{C78} THEUREAU J., JEFFROY F. & VERMERSCH P. (2000) Controling a nuclear reactor in accidental situations with symptom-based computerized procedures : a semiological & phenomenological analysis, CSEPC 2000, Taejon, Corée, 22-25 Novembre.

Controling a Nuclear Reactor in Accidental Situations with Symptom-based Computerized Procedures : a Semiological & Phenomenological Analysis

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Abstract

Accident control activity of operators in nuclear power plants is guided through various guidance systems throughout the world. But international scientific and technical litterature reveals a poor interest in the precise effects of the guidance systems on this control activity. The present empirical study develops a phenomenological and semiological analysis of video recordings of operators'activity in different accident scenarios on a full scope simulator. It shows the effects of the "style of guidance" and "breacks in the style of guidance" on operators'activity, appreciated in terms of "strategic view as opposed to narrowing" and "concentration on the process as opposed to distraction". It paves the way to progress, both in terms of human factors knowledge and design.

Introduction

Since the accident at Three Mile Island, many conceptual approaches have been adopted at international level as regards the creation of procedures for operating a nuclear reactor in incident and accident situations.

In France, "symptom-based" procedures are gradually replacing "event-based" ones. In the control rooms of the latest generation of power plants, the N4 series, on which the study focuses, the majority of these procedures are computerised. **The reactor operator, the water-steam operator and the technical supervisor** interact with the computerised operating system via various graphic screens, alarm screens, touch-sensitive screens and keyboards. Symptom-based procedures are presented to the operator in the form of flow diagrams, a series of steps to which he must answer YES or NO. These steps cover parameter values (test steps) and requests for action to be taken on the process (action steps). Some of them are checked automatically (when the choice made by the operator is not consistent with the data in the computer system, the link with the previous step turns red, informing the operator of the discrepancy; he can then make another choice or "impose" his first choice). Within a procedure, the steps are grouped into operating sequences which in turn makeup modules. When the operator reaches the end of a sequence, he starts at the beginning again. The sequence can then change if the operator gives a different answer to one of the questions. If the process changes significantly, the operator may be obliged to move to another sequence in the procedure being used or even move to another procedure. Whenever symptom-based procedures are used, the operator has to systematically go through a preliminary guidance procedure which mainly includes test steps, complete or partial answers to which are suggested by the computer system by means of windows. The operator can decide to abandon a procedure at any time, be it a paper or computerised one; in this case he has to finish the sequence in hand then go through a selection module in which he indicates which new procedure he wishes to apply.

Quite apart from the purely technical aspects, the design of these symptom-based procedures is based on five facts concerning operator activity: (1) the fact that there are many events occurring at different times may make it difficult to manage them using event-based procedures, (2) thinking through stories, i.e. through events and actions where "one is the hero", which appears to be characteristic of the human thought process, may lead to operators becoming embroiled in « bad stories », sticking to them and considering each new event as a simple continuation of the story or malfunctioning of the measurement instruments, (3) operators are under stress and are likely to commit errors which they would not commit in normal situations, (4) accident situations are very rare and despite the regular simulator simulations in which operators participate, there is a chance they will be less competent in these situations than in everyday ones, (5) operators have to keep their initiative.

In other countries, such as the United States or Japan, choices have been made which range from slightly to radically different. For example, in nuclear power plants in North America, a compromise has been reached between event-based procedures and symptom-based ones: operators attempt first of all to diagnose the events which have occurred and to use the corresponding event-based procedures; if, after a certain period of time has elapsed, this proves impossible or if the equivalent of the supervisor notices a deviation in the major parameters of the installation, they switch to symptom-based procedures.

A glance at international scientific and technical literature on human factors and cognitive engineering reveals that operator activities are not differentiated as a function of the various guidance systems and the general operating situations in which they are applied. If these differences are to become apparent, the activities of the operators and the ways in which they are guided through them must be detailed. It is the case in the study we present here.

1. Data creation, analysis approach and analytical concepts

Our study was based on **video recordings of tests carried out on a full-scope simulator** of the N4 control room at a given stage in its development (13 test recordings, approximately 2 hours and a half each, involving 7 different accident scenarios and two different operating teams), followed by short, collective debriefings. It should be emphasised that the performance of the joint "technical system - guidance system - operators" system, when evaluated in terms of "deviations from prescribed operation" proved satisfactory from a safety point of view. From the outset, our aim was to glean further information on how this satisfactory performance was obtained. Our objectives were twofold: to step up performance even further by improving certain constituent parts and to base predictions of future performance on scientific knowledge of the dynamics of the joint system mentioned above.

Our study focused on the **activity of the reactor operator**, with the activities of other operators only being considered in relation to his. We supplemented the data with separate comments from two experts whose skills were complementary; they were instructed to first of all understand the operators' points of view before assessing the effectiveness of their actions. In order to understand the impact of computerised procedures on operator activity, we analysed the same scenario involving operation with computerised procedures and operation from the auxiliary control panel on the basis of paper procedures (the auxiliary control panel is the conventional interface for operating the reactor when the computerised interface is defective).

Once transcribed and enriched by commentaries from technical experts, we developed a peculiar **process-tracing method**, that is a kind of inductive method we coin as semiological & phenomenological. This peculiar process-tracing method is related, on the one end to the methods of French-language occupational ergonomics analysis, and more specifically to those of course-of-action analysis and courses-of-action collective interlinking analysis (see, for example: [5], [1]), on the other end to the present renewal of psycho-phenomenology (see, for example, [7]). The theoretical and epistemological background of this semiological & phenomenological method can be summarized by the notion of **dynamic, living, social, & cultural complexity** ([4]). This notion combines the usual notion of complexity, along which a complex system is a system made up of a large number of elements which interact in multiple ways, with the notion of **autonomy** as applied to actors, groups of actors and cultures ([6]). This autonomy means that the human actor (or group of human actors) constantly interacts with the larger system of which it is part, but in a dissymmetrical way, i.e. with the elements of this larger system which are relevant from his point of view here and now. Whence two epistemological consequences: first, a primacy of analytical method relatively to synthetic method ; second, in the analysis of the dynamics of the system at every moment, a primacy of the point of view of these actors at every moment relatively to the point of view of the observer.

To perform such an analysis into its details, one needs, on the one end data about the point of view of the actors (hence, ideally, different forms of verbal data : communications, but also instigated verbalizations like simultaneous or interruptive verbalizations or self-confrontation interviews, that is much more than the data available in this study, but it is always possible to begin with non ideal data), on the other end methods and notions of analysis which concern the construction of this point of view of the actors through their activity at every moment. In this sense, these methods and notions of analysis are **phenomenological**. They are also **semiological** because the notions of analysis concretize abstract semiological notions : sign (or rather semiosis, that is sign dynamics), sign components (or rather moments of semiosis) and dynamical semiotic units and structures .

Using the video recording, its transcription (an account of the actions taken by the operators and their utterances), supplemented by the comments of the experts, the analytical approach consisted in tracing the sequence of operator activities in an attempt to establish the continuity of its intelligibility. This was done according to three principles: firstly, all expectations were **set aside**, the only goal being to seek to understand operators' activity as a whole; secondly, we tried to **detect** what **seemed** to us to be **incomprehensible** and **broke the continuity** of intelligibility; finally, we sought to **restore** this intelligibility as much as possible by using all the information available. In our attempts to restore intelligibility, the entire procedure had to be broken down into analysis units which we refer to as cases.

The empirical results of this analysis cover the effects of the **style of guidance** and **breaks in the style of guidance** on operator activity (**strategic view as opposed to narrowing, concentration on the process as opposed to distraction**). The concepts of **style of guidance** and **breaks in the style of guidance** characterize semiotically the computer and paper procedures. The concepts of **strategic view/narrowing** and **concentration on the process/distraction** refer to the subjective **horizon** of the operator. We talk of **narrowing** (as opposed to **strategic view**) when the subjective horizon of the operator is strictly limited by the step in the procedure or the screen page. We talk of distraction (as opposed to concentration on the process) when the subjective horizon of the operator is turned away from the process (the dictionary definition of distraction is "to draw aside, especially of the mind") in favour of something else (mainly, but not only, operation of the computerised guidance system). Characterizing the activities in this way does focus our attention on the characteristics of the subjective horizon of the operator, the degree to which they are beneficial and effective and on their determining factors.

2. Style of guidance, narrowing and distraction

Let us now consider three actual cases, the first two being examples of narrowing and the third both narrowing and distraction.

Case of the difficulties to take into consideration events extraneous to the procedure in progress

In a first example, we can see the reactor operator following a procedure of "primary pressure stabilisation". The water-steam operator tells him that a turbine bypass valve opened, introducing a secondary flow. Also the reactor operator sees that the pressure increases too much. But, at no time did the reactor operator consider that increasing secondary flow, by opening the turbine by-pass valve, might have an effect on the adjustment operation he was carrying out.

Now, when this valve is opened, it can, by a "cold blast" effect, increase the primary pressure gradient which is obtained by adjusting the spray system and heaters (10:52), and whose value (-4/-5 bar) was considered by the operator to be too steep. Likewise, closure of the turbine by-pass valve could account for the slight increase in pressure noted by the operator at 10:55. The operator knows that perfectly. Several hypotheses can be put forward to explain why the operator did not consider the opening of the turbine by-pass valve:

1) the fact that the operator is guided step-by-step and the information selected for display on the screens tend to reduce his view of how the process is evolving. Since he is involved in adjusting pressure by means of the spray

system and the heaters, the operator tends to consider the effects of these two actions only. The turbine by-pass valve is therefore not on his operating horizon at that particular moment,

2) operating actions are often interdependent; symptom-based procedures mean that operators have to carry out actions in sequence, in an almost independent manner, with adjustments being made as the various loops in the procedure are reached. Thus in Sequence ECP2.1b, the operator first of all deals with the "primary pressure stabilisation" module, then moves on to the "pressuriser level check" module. This operating mode obliges the operator to refrain from wanting to deal with everything at once and forces him to follow the order set by the procedure. It therefore saves him a considerable amount of effort if he restricts his view of operation to what is put to him by the step or module in the procedure. It avoids him being in a position of having to think what the next step should be; this would be extremely demanding since he would have to be constantly determining the correct action to be taken,
3) the operator could have realised that opening the turbine by-pass valve would have an effect on the adjustment operation he was carrying out, but if he took this event into account, he would have to deviate from strict adherence to the procedure. Finally, he considers that it is potentially more energy-consuming to deviate from the procedure than to apply it to the letter. He therefore complies with the instructions for applying procedures.

To explain the first hypothesis described above, it is interesting to note that when the pressure system is put back into service from the auxiliary control panel in case of computer breackdown, the operator uses the valves to align the systems correctly. He adjusts the flow rate to 10 m^3/h, then turns his mind to the devices which are represented in the immediate vicinity of the pressure system indicators and which are therefore directly within his field of vision. He says to himself: *"here I am putting the pressure system back into service, the flow rates through the reactor coolant pump seals are still correct ..."*. It can therefore be seen that the amount of information available and the fact that it is displayed constantly makes it easier for the operator to grasp the overall operating situation, whereas computerisation, which drastically reduces the quantity of data displayed, makes this more difficult.

Case of the difficulties involved in remembering which operating actions were taken previously

In a second example, the operator has failed to appreciate that the letdown line is still isolated. This explains the difficulty he has in stabilising the primary pressure and the pressuriser level between 10:50 and 10:56. The operator does not understand why the pressuriser level is *"so high"* when he is injecting 8 m^3/h into the primary system via the pressure system and not removing any water (letdown line isolated)! His lack of comprehension is also apparent when, at 10:57, the procedure indicates that he should adjust the letdown flow rate. The operator discovers, to his surprise, that the letdown line is not in service. When he discovers that the letdown line is isolated, the operator wonders *"did I put the letdown line into service at any time ...?"* We can therefore suppose that the operator has fully understood that the letdown line was isolated automatically during the reactor scram (first phase of containment isolation) since he assumes it has to be put back into service. On the other hand, he is surprised that he has not already done so. Furthermore, the rhythm and intonation of the sentence show that the situation is interpreted in two stages: 1 - the surprising realisation that the system has not been put into service 2 – the surprise that the procedure never asked for this to be done.

We assume that when the operator wonders whether he put the letdown line into service, he is not putting himself into an active position as regards his previous actions and is not trying to remember or recreate his previous control activity; it is not a question of: *"I don't remember putting the letdown line into service"*. On the contrary, his mind remains fixed on following the procedure and he is surprised to note that: *"I followed the procedure correctly, how is it that I was never asked to put the letdown line into service?"*. The fact that the operator does not delve into his previous actions is consistent with this hypothesis. This passive positioning in relation to control may explain the fact that the structure of the procedures is not supporting adequately operators' remembering of actions they have already taken. In the 60 minutes since the beginning of the accident, the operator has taken only a few operating actions: reagent injection system isolated at 10:02, automatic boration system taken out of service at 10:16, makeup line put into service at 10/24 and adjusted to 30 m^3/h, diesel generators shut down at 10:37, temperature stabilisation at core outlet (Tric) requested at 10:40 and spray system started up and heaters shut down at 10:50.

And yet, he is incapable of remembering that he did not put the letdown line back into service. Operating actions are "drowned" among a host of micro-actions taken at the test steps of the procedure (YES/NO answers). They do not stand out from the crowd. Furthermore, there is no way of giving the operator a synthetic view of the actions he has taken.

In addition, the steps in the procedure limit the angle from which the operator sees the evolution of the process. Between 10:50 and 10:57, the operator has difficulty stabilising the primary pressure and the pressuriser level. However, at no time does this prompt him to consider the primary system as a whole (input/output balance) and take the letdown line into account. The operator stays locked in the part of the process presented by the procedure.

Case of time spent managing certain functionalities of procedures (awakening and redirecting functions)

In a third example, it can be seen that the operator is distracted from process operation by the on-going operation of the computerised procedures. This distraction effect is heightened by the fact that the operator is locked in the step-by-step sequencing of the procedure. At the end of the first run-through of an operating sequence, the operator has to run through the "redirecting" module of the sequence in question and the "redirecting between ECP" module to "prime" monitoring of the path taken in these two modules. In this case, the operator spends two minutes looking for a reply to a question which has no significance in relation to the actual evolution of the process. The operator completes this step simply to "prime" the monitoring of the module, i.e. to ensure correct operation of the computerised procedure. The two minutes spent in this way are enough for the operator, who, two minutes earlier had finished going through Sequence 1 of ECP2, to be surprised by the question "have the criteria for leaving ECP2 been met?" The question has a destabilising effect on the operator and makes him doubt the way in which he has gone through the entire procedure.

3. Breaks in style and operator activity

Let us consider a single example, a double break in guidance style between "on-off actions" and "adjustment actions".

Case of cohabitation between carefully guided operating actions and loosely guided adjustment actions

We have just seen the case of the unchecked step "Have ECP2 criteria been met?" which is already an example of a break in style. We shall go on to examine a more complex case.

As we have seen, the flow diagram in the procedures combines two types of tests, "test steps" and "action steps". When an operator has to reply to a question, he does so in the context of a test step. He has finished with it when he moves on. This principle also applies to steps covering on-off type actions (opening valves, shutting down pumps etc.). But it does not apply to adjustment actions (stabilising primary pressure to the value reached by spraying and heaters, adjusting letdown flow rate, etc.). The operator has to adapt the extent of his action to the effects of it and in most cases, adjustment is carried out in stages, which can take several minutes. If the operator finishes his adjustment operations before moving on, it takes too long to go through the procedure. The operator therefore starts the adjustment operation, through the corresponding action step, but he then goes back to it after he has moved through the flow diagram.

This guidance characteristics leads to a double "break in style". Firstly, although operator action is dictated by the procedure, the way in which adjustment operations develop is left to the operator's initiative since the flow diagram simply gives the start signal. The "adjustment" step should be taken as "starting to carry out adjustment" and not "completing adjustment". The operator has to use all his operating skills to determine when and to what extent he should take action. Also, when the flow diagram requires that actions be taken in sequence, adjustment actions are taken in parallel with the rest of the procedure, meaning that the operator's time is divided between the two activities.

In this case, the operator spends a few seconds at most on the majority of steps in the flow diagram but almost five minutes on one of the steps (minus the time spent to take into account the water-steam operator's request concerning a valve which was opened spuriously). And he continues to act within the continuity of this step even though he has moved on from it, since the primary pressure adjustment requested in the procedure takes time and has to be done in several stages; this is the case between 10:55 and 10:56. This same approach, consisting in continuing with adjustment without being at the adjustment step proper, can be seen when the letdown system is put into service. At 10:58, the operator puts the letdown system into service by opening a port. At 11:03 he moves on to a step concerning the level in the pressuriser, notices that it is high and decides to open a second letdown port, thereby fine tuning his previous adjustment, even though the procedure does not ask him to do so at this stage.

Several hypotheses can be put forward to explain the problems encountered in carrying out adjustment operations within the framework of procedures:

1) During normal operation, adjustment actions constitute one of the advantages of manually-controlled operation as opposed to automatic adjustment. These adjustment operations require special skills combining theoretical knowledge of the process, knowledge of equipment technology and know-how. We have seen that the procedure tends to lock the operator into a given step, giving him less possibility to use his skills. The operator seems to have trouble staying within the step-by-step logic as imposed by the procedure and simultaneously taking the initiative to carry out adjustment actions. This is particularly obvious when he has to decide whether to continue with adjustment or return to the procedure. The operator has to reach a compromise between his adjustment skills exercised during normal operation, which prompt him to fine tune the adjustment (time spent on the step and continued adjustment while following the rest of the procedure) and the procedure application logic in accident situations which requires that the procedure be followed rapidly with approximate adjustments.
2) Following on from the above point, the accident operating procedure is designed according to the loop principle, which means that optimisation is not sought at the first attempt. This principle, which has proved very effective in picking up and correcting errors of direction at certain steps, is also valid for adjustment. The step in the procedure does not require optimised adjustment; it simply requires an initial adjustment which will be improved on at the next loop. This logic differs considerably from that on which adjustment skills are based during normal operation. Grasping it constitutes another problem for the operator. There is also the general problem of transferring skills used normal situations to accident situations.
3) Some adjustment actions involve a single parameter which can be changed directly, for example adjusting the makeup flow rate to 30 m^3/h, but other parameters can only be modified indirectly. This is true of the primary pressure which is adjusted by altering the makeup and letdown flow rates, core temperature, spray flow rate, number of heaters in service etc. During normal operation, the operator is not guided and can adopt an overall approach to the parameter before adjusting it, so that he can determine the most suitable combination of actions. The step-by-step operation imposed by the procedure makes it difficult to reason in this way. The operator is no longer in control of the order in which he will take his adjustment actions and he may tend to overestimate the effect of a particular action, since he cannot see it in the overall context. This proved to be the case when the operator tried to optimise primary pressure adjustment using the containment spray system and heaters (between 10:50 and 10:55), without considering the next module in the procedure which would have given him the chance to put the letdown line back into service, a necessary condition for stabilising the pressure. Furthermore, the sequence of adjustment actions imposed by the procedure is not clearly visible in step-by-step operation but has to be recreated by the operator by reading ahead in the procedure. By reading the following module "pressuriser level check", the operator could carry out the actions required to stabilise the primary pressure (10:51). It is possible to read ahead with paper procedures, even though

it is not very easy (it takes practice to be able to read procedures) but it is very difficult when procedures are computerised.

4) During accident condition operation, the operator makes adjustments in a particular facility configuration: systems have been isolated, protection and safety systems have been put into service etc. These actions have all been taken automatically and it is not easy for the operator to include them in his overall view of the facility at a given time. It is made even more difficult by the fact that the step-by-step guidance offered by the procedure makes it hard for the operator to position his action in a sequence which started in the past and stretches into the future. Thus, in the case being analysed, the operator attempts to stabilise the primary pressure without making allowance for the fact that the letdown line has been isolated.
5) Computerisation of procedures makes it more difficult to make adjustments while following the rest of the procedure. Indeed, on a conventional control desk, the context in which the adjustment is being made is ever present and the operator can "cast a quick glance" to monitor the effects of his actions on the process. With a computerised system, the operator has to display one or more specific images on his third graphic screen to monitor the evolution of the process. He may then be required to display other operating images on this screen and he then has to redisplay the previous images to continue monitoring the adjustment in hand. The overall context is no longer present.

4. Apply procedures intelligently !

In the precedent sections, we showed that procedures often tend to lock operators into passive positions where they merely do what they are told and that this is a problem, particularly when operators are confronted with a break in the style of guidance they receive. In this section, we describe the case of an operator who has trouble following the procedure and acting as guided.

Given the technical problems associated with covering operating situations in a homogeneous manner and the corresponding cost and other factors, the logic for strict application of procedures by operators has not be fully thought out. Operators are expected to ensure redundancy as regards the prescriptions contained in procedures, which supposes that they follow them with sufficient detachment as to be able to judge whether or not they can deviate from them; this can be summed up as follows, to use the expression employed by [3], by the slogan: "Apply procedures intelligently !". With computerised procedures we have seen above that the operator has the possibility to deviate from the procedure by "forcing" a red link, thereby having his opinion take preference over that of the procedure. He is also in a position to decide not to apply an operating sequence laid down by the procedure but to select another. This situation, in which the operator has to allow himself to be guided and follow the procedure at certain times and yet be able to step back and consider the contents of the procedure critically at others, is a highly paradoxical one. Indeed, the operator cannot stand back instantly. To be able to take the initiative and determine whether he can act outside the procedure or follow it through to the end, the operator has to be in a permanently active position, using his skills and developing his own point of view as to how the process is evolving and how it should be controlled. He is therefore required to be active and passive at the same time! Let us consider three examples.

Case of the difficulty in agreeing to consider the immediate state of the process only

As its name implies, the symptom-based approach takes the successive states of the process into account. At each step of the procedure, the operator is required to consider the value of a parameter at instant t. In this fifth example, we can see that it is not always easy for the operator to accept this limited view of the process at instant t. The first time the reactor operator reaches the test relating to exit from the pressure-temperature domain at 10 :49, he remains within the logic of the procedure in that he simply makes an immediate assessment of the process: *"exit on the left-hand side: no"*. It should be noted, however, that formulation of his question (*"where are we exiting by?"* then: *"are we tending to exit at the left-hand side?"*) falls into a context of evolution and not one of immediacy, where the question would have been: *"have we exited from the domain?"*.

When he reaches the test for a second time at 11:04, the operator immediately approaches the process in terms of evolution (*"therefore we are in the process of ..."*) and does not simply consider the immediate instant in the process as the procedure asks him to do. This attempt at anticipating the situation is illustrated by the fact that to reply to the test on the immediate state of the process, the operator goes down the paths opened by the two possible replies YES and NO to find information which will help him come to a decision. The operator takes an active stance in relation to the procedure and does not simply follow it step-by-step.

Furthermore, the analysis of the test conducted from the auxiliary control panel reveals that, in contrast, assistance is offered by the direct presentation of the operating point in the computerised pressure/temperature diagram. Until now, we have been focusing on the negative effects of computerisation on the control operators have on their activity. Here we find an example of positive effect. On the auxiliary control panel, the operator has to read off the pressure and temperature values and mark them on the "paper" diagram to determine the position of the operating point. This takes time and it is therefore not possible for the operator to accurately monitor the effects of his actions on the position of the operating point.

Case of the reluctance to adopt safe but non-optimised operation (operation close to the left-hand edge of the pressure/temperature diagram)

To understand why it happens that the operator opposes to step-by-step guidance, allowance must be made for the characteristics of the specific context in which his resistance develops; this we do with the following example. In this example, the two operators adopt a different stance as regards the guidance given by the procedure. The reactor operator has started to follow the procedure and is locked into step-by-step guidance. On the other hand, the water-steam operator, who has isolated the break in the steam line, has few actions to carry out; he clostops making loops in his procedure and chooses making adjustments (level and pressure in steam generators). This adjustment activity gives him the chance to weigh up the procedure and he can forecast actions to optimise operation which are not included in the procedure (the procedure indicates that the temperature should be stabilised; instead, the water-steam operator proposes to increase it).

This example illustrates a specific configuration for which the procedure proposes safe but non-optimised operation. This specific configuration is due to the fact that eight minutes earlier, the operator probably made a directional error as he moved through the procedure; this error went unchecked as this specific part of procedure has been left on paper (« mixed procedure »). Actions taken outside the procedure on the water-steam operator's initiative (modification of the temperature) and at the request of the supervisor (modification of the pressure) therefore make it possible to optimise the process by moving the operating point from the left-hand edge of the pressure-temperature diagram.

The comparison of the same operation on the computer and from the auxiliary control panel shows that the "alarm clock" function of the computerised procedures can reduce the extent and duration of the differences between prescribed operation and the actual state of the process. This is a new example of positive effect of computerisation on the control operators have on their activity. In the test run from the auxiliary panel, the operator applies Sequence 1 of ECP2 "stabilisation with TIP" when the "steam generator pressure difference greater than 10 bar" criterion has been met. During this sequence, the pressure drops to below 10 bar but the operator has to follow the sequence through to the end, at which point he can be redirected through the redirection module. With the alarm clock function of the computerised procedure, the operator would have been redirected more quickly.

Case of trouble in adhering strictly to the order in which actions have to be carried out as indicated in the procedure

Following an unidentified directional error at a step, the operator begins to apply action sheet FMR02 "makeup". He is not sure that he is doing the right thing because he knows that the makeup line is in service and he thinks that FMR02 is used to put this line into service. So the procedure is telling him to put into a service a line which is already in service! While he is applying FMR02, he notices that the procedure tells him to close valves which will temporarily take the makeup line out of service and he decides to abandon the action sheet. In this context, he tries to access the makeup adjustment image. Our assumption is that action on the makeup line takes place in two stages. Firstly, the operator simply wishes to check the makeup flow rate and the system alignment. Secondly, when he notices a pressuriser level considered to be high, he reduces the makeup flow rate from 30 m^3/h to 8 m^3/h (which is the minimum flow rate for this system). During the remainder of the test, the operator adjusts the level several times since it continues to increase despite the action taken to stabilise it, until he puts the letdown system back into service.

Three factors can be put forward to explain why, during operation which is carefully guided by the procedure, the operator uses his initiative and takes action which is not included in the procedure:

1) This action is taken in a context when the interaction between the operator and the procedure slackens off following a directional error at a step. The operator is in some doubt as to the guidance being offered by the procedure which is obvious by the fact that he hesitates to apply FMR02, then abandons it before reaching the end. The operator is all the more doubtful since he is convinced that his opinion of the process is the right one. In this case, he is sure that the makeup line is in service; on the other hand, he is in some doubt as to the function of FMR02 (is it not only used to put something into service ? can it also be used to make an adjustment ? can it be applied without any action being taken on the facility ?). Finally, because he is in doubt, he agrees to go through the action sheet. The particular context makes the operator more willing to take action which is not included in the procedure.
2) The operator is not capable of anticipating the operation proposed by the procedure: he does not know whether the procedure is about to tell him to take action to adjust the level in the pressuriser. There are two aspects to this problem. Firstly, the operator has trouble moving on from the step in progress to read ahead in the flow diagram, which is perfectly feasible with a mixed procedure (the "pressuriser level check" module is on the following page). Secondly, the operator is struggling to view the process as a whole. He considers it necessary to reduce the makeup flow rate because the procedure told him to go through the "Makeup" module. Conversely, he is not preoccupied by the letdown flow rate, which is nil, because this system is still isolated.
3) When the "makeup/letdown adjustment with Chemical and Volume Control System" is displayed, the operator has the chance to adjust the makeup flow rate immediately as regards the time taken to act, access to the command and display of the relationship between action and effect. This chance to act pushes him to actually take action.

Conclusions

The examples described all illustrate that analysis of deviations from an expected performance level is insufficient for understanding the impact of a technical system, namely a guidance system, on reliability and operator activity. Replacing the idea of "deviation", which implies a logic external to the activity, a logic determined by the expectation of designers and prescribers, by that of "break in the intelligibility of the activity", which implies a logic of the organisation of the activity itself, paves the way for progress, both in terms of knowledge and design.

In the present study, analysis of the intelligibility of the activity shows the relatively fragile control the reactor operator has over his activity in accident situations, as well as the way this fragility is linked to the style of guidance adopted. Even if this fragility only comes to light after analysis, it should be considered as a part of the design problem. That is the first conclusion.

The second conclusion concerns the process by which the explanatory hypotheses we used came about, given the limitations of the data available. For each case, we made several hypotheses and attempted to class them in order of likelihood. However, we decided to always retain all the hypotheses made, including those which seemed less likely for a given situation, since they always include characteristics of the guidance system, particularly its potential. It seems to us that this special feature of the analysis should be associated with the nature of technical systems which are not determined but which are open and full of potential.

To go further, it is necessary to conduct new studies with more satisfactory data, both in simulated incident and accident situations and in a natural, normally perturbed situation (see [4]). It is what we have now begun, with an EDF development & research group, using a new observatory of nuclear power plant accident operation [1].

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