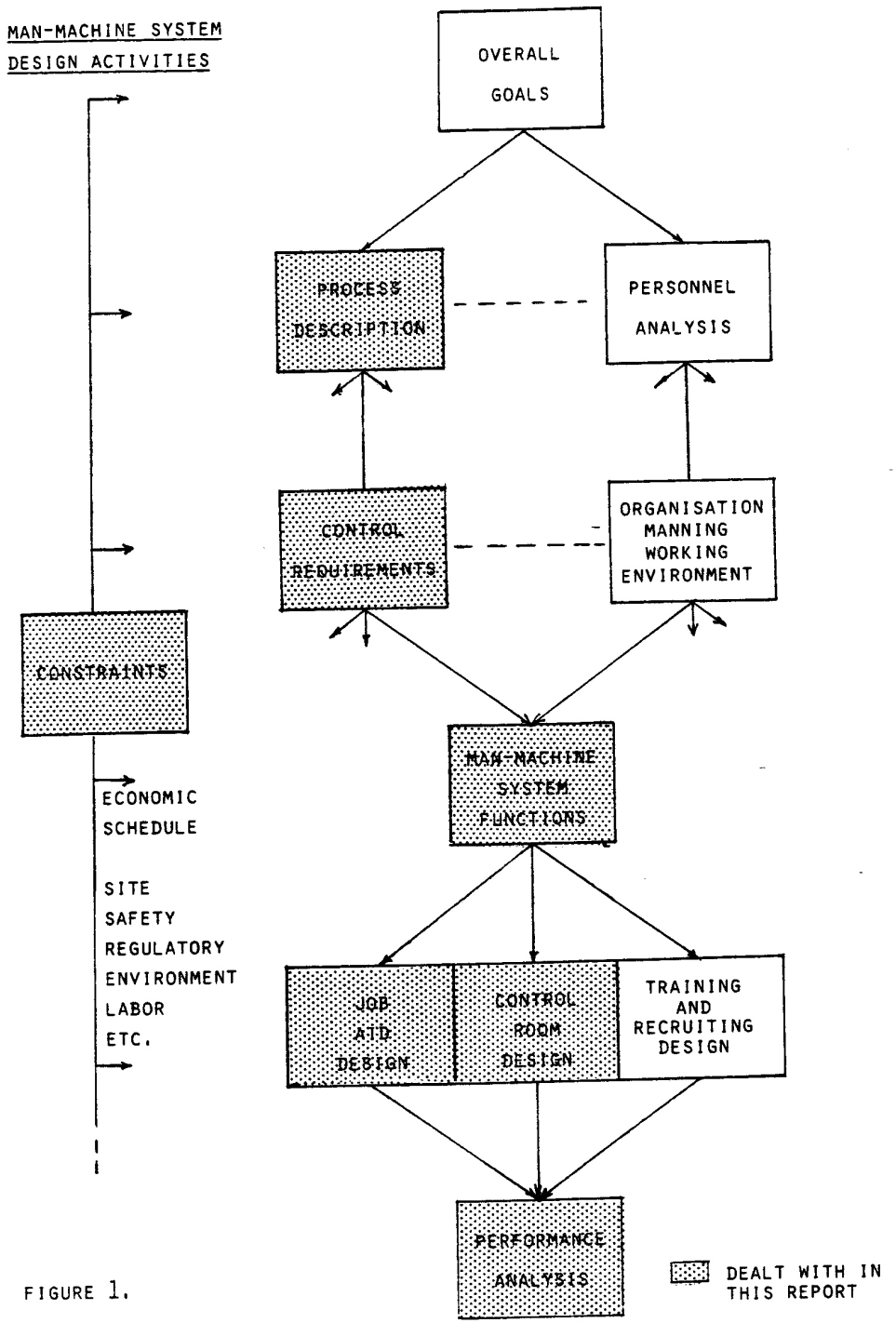

FIGURE 1.

REFERENCES TO KRU-PUBLICATIONS BY DESIGN AREA

A. CONTROL ROOM - GENERAL

RETROFITTING: 49
DESIGN: 50, 53, 57, 59, 60, 61, 67, 68

B. PROCESS DESCRIPTION

METHODS: 8, 50, 55, 56, 58, 62

C. CONTROL REQUIREMENTS

CONCEPTUAL: 9
METHODS: 58, 63, 64, 65, 66

D. MAN-MACHINE SYSTEM FUNCTIONS

CONCEPTUAL: 1, 3, 4, 6, 7, 9, 10, 11, 12, 16, 17, 40, 41, 42, 43, 44, 45, 46, 47, 51, 52, 54
DESIGN CRITERIA/RECOMMENDATIONS: 2, 5, 7, 10, 11, 12, 14,15
METHODS: 8, 13

E. CONTROL ROOM JOB-AID DESIGN

TRENDS: 33, 34, 35, 36
DESIGN CRITERIA/RECOMMENDATION: 11, 12, 13, 37, 38, 39, 40, 68, 69
METHODS: 48, 58

F. PERFORMANCE ANALYSIS

CONCEPTUAL: 20, 21, 28, 29 (SEE ALSO UNDER D.)
METHODS: 18, 19, 30, 31, 32
RESULTS? 22, 23, 24, 25, 26, 27

Fig. 2

ANNOTATED PUBLICATIONS LIST

(1) NKA/KRU-P2(78)1 J. Rasmussen.
Notes on diagnostic strategies in process plant environment.
(January 1978)

In the report are discussed some aspects of state identification and diagnosis in process plant control which must be considered in connection with automatic disturbance analysis and man-machine interface systems.

In the process plant environment, a diagnostic task implies a search to identify a change from a normal or planned plant state. Several elementary strategies can be identified. In the report a distinction is drawn between two main groups - topographic search strategies, performed as search through the system with reference to a model of normal plant state; and symptomatic search strategies, performed as a search through a library of abnormal state models with reference to the actual plant state.

Typical properties of the different strategies are discussed such as processing capacity requirements and dependence upon a priori analysis.

(2) NKA/KRU-P2(78)7 J. Rasmussen.
Notes on human system design criteria.
(September 1978)

The technological development during the recent decades has caused a need for human system design criteria which is increasing more rapidly than the research effort required to supply the basis for such criteria.

Several factors have been important contributors to this situation: The rapid increase in size and complexity of technical systems; the flexibility and capacity of digital computers used for man-system interface functions; and, finally, the widespread movements towards industrial democracy and work enrichment.

The importance of design criteria as judgement aids increases directly with the variety of solutions available to meet functional requirements and with the degree of difficulty met in establishing the quantitative specifications of the various functions considered. For this reason, the self-organizing and learning properties of the human element in systems lead to an urgent need for design criteria; a need which is further emphasized by the fact that the system should also present an acceptable work environment for the human operators.

Two categories of human system design criteria must thus be considered:

- Criteria related to the consideration of man as a system component.
- Criteria related to consideration of the system as man's environment. Locally in terms of "working life quality"; globally, large, centralized systems mean potentially large consequences from maloperation and thereby create the need for criteria to protect man in general and to formulate responsibilities of system operators in particular.

(3) NKA/KRU-P2(79)11 J. Rasmussen.
Man as a systems component (in "Human Computer Interaction", H.Smith, T. Green (eds.), Academic Press).
(January 1979)

This report deals mainly with the functional aspects of human data processing and treats the following areas:

A Model Of the Human Data Processor
  The Subconscious Processor
  The Conscious Processor
Structure of Task Sequences

Analysis of Real Life Strategies
  Data, Models and Strategies
Data Processes and Human-Computer Co-operation
Human Error Analysis and Prediction
Conclusion

(4) NKA/KRU-P2(79)21 J. Rasmussen.
On the structure of knowledge - A morphology of mental models in a man-machine system context.
(Also Risø-M-2192)

This report is a working paper which describes and illustrates different forms of mental representations of the functional properties of a physical system as found in a man-machine system context.

The outlines of a morphology of such models are discussed in terms of different levels of abstraction related to physical form; physical function; functional structure; abstract function; and functional meaning or purpose. The distinction between deterministic quantitative models based on variables and relations, and causal, qualitative models based on objects or functions which have properties and interact by events, is discussed. The dependency of the different levels of abstraction upon representation of aspects of the material basis of the system versus aspects of human reasons for the existence of the system is described. Finally, the different strategies of humans to cope with complexity is briefly discussed in the context of the morphology.

(5) NKA/KRU-P2(80)23 L.P. Goodstein and J. Rasmussen.
Man-machine system design criteria in computerised control rooms.
N-7-80, February 1980. (An abbreviated version is included in the proceedings

of the IFIP/IFAC "Assopo 80" conference, Trondheim 16-18 June 1980).

The advent of advanced computer-based VDU systems in process control rooms has been handicapped by the lack of a sound basis for their incorporation as an improved aid for the operator. This paper attempts to define and illustrate the use of a set of universal criteria for the design of man-machine systems based on the conception of the human as an information processing system with a limited set of resources and methods for coping with the wide spectrum of normal and unexpected situations which can arise. See also reference (2).

(6) NKA/KRU-P2(80)27 J. Rasmussen.
Some trends in man-machine interface design for industrial power plants.
Risø-M-2228, March 1980.

The demands for an efficient and reliable man-machine interface in industrial process plant are increasing due to the steadily growing size and complexity of installations. At the same time, computerized technology offers the possibility of powerful and effective solutions to designers. In the paper, problems related to interface design, operator training and human reliability are discussed in the light of this technological development, and an integrated approach to system design based on a consistent model or framework describing the man-machine interaction is advocated.

(7) No NKA/KRU-number J. Rasmussen.
Models of mental strategies in process plant diagnosis.
Risø National Laboratory.
In "Human Detection & Diagnosis of System Failures." J. Rasmussen & W. B.

Rouse (eds.), Plenum 1981.

In the case of abnormal operation of an industrial process plant, a critical task of the operating staff and/or the automatic control system is the diagnosis, i.e., the identification of the change in plant conditions which has taken place. The diagnostic task is basically a search to locate the change in a representation or map of the system and thereafter to choose a correcting action. Several representations and search strategies can be used, and the actual choice will depend on the plant condition and on the operator's personal experiences and preferences.

A model of the operator's performance in the diagnostic task is necessary to design an effective man-machine interface. Since the actual task performance will depend on very person and situation specific features, a detailed model of the operator's mental process is not feasible. A more realistic approach is a competence model in terms of a repertoire of strategies available to the operator and their characteristics with respect to human preferences and limitations. Actual task performance can then be described by a sequence of subroutines belonging to different formal strategies together with heuristics rules for jumps between these.

The paper discusses such a repertoire of formal strategies and their characteristics with reference to features of human and computerized data processing. Two main categories are described: strategies based on a search through a library of symptom patterns and those based on a search in a representation of system function or anatomy with reference to normal state. Their relevance for different plant conditions is discussed.

(8) No NKA/KRU number M. Lind.
The use of flow models for automated plant diagnosis.

Risø National Laboratory.
In "Human Detection & Diagnosis of System Failures." J. Rasmussen & W. B. Rouse (eds.), Plenum 1981.

Automatic, computerized diagnosis can be based on several different search strategies, e.g. a search for a match between a pattern of measured data and some stored symptom patterns, or a search to locate a change in the system's functional state with reference to a stored model of normal or specified plant state. The latter strategy has a number of basic advantages: it is independent of the prediction and analysis of specific faults and events; the reference for search, the normal state, can be derived from actual plant operation by the computer; the strategy can be based on invariate relations such as conservation laws; etc.

In the paper we will explore the use of conservation laws for mass and energy for diagnosis of plant malfunction. An advantage of this approach is that it is possible to diagnose unforeseen plant disturbances; this is due to the general nature of the conservation laws. Furthermore, accumulation of mass and energy is a potential source of risk in plant operation, and the identification, counteraction and location of unbalances is thus an important aspect of process plant diagnosis.

We will discuss how a category of plant models, developed by the writer, can be used as a formal basis for diagnosis using conservation laws. A plant flow model describes the topology of the pattern of mass and energy flows and represents qualitative aspects of plant function in a given operational regime. A description of flow models will be given in the paper.

Diagnostic strategies based on flow models can be used in the design of automatic disturbance analysis and control, but they can also be used for organising the available

measured plant data in a meaningful way for an operator and for supporting him in the need for rapid "zooming in" on the relevant details in a complex situation.

(9) NKA/KRU-P2(81)43 J. Rasmussen and M. Lind.
Coping with complexity.

The complexity of the work situation in process plant control rooms during emergencies has caused widespread activity to support operators by means of modern information technology for improved data analysis, information display and procedure support.

The complexity is related to high numbers of data sources, variety of faults and errors and of their effects, and to the fact that operator procedures are formulated as long sequences of detailed actions, i.e. at a level where there exist numerous alternatives for these actions.

The way to cope with complexity basically is to structure the huge variety of the attributes of the work situation so as to allow "chunking" into a lower number of higher level concepts. To do this systematically, the independent dimensions of the complexity should be sought together with a meaningful structuring in terms of decomposition/-aggregation and of abstraction/concretisation. The paper discusses a frame of reference for coping with complexity in this way. The structuring mentioned depends on a description of the plant system at various levels ranging from operational purpose to physical equipment, and at various levels of decomposition from total plant to physical components and parts.

Similarly, operator control tasks must be formulated in various generic classes related to operational states of the system, and the information required for these tasks at the various levels of description must be defined. The

argument of the paper is that the efficient use of computers to structure complexity in order to support operators must be based on the use of a mutually consistent set of levels of representation when structuring plant data, operator tasks and plant properties. This consistency is the basic requisite for using a computer to structure complexity and guide the operator. The necessary freedom of evaluation and decision will only be maintained for the operator, if the structuring mentioned matches the capabilities of the operator for perceptual integration, conceptual reasoning and motor-skill formation at various levels.

The paper is based on analysis of operator tasks and errors in nuclear power plants.

(10) No NKA/KRU number L.P. Goodstein.
Discriminative display support for process operators.
Risø National Laboratory.
In "Human Detection & Diagnosis of System Failures." J. Rasmussen & W. B. Rouse (eds.), Plenum 1981.

In a companion paper (ref. (7)), Rasmussen discusses the mental strategies which underline operators' diagnostic behaviour when coping with process plant abnormalities. He also sketches in broad outline appropriate forms for computer support. It is the goal of this paper to utilize this framework for illustrating the use of computer-based processing and display techniques for generating appropriate informational aids during the detection and identification phases of a diagnosis.

According to the conceptual base employed, operators have a set of strategies as well as mental models of the plant for which they make use of appropriate data for describing

system state. However, the actual utilization of these strategies and models at any particular time is an individual matter depending on the operator's attempts to satisfy his own set of performance criteria - relating, for example, to mental loading, effort ... This creates for the display system the requirement to be able to cater to a relatively wide spectrum of informational needs in an acceptable and trustworthy fashion.

Diagnosis is essentially a search process to "narrow" down the problem to the point where an appropriate identification having an acceptable solution can be found. Thus the initial detection of a potential disturbance should be supported so that the operator's attention and interest are channeled in the appropriate direction - and preferably without activating a premature and hasty response. The paper will discuss and illustrate the use of patterns of critical system variables for this purpose as a component in a potential alternative to conventional alarm systems.

The ensuing search through the system can be characterized by two complementary concepts which have significance for display design - "field of attention" and "level of abstraction". The first corresponds to "windowing and zooming" and calls for display support which follows the operator's need for higher amounts of detail about more restricted portions of the system as attention becomes more concentrated. The second is more subtle concept which reflects human ability and tendencies to speculate consciously about the world (process plant) in different ways depending on needs and abilities. Thus at the earlier stages of a diagnosis where attention has to be paid to the entire system to evaluate the propagation effects of changes, deviations, possible counteractions, the operator will/should use abstraction levels which involve fundamental mass flows (affecting inventories and levels) and energy flows (affecting power control and distribution).

When attention at a later point is directed to a particular sub-system, the level of abstraction will probably move "down" to considerations of physical-function relating to parts, components and their interaction and/or physical variables and their relations. Thus a "high" abstraction level usually demands a large field of attention with limited detail and vice versa. This creates the need for a large set of displays to enable different portions of the system to be presented in support of thinking at the various levels of abstraction. The paper will illustrate these concepts using the flow structure approach (described by Lind in a companion paper (ref. (8))) as the basis for display design at the higher abstraction level.

(11) NKA/KRU-P2(79)13 L. P. Goodstein
Procedural support. (February 1979).
See also
"Procedures for the operation - their role and support". IWG/NPPCI Specialists Meeting on Procedures and Systems for Assisting an operator ... 5-7 Dec. 1979, Munich, FRG.

These reports take a fresh look at procedures by first examining the operator's work situation, his behavioral characteristics and then at his need for suitable support, for example, in the form of procedures - and all of this in light of his responsibilities for monitoring and controlling a dynamic, complex and occisionally unpredictable process. An added impetus for doing this exists in the form of the process computer and the possibilities which it offers for providing support for procedures. These papers conclude with a brief description of such an application.

(12) NKA/KRU-P2(81)37 L. P. Goodstein
Suggestions for incorporation of procedural support in the KRU-experiments.

This is a followup to earlier published work (see ref (11) on the use of computer-based display systems for assisting operators in so-called "rule-based" tasks where the preferred or "standardized" approach to executing the task is specified in a written procedure. This particular report includes two specific examples of recommendations for incorporating the computer and VDU's as a procedural aid for the subjects who participate in the NKA sponsored experiments at the Halden Project and - as such - the report deals with illustrations of only one aspect of the total concept for an MMIF design which has grown out of the KRU-project.

(13) NKA/KRU-P2(79)26 M. Lind.
The use of flow models for design of plant operating procedures.

The succesful operation of process plant is dependent on a variety of procedures, for e.g. plant control, testing, maintenance, etc., which are carried out either by operators or automatic sequential control systems. Here we will consider co-called operating procedures which are provided for plant control. We will especially be concerned with the plant information which is a sufficient basis for a systematic approach to the design of operating procedures.

In the paper we will show how operating procedures can be structured into logically consistent parts by a decomposition into sequential and concurrent action sets. The decomposition is shown to originate from the topology of the pattern of material and energy flow in the plant, and to the nature of the specific control task considered.

This analysis provides valuable information of how plant structure can be used explicitly in procedure design. It is shown how a category of models called flow models in material and energy processing plants. Flow models will be used as a way of dealing with plant topology in procedure design.

(14) NKA/KRU-P2(79)20 L. P. Goodstein.
Working paper on displays for startup.

This material is based on the contents of references (65) and (67) on a PWR startup. For each of the steps starting with 35 in the procedure (just after criticality) and continuing up to step 44 (10% power), suggestions for appropriate display support are given. Some generalizing remarks are made at the end.

(15) NKA/KRU-P3(78)2 Jens Rasmussen.
Human reliability lecture notes.
(August 1978)

The complexity of modern process plants together with the rapid technological development, when combined with the low probability of the hazards we are attempting to control, lead to the situation where risk analysis and control cannot be based on empirical design guides and standards. Instead it will require a quantitative analysis of the risk of a system, based on empirical data on the properties of the components and parts of the system. If we sketch the anatomy of an accident in a modern industrial plant, it turns out that the human element often plays a very significant role in the overall performance of the system. Consequently, an increasing effort is being put into the study of human error analysis and quantification. Unfortunately, the need for results has been growing more rapidly than the research needed to supply

the basic konwledge on human functions in industrial installations and the related human failure mechanisms. Accordingly, the following review will be as much a review of problems as a survey of possible solutions. However, if the conditions under which present methods are applicable can be stated explicitly, then these conditions can be used as design criteria for systems by serving as "criteria of analysability". Those criteria can then be modified or released as more efficient methods of analysis and better data become available.

(16) NKA/KRU-P2(79)18 Jens Rasmussen.
What can be learned from human error reports.
(June 1979).

(17) NKA/KRU-P2(79)19 Jens Rasmussen.
Event reports as a source of human reliability data.

These reports are both concerned with conceptions of "human error" and their role on system design strategies, - especially in the light of today's trends towards complex, centralised and lightly automated systems. The two papers treat the findings of reviews of event reports with relation to human behavioral categories, design for error tolerance and analysability and the process of event reporting itself.

(18) NKA/KRU-P2(78)10 Erik Hollnagel.
Design criteria for experiments on reference situations.
(October 1878).

(19) NKA/KRU-P2(79)23 Erik Hollnagel.
The methodological structure of the KRU-experiments:
Notes on the nature of qualitative research.

These papers deal mainly with the rationale behind and the structure of the experimental methodology. The conceptual structure used in the analysis of the experimental results will be described separately (see ref. (21)).

The most important characteristic of the experiments is that they are of a qualitative rather than a quantitative nature, i.e. that they serve the purpose of gathering knowledge (data or information) with regard to a certain problem area of phenomenon, rather than the testing of one or a set of specific hypotheses. The qualitative nature of the experiments has been decisive in the selection of the experimental paradigm which relies on a controlled retrospection using a replay of the experimental session.

(20) NKA/KRU-P2(79)24 Erik Hollnagel.
A framework for the description of operator behaviour.

From the point of view of behavioral sciences; one of the main problems in the study of man-machine interaction is the description of the behavior of the operator. This description is essential, because we want to understand why a person behaves the way he does, why he becomes stressed, why he makes mistakes (also called errors), why he forgets or neglects things, etc.

One essential point, however, is the distinction between actual behavior (performance) and possible behavior (competence). This distinction is important to maintain, because it underlines that whatever the operator does, it

is always just one of the possibilities for action which he has, rather than the only possible action. Actual behavior is thus always the result of a choice or a selection from possible behavior. Consequently, a description of operator behavior cannot restrict itself to actual behaviour, but must also include the possibilities for behaviour, i.e. the competence for behaviour.

One possible way of doing this is to use a grammar of behavior. A grammar may be thought of as a competence theory, since it is able to generate an infinite set of sequences of signals, which are the sentences of the language, i.e. grammatically correct. Although a grammar cannot explain why a person produces a given sentence (or behavior), it may describe how it is produced.

The purpose of the present paper is therefore to suggest a possible grammar which can be used in the description of operator behavior.

(21) NKA/KRU-P2(80)25 Erik Hollnagel.
The role of conceptual structures in analysing operator behaviour.
Risø-M-2217, February 1980.

A consistent description and explanation of operator behaviour must be based on the conceptual structures of the operator - his mental models and representation of knowledge - which can be inferred from an analysis of the behavioral data. This paper gives a presentation and discussion of three major problems in this analysis: (1) the level or abstractness of the language used in the description of operator behavior, e.g. natural language versus a theoretically loaded terminology; (2) the degree of concreteness of the conceptual structure and the depth of explanation, i.e. the criteria by which the explanation is considered sufficient; and (3) the relation between

competence and performance, in particular the role of performance criteria and the role of a demand-resource fit. The paper also discusses the relation between strategies and models and concludes with a description of the essential concepts in the conceptual structure.

(22) NKA/KRU-P2(80)28 Erik Hollnagel.
Report from the NKA/KRU pilot experiment - an evaluation of the use of a qualitative methodology in the investigation of operator performance.
N-18-80, April 1980.

(23) NKA/KRU-P2(80)30 Erik Hollnagel.
Report from the second NKA/KRU experiment: The performance of non-professionals in controlling a complex process.

(24) NKA/KRU-P2(81)36 Erik Hollnagel.
Report from the third NKA/KRU experiment. The performance of control engineers in the surveillance of a complex process.

(25) NKA/KRU-P2(80)34 Erik Hollnagel.
Report from the third NKA/KRU experiment. Tape transcripts and diagrams.

(26) NKA/KRU-P2(81)42 Erik Hollnagel.
Report from the fourth NKA/KRU-experiment: The performance of experienced BWR operators in a PWR simulator.

(27) NKA/KRU-P2(81)41 Erik Hollnagel.
Report from the fourth NKA/KRU-experiment: Tape transcripts and diagrams.

These publications constitute the reporting to date of the four experiments which have been run on the Halden reactor simulator as part of the NKA/KRU experimental program. The first was a pilot experiment to check the experimental methodology and equipment. The second, third and fourth experiments employed these facilities in studying the diagnostic and decision making behavior of three different groups of subjects - computer science students, process engineers and experienced reactor operators. Detailed descriptions of the individual subject's response are given together with a more general discussion.

(28) NKA/KRU-P2(80)33 Erik Hollnagel.
On the validity of simulator studies: Problems and preliminary precepts.

(29) NKA/KRU-P2(81)40 Erik Hollnagel.
Experimental evaluation and validation.

These papers address some of the basic questions related to the use of experiments for the testing, evaluation and verification of concepts and designs for a man-machine system.

(30) NKA/KRU-P2(81)39 Erik Hollnagel.
Comments on the use of nuclear plant simulators: A myopic view.

This is a summary of a user's view of the simulator based on experience in the KRU project; the primary function of a simulator is, of course, to simulate a specifiv (actual or generic) plant, and a substantial effort is made to

accomplish this. But in every case where the simulator is used there is also a user. In the case of research simulators it is the experimenter, and in the case of training simulators it is the instructor. From the user's point of view it is naturally important that the simulator functions according to specifications. But it is likewise important that the simulator can be adapted to a specific purpose, i.e. as a training device or as a piece of experimental apparatus. That means that the interface between the simulator and the user is just as essential as the fidelity and reliability of the simulator as a simulator. The simulator is an important source of information both in the case of training and research. But if that information is hard to come by, or if the manipulation of the simulator in other ways is inefficient, the opportunity may be wasted.

(31) NKA/KRU-P2-81(35) E. Hollnagel, O. M. Pedersen & J. Rasmussen.
Notes on human performance analysis.

There is a growing need for human performance data for design of man-machine interface systems based on new control room technology and for quantification and prediction of human performance in high risk systems and situations.

Several different sources of data are at hand:

Operating plants
- event reports
- post-incident studies/interviews

Simulators
- training simulators
- research simulators

Each of them has particular features with respect to problems of data collection and the quality of data which it is practically feasible to collect. The present report is an attempt to summarize the features of data collection and analysis as we have met them during a number of cases. The aim will be to be able to coordinate future analysis and to interrelate results from different sources.

(32) NKA/KRU-P2(81)38 E. Hollnagel & Jens Rasmussen
Simulator training analysis

Limited training simulator capacity makes it evident that any improvement of the efficiency of training simulators is of value. And since the primary purpose of a training simulator is training, anything which can improve the training should be given serious consideration. The suggestion put forward here is that the need for a better understanding of operator performance may be combined with the need for using the training simulators more efficiently. This is because the detailed psychological study of operator performance brings with it a repertoire of methods of observation and analysis, which may improve the daily use of a training simulator, without interfering with it. This report describes the details of this suggestion. It will be evident that the suggestion represents an integration of knowledge and experience from the study of real-life incidents, research simulator experiments, research on operator performance in a variety of situations, and cognitive psychology. The result is a guideline for a methodology which can easily be implemented in a concrete training simulator. The report concludes with a description of how such an implementation can be made.

(33) NKA/KRU-P2(78)100 J. Ø. Hol, K. Netland
"State of the art" of control room design.
(1978-02-10)

(34) NKA/KRU-P2(78)101 J. Ø. Hol.
Spörreskjema - version 2.
(1978-07-07)

(35) NKA/KRU-P2(79)104 J. Ø. Hol.
State of the art - status of questionnaire response.
(June 1979)

(36) NKA/KRU-P2(79)113 J. Ø. Hol & E. Edsberg
Recommendations and guidelines for design of future control rooms - analysis of questionnaires 1978/79.

Within the project, the general question of design guidelines has been approached in several ways. For example, a questionnaire dealing with the state of the art and the predicted trends within control room design design was distributed to utilities within the Scandinavian countries and the Halden project signatories. These reports treat the results of this study and other interviews.

(37) NKA/KRU-P2(78)102 J. Ø. Hol, G. Øhre, K. Netland.
Design of pictures and use of colours and symbols for a CRT-based supervision system.

(38) NKA/KRU-P2(78)105 M. Holmgren, J. Ø. Hol.
Use of colours as information carrier in computer based control rooms.
(1978-11-29)

(39) NKA/KRU-P2(79)106 M. Holmgren.
A working paper on the usefulness of standards for CRT-colours.
(June 1979)

(40) NKA/KRU-P2(80)103 J. Ø. Hol, Gunnar Øhre.
Development of guidelines and recommndations for colour display based information presentation systems.

Laboratory studies have been done on the use of colours as information media. It is studied how colours are perceived and valued, and the physical limitations in use of "standardized" colours on CRT systems. The study so far has revealed some new challenges for the designer of information presentation systems.

These papers describe some of the results obtained at the Halden Reactor Project in use of colours and symbols in a CRT based information presentation system.

(41) NKA/KRU-P2(78)106 M. Holmgren, J. Ø. Hol
Information presentation in computer based control rooms.
(1978-11-30)

(42) NKA/KRU-P2(78)108 M. Holmgren, J. Ø. Hol.
Information presentation in computer based control rooms.

(43) NKA/KRU-P2(79)111 M. Holmgren & J. Ø. Hol.
Attitudes to computer control systems - an industrial application.

(44) NKA/KRU-P2(80)102 M. Holmgren.
Performance of unexperienced subjects in a computer-based control room.

(45) NKA/KRU-P2(80)104 M. Holmgren.
The development of "process feeling" and problem solving behaviour in computer-based control rooms.

(46) NKA/KRU-P2(81)104 M. Holmgren.
Attitudes towards computer-based communication devices within process industries.
(May 1981)

(47) NKA/KRU-P2(81)106 M. Holmgren.
Experience from VDU-presented information.
(May 1981)

Independently of the experiments reported on in references (18) - (27) on diagnostic behaviour, an experimental program was carried out at Halden to study transitional problems when changing from conventional to computer-based system. The following points were looked at:

- operators' plant representations
- information preferences
- attitudinal information.

(48) NKA/KRU-P2(80)106 B. B. Thomassen and J. Augustin.
Alarm generation, a concept based on automatic logical filtering.

This paper describes a concept of improved alarm handling in a complex process by introducing a logical filter technique. It deals with alarm display, alarm journal and documentation of the system as seen from the user's point of view.

(49) NKA/KRU-P2(81)102 J. Ø. Hol, G. Øhra, E. Edsberg and F. Pettersen.
Retrofitting of Control Rooms with Computer-based systems.
(May 1981)

What we may term conventional control rooms are often hampered by widely scattered and sometimes illogical arranged control instrumentation, which may increase the potential for plant outage or equipment damage. As a consequence, additional computer-based systems for supervision and control in normal and off-normal situations, working alongside the old instrumentation, are being implemented to alleviate some of the shortcomings.

The purpose of this paper is to discuss some of the problems that have been encountered in retrofitting projects for introducing modern computerized operator aids, where colour Cathode Ray Tubes are used as information carrier to the operators. Particularly is addressed the consequences as seen from a human standpoint; user participation at the time of system conception and comprehensive user training are strongly recommended. Recommendations and viewpoints are illustrated with cases and situations from industrial applications, handled with apparent success - and with not so apparent success.

(50) NKA/KRU-P1(78)201 Leena Tuominen, Björn Wahlström and Juhani Timonen.
A system and task description for the operating personnel of the Loviisa nuclear power station.

Correct and appropriate actions of the control room personnel are to a large extent contributing to the safety and economy of a nuclear power station. It is therefore natural that considerable effort is spent in ensuring that the knowledge and skill of the operating personnel is brought up to and maintained on an appropriate level. In order to methodically train the operating personnel both initially and on a continuing basis the tasks to be performed in the control room are the basis of the training.

The present study of the Loviisa nuclear power station has been made in order to provide a systematical description of the tasks in the control room. This description will be used while planning the training of the operating personnel using a training simulator. The initial training of the operating personnel at Loviisa power station was performed prior to start up, without the benefits of a simulator. Attempts have also been made to define the requirements and importance for each task.

(51) NKA/KRU-P2(78)210 Juhani Timonem, Björn Wahlström.
On the modelling of human process operator.

This paper contains some thoughts about how the behaviour of the human operator in an automatized process supervision task could be modelled. The structures are called models though they are not meant to be executable mathematical models. They should rather be understood as aids for thinking.

(52) NKA/KRU-P2(79)217 Juhani Timonen.
On the control theoretic modelling of human process operator.

The report reviews various mathematical modelling approaches of the human instrument monitor and controller with the special emphasis on the applicability in the description of an operator's work in a modern automatized process control room. Typical tasks, which have been studied, are instrument monitoring, monitoring and control and dynamic allocation of supervising responsibility. The mathematical methodology, which is used in the modelling of the monitoring task, is the same as commonly used in the modelling of the aeroplane pilot, like information theoretic approach, queueing theoretic approach, optimal control theoretic approach, probabilistic and decision theoretic approach. The applicability of each method is reviewed and special attention is paid to the problems which arise in attempts to transfer these methods to process control room environment. In the monitoring and control task modelling the main emphasis is laid on the decision making procedures and the goal seeking process. The dynamic allocation of supervising responsibility is described as a multitask optimization process or a multicriteria decision making process. Finally the special need for the modelling work, originating from the nature of the process control room situation is discussed.

(53) NKA/KRU-P2(80)220 Björn Wahlström.
Om planering och konstruktion av man-maskinsystem. (On the planning and design of man-machine system).

General requirements and criteria as presented in reference (2) are important when man-machine systems are designed and evaluated. Such requirements and criteria are however difficult to apply for the steering of the design

process. In order to concretize the requirements and criteria the design process leading to an actual solution has to be studied. The key decisions of the designers have to be identified and appropriate guidelines and checklists have to be provided to support the designers in his decisions.

The paper describes a typical design process as applied in the power industry. The decisions the designer is making in the different stages of the design are also indicated.

(54) NKA/KRU-P2(80)221 Juhani Timonen, Björn Wahlström, Leena Tuominen.
On the modelling of the tasks of operator in automated process plants.

There has been a considerable work made in describing the behaviour of the human operator in performing monitoring and control. The descriptions and the models have mainly been used in the avionics field although an effort has been made for generalising the models to the process field too. The models are discussed in the paper and reference is made to a task analysis study in a nuclear power plant. As a conclusion a need for new descriptions of the human operator is indicated.

(55) NKA/KRU-P2(79)207 Sauli Päkkilä & M. Lind.
Working paper: Mass and energy balance analysis of reactor auxiliaries of Loviisa I plant.

A mass and energy balance analysis was made of four reactor auxiliaries of Loviisa I plant under the assumption of normal operation.

The aim of this research was to test the method in a sufficiently complex application and then further develop

the theory using the experience achieved here. The suitability of the method is also estimated.

(56) NKA/KRU-P2(79)216 Sauli Päkkilä.
Working paper: Mass and energy balance analysis of Loviisa I plant.

This paper is a continuation of the reference (55) which presents the mass and energy balance analysis of the reactor auxiliaries. The analysis has now been completed for the whole Loviisa I plant. The analysis covers the drawing of flowstructures of primary and secondary circuits and the decomposition of the flowstructures into aggregates.

The basic concepts as well as the detailed analysis was presented in the previous paper and are therefore not presented here. The primary and secondary circuits of the Loviisa I plant are analysed and some conclusions drawn from the analysis itself. Proposals for future steps are also made.

(57) NKA/KRU-P4(80)222 B. Wahlström and L. Tuominen.
Man-Machine communication in nuclear power plants; a Nordic cooperation project.

The background and motivation of a Nordic cooperation project studying man-machine problems in the nuclear power field is described. The work has been done in the areas of control room layout, human reliability and operator training. The methods and results of a system description and a task analysis are considered in more detail. The system description was used to structure the information of the plant and to guide the interviews with the plant operators. The task analysis was intended for the planning of the operator training using a full scope simulator. The

training of operators is discussed and the layout of a training session is given.

(58) NKA/KRU-P2(80)224 Björn Wahlström
Inhibition of alarms during nuclear power plant operation.

Alarming systems are used in the control rooms of nuclear power plants to alert the operator that a change in the operational state has taken place. The main difficulty in using alarms to cue the operator actions is that important alarms could be hidden by an abundance of alarms active at normal operation conditions. One possibility to cope with the situation is to use some method for alarm inhibition. In the paper some approaches for alarm inhibition are discussed.

(59) NKA/KRU-P2(80)239 Jukka Ranta, B. Wahlström, R. Westesson
Guidelines for the design of man-machine interfaces.
May 1981.

These guidelines for the design of man-machine interfaces (MMIE) have been developed as a part of the KRU project. The preparation of the guidelines has been supported by the theories and design criteria developed within the KRU Project.

The KRU Project has worked in close co-operation with the Purdue Workshop on Industrial Computer Systems and with the European Workshop of Industrial Computer Systems TC6. The format of the guidelines relies on earlier work done at these two Workshops. The earlier guidelines have been adopted and developed according to the design standards and practices used in the design of large process plants in the Nordic countries. On the other hand, results and

viewpoints originating in the KRU Project have been included, and this part of the guidelines exceeds the scope of the Purdue Workshop. The planning and design of a process automation system, however, is quite similar in all industrialized countries. It is accordingly the authors' belief that, subject to minor modification, the guidelines will have a general applicability.

The guidelines are presented in the form of a handbook and can be used as a checklist in the various phases of MMIF design. This basic structure was chosen because the authors believe that most of the deficiencies of existing process control rooms are the result of items "neglected" or "overlooked" at different design stages. Most of the deficiencies could therefore be avoided by improving the design process itself, and by ensuring that the designers include to an adequate degree all the factors which are relevant and essential to the MMIF system and to the operating on the plant. These guidelines are intended to provide support in ensuring that everything essential is included in MMIF design.

(60) NKA/KRU-P1(81)235 Björn Wahlström
The control room situation

The control room of a large process plant such as a nuclear power plant is unique as working environment. The present control rooms are the result of an evolution where new solutions have been tried on a smaller scale before the realization. A conservatism in the design will therefore tend to preserve technically obsolete solutions, where existing deficiencies could be accentuated by a thoughtless increase in automation. Considering the basic goals of the process together with resources and limitations of the human operator it seems evident that a suitable automation level and control room lay-out could be arrived at. The design process itself is crucial when

deficiencies are to be avoided in the control room realization. The ultimate question is, however, to design the control room in such a way that the human operator will be able to cope with the very rare disturbed situations.

(61) NKA/KRU-P2(81)236 Jukka Ranta
The design process leading to a control room

Basic trends in the development of automation technology have had their influence on the design process of automation and especially on the control room design. The design phases, the automation system design as a part of plant design and the control room design as a part of automation design include critical decision stages, which have a special and in many cases crucial influence on MMIF design. Design criteria and technological decision variables must be clearly pointed out and design work must have global criteria, a system engineering view, which incorporate human factors in the design process from its very beginning. The complexity of design work and information management during design process needs special design aids, e.g. guidelines, CAD etc., to guide the practical design work.

(62) NKA/KRU-P1(78)306 Per-Gunnar Sjölin.
System- och befattningsbeskrivning vid ett svenskt kärnkraftverk. Systembeskrivning, tillstånd och procedurer.
(1978-06-08).

En sytem- och befattningsbeskrivning har genomförts vid det svenska kärnkraftverket Oskarshamn II. Denna rapport behandlar en systembeskrivning i tekniska och operativa termer. Denna beskrivning utgör ett nödvändigt underlag för befattningsbeskrivningsarbetet inom samma projekt och

även för kommande arbeten inom ett pågående internordiskt samarbete i kontrollrumsfrågor.

Rapporten innehåller en redogörelse för de metoder och formateringar som kommit till användning. Resultatet redovisas med förteckningar, tillståndsdiagram och exempel på beskrivningar av procedurer och delsystem.

(63) NKA/KRU-P2(78)308 Helge Tuxen-Meyer.
Arbetssituationer för kontrollrumspersonal vid värmning av reaktorsystemet och uppkörning genom kriticitet till 5 procent reaktoreffekt (BWR).
(Oktober 1978).

Rapporten behandlar konsekvenser och följdeffekter af några förslag till störningssituationer under start-up att användes i nordiskt kontrollrumssamarbete.

Analysen berör ett svenskt kärnkraftverk, typ BWR, som Oskarshamn 2.

(64) NKA/KRU-P2(78)310 Helge Tuxen-Meyer.
Arbetssituationer för kontrollrumspersonal vid värmning och uppkörning av en tryckvattenreaktor PWR typ R2.
(1978-12-08).

Rapporten beskriver dels
- de procedurer som erfordras för värmning och uppkörning av en PWR-station efter en längre tids avställning.

och dels

- de procedurer som erfordras för åtgärdande av en rad karakteristiska störningar som kan inträffa under uppkörningsperioden.

Materialer är sammanställt för att användas i et pågående nordiskt kontrollrumssamarbete.

Allt faktamaterial bygger på utdrag ur instruktioner för R2, Ringhals, daterade 1974.

Rapporten är en parallell till reference (63) som behandlar motsvarande för en BWR-station.

(65) NKA/KRU-P2(79)313 H. Tuxen-Meyer.
Sekvensanalys PWR typ Ringhals 2.
Värmning och uppkörning.

Rapporten bearbetar och sammanställer information beträffande värmning och uppkörning av en PWR-station enligt Reference (64).

Huvudsyftet är att sammanföra operatörspersonalens arbetsuppgifter i ett antal huvuduppgifter och i grafisk form återge dessa och delprocedurerna i dess normala sekvenser.

Slutsats

En grafisk framställning kompletterad med motsvarande för tänkta störningar under start-up fasen skulle ge en översiktlig presentation av kontrollrumspersonalens "Work Load" i aktuella situationer.

(66) NKA/KRU-P2(79)315 E. Forsyth och H. Tuxen-Meyer.
Sekvens- och time-line analyser för PWR type Ringhals 2.

Rapporten bearbetar och sammanställer information beträffande värmning och uppkörning av en PWR-station enligt Reference (64).

Huvudsyftet är att sammanföra reaktoroperatörspersonals arbetsuppgifter i ett antal huvuduppgifter och i grafisk

form återge dessa och del procedurerna i dess normala sekvenser.

Slutsats

En grafisk framställning kompletterad med motsvarande för tänkte störningar under start-up fasen skulle ge en översiktlig presentation av kontrollrumspersonalens "Work Load" i aktuella situationer.

Desuden foreligger der nogle rapporter udgivet af LUTAB.

(67) Om "Ergonomisk utredning av dou-personals arbetsuppgifter i kärnkraftverk - huvudstudie" - Reporter TA 895 r1 - r6 (1979).

(68) NKA/KRU guidelines for man-machine interface design level III MMIF design checklist.
Report LUTAB-R-3064.1

Copies of most of the documents can be obtained by contacting the following:

NKA/KRU ... 1-99	Electronics Department Risø National Laboratory DK 4000 Roskilde Denmark
NKA/KRU ... 100-199	OECD Halden Reactor Project Postbox 173 N-1751 Halden Norway
NKA/KRU ... 200-299	Statens Tekniska Forskningscentral VTT/SÄH Vuorimiehentie 5 SF-02150 Espoo 15 Finland
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