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Determination of PARs Capacity for HMS in EU-APR1400

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1. Introduction

The Hydrogen Mitigation System (HMS) is designed to control combustible gas, mainly hydrogen gas (H_2) inside containment within the acceptable limits by the Passive Autocatalytic Recombiner (PAR) with consideration of hydrogen generation during severe accidents.

In EU-APR1400 (European APR1400), a passive hydrogen control system which is composed of a number of PARs, is adopted for the mitigation of the hydrogen-induced risks. For the design of the HMS, the expected ranges for the global and local hydrogen concentrations in the containment and the increase rate of the concentrations should be examined to specify the required capacity and locations of the PARs.

This paper describes the determination of PARs capacity for HMS in EU-APR1400.

Fig. 1 Examples of PAR

2. Methodology for Calculation

2.1 Design Requirements for HMS

Based on European Utility Requirements (EUR) [1], the general requirements of HMS are as follows:

- If not inerted during power operations, the Primary Containment shall be equipped with hydrogen concentration limitation devices, including catalytic recombiners and/or igniters to cope with considered accident conditions and to comply with the deterministic requirements (EUR 2.9 4.1.3.3 A).
- System activation shall be passive or automatic if needed within 12 hours of accident initiation (i.e. no manual action can be credited in this timeframe) (EUR 2.9 4.1.3.3 C).
- If the containment atmosphere has not been inertised, the design shall assure, to provide additional margin against hydrogen detonation, that, assuming a hydrogen production equivalent to 100% of active fuel cladding/water interaction and a realistic production rate, then the average hydrogen concentration in the containment will not exceed 10% by volume in dry conditions, giving credit to hydrogen control measures as recombiners and/or igniters (EUR 2.9 3.1.7.5 C).

2.2 Calculation of Hydrogen Source Terms

The MAAP4.07 code [2] is used to evaluate the quantities of in-vessel and ex-vessel hydrogen generation. The MAAP4 calculation is performed until an amount of the hydrogen becomes equivalent to that provided by 100% fuel-cladding Metal Water Reaction (MWR) in compliance with the criteria, EUR.

2.3 Consideration of the Uncertainty on Hydrogen Source Terms

Conservative treatments are implemented for the analysis in consideration of the uncertainties on severe accident phenomenological modeling and accident progression relevant to the hydrogen generation. This result would be used to determine the required capacity of HMS in EU-APR1400 and to confirm that the HMS can maintain the hydrogen concentration below volumetric 10 % at any compartments within the containment

3. Determination of PARs Capacity

3.1 Selection of Accident Scenarios

For the hydrogen control analysis in EU-APR1400, most probable accident sequences of the APR1400 type plant, Shin-Kori Unit 3 and 4 were referred to encompass the sequences having high core damage frequency. PSA Level 1 works classify dominant accident sequences by those contributions on a core damage frequency. Although it cannot be credible for them to generate the hydrogen to the extent needed for the hydrogen control analysis, these accident scenario can be accepted as reasonable for severe accident analysis. Except for ones not applicable for MAAP calculation, a number of highly probable accident sequences are selected as follows:

- Station Blackout with Turbine Driven Pump operation of 8 hours: SBO
- Steam Generator Tube Rupture with ASC (Aggressive Secondary Cooldown): SGTR-S28
- Total Loss of Component Cooling Water with RCP seal failure: TLOCCW-S3
- Small Break Loss of Coolant Accident with ASC: SLOCA-S22
- Steam Generator Tube Rupture without ASC: SGTR-S29

For all the accident scenarios, the operation of ESFs (Engineered Safety Features) such as safety injection system is not considered. And, for escaping the inert condition of the containment atmosphere, it is assumed that the containment spray system is operable for all accident sequences. These seven accident sequences above are thought to properly present the representative release modes and rates.

3.2 Calculation of Hydrogen Generation

The numerical simulations for the selected accident scenario described above are performed using MAAP4 code. The hydrogen generation could be predicted by a simulation of selected accident scenarios considering several phenomenological mechanisms during accident progression. However, in MAAP4 input preparation, user-specified modeling parameters are so important for predicting the amounts and rates of hydrogen generation that a conservative approach is required for these parameters.

The accident progressions can be illustrated by Fig. 2 where total integrated masses of hydrogen generated within the containment are shown for all the accident sequences. In-vessel hydrogen generation begins when the fuel element has been uncovered and damaged due to the decrease of the coolant inventory undergoing. And continuing core melt progression accompanying core material interactions accelerates the hydrogen generation and then violent generation continues until the corium makes the core support plate failed. During this process, the hydrogen generation is limited by steam availability in the RCS and the time span of the core melt progression.

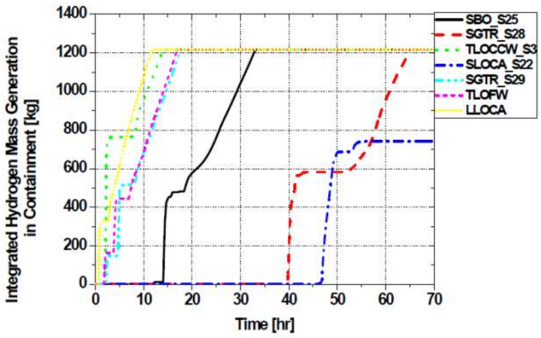

Fig. 2 Hydrogen Generation for the Selected Accident Scenarios

3.3 Determination of PARs Capacity

Basically, the design of PAR is performed by general finding that PAR behaves volume-specific manner and its function is independent of specific location in a compartment. For conservatism, the most severe consequence covering whole consequences is used as the hydrogen source term for the HMS design. Once the hydrogen source term is presented, a single-volume approach assuming a well-mixed condition of the containment atmosphere is applied for determining the PARs capacity to maintain the averaged hydrogen concentration below volumetric 10% limits.

The mass of hydrogen to make excessive hydrogen concentration over volumetric 10% should be depleted during the period when PAR can be operational for satisfying the criterion in EUR.

In this research, the PAR model with NIS correlation [3] of two PAR model types is applied for the conservatism because it shows lower depletion rated compared with the other model with Framatome (AREVA) correlation [3].

The volumetric averaged hydrogen concentration in dry condition is calculated as shown in Fig. 3. Among various accident scenarios selected, LLOCA (Large Break LOCA) shows the maximum required PARs capacity, 25.5 of full size NIS PARs in consideration of hydrogen depletion rate. The final capacity of PARs for HMS in EU-APR1400 was determined as 31 of full size PARs, which is 1.2 times of the required PARs capacity.

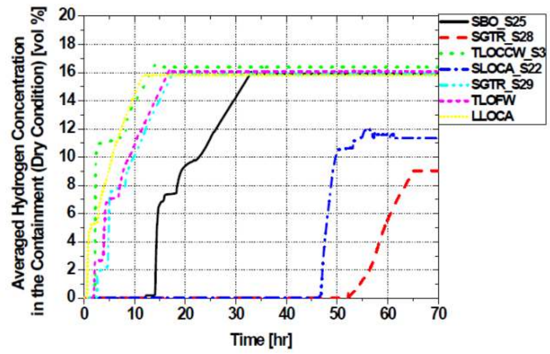

Fig. 3 Volumetric Averaged Hydrogen Concentration in the Containment without the HMS (In dry condition)

4. Conclusions

In this paper, the amount of hydrogen generation is predicted and the required PARs capacity is calculated for selected accident scenarios using MAAP4 code.

Based on the results, the final capacity of PARs in EU-APR1400 is determined to be equivalent to 31 of full size PARs considering the uncertainties and conservatism.

Acknowledgement

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