Computational Aid of Hydrogen Flammability in Reactor Building for Wolsong 2

See Darl Kim, Young Ho Jin, Soo Yong Park
Thermal Hydraulics & Safety Research Division KAERI, sdkim2@kaeri.re.kr

1. Introduction

Hydrogen generation and flammability is a concern throughout most of the guidelines in the Wolsong 2 SAMG. This computational aid (CA) is one of the tools that can be used to assess the hydrogen generation and challenges that may occur. The purpose of this CA is to define whether the hydrogen in the reactor building atmosphere is flammable, and to estimate the hydrogen concentration in the reactor building atmosphere based on an estimated oxidation percentage.

2. Basis

When the water level in the reactor vessel decreases and uncovers a portion of the core, overheating of the core cladding occurs. The high temperature Zircaloy cladding oxidizes in the presence of steam, forming hydrogen. The chemical reaction is : $Zr + 2H_2O \dashrightarrow ZrO_2 + 2H_2$

This hydrogen is likely to be released to the reactor building, although the release mechanism from the reactor vessel is dependent on the severe accident scenario. Nevertheless, guidelines have been established for estimating the hydrogen concentration in the reactor building atmosphere, if more detailed plant information is not available. If the accident is during the boil down process, the hydrogen resulting from a 50% cladding reaction is a bounding value. If recovery of the core has been attempted, a total of 75% of the active cladding should be assumed to have reacted with steam. This value is sufficient to encompass the potential uncertainties associated with sequence variabilities. It is a value which represents a realistic upper bound on the hydrogen limits for severe accident management, and is a reference number that both the NRC and industry have used since the accident at TMI-2. However, in core/concrete interaction (CCI) scenarios, the zirc-water reaction is not the only source of hydrogen production. If CCI occurs, additional hydrogen may be produced by water reacting with carbon, chromium, or iron.

3. Usage

To explain the general usage of this CA, it is helpful to consider it in relationship to the other tools that are available to address hydrogen concerns [1]. Therefore, for some hydrogen questions, there are multiple tools that could be referenced to find an answer. Generally, this CA is the tool referenced when the focus is the current condition, when the zirc reaction lines are needed to estimate current or future hydrogen percentage, or when the question is flammability versus non-flammability.

The input needed for this CA is the reactor building pressure and the reactor building hydrogen concentration. If the reactor building hydrogen cannot be measured, the 50% or 75% zirconium reaction curves within the CA can be used as a means to estimate the hydrogen. In addition, guideline refers to adding the hydrogen equivalent of 25% zirc reaction to the current measurement, and therefore this curve is also provided. There are several sets of figures within this CA to address different major assumption. For each set of conditions illustrated, there are two figures: one for the wet hydrogen percentage and one for the dry hydrogen percentage. Both the wet percentage and the dry percentage figures represent the same physical scenario, only the presentation of the data differs. The wet hydrogen percentage is the actual moles of hydrogen compared to the total moles of steam, air and hydrogen. The dry hydrogen percentage does not include the presence of steam, and is only a comparison of hydrogen to dry air and hydrogen. The use of the wet versus dry figures differs, since a fixed amount (moles) of hydrogen appears as a constant horizontal line on the dry figure, while it appears as a curved line on the wet figure. Therefore the user must understand that as the reactor building depressurizes, the hydrogen percentage will remain the same on a dry measurement basis, but it will increase on a wet measurement basis.

It is also important that the user refer to the appropriate set of figures. For the Wolsong 2 this CA, four sets of hydrogen figures were developed:

- o No venting, no core/concrete interaction
- o 15% venting, no core/concrete interaction
- o 30% venting, no core/concrete interaction
- o No venting, core/concrete interaction for 24 hours resulting in 50^oF superheat and addition of non-condensable gases.

Figure 1 and 2 should apply in the majority of accident scenarios. However, if venting has occurred, or if the reactor building is superheated, then additional figures should be referenced. If venting has occurred, there are two sets of figures which illustrate the shift in the flammability regions. For Wolsong 2 CA, venting of 15% and 30% has been illustrates. For the figures which address core/concrete interaction, 50°F of superheat and non-condensable gases from 24 hours of core/concrete interaction have been illustrated. Also, another line representing 100% zirc-water reaction has been added. Although 75% has been accepted as a reasonable upper limit, the 100% line is a reminder that additional hydrogen is produced during core/concrete interaction. If core/concrete interaction is occurring, the reactor building is generally predicted to become superheated. Therefore, elevated reactor building atmosphere temperatures can be a method of diagnosing that CCI is occurring. Figure 3 provides information on the temperature/pressure relationship expected for a saturated steam-air mixture, and for a superheated/CCI scenario. The temperature /pressure information should be used in conjunction with other plant data that could indicate CCI, such as the RCS at the same pressure as the reactor building, and limited water in the reactor cavity. Early in the accident, it would also be a good idea to be comparing actual temperature data to the predicted saturated steam/air mixture temperature, since the actual conditions may vary from the assumed conditions. In this manner, CCI could be detected based on relative temperature increases. Plant-specific input for Wolsong 2 is represented at reference [2,3].

4. Assumptions

- The reactor building environment is assumed to be a homogeneous mixture of air, steam and hydrogen for which the ideal gas law applies.
- Hydrogen igniters have not been used, and there have been no previously hydrogen burns.
- The reactor building environment is assumed to be at 100% humidity.

5. Results

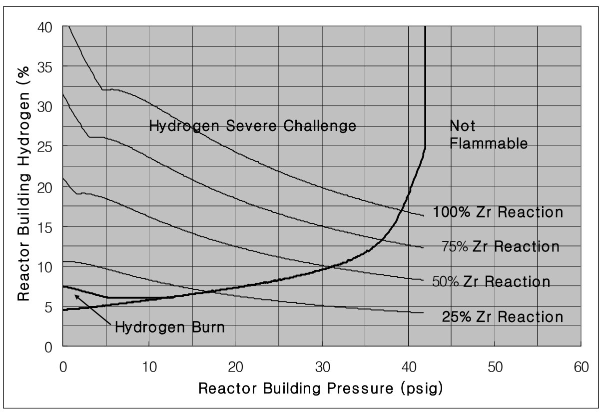

Figure 1 Potential for Hydrogen Combustion Based on Wet Hydrogen Measurement

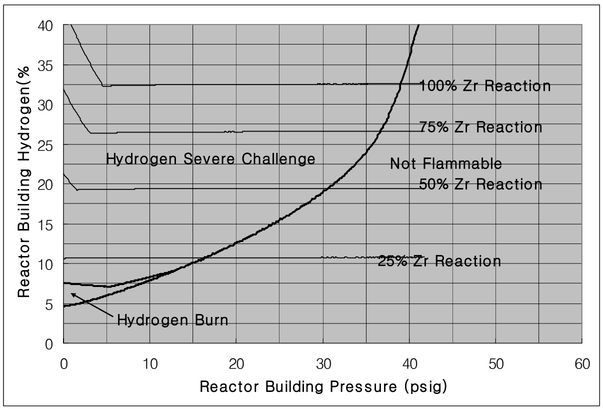

Figure 2 Potential for Hydrogen Combustion Based on Dry Hydrogen Measurement

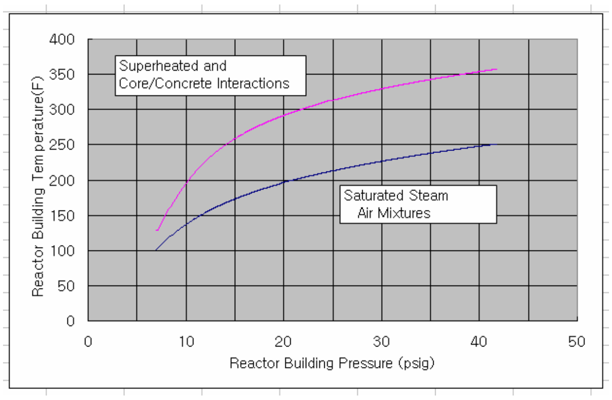

Figure 3 Reactor building Temperature and Pressure Correlation

Acknowledgement

This study has been performed as a part of the R&D program supported by Korea Ministry of Science and Technology.

REFERENCES

[1] WOG PROGRAM MUHP-2310 "WOG Severe Accident Management Guidance", June, 1994.

[2] KAERI/RR-2533/2004. "Development of Optimal Severe Accident Management Strategy and Engineered Safety Features", April, 2005.

[3] "Wolsong Nuclear Power Plant Units No. 2/3/4 FSAR" KEPCO, 1995.