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For Improvement of Hydrogen Mitigation Actions' Effect

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1. Introduction

The Fukushima Daiichi accident in year 2011 has considerable influence on the determination of the prioritization of nuclear safety research topics all over the world. While some topics may have experienced a change in priority, the importance of the study on hydrogen mitigation has been further stressed because of occurring explosive hydrogen combustion in Fukushima Daiichi accident. Most of experimental works up to now have mainly focused on clarifying the separate phenomenology related to the containment thermal hydraulics and the separate-effect performance tests of mitigation systems for hydrogen control. The SAMG (Severe Accident Management Guidelines) is a very important tool to mitigate the accidents. For an effective implementation of SAMG, it is important to know mitigation systems performance not only by means of separate effect tests but also by investigating their operation under coupled-effects as expected in the course of an accident/management. In this paper, hydrogen mitigation actions in SAMG are reviewed and topics to increase the effect are discussed.

2. Methods and Results

Topics for improvement of the effects of hydrogen mitigation actions in SAMG will be proposed by reviewing the means and the uncertainties for hydrogen mitigation in SAMG.

2.1 Hydrogen mitigation in SAMG

There are two guidelines for hydrogen mitigation of the W/H (Westinghouse) SAMG for PWR [1, 2] which are derived from the EPRI general SAMG [3]. The first guideline is, so called the "SAG (Severe Accident Guideline)-7: Reduce Containment Hydrogen". The objective of this SAG is to remove the risk by hydrogen combustion in the containment. The action means to reach this objective is to induce the hydrogen combustion by using igniters or the intentional combustion using the electrical spark by generator. This means that hydrogen concentration is in the range that is allowed hydrogen combustion. Nevertheless, the uncertainties of hydrogen combustion are 1) the information of the hydrogen concentration in the containment 2) measurements of hydrogen concentration in the containment atmosphere. Another action from this guideline meant to remove hydrogen by PARs (Passive Autocatalytic Recombiners) which don't need electric power. It is known that the uncertainties of hydrogen removal by PARs are 1) whether the hydrogen in the containment can be removed sufficiently by a PAR without adverse effects 2) the possibility of self-induced ignition source by a PAR 3) the prevention or hindrance of the recombination of hydrogen and oxygen by steam 4) PAR performance under the high concentration of airborne aerosols.

The second guideline for hydrogen mitigation is "SCG (Severe Challenge Guideline)-3:Control Hydrogen Flammability". This guideline is firstly taken than SAG-7 if the criteria of SCG-3 is satisfied. The criteria of SCG-3 is the hydrogen concentration of region that may happen deonation from the calculation aid. This means that hydrogen concentration is in the range that does not allow hydrogen combustion. The objective of this guideline is to prevent hydrogen combustion by maintaining steam-inerting. The action is meant to keep steam-inerting by stopping operation of heat sinks and/or opening of Reactor Cooling System (RCS) valve. Another action means is to isolate potential ignition source of non-safety valve or venting the containment. It is known that the uncertainties of steam-inerting is the operation of containment heat removal system such as containment spray and fan cooler. Other uncertainty of steam-inerting is the mass of hydrogen and hydrogen distribution throughout containment compartments.

The implementation procedure of hydrogen mitigation systems in SAMG can be different depending on the plant as the hydrogen mitigation system installed in the plant is different. Here the calculation aid, as shown Fig. 1, is first introduced because it is used for the implementation of hydrogen mitigation systems.

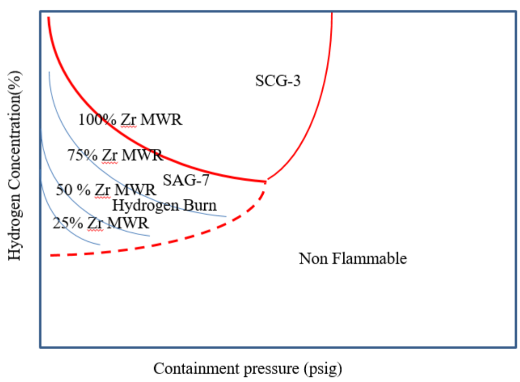

Fig. 1 Calculation Aids for Hydrogen Control

Fig. 1 is the typical example of calculation aid and is plant specific. TSC (Technical Support Center) uses this calculation aid to copy with the accident.

The implementation procedure in the plant adapting PARs as major means for hydrogen control like most of EU countries can be Fig. 2. There exists the possibility to take SAG-7 or SCG-3, as explained below, in the case the hydrogen is not sufficiently removed by PAR. If the information from the hydrogen concentration measurement is not available, the calculation aid will be used to decide the hydrogen concentration using the containment pressure and the oxidation of Zirconum, and then operator will take one guideline of SAG-7 or SCG-3. If the hydrogen measurement is available from hydrogen measurement systems, one of SAG-7 or SCG-3 depending on the hydrogen concentration will be taken. If the ignition is allowed, the hydrogen will be consumed by generating sparks by using all available means (SAG-7). If the ignition is not allowed, the action (SCG-3) which will not induce combustion will be taken.

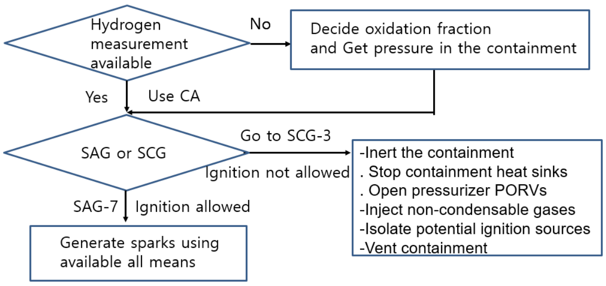

Fig. 2 Implementation Procedure for Hydrogen Mitigation of Plant with PAR

The implementation procedure of the plant adapting igniters as major means for hydrogen control like the U.S. will be as whown in Fig. 3. In this case, if the ignition is allowed, the ignition will be used to consume hydrogen either with an igniter or by using other available means because other than combustion there is no means to consume the hydrogen in the containment. It is highly possible to take one SAG-7 or SCG-3 at least.

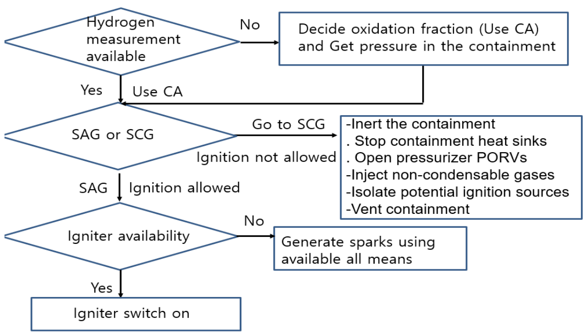

Fig. 3 Implementation Procedure for Hydrogen Mitigation of Plant with Igniters

Meanwhile, the implementation procedure of the plant adapting PARs and igniters at the same time ("dual concept"= as major means for hydrogen control) will be the same as shown in Fig. 3 because PARs don't need operator action for the operation. But, this combination of two systems will make the lower possibility to take SAG-7 or SCG-3 in the accident.

2.2 On improvement of hydrogen mitigation effect

As stated in the previous section, the PAR is one of major means for hydrogen control in the containment without operation action. In addition, the operation of Engineering Safety Features (ESFs), such as spray is inevitable to induce the low pressure of the containment and the mixing of gases even if hydrogen concentration can be controlled properly in the containment. There are several merits to run spray in accidents if hydrogen threat were removed. Accordingly, it is highly required by SAMG to spray the containment in order to decrease the amount of airborne radioactive aerosols and gases in the containment. The working of spray will greatly contribute to reduce airborne aerosols in the containment and considerably mitigate the release of fission products even if there happens containment failure. Another advantage in the use of spray is that the operation of spray induces a mixing in the whole containment. It can break stratifications of the hydrogen. If there were some small hydrogen clusters, they can also break-up thanks to the mixing induced by this measure.

It is known that only few experimental data at low hydrogen concentration in a small scale on the performance of PAR with spray is available and the data on hydrogen concentration change and ignition potential at a little high hydrogen concentration under the PAR operation with spray are not available. The report insists that ignition potential of PAR is one of major adverse effect for hydrogen control [4] because it causes the unintended combustion. The other insistence is that the ignition potential may be merit for hydrogen control because hydrogen can be consumed [5]. To be manifest is that the ignition potential of PAR is still on the discussion in the world. Meanwhile, the important result was recently found that PAR ignition potential is limited to a relatively small area of mixture compositions in the air-hydrogen ternary diagram. However, at this moment, there is no way to prevent such PAR from self-actuating or to shut PAR off in elevated hydrogen concentrations.

Accordingly, it is recommended to further investigate PAR operation under ESFs operation because the hydrogen concentration under ESFs may reach the ignition potential region. In addition, the effect of the ignition potential of PAR under operation of heat removal systems is the same with the effect of igniter operation under operation of heat removal systems. It is also necessary to consider PAR induced ignition behaviour in containment safety analyses for hydrogen control by using computer codes. Accordingly, This analysis has to include 3-dimensional analysis to see the possibility of DDT considering containment geometry and the PAR location.

Meanwhile, if the ignition potential by PARs can be excluded, the negative effects of ignition potential accompanied with the operation of engineered safety systems will be removed and the operator is free to use the engineered safety systems without a fear of unintentional combustion. Then, the guidelines to be taken in severe accident can be very simplified because operator don't need to consider the negative effects caused by operation of ESFs. Accordingly, it is important to develop the PAR without malfunctioning of ignition potential.

Meanwhile, there have been some efforts to develop PARs without ignition potential. However, the pros and cons shall need to be considered of such development work considering H_2 combustion at elevated concentration (> 8 vol. %) may occur by random ignition sources available in containment. Nevertheless, it is important to assess PAR performance under a broad spectrum of accident scenarios, e.g, interaction with airborne fission products, late phase MCCI conditions (e.g. CO presence) and under different oxidation potential (or rich or O_2 lean conditions). The assessment is necessary to ensure that the PAR recombination capacity remains in agreement with its design values as considered during their installation mythology, e.g. number of PARs.

3. Conclusions

From reviewing the hydrogen mitigation actions in SAMG, it is recommended to study on PAR operation under ESFs operation including experiments. In addition, ignition potential of PAR has to be included in plant safety analysis. It is also necessary to assess PAR performance under a broad spectrum of accident scenarios to ensure that PAR installation methodology, such as number of PARs, remains optimal for the entire course of an severe accident.

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