A reliability assessment and optimization for a passive system of the very high temperature reactor

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1. Introduction

Most modern engineering systems are multidisciplinary and their analysis is very complex. This makes it difficult for users to make a decision optimization.

Optimization is powerful design improvement tool that is available nowadays. There are many optimization programs in modern society and it is used in various fields. Recently, a response surface was used to perform reliability analysis of a passive cooling system. In this study, PIAnO (Process Integration, Automation and Optimization) is used for assessing a reliability and optimizing a reference gas cooled reactor.

2. Methods and Results

2.1 Objectives of optimization for the VHTR

VHTR (Very High Temperature Reactor) is under development for the purpose of massive hydrogen production using high temperature coolant over 950 ℃ as well as co-generation of electricity. It is currently developed under the conceptual design phase, and it is necessary to perform more case study and progress.

Because of economics, safety, and reliability of the VHTR, it is an indispensable condition of the optimization. Fig. 1 is the procedure of optimization.

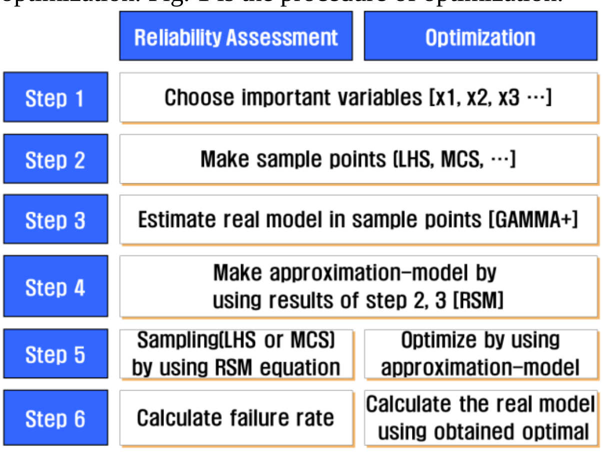

Fig.1. Reliability assessment and optimization by RSM

2.2 GAMMA+ code

The GAMMA+ code (The Gas Multicomponent Mixture Analysis) (T-H code) having been developed at the KAERI (Korea Atomic Energy Research Institute) was used for predicting the physical phenomena expected following the postulated accidents in a MGR-300[1]. The accident, the Low Pressure Conduction Cool-down (LPCC), which can reach the highest temperature of nuclear fuel was adopted in this study.

2.3 Choose important variables (sensitivity analysis)

Variables were selected that are expected to be able to influence fuel temperature when LPCC accident. Selected 9 variables, distribution and range of each variable were referring to the references and expert opinions [2]. Below is the result of sensitivity analysis.

Table I: Result of sensitivity analysis and 9 variables

	Nominal value	Range (%)	Max Tem.	Min Tem.	Importance
Decay heat ratio	Table	±5%	1563.5	1473.0	5.79%
Emissivity on metal surface	0.8	±20%	1510.1	1528.2	1.20%
RCCS loop junction area	Table		1517.8	1519.2	0.09%
Emissivity on RCCS surface	0.8		1517.8	1518.9	0.07%
Air inlet Tem. in RCCS loop	43℃		1518.8	1517.8	0.07%
Effective conductivity on fuel columns	Table		1518.5	1517.9	0.04%
RPV heat transfer multiplier	1		1518.5	1518.1	0.03%
Thermal heat conductivity in RCCS loop	Table		1518.3	1518.4	0.006%
Emissivity on graphite surface	0.8		1518.3	1518.3	0.001%

Maximum temperature of the fuel is very important. Because when it goes over more than 1,600℃, fuel cladding will be damaged and it leads to increase the probability of an accident. By optimizing through the above 9 variables tried to find the best way to lower the maximum temperature. Below is the result of 90 samples performed by GAMMA+.

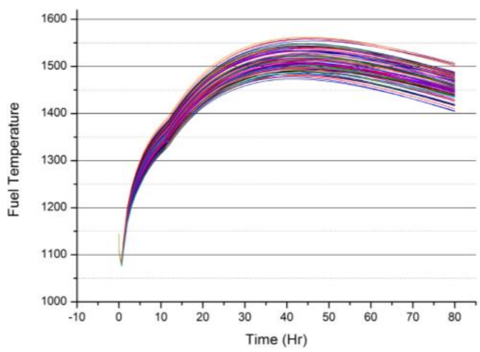

Fig 2. Result of 90 samples performed by GAMMA+Code

The distribution out of the highest temperature of nuclear fuels as a result the uncertainty analysis has the normal distribution, N (1514.011, 21.492).
The numbers of sampling are decided by equation:

$$X = 0.5(n+1)(n+2)\times 1.5$$

Where X is the proper number of the sample points, n is numbers of variables and 0.5(n+1)(n+2) is the least numbers of sampling which can make approximate model, and 1.5 is increasing the accuracy of the weights. If 9 variables are used, 82 sample points are required to make a more accurate equation.

2.4 Reliability assessment using RSM equation

Using the load and the capacity model generated in this study, the probability of the functional failure of the passive safety system was evaluated. The capacity model is not the single value but the distribution with error factor of 1.008. In Fig. 4, The load distribution assumed to follow a normal distribution and the capacity distribution assumed to follow a lognormal distribution values of each distribution N (1514.011, 21.492) and N (1600, 0.03).

2.5 PIAnO and Application

PIAnO is a PIDO tool supporting distributed computing, coupling analysis, and have various design methodologies. PIAnO associated with CAE can integrate and automate all the processes. It integrates analysis procedure, enables us to build automated design process and easier to use the latest techniques to optimize design [3].

It generates approximating models based on experimental data or analyzed results. It automatically generates samples using method of MCS or LHS and RSM model corresponding to the specified objectives. It is more effective and reduces analysis time when we use real model. Through this process, equations of five kinds of methods are available. Generally, the exact value can be obtained by using the more complicated equation. The below are equations:
1) Linear 2) Linear + interaction 3) Simple Quadratic 4) Full Quadratic 5) Simple Cubic
Select proper equation and then, optimize using PIAnO.

2.6 Results

In this study, LHS is used to sampling, simple cubic is used to build approximate model and STDQAO is used to optimize.

Reliability assessment is performed sampling the number of 1,000 by LHS using RSM equation shows the results the normal distribution, N (1514.142, 21.379). It is very similar to result of 90 samples. RSM equation can be adaptable to real estimates. The R^2 of RSM equation, optimization, and the result of the samples are shown below:

Table Ⅱ: The R^2 of RSM equation

Model	**1**	**2**	**3**	**4**	**5**
$\mathbf{R^2}$	93.887	96.193	94.405	97.310	98.303

TableⅢ: Optimization Result

		Lower bound	**Initial value**	**Optimal value**	**Upper bound**
Design Variables	x1	0.950	1.000	0.950	1.050
	x2	0.640	0.800	0.960	0.960
	x3	0.640	1.000	1.200	1.200
	x4	0.800	0.800	0.960	0.960
	x5	0.640	43.000	34.000	52.000
	x6	34.000	1.000	1.107	1.200
	x7	0.800	1.000	0.8000	1.200
	x8	0.800	1.000	0.800	1.200
	x9	0.640	0.800	0.960	0.960
Objective Function	G1	-	1517.955	1377.104	0.-
Constraints	G1	-	-	-	1600

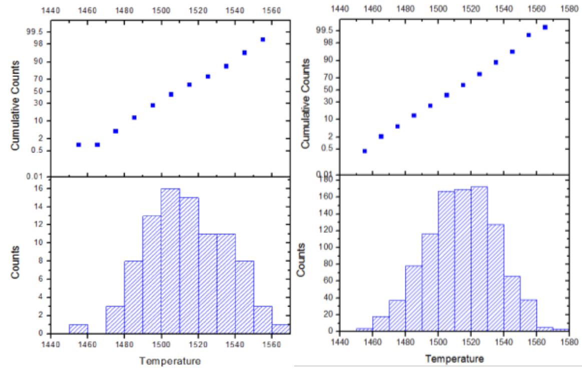

Fig 3. Result of samples performed by LHS using model2

3. Conclusions

The PIAnO can be applied in many parts of nuclear engineering. It is considered to save valuable work force and time from lots of sampling, reliability assessment, and optimization. It can reduce whole process time that takes more than 10 hours to a few seconds. Uncertainty analysis and optimization, design process is performed for at least one hundred times. However, by utilizing PIAnO, the RSM methodology is shown to reduce the calculation time. Therefore, it can be reached high quality with convenient and minimal trials.

ACKNOWLEDGMENTS
This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST) (No. 2011-0006354)

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