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Scram Incidence Statistic Survey in a Research Nuclear Reactor Considering System Hardware and Human Errors

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ABSTRACT

One of the major events in nuclear reactors is scram or immediate emergency shutdown. Qualitative and quantitative study of this event, as well as the main causative factors in evaluating reactor safety is an important point. In this study, safety of Tehran research reactor is assessed probabilistically and the human error possibility is evaluated using SPAR-H method. In this regard, scram fault tree associated with hardware failures and human errors are drawn by using SAPHIR software. The calculated total scram possibility is found to be 0.1E-3.

KEYWORDS: immediate emergency shutdown, human error, software error, SPAR-H method, SAPHIR software.

1. INTRODUCTION

The immediate emergency shutdown is one of the most events in a nuclear reactor which is controlled by the reactor protection system. Automatic protection system in crisis, with sending scram signal, cut off the magnetic rods current which in turn, unplugs the reactor immediately .Therefore, having knowledge about protection system, qualitative and quantitative study of scram as well as the main factors causing the effects in evaluation of reactor safety are of great importance. Also nowadays the human as designer, programmer and operator has key roles in industrial safety; so his behavior in a complex system such as a reactor has the potential for errors and mistakes, which could create some events like Chernobyl or Three Mile Island. Table1 represents the different reliability models for evaluated human error. The Reactor control system protects reactor against abnormal conditions. there are four independent channels in Tehran research reactor(TRR) protection system, they are incorporated to monitor the neutron flux from the start up level to full power . These channels take input data from four, ex-core neutron detector, namely one fission chamber , and three ion chambers. The protection system operates by 2oo3 (2out of 3) logic of three safety channel, i.c., one fission chamber and two un compensated ionization chamber.

The main objectives of the safety channels are as following:

1. To start protectiv corrective action such as scram, reverse and inhibit withdrawal of control elements.
2. To keep reactor parameters within operational limits.
3. To provide and present to the operator enough information to readily determine the statues of the protection system and take the correct safety related action.

Moreover, The condition initiating reactor scram signal is shown in Table2.

The SPAR-H[1] model combines elements of the stimulus response and the information processing approaches. This is because the HRA[2] needs to be able to consider aspects of diagnosis and planning as well as the likelihood of the operators' ability to successfully carry out actions often identified through procedures. This distinction between diagnosis (i.e., information processing) and action (i.e., response) is the basis for separate diagnosis and action worksheets, with separate probability calculations. SPAR-H also acknowledges the role of

Environmental factors upon diagnosis and action. For example, during evaluation of performance shaping factors, analysis note whether interactions might be difficult to analyze due to misleading indications, complexity, time-dependent aspects and the effects of combinations of unavailable or faulted equipment. Information flow from the environment can be across different sensory modalities: visual, auditory, and kinesthetic. Environment factors can act to filter this information.

The operational factors in SPAR-H that are mapped to the information and behavioral model discussed above is presented in Table 3. These operational factors can be directly associated with the model of human performance. Within the table, various aspects of performance and their relation to the PSF[3]s are indicated. For example, perception is limited based upon human sensory limits, is susceptible to disruption or interference, and occurs as a function of modality (auditory, visual, or kinesthetic). Perception by operators is often a function of the quality of the human machine interface.

[1] standardized plant analysis risk- Human
[2] Human reliability analysis.
[3] Performance shaping factor.

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For example, for Experience/Training, as it can be seem in low level, the failure probability coefficient is 3. For high level the failure rate is 0.5 and to nominal level is1.the probability of failure for the rest is the same. It should be noted that there is always a nominal level for each factor. The nominal level is a level with the maximum efficiency between a desired and human error.

Many, if not most, HRA methods use PSF information in the estimation of HEP[4]s. In general, PSF analysis enhances the degree of realism present in HRA analysis. The extent and resolution of PSF analysis should only be specific enough to identify potential influences and rate them on the corresponding SPAR-H worksheets. When assigning the PSF level, the analyst evaluates the PSF from the perspective of the operator. Thus, the analyst would evaluate the complexity of the diagnosis or action required for a scenario or range of scenarios from the perspective of the operator as opposed to the analyst's view of the complexity as a whole. The changes made at this stage were in error type, PSFs, and in their definitions. PSFs are accounted for SPAR-H quantification process. These factors include:

1. Available time
2. Stress and stressors
3. Experience and training
4. Complexity
5. Ergonomics (including the human-machineinterface)
6. Procedures
7. Fitness for duty
8. Work processes.

For calculating the Action Failure Probability;

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3

(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

The Nominal HEP (NHEP[5]) is 1.0E-3 for Action.

For calculating the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2

(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis.

The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot (PSF_{composite} - 1) + 1} \qquad (1)$$

We offer a simple modification of the nominal error probability that meets mathematical requirements. It is not formulated on the basis of underlying theory regarding the relative orthogonality or nonorthogonality of the eight PSFs used in SPAR-H. Where NHEP is the nominal HEP. NHEP equals 0.01 for diagnosis, and NHEP equals 0.001 for action. In this paper, the nominal or ideal condition is considered. The probability of human as well as hardware error, by drawing the fault tree, will be gotten by using SAPHIRE[6] software after identify the Tehran Research Reactor Protection System. Figure 5 and6 show the Fault- tree quantification for hardware and human errors [1].In this software

$$Meanfailureprobability = 1 - e^{-\lambda t} \qquad (2)$$

is used for calculating the average failure. Here t is 336 days, and **λ** is identified in each hardware segment using table 4. After plotted fault tree by using SAPHIRE software, the calculation of occurrence frequency of each event is obtained and shown in Table5.[3],[2]

Failure fault tree of Tehran reactor shown on Figure1 .it has an OR-gate which is consisted from human error and hardware failure. Each of these branches has its sub-branches which are drown in Figures 4 &5[4]. Here levels of each human factors are connected by an OR-gate. While selecting each factor one by one ,the total probability of human error is finally obtained by multiplying then together & to NHPE .There for it can be said that all human factor are connected by AND-gate.

[4] Human Error Reliability
[5] Nominal human error reliability.
[6] Systems Analysis Programs for Hands-On Integrated Reliability Evaluations.

Table 1. *HRA methods used in SPAR-H comparisons*

HRA Method	Date	Authors	Focus - Purpose
[1]CREAM	1998	E. Hollnagel	Human performance classification based on error modes and consequences (phenotypes) and causes (genotypes). Uses simple Contextual Control Model (CoCoM) of cognition that includes continuous revision and review of goals and intentions. Assesses cognitive function failures and common performance conditions (CPCs) to support failure rate estimations.
[2]HEART	1988	J. Williams	HRA based on nine generic tasks with individual nominal error rates. Analysts identify error-producing conditions (EPCs). EPCs operate as multipliers to increase base failure rates; their basis is in the behavioral sciences literature.
[3]THERP	1983	A.D. Swain and H.E. Guttmann	Developed to provide representational modeling of human actions (HRA Event Trees) and estimation of HEPs. Emphasis is on nuclear power plant applications to support PRA provides HEP tables based on data gathered from Various domains.
[4]ASEP	1987	A.D. Swain	Developed to provide an efficient method for estimation of screening HEPs for pre- and post-accident human actions. Based on THERP.
[5]SHARP1	1990	Wakefield, et al	Developed to provide a consistent approach to HRA assessments. Contains performance shaping factor information. Addresses pre- and post initiator conditions. Revision to early work in this area under the same name.

[1]Cognitive Reliability and Error Analysis Method(CREAM).
[2]Human Error Analysis and Reduction Technique (HEART).
[3]Technique for Human Error Rate Prediction (THERP).
[4]Accident Sequence Evaluation Program (ASEP)
[5] Systematic Human Action Reliability Procedures (SHARP)

Table 2. *which cause emergency shutdown in(TRR).*

No	Scram signal	Action conditions
1	High power level	>110% Nominal
2	Bridge unlock	Un lock
3	Short period	< 7 secend
4	Earthquake shock	>4 richter
5	Safety flapper open	Opening flapper
6	High radiation	>10 mr /hr
7	Very low pool water level	>36 inch
8	Temperature in core	>46 ºC
9	Manual scram buttons pressed	is activated by pressing the button to stop the reactor operator
10	Primary pump failure	the contactor power failure
11	Low primary coolant flow	>90%Nominal

Table 3. *Operational Factors in SPAR-H. (The numbers after each entry refer to the PSF list at the bottom of the table.)*

Inflow and Perception	Working Memory/ Short-term Memory	Processing and Long-term Memory	Response
Presence [6,3] (is the signal there?) and opportunity (is anyone present to receive the signal?) **Human sensory limits [2,5,7]** **Modality [6,5] (verbal, graphic/symbol, text)** **• echoic** **• iconic** **• kinesthetic** **Interference [6,5,4,7] (signal, noise)**	Limited capacity[5] *Serial processing *Good only for a short time [2,3,5,4] (20 seconds) Right amount of attention [2,3,4,5,7] required Rehearsal [2,3,5,7] Physical and mental health [7]	Training4 (models, problem solving, behaviors) • learning Experience[4] (models, problem solving, behaviors) • learning Culture 8 (societal, organizational, interpersonal, (crew)) • learning Intelligence/cognitive skills[3,4,1,5,7] (decision making, problem solving) Interference factors [6,2,3, 7] (distraction) Available time [1,3] Physical and mental health [7]	Training (actions) [4] *Existing models of behavior *Practice and skill Experience [4] (actions) • practice and skill • existing models of behavior Proper controls available[6] Human action limits [6,7] (physical strength and sensory acuity) Ergonomics of controls [6,3] complexity Environmental degradation [2,3,6] Time to react versus time available[1]

Performance Shaping Factors:

[1]Available time
[2] Stress and stressors
[3]Complexity
[4] Experience and training
[5]Procedures (including job aids)
[6]Ergonomics and human-machine interface
[7]Fitness for Duty
[8]Work processes

Table 4. *Matrix methods match the PSF (power PSFs = 8)*

SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers
Available Time	Inadequate Time	*P(failure) = 1.0*
	Time available = Time required	10
	Nominal time	1
	Time available > 5 x time required	0.1
	Time available > 50 x time required	0.01
Stress/ Stressors	Extreme	5
	High	2
	Nominal	1
Complexity	Highly complex	5
	Moderately complex	2
	Nominal	1
Experience/ Training	Low	3
	Nominal	1
	High	0.5
Procedures	Not Procedures	50
	Incomplete	20
	Available, but poor	5
	Nominal	1
Ergonomics/HMI	Missing/Misleading	50
	Poor	10
	Nominal	1
	Good	0.5
Fitness for Duty	Unfit	1
	Degraded Fitness	5
	Nominal	1
Work Processes	Poor	2
	Nominal	1
	Good	0.8

Table 5. *Failure rates for typical components which cause the scram of Tehran Research Reactor*

No	Probability	Fault tree name
1	1.142E-4	BRIDGE-LOCK
2	1.000E-7	EARTHQUIKE
3	1.424E-6	HIGH-POWER
4	1.000E-1	HIGH-RADIATION
5	9.701E-3	HIGH-TEMPRATURE
6	5.000E-1	MANUAL-SCRAM
7	3.686E-3	PERIOD
8	1.241E-2	POOL-LEVEL
9	2.294E-3	PRIMARY-FLOW
10	2.784E-3	PRIMARY-PUMP
11	1.645E-3	SAFTY-FLAPPER

Table 6. *Failure rate of component(λ)*

Basic event	Failure rate/hr*10^{-6}	Failure probability/demand	Test period	reference
High power				
HPS-FCH-Bistable-Fail	37.3	3.729E-4	0	TD930
HPS-FCH-relay-Fail	8.3	1.393E-3	336	TD930
HPS-UIC1-Bistable-Fail	37.3	3.729E-4	0	TD930
HPS-UIC1-ralay-Fail	8.3	1.393E-3	336	TD930
HPS-UIC2-Bistable-Fail	37.3	3.729E-4	0	TD930
HPS-UIC2-ralay-Fail	8.3	1.393E-3	336	TD930
High radiation				
HRS-BHFN-Bistable-fail	37.3	3.729E-4	0	TD930
HRS-BHFN-Detector-fail	6	6.000E-5	0	TD930
HRS-BHFN-Relay-fail	8.3	1.393E-3	336	TD930
HRS—Bridge-Bistable-fail	37.3	3.729E-4	0	TD930
HRS- Bridge -Detector-fail	6	6.000E-5	0	TD930
HRS- Bridge -Relay-fail	8.3	1.393E-3	336	TD930
HRS-PFloor-Bistable-fail	37.3	3.729E-4	0	TD930
HRS- PFloor -Detector-fail	6	6.000E-5	0	TD930

HRS- PFloor -Relay-fail	8.3	1.393E-3	336	TD930
HRS-Stack-Bistable-fail	37.3	3.729E-4	0	TD930
HRS- Stack -Detector-fail	6	6.000E-5	0	TD930
HRS- Stack -Relay-fail	8.3	1.393E-3	336	TD930
Low flow				
LFS-Bistable-fail	37.3	3.729E-4	0	TD930
LFS-Relay-fail	8.3	1.393E-3	336	TD930
LFS-Sensor-fail	53	5.299E-4	0	TD930
Pool level				
PLS-Float-fail	28.2	2.820E-4	0	TD930
PLS-micro switch-fail	4.2	7.556	336	TD930
PLS-relay-fail	8.3	1.393E-3	336	TD930
Primary pump				
PPS-power relay-fail	8.3	1.393E-3	336	TD930
PPS- relay-fail	8.3	1.393E-3	336	TD930
Safety Flapper				
SFS-Open -fail	7	7.000E-5	0	TD930
SFS-Micro switch-fail	4.5	4.500	0	TD930
SFS-relay -fail	8.3	1.393E-3	336	TD930
SFS-connecting rod -fail	13.7	1.370	0	
Safety channel				
Safety ch1-instr-fail	123	1.229E-3	0	TD930
Safety ch2-instr-fail	123	1.229E-3	0	TD930
Safety ch3-instr-fail	123	1.229E-3	0	TD930
Safety ch2-UIC-fail	50	5.000E-6	0	TD930
Safety ch3- UIC-fail	50	5.000E-6	0	TD930

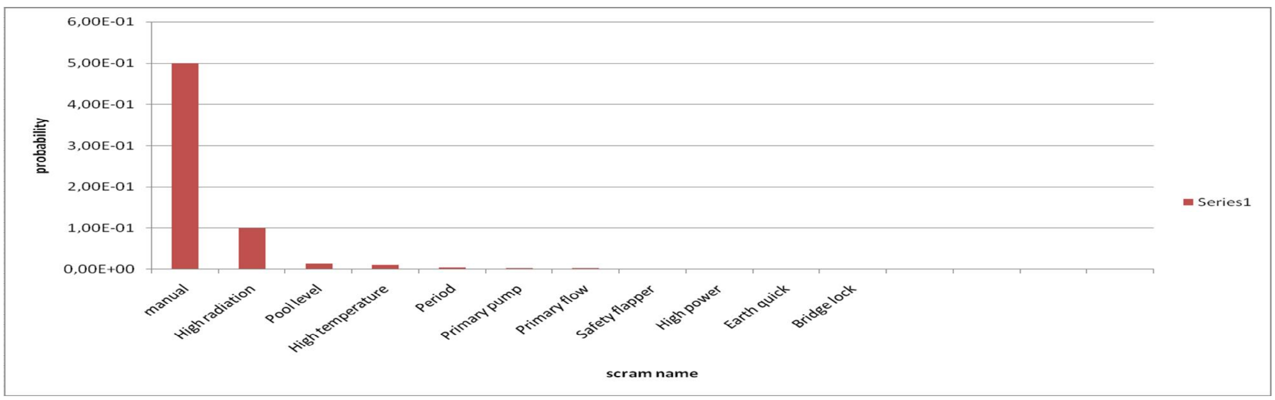


Figure 1. *plot of fault –tree of the failure rates components against the probability occurrence*

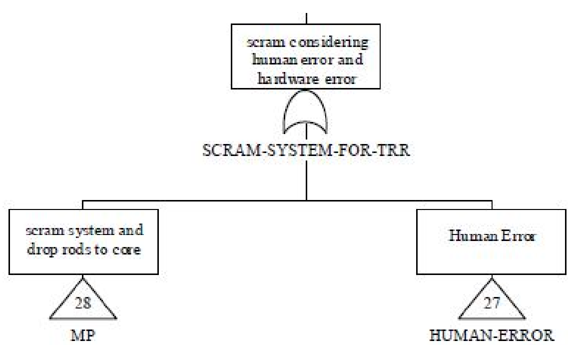


Figure 2. *Fault -tree quantification for maintenance and control system of the tehran reactor considering hardware and human error*

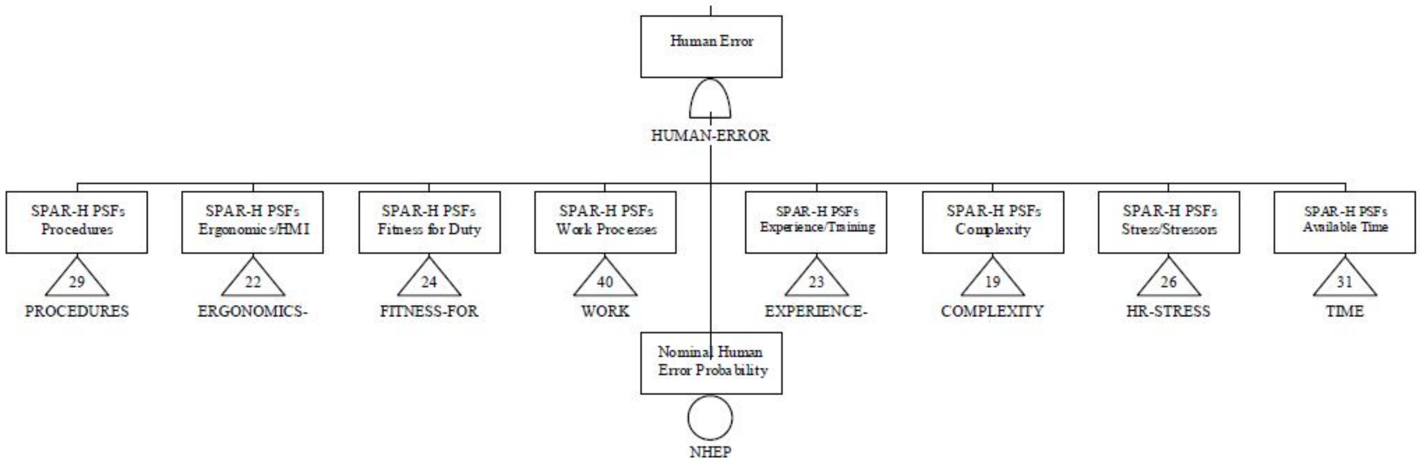


Figure 3. *Fault-tree quantification for human error*

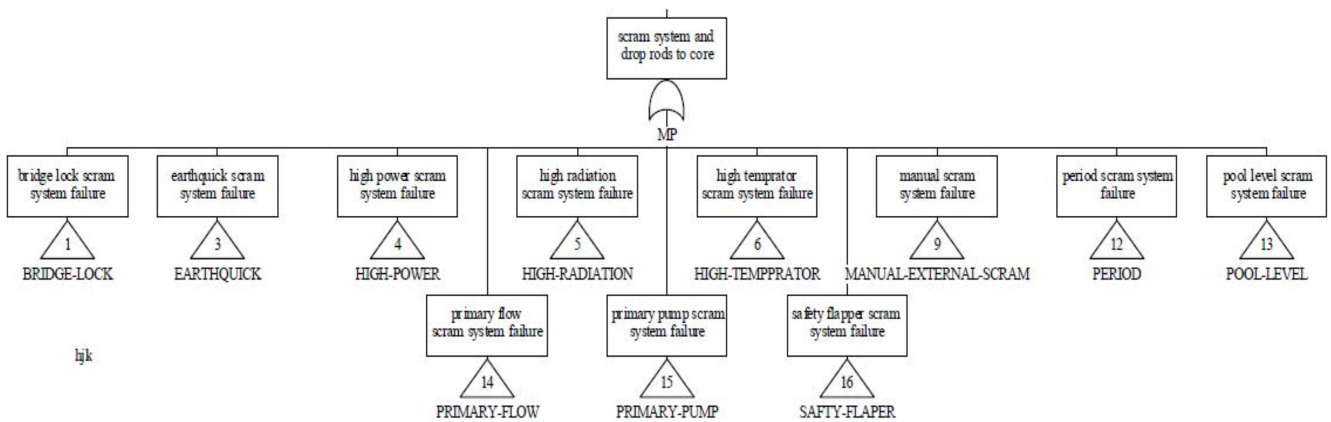
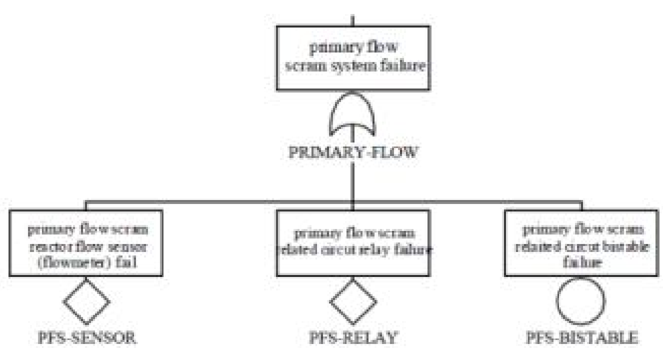
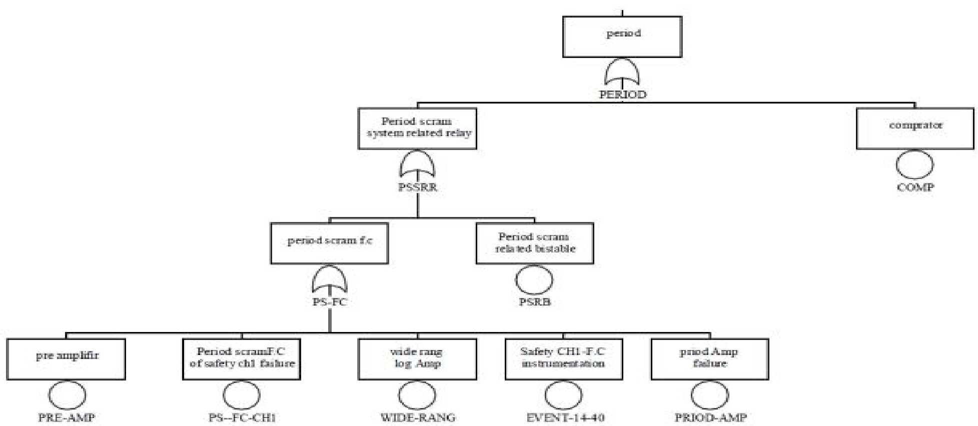


Figure 4. *Fault-tree quantification for hardware error*

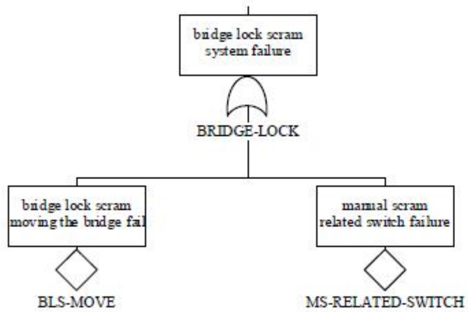


A :*Low primary coolant flow*

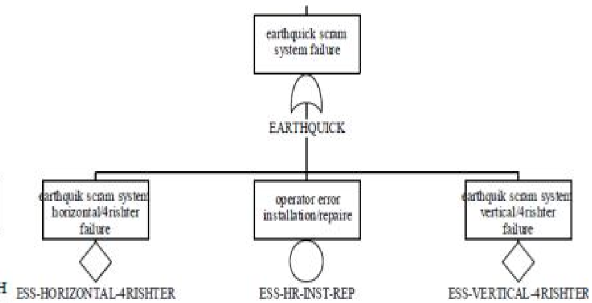
B: *High radiation*



C: *Short period*

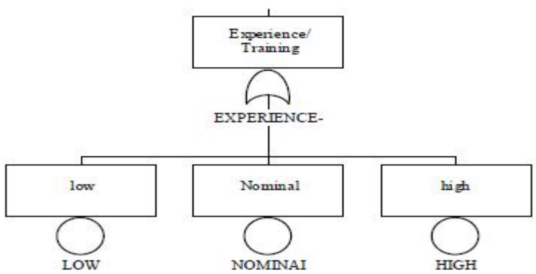


D: *Bridge unlock*

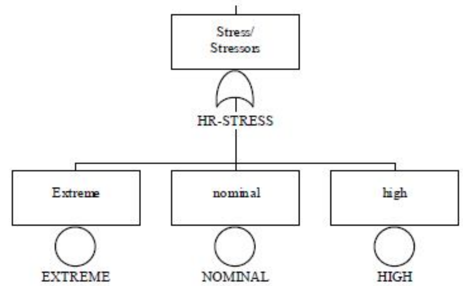


E: *earthquick*

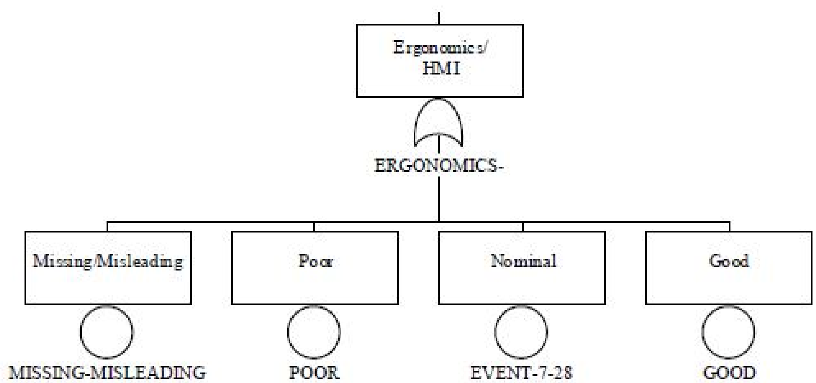
Figure 5. *Fault-trees quantification for human error :*



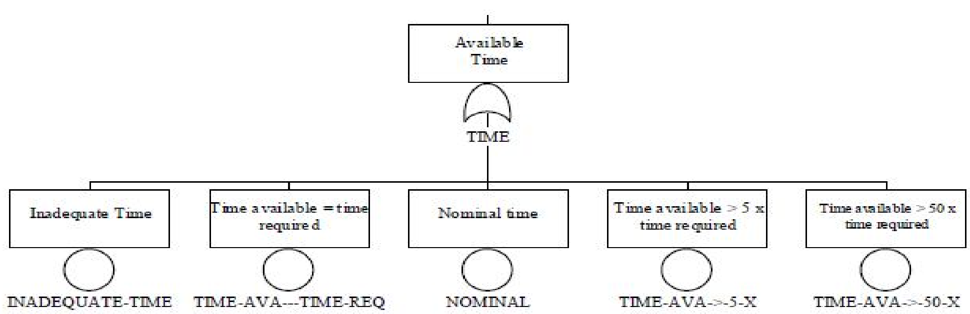
A : *Experience/training*



B: *Steress / stressor*



C: *Ergonomic/HMI*



D : *Availabel time*

After calculating the probability of errors in SAPHIRE software, the probability of the reactor scram related to total system hardware error obtained is almost: 8×10^{-6} and in nominal situation for human error come to be 10^{-2}. The probability of scram for Tehran Reactor, considering both human & hardware error factors is equal: 10^{-2}. It is clear from the results, that the probability of human error in nominal condition is high in compression hardware error (about 1000 times. Moreover, Table5 shows the most occurrence of emergency scram in accordance with international standards which is:

1. Manual scram buttons pressed,
2. Exposure exceeds,
3. Pool water level is low.

Where as in the case of Tehran research reactor the results shows the following most occurrence of emergency scram during the period of 32 years.

1. Network power outage,
2. Short Period,
3. Manual scram buttons pressed .

These results need further study in the field of human as well as hardware error.

Acknowledgements.

λ Hardware failure rate of a component.

t Periodic testing time duration.

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