ANALYSIS OF RELIABILITY OF COOLING SYSTEM OF TEHRAN NUCLEAR RESEARCH REACTOR BY DETERMINATION OF IMPORTANCE AND SENSITIVITY

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ABSTRACT

Mechanical parameters such as dimensions, forces and stresses are never absolute and in reality are a function of process changes, human factors, operation and time. Therefore, their analysis and attaining the results of importance and sensitivity analyses can be used in determination of their safety category and enhancement of their reliability and maintenance. In this paper, using fault tree analysis method, the importance and sensitivity of Tehran Nuclear Research Reactor coolant system components are determined by analysis of four probable accidents: Loss of Coolant Accident (LOCA), Loss of Flow Accident (LOFA), Loss of Heat Sink Accident (LOHA) and Loss of Offsite Power Accident (LOOP) by the help of RELAB computer code. The results are used to identify the important and sensitive components. This recognition helps to optimize the repair and maintenance resources and enhancement of reliability and availability of the reactor components.

KEYWORDS: Importance, Sensitivity, Nuclear Research Reactor, Reliability, Relab

The objective of importance and sensitivity analysis is to determine the share of each subsystem and component in the probable hazards to the system. When the importance of the components are determined, they are categorized and based on that suggestions are made for the enhancement of safety by due improvement in quality, inspection, repair and maintenance programs. To do this, fault tree analysis (FTA) method is used. FTA is a systematic process of identifyingfailure modes and the combination of events leading to unfavorable conditions.For the first time, FTA was developedin 1961 in the Bell telephone laboratory to analyze the safety ofthe control system in Minuteman military missile projection program.Minimal cut sets (MCSs) are the combination of basic events which the occurrence of each can result in the occurrence of the tree top event. MSCs are determined through applying Boolean algebra in reduction of the cut sets into the sets which removal of even one basic event prevents the top event.

Due to the fact that happening of each MCS can cause the top event it can qualitatively concluded that the more a component appears in the MSCs the more importance it has. In this paper, using the reliability computer code, RELAB, the MCSs are determined applying MOCUS algorithm. The probability of occurrence of the top event is calculated by applying two approximation methods: Rare Event Approximation (REA) and Min Cut Upper Bound (MCUB). The importance and sensitivity analysis is done for four top events: LOCA, LOFA, LOOP and LOHA.

COOLING SYSTEM OF TEHRAN NUCLEAR RESEARCH REACTOR

The cooling system of the reactor consists of two primary and secondary cooling loops having the task of transferring produced heat in the reactor coreto the secondary loop. The coolant (water) passes through the fuel plates (coolant channels) by the gravity force and then enters plate network where it pours into the storage tank. On the top of storage tank there is a porous plate. At the end of the tank there is an exit pipe where the outgoing coolant fluid is pushed through the fuel plates towards the reactor pool exit and then the water enters the delay tank. (AMF, 1966)

The reactor control system has two main tasks: 1) startup of the reactor and determination of the neutron production rate; and 2) control of reactor power against abnormal conditions caused by failures in structures, systems and components (SSCs). The reactor shall be immediately shut down in case of occurrence of an abnormal state. The control system consists of five control rods (neutron absorbents), four of them are safety rods and one is regulating (shim) rod (Argentina T.R.R., 1988).

TheI&C equipment including the detectors are installed in the reactor for determination of temperature, core neutron flux, coolant flow rate, etc. in normal and abnormal conditions. The devices continuously are monitored (by alarms) and controlled by the operators in the control room.

The initiating events (IEs) may interrupts the removal of heat from the fuel plates surface leading to unbalance in production and removal of heat in the reactor core which if not remedied the residual heat can cause the fuels to heat up and finally to be damaged and the radioactive material released to outside. Four accidents that can cause the lack of cooling in the core,

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i.e. LOFA, LOOP, LOCA and LOHA are analyzed in this paper.

REA AND MCUB APPROXIMATIONS

In RELAB, the probability of top event is approximated by using two methods of REA and MCUB. The approximate probability of the top event is calculated by the equation (1). The main assumption in this method is that the intersections among MSCs can be ignored.

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

MCUB approximation uses Sylvester – Poincare complete expansion. In case that all MSCs of fault trees are independent this method gives more accurate results for the top event probability. In equation (2) the calculation of top event probability is simply given.

SENSITIVITY ANALYSIS

Sensitivity analysis is the determination of amount of sensitivity of total risk of the system to the reliability of a component or its conditions /5/. The analysis is done by calculating the resultant of effects of input variables the probabilistic analysis model (FTAs). This process is repeated several times to find the components or systems which their reliability parameters variation have the most impact on the final risk of the reactor.

SENSITIVITY CRITERIA

In sensitivity analysis the increase or decrease of basic events are considered. In determining the sensitivity criteria, first the probability of the basic event or its corresponding parameters are multiplied with a number greater than one and the top event probability is calculated. Then the same calculation is repeated but with basic events divided by the same number. The sensitivity criteria is the ratio of the two resulted probabilities and is calculated according to the equation (3) where SensFactor represents the sensitivity factor which is by default assumed to be 10 in RELAB.

$$\text{Sensitivity} = \frac{R(E_i \rightarrow E_i * SensFactor)}{R(E_i \rightarrow E_i / SensFactor)} \qquad (3)$$

IMPORTANCE ANALYSIS

Importance analysis can be categorized in probabilistic safety assessment as qualitative and quantitative. Qualitative importance can be deduced from the analysis of logic model structures such as FTA. Quantitative importance which is the share of the components in collective probability density function is calculated by using systems failure probabilities, events sequence frequency or their collective density functions.Quantitative importance provides more details but requires uncertainty calculations(Modarreset all,2010).

IMPORTANCE CRITERIA

Importance criteria show the amount of importance of the component or system on the final risk results in the probabilistic safety assessment model. Importance criteria can be divided into two general categories of absolute and relative criteria. Absolute importance criteria shows the absolute alteration in final results of the risk analysis caused by variation in the model input parameters while relative importance criteria represents the change ratio of the final probabilistic safety results. Fussell – Vesely criteria is one of the main methods in probabilistic safety assessments and is used in this project.

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

a.Fussell – Vesely Criteria

In this method, the importance is defined as the relative share of an event in the accident chain frequency.Fussell – Vesely criteria for a basic event is the ratio of share of MSCs containing that event in the top event probability. In other words, Fussel-Vesely criteria for an event is the probability of occurrence of that event when the top event has occurred (Smith, C., 2008).

In view of this definition, Fussel – Vesely criteria for a basic event is the ratio of top event probability resulted from the MSCs which contain that event and the top event probability that contain all MSCs as presented in the equation (4) below.

$$\text{FV} = \frac{R(E_i)}{R_{base}} \qquad (4)$$

ANALYSIS AND RESULTS

Importance and sensitivity analysis provides a valuable tool for using probabilistic safety assessments in decision makings especially on allocation of resources. Furthermore, a proper importance and sensitivity analysis provides verification of the

credibility and quality of the model used in a probabilistic safety analysis. Usually, those components which have multiple effects on the results e.g. common cause failures (CCFs) or common mode failures (CMFs) are the best candidates for the importance and sensitivity analysis. A good sensitivity analysis consists of the following steps:

1. Identification of the components on which the final risk calculation resultsmight be sensitive.
2. Changing the components input data parameters.
3. Determination of the impact of the changes on the final risk results and identification of sensitive components.
4. Suggestions for further new candidates (components, systems, data, and models) based on the results from the previous stage.

At first, using FTA method, the IEs and the chain of events leading to the accident are identified. Then, by using the deductive methodology, assuming the four top events (accidents), the causing events such as inadequate response of safety systems are identified and modelled. The base reference for constructing the model is the Safety Analysis Report of Tehran Nuclear Research Reactor. Completion of the model and determination of IEs' frequencies and basic events and chain events probabilities has been done in close consultation with the experienced operators and safety experts of Atomic Energy Organization of Iran. In cases where no data was available, the generic data from references (IAEA-TECDOC-478, 1988) and (NUREG/CR- 6928, 2007) were used.

Considering LOCA accident, the results of importance and sensitivity analysis with Fussell-Vesel criteria, are shown in (Fig. 1) in which, 4 events have the highest sensitivities shown with numbers 0, 12, 13 and 14 in the figure that are respectively representative for the events: control rods failure, leakage from the ion filtration system, electrical failure of the primary pump, and mechanical failure of the primary pump.
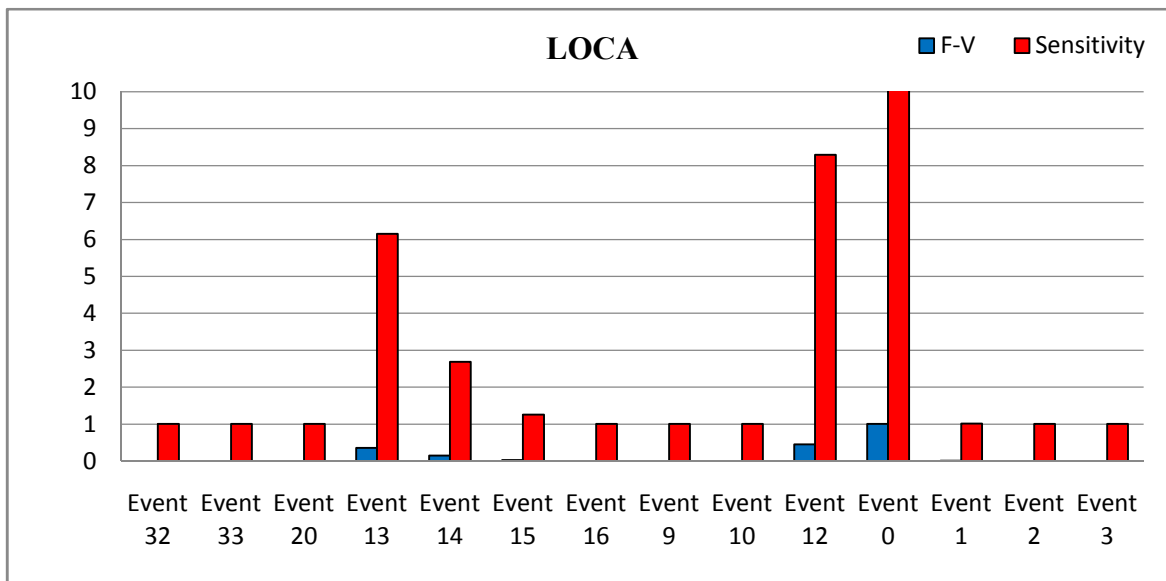

Figure 1. Results of Importance and sensitivity analysis for 34 basic events in LOCA

The results of the importance and sensitivity analysis for LOFA accident are shown in (Fig. 2.) The numbers 16,5,27,1,2,4 and 15 are representing respectively the most sensitive events: failure of control rod magnet, electrical failure of the primary pump, human error in opening and closing reactor pool valves (events 27, 1, 2), mechanical failure of the primary pump and control rod stuck failure.
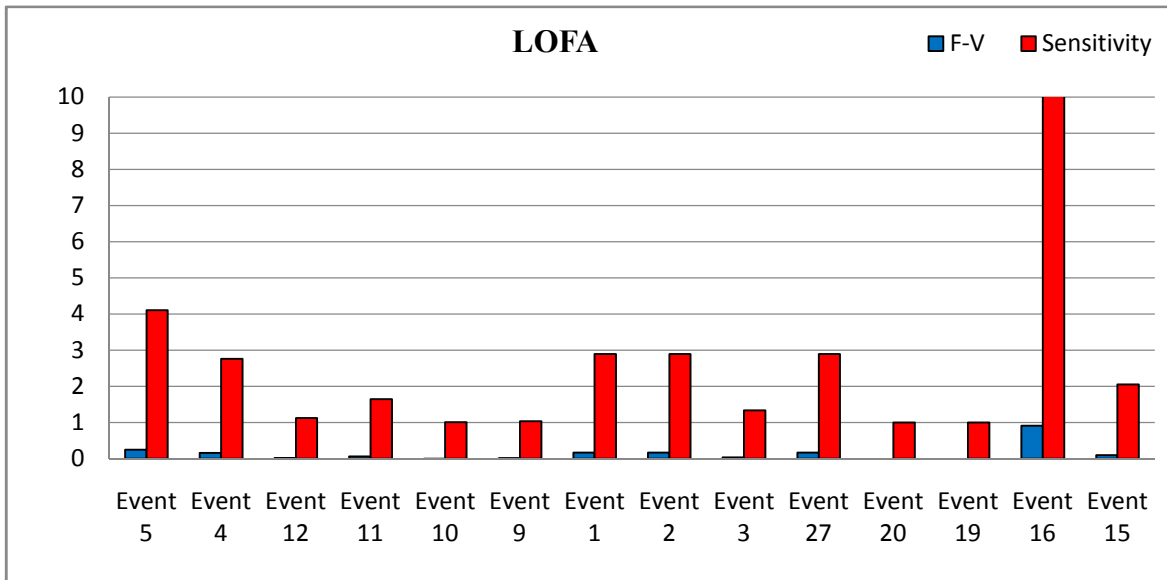
Figure 2.Results of importance and sensitivity analysis for 21 basic events in LOFA

According to (Fig. 3), the most sensitive components causing the top event LOHA, are the basic events numbers 10, 5 and 9

which respectively represents the events: cooling tower spray system pipes blockage, mechanical failure of the secondary pump and failure in closure of secondary loop valves.
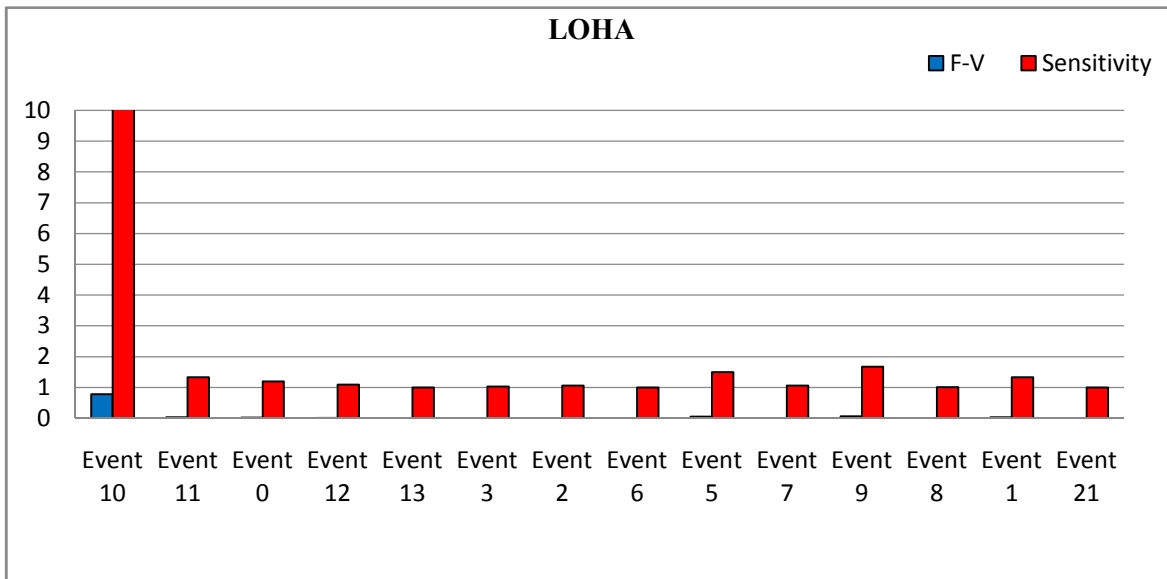

Figure 3.Results of importance and sensitivity analysis for 14 basic events in LOHA

Regarding LOOP accident two basic events are identified as the most sensitive which in (Fig. 4) is shown as 1 and 2 that

are respectively representative of the basic events: failure of the diesel no. 1 (450 KW) and loss of offsite power.
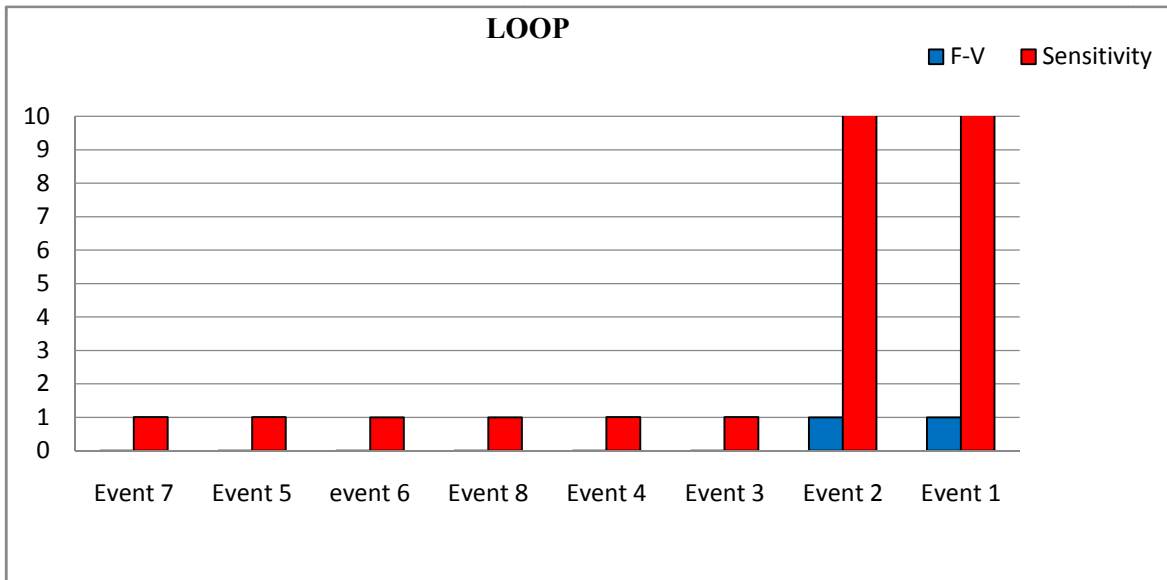
Figure 4. Results of importance and sensitivity analysis for 8 basic events in LOOP

DISCUSSION AND CONCLUSION

Generally, the most sensitivity in two accidents LOCA and LOFA are related to the failure of correct performance of control rods including failure of gear box, magnet and relays. The second sensitive event is mechanical failure of primary and secondary pumps. Reliability of the sensitive components shall be proactively enhanced through implementing preventive repair and maintenance measures. For LOHA accident, failure to remove the heat (improper performance of the cooling tower) are caused due to failure of the sprinkler system, blockage of the pipes or failure of the fan. In LOOP accident, failure to supply the power (failure of 450 KW diesel and the offsite power failure)are the most important factors. Improvement of the reliability of the diesel can be achieved through improvement of fuel supply system, startup air system, oil lubricating system, exhaust system, air intake and water cooling system. (Fig. 5) shows the most important and sensitive components in 5 basic events leading to all the accidents in Tehran Nuclear Research Reactor.
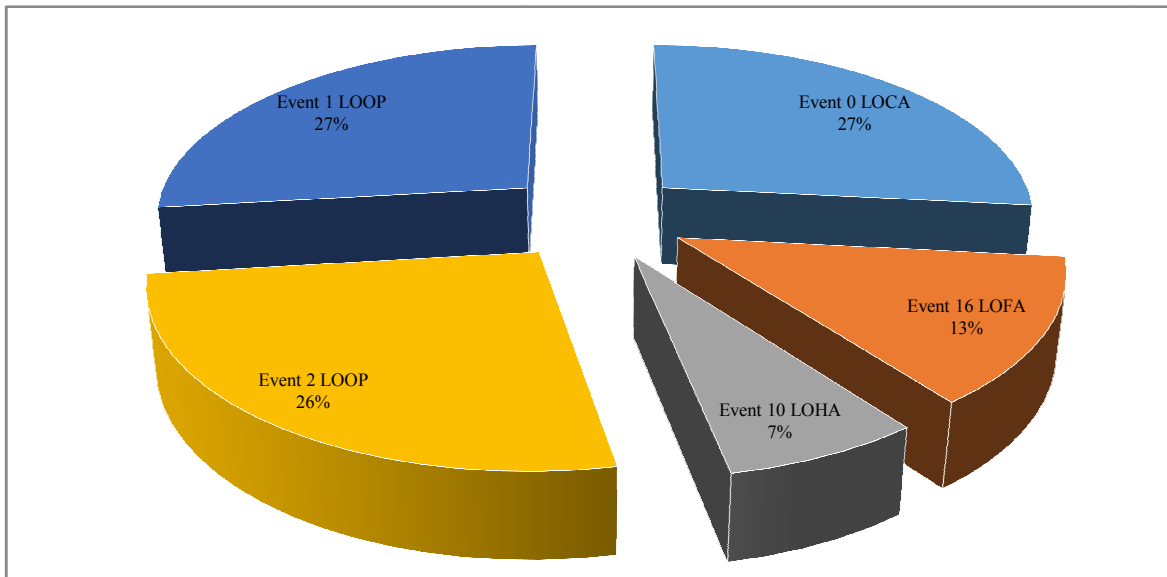

Figure 5.Results of importance and sensitivity analysis for 5 basic events for all probable accident in Tehran Nuclear Research Reactor

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