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Nuclear Reactor Control Room Simulators: Human Factors Research and Development

J. Theureau

Centre National de la Recherche Scientifique, Université Technologique de Compiègne, Compiègne, France

Abstract: Simulator studies are powerful means for understanding, designing and managing the complexity of nuclear reactor control if, along with their scenarios, they are correctly designed for that purpose. This contribution to an international state of the art of the use of nuclear reactor control room simulators in human factors research and development summarises the trends and novelties in the theories and methodologies (the reduction of the ambitions of cognitive simulation and the renewal of process-tracing methods, the eclectic search for theoretical and methodological complementarity, the conquests of situation awareness and their limitations, the study of cooperation), in the use of the results (with stress on probabilistic human reliability analysis and design of procedures) and in the construction of simulated situations (with stress on part task simulations and on relations between testing practical and empirical hypotheses and testing theoretical ones).

Keywords: Complexity: Human factors; Nuclear reactor control; Simulator design; Simulator use

1. INTRODUCTION

In 1985, it was perfectly reasonable for an overview of 'human factors aspects of simulation' (Jones et al 1985) to be practically entirely devoted to flight simulators, and just military flight simulators at that. These days, it would be impossible not to consider also the nuclear industry and – though to a lesser extent – car driving, navigation, air traffic control, processing industries and even anaesthesia and surgery.

Subsequent to a scan of the existing literature, discussions with some French researchers, and visits to Japanese, North American and European research centres, we will examine current trends in the use of simulators of nuclear reactor control rooms for human factors research and development purposes (see Theureau 1997 and Theureau et al 1997). We will consider also some studies using cockpit simulators which have been influential on research in the nuclear industry.

Our presentation will be neither neutral nor detached. It will be based on what we have learnt from our own studies, mainly on nuclear reactor control room simulators (Jeffroy et al 1998) but also on navigation and driving simulators and, more generally, on our experience in the construction and use of simulated situations in relation to course of action centred design (Pinsky 1992; Theureau and Jeffroy 1994). This experience results in placing the emphasis, in this presentation, not on the techniques of simulator and scenario design but on the theoretical and epistemological conditions for their efficient use.

2. LIVING, SOCIAL AND CULTURAL COMPLEXITY

Interest in the use of simulators in research and development concerning nuclear reactor control rooms stems from the necessity we have today to design and manage their living, social and cultural complexity. For that purpose, we must know sufficiently the underlying dynamics of this complexity. Knowledge of the deviations from what is prescribed by the management helps to set up the problem but not the solutions. What do we mean by 'living, social and cultural complexity' in matters of nuclear reactor control? We characterise in this way the system composed of the control room, including its diverse operators. In fact, if we consider the control room, the classical definition of complexity (many elements and many different kinds of relations between them) is not sufficient. We need at least the Santa Fe Institute definition: 'systems with many different parts which, by a rather mysterious process of self-organisation, become more ordered and more informed than systems which operate in approximate thermodynamic equilibrium with their surroundings' (Cowan et al 1995). But in itself it is not sufficient to take into account the presence of human actors who have the peculiarity of being autonomous, i.e. to behave at every moment in relation to a subjective view of the whole system, including themselves (their 'situation at hand') and who interact at that moment with elements of this situation that have been shaped as relevant by their past interactions up to that moment (Varela 1979).

To be studied, such a living, socially and culturally complex system cannot be broken up into simpler subsystems to be studied apart from each other and aggregated afterwards to arrive at the complex system. The reason is that complexity gives rise to important phenomena which can be missing in the simpler subsystems studied separately. It does not mean that only natural control situations should be studied, which would result in limited kinds of hypotheses and validation. It means that, through systematic studies of natural control situations, that is, of the real complexity to manage, hypotheses can be made which give way to the design of relevant simulated situations that become increasingly less complex and easier to manage, the study of which allows more precise hypotheses to be more thoroughly tested. It is not a matter of breaking up into simpler subsystems, but of building up simpler, thus more manageable, but still relevant situations.

To study such a living, socially and culturally complex system, one needs also, ideally, to practise both inductive and deductive methods. Inductive methods proceed from data to concepts by descriptive generalisation. Deductive methods proceed from an a priori mathematically organised view of the tasks to be performed to the concrete concepts describing empirical systems. If one sticks to the first, one risks obtaining pure clinical analysis, that is, poor generalisation. If one sticks to the second, one risks 'misplacing concreteness' (Whitehead 1978), that is, of taking the a priori for the real, of finding in the real what one has put, a priori, into it.

With that in mind, we can now address the current trends in human factors simulator studies with reference to the theories and methodologies (section 3), the use of results (section 4) and the construction of the situations simulated (section 5).

3. THEORIES AND METHODOLOGIES

Much work is being done practically everywhere on innovation and development of data collation and analysis methods. This work can be characterised by:

1. a reduction in the ambitions of cognitive simulation and a return to process-tracing methods;
2. a trend towards eclecticism, that is, the coexistence of heterogeneous or even contradictory theories and methods, and a search for theoretical and methodological complementarities;
3. a tendency to go beyond traditional cognitive psychology by means of the still-confused notion of situation awareness derived from human factors research in aircraft piloting;
4. a tendency to consider cognitive aspects of cooperation within the control crew, with distributed computerised information, and to develop corresponding methods and theories.

All these trends or novelties represent different ways of dealing with the complexity of nuclear power control, and we will describe them in further detail. We must also point out an important issue only recently tackled in VTT Espoo: the evolution of operators' competence and confidence in automated systems, which requires longitudinal studies and theoretical developments.

3.1. Reduction in the Ambitions of Cognitive Simulation and the Return to Process-Tracing Methods

Just a few years ago, cognitive simulation – computer modelling of control activity, based on a symbolic representation of the task and considerations derived from experimental psychology – was the lodestar for simulator studies. It still is today, but instead of expanding this perspective is vanishing. For example, the series of studies by (Roth et al 1994) was developed within a broader project undertaken by the Nuclear Regulatory Commission (NRC) to study the performance of the control crew during simulated emergencies and make a cognitive simulation of the cognitive activities involved. In a past series of studies, two variants of an ISLOCA (leak from the high-pressure reactor coolant system to the low-pressure residual heat removal system) were studied on a full-scale simulator. But generalisation of the results of this study was responsible for many limitations: solely ISLOCA incidents; control crews made up of one or two training staff and not the usual three to five actual operators. Also, the cognitive simulation developed dealt only with certain of the cognitive activities engendered. It was therefore decided to develop a new, more extensive series of empirical studies with richer simulated situations. It was planned at the same time to develop cognitive simulation, but it was decided to focus first on the empirical study because of the difficulties, cost and time entailed. To our mind, this postponement implicitly reflects the relative failure of cognitive simulation in its current form, with respect to both knowledge of activities in complex dynamic systems and to design and management. We feel that at the moment use of this tool is of interest only if: (1) it develops in connection with a systematic analysis of activities and not on the basis of symbolic representation of the task and general considerations derived from experimental psychology; (2) it is restricted to modest objectives in both theoretical and practical terms. This is the case, for example, in collective activities in an emergency rescue service or in air traffic control, as presented in Pavard (1994).

This limitation on the ambitions of cognitive simulation raises the problem of seeking out new channels for modelling obeying a new paradigm of cognition, that is, new deductive methods. Waiting for the solution of this problem, at the moment it is leading to a renewal of what some authors call 'process-tracing methods', i.e. a kind of inductive method. These process-tracing methods are related to the methods of French language occupational ergonomics analysis, and more specifically to those of course-of-action analysis and their collective interlinking (Theureau and Jeffroy 1994). This is not entirely fortuitous since, like course-of-action methods, they go back to different researchers like Newell and Simon (1972) – to quote the more famous ones – who, at the dawning of cognitive psychology and artificial intelligence as we know it today, developed a new – or at least renewed – fashion for validation of theories and models which stressed systematic description of verbal protocols collated at the same time as the activity was in progress and which gave a secondary status to conventional experimentation and statistical analysis. The essential instruments for this kind of validation were the problem-solving graph and computer simulation, the ancestors of process-tracing methods and cognitive simulations. The decline in the ambitions of cognitive simulations resulted in process-tracing methods being reinstated to a position they had lost since Newell and Simon (1972), except in certain French language research in ergonomics.

Let us look at another example of the development of process-tracing methods: the 'realistic' approach developed in studies by the VTT Espoo research group on a full-scale simulator. As is explained in Hukki and Norros (1994), the approach is contextual (including the social situation), dynamic (acts are not considered as isolated events) and subject-centred (the operators' point of view is considered to be essential). The researchers speak of situation activity or socially constructed activity, or quite simply of activity in the sense of Vygotsky (1978). Today, therefore, the main references in the psychological literature that interest these researchers are those which are associated with an effort to set up process-tracing methods (Klein et al 1993; Harré and Steams 1995; Smith et al 1995). Similar process-tracing methods are developed in the ANACONDAS project at EDF (Filippi et al 1998), but in line with French language occupational ergonomics analysis (Theureau and Jeffroy 1994).

3.2. Eclecticism and Searching for Theoretical and Methodological Complementarity

Eclecticism – the coexistence of heterogeneous or even contradictory rationalisations – has been frowned on in the academic world since the philosophical debates of the nineteenth century. Indeed, if one looks no further, eclecticism seems to be a major hindrance to research. But if it is considered that it reflects both recognition of a complexity and the limits of the methods and theories available for controlling this complexity in a given scientific and technical conjuncture, eclecticism is certainly to be preferred to dogmatism, from the points of view of the future and of the resolution of immediate practical problems.

Let us examine, for example, Amalberti (1996) on the control of hazardous situations. This author proposes to link two models: an 'understanding/action model' dealing with control activity, and a 'contextual control model' dealing with in-depth defences which make it possible to accept the initial risk and/or to check that the accepted risk does not degenerate into loss of control. But he also proposes at the same time to consider a 'pot-pourri' combining 'workload', 'stress' and 'fatigue' for which – quite rightly – he is careful not to formulate any kind of model.

Similarly, in nuclear reactor control room simulator studies carried out at OECD Halden, experiments were run with a range of different methods based on different concepts between which the links were tenuous or non-existent. This is the case in many cockpit and nuclear studies and – it must be stressed – the case of those with the greatest ambition and the closest connections with the practical problems of design.

This eclecticism is expressed as a principle in the current programme of tests on a Japanese nuclear simulator (Kijima 1993). In the Japanese research, as in most research in the nuclear field in other countries, Rasmussen's 'model' is used to classify the data of verbal protocols (Kawano and Fujiie 1996), or to isolate certain phenomena within the overall activity (Salazar-Ferrer 1995), because of its heuristic value, certainly, but above all because of the few constraints it implies to the use of other theoretical imports.

We would point out that eclecticism often rhymes with consideration of new problems. This is the case for the night control simulator studies which are starting to be carried out at OECD Halden (Morisseau et al 1996) and those carried out recently for the US NRC (Baker 1995). It is also the case for simulator studies of cooperation and collective aspects of control activity (Hallbert et al 1996).

It should also be noted that each moment of scientific progress builds on the sediment left by previous steps. Thus, with regard to the reactor emergency control study in Japan, things went from behaviourism (phase 1, 1984–

1986, centred on the notion of human error) to cognitive psychology (phase 2, 1987–1989, centred on clarification of cognitive processes), then to social psychology (phase 3, 1990–1992, centred on the relationship between communication and control crew performance). Today, notions and methods derived from these three theoretical and epistemological paradigms coexist (Kijima 1993).

If today's build-up of heterogeneous methods and notions requires clarification, the same applies to most of these methods and notions individually. This is the case, in particular, of the notion of workload and of methods for assessing it, be they objective or subjective. As will be seen in what follows, it is also the case of the notion of situation awareness and its evaluation methods.

3.3. The Conquests of Situation Awareness

The notion of situation awareness that came into being in cockpit studies is invading the nuclear field. It has become emblematic of the presence of man in highly automated technical systems. Still, situation awareness is unanimously considered to be a vague notion which has multiple definitions and gives rise to multiple complementary or alternative methods (Garland and Endsley 1995). The definitions that follow are just two chosen from a multitude of others presented in that book because of their radical theoretical heterogeneity: 'a person's state of knowledge or mental model of the situation around them' (Endsley 1995, p. 18); 'dynamic cognitive coupling between an actor and a situation' (Flach 1995, p. 25). According to other authors, situation awareness is thus: 'a lumping concept rather than a splitting concept' (Billings 1995, p. 1); 'too neat, too holistic, and too seductive' a construct about which, in short, one might wonder if its utility compensates its complexity (Billings 1995, p. 3); 'a default construct. Namely, that you know it best when it fails, when someone loses SA and the result is a crash' (Charness 1995, p. 36). Some authors stress the 'family resemblance' between the notion of situation awareness and that of workload, especially mental workload: same fuzziness, same practical necessity in the absence of better established notions, same measurement problem (Reid 1995, pp. 101–104). In fact, the notion of situation awareness reflects both the incapability of traditional cognitive psychology to answer the practical questions of control of complex dynamic systems, and the efforts to go beyond this traditional cognitive psychology, whereas no alternative has yet fully asserted itself. Its fuzziness is evidence of a scientific crisis that has not yet been resolved, but its very existence evidences the need to give the designers of complex dynamic systems, if not clear criteria, then at least a principle concerning the relationships to be established between human operators and automatic systems: maintain the situation awareness of operators. It is therefore worth examining what can be done to clarify this notion.

In Sarter and Woods (1991), a preliminary clarification of the notion is made by showing that it cannot be the equivalent of 'effective conscious knowledge, for 'that would suggest that only the information in work memory could be considered to be aware', and by considering that 'any definition of situation awareness must refer to the information that is available or that can be activated, when it is relevant for evaluating a situation and dealing with it'. If one agrees with these authors, the notion of situation awareness can be assimilated to that of potential actuality proposed in the course-of-action theory (Theureau and Jeffroy 1994; Jeffroy et al 1998) as part of a human cognition paradigm alternative to that of 'man as an information-processing system' most authors dealing with situation awareness continue to refer to. The definition of potential actuality is close to Flach's definition of situation awareness mentioned previously. The potential actuality at a given moment is considered as a set of expectations selected and structured by the 'agent's involvement in the situation' at that moment among the expectations produced by the past course of action. This 'agent's involvement in the situation' is itself the product not of the situation at hand but of the entire course of action up until that point. The notion of potential actuality is thus built up in a way that is strictly the converse of the usual notion of situation awareness. Along this usual notion of situation awareness, what comes first is the situation independently of the person involved or agent, whereas along the notion of potential actuality, what comes first is the involvement in the situation inherited from the past course of action, independently of the instantaneous situation.

This divergence between the current notion of situation awareness and that of potential actuality has important methodological consequences. If the situation does indeed come first, a method for documenting situation awareness which involves freezing the simulator at certain times during the scenario and asking the operators to answer a questionnaire on the situation is legitimate. If, on the other hand – as in the course-of-action theory – the involvement in the situation comes first, this sort of intrusion into the control activity changes radically this involvement in the situation and is incapable of producing data reflecting the potential actuality. Potential actuality can only be reconstructed indirectly, through analysis of the control activity, that is, through process-tracing methods.

The freezing method is used in the SACRI (Situation Awareness Control Room Inventory) method, as part of the OECD Halden international research and development programme, which adapts to the nuclear power industry the SAGAT method (Situation Awareness Global Assessment Technique) developed in cockpit studies. Conversely, in Roth et al (1994) and Zsambok and Klein (1995), the question of situation awareness is re-examined following Klein (1995). These authors propose to study situation awareness through the control activity, that is, in the same way as one studies potential actuality, by process-tracing methods.

3.4. Discovery of Cooperation

Problems of cooperation in aircrews, as in nuclear reactor control crews, are increasingly being dealt with on simulators. This is the case of the Japanese nuclear simulator test programme (Ujita et al 1995; Kijima 1993). It is the case in the OECD Halden international programme (Hallbert et al 1996) and in the Westinghouse Pittsburg programme. It is also the case in different cockpit studies (Rogalski et al 1994; Smith et al 1995).

Some of this research into collective activity develops evaluations of the situation awareness of the crew as well as of its individual members (Prince et al 1995; Zsambok and Klein 1995).

Despite the difficulty of addressing collective phenomena from the point of view of conventional cognitive psychology, the principle of which is ‘methodological individualism’, these studies do not generally develop new theoretical notions, and restrict themselves to eclectically aligning individuals and groups, individual cognitive psychology and non-cognitive social psychology. A good example of this trend is that of the research by Salazar-Ferrer 1995): to an innovative cognitive analysis of the reasoning of operator diagnosis is added an analysis of the cooperative activity of the operators, which is restricted to a statistical study of communications that eliminates any consideration of their dynamics and of their relationship with the dynamics of the activity as a whole. We would wish, however, to draw attention to a series of studies developed since 1991 by E. Hutchins and his colleagues on different full-scale flight simulators which suggest, in line with Hutchins (1995), a new approach in terms of ‘socially distributed cognition’ which is both social and cognitive.

4. USE OF THE RESULTS

The results of the studies in full-scale simulators or in sufficiently rich and relevant part-task simulators, like those of studies in natural situations, are by construction multi-uses: evaluation and design of control rooms and of their organisations, devices and procedures (human–machine interfaces, in particular alarms and information presentation, paper or computer-driven procedures, operation manuals). Nevertheless, a few of these uses are dominant and increasing:

1. An increasing number of simulator studies aim at evaluating computerised support systems (expert systems and so on) and at preventing potential negative effects of automation, following cockpit studies (Mosier and Skitka 1996).
2. Verification and validation are less and less restricted to the technical aspect of software certification. But there still exist more verification and validation studies than studies integrated in the design process, in spite of the limitations of the first ones (due to the post hoc position relative to designers that they imply) and of the possibilities open by part-task simulators to overstep these limitations (see section 5).
3. More interest exists in the improvement of training and certification, in particular in Westinghouse Pittsburg (Mumaw and Roth 1992; Mumaw et al 1994) and in the Japanese program (Ujita et al 1998).
4. More emphasis is put on qualitative aspects of human reliability analysis than on its quantitative aspects.
5. A poor interest is still expressed in testing from a human factors point of view the design of procedures, although drastically changed and computerised in different ways all around the world since the Three Mile Island event.

We will focus here on points (4) and (5), a positive one and a negative one, as they appear to us.

4.1. Probabilistic Human Reliability Analysis

As the essential purpose of studies on nuclear power plant control room simulators is often to provide data for probabilistic human reliability analysis (PHRA), we will consider more thoroughly this point. Many studies continue to implement the conventional methodology initiated by A. Swain, which bypasses the operators’ cognitive activity (Miller and Swain 1986). Different research and development teams tend to query the relevance of this conventional methodology in various ways. At VTT Espoo, a recent objective of the psychological research group is to integrate cognitive analysis of control activity into the new stochastic dynamic model called the ‘marked point process’ (Arjas and Holmberg 1995). It matches well with the idea that one should analyse the construction of the action and not model it in some way as a predefined sequence. At Westinghouse Pittsburg, the human factors research group works upline of PHRA by implementing a checklist of cognitive task requirements produced from simulator tests (Roth et al 1994). At OECD Halden, one integrates a similar concern to a structured approach for contribution to PHRA, through a method called CREAM (cognitive reliability and error analysis method), which was first developed by Erik Hollnagel. The principle of the approach is to combine two interpretation methods, the first of which (‘basic method’) is a determination of the general likelihood of failure based on an analysis of the performance conditions rather than 'human error tendencies' as in customary PHRA, and the second ('extended method') a logical progression of cognitivism (Hollnagel 1998). Let us consider the second method. Through it, the sequences of events occurring are interpreted in terms of the cognitive activity profile required by the task, and the errors likely to occur are determined (qualitative step). One then calculates a probability of failure (quantitative step). The qualitative step of this second method is a clear recognition of the kind of complexity which is involved in nuclear power control, or at least of a crucial aspect of it. It is likely to produce empirical and practical results without waiting for the quantitative step. This introduction of a qualitative and cognitive step before the quantitative step is also present, but with the emphasis on cooperation in the control room and the inspiration of the 'socially distributed cognition' framework (Hutchins 1995), in the French EDF project MERMOS (Le Bot and Bieder 1997).

4.2. Procedures

In the nuclear field procedures occupy a particularly important place and, since the Three Mile Island incident, new paper-based and computerised procedures have been developed throughout the world. In Electricité de France, computerised 'state-based procedures' are now replacing 'event-based procedures' for emergency operation. It is also planned for them to replace event-based procedures in normally disturbed situations in the future. At Westinghouse, a system of emergency procedures has been developed that combines rather than substitutes symptom-based procedures (developed along principles similar to state-based procedures) for event-based procedures. These different sorts of procedures have led to very few cognitive studies, particularly on simulators. Apart our own recent study (Jeffroy et al 1998), the only study of this type that we can refer to was carried out at OECD Halden when two support systems were compared (Hallbert and Meyer 1995). These cognitive studies of procedures should develop in the future.

5. CONSTRUCTION OF THE SIMULATIONS

Studies of human activity using simulators run into the problem of what it costs to conduct them, the problem of integrating them into the process of designing new systems, and the problem of relationships between the simulator and its scenarios and real situations. We observe:

1. increasing use of part-task simulators, increasingly rich and flexible and less and less expensive, owing to the progress in computer techniques, in order to test alternative design options;
2. more use of usual training or certification simulated situations, with methodological cautions and limits and a consideration of training design issues;
3. more linkage of incidental/accidental simulator studies with retrospective incident/accident studies;
4. a growing but still modest interest in the study of natural, normally disturbed, situations, in order to ensure greater relevance of the simulations and to better understand the transfer made by operators from the normal situation to incidental/accidental situations;
5. a tendency to build simulation scenarios from theoretical hypotheses concerning control activity, and not only from practical and empirical hypotheses.

We will focus on trends (1) and (5), because of their epistemological and practical consequences.

5.1. Full-Scale and Part-Task Simulations

When people talk of simulators, they usually mean an ideal simulator, a full-scale one. The point of part-task simulators is to represent another ideal fulfilling another function. For example, at the NASA AMES aerospace research centre, part-task simulation begins when pilots are not put in an exact replica of a real cockpit that reproduces the accelerations and movements of the actual aircraft. From this point of view, the HAMMLAB nuclear reactor control room simulator of the international OECD Halden programme is a highly sophisticated part-task simulator. What is new is less the reality of part-task simulation (it might be said that traditional human factors studies concern situations of this type) than the very notion of part-task simulation (as a simplification and reduction of full-scale simulation and not as a complication of psychological experimentation) and the fact that today's information technology brings part-task simulation closer to full-scale simulation. Several considerations lead to studies being carried out on part-task simulators. The first two are the interconnected considerations of cost and integration into the design process: a part-task simulator costs less and is more quickly designed, transformed, or enhanced with new systems than a full-scale simulator. It therefore allows for easier comparison – from the point of view of control activity – of design alternatives for such new systems. The other considerations are of a theoretical and epistemological nature, and imply two parallel orientations.

The first orientation arises explicitly or implicitly from a recognition of the living, social and cultural complexity. For the supporters of such a theory and epistemology, natural situations do not simply add complications to experimental situations. As we have stated in section 2, they add complexity and thus engender cognitive phenomena, some of which can be radically different. The resulting method for acquiring scientific knowledge of these cognitive phenomena starts from studies in natural or close-to-natural conditions (particularly when, as for certain emergency situations, it is absolutely necessary to use the simulator) in order to determine the cognitive phenomena involved. It works towards studies on part-task simulators especially designed to examine these cognitive phenomena more exhaustively and better validate them, but the pertinence and validity of these studies depend on the first studies. In the context of this recognition of the living, social and cultural complexity, both full-scale and part-task simulators take on a scientific function instead of just a practical function or a role as ill-adapted substitutes for experimental situations in the laboratory.

The second orientation arises out of a theory (implicit) and epistemology (explicit) of 'Lego' (internationally reputed children's building-block game) by which complexity is considered to be both capable of and having to be attained by putting together simple elements – or generic concepts of what is simple – produced by the laboratory situation studies. Part-task simulation is then thought out in relation to the ideal of laboratory experimentation. It is no longer thought out from the point of view of simulation. This is similar to traditional human factors studies. The only difference between a part-task situation and a laboratory situation, from this point of view, is that because of the practical interests involved researchers benefit from greater material resources than if they were to remain in their laboratory.

A large number of studies on part-task simulators encountered in the literature result from this second orientation. Their scientific interest is secondary relative to rigorous experimental procedures in the laboratory and field studies, full-scale simulator studies or sufficiently rich part-task simulator studies developed from the simulator point of view. Nevertheless, their practical merits are not to be overlooked. They help demonstrate the interest in developing part-task simulators for integration of human factors into design processes. Their results can be reinterpreted in connection with a theory and epistemology of complexity if one also undertakes rigorous studies in the natural situation or on a full-scale simulator. On the contrary, the research of the Westinghouse Pittsburg group is along the first orientation (Roth et al 1994). At OECD Halden both orientations coexist. In summing up 10 years of test and evaluation studies (Folleso and Volden 1993), it is considered that a high degree of realism was attained, to the detriment of systematic control of the experiments, and therefore suggested reducing realism in order to increase control, starting with the less realistic and more controlled studies in order to 'demonstrate effects of vital aspects of the system', and then using more realistic situations to more broadly test the validity of their hypotheses. Conversely, in Kvalem et al (1996), it is suggested placing 'less stress on well-controlled experimentation and more on simulated field studies to analyse complexity' as a long-term prospect for the use of the HAMMLAB simulator.

5.2. Design of Simulation Scenarios

It is commonplace to design the simulation scenarios in order to test practical and empirical hypotheses, such as the hypothesis of performance improvements due to a given system, or various organisational arrangements for the control crew. What is new is the trend to build scenarios from theoretical notions in order to test theoretical hypotheses regarding control activity, and not only practical and empirical hypotheses. This trend is seen in certain full-scale simulator studies and in most part-task simulator studies, both in those that tend to stick closely to the epistemological paradigm of Lego and those that – more or less implicitly, it must be said – consider part-task work from the simulator point of view, and therefore in relation to the paradigm of living, social and cultural complexity. The series of studies by Roth et al 1994), for example, dealt with two variants of ISLOCA (interfacing system loss of coolant accident) and two variants of LHS (loss of heat sink) with 11 complete crews of real operators for each event. The model of cognitive activities linked to operator behaviour in the emergency situations involved comprises two components: situation assessment and response planning. Situation assessments are the building-blocks of situation awareness (see above). Response planning corresponds to the decision to take a course of action, bearing in mind a particular situation assessment. The two ISLOCA variants were especially designed to be difficult from the point of view of situation assessment. The objective was to create situations in which the control crews would have to identify and isolate the breach without explicit guidance. The emergency procedures did indeed include ISLOCA procedures, but it was possible to create situations where the control crews could not find the ISLOCA procedure through the network of emergency procedures. The specific dynamics of the event led the operators to a LOCA (loss of coolant accident) procedure. As for the two LHS variants, they were designed to be demanding in terms of both situation assessment and response planning.

Testing theoretical hypotheses and not only practical and empirical ones on simulators is, properly speaking, carrying out scientific research on simulators, that is, creating the conditions for the development of effective and innovative practical and empirical methods.

6. CONCLUSION

On the whole, such trends are clearly positive. Although the present eclecticism should certainly be abandoned in the future, it is the case in the matter of theories and methodologies. Apart from the poor contribution to the design of procedures, it is also the case concerning use of the results. The same judgement can be made concerning the construction of the simulations, even if the epistemological problem of simulation studies is still a matter of debate. All these trends leave room for use of the techniques of simulator design in matters of knowledge, design and management of the complexity of nuclear reactor control, which will prove increasingly efficient in the future. At first sight, a synthesis and integration of these different trends appears conceptually and practically impossible. We think that the perspective, sketched in section 2, of a 'science of complexity' which is now developing in different empirical fields, from physics to biology, economics and social sciences, and also in engineering, unifies this multiplicity of trends. Now, to be sure, it is still a perspective. The time is more to make epistemological reflection a part of the use of simulators in human factors research and development than to lay down and follow a 'one best way'.

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Correspondence and offprint requests to: J. Theureau, Centre National de la Recherche Scientifique/Université Technologique de Compiègne, BP 649, 60206 Compiègne, France. Email: theureau@ext.jubbieu.fr