

Operators' conceptions of Procedure Guidance in NPP Process Control

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ABSTRACT

Introduction: Resilience in NPP process control depends on balance between operators' autonomy for decisions and pre-defined guidance.. Finding balance is a strategic decision by the organisation, but finally it takes place at the sharp-end, by the operating personnel. Balancing was studied by analysing the role and usage of procedures. **Method:** Conceptions of 62 control room operators at two Finnish nuclear power plants (NPPs) were queried under three themes relevant to the autonomy-guidance balancing. Answers were classified into theory-based categories, i.e., interpretative, confirmative or reactive, which are epistemic attitudes, portraying more or less potential for resilience in process control activity. **Results and discussion:** In both NPPs, the confirmative orientation, emphasising the importance of acting according to rules prevails. Orientations reflect operator roles and their demands. Interpretative orientation that values operators' competence but does contrast autonomy and procedures should be actively supported to facilitate resilience in NPP activity.

KEYWORDS

Resilience; procedure guidance; autonomy; NPP operators.

INTRODUCTION

In safety-critical domains like nuclear power production there is a good reason to develop different kinds of organisational routines: Commitment to obeying these routines facilitates transparency and predictability in the organisation. The routines also support control of changes in practices and technologies so that the impacts of these changes on the very complex organisation may be comprehended in sufficient breadth and depth. These and further reasons for organisational routines are analysed in a thorough review article by Becker (2004). One form of organisational routines in safety critical environments are operating procedures which are important resources for the personnel in normal daily work, and are particularly significant tools in coping with demanding disturbance or accident situations.

Advances in automation technology, and especially the digitalisation of process automation including improved possibilities of presentation of process information, appear to increase interest to standardise further the human-automation interaction. As an example we may take the French computerised control room of the N4 nuclear power plant (NPP) in which implementation of computerised emergency operating procedures led to increased procedure control of operations in disturbance and accident situations. Operating experience and human factors studies indicated, however, that procedure control probably was too tight and inoptimal causing some unanticipated difficulties to the operating crews to understand the process situation while applying procedures during the event and coordinating own actions appropriately (Filippi, 2006).

While it may be effective and sufficiently safe to rely on standardised ways of taking the plant into control in design-based accidents, concerns have arisen in particularly after the Fukushima nuclear accident concerning the capability of the operating organisations and personnel to act in innovative ways in very complex and unanticipated accidents. A too straight-forward reliance on standardisation as a means to improve safe operations has also been one of the issues raised by the so-called resilience engineering school (Hollnagel, 2006). The claim is that a continuous balancing between innovative and standardised forms of acting is needed for maintaining the system within safe boundaries of operations. Also Papin discussed the issue of creating resilience in the safety-critical organisations (Papin, 2010). Papin's perspective is the design of complex systems. On the basis of analyses concerning optimal operator guidance the author concluded that when searching for resilience in NPP processes, the problem is to find a justified balance between the actors' autonomy and guidance.

Most studies that raise the problem of balancing between guidance and autonomy consider the issue on the level of organisational safety management. The intention of our study was to try to understand resilient behaviour on the level of the sharp-end actors, in our case main-control room operators daily practices. We assumed that the



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operators have conceptions of the constraints regarding striking balance between autonomy and guidance, and that they have developed practices to do that in their daily work. The operators' conceptions of an appropriate balance can be uncovered by investigating operators' opinions of the role of procedures and of the importance of professional skills in their work. The operators' conceptions are of course influenced by the position that the organisation has taken to the very issue.

METHODS

We conducted a simulator study focusing on an analysis of operators' activity in disturbance and accident situations. As part of the study, interviews about the NPP operators' professional orientation, i.e. epistemic attitude towards work, were accomplished, including operators' conceptions of the role of procedures in work and professional expertise. Data was gathered via observing activity and interviews. This paper focuses on the interview data.

Interview Characteristics

The interview was conducted in two Finnish NPPs during the years 2008 and 2009. In the first NPP (NPP1) all operators (12 shifts, 44 operators including two trainees) were interviewed. In the other (NPP2), half of the operators (6 shifts, 18 operators) were interviewed. Interviews took place in the beginning of a simulator session and lasted about 20 minutes in maximum. A number of themes were covered as the scope of the interview was wider than just procedure usage. Here, only a subset of questions is focused on, namely the ones that is related with the dimension of autonomy vs. guidance in operator's work.

The dilemma of the balance between autonomy and guidance in operator's work was dealt in the interviews with the themes of

- (1) Control of action
- (2) Initiating action
- (3) Concept of a good operator.

Control of action and Initiating action are directly related to the question of autonomy and guidance whereas the Concept of Good Operator sheds light to the question from a more general viewpoint revealing the operators' basic assumptions concerning the demands of their work.

Data concerning the three above-mentioned themes was acquired by posing the following interview questions:

- What is the role of procedures in process control?
- Do such situations exist to which no dedicated procedures exist?
- Do the procedures determine the course of actions totally in some situations?
- Are alarms the primary starting point for action?
- How would you characterise a good operator?

The interviews were accomplished individually in a face-to-face contact and they were audio recorded. Eventually, the recorded interviews were transcribed into written protocols and analysed.

Interview Data Analysis

In each reply, the operator's conception is classified in one of the three categories: reactive orientation, confirmative orientation and interpretative orientation. This classification draws on the ideas of the American pragmatist philosopher Charles Sanders Peirce (Peirce, 1998). In his writings he proposes that in coping with the contingencies of the environment a human being has a possibility to survive via his/her interpretative effort, i.e. via personal attempts to make sense of the environment by developing hypotheses and forming beliefs about it. A contrary basic form of facing the environment is reactivity, i.e. by being directly steered by the events of the environment. On the basis of this distinction we developed the classification of people's orientation to their work, and used the classification with regard to different aspects of work orientation (Norros, 2004). Interpretativeness is characterised by presence in the particular situation and questioning the observed phenomena, building hypotheses concerning the situation and future events. Reactiveness reflects passivity and lack of hypotheses concerning the situation; confirmativeness is an intermediate position and is characterised by mapping the situation with known possibilities and acting in a predefined ways. In the following, the analysis is described according to the factor in question. Also an example is provided for each reply type. The theory-based claim is that interpretative qualities are assumed of such practices that are capable of facilitating resilience in action (Norros, 2012).

Control of action

The theme Control of action focuses on the operators' conceptions of agency in process control and how agency is seen to be distributed among the operator himself and the procedures. The issue of control was investigated by four different sub-themes (in italics below).

Role of procedures : This sub-theme was studied by the question "What is the role of procedures in process control". The replies were categorised according to the following principles :

- Interpretative: Procedures provide framework and method according to which the operations are performed. For example: "We operate according to them. They provide such a framework that they support [our work]."
- Confirmative: Procedures support actions, procedures are needed in rare or demanding situations; procedures unify the ways of working and guarantee safety. For example: "They are central. About everything is done according to the procedures. Of course, routine tasks are such that procedures are not needed. But procedures are important. And we must work according to them."
- Reactive: Procedures support if the operator is insecure or when he has problems with memory; procedures prevent memory-dependent or other mistakes; procedures define the correct procedures and their order; put-down of procedures. For example: "Procedures support my work and provide security, you can have a look at them whenever in doubt."

Coverage of procedures : For this sub-theme, the question "Do such situations exist, to which no dedicated procedures apply" was used. The replies were categorised as follows :

- Interpretative: States the principle that it is not possible to define everything with procedures. For example: "Usually, procedures determine but there are situations for which there are no procedures, then we think what to do. You cannot write a procedure for every situation, it is impossible".
- Confirmative: Surely there can be some unexpected situations or small incidents for which there are no procedures. For example: "Yes, and there can be also such situations that we have not met yet. When we changed the ejector... (the interviewee describes a situation for which there was no procedure)."
- Reactive: Possibly such situations exist which have no procedures but such situations do not come to the interviewee's mind; procedures describe the total of work practises except for some routines or revision. For example: "Yes I guess there are, but I don't remember right now any example."

Focus of procedure control. This sub-theme was studied by the question "Do the procedures determine the course of actions totally in some situations". The replies were categorised in the following way :

- Interpretative: The focus is on the control of process and process disturbances; the grounds for procedures are found interesting. For example: "No, I don't think so, it can never be like that [that procedures would determine the proceeding of actions totally in some situations]. Of course procedures are the framework for what we do but if it, if you feel that this is not applicable, and of course for us it is the shift supervisor who conducts this ballet, so we talk with him, that now it feels like this will not go according to procedures".
- Confirmative: The focus is on tasks that the procedure is for; what should be done in each situation. For example: "Well it [the role of procedures] is very important. Whatever we do, we have procedures for it. Especially in disturbances we get an alarm, alarm in the system, so then we start to look from the procedures for disturbances for what to do regarding this alarm. And then, similarly, were it start-up or shut-down or a scheduled testing in question, what ever, for everything we have procedures and we perform according to them."
- Reactive: Procedure is a means to guide human; we operate according to procedures; procedures determine operations. For example: "Well... In principle you can say like that, because we have to operate according to procedures (...)"

Procedures and professional competence : The sub-theme was studied, again by the question "Do the procedures determine the course of actions totally in some situations". Even if the question is the same as with the previously described subtheme, its analysis is different. The replies were categorised by the following principles :

- Interpretative: The usage of procedures is understood to facilitate work and the operators' understand that the situation may deviate from the one that the instruction is based on ; thus, procedures must be trusted on and procedures must be used professionally,.
- Confirmative: You are obliged to perform according to procedures, procedures are not questioned. For example: "Everything is done according to procedures. They are important, because they are designed in advance and produced for taking care of the work".
- Reactive: Procedures and professional competence are perceived as opposites, procedures compensate for experience and vice versa. For example: "Yeah, it can be that when you haven't been here for a long time, yes and such situations that repeat very seldom: you might be forced to perform according to procedures in such situations".

Initiating action

While the control of action focused more on the operators' conception of agency in on-going activity, this theme was tuned to identify how activity is initiated in the first place. For finding out what triggers actions, a following question was asked: "Are alarms the primary starting point for action". The replies were classified as follows :

- Interpretative: Repudiates the idea presented in the question that alarms would be the main trigger for action. Operator identifies that observation and monitoring are active actions, he considers weak signals, and finds anticipation most important in acting. For example: "Not really, you have to monitor the process, it doesn't... Changes are primary. By following the process we strive for, if some process is starting to change we want to see what it originates from. An alarm may follow later. It is the monitoring of the process that is primary and alarms only come after that".
- Confirmative: Alarm or other external factor such as some deviation in the process is the starting point, highlights context dependence. For example: "Alarms at the latest, then we start action. We may get indication also before alarms. When possible we try to react upon them immediately if we see such things. Some temperature is climbing or a blockage (...)"
- Reactive: Alarms trigger action. For example: "Well yes they are. Depends on the disturbance, if it is a big one, these are gone already, it has no meaning. [If the disturbance is minor] then it goes according to alarms".

Concept of a good operator

The theme Concept of a good operator was studied as an indicator of what the operators within their community of practice consider as professional acting and hold meaningful and valuable (drawn from the idea of "internal good of practice" by Alasdair MacIntyre (1984)). It was assumed that the issue of autonomy would probably be reflected in the conceptualisation of a good operator. This theme was studied by the question "What are the qualities of a good operator". The replies were classified in the following way.

- Interpretative, personal qualities: Explains features of practice that have a positive contribution to work and its purposes. For example: "Good education and level of knowledge and skills so that you understand what happens in the plant; you have to have an overview so that you can interpret very small incidents [whether it is serious or not]. Calm, capable of analysing so that when it gets tough you can think reasonably".
- Interpretative, qualities describing action: Personal interpretation, understanding. For example: "but a good operator... knows the process, knows what affects and where it affects, can piece together these what happens next, these consequences".
- Confirmative, personal qualities: Connected to work in a superficial way. For example: "Takes care of his worries and employees, does what is needed and ordered, may not perform independently of others".
- Confirmative, qualities describing action: Relates to rules. For example: "Can read this process, knows the procedures, can use them correctly. One can perform correctly in rapid situations".
- Reactive, personal qualities: General characteristics of performance that are not connected to work. For example: "Accurate and prompt and conscientious".
- Reactive, qualities describing action: Superficial, reacting to demands from the outside. For example: "Takes care of his duties conscientiously".

RESULTS

The results of the analysis of the interview data are presented from the two plants separately and, also by role (shift supervisor, reactor operator and turbine operator) within the plant. Due to limited number of pages, the results are presented in the level of themes only.

Results for the theme Control of Action

Regarding the conceptions related to the role of procedures, the share of confirmative orientation of both was prominent in both NPPs (see Figures 1a and 1b). Operators also think that a procedure will be found for disturbance situations, except for unexpected or small disturbances. According to the majority of operators of both plants, the procedures steer accomplishment of the task and must be used without questioning it at all.

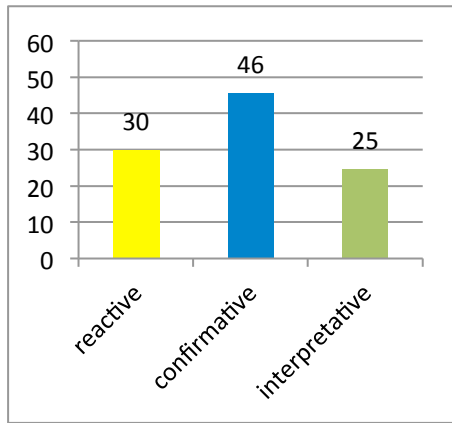


Figure 1a. Conceptions related to Control of Action in NPP1; N= 44. The share of replies as percentage in each category (reactive, confirmative and interpretative).

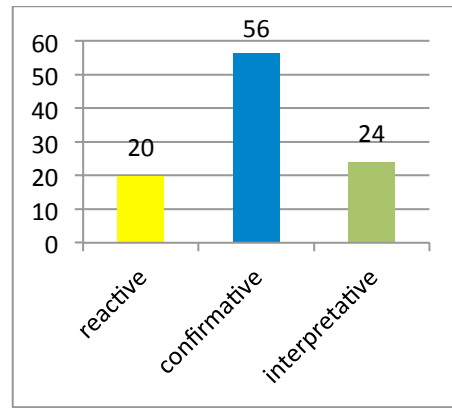


Figure 1b. Conceptions related to Control of Action in NPP2; N=18. the share of replies as percentage in each category (reactive, confirmative and interpretative)

When scrutinising the replies from the perspective of the various operator roles, some differences were found in the percentages. In both NPPs, the turbine operators expressed interpretative orientation the most and reactive the least. The contrast to reactor operators' far less interpretative orientation is clear. (see Figures 2a and 2b).

The higher share of interpretative orientation among turbine operators in the control of actions may be due to the task demands in turbine operations: The turbine systems are typically not safety classified and, hence more, freedom in operations is allowed for on-line decisions. Moreover, a great number of active operations from turbine process are typically needed in the controlled reduction of power and cooling the plant. In contrast, caution and patience in dealing with the reactor systems is evidently reflected in a stronger confirmative orientation what regards the reactor operators' control of action.

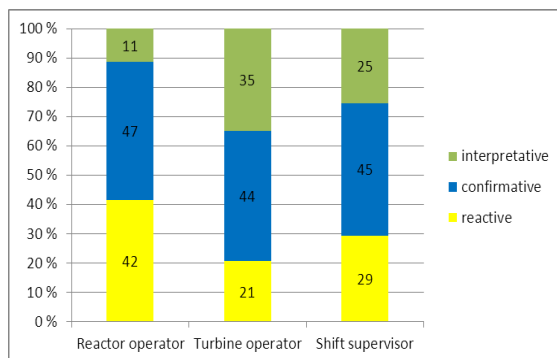


Figure 2a. Conceptions related to Control of Action classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP1; N=44. The share of each category (reactive, confirmative and interpretative) shown as percentage.

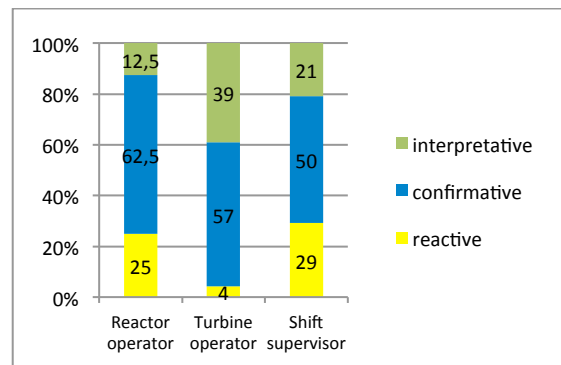


Figure 2a. Conceptions related to Control of Action classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP2; N=18. The share of each category (reactive, confirmative and interpretative) shown as percentage.

Results for the theme Initiating action

The conceptions of the operators of the two power plants about how actions are initiated are depicted in Figures 3a and 3b. The histograms indicate that in NPP1, most operators found the alarms (reactive orientation) or other external events (confirmative orientation) as triggers for actions, whereas operator-driven anticipatory identification of changes in the process were mentioned quite rarely. In NPP2, the share of conceptions were equal in all categories so that the same amount of operators found weak signals and proactive work to be the important way of working (interpretative orientation) as the amount of operators that valued alarms as a primary signal for action (reactive orientation) or found external factors in general as triggering events (confirmative orientation).

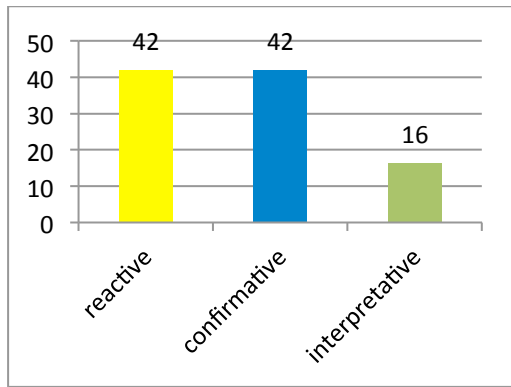


Figure 3a. Conceptions related to Trigger for Action in NPP1; N=44. The share of replies as percentage in each category (reactive, confirmative and interpretative).

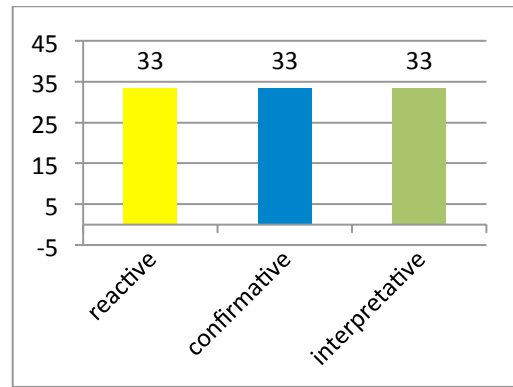


Figure 3b. Conceptions related to Trigger for Action in NPP2; N=18. The share of replies as percentage in each category (reactive, confirmative and interpretative).

The results concerning Trigger of Action were also arranged according to operator roles in both plants (see Figures 4a and 4b). Evident difference between the plants become visible. In plant 1 reactive orientations are typical for all roles, and the share of interpretative orientation scarce. In NPP2 reactor operators and shift supervisors of the portray high numbers of interpretative orientation with regard to initiating action, which speaks of proactiveness in work. We may also notice that in both plants the turbine operators show least interpretativeness and most reactivity. If we compare these results of Trigger of Action to those with regard to Control of action (Figures 2a and 2b) it appears that the found interpretative orientation by turbine operators in action is connected to reactivity in starting action.

The results complete the earlier interpretation that the role and demands of work reflect readily in the orientation. Turbine operators tend to be autonomous in acting when the situation demands that, whereas the shift supervisors and reactor operators express proactiveness and anticipation the process situation, while they are confirmative and cautious what regards action. This interpretation holds in particular with regard to Plant 2.

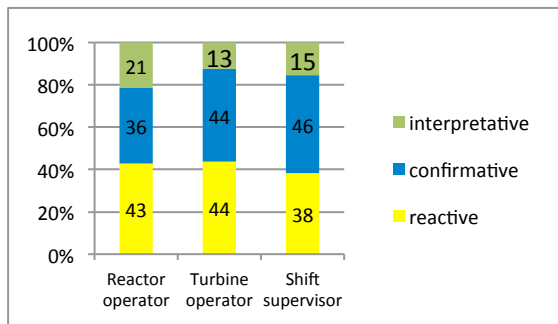


Figure 4a. Conceptions related to Initiating Action classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP1; N=44. The share of each category (reactive, confirmative and interpretative) shown as percentage.

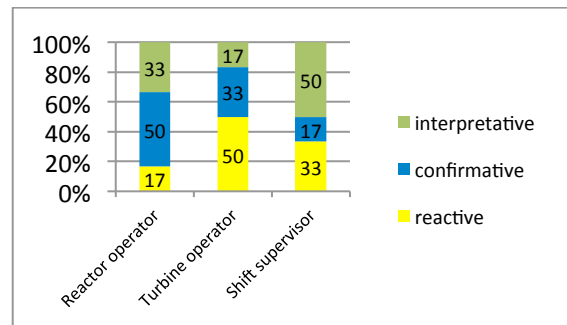


Figure 4b. Conceptions related to Initiating Action classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP2; N=18. The share of each category (reactive, confirmative and interpretative) shown as percentage.

Results for the theme Concept of Good Operator

Opinions regarding the qualities of a good operator were emphasised slightly differently in the two NPPs. In NPP1, the share of interpretative orientation was prominent, meaning that operators valued qualities justified by their effect on work practices and that they produced personal interpretations of good personal qualities (opposed to valuing the meeting of external demands) (see Figure 5a). In NPP2, the opinions of confirmative type were expressed more often (see Figure 5b). Such opinions are characterised by connecting good qualities to work in a superficial way and that the performance according to rules, “doing it correctly” is regarded as of highest importance. It is interesting that in NPP1, where orientations with regard the starting and control of action tended towards confirmative or even reactive direction, the operators still find interpretative qualifiers of practices and professional identity most appropriate. In the case of NPP2 the tendency for a dominantly confirmative orientation in acting is strengthened by a dominantly confirmative orientation also what regards an ideal operator.

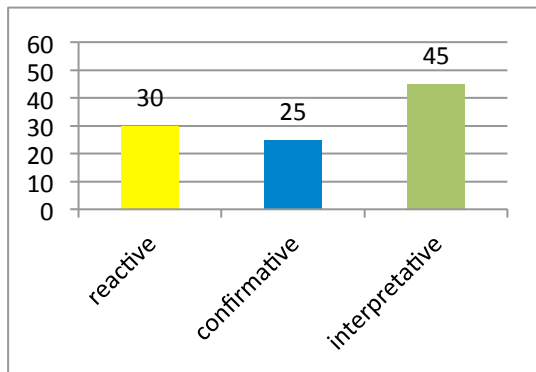


Figure 5a. Conceptions related to Concept of Good Operator in NPP1; N=44. The share of replies as percentage in each category (reactive, confirmative and interpretative).

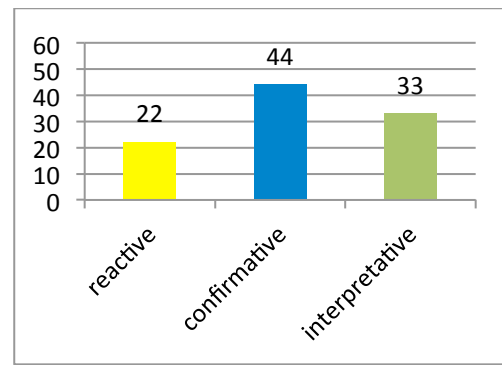


Figure 5b. Conceptions related to Concept of Good Operator in NPP2; N=18. The share of replies as percentage in each category (reactive, confirmative and interpretative).

Investigating the replies from the perspective of operator roles, it becomes clear that the stronger interpretative orientation in the NPP1 compared to NPP2 appears to be due to the clearly stronger interpretative orientation of the turbine operators in the plant 1. In both plans the shift supervisors conceptions of good operator are both strongly interpretative. (see Figures 6a and 6b).

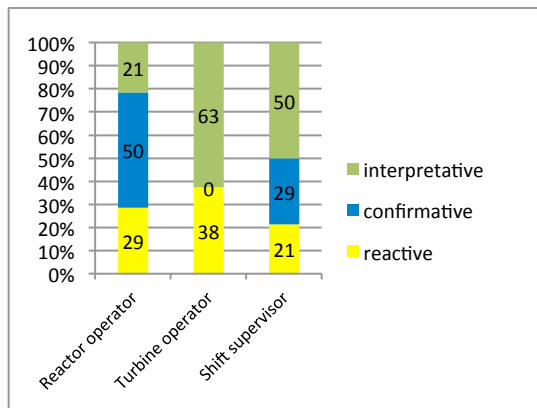


Figure 6a. Conceptions related to Concept of Good Operator classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP1; N=44. The share of each category (reactive, confirmative and interpretative) shown as percentage

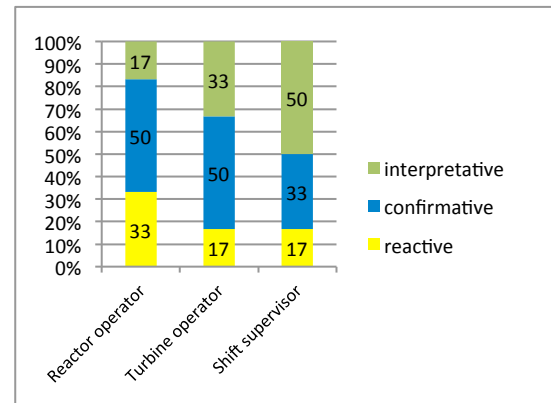


Figure 6b. Conceptions related to Concept of Good Operator classified according to the operator role (reactor operator, turbine operator, shift supervisor) in NPP2; N=18. The share of each category (reactive, confirmative and interpretative) shown as percentage

Finally, we summed up the findings with regard to all indicators of procedure orientation by both plants. The results indicate that in NPP1 the overall share of interpretative orientations was 27%, confirmative 41% and reactive 32%. In the NPP2, the same percentages are interpretative 27%, confirmative 50% and reactive 22%. The distributions are not statistically different ($\chi^2 = 7,61$, $df=2$, $p=0.472$), indicating that overall the orientations to procedures are equal in both plants. When the data from both plants is pooled and the differences in orientations between operator roles were analysed, statistically significant differences were found with regard to the Control of action, specifically in the Focus of Procedure Control ($F_{2,58} = 4,565$, $p=0,014$) and Procedures and Professional Competence ($F_{2,58} = 5,333$, $p=0,007$). The work orientations regarding Focus of Procedure Control ($t(41,884)=2,865$, $p=.015$) and regarding Procedures and Professional Competence ($t(35,067)=-3,076$, $p=0,008$) indicate higher level of interpretativeness by turbine operators compared with reactor operators.

DISCUSSION AND CONCLUSIONS

The conceptions of procedure guidance and operator autonomy express the operators' personal interpretation of how these demands, as well as goals of the production should be met. In both NPPs, the confirmative orientation, emphasising the importance of acting according to rules and procedures, prevails. This corresponds to the official principles of NPPs.

It can be argued, however, that an interpretative attitude towards initiating and control of action bring forward features which could support appropriate acting under changing demands and in possible unexpected situations. Hence interpretativeness is a qualification that would facilitate on-line resilience in the system. Our results

indicate that operators themselves value interpretative features as those charactering a good operator. Against this, the overall share of interpretative conceptions being 27% in both NPPs appears unnecessary low. Some reference to this result is provided from an analysis of the conceptions of safety and the role of procedures to maintain safety among two other safety-critical domains: Pezzullo and Filippo (2009) identified conceptual differences among drivers transporting hazardous materials. They found that only about 17 % of the expressed conceptions belong to the category of "green workers" which has connections to our definition of interpretative orientation. In an analysis of expert anaesthetists orientation to their work Klemola and Norros (1998) applied a corresponding method as used here and found that 33% of the expressed conceptions portrayed an interpretative attitude.

Especially low share of interpretative orientation among shift supervisors and reactor operators, and stronger interpretative orientation among the turbine operators with regard to control of action, but a stronger emphasis on interpretative and anticipatory practices in initiating action by reactor operators and shift supervisors, demonstrate that process characteristics and the role-based task demands are reflected in orientations in a consistent way. Due to the possible role of interpretativeness for resilience the development of this epistemic attitude should be supported beyond the level of its spontaneous development in daily activities.

According to our understanding, the interpretative orientation does not posit procedure-based action and professional competence against each other. Instead, such an orientation means that procedures are used reflectively, both using professional competence and taking the situational demands and constraints into account. Thus, we claim that interpretative orientation goes beyond the dichotomy of guidance and autonomy. It enables the comprehension of procedures and their intelligent use as part of professional competence and as an expression of resilient acting. Interpretative orientation would be especially important in responding to beyond design bases situations, for which no procedures exist. From this point of view the relative low share of this orientation should be of concern by the power plant operative management.

The results of this study will in the next step be compared with results of the same operators' actual practices in proceduralised process control situations (Savioja, Norros, & Salo, submitted). The characterisation of orientations and practices with regard to the strength of interpretative attitude these portray is a novel way of comprehending resilience in the sharp-end activities, which process has so far not been sufficiently elaborated empirically in the resilience engineering literature.

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