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Sensitivity Analysis of the Oxidation Rate of Cladding for the BDBA Condition using SCDAP/RELAP5

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1. Introduction

After Fukushima accident of March 2011, enhancing the accident tolerance of LWRs became a topic of serious discussion. A three-phase approach was suggested in the Advanced Fuel Campaign of US-DOE [1]; Phase 1 focuses on the feasibility assessment and down-selection, in Phase 2, the fabrication process will expand to industrial scale with development and qualification, and the last phase is commercialization. KAERI also is developing the accident tolerant fuel (ATF) candidates for the fuel cladding and pellet as Phase I. The decline of the oxidation rate on the cladding surface is a major issue to mitigate the hydrogen generation and to reduce the oxidation reaction heat.

In this paper, the effect of the oxidation rate on a cladding material was evaluated for the BDBA (Beyond Design Basis Accidents) condition with SCDAP/ RELAP5 computer code. The selected baseline accidents for examining the safety merits of the ATF concepts were the TMI-2 LOCA accident [2] and SBO accident of BDBA condition. The input data of both scenarios were the sample inputs of SCDAP/RELAP code.

2. BDBA System Code and Analysis

2.1 SCDAP/RELAP5

The SCDAP/RELAP5 computer code is designed to simulate severe accident situation including the overall reactor coolant system (RCS) thermal-hydraulic response, core damage progression, and reactor vessel heatup and damage [3]. The computer code is the result of a merging of the RELAP5 to calculate the overall RCS thermal-hydraulics and the SCDAP to calculate the progression of damage in the reactor core. The oxidation rate of the fuel cladding in this study was calculated by the parabolic kinetic model based on Cathcart-Powel correlation in the subcode, MATPRO [4], which is used to calculate the material properties in the SCDAP code.

2.2 SBO Analysis

The SBO scenario was applied to PWR system. The effect of oxidation rate for the maximum cladding temperature is illustrated in Fig. 1. In the case applied the original C-P oxidation model, the surface temperature was rapidly increased by the additional heat generation of metal-water oxidation reaction above 1200 K. In the SBO, if the auxiliary safety system was not operated, the water level of the reactor vessel was gradually decreased by the boil-off, which is primarily dependent upon the fuel decay heat. In this situation, the decrease of oxidation rate did not show a significantly profitable effect even if the oxidation rate was reduced down to 1% of original rate. The grace time at the cladding temperature of 2200 K was estimated below 600 sec.

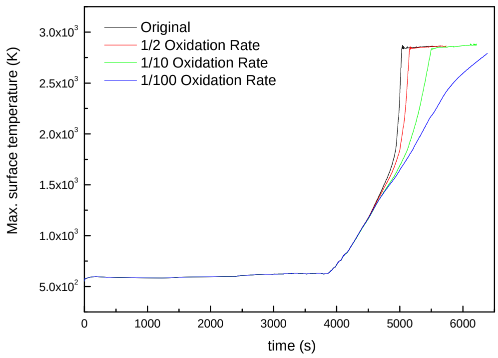

Fig. 1. Maximum cladding temperature according to the reduced oxidation rate for the SBO scenario of PWR.

2.3 TMI-2 Accident Analysis

The Three Mile Island Unit 2 (TMI) accident was caused by a small-break LOCA without safety injection. As a result of the accident, the damage progression included; (1) ballooning of fuel rods, (2) intense oxidation and rapid heatup to temperatures that melted a part of the reactor core, (3) reflood of a hot, partially oxidized core, (4) formation of a molten region across the entire diameter of the reactor core, and (5) slumping of a significant amount of molten material to the lower head. As the interest in this analysis was focused on new conceptual fuel rod, the calculation was carried out until the fuel melting sequence.

The total oxidation heat generation is illustrated in Fig. 2. In the original case, the heat generation rate by metal-water reaction was sharply increased after 130 minute due to increasing cladding temperature. When the oxidation rate was reduce by a half, the starting point of oxidation heat generation was slightly delayed but the decrease of the amount of heat generation was not large enough to notice. In the oxidation rate of 10%, however, the maximum oxidation heat generation was obviously decreased by 13% of the original case in view point of maximum value.

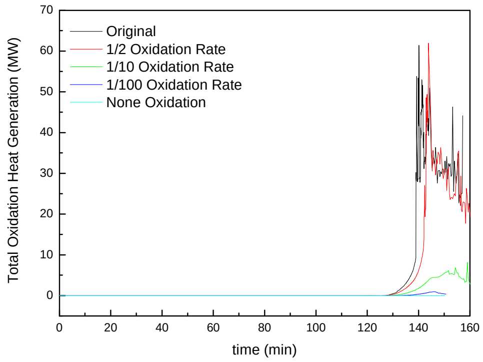

Fig. 2. Total oxidation heat generation according to the reduced oxidation rate for the TMI-2 accident scenario.

The maximum cladding temperature trends are illustrated in Fig. 3. As mention in oxidation heat generation, the cladding temperature in oxidation rate of a half reached above 2500 K. But the peak cladding temperature in the oxidation rate below 10% was below 2000 K which is regarded as under the melting temperature of Zircaloy cladding. This result demonstrates a potential safety advantage over Zircaloy for an accident where cladding oxidation becomes a dominant heat source.

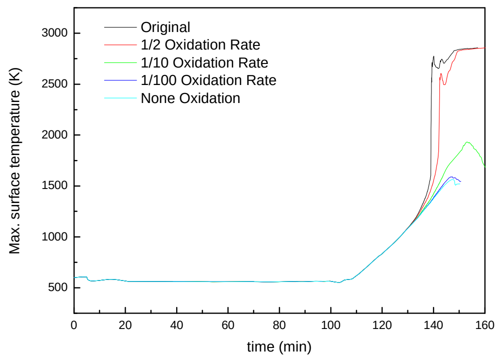

Fig. 3. Maximum cladding temperature according to the reduced oxidation rate for the TMI-2 accident scenario.

3. Conclusions

The effect of oxidation rate on the cladding was estimated using SCDAP/RELAP code for the severe accident scenarios to evaluate the safety enhancement for candidates of ATF fuel cladding.

As the cladding temperature in the SBO accident was increased by boil-off and uncovering of core due to the fuel decay heat, a reduced oxidation rate of a cladding material has a minor impact of increasing the grace time of 600 sec.

In the TMI-2 accident analysis, the cladding temperature was significantly decreased at the oxidation rate below 10%. A reduced ~~the~~ oxidation rate of fuel cladding will result in a potential safety advantage for an accident where cladding oxidation becomes a dominant heat source like the TMI-2 accident.

This analysis is preliminary study for applying the oxidation rate for ATF claddings. In the next phase, the real properties including mechanical characteristics will be applied.

ACKNOWLEDGEMENTS

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