Assessment of the human factor for accident condition in NPP

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In this paper is developed an interactive model of the human factor analysis for accident conditions in NPP operation using Human Reliability Analysis (HRA) methods (THERP and SPAR-H). It is achieved a framework to analyze and estimate the human action in the man-machine-organization system. In order to demonstrate the applicability of the purposed model are performed three case studies for Cernavoda NPP. In addition are emitted some recommendation which could improve the human performance for the mitigation of undesired plant conditions.

Keywords: human, action, error, accident

1. Introduction

The facilities operating experience (both nuclear field and non-nuclear field) have emphasized the importance of the human factor in their reliability and safety. Many accidents (for example the accidents from Three Mile Island, Chernobyl, Bhopal, space shuttles Challenger and Columbia) have all been attributed to human error.

Although, Human Reliability Analysis (HRA) has practiced for more than three decades and many new technologies have developed, the human factor has a major contribution to plant risk yet. In order to perform a realistic analysis of the human factor is necessary a strong underlying basis for each human action [1].

The purpose of this paper is to perform an interactive human performance analysis model in accident conditions for the operating NPP in the man-machine-organization system (MMOS) context. This model is realized using tools of HRA methods in order to a good knowledge of the human actions both at the occurrence of an event and in time the evolution of the event. It is considered that along with the evolution of the event could appear the modification of the cognitive state of the operator, the man-machine interfaces, work environment and performance shape factors (PSFs).

The goal of the model is to aid to understand of MMOS in time the evolution of the abnormal event and be found and analyzed the ways and the mechanisms of reducing the likelihood of human errors, so that the impact of human factor to systems availability, reliability and safety is realistically estimated.

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2. Human factor analysis model

For the development of a model of human factor analysis in MMOS are purposed the following steps:

(a) identification of the important human interactions in MMOS which mitigating or exacerbation of the accident conditions
(b) task analysis
(c) context analysis
(d) representation of the analyzed tasks
(e) estimation of the basic human error probabilities (BHEP)
(f) evaluation of the dependence levels between actions
(g) identification of the performance shape factors (PSFs)
(h) estimation of the influences of PSFs
(i) estimation both the success probabilities and the failure probabilities

Because in time of an accident could be modified the human behavior, the equipments or/and work environmental is important to identify PSFs taking into account many possible scenarios. There is the possibility to be identified and other PSFs.

For the quantification of the human performance to the performing of an activity which have n tasks is purposed the following formula to estimate the joint probability error human (JHEP):

$$JHEP = \sum_{i=1}^{n} (BHEP_i \prod_{j=1}^{m} CHEP_j \prod_{k=1}^{r} X_k \qquad (1)$$

Where: BHEPi – BHEP for each action
CHEPj – conditional human error probability for each dependented action
The dependence can be between the performed actions by a person or by different persons. The level dependence is classified so [6]:

- Zero dependence (ZD);
- Low dependence (LD);
- Moderate dependence (MD);
- High dependence (HD);
- Complete dependence (CD).

The establishing of the dependence levels and quantification of CHEPs between two dependent tasks are achieved according to a general guide [3].

Xk - the modification parameter of BHEP according to one performance shape factor (PSF).

PSF is any factor that influences the human performance by human error mechanisms (attention, situation assessment, response planning, and response execution) for the circumstances under which they are performed (plant conditions) [2].

The characterization of human performance under influence of all PSF at a given moment is realized by work context. In figure 1 is presented the relationship between work context and human performance.

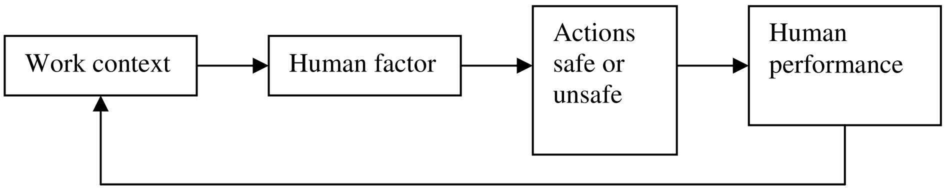

Fig. 1 - The relationship between work context and human performance

In order to characterize the human performance in a work context at a given moment of the occurred event in NPP can be emitted three conditions:

(a) If $X_k < 1$ then the work context has a positive influence on the human performance
(b) If $X_k = 1$ then the work context no influences the human performance
(c) If $X_k > 1$ then the work context has a negative influence on the human performance

In respect that each PSF has their characteristics and for many cases can't be equalized, it is purpose a general model. This consists in a continuous spectrum in closed interval between 0, 5 and 5 values. It is established so that to can consider many levels of PSFs. In table 1 are presented major PSF with the some levels which could be considered. The definition of PSFs is according to [3],[4],[6].

If JHEP >1 then is purposed the following formula:

$$JHEP = \frac{\sum_{i=1}^{n}(BHEP_j \prod_{j=1}^{m} CHEP_j \prod_{k=1}^{r} X_k)}{\sum_{i=1}^{n}[BHEP_i \prod_{j=1}^{m} CHEP_j (\prod_{k=1}^{r} X_k - 1) + 1} \qquad (2)$$

Representation of the actions is realized by HRA event tree (HRAET). This is base tool of HRA method by which can be generated the quantitative estimating of the action reliability.

Each HRAET is developed according to necessary action and dependence. It isn't possible a generalization for this by season of the individuality for each action.

Evaluated PSF levels for actions *Table 1*

PSFs	Level	X
time	inadequate	5
	nominal	1
	extra	0.5
stress	low	2
	optimum	1
	moderately	2
	high	5
complexity	High	5
	nominal	1
	very simple	0.5
experience	high	5
	nominal	1
	low	0.5
training	high	5
	nominal	1
	low	0.5
environmental	inadequate	5
	nominal	1
	good	0.5
communication	inadequate	5
	nominal	1
	good	0.5
procedure	incomplete	5
	nominal	1
work processes	poor	5
	nominal	1
	good	0.5

In order to find ways to reduce the human errors must identify these mechanisms by which PSFs could influence the human errors. In [3] and [2] are presented the correlations between major PSFs and their mechanisms which could modify the human actions.

3. Case Study

The developed model is applied for the following three cases from Cernavoda NPP (the analysis of these events is hypothetical and theoretically performed):

- loop no isolation automatically in the time of large LOCA;
- main steam safety valves no open automatically in the time of large LOCA;

- low pressure stage no opens in the time of small LOCA

Although, both large LOCA event and small LOCA event lead toward the loss of reactor cooling capacity, the approach, the complexity and the consequences them are different. If they are not prevented, mitigated or stopped could lead to late core damage or late core damage with containment by-pass.

Because of the complexity of Cernavoda NPP was needed to be used many assumptions:

-large LOCA event is considered for the break of the input collector (100%)
-the diagnosis established only to perception and discrimination level
-it is not considered decision making about the need actions
-all equipments are available
-only the important actions are considered for analysis
-only the commission human errors are analyzed

4. Results

After the performing the steps (a), (b), (c), (d), (e), (f) from the human factor analysis model the results for all three cases were obtained. These are presented in tables (2, 3, and 4) and the actions are represented in figures (2, 3, and 4).

The analysis of event: loop no isolation automatically in the time of large LOCA *Table 2*

Equipment	Failure action	BHEP	Symbol HRA event	Dependence level	CHEP	PSF*	X
Alarm	The operator errs diagnosis	0.001	A	------	....	time	5
						complexity	2
						procedures	3
						training	0.2
						stress	5
						experience	2
Indicator (8 actions)	The operator errs to read the indication	0.001	B1..B8	independent	......	time	5
						complexity	2
						procedures	3
						training	0.2
						experience	2
HS with 4 position (8 actions)	The operator errs to select the HS position	0.003	C1...C8	CD	1	time	5
						complexity	2
						procedures	3
						training	0.2
						experience	2

* PSFs are related to large LOCA event

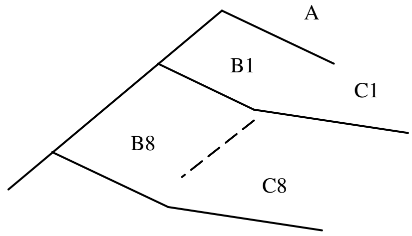

Fig. 2 - HRAET for loop no isolation automatically

JHEP = 0.001*60 + 8*(0.001*1*12) = 0.156

The analysis of event: main steam safety valves no open automatically *Table 3*

Equipment	Failure action	BHEP	Symbol HRA event	Dependence level	CHEP	PSF*	X_k
Alarm	The operator errs diagnosis	0.001	A	------	....	time	2
						complexity	2
						procedures	3
						training	0.2
						stress	5
						experience	2
Indicator	The operator errs to read the indication	0.001	B	…….	......	time	2
						complexity	2
						procedures	3
						training	0.2
						experience	2
HS with 4 position (10 actions)	The operator errs to select the HS position	0.003	C1...C10	…… CD between the actions on HS	0.003	time	2
						complexity	2
						procedures	3
						training	0.2
						experience	2

* PSFs are related to large LOCA event

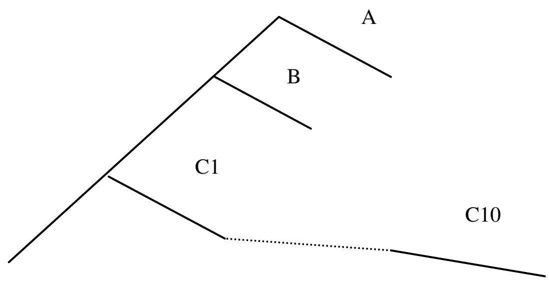

Fig.3 - HRAET for main steam safety valves no open automatically

JHEP = 0.001*0.003*2.4 = 0.0000072 (Using the equation 1)

The analysis of event low pressure stage no opens in the time of small LOCA *Table 4*

Equipment	Failure action	BHEP	Symbol HRA event	Dependence level	CHEP	PSF*	X
Alarm	The operator errs diagnosis	0.001	A	------	....	complexity	2
						training	0.2
						procedures	3
						stress	2
HS with 2 position	The operator errs to select the HS position	0.003	B	ZD	0.003	......	.....

* PSFs are related to small LOCA event

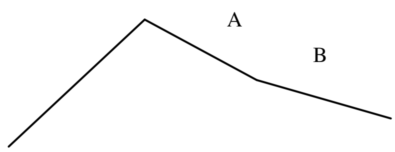

Fig. 4 - HRAET for low pressure stage no open

JHEP = $0.001*24 + 0.001*4.8 + 0.003^{10}*4.8$ = ~0.0288

Using the results from table 2 can be modified the levels of PSFs. These modifications are considered in time of the evolution of the analyzed event. In table 5 is presented an example of the variations of JHEP in according to some changes of the PSFs level for the event: loop no isolation automatically in the time of large LOCA

JHEP in according to modified PSFs level *Table5*

Modified PSF	X_k	New JHEP	New JHEP/ JHEP
Time: nominal Complexity: very simple Stress: moderatelly	1,5	0,0073 (eq. 1)	21,37
Environmental : inadequate Comunication : inadequate	25	0.82 (eq.2)	0,19

By the variation of the condition in time of event is modified JHEP both for positive influence and negative influence.

5. Conclusions

The developed model demonstrate by its approach that the human error probabilities can be estimated taking into consideration all factors which could influence the human actions both positive and negative. So, the quantification of the human factor can be realistically estimated in the context of probabilistic safety assessment.

After the application the model for the case studies were identified PSFs which have a major contribution in the increasing of JHEP:

- stress/stressors
- complexity
- equipments with many position (two or three);
- procedure;
- available time;

In order to reduce the JHEP and to improve the human performance in case the mitigation or stopping of the analyzed abnormal event some recommendations could be emitted:

- reductions of the number annunciating that should be perceived and distinguished by the operator for an abnormal event (simplification of the presentation of event)
- reductions of the parallel tasks, the transitioning between multiple procedures and the multiple faults
- improving of the decision-making to all levels of organization to reduce stress level and to improve external memory (i.e. adequate procedure).
- discussions with a leading expert in area of cognitive psychology to the elaboration of procedures for emergency situations from NPP

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