Sensitivity Study on Hydrogen Generation in APR1400 RPV by MELCOR code

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1. Introduction

In the severe accidents of nuclear power plants, hydrogen can be generated in the reactor pressure vessel (RPV) by the chemical reaction of the metals with water called metal-water reaction (MWR). The amount of metals such as zirconium (Zr) and stainless steel (SS) in RPV and of water available which depends on the accident sequence will affect the hydrogen generation along the accident progression. The initial mass of structural materials including Zr and SS in RPV are known to be one of the most important sources of uncertainties in the input parameters. In this paper, the MELCOR code version 1.8.6 [1] is used to estimate how much hydrogen will be generated for the various accident scenarios. A sensitivity analysis has been performed to study how the initial mass of SS in lower plenum affects the hydrogen generation in RPV of APR1400 [2] for typical severe accident sequences such as loss of coolant accident (LOCA) and station blackout (SBO).

2. Results and Discussion

For LOCA, three break sizes are considered: 6 inch, 9 inch and 20 inch inner diameter piping. A guillotine break is assumed to occur at 0 sec at one of the cold legs. The break size is assumed arbitrarily to facilitate the accident progression fast. As for another accident scenario SBO, station blackout is assumed to occur at 0 sec and a PSV valve will open and close repeatedly depending on the RPV pressure. Initial RCS water inventory is assumed to be 285 tons.

Simultaneous trip of the reactor, *RCP* and main feed water flow (MFW) is assumed to occur at 0 sec for both LOCA and SBO. In all the sequences the worst case assumptions are made on the availability of engineered safety features to facilitate the accident progress fast; i.e., Safety Injection system (SIS) and Auxiliary Feed Water System (AFWS) are assumed to be unavailable in all sequences. Only the four Safety Injection Tanks (SIT) are assumed to be working to inject water (210 tons) into RPV when RCS pressure falls below 4 MPa.

The core is modeled by 5 radial annular regions and 16 axial levels in the COR model for APR1400 reactor core [3,4,5,6]. The major materials of core and lower plenum are Uranium dioxide (UO2, 118 tons) in the fuel, Zr in the fuel cladding and SS in the structures. When the water level drops below core top and fuel begins to uncover, Zr begins to be oxidized by high temperature steam and produce hydrogen. If water level drops below core bottom level, SS in lower plenum is oxidized and produces hydrogen, too. In the MELCOR code, for the purposes of oxidation, SS is divided into the constituent elements of Iron (Fe) and Chromium (Cr) according to the mole fractions optionally specified in Material Properties (MP) package. The reaction equations for Zr and SS are given by

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2 + Q$$
$$Fe + H_2O \rightarrow FeO + H_2 + Q$$
$$2Cr + 3H_2O \rightarrow Cr_2O_3 + 3H_2 + Q$$

In the MELCOR code, the in-vessel structural materials can be modeled in the Core (COR) package or in the Heat Structure (HS) package. If the materials are modeled as COR material, it would be melted automatically. If the materials are modeled as HS as of *core shroud* or *upper plate* of PWR, then it can be melted or not melted depending on the user's choice of "*Degassing*" option in HS package. So the initial amount of SS can be different depending on the user's option. In this paper, the initial amount of Zr is assumed the same (28 tons) for all the accident scenarios. Only the initial amount of SS varied. Two cases of different initial SS mass are considered; 34 and 44 tons (designated as SS34 and SS44 cases in figures and tables) .

As accident progresses, the water level in the RPV is decrease as shown in Fig. 1. Decreasing of water level makes heating of Zr in core and SS in lower plenum. When the coolant temperature is high (>1000K), the exothermic oxidation process occurs. Depending on the accident sequences, the water level behaviors in the RPV are different, which result in different amounts of oxidization of Zr and SS. The hydrogen production will cease when the water inventory in the RPV is exhausted or when all of the metals such as Zr and SS are fully oxidized. Then they will be discharged to the cavity when the vessel failure occurs. Fig. 2 and Fig. 3 show the behaviors of mass change in RPV for Zr and SS, respectively. In Fig. 2, the slow progressive decrease of Zr is due to the oxidation of Zr in the active core region and slumping down to lower plenum, while the fast rapid decreases are discharge from RPV due to the failures of reactor vessel lower head ICI penetrations. Zr can be discharged fully to the cavity. However, some amount of SS in the outer most annular region can remain in the RPV if it is not fully melted in the lower plenum as shown in Fig. 3. The masses of metals oxidized are different among different sequences as shown in Table 1. Even in the same sequence, the amounts of Zr mass change are different between SS34 and SS44 cases.

As a result, the amounts of hydrogen generation are different depending on the accident sequences (6, 9, 20 inches LOCAs and SBO) and on the initial conditions (SS34 and SS44). The amounts of hydrogen generation in the RPV vary from 406 kg to 754 kg (Fig. 4 and Table 2). The SBO sequence has generated the largest amount of hydrogen compared to the LOCA sequences. This is because the time duration during which the metals (Zr and SS) react with high temperature water is longer in SBO sequence than that of LOCA sequences (the time for water level reaches to the bottom of lower plenum is longer, so more metals is oxidized in SBO).

Table 1. Masses of metals oxidized (Unit: Tons)

Sequence	SS34 Case		SS44 Case	
	Zr (%)	SS (%)	Zr (%)	SS (%)
6LOCA	9.39 (33)	4.50 (13)	9.67 (34)	5.10 (15)
9LOCA	8.04 (28)	2.24 (7)	5.30 (18)	5.70 (16)
20LOCA	7.01 (25)	7.38 (22)	7.42 (26)	6.82 (20)
SBO	12.75 (45)	6.54 (19)	12.99 (46)	6.08 (17)

Note; (%) indicates how much % of metal oxidized.

Table 2. H_2 produced in core by MWR (Unit: Kg)

Sequence	SS34 case			SS44 case		
	From Zr	From SS	**Total**	From Zr	From SS	**Total**
6LOCA	415	144	**559**	427	156	**583**
9LOCA	355	96	**451**	234	172	**406**
20LOCA	310	194	**504**	328	177	**505**
SBO	563	151	**714**	574	180	**754**

3. Conclusions

Using MELCOR 1.8.6 code, the amount of hydrogen generation from the reaction of zircaloy cladding and stainless steel structural materials with high temperature water in RPV is compared among various LOCAs and SBO sequences. The hydrogen generation is largest in SBO case. This is because the duration during which the metals interact with high temperature water is longer in SBO than LOCA cases. Depending on the water available during the accident and on the amount of metals in RPV, the amount of hydrogen generation can be different. This means that the hydrogen production depends on the different accident scenario and different user's options on the initial metal masses which can be melted during accident in the RPV.

REFERENCES

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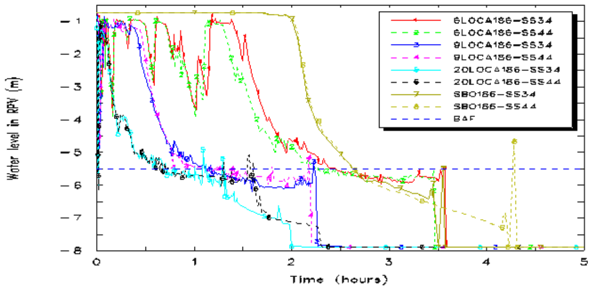

Fig.1 Water level in RPV

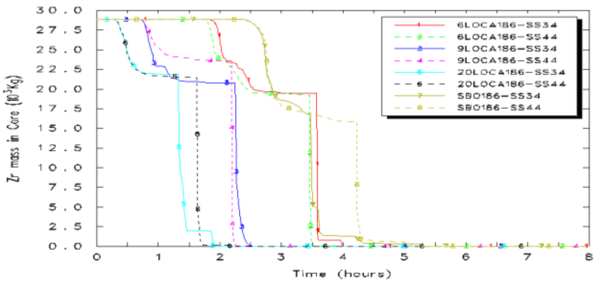

Fig.2 The change of Zr mass in RPV

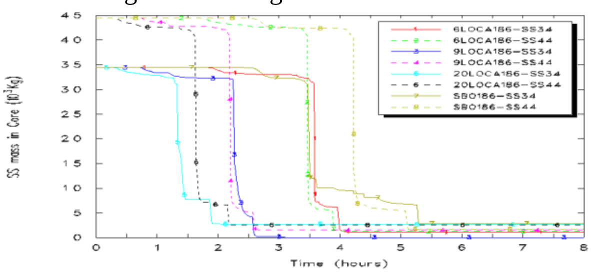

Fig.3 The change of SS mass in RPV

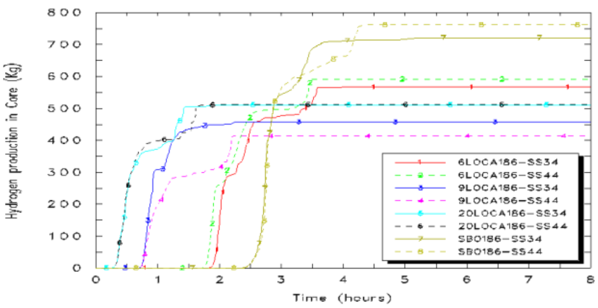

Fig.4 Total hydrogen production in RPV