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Cultural issues of nuclear power plant collective control in accidental situations and their impact upon design issues

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ABSTRACT

Using modelling of emergency operation of a nuclear power plant involving hard-copy instructions distributed among different operators, the research described here tackles different cultural cognitive issues and their impact upon design issues. The modelling concerns both the *dynamics of attention windows* and the *dynamics of openings*. The paper emphasizes the second aspect, i.e. the diachronic and synchronic relationships within and between the courses of action of the different operators. It shows that these cultural issues go far beyond the safety-culture issues which are usually considered.

Keywords: Situated action, Emergency operation, Computer-Supported Cooperative Work, Cultural dynamics, Procedure design, Organization design.

INTRODUCTION

If we take a cognitive view of culture and consider it as whatever it is one has to know or believe in order to operate in a manner acceptable to its members , to use Ward Goodenough s terms which gave way to what has been called cognitive anthropology , many questions arise. The main ones are: what is that knowledge or belief? how does it operate? how and with what criteria does the way it operates become acceptable? what are the relations between conduct of the activity (the culture in practice), the development of the practitioners (the development of personal culture, both the individual style and the individual embodiment of the shared culture), and the development of the practice (the shared culture)? (see D'Andrade, 1995, and Hutchins, 1994). To answer or at least clearly set these questions today, even if we limit ourselves to work situations, would mean striking a balance between the different aspects of the cognitive anthropological approach to work activity, which is common to research done under many disciplinary labels, due to the interdisciplinary character of this approach (see Theureau, 1992, Theureau, Jeffroy, 1994, and Theureau *et coll*., 2001). In this paper, we would like to tackle some of these questions through a study of what can be considered, from this point of view, as a privileged work situation, that of collective nuclear-power-plant control in accidental situations.
Indeed, for the study of cultural cognitive phenomena, this situation is privileged for different reasons: the importance of culture is widely recognized in nuclear power operations (the so-called safety culture, see Misimi *et coll.*, 1999, and Wilpert *et coll.*, 2001); control is collective and the construction of knowledge is at least partly shared; emergency operations have special procedures and special organization; emergency operations are exceptional for the operators - even if to real situations we add full-scope simulator situations - and the development of the practitioners and of the practice occurs mainly in relation to normal or normally disturbed situations and with outage situations.
After presenting a brief summary of all the research, we will present details of a part of it, namely the modelling of the *dynamics of openings* and its theoretical background. This will enable us to show the variegation of openings for two of the operators, the reactor operator and the supervisor, and the variegation of competencies this entails. As we do so, we will show the extent to which these operators act beyond their prescribed roles. By relating the openings of these two operators, we will also show how they adjust the durations for which they follow their respective distributed procedures and their relations with the dynamics of the process. We will conclude by relating the cognitive cultural issues involved with design issues and by presenting future developments for such research.

THE RESEARCH AS A WHOLE

This ongoing study of collective nuclear-power-plant control in accidental situations is part of a long-term dialectic between ergonomics research and ergonomics practice undertaken some time ago by the two research groups of EDF and CNRS involved (see Filippi, Saliou, 1997, 1998, and Theureau *et coll.*, 2001, and, more remotely, Theureau, 2000b, Theureau, Filippi, 2000, and

Theureau *et coll.*, 2000). It looks at emergency operation of a nuclear power plant in which hard-copy instructions are shared out among the reactor and water-steam operators, the supervisor, the operations manager, and the safety engineer, and is based on full-scale simulator tests. The five operators who may be joined by auxiliary operators work in a space divided into functional zones, written instructions in hand. In this ongoing study, audio-video recordings of all control-room activity and of very short self-confrontation interviews of the reactor operator and supervisor were systematically analyzed for two tests chosen for their common complexity and their differences, which we will call test A and test B in what follows.

The research picks up from data previously recorded and analyzed by the EDF team (see Filippi, Saliou, 1997, 1998) concerning these two tests, but also many other tests: construction of recording, observation, and verbalization data from emergency-operation tests (verbalization = self-confrontation of the main operators); transcription of each test (lasting between 120 and 150°minutes); special transcription of data concerning the reactor operator and the supervisor (which gives rise to different theoretically-based decisions, in particular with respect to the description of the actions performed); reconstitution of the tracking of instructions based on pages of the hard-copy emergency-operation instructions used; salient events noticed by observers; preliminary analytical modelling in terms of significant elementary units (SEU), sequences, and macro-sequences of each operator, and in terms of the collective interaction of those significant elementary units, sequences, and macro-sequences; preliminary series of empirical and ergonomics comments arising out of this preliminary analytical modelling.

Starting from this first kind of analysis, both transcription of data and preliminary analytical modelling, the research makes two kinds of progress in analytical modelling, in relation with a characterization, as score reading , of what constitutes the centre of operators' activity. The first kind, using a finer grain of analysis than that of the SEU, concerns the *dynamics of attention windows* during score reading and its perturbations. The second kind, revealing the diachronic and synchronic relationships between the SEUs of the courses of action of the different operators, concerns the *dynamics of openings*, or themas of action, of these operators. We have already presented a broad outline of this modelling in Theureau *et coll.* (2001).

In this paper, as already stated, we will focus on the *dynamics of openings* and the cultural and design issues its study allows us to tackle. But, as the studies of the *dynamics of openings* and of the *dynamics of attention windows* are complementary, we will first present a summary of the research as a whole. Such an analysis of the *dynamics of openings* and of the *dynamics of attention windows* reveals some of the real individual and collective competencies of the operators in dealing with accidental situations.

Score reading and control with procedures

Whenever information is acquired by reading signs (as opposed to simply identifying presence/absence or threshold overruns, which are a matter of indices or signals), attention has to be focused. In other words, there is a moment when the operator can pay attention to a single thing, when he momentarily excludes other information from his field of conscience, when he sets his mind to taking in the meaning of the information read, something he can do only if he does only that. It is therefore reasonable to assume that there is a strong relationship between reading activity (reading of hard-copy, but also reading of screen displays or plots) and a temporary mind-set in which the field of attention is focused on a single thing, temporarily inhibiting and excluding everything else. Now it is precisely this sort of reading activity which dominates emergency-operation activity driven by procedures. In general terms (with substantial variations depending on their role), operators read text, move to a different location in the control room, adjust controls, communicate, and wait. But first of all, they read and read: main procedures, auxiliary procedures, etc. This reading can in fact be called score reading : each item or set of information read (an individual instruction, a test, etc.) on hard copy corresponds to an action to be carried out (go get information to document an instruction) or a test to be done (change documents and open another, communicate information, phone another operator, carry out a control action, make an adjustment, etc.). The notion of score is that of sheet music, where each sign is meant to produce a determined action: play a certain note, for a certain time, with certain alterations, with a certain expression, etc. Like in sheet music playing, if operation instructions are the end result of a whole process of knowledge management and experience, operators have to add a good dose of knowledge of their scores in order to apply them correctly. It is a matter of expertise, constitution of a procedure-reading habitus which appears to be broadly underestimated, yet which is foremost among the preoccupations of simulator-training teachers who see it as a central requirement. They have also and here we have to leave the strict analogy with musical action to relate their scores to their interpretation of the situation dynamics, which includes activities of the different members of the team, procedures and process (see the notion of situation awareness, in Garland, Ensley, 1995, its use in activity analysis, in Klein, 1995, and its critical appraisal in Sarter, Woods, 1991, and Theureau, 2000b).

Score reading, attention-resource allocation, and interruption management

What must also be stressed is that there are constant changes in the focus of attention of the operators. A line is read, an instruction is taken in. To do this, the operator has to discern precisely what he perceives, so he restricts his field of visual perception. In most cases this reading leads both semantically and spatially to another instruction, but also to movement of the operator towards another place in the control room, and to another kind of reading as occurs when the operator reads a value off a display , or it can take him to another document which must be extracted from its classification system and thumbed through until the right sheet is found. There is then a new focus of attention, etc., one characteristic of which is that sooner or later the operator will go back to the main document that he set down previously, and pick up again precisely where he left off, so as to ensure the imperative of continuity of his sequential reading. To these changes in focus which must be managed by the operators working memory are added interruptions which can cause them to lose the thread they are following. These interruptions can be diversions of opening, i.e. diversions of the theme of action (and therefore of focus): while the operator is proceeding with an adjustment, something extrinsic to that activity interrupts him and requires him to suspend his current opening and turn to something else.

These interruptions, and particularly interruptions which are diversions of openings, are potentially sources of errors when operators return to pick up an activity where they left off. For instance, a phone rings during a basic-cycle phase, just when the reactor operator is documenting a test from the readout on a screen. The operator decides to interrupt this phase of work in progress, i.e. without completing it and mentally bookmarking his instructions. When he comes back to it, he picks up at the phase of work interrupted, but at the wrong place in the procedure sheet. Interruptions such as this require operators to perform additional marking and verification tasks in order to ensure the continuity of their activity. For example, during the same phase, the supervisor asks for information while the reactor operator is reading off values from plotters. The operator does not reply immediately; first, he finishes his readings, then goes back to his procedure, and finds that he has to go to a new page; he turns to that page and only then turns to the supervisor to answer. He does not take the risk of interrupting the continuity of application of the instructions before reaching a stable and easily identifiable point. Conversely, operators whose activity requires them to interrupt the activity of other operators develop an additional activity of monitoring the other operators activity and controlling the interruptions they have to provoke. These two sorts of additional activity dovetail together. What must be stressed is that interruptions are local interaction events for agents who act before and after their occurrence. The analysis above emphasises the activity - namely that of attention resource allocation and management of openings - developed by each of the interacting agents, during, before and after this kind of local interaction event.

Control with distributed instructions, anticipation structure and synchronic management of openings

We call *openings* the different themes of action which appear to the operators in order to stress the fact that each of them opens a structured set of anticipations (expectancies) of different kinds. For example, as soon as any operator gets involved in an emergency procedure, an opening is created: the situated following and interpretation of the instructions, until the procedure has been successfully accomplished or until the evolution of the process means he changes procedure. Also, new openings can be created within the original opening, for example when, in relation to one of his openings already created, an operator makes a phone call and cannot speak to the right person, so leaves a message asking to be called back. In this case, when he hangs up, he creates a new opening which will remain open to a future progress, a call back which will interrupt him or renewed attempts to find the person using other means. On the contrary, an elementary action can be fully completed: thus, looking at the simplest example, the operator makes a phone call, gets hold of the right person, and gives his message: You re wanted in the control room . In this case, once he has hung up, the operation has been carried out and completed. But, we are again in the first case too if the operator expects other contingencies accompanying that of arrival of the person called, such as briefing him on the situation.

Openings and attention windows should be considered jointly. Let us look at an opening. The moment at which an opening is created, progresses, or closes may fit into the sequence of action managed coherently by the operator; it may also occur out of the blue at any moment, while an attention focus is going on. Consequently to take up the previous example again the moment the person calls back, having been given the message, may be precisely when the operator is recording information to document the response to an instruction, causing him to interrupt his reading to answer the phone. There is a break in the focus of attention, and once the opening has been closed (or has progressed) i.e. the phone has been answered , the operator has to pick up again exactly where he left off, or just afterwards, having often moved several metres from the panel to the telephone. The structure of such an opening therefore leads towards potentially inopportune closure or progression. In all cases, whatever happens, or when it happens, is beyond the immediate control of the operator who initiated the opening. The graph of the reactor operator s and supervisor s openings during a test (an example of part of which we will present in the next section) allows for analysis of the interruptions in focus of attention and of their diachronic and synchronic management of openings. It also serves as a base map for closer local analysis of the dynamics of attention windows generally.

The number of openings in place simultaneously and the operator s skill at managing them synchronically are part of conditions which can diminish vigilance, induce moments of confusion, and lead to distraction. To the description of the different kinds of simultaneous openings of the individual operators at a given moment must be added openings concerning what each of them has to do with the work of the other within the control process. Parallel modelling of the openings of two operators and of the interactions between them thus gives a vision of the collective activity as it is co-constructed by these two operators and their particular dynamic situations, including other operators. The procedures including auxiliary procedures , sheets, logs, and the entire control room are tools for capitalising on and managing the knowledge which contributes more or less successfully to this co-construction. The reason for this is that the control activity itself is distributed, due to the distribution of hard-copy instructions, but also, beyond these instructions, due to the complexity of the process to be kept under control.

NOTIONS AND METHODS FOR MODELLING THE DYNAMICS OF OPENINGS

Enquiry into anticipation

For several years the scope of studies of human activity (in the cognitive sciences, neurosciences, psychophysiology, psychology, cognitive anthropology, robotics, or ergonomics) has seen the emergence of a new consideration of **anticipation** and its **conditions**. In physiology, for example, we have moved on from a reflexology to a physiology of anticipation, of projects, of action, in which action and perception are indissociable, in which there is no perception without action, and neither perception nor action without anticipation. In other words, contrary to what was once believed, the brain is not a transformer converting passive sensorial information into reconstructions of objects in the world. The brain pre-specifies the objects it wants to analyse, builds the world on the basis of assumptions and anticipations. In modern experimental neurophysiology and psychophysiology, these words correspond to a biological reality.

In work analysis and ergonomics, the course of action is defined as the part of the agent's activity which provides him/her with experience at every instant, or, alternatively, as his/her pre-reflective activity. Research into courses of action tended first to deal with the question of anticipation by introducing the notion of opening of a range of possibles for the agent and by considering the course of action as a process of creation, selection, transformation, and closure of such ranges of possibles for the agent" (Theureau, 1992). After a range of empirical research carried out mostly in connection with ergonomic studies within design processes, which revealed both its promise and its limits, this notion of ranges of possibles for the agent" was made broader and deeper by introducing the new notions of **Involvement in the situation** , **Potential actuality** and **Frame of Reference** (Theureau, 2000a). These notions concern only the course of action, as defined above. But, in connection with observational data concerning the state of the agents, their situation, and their culture, together with some additional assumptions, they also make it possible to describe the constraints and effects of that course of action.

Openings and relations between openings

We call an **opening** the theme which demarcates a certain range of possibles for a given operator among all the possibles for that operator at a given moment. This particular range of possibles can be detailed in terms of anticipations of different kinds (the opening and the anticipations constitute the **Potential actuality**, i.e. the structure of anticipation at a given moment) and in terms of the types and relations between types that are possible for the operator. These types and relationships between types belong to the operator s culture and are available to him, taking account of his structure of anticipation. They constitute the **Frame of Reference** at that time. The openings are part of the operator s course of action. It could be said that they are subjective . They must not be confused with what results from the **constraints and effects of that course of action**. As stated above, these constraints and effects can be detailed by observational data on the state of the operator, the situation he is in (including the procedures he is supposed to follow), and his culture. In particular, hard-copy procedures require actions to be carried out by operators, specifying tasks to be carried out here and now, but they are also a support for a very wide range of anticipations with respect to the actions to be carried out in future, the events that can be expected in terms of the evolution of the process, the actions that have been and will be carried out by other operators, the problems that are likely to arise, given the skills that each party involved feels he possesses, etc. By considering the act of following instructions as the creation, filling, and closure of a given opening and not simply as performance of a task, one opens an enquiry into the associated structure of anticipation.

In connection with the set of assumptions presented in Theureau (2000a), the set of openings $\mathbf{o_i}$ at any given time consists of the openings that have been created in the past and have not yet be closed. However, with respect to this set of assumptions, the openings $\mathbf{o_i}$ are openings/closures, or marker-fences or demarcations for the anticipations built by the agent in the past, up until the moment considered, and consequently also for the elements of his past experience (**Frame of Reference,°S**) that he can use in his response to an event (e.g. arrival at a certain point of the instructions in a certain APE instruction, or an interruption by one of his colleagues), in his interpretation of the event. Finally, such an event selects one or more openings $\mathbf{o_i}$ among the openings available to the agent at that point, and also introduces a new opening embedded within the first openings i.e. respond to the event considered, or interpret it which can be called **o(R) /** $\mathbf{o_i}$, i.e. **o(R)** against the background of $\mathbf{o_i}$.

Between any two openings, $\mathbf{o_i}$ and $\mathbf{o_j}$ whether they pertain to the operator considered or whether they concern what he perceives of the activity of other operators , from the point of view of the operator there can be:

- a **diachronic or serial dyadic relationship:** from the point of view of the operator at the moment considered, $\mathbf{t_j}$, openings $\mathbf{o_i}$ and $\mathbf{o_j}$ $\mathbf{(t_i > t_j)}$ are the same, apart from the determinations resulting from the course of action between moment $\mathbf{t_i}$ and moment $\mathbf{t_j}$;
- a **synchronic dyadic relationship or dyadic relationship of subordination** (valid for a given time interval): $\mathbf{o_i}$ is subordinated to $\mathbf{o_j}$ if, from the point of view of the operator in that time interval, the closure of $\mathbf{o_i}$ helps bring about the closure of $\mathbf{o_j}$;
- a **synchronic or contextual dyadic relationship** relative to a given opening (valid for a given time interval): for the operator, openings $\mathbf{o_i}$ and $\mathbf{o_j}$ are independent, but both are subordinated to an opening $\mathbf{o_k}$.

In fact, all openings at a given moment have a synchronic dyadic relationship with the overall involvement of the operator in the situation, **E**, something we will not go into any further here.

Relationships such as this between $\mathbf{o_i}$ and $\mathbf{o_j}$ gradually build **series**, **chapters**, and **synchrones**. A diachronic set of SEUs revealing the gradual achievement and therefore the determination of a given opening constitutes a **series**. A series can be broken down, sequentially or in parallel, into **chapters** when a given opening breaks down into several openings as it is accomplished. SEUs can also be formed from a synchronic set or **synchrone** when several independent openings between them are linked to a broader opening.

Although the available data in this research field does enable series and chapters to be identified satisfactorily, the same is not always true of synchrone. Where they are best revealed is when the activity of one operator is interrupted by another operator. Consider, for example, an operator involved in a score-reading activity. When his activity is interrupted, from his point of view a relationship is established between his immediate score-reading activity **o(R)**, his wider score-reading activity $\mathbf{o_i}$ against the background of which **o(R)** develops, and his opening concerning the activity of the other operator, as he sees it, $\mathbf{o_k}$. From the point of view of the operator making the interruption, on the contrary, a relationship is established between his own openings that took him to the other operator and his opening with respect to the accomplishment of the activity of the other operator, as he perceives it.

The analysis graph of the parallel dynamics of openings of the reactor operator and the supervisor during test A and B are the results of a qualitative analysis. It should be stressed that this qualitative analysis leads to a development of quantitative analysis we will not present here. The quantitative analysis can be done, for example, in terms of occurrences, durations and time sharing of openings of a given category, occurrences of diversions of openings, etc. It differs from the usual quantitative analysis in terms of error-occurrence, digressions from the procedure, etc., which can be seen to complement it.

Openings at any moment as an interpretation framework for the operator

For the operator, the set of all the openings at moment t constitutes the basis for a **framework for interpretation** of the events that might occur since it determines the relevance (relationship between what happens and what concerns the operator), the strength of determination (relationship between what happens and the anticipations linked with those openings), and the response that these events engender (relationship between what happens and the past experience the operator can call on). For example, in the reactor operator s and supervisor s analysis graph of the dynamics of openings for test A, about an hour after the start, the reactor operator is simultaneously managing situated following and interpretation of the ECP2 instruction, in the knowledge that the emergency continuum will eventually require the next set of instructions up, ECP3 (following a previous message from the supervisor), while carrying out the instructions of an auxiliary instruction sheet (RFLE58); at the same time, the supervisor is simultaneously managing situated following and interpretation of the corresponding ECT2 instruction, in the knowledge that the emergency continuum will eventually require the next set of instructions up, ECT3 (following a previous message from the operations manager), is looking through the instructions regarding the criteria for changing to ECT3, is examining and carrying out actions concerning the state of a particular system (ASG Auxiliary Feedwater), and is also awaiting the results of an *in situ* inspection of the system by an auxiliary operator.

While modelling of the dynamics of openings concerns the course of action of individual operators, i.e. that part of their individual-social action which is experienced by them at different instants, it in fact points towards the collective activity of the entire control team, for these events are the result not only of the specific activity of each operator, but also of the relationships each operator has with activities of other operators. So to the above description of the simultaneous openings of the reactor operator and supervisor respectively one hour after the start of the test must be added openings concerning what each of them thinks of the work of the other.

SOME RESULTS CONCERNING CULTURAL AND DESIGN ISSUES

Diversity of openings for the reactor operator and the supervisor

By considering that the diversity of openings, it is possible to specify in what way, for the supervisor and reactor operator, emergency operation amounts to more than just following ECP and ECT instructions. By considering this diversity, within the limits imposed by the availability of information, it is possible to examine the differences between the activities they give rise to, to be carried out by the operators, and the different ergonomic improvements that might be of help for those activities.

For the reactor operator, in addition to openings concerning *calling the operations manager, the safety engineer, and the supervisor, and informing them* when they arrive in the control room things we have already mentioned and which are not insignificant, for they can be opportunities for omissions and errors and concerning the following up of his own symptom-based procedure, there are all kinds of openings:

-°openings relative to *requests made of auxiliary operators* which must be closed by a report back from the auxiliary operator. There is a period of between 6 and 32°minutes between the request and the report back during which the operator could forget that he made the request.

- openings relative to *application of auxiliary-procedure instruction sheets*, on request by his symptom-based procedure or by the supervisor, which more or less take the operator out of the framework of his symptom-based procedure.

-°openings relative to *waiting for other operators and co-ordinating with them.*

-°a large number of short openings, due to interruptions by other operators or to adjust to the timing of other operators.

-°openings relative to *problem solving*, which can, for example, concern interpretation of instructions, of their apparent contradictions, and their relationships with the accomplishment of the process, and which generally leads to the establishment of co-operation with other operators.

For the supervisor, openings can be:

-°openings relative to *requests to auxiliary operators and other persons outside the control room.*

-°openings relative to *application of auxiliary-procedure instruction sheets*, on request by the instructions or by the operations manager.

-°openings relative to *waiting for other operators and co-ordinating with them.*

-°openings relative to *problem solving*, generally in conjunction with the operations manager.

The supervisor s short openings are fewer in number than those of the reactor operator, and are opened by other members of the control crew (chiefly the operations manager).

Organisational roles and beyond

Of particular note is the accumulation of roles by the supervisor. Not only must he follow a procedure (ECT) for checking the actions performed by the reactor operator and water-steam operator and think about the process beyond the instructions, in conjunction with the operations manager and the safety engineer, but he also implements different auxiliary procedures, especially in case of loss of support functions (loss of power, compressed-air, water supplies, etc.).

It can also be seen that the various operators go beyond their respective roles. In fact, the agents interact with each other well beyond the particular moments when it is prescribed by the symptom-based procedure. They observe each other, organise their access to resources (binders, operations sheets and logs, for example) and their respective instructions to auxiliary operators, express their feelings, co-ordinate with each other, wait for each other *extra*-instructions, exchange information and diagnoses/prognoses on the dynamics of the system, criticise each other s actions and movement through the instructions, and sometimes even put their minds together to collectively solve problems. They do this to help each other, and not just when asked, but also spontaneously.

It is in the case of spontaneous assistance that operators best exhibit their openings concerning the activity of other operators. For example, during test B, the supervisor mutters to himself Yeah, they tell you to disconnect the LBAs; I should have disconnected the LBAs, I should have disconnected them straight away, I should have bypassed. Great, that’s just great! The reactor operator is going past and says Disconnecting the batteries, that's what the auxiliary procedure does, Bernard! , which allows the supervisor to establish the link between what his instructions tell him to do, i.e. disconnect the LBA batteries, and the auxiliary procedure he had an auxiliary operator carry out. In this example the reactor operator incidentally hears (overhears) the comment of the supervisor. Incidental observation (overseeing) etc. can also occur. Such overhearing, overseeing , etc. by each agent does not concern solely the accomplishment of actions pertaining to each agent s own role, but is also intended to help other operators. It occurs as part of openings concerning the activity of others.

Until now we have examined local examples of appearance, at a given moment, of these openings concerning the activity of others. To conclude on this point, let us look now at an example which shows these openings concerning the activity of others over a relatively long period of time. The case during test A is where the reactor operator informs his supervisor that the instructions being followed (ECP2 and ECT2) are not appropriate to the way the process is turning out. One of the reactor operator s openings is to not disturb the supervisor during his laborious search for the criteria for changing to ECT3, and to get through ECP2 as quickly as possible and find a way to ECP3 that would overcome the problem; one of the supervisor s openings is to wait for the reactor operator to change to ECP3.

Temporal adjustments

The symptom-based procedures are distributed between the different operators. Each operator is supposed to follow his instructions (ECP for the reactor operator, ECV for the water-steam operator, ECT for the supervisor) without giving a thought to the others, except at special predetermined times when either he has to give some of the others information about the system controlled or the point he is at in his instructions, or he and the others have to change instructions. We saw an example of the latter case above, concerning the change from OSD to ECP1. This interplay of independence and dependence is a result of the oneness of the process under control and of the breakdown of the roles of the different operators. In particular, through the instructions he implements, the supervisor checks the operations carried out by the reactor and water-steam operators. If he is ahead of them, nothing prevents him reading even further ahead, but he will have to go back over the instructions to actually carry out the checks. If he is too far behind them, his verification will be too late.

It was precisely to take account of such constraints that the times to go through instructions were calculated. And the distribution of instructions was designed in accordance with the results of these calculations. The problem is that these calculations were essentially based on tasks supposed to be carried out by all the operators, i.e. tasks corresponding to their openings in following instructions, be they main or auxiliary procedures, whereas, as we have seen above, their respective openings go well beyond that. Empirical observations during simulator tests have resulted in the distribution of tasks being adjusted as time goes by. Whence, in particular, the attribution to the supervisor whose job title initially matched his role, that of simply supervising of some of the auxiliary procedures to be carried out. The limitation of these empirical observations of discrepancies between the calculations and real occurrence, and of the adjustments to the distribution of instructions, is that the rational basis of the calculations carried out has been left untouched.

In the tests analysed, we find that the co-ordination when a change in instructions takes place goes well beyond what is stipulated in the instructions (e.g. by agreement with the supervisor present, take the ECP2 instructions). A lot of co-ordination not laid down in the instructions also takes place. All this co-ordination, whether in accordance with the instructions or independent of them is often accompanied by waiting periods. Sometimes these openings of mutual waiting can be prolonged, as in test A, for example, where the supervisor and reactor operator wait 27°minutes for the water-steam operator to check off the steam generators.

The different speeds at which people work through their instructions (bearing in mind the other openings to be filled) can result in problem-solving openings. This is the case in test°B, for example, where the requirements for two auxiliary procedures to be carried out by auxiliary operators arose at the same time, one in the reactor operator s ECP instructions, and one in the supervisor s ECT instructions. The two procedures appeared to be contradictory. In fact, the first, which should have been required of the reactor operator some time sooner, is intended to check that the system the auxiliary operator will intervene on as a result of the second procedure is working correctly. This engenders a problem-solving period for the supervisor and reactor operator, and results in a somewhat insecure decision to disregard one procedure, the first. The feeling of unease resulting from this (in their eyes) questionable decision certainly plays a role in the development of errors committed later in the test concerning follow-up by the supervisor of all the auxiliary procedures to be carried out by auxiliary operators.

CONCLUSION

Even within the limitations of the modelling of the dynamics of openings, there is evidence that the cultural issues in these accidental situations go well beyond the issues of safety culture usually considered. They concern the competencies of each operator:

- in score reading: understanding the instructions and the way to implement them, managing attention resources for doing that, but also building expectancies concerning the future of the process, of his own procedures and of the other operators procedures;
- in managing the openings created by his procedure and the demands from his colleagues;
- in co-operating with the other operators by judiciously accepting, postponing or rejecting the interruptions they make to his own activity, and judiciously interrupting, overhearing, overseeing , and helping them;
- adjusting the different temporalities of his procedure, the other operators procedures, and the process.

The cultural issues involved also concern the sharing of these competencies with the other operators. They have an impact upon design issues like those of designing instructions and their supports (hard copy, computer, etc.), designing organisational roles, and designing training systems. In Theureau *et coll.* (2000), through a local analysis of the reactor operator s course of action, we stress the guiding style of symptom-based computerized procedures and its variations which often troubled the operators. The analysis of the dynamics of openings for the reactor operator and supervisor paves the way for improvements in the guiding style of the symptom-based paper procedures, but also in their overall design and distribution.

As the culture of the control crews, which is more or less common to all the operators, is essentially constructed through normally disturbed and scheduled outage situations, the cultural and design issues in emergency operations cannot be confined to this analysis in simulated accidental situations. This is the reason why the analysis requires a comparison of the competencies involved in accidental situations with those involved in normally disturbed and scheduled outage situations, in order to document the positive or negative transfers from the latter to the former. Accident situations have already been analysed by different EDF clinical studies. Modelling of the dynamics of openings present in them should make it possible to determine more specific information on the comparisons we have been able to make so far.

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