ON THE USE OF THE THERP METHODOLOGY IN THE HUMAN RELIABILITY ANALYSIS OF NUCLEAR POWER PLANTS - COMPLIANCE WITH THE USNRC GOOD PRACTICES CRITERIA

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ABSTRACT

THERP is largely used by the industry in general, mainly by the nuclear industry. This methodology belongs to the group of the human reliability first generation methodologies. However, in spite of the enormous contribution of these methodologies for the understanding of the subjects related to the human reliability, they present a variety of deficiencies that were identified along the history of practical application to the industrial projects. Considering the state-of-art in the analyses of these deficiencies, it was elaborated a set of good practices to be fulfilled by all methods of human reliability. This set of good practices is described in the recent documents of USNRC, NUREGs 1792 and 1842, of April 2005 and February 2006, respectively. In this article, the authors discuss the main technical deficiencies of the THERP methodology, when compared with the good practices criteria from USNRC. They point also possible solutions to eliminate such deficiencies. Many of these solutions can only be accomplished, in the authors' opinion, with the use of methodologies of second generation. We can mention four, among them, that stand out due the complexity and comprehensión in the treatment of the subjects of human reliability. These four methodologies are denominated ATHEANA, CREAM, CAHR and DYLAM. The authors present a concise comparison between two of these four approaches and identify the main characteristics of each one in the attempt of solving the deficiencies of the THERP methodology. In this comparison, a revision of the technical literature was used, considering some of the main specialists in the area.

1. INTRODUCTION

The methodologies used in the Human Reliability Analysis (HRA) are classified as methodologies of first or second generation. The most important methodology of first generation is THERP, A Technique for Human Reliability Analysis [1], together with the methodology ASEP, Accident Sequence Evaluation Program Human Reliability Analysis Procedure [2], a simplified form of THERP. The first generation is characterized by the Stimulus-Organism-Response (S-O-R) paradigm. The methodologies of second generation are characterized by not considering the previous paradigm. Instead, the cognitive process and the influences of the socio-technical context are placed.

Two methodologies of second generation, CREAM, Cognitive Reliability and Error Analysis Method [3] and ATHEANA, Technique for Human Event Analysis [4], were chosen for analysis and comparison with the good practice criteria of USNRC. USNRC published in 2005 (NUREG - 1792) [5] a regulatory guide on good engineering practices for the human reliability analysis and, in the year 2006, it also published a comparison of the principal methods of human reliability in relation to the good practice criteria (NUREG - 1842) [6]. In the next section, the disadvantages and deficiencies of the first-generation methodologies will be described, considering these two documents and the evaluations that were raised in the international technical literature, as well as their main characteristics and their intrinsic
importance. Soon after, the descriptions above are presented for the methodologies of second generation, including those necessary to correct the pointed deficiencies.

2. EVALUATION OF THE METHODOLOGIES

2.1. The THERP Methodology

The acronym THERP was used for the first time to designate a technique applied to the Human Reliability, in 1962, in a Congress about human factors (Sixth Annual Meeting of the Human Factor Society) and it had been developed by Sandia National Laboratories, standing out Dr. Alan D. Swain as its principal creator. In 1983, NUREG/CR-1278 [1], Handbook of Human Reliability Analysis with Emphasis Nuclear on Power Plant Applications, was published. NUREG/CR-1278 [1], elaborated by A. D. Swain and H. E. Guttmann, is known as the THERP Handbook, and it is still used in HRA studies of Probabilistic Safety Assessment (PSA) as a main tool for the Human Reliability Analysis.

Main characteristics:

1. It is a technique of first generation, influenced by the focus in the PSA [7] point of view;

2. The human performance is compared to the equipment performance. The operator action is represented through a binary logic, success or failure. The model of human events tree, used in THERP, characterizes in a practical way that binary logic, as a sequence of steps of the operator tasks in an industrial plant [8] [9];

3. THERP uses in its model the Stimulus-Organism-Response Paradigm and the Decomposition Principle, in which the human being is viewed as a control system used in engineering, a vision not more accepted in psychology [8] [9];

4. The Human Error Probabilities (HEPs) are contained in 27 tables in the chapter 20, Tables of Estimated Probabilities of the Human Error, from the reference [1]. The values in these tables refer to the probability that, when an element or step of a task or subtask is being executed, an error will happen. The tables stress the commission and omission errors [7];

5. The values of HEPs are originated from the specialists’ estimates, own data obtained through the plant operational experience or similar facilities and measured data from similar activities and contexts (for example, simulators) [7];

6. THERP in its initial versions was criticized due both the exclusive focus in certain types of behavioral errors and for neglecting errors in the cognition level based in knowledge (mistakes), such as erroneous diagnoses or selection of an inadequate strategy to correct operational situations, error type that contributed to the accident of TMI in 1979. In the 1980s and 1990s, Swain and Guttmann revised the original work and altered the initial vision of error probabilities originated from specialists, that vary much, changing to time dependent error frequencies, based on simulator data (HCR - Human Cognitive Reliability methodology), in which different operation teams and operation procedures...
are used. These data make it possible to differentiate between pre-event incorrect
diagnosis incorrect and pos-event incorrect diagnosis [7];

7. It lists and defines the Performance Shaping Factors (PSFs) that affect the human
reliability. These factors are identified in THERP Handbook, chapter 3. The error
probability associated to each element or step of the task is corrected by means of
correction factors that are obtained through the quantification of PSFs [8] [9].

Disadvantages and Deficiencies:

1. The enormous discrepancy in the socio-technical profile of the tables after 24 years of
existence [3] [4];

2. In spite of the incorporated modifications to THERP [1], in the 1980s and 1990s, doubts
on the HEPs data still remain, especially concerning to the limited focus upon external
error form (omission and commission errors, the latter only in the level of slips, in other
words, in the perceptual-motor level) [7];

3. The modeling is still based on the Stimulus-Organism-Response paradigm, which is no
more accepted in psychology [8] [9];

4. It does not treat in an appropriate way the cognitive process that cannot be reduced
merely to commission and omission errors. The cognitive process involves an information
processing with the following phases: detection and perception, decision making and
response selection, execution of actions and control of the attention resources, being
influenced furthermore by the context [8] [9];

5. It does not consider the factors linked to the context of the plant, that can induce the man
to the error (error-forcing context), including the plant organizational factors [3] [8] [9]
[10];

6. The training process is treated summarily, showing a mechanist vision of human beings
[4];

7. The HEPs tables are focused upon tasks, therefore, human errors are treated in a
standardized way (error in the choice of a command, error in the reading of an instrument,
error in the checking of an action, etc.), reflecting erroneously a mechanist relationship
between human beings and the plant, not being rich enough to capture the dynamics and
the complexity of the interaction [11];

8. It does not also take into account the context of the tasks in a comprehensive way,
because it works with some few Performance Shaping Factors “considered the most
important ones”. The development of the context through the interaction between
Performance Shaping Factors and special conditions of the plant (operation, maintenance,
etc.) is not evaluated, as it would be in a human reliability method of second generation
such as ATHEANA [4], for example [3];

9. As a consequence of the Decomposition Principle in the S-O-R model, the human
reliability analysis of first generation is carried out as step-to-step analyses of sequences
of static events and the human action is only considered in the step level or individual action, considering the dependence between steps and the possible recovery errors. This dependence, however, holds in only the level of individual steps and it does not take into account the action as a whole, considering all the steps. The representations in event trees, such as those used in THERP [1], are not appropriate to show the steps of tasks with dependence, unless the condition refers to the step immediately precedent [9].

Importance: it is still quite used as a quantitative indicator of the human error probability, due the HEPs tables. Several segments of the industry use the THERP tables [1], among them: nuclear, aeronautical, naval, chemical and petrochemical.

2.2. CREAM Methodology

The CREAM methodology [3], elaborated by Erik Hollnagel, a Linkping University teacher in Sweden, is described in the book of his authorship, which has the same title of the methodology. Hollnagel made a revision of the principal conceptual aspects of HRA. The first of these concerns the metaphors for modeling of operators. In his retrospective analysis, the most spread model of human operators is probably the Stimulus-Organism-Response paradigm. Not more accepted as a paradigm in psychology, it is still used broadly in the technological fields. It appears in the control theories used in engineering, such as supervised control theory or optimal control theory.

A more elaborated metaphor is that of the human being as a mechanism of information processing. In agreement with this metaphor, the mental processes are considered procedures and mental states are defined as causal relationships with sensorial inputs, motor behavior and other mental states. This vision can be found in several models of information processing, like the step - ladder model for decision-making formulated by Rasmussen [12]. Another version of this metaphor is the Reason’s model of fallible machine [7], incorporating specific mechanisms of generation of errors, by means of activators of knowledge units in the declarative and procedural memories of human beings.

A third metaphor is the cognitive model proposed by Hollnagel, which differs from the above metaphors because the cognition is seen more as an active phenomenon than reactive one, for instance, as a set of self-sustain ed processes or functions that happen simultaneously. This is accomplished by a detailed retrospective analysis as described in the next items [3] [8] [9] [10].

Main characteristics:

1. It accomplishes an event retrospective analysis that aids in the identification of the terminal causes (specific antecedents) of the error, through an effect-cause interaction, that is established through a general-consequent/general-antecedents relationship between causes and effects (error modes) and between the several categories of causes to each other [3];

2. It accomplishes an event prospective analysis that aids in the prediction of human actions, starting from an initial action to define its effects [3];
3. It proposes a general structure of a methodology of HRA based on three essential elements: cognitive model, error classification scheme and method of retrospective and/or prospective analysis. An outline of a consistent error classification is necessary to analyze the event and to identify the possible or probable causes. To do this, Hollnagel created the concepts of phenotypes and genotypes (table 1) with the intention of separating the activities of observation and interpretation of human errors, and consequently the separation between effect or consequence and its causes [3];

4. It analyzes the work conditions related to the context, called Common Performance Conditions (CPCs), and that are chosen among PSFs: adequacy of organization; working conditions; adequacy of man-machine system and operational support; availability of procedures and plans; number of simultaneous goals; available time for the achievement of the goals; circadian rhythm or time of day; training preparation and crew collaboration quality [3];

5. The probable modes of contextual control are determined in agreement with its characteristics and are grouped in four types, according to the table 2. These control modes are based on the premise that cognition is not merely a reactive process, but an active one, that is formed by the operators’ objectives and the prevalent situation or context [3].

### Table 1. Categories of phenotypes and genotypes of CREAM [3]

<table>
<thead>
<tr>
<th>Categories of Genotypes</th>
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<tbody>
<tr>
<td>Human Being</td>
<td>Treats the cognitive demands - observation, interpretation, planning and temporary and permanent specific cognitive functions.</td>
</tr>
<tr>
<td>Technology</td>
<td>Treats the functions related to the systems, procedures and interfaces.</td>
</tr>
<tr>
<td>Organization</td>
<td>Treats the functions related to the socio-technical context, communication, organization and training.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Categories of Phenotypes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong Time</td>
<td>Error mode of an action, not executed in the correct moment or in the correct duration.</td>
</tr>
<tr>
<td>Wrong Type</td>
<td>Error mode of an action that includes incorrect physical characteristics related with force, distance, speed and direction.</td>
</tr>
<tr>
<td>Wrong Object</td>
<td>Error mode of an action accomplished through a wrong object, which was used due the proximity, similarity, or a mistake.</td>
</tr>
<tr>
<td>Wrong Position</td>
<td>Error mode of an action accomplished out of a normal sequential order.</td>
</tr>
</tbody>
</table>

### Table 2. Contextual Control Modes of CREAM [3]

<table>
<thead>
<tr>
<th>Control Modes</th>
<th></th>
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<tbody>
<tr>
<td>Scrambled control</td>
<td>The choice of the next action is unpredictable or haphazard.</td>
</tr>
<tr>
<td>Opportunistic Control</td>
<td>The next action is determined by the salient features of the current context rather than on more stable goals.</td>
</tr>
<tr>
<td>Tactical Control</td>
<td>The action is based on the planning; consequently the action follows more or less a known procedure or rule.</td>
</tr>
<tr>
<td>Strategic Control</td>
<td>The person involved in the action considers the global context, therefore uses a wider time horizon and looking ahead at higher-level goals.</td>
</tr>
</tbody>
</table>
Disadvantages and Deficiencies:

1. The development of the method is difficult. It requires a meticulous analysis of the tasks and their cognitive and psychological processes involved [3];

2. The quantification is simplified, because focuses HEPs upon the effects (phenotypes). A quantification of the causes (genotypes) and the associated retrospective analysis does not exist, although CPCs and PSFs can alter HEPs. The PSFs are graded with a weighting sum of their influences in the error modes [3];

3. It shows a simplified relationship between the contextual control modes and their compatible reliability intervals of the action failure probabilities [3];

4. The probabilities of cognitive failures cannot be standardized, because they should be evaluated for each context and for each specific plant. The technologies can be identical, but the subjects linked to human being and socio-technical system are variable [3];

5. The prospective analysis of the event is focused upon the prediction of the human performance [3].

Importance:

CREAM [3] does not adopt the Decomposition Principle that governs the Stimulus-Organism-Response paradigm. The principal Hollnagel’s criticism against the Decomposition Principle is that it lacks an appreciation of the cognitive or mental internal functions, as, for instance, reasoning, association, interpretation and memory that govern the human behavior. The human operator is treated essentially as a black box [8] [9].

It is not in agreement with the basic hypothesis, taken from the technological area, that the system function (in the case, the operator) can be produced or deduced from the aggregation of the description of the functions of the constituent parts. The previous hypothesis requires, according to Hollnagel [8] [9], that: a) a description can be given of the function of each element; b) the function/characterization of each element separately is not significantly different from the function of each element in a wider or comprehensive context.

This requires that the effect of the context is quantitative (arithmetic) instead of qualitative. This hypothesis is valid for technological systems, at least as an idealization, except in the case of common mode failures, but it is not valid for the human action. The concept of common mode failure is important in this case, since in technological systems this failure type is the exception and it does not rule it. The inverse happens with the human failures [8] [9].

Hollnagel [3] proposes then that the concept of Performance Shaping Factors (PSFs) must evolve towards the concept of Common Performance Conditions (CPCs), that not only influence the error causes, as in PSFs, but they are themselves causes. The difference is that CPCs as causes have an impact in the situation as a whole instead of a specific effect for a specific type of operation. In contrast to the decomposition method, CPCs are not necessarily linear and independent, but they can be considered with relationship to their mutual
influences, because they reflect the characteristics of the human actions that are not independent but conditional.

Hollnagel [3] reminds us the criticism done by Swain on the HRA methodologies of first generation, in which several parameters were considered less appropriate than it would be waited: data, agreement in the use of expert-judgment methods, calibration of simulator data, proof of the accuracy of HRAs; psychological realism in some HRA approaches and treatment of some important PSFs related with cultural differences, managerial methods and attitudes, and irrational behavior.

This criticism, according to Hollnagel [3], faces us with a central problem in the first-generation methodologies: the need of using the concept of error mode instead of error probabilities. In terms of classification in omission and commission errors, an action is executed or not, or some other action is executed in its place. This is a binary vision of the error process.

In contrast, the error modes consider the failure in executing correctly an action, given some specific conditions. Instead of using a nominal probability of human error to modify it a posteriori with PSFs, it should be developed a principle or algorithm to calculate the probability in a specific failure mode given certain specific circumstances a priori. Then, instead of working with one unique value for each human error probability, a table of values should be used for a failure mode given a range of conditions [3] [9].

CREAM [3] approaches appropriately the distinction between omission and commission errors. Hollnagel says that another form of approaching the difference between failures modes and conditions for the failure concerns the distinction between omission errors and commission errors. An omission error can happen in three different ways: an action can simply be lacking, an action can be late and the action can be executed prematurely. These modes can happen due to a series of reasons, either external (work conditions) or internal (mental) ones. A fourth option is that the action can be substituted by other action, in other words, a commission error happens. Therefore, a commission error implies logically that an omission error exists, therefore, without the latter it would not happen the former. Due to this, one can verify that the traditional binary vision of HRAs is not valid, being needed a functional vision in which there is a relationship between multiple causes and multiple consequences [8] [9].

CREAM [3] considers the context, which is a vision of the modern approaches of cognitive reliability. In contrast with the vision of information processing, which postulates that the activities of information processing are essentially reactive, the Hollnagel’s paradigm is based on the premise that the cognition is an active process that is formed by the operator’s objectives and the prevalent situation or context. This element of the Hollnagel’s paradigm was implemented in his model COCOM (Contextual Control Model) [3] [9] and is part of his method of human reliability, CREAM [3].
2.3. ATHEANA Methodology

The PSA, NUREG-1624, Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis [4] is originated from a study accomplished by the Department of Analysis and Evaluation of Operational Data (AEOD), in the NRC, in 1995. AEOD analyzed various serious accidents that happened and it was verified that some operator’s actions of the operators not included in the procedures, which jeopardized the plant operational structure and worsened the accident conditions, were not represented, treated and considered by PSA studies as should be.

Main characteristics:

1. It treats the error-forcing context, due to the combination of the plant conditions and other influences (pre-initiators), which can contribute to human failures. It also treats the error types, error mechanisms, unsafe actions, Performance Shaping Factors of human actions and mental models (tendencies) of the operators by using informal rules, as a function of scenario operational characteristics and operational behavior of the process variables [4];

2. It accomplishes an analysis of the human error perspectives, by means of a retrospective analysis of significant events already happened and a prospective analysis, that identifies potential operators’ errors during the plant operation [4];

3. It verifies the existent vulnerabilities in the operators training processes and their qualification exams [4];

4. It makes possible a structured and differentiated analysis, due to the use and integration of knowledge and experiences in the areas of PSA, engineering, human factors and cognitive psychology. It also considers the specific plant information and experiences arising of the significant accidents analysis [4].

Disadvantages and Deficiencies:

1. It requires a deep knowledge of the plant operation;

2. The quantitative analysis of the human error probability is not still satisfactorily developed, although there is a proposal for calculation of conditional probabilities as a function of PSFs, error mechanisms and unsafe actions (error types).

Importance:

1. It presents a structured process to develop the integrated analyses PSA/HRA with larger conceptual rigor. Some of these analyses were already developed by other methodologies in the past, for example, the identification of human failures events, to be included in the PSAs studies, however, not completely detailed as in the PSA [4];

2. The retrospective analysis of events is of great usefulness in several situations, and can be used to aid in the understanding of the causes in the occurrence of specific events and what measures can be taken in order to preclude such events [4];
3. The retrospective analysis aids in the analysis of human actions, including the development of general or specific perceptions of the plant, recommendations to improve its potential and information to give support to the accomplishment of PSA and HRA. It also aids in the performance of the accident investigations and root-cause analysis [4];

4. The prospective analysis of events integrates the pertinent subjects into PSA and HRA, identifies the human failure events and important unsafe actions (base to identify the reasons of the occurrence of the event), quantifies the error-forcing contexts and the probabilities of unsafe actions, given the contexts [4];

5. The prospective analysis aids in the characterization of the human behavior, giving more options to manage the plant risks by means of better knowledge of the implicit causes of the human error and the vulnerabilities not noticed in the operator’s behavior, regarding the automatic devices, in specific contexts [4];

6. The prospective analysis concerning the training identifies the weak points not explored in the requirements of the training programs, the complementary scenarios in the simulator training exercises and the necessary improvements of the operators’ qualification exams [4];

7. It integrates in the modeling the progresses of psychology and engineering, and the actual plant conditions to the several aspects of PSA [4];

8. It presents tables that relate the error causes with the manifestations (operational activities). Consequently, the error causes, in subsequent tables, are linked to the error mechanisms, error types and Performance Shaping Factors, although the proposed quantification has not still been implemented [4];

9. Regarding the PSA his model is updated - it does not consider the Stimulus-Organism-Response paradigm and it is in concordance with the modern progresses of the Cognitive Science [3];

10. Concerning the PSA, it accomplishes a deeper qualitative analysis of the socio-technical context for the operators, because, for example, it treats the error-forcing context and its relationships with the cognitive process [3].

3. CONCLUSIONS

The second-generation methodologies should necessarily substitute the first-generation methodologies, because only methodologies as ATHEANA [4] and CREAM [3] are provided with an appropriate cognitive model to represent the human being and an error classification that is sufficiently complex to incorporate the principal error mechanisms. Moreover, they try to model the influence of the context in such mechanisms. However, for their practical application, it becomes necessary the implementation of an elaborated quantification of the several steps of the retrospective analysis that are used by these methods, in which a complex relationship exists between error causes and their manifestations or effects, through several cognitive mechanisms of error generation.
REFERENCES