A comparison of the risk measures between VHTR and LWR

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1. Introduction

Because the safety characteristics of a very high temperature reactor (VHTR) [1] are different to that of light water reactors (LWRs), it is necessary to develop an adequate probabilistic safety assessment (PSA) methodology in order to perform a risk assessment.

The inherent safety features of the VHTR are (1) simplified safety functions (2) the absence of the large release of radioactive materials such as a severe accident in LWRs as shown in Table 1. The PSA methodology for LWRs cannot be directly applied in a VHTR PSA.

This paper proposes a PSA methodology for a VHTR. The essential point of the proposed methodology is to define end states of accident sequences in order to establish the risk measures for a VHTR PSA. This paper compares them with that for LWRs to discuss the differences of them.

2. Risk Measures

In order to develop an adequate PSA methodology for the VHTR, one should consider specific features appearing in a VHTR PSA. These features are the following:

(1) Absence of core damage and
(2) Absence of severe accidents and a containment.

These cause a difficulty in establishing risk measures such as a core damage state in the LWRs PSA. That is, the typical risk measures in the LWRs PSA as shown in Table 2 cannot be applied to a VHTR PSA.

In order to establish an adequate definition of a risk measure for a VHTR, an assessment has to start from the fundamental basis of a PSA for nuclear plants. The final goal of a PSA is to estimate a risk due to the release of radioactive materials to the environment according to accidental situations during the operation of a plant.

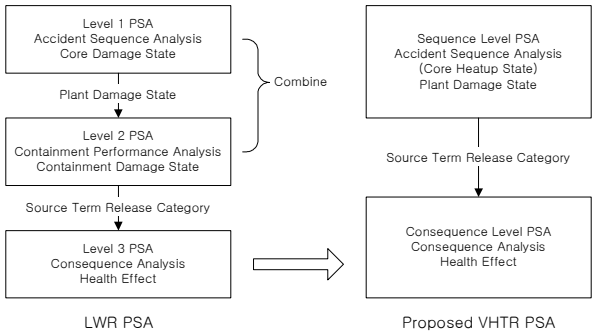

Fig. 1. A proposed PSA procedure

The typical PSA methodology for LWRs consists of 3 stages, i.e., level 1, level 2 and level 3 PSA as shown in the left-side of Fig. 1. Fig. 1 shows that the final results of a PSA are expressed by consequential effects, i.e., health and environmental impact from a radiation release. Because of the safety features of a VHTR, the level 1 and the level 2 PSA for LWRs can not be directly applied in a VHTR PSA. The essential point of a PSA methodology for a VHTR is to establish an adequate method to solve the above mentioned issues.

This paper proposes a 2-stage PSA for a VHTR as shown in the right-side of Fig. 1:

(1) Sequence level PSA and
(2) Consequence level PSA.

To apply 2-stage PSA, one should establish an adequate interface between a sequence level PSA and a consequence level PSA.

In LWRs, the plant damage state has been used for the interface between the level 1 and level 2 PSA and the source term release category (STC) has been used for the interface between the level 2 and level 3 PSA. This can not be applied to a VHTR PSA.

This paper proposes the STC as the interface between the sequence level and the consequence level PSA. For this purpose, risk measures which can summarize the results of the sequence level PSA are required, while a STC should have an adequate detail to be needed for a consequence level PSA. A degree of detail of a STC depends on the level of depth of that. In order to satisfy both requirements, this paper adopts 2-step clusters for the STC, i.e., plant damage state (PDS) and core heatup state. These cluster states look similar to that of a LWR PSA but the radiation release rates in each state of a VHTR PSA are much smaller than that of LWRs.

For example, if 15 STC are needed for the consequence level PSA, the end states of accident sequences are too large to summarize accident sequences. The results of the sequence level PSA can classify 5 different PDS which describe the end states of accident sequences of a VHTR. These can be grouped according their core heatup states, i.e., a normal core heatup and an unfavorable core heatup. Table 4 shows a hierarchy of risk measures for the VHTR.

The proposed classification of an accident sequence is different to that for LWRs because the amount of radiation release from a VHTR is much smaller than that from LWRs, but the proposed approach is useful to express a sequence level PSA.

3. Concluding Remark

This paper proposed a 2-stage PSA methodology for a VHTR PSA and discussed the differences of the proposed approach by comparing it with that of LWRs. The proposed approach will be applied to a VHTR PSA.

ACKNOWLEDGEMENT

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REFERENCES

[1] Jonhwa Chang et al, "A study of a nuclear hydrogen production demonstration plant," Nuclear Engineering and Technology, Korean Nuclear society, Vol. 39, No.2, pp.111-122, April 2007.

Table 4. Risk measures for the VHTR

Core Heatup State	Plant Damage State	Source Term Release Category
Normal Core Heatup	Normal (E)	IC, IP
	Release (D)	IT, IF, SPNR
	Release (C)	SPNB, SFNR, LPNB
Unfavorable Core Heatup	Release (B)	SFNB, SFAR, SFAB, LPAB, LFNB, LFAB
	Release (A)	DX, DU

Table 1. Safety features of the VHTR

	Safety Function	VHTR	Remarks
Prevention	Inherent Safety Features	Low Power Density Strong Negative Feedback Strong Fuel Configuration (Coated Particle) Large Heat Capacity of Graphite Core	ATWS / Return to Power
	Reactivity Control	Reactor Control &Protection System	ATWS
	Coolant Makeup	Helium Supply System	Leak &Pressure Conserve Function
	Auxiliary Cooling System	Auxiliary Cooling System Direct Vessel Cooling System	Heat Bypass to Ground (option)
	Long Term Cooling System	N/A	Possible Indirect Cooling & No Steam Generator
Mitigation	10CFR50.46 ECCS Rule*	N/A	Gas Coolant System
	General Design Criteria (10CFR50 App. A)	Single Failure Criteria	Not Applicable to Passive System (with loss of off-site power)
	Containment (10CFR50 App. A)	Confinement Purge System Emergency Air Purification System	LWR v. GCR N/A

Table 2. The risk metrics for LWRs

PSA	Mode & Interface	Factor or State	Measure	Remark
Level 3	Health Effect	Early Fatality	Exposure Dose	Direct Measure/Indicator
		Late Fatality (Cancer Fatality)	Exposure Dose	Direct Measure/Indicator
	Source Term	Source Term Release Category	Release Amount (Bq, Ci …)	Nuclides Release Fraction
Level 2			Source Term Release Category	Interfacial Measure
	Containment Damage	Containment Damage State	(Large) Early Release Frequency	Basic Measure/Indicator
			(Large) Late Release Frequency	
			Small Release Frequency, etc	
	Plant Damage	Plant Damage State	PDS Frequency	Interfacial Measure
Level 1				
	Core Damage	Core Damage State	Core Damage Frequency	Basic Measure/Indicator

Table 3. A proposed risk metrics for the VHTR

PSA	Mode & Interface	Factor or State	Measure (Indicator)		Remark
Consequence Level PSA	Health Effect	Early Fatality	Exposure Dose		Direct Measure/Indicator
		Late Fatality	Exposure Dose		Direct Measure/Indicator
	Source Term	Source Term Release Category	Release Amount (Bq, Ci …)		Nuclides Release Fraction
Sequence Level PSA			Source Term Release Category		Interfacial Measure
	Plant Damage	Plant Damage State	PDS Frequency	A	Proposed Measures for VHTR Risk Assessment
				B	
				C	
				D	
				E	
		Core Heatup State	Unfavorable Core Heatup Frequency		Supporting Measure