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A Simplified Quantitative Approach to the Reliability of a Passive Safety System

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1. Introduction

A simplified quantitative approach to the Reliability of a Passive safety System (RoPS) has been proposed for a risk estimation of a Very High Temperature Reactor (VHTR) for a hydrogen conversion.

A passive safety system that has a high reliability has being introduced to next generation reactors for a enhanced safety. The current risk estimation includes small parts of passive components such as pipes and check valves, but it does not consider a large-scale passive system adopted in the next generation reactor. There is no approved method to estimate the RoPS[1-3]. The RoPS is a technical issue for a future reactor development. There are two problems in the RoPS:

1. There is too little a population of a passive system to enable statistical treatment, i.e., there are no similar systems to obtain experience data.
2. There is an ambiguity in the failure criteria of a passive system for a nuclear facility, i.e., there is no reasonable reliability criterion as shown in Figure 1.

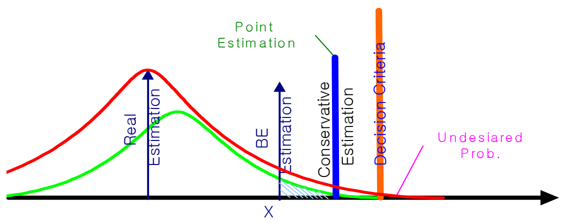

Figure 1. Reliability criteria and uncertainty

Numerous estimation approaches have been proposed in the world [2]. Most estimation methods are based on an uncertainty analysis by using a physical model of a passive system [3]. The uncertainty analysis by using a physical model is a complex and time-consuming approach.

1. It is necessary for a detailed analysis code to estimate physical characteristics.
2. The process to identify and define uncertainty parameters is complex and an uncertainty estimation of these parameters is another difficult problem.
3. This needs many re-runts of the code to propagate an uncertainty so an analysis often spends time according to the code scale.

Because of the above-mentioned reasons, this approach is not adequate to apply it to a conceptual design stage. In the conceptual design stage to compare several design options and conditions, an effective estimation approach is required rather than a precise estimation approach such as an uncertainty analysis by using a physical analysis code.

2. Reliability of Passive Safety System

A passive system is defined that a passive component does not need any external input (especially energy) to operate [1]. There are advantages of a passive system to be used in nuclear facilities:

1. Simplicity.
2. Reduction of the need for human interaction.
3. Reduction or avoidance of external electrical po wer.

On the other hand, it has disadvantages:

1. Detractions like lack of data on some phenomena.
2. Missing operating experience over a wide range of conditions.
3. A less effective performance as compared to acti ve safety systems.

The reliability of a passive system is defined as the probability to perform the requested mission to achieve the generic safety function. A passive system is classified by the following categories [1]:

A: physical barriers and static structures
B. moving working fluids
C. moving mechanical parts
D. external signals and stored energy

The unique features of the RoPS are that there is not yet an agreed approach towards their reliability assessment.

- Failure modes and unavailability of passive compone nts, i.e., the definition of success criteria, data bound ary.
- Testing or operative limited experience do not adequ ately demonstrate the successful operation of passive components.
- Engineering judgment is required to determine which existing data are most applicable to the new systems or which generic databases or models provide the bes t information for a new design

3. Simplified Quantitative Approach

This paper proposes a new approach to estimate RoPS based on a typical reliability model as shown in Eq (1).

$$R_{PS} = \prod_i R_i \quad (1)$$

Total reliability of a passive system can be divided into several elements. We propose six elements, which are extracted by considering the essential features of a reliability.

1. Completeness: the completeness is to estimate the consideration of all factors for the RoPS.
2. Parametric uncertainty: the propagation uncertainty by parametric uncertainty is a basis of the reliability estimation by using physical model.
3. Components reliability: the physical reliability estimation for a large passive system does not cover the reliability due to sub-components and structure. The reliability of components in a passive system should be estimated and included in the system reliability estimation.
4. Maintenance: it is expected that a maintenance strategy of the passive system is quite different from active systems. The unavailability of a passive system due to maintenance should be estimated and that due to test and inspection should be considered.
5. Human factor: a concept of the passive system is designed to minimize the operator action but this does not admit to reject an estimation of human factor. The estimation of human factor due to several kinds of operator's action should be considered.

The system reliability can be obtained by an integration that multiplies the reliability of each factor as shown in Eq. (2).

$$R_{PS} = R_c \cdot R_p \cdot R_r \cdot R_m \cdot R_o \qquad (2)$$

4. Example

An application example for a feasibility study was considered for a reactor core cooling system (RCCS) concept. The RCCS that consists of (1) an air cooling system and (2) a direct vessel cooling are designed to remove decay and residual heat of a VHTR without any active power. Figure 2 shows a brief conceptual layout of the RCCS [4].

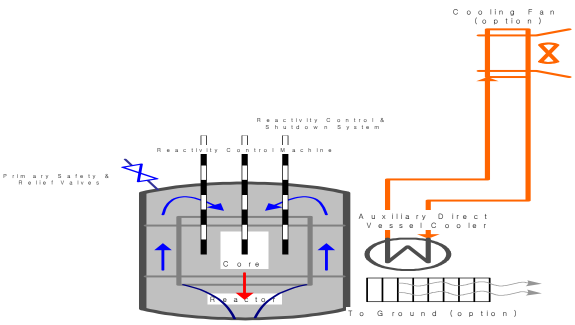

Figure 2. A brief concept of the RCCS

The estimation of each factor has used the subjective estimation method (Table 1). Because of the high reliability of a passive system in the current estimation, the maintenance factor is a major contributor of the RCCS. The estimation showed a crude schematic procedure of RoPS, so the numerical result was a less meaningful value, but this showed the feasibility of the proposed approach.

Table 1. Several approaches for the identification of the initiating events

Factors	Estimation (pro. per demand)		Items	Remarks
	Point E	EF		
Completeness	0.999	10	Rare experience	
Parametric Uncertainty	0.999	3.5	Design &safety analysis	Design &safety analysis code and methodology
Components Reliability	0.999	10	Reliability assessment	Design and spec. P&ID
Maintenance	0.97	2	Tech. spec. & experience	Inspection&test Maintenance strategy
Operator Action	1.00	2	No Estimation	Human factor
System	2.94E-02			

5. Concluding Remark

This paper has proposed a simplified and effective estimation of the RoPS for the conceptual design stage of a VHTR. According to the feasibility estimation, this paper has shown that the proposed approach can be useful in a estimation of the RoPS. To show the applicability of this approach, an effort for a detailed assessment and a precise estimation method for each factor is needed.

ACKNOWLEDGEMENT

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REFERENCES

[1] Passive system reliability-A challenge to reliability engineering and licensing of advanced nuclear power plants, International workshop (CEA), NEA/CSNI/R (2002)10, Cadarache, France, 2002.
[2] Luciano Burgazzi, "State of the art in reliability of thermal-hydraulic passive systems, Reliability Engineering & System Safety," In Press, Corrected Proof, Available online 17 April 2006.
[3] Michel Marquès, et al, "Methodology for the reliability evaluation of a passive system and its integration into a Probabilistic Safety Assessment," Nuclear Engineering and Design, vol. 235, Issue 24, pp. 2612-2631, December 2005.
[4] Seok-Jung Han & Joon-Eon Yang, "A Preliminary Neutral Framework for the Accident Sequence Evaluation for a Hydrogen Conversion Reactor," 2005 KNS Autumn Conference, 2005.