A Reliability Assessment Method for the VHTR Safety Systems

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1. Introduction

The Passive safety system by very high temperature reactor which has attracted worldwide attention in the last century is the reliability safety system introduced for the improvement in the safety of the next generation nuclear power plant design. The Passive system functionality does not rely on an external source of energy, but on an intelligent use of the natural phenomena, such as gravity, conduction and radiation, which are always present. Because of these features, it is difficult to evaluate the passive safety on the risk analysis methodology having considered the existing active system failure. Therefore new reliability methodology has to be considered. In this study, the preliminary evaluation and conceptualization are tried, applying the concept of the load and capacity from the reliability physics model, designing the new passive system analysis methodology, and the trial applying to paper plant. The Evaluation Method is as follows.

2. Methods and Results

The GAMMA+ CODE having been developed at the Korea Atomic Energy Research Institute was used for the reliability assessment of passive system, and the MGR400 was utilized for paper plant.

The Low pressure conduction cooling (LPCC) which has the highest temperature of nuclear fuel was chosen for the scenario of the accident. The fig.1. Below is the reliability of passive system procedure.

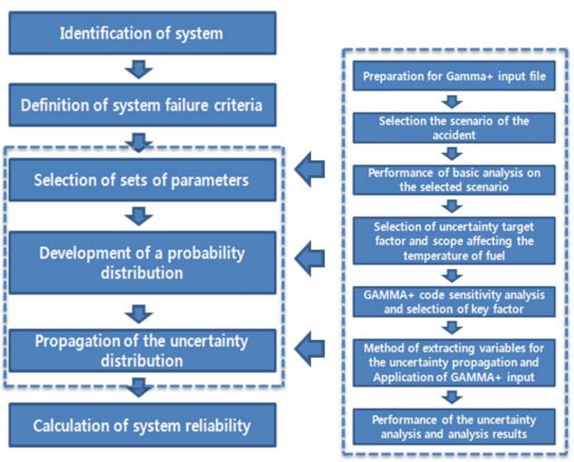

Fig.1. Reliability of passive system procedure

2.1 Identification of system

The Reactor core cooling system (RCCS) is the target of this reliability assessment. The RCCS removes the measure of decay heat when the normal core heat remover system like the intermediate heat exchanger and the shutdown cooling system doesn't operate.

2.2 Definition of failure criterion

After the LPCC accident happens, the temperature of nuclear fuels would rise because of the decay heat caused by the functional failure of the RCCS. Thus, 1600℃ at which the nuclear fuel can be maintained stable is defined as the failure criterion.

2.3 Selection of input parameters and Decision of distribution

Input parameters affecting the load are selected. In this study, 30 variables were chosen and the sensitivity was analyzed. After the analysis, 5 final variables were adopted and the distribution of the relevant variable did referring to the opinion of the specialists and reference.

2.4 Uncertainty analysis

The uncertainty of the load was analyzed from 5 variables selected above. The 90 different variable sets are extracted by using Latin Hypercube Sampling in Crystal ball. The number of variable sets is decided by using Wilks formula.

This formula is defined as following:

$$\beta = 1 - \gamma^N \qquad (1)$$

Where β is a reliability level, γ is percentile and N is number of simulation. We decide to perform simulation 90 times in 99% reliability level and upper 95% percentile in this study. The fig.2. Below is the result of the simulation. In the 13 of 90 cases, the results were over 1600℃.

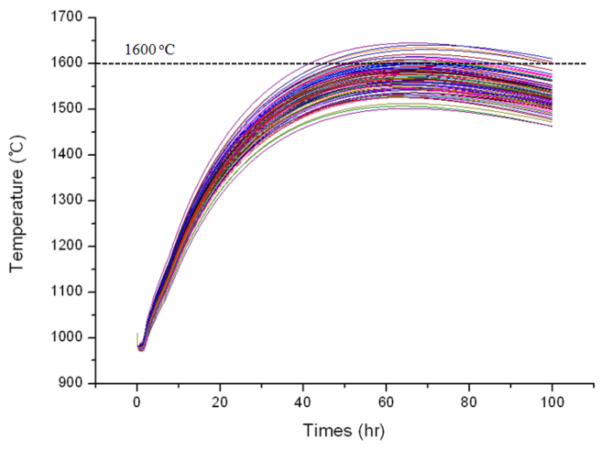

Fig.2. Realization for maximum temperature in the fuel

The distribution out of the highest temperature of nuclear fuels as a result of the uncertainty analysis has the normal distribution, N (1569.8, 28.96) and the characteristic is the table below.

Table I: characteristic of load distribution

Maximum temp.	*Minimum temp.*	*Average*	*Standard deviation*
1644.6℃	1501.5℃	1569.8℃	28.96℃

2.5 Calculation of failure probability

With the load and the distribution of capacity above, the failure probability was calculated. The Capacity is not the single value but the capacity model of probability applying EF=5. Fig.3. below is the load and the capacity model of this evaluation.

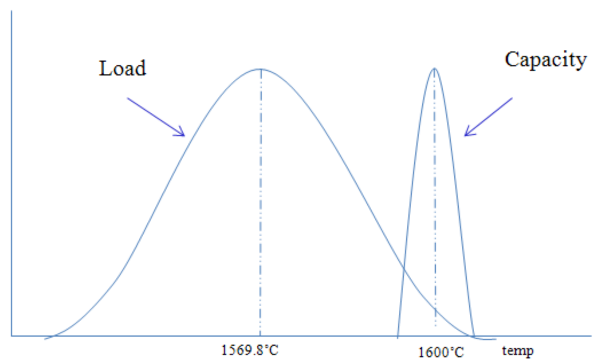

Fig. 3. Load and capacity of Maximum temperature

The program, POF, made using Visual C++ was utilized for calculation in order to analyze component life in nuclear safety part.

As a result, the failure probability was 0.148.

2.5.1 Probability of failure (POF)

POF, the program developed in the process of this study, is the program utilizing Visual C++ to analyze the component life in the nuclear safety part. It is possible to realize Monte Carlo method, which is more accurate, using Random function suggested by Visual C++ TR1 unlike Random function by the existing excel and it's easily available to lots of people. Failure in the specific components can be explained by the analysis of the relationship between the load and the capacity. Substituting the load on the system, structure, and component for L, the relevant capacity for C, Safety Margin is,

$$m = C - L \qquad (2)$$

The accident might happen, if the Safety Margin is negative number. But the load and the capacity for the each component exist stochastically, not a particular value. Through this, the parameter we can know is fixed and the failure rate is settled by the distribution. The load and the capacity of component have 5 kinds of distribution such as Uniform, Normal, Lognormal, Weibull and Beta. Based on this distribution, the POF program calculating the failure rate with the Monte Carlo method of each component is developed.

3. Conclusions

The result shows 0.157 after adjusting a final account using the passive safety system developed by this study. The reason that the failure probability is higher than expected is that the initial condition, 400MWt, makes the average temperature of nuclear fuels high in the accident. A new reliability analysis methodology developed by this study is not the method for design for system itself and the safety verification, but the result improved appropriately from the risk evaluative perspective.

Henceforth, the better result would be produced if the selection of major variable and the correlation of variables were considered with the GAMMA+ code.

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