Determining the Location of Hydrogen Recombiners in the Containment of VVER-1000/V446 Nuclear Reactor

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Abstract
An applicable approach for mitigating the hydrogen risk in severe accident conditions is the use of hydrogen recombiners inside the reactor containment compartments. In this study, three major possible hydrogen-producing accidents are simulated by Relap5/SCDAP and MELCOR codes including a large break loss of coolant accident (LBLOCA) in cold leg, station blackout (SBO) accident and LBLOCA+SBO to determine the appropriate arrangement of RVK-500 hydrogen recombiners inside the VVER-1000/V446 reactor containment. The results show that the final proposed layout for hydrogen recombiners is able to decrease the maximum peak of hydrogen mole fraction for the three mentioned accidents by 0.00, 14 and 10.3%, respectively.
Keywords: Severe Accident, Hydrogen Recombiner, VVER-1000/V446 reactor, Containment.

Introduction
A review of major nuclear disasters in the world illustrates that hydrogen production and its deflagration or explosion/detonation play an important role in threatening the reactor's containment integrity. One of the common approaches for reducing the hydrogen concentration inside the containment of nuclear power plants is the use hydrogen recombiners. The recombiners are passive systems commonly manufactured as boxes with catalytic plates embedded inside them. These plates combine hydrogen with oxygen and consequently remove the hydrogen from the containment atmosphere. There are several conducted researches in the literature that have been analyzed the effect of passive autocatalytic recombiners (PARs) on hydrogen concentration in the containment. [1-5].
In this paper in-vessel phase of the LB-LOCA, SBO and SBO along with LB-LOCA in the VVER-1000/V446 has been investigated and the location of 96 PARs is evaluated to reach an appropriate arrangement of them inside the containment compartments using MELCOR and RELAP-SCDAP codes.

Methodology
In this study, Relap5/SCDAP3.4 and MELCOR codes are applied to simulate the hydrogen concentration inside the containment of VVER-1000/V446 nuclear reactor. First, a verified model of VVER-1000/V446 primary and secondary systems in Relap5/SCDAP code is applied for in-vessel phenomena assessment. Results of this code including amount and enthalpy of the water, hydrogen and steam are used as boundary conditions in MELCOR code. Then, a model of VVER-1000/V446 containment developed using MELCOR code is utilized for the hydrogen gas distribution inside the containment for each accident. To find the best arrangment of PARs inside the containment's compartments for each accident, a trial and error method is applied. The goal is to minimize the peak of hydrogen mole fraction inside the containment with tuning the number of PARs in each compartment.

Results and discussion
Table 1 presents the best arrangement for each accident and the final proposed layout of HARs in different parts of the containment. Also, Table 2 compares the variation in hydrogen mole fraction for the final and best proposed arrangements and reference layout of the PARs in WWER1000/V446 plant as well as removing all PARs from the containment building.
The temporal variations of the hydrogen mole fraction inside the reactor containment are shown in Figure (1).
According to the calculated results, it is observed that during all three hypothetical accidents, the maximum peak of hydrogen mole fraction occurs in cell number 3 where contains the cold leg pipe and pressurizer's safety (relief) valves. Regarding the final layout for PARs proposed in this study, the hydrogen mole fraction remains below the flammability range (i.e. below 0.07) for all investigated accident scenarios (see Figure (1)). Also as Table 2 shows, while for the LBLOCA accident, the reduction in hydrogen mole fraction for the final proposed arrangment is very small relative to the designed layout in the reference plant, for the SBO and SBO+LBLOCA accidents a reduction in hydrogen mole fraction equal to 13 and 10.5 percent is achieved, respectively. It is worth mentionng that the LBLOCA is a design basis accident with lower amount of hydrogen production. The results show that the current designed

layout gives a satisfactory outcome for the LBLOCA scenario.

Table 1. Arrangment of PARs in containment cells for each accident and the final proposed layout.

Cell numbers	Best arrangment LBLOCA	Best arrangment SBO	Best arrangment LBLOCA +SBO	Plant Designed Location	Final proposed layout
1	1	1	0	1	1
2	9	1	9	10	12
3	11	74	59	9	21
4	1	1	1	1	1
5	1	0	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	2	1	1	2	2
10	2	8	13	1	8
11	1	0	0	1	0
12	1	1	1	1	1
13	1	0	0	1	0
14	2	0	0	2	1
15	1	0	0	1	0
16	2	1	1	2	1
17	5	0	0	6	2
18	3	1	1	3	2
19	3	0	0	3	1
20	2	1	1	2	1
21	11	1	1	6	14
22	10	1	3	10	9
23	24	1	1	30	15
Maximum peak - Peak time (s)	0.01999 - 26984.0	0.04493 - 12047.0	0.05738 - 15409.0		Best arrangment for each accident
Maximum peak - Peak time (s)	0.01999 - 26959.0	0.05319 - 12048.5	0.06357 - 12045.3		Final layout
	0.01999 - 26984.6	0.07092 - 14995.1	0.06180 - 12045.0	Plant Designed Layout	

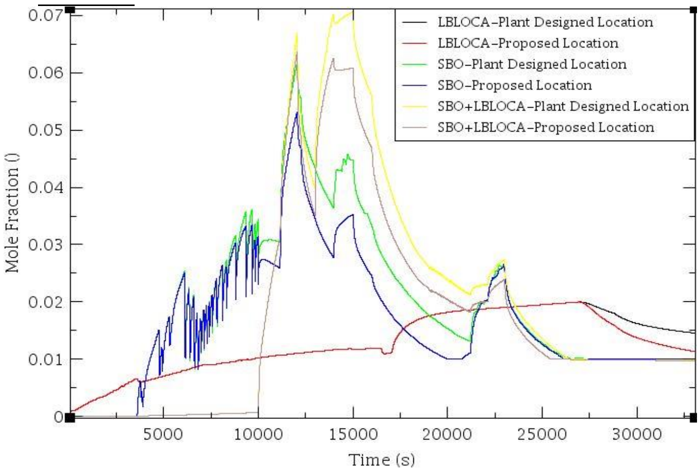

Figure 1: Temporal variation of hydrogen mole fraction.

Table 2. Hydrogen mole fraction reduction (in percent) in comparison with the designed layout and removing the PARs.

Case	LBLOCA(c)	SBO(c)	LBLOCA(c) + SBO(c)
Best for each scenario relative to designed layout	0.0	27.3	19.0
Final layout relative to designed layout	0.0	13.0	10.5
Best for each scenario relative to removing the PARs	65.1	55.0	42.6
Final layout relative to removing the PARs	65.1	46.3	36.5

Conclusions

The results show that the proposed final layout can significantly reduce the volumetric concentration of hydrogen inside the reactor containment relative to the designed layout given in the final safety analysis report of the reference plant. Also, if the proposed arrangment is used, the maximum of hydrogen mole fraction during all three hypothetical accidents will remain below the flammability range (<0.07) [5].

References

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