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Research Article

Engineering Learning in the Assessment of Human Error Probability

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Abstract

Generally, it has been found that skills, attitudes and human performance are shaped during change and transformation; greatly depending on learning. Learning is a cognitive process leading to observable change in behavior. Considering learning impact, reduction of human error probability is obviously seen in various tasks in hazardous potentially industrial systems. In this paper, using an innovative approach in engineering learning theory in to general tasks of Tehran Research Reactor (TRR), the impact on human error probabilities is discussed utilizing Human Error Assessment and Reduction Technique (HEART) method and Reliability Laboratory (RELAB) code. Probability of occurrence of four probable accidents in reactor without considering human error, by considering human error and contribution learning in various tasks is calculated quantitatively. Benchmarking of the method and the conclusion are done by comparing them with the results of similar reactors.

Keywords: *Human Error, Learning engineering, Probability, HEART, RELAB, TRR.*

Introduction

"Error" is a general term used to represent all events where the arranged plans fail to meet the expected objectives. Based on this definition, error might happen during incorrect planning or in unsuccessful execution of plans.

Results of accident investigations have shown that main cause of major socio-technological systems accidents such as core melt down in Three Mile Island nuclear power plant, Challenger spacecraft explosion and Chernobyl nuclear power plant disaster which have had great global impacts on social, political and economic aspects, are attributed mainly to human error. More speculation on the causes of these accidents has shown that the main reason is the lack of adequate consideration of human and organizational factors in the design and operation of those systems.

The errors not only include failure to follow certain operation procedures (omission) or failure to do it correctly (commission), but also encompass failure in cognitive processes of diagnosis and decision making which are of different nature and category. Generally, it has been identified that skills, reasoning, vision, and ultimately performance of humans are changing with time mostly due to learning.

There are many definitions for learning. Sometimes, learning is defined as an experience based on training with the purpose of making relatively permanent changes in the person. Learning is known as the result of experience and it cannot be compared with temporary physical conditions such as illness or fatigue. Thus, learning is often believed to be the change in behavior due to experience (O. Weinstein, N. Azoulay, 1999).

HEART Method

HEART, is a human reliability analysis method mostly used for quantification of human error in nuclear power plants, refineries, chemical and petrochemical industries. This method is designed for estimation of human errors based on a special table containing specific questions to identify errors. It is assumed that human reliability is basically related to the nature of the task, therefore hierarchical task analysis (HTA) is performed. In this method, nine general groups of tasks are identified to which numbers are attributed as human unreliability. The groups are identified as well as 38 Error Producing Conditions (EPCs) are specified such as shortage of time, unclear procedures, etc. Following identification of EPCs, the analyst ascribes a number between 0 and 1 to them which is called "Assessed Proportion of Affect" (APOA). Finally, all data are inserted into the performance formula (PF) to calculate the "human error probability" (S. Barry, 2002).

HEART is an effective tool to evaluate the important concepts related to human factors engineering and explains the main factors affecting human behavior in large socio-technological systems. Furthermore, this method describes the conditions that potentially forces the person to commit error and thus the root causes of the human–induced accidents.

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Learning Theory

Learning is a sensitive and at the sometime valuable process of achieving success. Economic success in most of cases requires innovation in provision of services, products and methods. Learning is a process in which the beliefs and subsequently performances change. Learning process happens when alteration occurs in one's mind, cognition, recognition and behavior (L. Barton, 1992), (P. Shrivastava, 1943).

The subsystems of organizations namely people, knowledge, technology and culture are required for the spread and enhancement of learning. Learning by itself, encompass other subsidiary systems including levels, types and skills of learning. These all are necessary in establishment and maintenance of organizations' learning and efficiency, which are dynamically interrelated and complementary (J.C.N. Valencia, R.S. Valle, D.J. Jimenez, 2010),(G.T. Hult, O.C. Ferrell, 1997). In case of lack or weakness of a subsystem, the rest would be damaged considerably. Fig. 1. shows a learning organization model including its subsystems. Fig. 2. delineate subsidiary systems (D. Davies, 1994),(N. M. Dixon, 1994),(D. Garvin, 1993),(S.C. Goh, 2003).

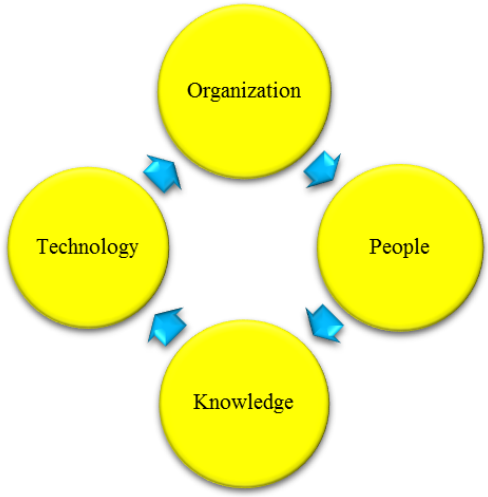


Fig (1) Organization Systemic Learning Model

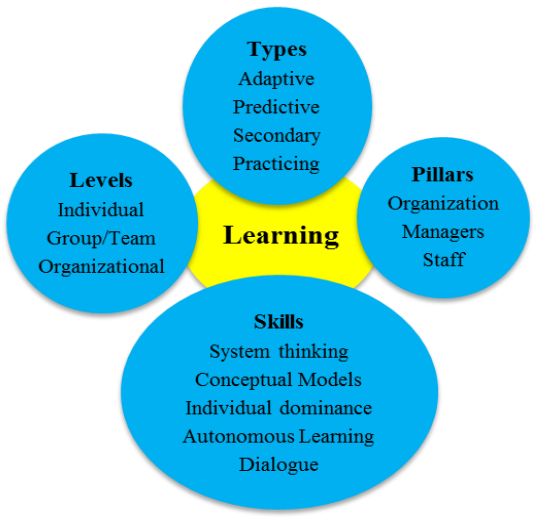


Fig (2) Subsidiary Learning Systems

Analysis

In this analysis firstly, the initiating events, which might occur at the start up or during operation of the reactor, are identified. These events will lead to accidents if the safety systems do not intervene timely and appropriately. The reference document where these initiating events are identified is the Log Book of Tehran Nuclear Research Reactor (American Machine & Foundry Company (AMF), 1966), (S. Bahrebar, S. Rastayesh, K. Sepanloo, 2014).

In addition, some of experienced experts and operators of the reactor are also consulted. In this paper, Loss of Cooling Accident is analyzed; Occurrence of failure of cooling system causes disorder in removal of heat from the fuel plates leading to unbalance between the production and removal of heat. The remaining heat causes fuel plates heating up and if not cooled timely it can causes damage to the fuel plates and eventually release of radioactivity.
It was found that in the reactor emergency condition loss of cooling can be caused by occurrence of any of four accidents: Loss of Flow Accident (LOFA), Loss of Off – site Power (LOOP), Loss of Coolant Accident (LOCA), and Loss of Heat Sink Accident (LOHA). (S. Bahrebar, S. Rastayesh, K. Sepanloo, 2014).

The probability of occurrence of each of the top event is calculated by determination of minimal cut sets (MCSs). Top event probability is calculated by two methods: Rare Event Approach (REA) and Minimal Cut set Upper Bound (MCUB). Probability of top event is estimated using REA approximation according to the following formula in which it is assumed that the intersection among the MCSs are trivial.

$$P = \sum_{i=1}^{m} C_i \quad (1)$$

To estimate the value of MCUB, Sylvester – Poincare full expansion is used. In case that all MCSs are mutually exclusive, this method results in more precise estimation for the top event probability. Calculation of the top event probability using this approximation is simply done as below.

$$P = 1 - \prod_{i=1}^{m}(1 - C_i) \quad (2)$$

The fault trees related to these accidents are developed and quantified using the relevant failure data, furthermore the reliability calculations are done by RELAB code. At first, the probability of top event (Loss of Cooling) is calculated assuming no contribution of human errors.

For quantification of learning and its impact on components through human activities, 22 criteria and effects of learning on performance, understanding and human ideas are determined and analyzed. Then effect of each on EPCs is weighted by including learning ratio (number of learning impact divided by total effects). Table(1), shows 22 criteria affecting learning which decrease human error. It should be emphasized that each of the factors is extracted from: behavioral and cognitive reliability in levels of individual, group and organization. The criteria are used for assessment and predicting

Table (1) Factors affecting learning

Row	22 learning criteria
1	change in behavior and performance
2	change in understanding and Recognition
3	change in behavior and habits
4	Innovation
5	Prediction
6	continuous change, focus on values and performance consequence
7	Not only circumstances improvement, but also scientific and practical advances in tasks
8	human resources Having knowledge and technology
9	Having creative mind/have a dynamic and impressive thinking
10	Have great flexibility in face of rapid and unexpected changes
11	Enhance the operational capabilities of human resources
12	Increasing access to updated information
13	Increasing motivation and human interaction
14	Finding systematic thinking skills, subjective modeling, and constructive dialogue, etc. among employees
15	Better and faster reminder of lessons and data
16	Buildup of alliances, perspective and a common purpose among all individuals
17	The ability to gain knowledge from others people experience
18	Development of knowledge related to cause and effect relations and environmental influence on them
19	Change and modification of Individual and organizational knowledge and memory
20	Create a sense of trust and satisfaction among employees
21	Ability to perform effective actions and increase capacity and capability to solve problems
22	Knowledge generation and support search and questioning sense

different accidents which may occur in future. Furthermore, utilization of 4 learning elements and 5 key skills are done to analyze initiation, development and maximization of learning process in the three pillars of organization, managements and personnel. Overall process can be investigated in three status: production, transmission and dissemination of idea to explore, identify and remove barriers to establish and develop learning capacity.

Table 2 represents effect of each learning factor is presented in 38 EPCs.

By considering the effect of each EPC and estimation of Learning Ratio (LR) and multiply of it by LR' in predicted numeral value of uncertainty of each EPCs or dedicated amount for each condition, new coefficient (A) obtained as the highest level of predicted value of learning in EPCs using HEART method.

APOA is estimated by observations and survey of the author in training workshops, discussions with operators, holding several intellectual sessions and providing systematic thinking, accidents modelling. Moreover, using experts especially experienced safety department of AEOI, calculation of human error probability is done. Afterwards, Performance Factor (PF') and Human Error Probability with Learning (HEPWL) has been calculated. Furthermore, new predicted value of uncertainty in addition to human error probability affected by learning is obtained for each designated condition. General form of human error calculation by introducing learning using HEART method is illustrated in table (3).

To analyze the impact of human error, those components of the system which could be affected by the human actions are identified and then according to hierarchical task analysis the human interventions are classified into three groups: inspection, maintenance and operation. These activities are specified with Generic Task Types (GTT). Then the Generic Error Probability (GEP) of each is inserted. The EPCs of each task are specified and finally their weight coefficients (proportion of effect) are determined and Performance Factor is calculated.

Impacts of learning on the errors probability are determined. The impact of it on the error producing conditions is calculated by including a multiplication factor, LR:

$$LR' = 1\text{- (No. of affecting impacts) / (total No. of impacts)} \quad (3)$$

$$A = a*(1-LR) \quad (4)$$

$$PF' = ((A-1)*b)-1 \quad (5)$$

$$HEP \text{ with Learning} = GEP * PF'_i \quad (6)$$

In these equations, "a" is coefficient EPCs, "b" is APOA and "PF'" is similar to PF in HEART method by interfacing learning.

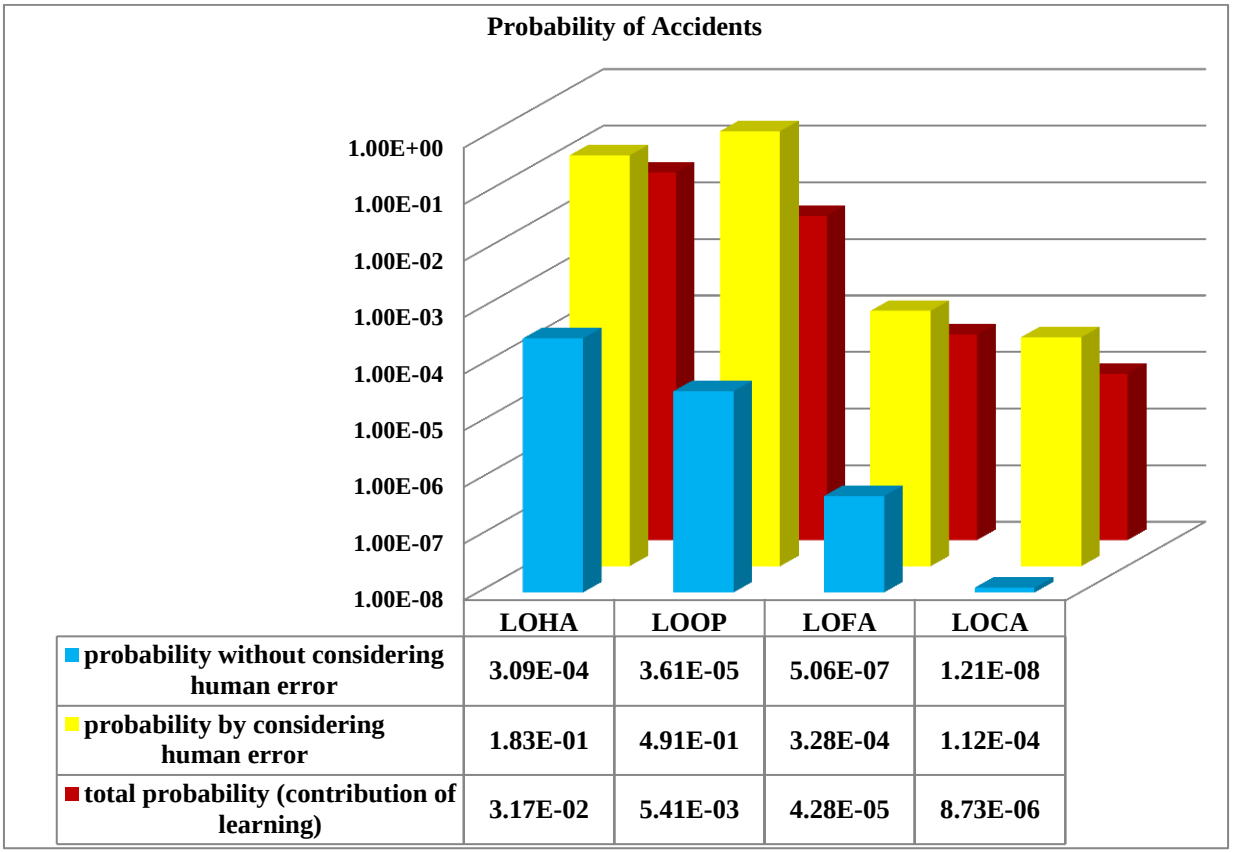
The advantage of this method is inclusion of learning impact in the situations and components which have a large share in causing human error. In this way, the results of human error probabilities approach actual values, since calculation is based on the records of errors in the reactor which more accurately represents system failure probability.

Table (2) Learning effects on uncertainty prediction of different conditions

EPCs	Factors affecting learning	The largest predicted number of effects of learning on EPCs
1	22-21-18-17-14-12-11-10-9-8-5-4-3-2	14
2	21-19-18-17-15-14-12-11-10-9-5-4-3-2-1	15
3	22-21-18-17-14-11-8-5-4-2	10
4	22-21-19-18-17-16-15-14-13-12-11-9-8-6-4-3-1	17
5	21-19-18-16-14-13-12-11-9-8-5-4-1	13
6	22-21-19-16-14-12-11-10-9-8-6-3-2-1	14
7	20-16-14-13-11-8-1	7
8	22-19-18-16-14-13-12-9-8-7-6-5-4-3-1	15
9	22-21-19-17-15-14-13-12-9-8-6-3-2	13
10	22-19-18-16-15-14-13-12-11-9-8-6-5-4-3-2	16
11	21-19-15-9-8-7-6-3-2	9
12	21-17-15-14-11-9-8-2	8
13	No human intervention	0
14	No human intervention	0
15	22-21-19-18-17-14-13-12-11-10-9-8-5-3-2-1	16
16	20-19-18-17-16-14-13-12-11-7-5-3-2-1	14
17	19-18-13-12-9-8-6-3-2-1	10
18	19-16-14-12-9-8-7-5-3-2-1	11
19	22-19-18-14-12-9-8-6-4-3	10
20	22-19-18-14-12-11-9-3	8
21	17-16-14-12-9-8-3-2-1	9
22	14-13-11-9-6-3-1	7
23	No human intervention	0
24	14-13-9-7-3	5
25	21-19-16-14-13-11-9-6-3	9
26	17-12-4-3-1	5
27	21-18-17-14-11-10-9-6-4-3	10
28	20-19-14-13-1	5
29	21-20-14-8-1	5
30	21-20-13-11-8	5
31	20-14-6-13-3	5
32	No human intervention	0
33	No human intervention	0
34	22-16-13-12-9-7-6-5-4-3	10
35	13-3	2
36	17-16-14-13-11-8-1	7
37	14-1	2
38	21	1

Table (3) General form of human error calculation by introducing learning using HEART method

Job tasks Time to initiate evaluation Time to finish evaluation Calculated error probability without learning									
Generic Task Types (GTT)	Generic Error Probability (GEP)	Error producing conditions (EPCs)	Coefficient (a)	Learning ratio (LR)	LR'= 1-(LR)	Coefficient (A)	Effect ratio (b)	Calculation of PF' ((A-1)*b)+1	Human error probability (HEP) with Learning



	LOHA	LOOP	LOFA	LOCA
probability without considering human error	3.09E-04	3.61E-05	5.06E-07	1.21E-08
probability by considering human error	1.83E-01	4.91E-01	3.28E-04	1.12E-04
total probability (contribution of learning)	3.17E-02	5.41E-03	4.28E-05	8.73E-06

Fig (3) Accidents probabilities by RELAB

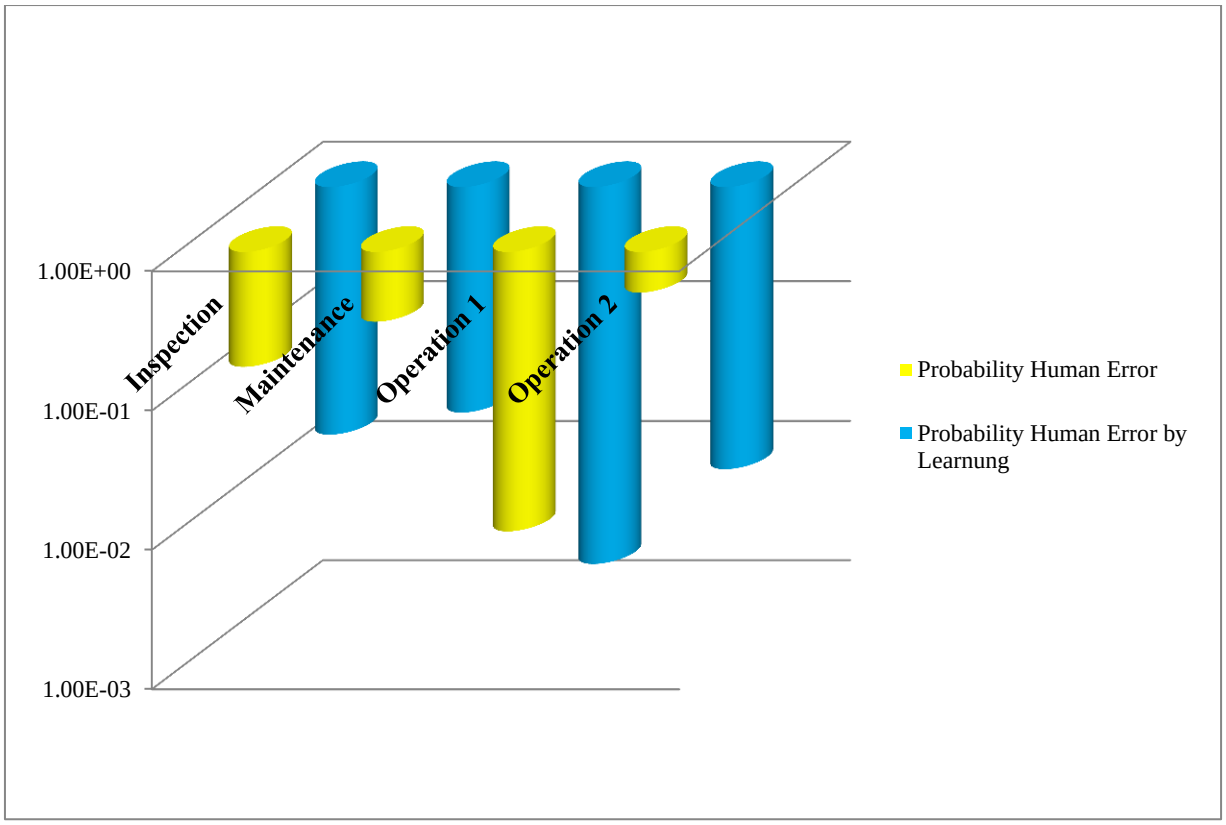


Fig (4) Probability of career error

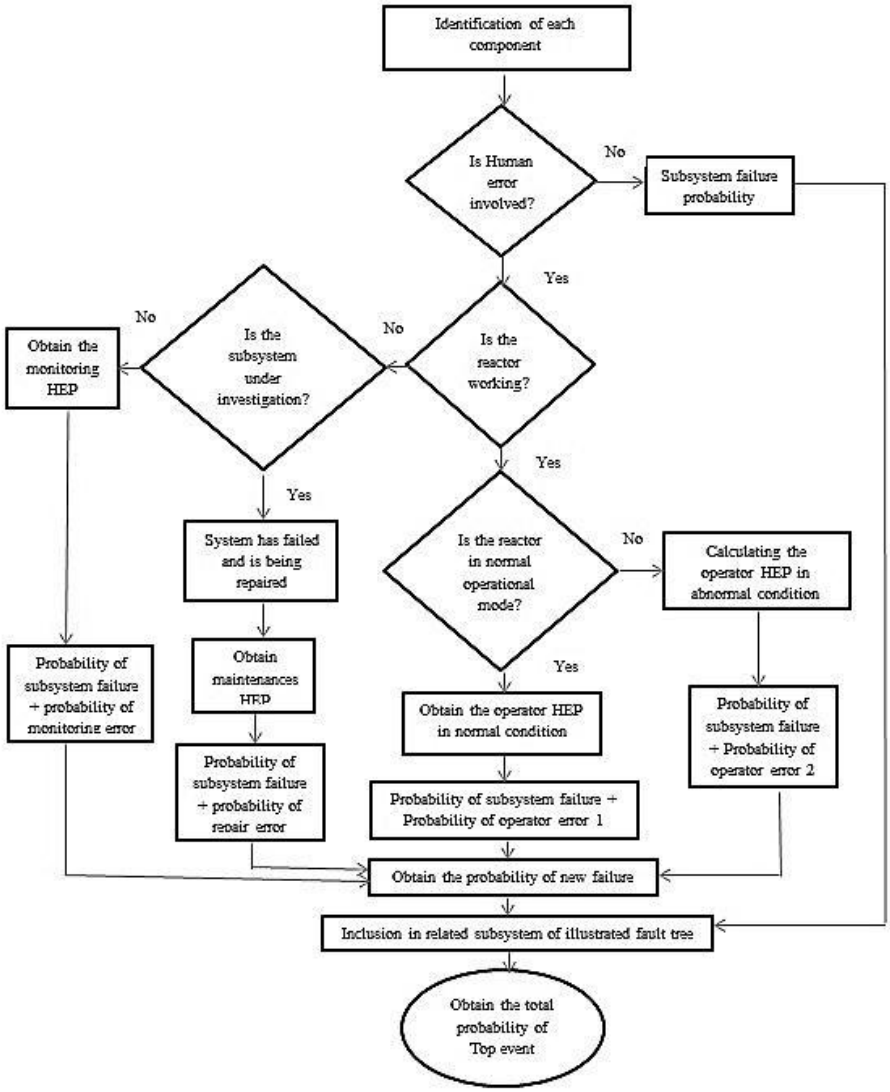


Fig (5) Analysis of human error contribution

Results

In the analysis of impact of human error, with consideration of learning, on the occurrence of accidents in Tehran Nuclear Research Reactor, the following results were achieved:

1. The impact of learning in the LOOP accident is much more than other three accidents (LOFA, LOCA and LOHA). Since human intervention in this accident is high it undoubtedly shows the high value of improvements in skills, experience and in fact learning.
2. The contribution of learning to the probability of occurrence of top event has been found decreasing for the accidents LOFA, LOCA and LOHA, respectively.
3. Fig. 3. shows the calculated error probabilities for the four accidents. Human Task Analysis results for three chosen tasks with and without learning using optimization method in HEART is given in Table (5) and Fig. 4.
4. Derived probabilities for electrical and mechanical equipment failure of water cooling system of TRR in occurrence of LOCA was in range of 10^{-8}, since in this reactor human factors engineering is ignored and due to low level of automation, tasks have been done manually. Considering human error intervention, the probability of occurrence of LOCA is calculated as 10^{-4}. The accident probability are observed about 100 times by introducing learning decrease. That final probability of accident occurrence of LOCA in TRR becomes 10^{-6}which is in complete agreement by comparing it with numeral value of probability from generic data. For calculating the probability of occurrence of other accidents (LOFA، LOHA and LOOP), same approach was taken and three state (probability without considering human error, probability with considering human error, total probability contribution of learning) are shown in table and figure 4. For assessment, the results, the probability of each accident from generic data that is shown in table (4) is compared with final results (total probability contribution learning) so it is found that the order of magnitude are at the same range.
5. In evaluation for human error for different tasks, operator task in emergency (operator 2) is found to be in an especial condition by its maximum number of

EPCs and having highest error probability which indicates a large difference with normal state of an operator(operator 1). The influence of conditions such as unfamiliarity, shortage of time of identification and correction, lack of experience, lack of training in critical, dangerous and potentially cases and the most important among them is high emotional stress (APOA=0.9), are the cases that increase error probability greatly.

6. Following operator 2, the task of system repair and replacement of parts have the most error probability. Dangerous workplace, physical limitations, insufficient review of components for maintenance, lack of spare parts for the reactor, unfamiliarity with of alternative components during replacements, are the most affective examples of increasing error probability. Repair task compared with inspection, possess some similar EPCs that often is caused by lack of sufficient accuracy and time, lack of adequate and relevant training and lack of physical access to all components for separate measurements.
7. The influence of learning on human error reduction has been higher respectively for operator 2 (maintenance and inspection) and operator 1. Reduction of human error in operator 2 by introducing learning is 10 times more than operator 1. This indicates that although the situation considered is critically but by learning how to behave in emergency conditions, accurate and reasonably response can be provided by operators calmly and with confidence.
8. By entering learning factors on EPCs and calculated error probability for each tasks, on the average human error probability is reduced in maintenance and inspection task about 10 times, operator 1 about 5 times and in operator 2 about 50 times.

Table (4) generic probability of accidents

Reference	Probability	Accidents
NUREG/CR-6928	8.09E-2	LOHA
NUREG/CR-6928 and compliance with TRR Logbook	1.7E-3_3.59E-2	LOOP
NEA/CSNI/R(2012)	1.07E-5	LOFA
NUREG/CR-6928	6.78E-6	LOCA

Table (5) Human error probability using HEART method for various tasks

HTA	GTT	GEP	HEP	HEP with Learning
Inspection	F	0.003	1.498E-1	1.68E-2
Maintenance	F	0.003	3.159E-1	2.42E-2
Operation1	G	0.0004	9.886E-3	1.98E-3
Operation2	G	0.0004	5.106E-1	9.49E-3

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