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EXPERIMENTS ON DATA PRESENTATION TO PROCESS OPERATORS IN DIAGNOSTIC TASKS[1]

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Abstract: Safety and reliability considerations in modern power plants have prompted our interest in man as an information receiver - especially in diagnostic tasks where the growing complexity of process plants and hence the amount of data involved make it imperative to give the staff proper support. The great flexibility and capacity of the process computer for data reduction and presentation and for storing information on plant structure and functions give the system designer great freedom in the layout of information display for the staff, but the problem for the designer is how to make proper use of this freedom to support the operators efficiently. This is especially important in connection with unique, high-risk, and generally improbable abnormalities in plant functioning.

Operator tasks and mental models and the need for matching the encoded information about the plant to these models are treated. Mention is made of scant information available to the designer and the difficulty involved in per forming experiments in a realistic environment. Results from the use of verbalization techniques in an electronics maintenance shop in order to gain insight in the structure of mental procedures are described, and the paper concludes with a discussion of experimental work in display coding and for matting being carried out at the DR 2 reactor.

1. INTRODUCTION

Safety and reliability considerations in modern power plants prompted our interest in man as an information receiver in diagnostic tasks. Al though power plants are amply protected by automatic safety systems, we found that there are critical periods during which plant safety to a consider able degree depends directly upon supervision and protection by the operating staff. Examples are initial plant start-up, re-start following major repair or modifications, etc. After such periods the plant may be left in an unsafe condition, not covered by the automatic protection system.

When abnormal plant conditions are detected during these phases, the staff has a diagnostic task which is, in fact, a very complicated data processing job, and it becomes increasingly important to give the staff proper support in view of the growing complexity of process plants and hence the amount of data involved in the task.

The great flexibility and capacity of the process computer for data reduction and presentation and for storing information on plant structure and functions give the system designer great freedom in his layout of information

[1] In: Aspects of Research at Risø. Risø Report No. 256, 1972, pp. 69-84.

display for the operating staff, but the problem for the designer is how to make proper use of this freedom to support the operators efficiently.

2. OPERATOR TASKS AND MENTAL MODELS

The process plant operator works in a symbolic world. His task is to select relevant data from the multitude of data presented to him, to decode the information, and to transform it into a set of manipulations appropriate to the current plant condition.

During this task he needs not only the relevant set of data, but also a decoding and transformation model as well as a data handling procedure. Therefore it is important that the encoding of the data presented - i. e. the display formats or layouts - fits the operator's decoding models or allows him to form models and procedures well within his mental and perceptual capacity. The mental models and procedures of the operator are in some way modelling system information which describes plant responses and/or plant structure and internal functioning.

The problem of the designer is that the system information used by the operator is not only that supplied by the designer in the form of manuals, instructions, and education of the operator, but is also to a high degree extracted from the system itself by the operator as he acquires his extensive operating experience. The basic difference is that system information used by the designer is related to internal system functioning, while the information forming the operator's experience is related to the external responses of the system.

One major experience from our studies and discussions with designers and operators has been the great discrepancy between the actual procedures or transformation models used by the operators and the imagining of these procedures by the designers at their writing desks.

For example, we find data presentation by digital indicators or alpha numeric listings on CRT's, as commonly found in computer-controlled display systems, a bad substitute for conventional operator consoles in many operating conditions. In the latter case, the operator normally does not read the instruments, but merely judges the position of the pointers. In addition, the geographical distribution of meters and indicators relates data to plant structure, and properly arranged groups of meter readings are viewed as patterns.

The problem of the display designer is further complicated by the fact that the conceptual transformation models and procedures used by the oper ator will be different under the different working conditions.

In frequent, recurrent tasks, the operator may be expected to work from "the expression on the face" of the system; that is, to apply subcon scious procedures based upon recognition or experience. His data handling may be likened to high-capacity parallel processing in his "peripheral system" (as in car driving), whereas, in infrequent or unique diagnostic situations, he will have to place his attention inside the system and relate his procedures to the internal functioning of the system by careful and sequential data handling in his slow, low-capacity, conscious "central processor".

If the coding and formatting of the data sets presented to the operator are to fit his procedures and models, they will have to vary greatly in the different operating situations. No one would expect the same coding of data to be appropriate for the ordinary driver's control panel in a car and for advanced diagnostic instrumentation in a test station for cars. Yet the operator's console in most process plants has to fit both types of needs. As mentioned above, the nature of the system information used by the operator to relate plant response to his manipulations is related to the frequency of the events and may have elements of subconscious training, experience from previous cases, instructions and station orders worked out by de signers for infrequent but foreseen events, and - in extreme cases of unforeseen and generally improbable situations - his actions must be based on familiarity with plant anatomy and its physical functioning.

In our context of plant safety, we have a special interest in diagnostic procedures during events implying high risks - which, in well-designed plants, are those of very low frequency - i. e. the generally improbable, unique events. While the great adaptability of man will very often reduce the importance of a proper layout of displays in recurrent and familiar tasks, the coding and formatting of displays may be very important in connection with the unique, high-risk events. Very little information is avail able to a display designer about mental models and procedures used by system operators in real-life environments, and we therefore have an experimental programme to supply us with such information.

3. MAN AS INFORMATION RECEIVER

We found that a reasonable way to gain insight into the structure of the mental procedures used by the operator was to ask him to verbalize his thinking.

Owing to the low frequency of events calling for real diagnostic procedures and the stress laid upon the operators when paced by the dynamics of a plant, it is difficult to perform experiments in an actual control room environment.

We therefore found it convenient to carry out preliminary experiments in an electronic maintenance shop in order to test out methods for recording and analysing verbalized records and to have an indication of the more basic features of man in a realistic diagnostic task.

Of course, detailed results from such experiments are not directly applicable to the control room environment, but some of the more general results may be helpful in display coding and for future experiments in the control room. This will be discussed later.

For the experiments we selected electronic systems with fairly complex displays, which permitted a rather close localization of the fault by rational deduction from the information available from the external response of the system. These systems included TV-receivers, oscilloscopes, and multichannel analysers .

The procedures found will not be discussed here; a review [1,2] is published elsewhere, and some conclusions relevant to the present discussion will be presented here instead

When a diagnostic task is not characterized by mere recognition of the faulty system response, the search for the fault is a multiple task.

The man has to collect data sequentially and control the route of search; he has to maintain or establish an overall conceptual model of the system and the interconnections of its subsystems. He has to identify the proper sources of the data needed amongst the many sources of data available. To judge the data, he has to establish a conceptual model of the related equipment at a more detailed level, and, finally, he has to keep track of his over all plan for the diagnosis.

In our studies we found - as could be expected - that difficulties in one of the subtasks may impair the performance in the other tasks greatly, and from this we drew two conclusions:

One is that great care should be taken when generalizing from clear-cut laboratory experiments with special equipment which strips all secondary or seemingly trivial activities from the main diagnostic task.

The other is that when using computer-controlled displays, not only the data should be presented to the operator as is done in alphanumeric listings or digital indicators, but the data should in some way be related to plant anatomy in order to support the operator's conceptual models. In conventional control rooms this is to some extent done by proper geographical layout of meters, indicators, and alarm panels.

Although response data in our experiments were clearly available to and observed by the man, making it possible to locate the fault by a rational deductive analysis of the data and the relationships between them, the actual search procedure was normally based upon rapid streams of simple good/bad judgements made on the data individually.

Considering the difficulty of keeping track of the different subtasks, this seems quite reasonable since the procedures used do not call for high short-term memory capacity. This may also be an important feature of the corresponding procedures followed in stressed control room operations. It seems to be convenient for the man to map the system by means of good/bad judgements. However, when information has been treated in these judgements, only the result - good or bad - seems to be remembered, and the original information is discarded and not later recalled for further control of the search.

Again, it is to be expected that presentation of accurate information in digital form will not in many circumstances be of great help to the operator. He should rather be given data in analogue form including reference to normal data in some sort of graphic, symbolic display.

We found that a general rule controlling the search procedures seems to be that as soon as information is perceived which refers to a procedure of search normally found to be successful, attention is switched to this procedure, even though information is also clearly available showing either that the procedure will be inefficient in the actual case, or indicating the possible existence of a short-cut method, if the situation is more carefully considered.

As discussed by Bartlett[3], there seems to be a point of no return in the operator's attention to data. As soon as a familiar routine is found to be waiting ahead, this prevents further use of the information in the data currently treated.

To us this indicates that data should be presented or be available to the operator in clearly formatted sets or patterns related to relevant systems and operating conditions, to force the operator to include all pertinent in formation in his initial hypothesis rather than in the form of information in alphanumeric listings calling for sequential reading during which the operator's attention may switch to a familiar procedure involving an inadequate subset of data.

In our studies, as in other published experiments), operators have demonstrated a marked tendency to hang on to procedures they have normally found successful and, when in trouble, they have tried to repeat these procedures more carefully instead of returning to the original information at the starting point and considering it with a more open mind.

This may be an important point to consider in plant environments since poor data presentation may cause the operator to spend too much effort in considering familiar procedures related to familiar subsets of the data presented.

This tendency may be countered if automatic data and alarm analysis by a computer are used to classify plant conditions, group data in relevant sets, select and edit display formats, and relate data to plant structure.

The general diagnostic procedures found in our experiments may seem inefficient if the man is supposed to minimize the number of decisions necessary in order to be rational, informationally speaking. If, however, he is supposed to minimize the time generally needed to identify the system condition by use of procedures based upon operating experience and well within his limits for short-term memory and inference, the procedures are highly efficient, except in very infrequent cases.

The influence from man's objectives and from the cognitive strain upon his choice of procedure has been treated thoroughly in the experiments on concept formation by Bruner et al.[5].

4. EXPERIMENTAL WORK ON DISPLAYS

As mentioned earlier, very little information is available to process plant designers about the functioning of the human operator in the control room. As a step towards increasing the available information, a computer controlled instrumentation was developed and is running "on-line" at the DR 2. This instrumentation includes a control console with an advanced display facility for conducting experiments in display coding and formatting and interactive data retrieval (see fig. 1).

The console forms the basic man - machine interface of the digital instrumentation system. It will be used by both engineering and operational personnel under all conditions of reactor operation in an environment which could be said to approach the "industrial". It should be stressed that the console performs only a display function; basic reactor monitoring and control are carried on from the existing control room.

The control console is equipped with several types of display equipment. The most prominent and important is the cathode-ray-tube (CRT) display which comprises three tubes - two large conventional ones and one small storage tube. These are driven from two display processors with associated character generators. The computer can communicate with each display processor and cause any desired pattern of lines, curves, dots, and characters to be generated on the CRT's. By splitting the screen of the two large tubes into a right and a left half via programming, a total of five different pictures can be maintained simultaneously. In addition, there are two digital displays, a status display, four keyboards, and a light pen. How ever, the point is not the quantity of equipment, but the uses to which it can be put to satisfy the various needs for information coded in an effective manner for the tasks at hand. The digital displays and the five selectable CRT pictures are meant to serve as a compressed and integrated substitute for the large panorama of displays, controllers, meters, and recorders found in present-day control rooms.

The strategy intended for use here is that of using the various CRT pictures as a supplement to the normal alarm system to give the operator the information he needs to formulate his diagnosis, Whereas, at present, his survey consists in running his eye over many square feet of control room panels, the operator substitutes, in our system, a sequence of "picture select" and "examine" operations. In a conventional plant he gets his detailed information by waving over to a particular meter or recorder; with the control console the operator can use the light pen or keyboards to get the same information. It is appropriate to say here that our first efforts in display formatting were directed at retaining commonly used data types and symbols - such as the equivalent of meter pointers and faces, mimic panels, text, etc. - and using them within the framework of the CRT display. A later step, based on experience and further experimental work, might be to broaden the spectrum of symbolics for better matching to the operator's peripheral system.

5. OPERATION

If a process status change is detected; several things occur automatically:

> A bell sounds, and the appropriate status display window - pinpointing the affected reactor sub-system - blinks to indicate whether a new alarm has been detected, or whether a previous alarm has become normal again.
>
> In addition, the detected status change and the time are listed automatically in text form on one of the CRT half sectors. The original presentation is lost until the operator acknowledges the change.

Multiple status changes will appear on the CRT in order of detected occurrence, and each will give rise to an appropriate indication on the status display. No kind of pre-processing of alarms is performed at the present time. On the basis of this initial information - i. e. affected reactor sub system(s) and channel numbers within the sub-system - the operator can now seek further information from the display system. By use of either of two "CRT Display Select" keyboards, he can build on the four CRT sectors the set of process status information he feels is best suited to the existing situation. figures 2 to 4 illustrate several of the CRT display formats used at the present time. A short description is included with each figure. In general, they are analogue in form to permit quick comparison of actual multi parameter-process information to be made with a reference pattern existing in the operator's mind for the particular sub-system. Rather than accuracy, capability of inspiring a quickly grasped appreciation of the actual situation is required.

The light Pen can then be used in several ways to request further in formation via the analogue presentation. For example, by pointing first to the dot inside any desired variable-indicating diamond, box, arrowhead, cross, etc. . and then to one of the light dots on the screen, an updated digital. value for the selected channel will be displayed.

The operator can also request "trend" information for any two (at one time) of the displayed process variables on any one of several time scales by means of similar light pen and keyboard operations. These curves, which can give valuable insight into plant behaviour up to the present moment, will appear automatically on the other half of the "requesting" screen. Use of the light pen on a "trend" curve will permit the recovery in digital form of any desired point on the curve. This can be useful in, for example, post-incident analyses

In this way, the operator has easy access to detailed data through the selected sub-system analogue display, but he is actually forced to examine a significant part of the process behaviour before gaining this access. He is thus somewhat more restricted in the automatic reflex type of reaction he can make which, for example, might limit his attention to a minimum set of probably inappropriate variables or instruments when a true emergency arises.

The light pen can also be used to change alarm limits. Most analogue process variables have associated high and/or low alarm references which are used by the computer programme to check the status. Some of these references are fixed by the designer, and others can be adjusted to match operating conditions. This can be especially useful during commissioning or repair. Alarm limits are displayed as short horizontal line segments. If the light pen is pointed at the desired-limit, two extra lines appear automatically, one above and one below the existing line, corresponding to a + 5 to 10% spread. The limit line segment will then blink. Moving the light pen up or down results in the set of added bound-lines following. When the desired value is reached, the "GO" key is pressed, the new alarm value is accepted (various criteria can be employed here) and inserted in the appropriate lists in store, and the display is adjusted to show the limit in its new position without the two extra bounds.

Although the present system capability is limited to display and process information retrieval, there is no technical reason for not employing the light pen (or some similar device) to take any ultimate control action that may be required

In conclusion, a few words about the future programme. The operating staff of the DR 2 will soon begin to use the control console to follow start ups and shut-downs of the reactor. We are very interested in obtaining their comments on and criticism of the operation of the system. It will also be possible to use the computer to measure quantitatively the operators' utilization of the various console features under the various reactor operating conditions .

The department is also about to acquire an off-line interactive display terminal which, among other things, can be used for investigating more restricted problem areas which arise from the experimental work. For example, future work will deal with a more fitting format for alarm presentation which we feel should tie the alarm situation more closely to the anatomy of the plant, a feature which alphanumeric text listings do not offer.

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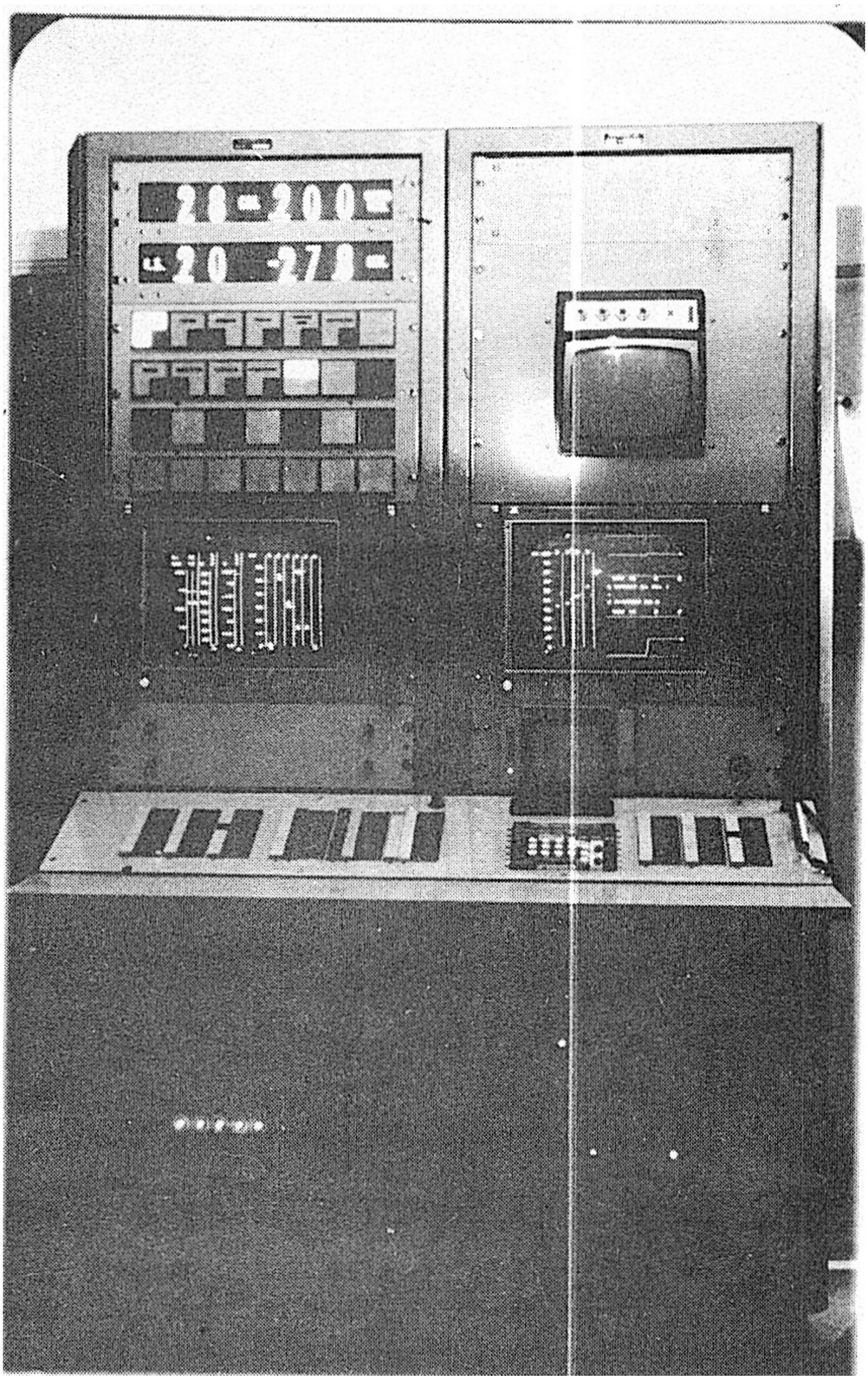

Fig. 1. Control Console.

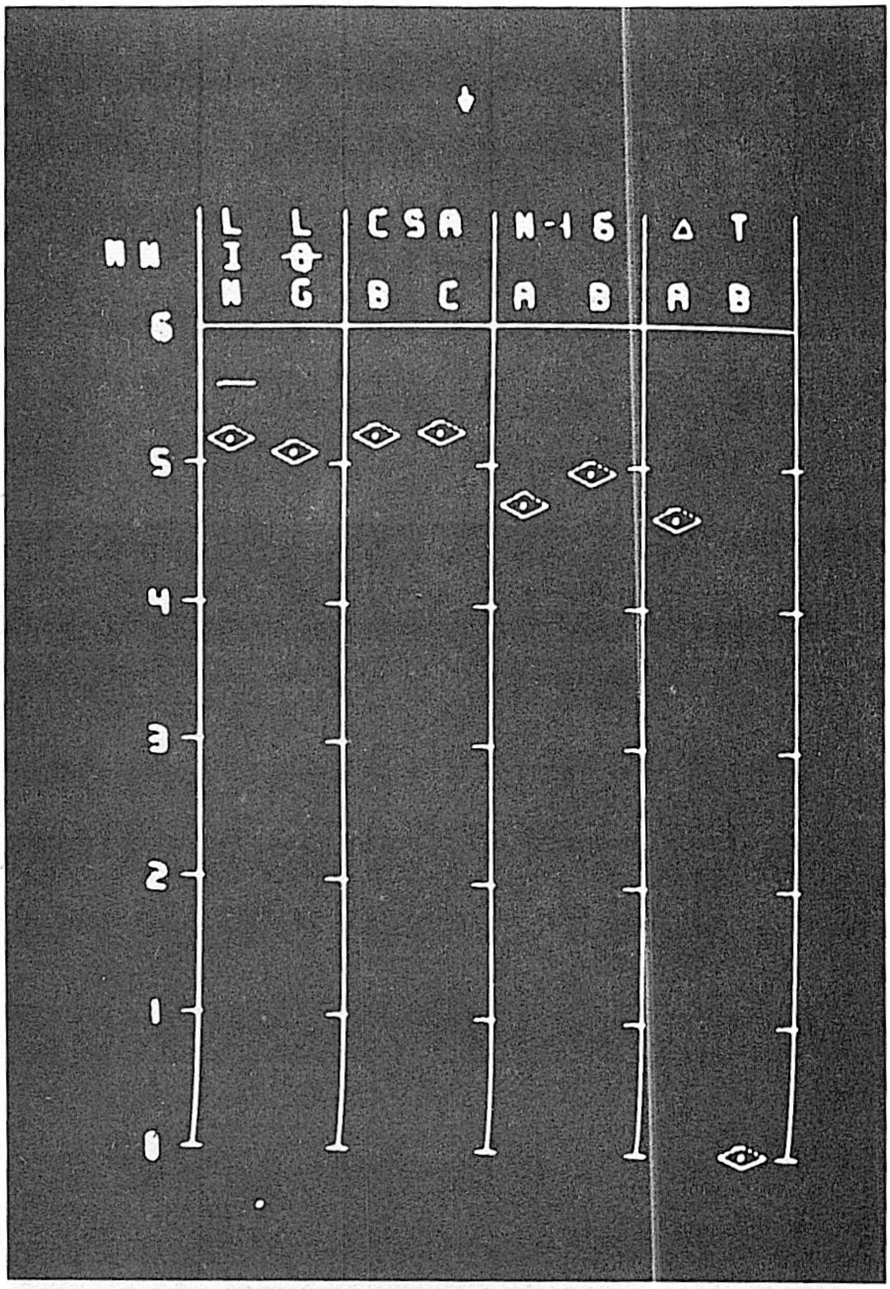

Fig. 2. Reactor power at "full power". Channels corresponding to three different methods of measuring power are displayed simultaneously. A typical analogue survey presentation.

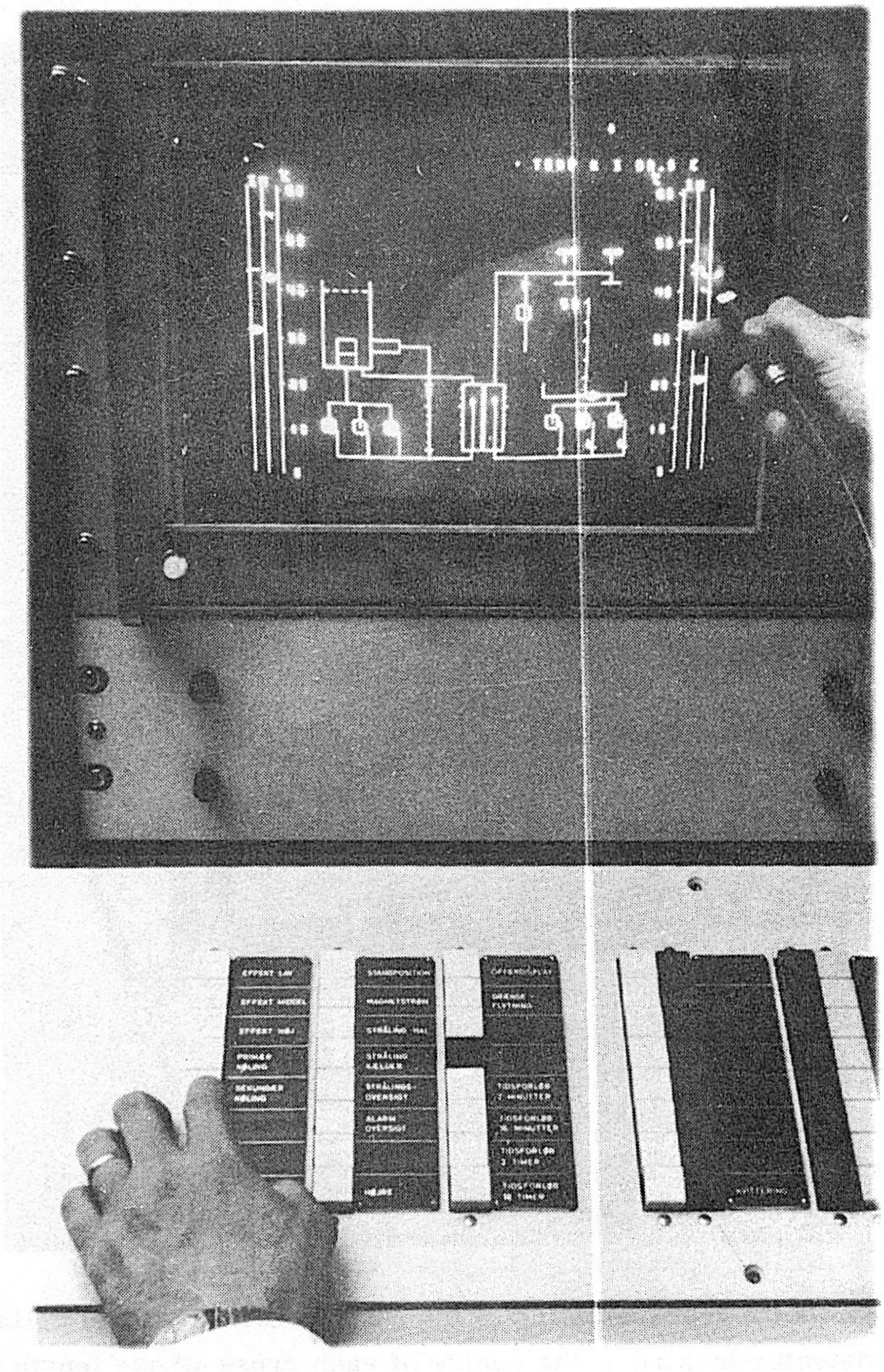

Fig. 3. Reactor cooling system. Quantitative data on temperatures, flows and water level are combined with a symbolic representation of the reactor core, cooling pumps, heat exchanger, cooling tower, and blowers. On/off status of pumps plus cooling fen speeds are included. A portion of the "display select" keyboard and the light pen can also be seen.

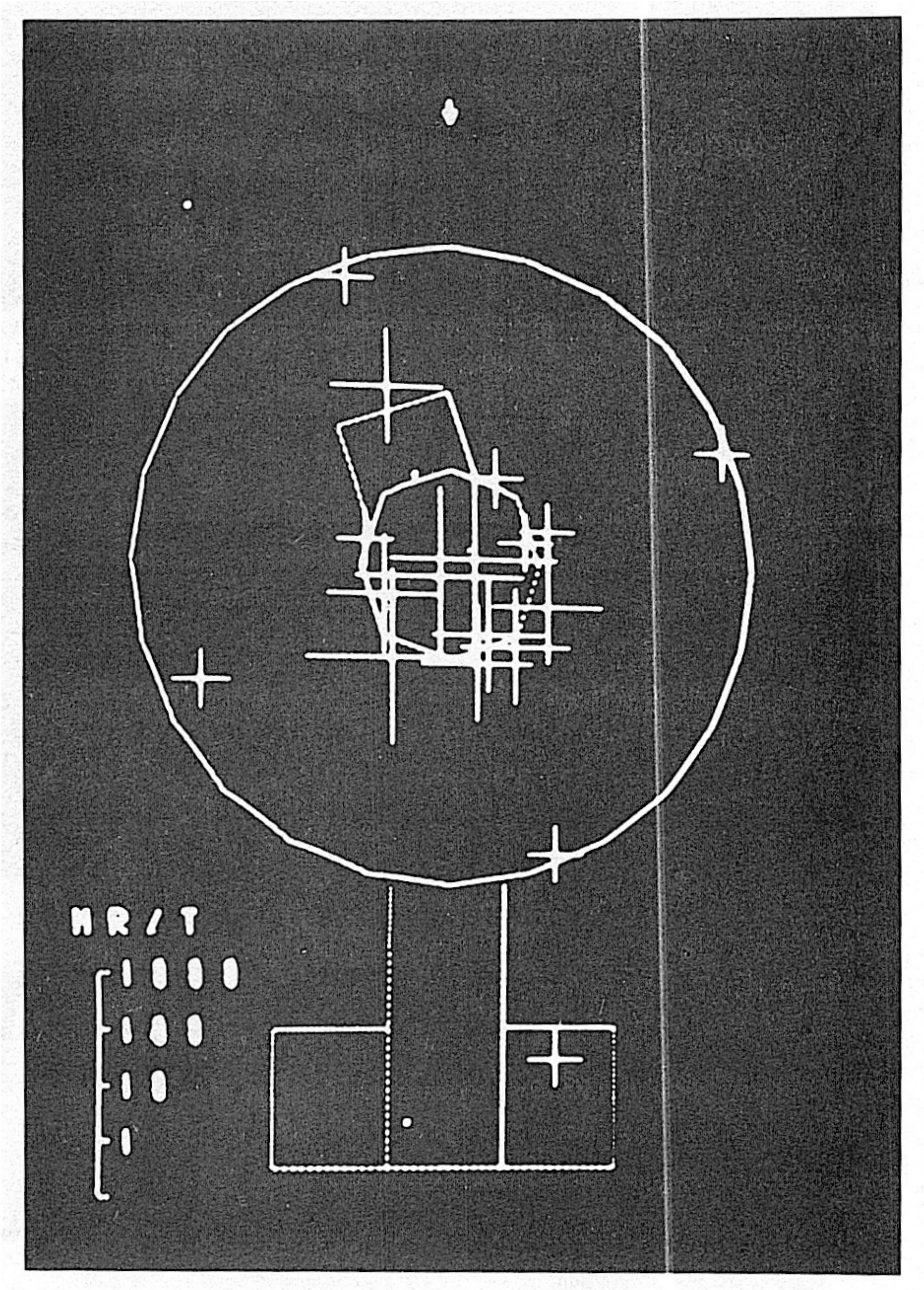

Fig. 4. A symbolic representation of the DR 2 reactor hall and cellar with a radiation detector located at the centre of each cross whose length is proportional to the radiation intensity measured at the detector. The included scale allows a rough quantification to be made..

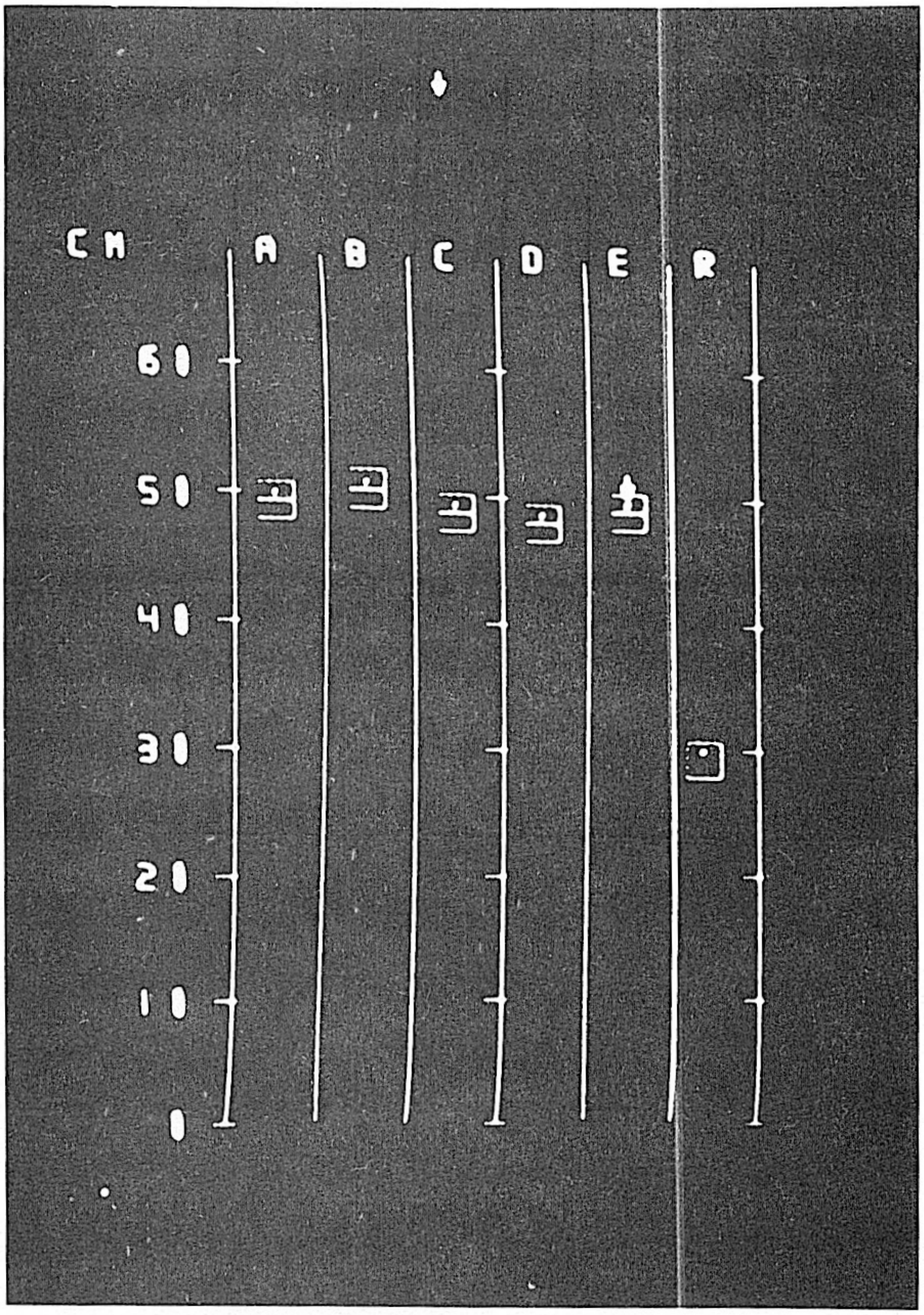

Fig. 5. Survey of the reactor control rods. Each rod has a magnet (upper rectangle) which holds the rod (lover rectangle). Movement of the rods is indicated approximately by the arrows.