Potential Safety Benefit of Oxidation-Resistant CrAl Coated Zr Cladding Under Severe Accidents such as TMI and SBO conditions

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1. Introduction

Following the Fukushima accident, there have been aggressive research activities in nuclear industry and research institutes to develop accident tolerant fuel [1]. KAERI has been interested in CrAl_Coated_Zr base Cladding [2], as one of the promising candidates. Having various out-of-pile tests, the CrAl coating has shown an excellent property in oxidation-resistance particularly to high temperature steam environment expected during the Beyond Design Bases Accidents (BDBA) as well as the DBA in PWRs. Hence, a potential benefit of this CrAl_Coated_Zr base cladding against the conventional Zr-4 is assessed in terms of severe accidents such as TMI and SBO conditions.

In this analysis, the SCDAP-RELAP5 code was used for the overall severe accident simulations of plant response and core damage progression [3]. A sole modification of the model in the code is the oxidation-kinetics for CrAl_Coated_Zr base cladding. It is assumed here 1/10 tentatively and conservatively over the temperature range relative to Cathcart-Powel correlation for Zr4 cladding [4] since being widely examined currently through the autoclave oxidation tests.

2. Accident Analysis Results

2.1 TMI Accident

The TMI accident is a severe accident starting from a SBLOCA type incident and being followed by operator wrong decision in the beginning of accident managing. The intricate accident scenario including the operator multiple actions such as PORV close, RCP and HPSI activations was well represented in the analysis of G. Bandini [5]. In this work, the same scenario as well as reactor core and system models were adopted expect for the oxidation-kinetics of accident tolerant cladding.

Fig. 1 demonstrates the variations of peak cladding temperatures (PCT) for Zr4 and CrAl_Coated claddings. Around 100 minutes after the PORV opening accidently, core uncovery starts and cladding surface temperature begins to rise slowly. As the RCS pressure decreases below the low pressure setpoint, the HPSI was activated automatically but operator stopped it manually by a misunderstanding of RSC inventory situation. So, no emergency coolant was supplied to the core and the Zr4 cladding temperature increases fast when it went over 1000 K. Finally, fuel melting occurs and molten pool is formed in the core center as shown in Fig. 2. While, the PCT of CrAl_Coated cladding kept increasing almost constantly and turned to decrease at 139 min of PORV closure by operator. The PCT increases again because of the fuel heat-up and RCS pressure increase by the decay heat. But the PCT goes down quickly by the RCP starting at 174 min, maintains for a while, and then rises again. After the HPSI is activated by operator to supply the emergency coolant, the core becomes inundated and cooled down safely without experiencing a fuel melting.

Fig. 3 shows accumulated hydrogen mass of Zr4 and CrAl_Coated claddings. The accident tolerant cladding is about 50 kg far less than the conventional cladding of 360 kg.

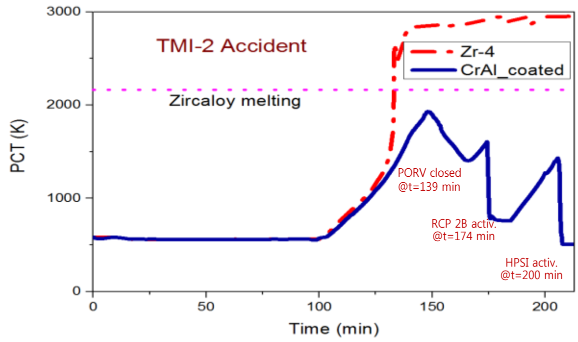

Fig. 1 PCTs of Zr4 and CrAl_Coated claddings in TMI accident condition

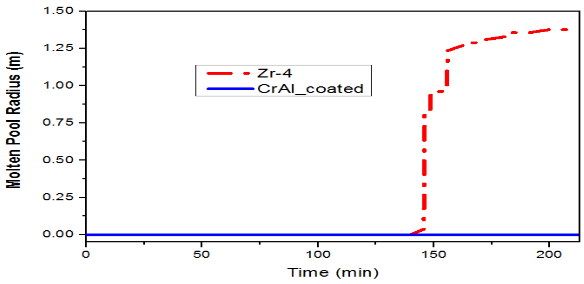

Fig. 2 Molten pool radius of Zr4 and CrAl_Coated claddings

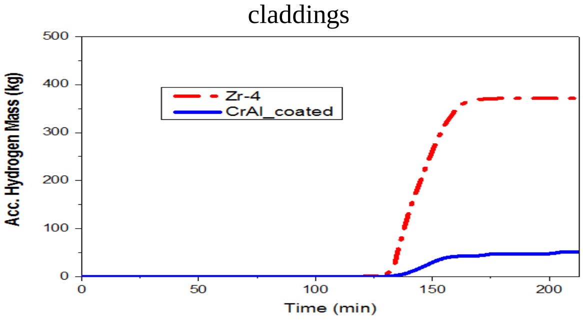

Fig. 3 Accumulated hydrogen mass of Zr4 and CrAl_Coated claddings

2.2 SBO Accident

The SBO accident is simulated with OPR-1000. A loss of off-site power as well as failure of AC power of emergency diesel generators are assumed same, but the DC battery power for activations of reactor coolant pumps and reactor trip signals available during a certain period of time before depletion. Two motor-driven pumps do not work also, while two turbine-driven pumps can operate for a supply of aux-feed water with some delay time after Steam Generator low level signal. With single failure condition, only one turbine-driven pump with a delay time of 1.5 hrs following the SG low level signal is assumed conservatively here. It will remove some heat from the primary side and cause a natural circulation in the primary coolant loops.

Fig. 4 shows the PCT trajectories of Zr4 and CrAl_Coated Zr base claddings in the above condition. The PCT of CrAl_Coated_Zr cladding reaches around 1,700 K at the time of 8,150 sec and then decreases afterward due to the heat removal by turbine-driven pump in secondary side and natural circulation in RCS and decisively minor chemical heat generation on the CrAl_Coated Zr cladding surface even at the high temperature. But the PCT of Zr-4 cladding runs rapidly from 1200 K and goes beyond the Zr melting point regardless of the turbine-driven pump working.

Fig. 5 indicates the pressurizer (PZR) pressures of the Zr 4 and CrAl_Coated Zr base cladding cores. The pressures oscillate during SBO accident as the pressure relief valve at the top of PZR opens and closes. When the turbine-driven pump operates, the RCS pressure decreases for both cases. The pressure of the accident tolerant fuel core reduces more drastically than that of Zr4 conventional fuel core.

5. Conclusion

Safety benefit of CrAl_Coated Zr base cladding is assessed along with typical severe accident conditions of TMI and SBO. In the case of TMI accident, the core with CrAl_Coated cladding fuels are possibly quenched thanks to the deferred oxidation heat addition and operator's manual PORV close and short HPSI operation during the latter accident management. On the other hand, the SBO condition can be also controlled in the core of CrAl_Coated cladding fuels along by one turbine-driven pump with a significantly delayed activation.

Therefore, it is anticipated that this ATF candidate of CrAl_Coated Zr base cladding would provide much more flexibility to the accident management for the BDBA conditions.

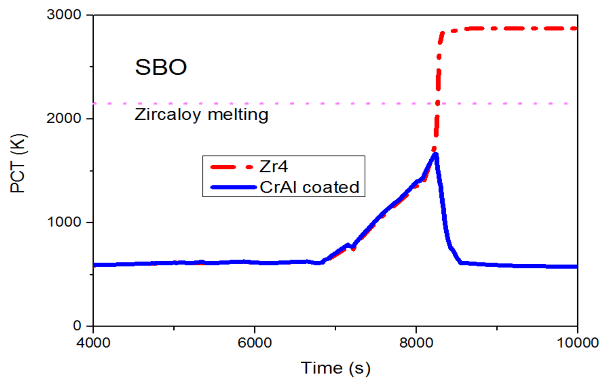

Fig. 4 PCTs of Zr4 and CrAl_Coated claddings in SBO accident condition

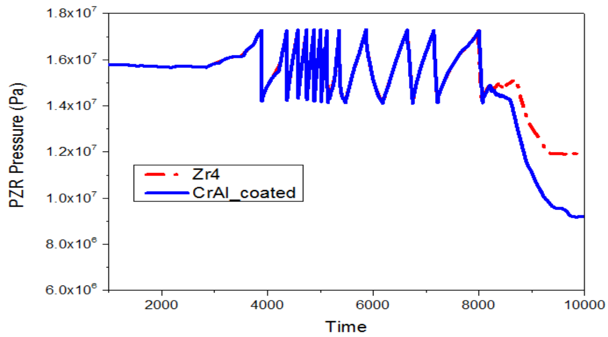

Fig. 5 PZR pressures in Zr4 and CrAl_Coated cladding cores

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