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FIABILITE HUMAINE ET FACTEURS HUMAINS DANS LES ORGANISATIONS COMPLEXES : ANALYSE EPISTEMOLOGIQUE ET CRITIQUE VOIES PRATIQUES POUR L'ACTION

HUMAN RELIABILITY AND HUMAN FACTORS IN COMPLEX ORGANIZATIONS : EPISTEMOLOGICAL AND CRITICAL ANALYSIS - PRACTICAL AVENUES TO ACTION

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SYNTHÈSE :

Cet article prend comme point de départ l'existence de problèmes persistants dans les évaluations probabilistes de sûreté (EPS). Une revue bibliographique de documents américains est d'abord présentée ; ceux-ci émettent un certain nombre de critiques vis-à-vis des analyses de fiabilité humaine : limitations dues à l'insuffisance de données ; absence de modèle théorique de base ; non-reproductibilité des analyses... On est conduit à revenir aux fondements épistémologiques de ces analyses et à en présenter une critique. L'un des points fondamentaux mis en exergue est que les analyses de fiabilité humaine s'affranchissent de toutes les caractéristiques singulières de la situation de travail qui conduit à l'erreur humaine (afin de pouvoir élaborer des données statistiques sur un nombre de cas suffisant), mais du même coup perdent ces "relations" entre erreurs humaines et les différents aspects du contexte de travail. Les autres points critiques principaux résident dans le caractère **collectif** du travail qui n'est pas pris en compte, et dans la confusion fréquente entre activité réelle des opérateurs et tâches prescrites, formelles.

L'article suggère des pistes de réflexion pour surmonter ces difficultés : l'évaluation quantitative du climat social au sein d'une entreprise ; un modèle non-linéaire d'évaluation du taux d'accident ; l'analyse du stress du personnel de plates-formes "off-shore". Les méthodologies utilisées dans ces trois études sont du même type et pourraient être transposées aux problèmes de fiabilité humaine.

L'article prolonge enfin la réflexion en vue de développer une vue "positive" du facteur humain (et pas seulement "négative", c'est-à-dire centrée sur les erreurs humaines et les dysfonctionnements organisationnels), en utilisant les méthodes d'investigation développées dans les sciences humaines du travail (psychodynamique du travail, ergonomie, sociologie du travail). L'importance des opérateurs comme **acteurs** œuvrant collectivement est soulignée.

 Reliability Engineering and System Safety 0951-8320/92.

EXECUTIVE SUMMARY :

This article starts out with comment on the existence of persistent problems inherent to probabilistic safety assessments (PSA). It first surveys existing American documents on the subject which make a certain number of criticisms on human reliability analyses, e.g. limitations due to the scant quantities of data available, lack of a basic theoretical model, non-reproducibility of analyses, etc. The article therefore examines and criticizes the epistemological bases of these analyses. One of the fundamental points stressed is that human reliability analyses do not take account of all the special features of the work situation which result in human error (so as to draw up statistical data from a sufficiently representative number of cases), and consequently lose all notion of the "relationships" between human errors and the different aspects of the working environment. The other key points of criticism concern the **collective** nature of work which is not taken into account, and the frequent confusion between what operatives actually do and their formally prescribed job-tasks.

The article proposes aspects to be given thought in order to overcome these difficulties, e.g. quantitative assessment of the social environment within a company, non-linear model for assessment of the accident rate, analysis of stress levels in staff on off-shore platforms. The method approaches used in these three studies are of the same type, and could be transposed to human-reliability problems.

The article then goes into greater depth on thinking aimed at developing a "positive" view of the human factor (and not just a "negative" one, i.e. centred on human errors and organizational malfunctions), applying investigation methods developed in the occupational human sciences (occupational psychodynamics, ergonomics, occupational sociology). The importance of operatives working as **actors** of a team is stressed.

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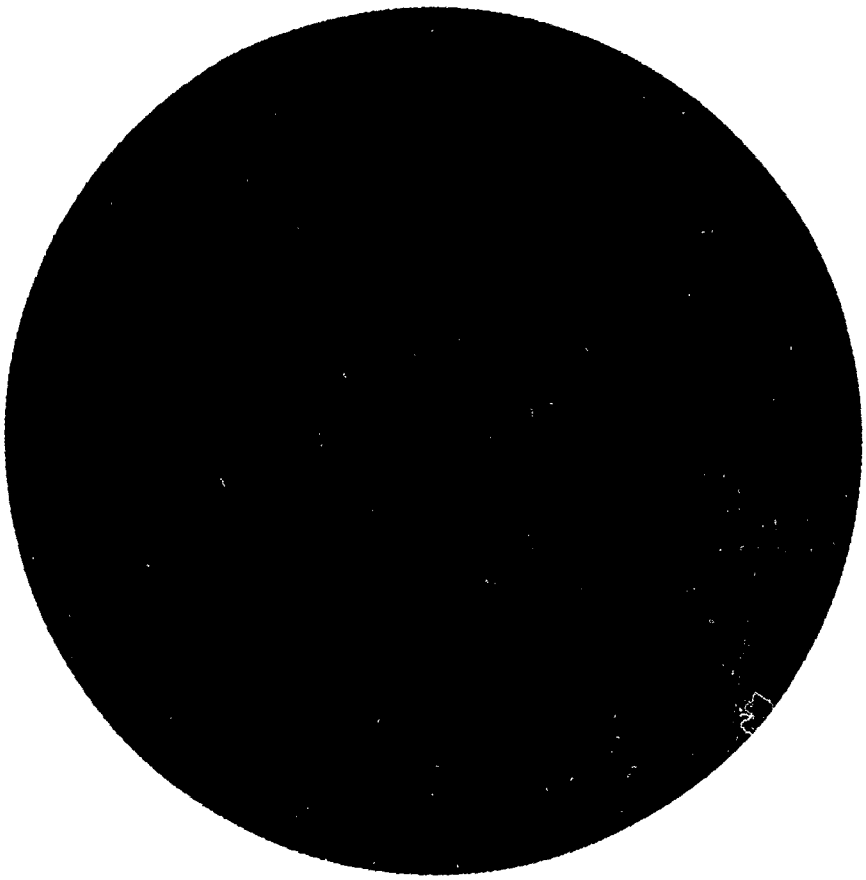

Human reliability and human factors in complex organizations: epistemological and critical analysis—Practical avenues to action

1 INTRODUCTION: STATUS OF THE PSA METHODOLOGY

This work originates in the realization that persistent problems exist in probabilistic safety assessments (PSAs). Decison makers are troubled by the complexity and intricacy of human factors problems.

Specialists themselves feel discomfort even if they cannot always explain why and formulate the reasons for their attitude.

The question is: are PSAs credible? Ambiguities are inherent in the way these studies are presented, as illustrated by the title of a recent article 'Les évaluations probabilistes de la sûreté: peut-on s'y fier?' (Probabilistic Safety Assessments: Are they Reliable?)[1]

One of the main ambiguities lies in the 'objective' character of these analyses. Indeed, can we 'objectively', that is scientifically, identify and assess risks or does the notion of risk necessarily and inevitably involve subjectivity?

These studies and the associated research are undeniably performed to master technological risks and improve safety. But what does mastering technological risks mean? What does it imply?

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Ambiguities and misconceptions, epistemological among others, make the situation perplexing. We feel the studies are stagnating. Have we reached an impasse? We assume that the lack of a thorough, penetrating and uncompromising critical evaluation of the foundations and developments of probabilistic approaches is eventually detrimental. The often *defensive* attitude of experts in this field is striking. From our experience of congress discussions and of working groups and from our contacts with experts, we can conclude that this necessary reconsideration is difficult, if not impossible.

Human factors are at the heart of the discussion (hard to open), as they are also at the core of the real, concrete, everyday problem of the safety in high-risk facilities. We will further examine this point below.

When you examine the problem more closely, difficulties further increase: the models of man used in probabilistic assessments are highly problematic and still controversial. Questions remain and resist solution, in particular on the way organizational factors are taken into account.

Swain, in his last book's conclusions, makes the following comment: 'I am convinced that without better support the HRA portions of PRAs will continue to be the least convincing aspect in the PRA'.[2]

The study undertaken by the Council's Human

Factors Committee at the NRC's request concluded in 1988. '*There are many problems of human performance* which require further research at a fundamental level. Foremost among these is *human error*, and the development of cause models rather than statistical estimates for use in predicting reliability. The current methods for *predicting human reliability* are simply inadequate' (Author's italics).[3]

Already in 1982, in a first study carried out for the Human Factors Society at the NRC's request, it was noted:

> 'Thus, the constraints to obtaining valid HEP [human error probability] data are substantial, and the application of such data, under current conditions at least, is *virtually impossible*.' (Ref. 4, p. 36. Author's italics.)

> 'There is scant empirical basis for HEP provided in NUREG/CR-1278. Improvement of this deficiency would be tremendously expensive, and validation of the resulting HEP is, while *theoretically possible*, *practically infeasible*.' (Ref. 4, p. 39. Author's italics.)

The revised version of the study[5] published in 1982[4] and whose main conclusions only are mentioned in Ref. 3 contains a relatively extensive discussion on the problem of how to predict human error probabilities (Chapter 6 in Ref. 5). Several important points are worth mentioning:

> 'The panel believes that research to further improve subjective estimates of human error should not receive a major emphasis in the future. A more fundamental understanding of the nature and causes of human error is needed if the nuclear industry is to make further progress in measuring, predicting and reducing human error and the human contribution to risk.' (p. 72)

> 'Without such a (theoretical) framework, the ability to interpret data and advance beyond simply counting and categorizing human error is severely restricted.' (p. 72)

> 'Considerable effort has been expended, primarily by INPO and the NRC, to develop extensive data banks of task analyses for different purposes. There is no need to continue to develop task analytic data banks of this nature.' (p. 74)

Finally, to go on with this brief survey of the criticisms against probabilistic assessments of human errors, let us quote the NRC report (NUREG-1420) on the Committee Review of the report on severe accident risks (NUREG-1150).[6]

First, it is worth comparing the results of two analyses of human errors, that is the failure to start the standby liquid control, during an ATWS sequence. The two analyses were performed:

—by the Brookhaven National Laboratory for the Peach Bottom plant PSA. The probability of this human error was estimated at 0·02 ($0{\cdot}01 < P < 0{\cdot}26$).

—by the Sandia National Laboratory for the Grand Gulf plant. The computed probability is 10^{-4}! Furthermore, in the analysis performed, two factors are mentioned which could bring this figure above the Peach Bottom figure! (Ref. 6, pp. 34–5).

Let us quote now two comments on these results:

> 'The question that inevitably arises is how much of this substantial difference in HEPs is due to the different methodologies employed and to the different groups of analysts using them. The documentation fails to reveal any differences between the layouts of the two control rooms of major significance to the HEP in this sequence.' (p. 34)

> 'Indeed, it may be questioned if the relatively simple models used in NUREG-1150 for the ATWS cases are the most appropriate ones, *when analyzing a complex, high-stress situation involving communication* between several persons, each with multiple tasks to perform.' (p. 25. Author's italics.)

There is therefore good reason to wonder how progress can be achieved in the area of human factors. How can the ambiguities and limitations inherent in probablistic (human reliability) assessments be overcome?

Our research into this problem has produced three successive and complementary approaches:

(1) an *epistemological* critique of the foundations of human reliability analyses (HRA);
(2) a *pragmatic* critique of the way these analysis results are used;
(3) an investigation into the gaps or deficiencies in the present conventional analyses of human factors.

We are guided in our approach by the experience and learning drawn from advanced studies of human factors in our company and in the French research community with which we closely collaborate (ergonomics, industrial psychology).

Our main objective is to sketch a human factors construct that can open on to action in the field by raising the question of *everyday* safety as it is understood and put into practice by control and maintenance operators in nuclear power plants.

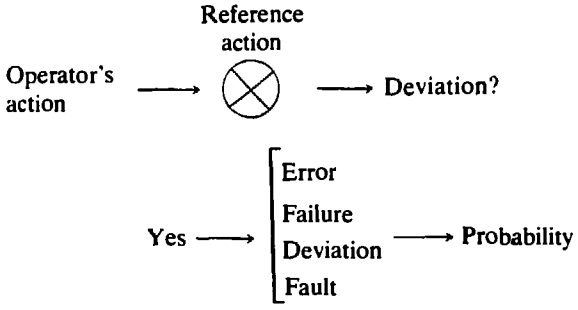
2 EPISTEMOLOGICAL ANALYSIS OF THE FOUNDATIONS OF HUMAN RELIABILITY ANALYSES (HRAs)

In human reliability analyses (HRAs), the operator is inevitably regarded as an *executant* or as a *component* of the technical system studied. The analysis (HRA) methodology initially took after the component analysis. 'Initially' means in the first documents (Ref. 7, for instance).

The foundations of the analysis are briefly summed up as follows:

—A list of pre-established, unequivocal, unambiguous 'actions' (movements, decisions, reasonings, diagnoses) the operator must perform is drawn up.

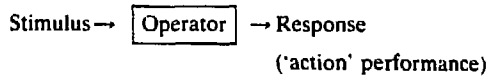
—The operator's 'performance' is characterized by a failure probability of this action as shown below



—In principle, this approach should not raise problems. The deviations have just to be identified and quantified in terms of probabilities.

—Two essential points should be stressed:

(1) The models of man used in the probabilistic approach have behaviouristic foundations. The analyst is not interested 'in what is inside the black box'. He even tries not to be influenced by it! He tries to have a 'scientific' (objective) approach and to consider only what is observable from outside. We shall see that, in some cases, the analyst should not keep to this very restrictive methodological attitude. Thus he assumes that the operator functions according to the pattern below.



Stimuli may be different in nature: series of previous actions (while following a procedure); alarms in the control room; request for aid from another operator; preplanned operation...

(2) The analyst is not interested in the operator as such but in the technical system. Errors (or deviations...) are considered from the technical system point of view, that is errors which will affect the technical system operation are considered.

—The analysis of human reliability in the framework of probabilistic safety assessments points to two major categories of operator actions:

(A) Specific actions, easily spottable, limited in time, repetitive and relatively simple (not involving complex cognitive processes): operate a valve locally; check an indicator; stop a pump in service...

(B) Complex actions involving complex cognitive processes spreading over a long period of time, like the application of an accident procedure.

—For these actions, the nonsuccess or failure probability is defined by the general formula below

$$P = P_0 f(\alpha_i)$$

where P_0 is the probability of the action being performed under 'normal', standard and 'usual' conditions, and the α_i are performance-shaping factors (PSF) to allow for the impact of physiological factors, stress, the task complexity...

The function $f(\alpha_i)$ is generally *linear* or simple *continuous* function of these factors.

The potential variability with respect to this 'average' method (operator's variability among others) is allowed for by the error margin assigned to P.

In many analyses, an overall correction factor α—evaluated by expert judgement—is taken to this end. This factor is the result of a *rough* appraisal.

3 CRITICAL ANALYSIS

(1) The strength of the probabilistic approach to human reliability is also its inherent weakness. Indeed the probabilistic approach is not bound by a specific working context, the singularity of individuals, the history of a given sociotechnical system, during data collection; but at the same time these influencing factors cannot be identified in the studies.

The aggregation, amalgamation of all these factors, of a great number of causality factors, makes it impossible later on to go back to the characteristics which specifically shape the work. In other words, this approach does not identify the truly human factors

which need to be acted upon (like stress, the quality of the work organization, the quality of working relations). Let us also underline here that human reliability analysis techniques, a fortiori, do not provide a method for introducing modifications in the organizations.

More precisely, probabilistic human reliability analysis methods do not provide an answer to the fundamental question: what evolution, modification, conversion process should be promoted, developed, reinforced in the operators and management? How can this process be actually carried through without running the risk of disorganizing the facility productivity and safety?

(2) This type of analysis introduces a series of organizational and relational as well as methodological and epistemological discontinuities and hiatuses between the operators working in the field and the analysts and experts. This is the reason why it is so difficult to go back to the field and action level. Experts and analysts must thus be content with merely 'transmitting the message to the operators'.

(3) Moreover these analyses contribute to a reductionistic vision of man at work, thus introducing biases specific to these approaches, preassumed and implicit notions which cannot be corrected easily and limit the ways the sociotechnical system can be acted upon:

—They are characterized by a derogatory vision of man: the analyst essentially focuses on the negative manifestations of the operator's activity (failure, deviation...).

—They are constructed on an idealized, theoretical and abstract approach to working conditions and man. They do not take the field realities sufficiently into account: the context and its variability, the limitations of the formal and prescribed organization, human relations inside the teams, the fundamental difference between the prescribed tasks and real activity.

Let us merely underline here some points, without going into detail, and refer to precise studies illustrating these points:

—In complex organizations, members constantly adapt-readapt the formal, prescribed tasks to take account of contingencies, unknown factors and the variability of the detailed factors defining the tasks. It was clearly demonstrated that the members of an organization make constant individual and collective adjustments-readjustments to optimize the different objective and subjective factors characterizing the tasks.[8] Field investigations conducted by experts in industrial psychopathology provide numerous examples of these adjustment processes.[9]

—Operators and the management constantly try to make an effort to understand and discuss the way work should be performed. Here again, the analyses of work bring to light the efforts made by all those involved to characterize their role, their function, to give a practical definition of their responsibilities, to express their concerns about safety at work... The analyses revealed misgivings, ambiguities and misunderstandings on the way the tasks should be performed, and these can be a source of suffering.[10]

—Apparently imponderable, unforeseeable, when not irrational, aspects (though, in fact, they can be clarified using other forms of rationality) can be defined, 'modelled' and explained with psychological concepts (operators' commitment to the work process; mutual trust; working climate within the teams which is one of the expressions (though not the only one) of the quality of human relations.

—In other words, an informal organization is superimposed on (and closely interconnected with) the formal work organization. From another standpoint, the informal organization can be said to result from the *impracticability* of wholly formalizing the tasks and of separating the design of the tasks from their execution.[8]

One could think, at first sight, that an ever-growing proceduralization and formalization, based on procedures, operating guides, quality organization and insurance and multiplication of controls, necessarily accompanies the development of the nuclear industry and, more generally, of complex systems and guarantees mastery over them. Admittedly, the development of operator aids in the form of written documents, the introduction of control devices and reflection efforts before operations are conducted on the facilities, all contribute to improve safety and quality.

But is should also be stressed that the entire activity of the members of an organization cannot be formalized and proceduralized in detail. Our effort to reach this objective would result in a combinational boom of actions, decisions, communications... to predict. In fact, operators adapt, interpret and transpose the planned activity (beside handling contingencies and unexpected events), and do this *collectively*. As everything cannot be anticipated and to avoid organizational unwieldiness, the concepts of initiative and professionalism were developed.

Let us take, as an example, the job of an auxiliary operator. Actually there is a procedure for the patrol inspection, specifying the actions, checks, recordings... the operators have to perform. Field investigations reveal that the job is complex and covers varied tasks: the auxiliary operator 'observes', 'around' the vulnerable points, the key points of his

patrol. His activity involves touch (temperature of a pump bearing), hearing (perception of abnormal vibrations), smell (abnormal heating, fire risk)... Future problems or failures can thus be anticipated.

(4) If, undoubtedly, human reliability assessment is indispensable to the more global evaluation of sociotechnical systems, we cannot, considering our present knowledge, hope to anticipate all the possible error sequences and to quantify them with a fair accuracy.

The HRA is essential for risk studies, and the imprecision of the quantified assessment is not a fundamental obstacle. Of course, the PSAs and the corresponding HRAs represent a permanent study and analysis process that can be brought up to date, submitted to sensitivity studies and hypothesis tests. Here also, all the complex cases, with multiple interdependences between tasks, cannot be anticipated and quantified (cognitive biases, collective errors, event misinterpretation, stress-induced inhibitions...). The potential sequence of successful or failed actions can be considerably influenced by the operator's mental state (his mental or psychological load), his representation of tasks to be performed, their complexity, existing contingencies or unforeseen occurrences that must be dealt with, and beyond that, by the team cohesion and the climate in the organization at a given time. Admittedly, human reliability analyses are conducted with a sufficiently structured, rigorous and realistic methodology, partially verified by industrial experience and receiving support from the entire technical and scientific community; this methodology has, in fact, a *conventional aspect*. It allows assessment of sociotechnical systems, referring to usual operating modes, operators' normal behaviour in a normal context, under average working conditions (see Section 5).

Considering the limitations and inadequacies we have underlined and discussed, what are the possible paths to progress in the coming years?

4 POSSIBLE ANALYSIS MEANS

To address one of the major criticisms against human reliability analyses which fundamentally fail to allow for the *psychological* aspects of human factors,[11,12] we must determine to what extent we can establish quantitative causality relations between a number of working situations and variables defining the basic characteristics of human, individual and collective behaviour.

We quote three *brief* examples which point to possible research lines and improvements of our knowledge on human factors assessment. These examples were initially sought in fields not related to human reliability strictly speaking.

4.1 Quantitative assessment of the psychological climate inside a company

Many research studies in applied psychology are aimed at assessing the psychosocial climate in a company; they consider the organizational climate as the way individuals perceive and see the work organization.[13] The climate corresponds to a *global perception*, which is the sum of individual perceptions of a common real context. The climate acts as an *intermediate variable* between the characteristics of the context and of the individuals. It is a kind of model the individual refers to to formulate his expectations, his strategies, his affective reactions and to adjust his behaviour to the company functioning. The climate can therefore be regarded as a telling *indicator* of the functioning of a human organization. Eight large fields were initially defined to characterize the climate. In each of these fields, a number of variables describe the contextual attributes directly and immediately related to individual experiences.

The climate is measured with a questionnaire based on descending hierarchical clustering methods. From the results obtained on a sample of over 1200 people working in a dozen different companies, 14 climate scales were defined:

1. coherent strategy and operation
2. social policy
3. material and moral comfort
4. clearly defined task and role
5. available and freely flowing information
6. flexible supervision
7. innovative ideas encouraged
8. team spirit
9. quality of interpersonal relations
10. feeling of fairness
11. responsibility and autonomy
12. motivation (personal commitment to work and the company)
13. freedom of speech
14. consideration

The analysis of the cross-correlations between these different scales emphasizes a pattern of the scales in which the 'consideration' scale (scale 14) appears as a centre.

The study above proves that a quantitative approach to the psychosocial climate in companies can be defined using questionnaires as well as cluster and cross-correlation analyses. The same kind of approaches could be used to determine indicators characterizing the human organization 'state'; they open the way to many studies, among which the study on how the climate and the overall state of the organization, some terms or part of the organization (operation and maintenance, for instance) are interrelated. It would also be interesting to try to

correlate the overall state with the climate and with some performance indices such as the error and failure probability in task performance.

4.2 J. S. Guastello's model[14]

We shall only briefly speak of the studies conducted by J. S. Guastello and D. D. Guastello who try to *forecast* the accident rates for teams working in high-risk industries (underground mines, mills, foundries) from questionnaires developed and validated in other works.

We shall merely quote here some fundamental conclusions of the studies with respect to the criticisms we levelled in the sections above:

1. The authors of the model suggest that the variations of the accident rate result from a *non-linear* dynamic process.
2. The distribution of the accident rates is *bimodal*, with one level nearing zero and a second notably higher.
3. The predicted variation of the accident rate is based on four main factors:
   (i) ambient hazard and risk level
   (ii) variables that impact human performance capability
   (iii) initial accident rates
   (iv) the mathematical function relating these variables

The environment (i) and human performance (ii) factors can be broken down into groups of specific variables including, among others, the adequacy of safety management in the company, stress, anxiety, the perception of and beliefs about accident control and the working team size.

Such approaches, which have sound mathematical and statistical foundations and are based on validated empirical data, could be used to forecast the error probability in complex working situations (control of accident sequences for instance).

4.3 Analysis of the personnel's stress on off-shore platforms[15]

The objective of the study is to analyse the psychosocial and work-related sources of the stress experienced by the personnel working on off-shore oil and gas rigs in sectors of the North Sea under Dutch and British control. The data were derived from a questionnaire sent to the personnel of some 30 platforms.

The statistical analyses performed tried to find a relation between stress and industrial injury rates. The questionnaires were based on the answers of 31 persons to *clinical* enquiries, so that the important fields needing to be covered and the special variables to be ticked off could be determined.

Like the previous analyses mentioned above, this study rests on a great number of psychological and psychosocial considerations: heterogeneity of the platform populations, anxiety, satisfaction at work, cooperation level within the teams, quality of interpersonal relations. . .

We will merely note here that these variables do not appear at all (or only seldom) in standard human reliability models. The task complexity or certain objective parameters characterizing the work (comfort, for example) *cannot alone* account for the performance or safety level reached at a given moment in a team or organization.

5 FROM GENERIC TO SPECIFIC RISK ANALYSIS—FROM ANALYSIS TO ACTION

As seen in the previous sections, human reliability analyses are in fact analyses of the operators' 'average', i.e. standard, behaviour made by using the best data available, systematizing the analysis and clarifying, to the utmost, the assumptions on which the analyses are based.[16] This analysis is based on expert judgements. The biases and risks inherent in any human activity are identified and integrated as much as possible, to the extent that they seem 'reasonable'. As already mentioned in Section 3, these analyses have a conventional aspect.

Thanks to the analysis, *human* reliability considerations are incorporated into technical systems, and the systems can be evaluated. In other words the overall, average, i.e. *generic*, risk can be assessed for a technically homogeneous unit series. However, this analysis does not provide an estimate of the risk *specific* to a given human organization (a particular nuclear unit) at a precise moment in its history.[17] The data are indeed heterogeneous (against a given unit): they are obtained for all the units of a series and for a number of simulated accident sequences. Some data are inferred or extrapolated by expert judgement.

It certainly takes time to collect, process and validate data as well as appraise and interpret statistically significant changes. At present, the probabilistic safety assessments of nuclear units can possibly be updated only every 3–5 years (Ref. 18, for example). Hence, these reassessments can only be incorporated in long-term safety management processes involving a set of technically homogeneous units. We called these processes 'long-term safety management loops'.

However, for the short-term management of safety in a specific unit, corrections must be introduced rather rapidly. On-site investigation would show that such analysis and correction processes are per-

manently at work, as far as human factors are concerned. Considerable gains in time and efficiency are achieved by directly analysing the staff activity in the field as evidenced by ergonomics[19] and occupational psychopathology.[10]

6 TOWARDS THE ANALYSIS OF 'POSITIVE' HUMAN FACTORS

Clearly, the last few decades were marked by the development of human factors studies focused on human errors (classification, identification of error mechanisms),[20] on the improvement of man–machine interfaces as well as on the formalization of work (procedures) and the analysis of operating experience (incidents).

These analyses resulted in significant progress. Our purpose here is not to discuss the contribution of these analyses. Rather we intend to examine the preassumed, implicit notions human factors analyses are fraught with as well as the aspects of human factors that are disregarded or obliterated.

Thorough investigation into the *collective* ergonomic and human factors practices and into the way human factors problems are conceptualized can open up new areas of research, as came out of a two-years long interdisciplinary workshop.[21] We will try to summarize some of the difficulties and implicit notions presently existing in standard human factors analyses:

(a) Analyses are relatively *abstract*, when not conducted completely out of context. A wealth of behavioural or situational details are most often left out or disregarded.

(b) The collective character of the studied activities is seldom considered. How are cooperation and communications established among the crew members? On this subject we have but fragmentary data.

(c) Some sort of epistemological conversion is necessary if we are to progress beyond the satisfactory point already reached now: we must also study how work is carried out on a day-to-day basis, that is 'ordinary' work. We must no longer focus only on the 'extraordinary' errors, malfunctions and incidents.

(d) Professions are of great significance. The operator is no longer regarded as someone who must apply the procedures and who commits errors, but as a unique individual with his own conception of work and organization. The organization is a set of collectives within which numerous specialists collaborate efficiently. Field analyses would enhance our knowledge of these professions and thus would permit transfers of expertise and know-how between people in the same or different lines of business.

(e) Versatile specialists' (engineers trained in human factors; engineers-ergonomists...) are essential in complex organizations. The development of a deep-reaching and concrete 'human factors' culture is at stake. Experiments to get engineers and designers familiarized with and trained in social sciences and ergonomics should be extended.

(f) Occupational human and social sciences cannot solely rely, for their development, on experts (specialists working as experts), that is people who analyse the operators and management from the outside, as an entomologist would do... The operators-actors are likely to *refute* the specialists' theories; the specialists should invest their subjectivity into field investigation. Some aspects of human reality can only be approached through *intersubjectivity*. To this end, specific methodologies were developed which include such phases as demand analysis, preliminary enquiry, the investigation strictly speaking and result feedback.[22]

(g) Field investigation comes up against collective defensive attitudes the staff progressively develops to face real or perceived, imagined risks and hazards. Studies in the nuclear field have shown that the representations of risks had changed (from TMI to Chernobyl) for people in the field as well as for experts and the public opinion. These defences should therefore be allowed for, when trying to understand situations. How, for example, should we interpret absence of speech, things left unsaid, stereotyped answers? And what about the experts' own defences?

(h) Thus the discourse of field actors should be increasingly studied in human factors analyses[23] and the more so as, in complex organizations, work implies not only man–machine relations but also *man–man relations* (collective decisions, information and instruction transmission, task sharing, mutual adjustments...).

7 CONCLUSION

At EDF, we are now discussing or devising a number of these new lines of research; decisions as to some of them have already been taken. Let us quote among others:

—The analysis of *good practices* in the operating experience, as opposed to the sole analysis of incidents and human errors.

—The diffusion of operating experience under various forms: more or less formalized or with

different formulations. For instance, plant operators circulate a monthly called 'C'est arrivé dans les centrales' (It happened in the power plants) which analyses and presents the operating experience in a more journalistic and vivid way.

—The analysis of the operating experience and quality organization in the field tends also to focus on the *recovery* modes and factors used by the operators.

—Field studies are being carried out on *everyday work*, not including more or less severe incidents and abnormal occurrences in the technical process, and on the way operators collectively *implement* safety. In particular, we try to bring to light the *concrete* principles on which safety is based (human relationships, support in action performance, informal redundancies: collective forms of vigilance; discussion and adjustments of prescribed tasks; stabilization of working praxis, persistence of professional safety tricks.[24]).

The pursuit of permanent improvement of safety and quality raises the question of the implementation of modification processes in complex organizations: that is the question of the methodology that should be adopted, or the knowledge and competence that must be used and of the stability and efficiency of these modification processes. Indeed, such processes can only be efficient if behaviour can be adequately understood so as to avoid as much as possible misconceptions, obstruction and resistance, if not useless conflicts or lack of motivation.

This implies that the researchers themselves, human factors specialists, are ready to commit themselves to the changes, i.e. that they are ready to change personally, to question their prejudices and their stereotyped opinions. . . This implies the reconsideration of their cognitive and personal perception of field workers and of the latter's contribution to safety. This is not easy to do and involves many difficulties.

The conditions of an efficient collaboration of ergonomists, occupational physicians, occupational psychologists, engineers and field workers responsible for the facilities are thus sketched. Additional avenues to progress are open and are sometimes chosen.

Interdisciplinarity is a requisite. Projects are set up at EDF towards this end.[25] There is still much room for progress. Interdisciplinarity implies that the actors themselves (on-site, in the plants) participate. Their knowledge, vision of the problems, experience, their know-how *and their subjectivity* can simply not be done without.

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