Conference Paper

Experiment for Justification the Reliability of Passive Safety System in NPP

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Abstract

This article gives an overview of the formation of the global nuclear industry, highlighted a critical issue of ensuring safe operation of nuclear power systems in modern projects. Considering the use of passive safety systems in the design of a nuclear power plant, and discussed the different mathematical methods for assessing the reliability of passive systems. Also it considers the possibility of finding the mean time between failures, using these methods to assess the reliability of passive safety systems.

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1. Introduction

Advanced nuclear power plants in the world consisted of many safety systems and equipment. These systems and equipment must be designed and installed at the station, and tested to ensure their quality and reliability, to perform three main safety functions: controlling the reactivity, cooling the reactor and containing the radiation.

2. Safety systems

Safety systems and safety equipment (component) are designed to prevent accidents and mitigate the effects of accidents once happened, according to the IAEA safety system defined as: *A system important to safety, provided to ensure the safe shutdown of the reactor or the residual heat removal from the core, or to limit the consequences of anticipated operational occurrences and design basis accident* [1].

The system which affecting the reactivity the NPP, are divided into active and passive. Passive systems do not need external energy sources for their work. As a rule, passive systems are less complex in their design compared to active safety systems, while active systems need an external power source for the operation, which reduces their reliability.

3. Passive safety systems

A safety system is basically composed of safety components, which are defined (by the IAEA) passive if they do not need any external input to operate [2]. If a component is not passive, it is necessarily an active one. This applies to whole safety systems as well: A passive system consists of passive components only, otherwise it is defined active. However, if a system uses active components in a very limited way, it can be labeled passive.

Passive component [2] defined as, a component whose functioning does not depend on an external input such as actuation, mechanical movement or supply of power, a passive component has no moving parts, and, for example, only experiences a change in pressure, in temperature or in fluid flow in performing its functions. In addition, certain components that function with very high reliability based on irreversible action or change may be assigned to this category.

These two types passive and active are distinguished from each other by determining whether there exists any reliance on external mechanical or electrical power, signals or forces. Passive safety systems are independent from such external factors and are instead reliant on natural laws, material properties and internally stored energy, this result in elimination of failures caused by human action or power failures. However, passive safety devices remain subject to failures due to mechanical or structural defects and they are not synonymous to absolute reliability.

There are four categories in total of passive systems and they are characterized as follows [1]:

- Category A
  - No signal inputs, external power sources or forces.
  - No moving mechanical parts.
  - No moving working fluids

For example physical barriers against the release of fission products.

- Category B
  - No signal inputs, external power sources or forces.
  - No moving mechanical parts.
  - Moving working fluids, which are due to thermal-hydraulic (T-H) conditions occurring when the safety function is activated.

For example emergency cooling systems based on air or water natural circulation in heat exchangers (HEX) immersed in water pools.

- Category C
  - No signal inputs, external power sources or forces.
  - Moving mechanical parts, whether or not moving working fluids are also present.
  - Mechanical movements are because of e.g. static pressure in valves.

For example checks valves and spring-loaded relief valves.

- Category D
  - Intermediary zone between active and passive. Execution of the safety function is made through passive methods.
  - External signal is permitted to trigger the passive process.
  - Passive execution/active initiation.
  - Energy only from stored sources.
  - Active components limited to controls, instruments and valves.

For example emergency core cooling systems based on gravity-driven flow of water, activated by valves which break open on demand.

Recently, passive safety systems are widely used due to their advantages in the innovative design of NPP in combination with active safety systems. Reliability of the passive system is higher than an active system because the risk associated with active (human error, power outage, etc.) can be neglected. However, the failure of passive systems may be mainly due to some physical phenomena or natural forces. Which need to be evaluated.

4. Reliability of passive safety system and methodology

The reliability of passive system can be defined as the ability to perform the requested safety function under dominates conditions when required and addressed mainly the related performance stability.

For calculating the reliability of a passive system and component, you need to remember that the failure rate depends on the mode of operation of this component, as well as operating conditions such as design factor, complexity and mechanical stress (vibration, shock loads, linear overloads), relative humidity, atmospheric pressure, sudden temperature changes etc. Thus, the failure rate of this type of component in real operation conditions is calculated by the formula:

$$\lambda_i = \lambda_{i0} * K_H * K_Э * K_t \ldots$$

λ_{i0} – is the failure rate of an element operating under normal conditions at a rated electrical load,

K – is correction factors, depending on various factors [4].

5. The relationships between the reliability and stresses

The relationship between system reliability and stresses mainly depends on the information obtained from operating experience that make us to understand the dependencies.

In the general form, the dependence of the failure rate of components from the environment has the form:

$$\lambda = f(t^0, h,\ x_g,\ P_p,\ \ldots), \tag{1}$$

Where t^0,h-temperature and humidity environment; x_g is the acceleration of the mechanical loads acting on the product; P_p-pressure load.

If the actions of these factors put independent, the failure rate of components in the operating mode is determined by the formula

$$\lambda_p{=}\lambda_0{*}k_1{*}k_2{\ldots}k_n, \tag{2}$$

$k_1, k_2, \ldots, k_n$—Coefficients characterizing the influence of certain types of impacts on the failure rate.

To assess the effect of operating conditions on the failure rate of components, we can limit ourselves to the consideration of the following factors: the effect of surrounding temperature k_1, pressure load k_2, mechanical loads k_3.

Let's consider a technique of definition of dependences (1) and (2) on experimental data. The analysis shows that, various empirical formulas can be adopted as such dependences, including polynomials of the nth power. In this case, the solution of the problem will consist in determining the constant coefficients of the desired dependencies, for which the "stretched thread" method, the "mean" method, the least squares method, and the maximum likelihood method can be used.

6. Mathematical methods for reliability assessment of passive system and component

6.1. The stretched thread method

This method is based on the geometric selection of the linear dependence $\lambda = f(t^0)$ on the eye. Taking two arbitrary points on the chosen line, find their coordinates $(x_1, y_1), (x_2, y_2)$ and make up a system of equations:

$$\begin{cases} a * x_1 + b = y_1 \\ a * x_2 + b = y_2 \end{cases}$$

solving it, find the coefficients a и b.

6.2. The mean method

This method is based on balancing experimental errors of the form $\Delta i = y_i - a * x_i - b$ for П observations $(i = 1, 2, ..., \Pi)$. All n observations are divided approximately in half and write a system of equations of the form:

$$\begin{cases} \sum_{i=1}^{m} \left(y_i - a * x_i - b\right) = 0, \\ \sum_{i=m+1}^{m} \left(y_i - a * x_i - b\right) = 0, \end{cases}$$

Solving this, find the coefficients a and b.

6.3. The maximum likelihood method

Let's assume that a priori we can accept the following relationship between the failure rate and the factors that affect it:

$$\Lambda(x, \vartheta_1, \vartheta_2) = \vartheta_1 \exp\{\vartheta_2 x\}$$

where *x*—is the magnitude of the external impact; ϑ_1, ϑ_2—are the parameters to be determined from the operation data.

Suppose that when operating system from N components of one type, acting in *r* devices in the modes $x_1, x_2, \dots, x_r$, received respectively $n_1, n_2, \dots, n_r$ failures. If the working conditions of the products in the circuits are independent, then the probability of obtaining a sample from $n_1, n_2, \dots, n_r$ of failures will be equal to

$$P(n_1, n_2, \dots, n_r) = \prod_{i=1}^{r} \frac{1}{n_1!} [\Delta\tau_i \vartheta_1 \exp\{\vartheta_2 x_i\}]^{n_i} - \exp\left[-\Delta\tau_i \vartheta_i \exp\{\vartheta_2 x_i\}\right],$$

Where $\Delta\tau_i$—duration of tests under external influences x_i.

Using the maximum likelihood method, equating partial derivatives with ϑ_1 and ϑ_2 from the logarithm of the reduced equation P($n_1, n_2, \dots,\ n_r$), we find the parameters solving the system of equations

$$\begin{cases} \vartheta_1 = \sum_{i=1}^{r} \dfrac{n_1}{\Delta\tau_i \exp\{\vartheta_2 x_i\}}, \\ \vartheta_2 = \dfrac{\left(\sum_{i=1}^{r} n_i x_i\right)}{\sum_{i=1}^{r} \Delta\tau_i x_i \exp\{\vartheta_2 x_i\}}. \end{cases}$$

7. Conclusion

Passive safety systems are believed to be more reliable than the active safety systems because of elimination of the need for human intervention, avoidance of external electric supply.

Evaluation of passive system reliability is a challenging task. It involves a clear understanding of the physics of the phenomena and failure mechanism of the system, which the designer must do before prediction of its reliability.

More research is needed to determine the applicability of the proposed method to evaluate the reliability of passive systems.

Logical continuation of the work will be carrying out experimental research work, which includes conducting field experiments with electrical products that are part of safety systems of nuclear power plants.

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