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MARS-KS code Modification for Re-evaluation of Post-LOCA Long Term Cooling Behavior with in-vessel Downstream Effect of Debris in APR1400

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1. Introduction

Fiberous debris generated during the Loss of Cooling Accidents (LOCA) can be entrained into reactor core during the long term cooling period by Emergency Core Cooling System (ECCS) operation. Debris induced degradation of core cooling capability is the main issue of Generic Safety Issue 191(GSI-191).[1] Experimental and analytical approach were have researched to resolve the issue.

Methodology developed by US PWROG described in WCAP-16793-NP Rev.2 has been approved by US NRC and applied various plant strainer design, in which head loss by debris is measured by relevant experiments then the calculated available driving head is compared and finally evaluate the thermal response of the clad material with accumulated debris on the surface to evaluate the conformity of the acceptance criteria.[2]

KINS developed LOCA and long-term cooling analysis methodology considering the downstream effect for the independent evaluation of the licensee's method as shown in Fig. 1[3]

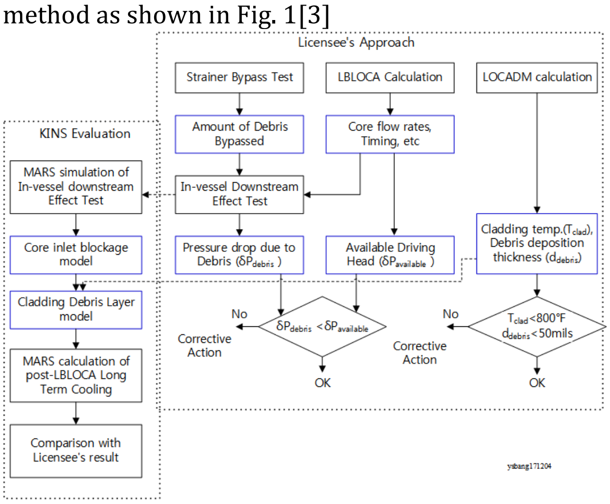

Fig. 1. Evaluation methodology of core downstream effect by debris [3]

Plant modeling and hydraulic modeling for core inlet blockage and thermal modeling of debris layer on clad surface are major part of above methodology.

Earlier evaluation introduced 4-layer model for debris modeling on the fuel clad to identify whether it is reasonable or not, if not, what is the additional action is needed that the gap conductance, clad deformation and metal-water reaction model is not used during the assessment.[3]

Current MARS-KS code[4] allows 3-layer model composed of fuel pellet, gas gap and clad for the gap conductance, clad deformation and metal-water reaction models.

In this study, MARS-KS 1.4 code was revised to accommodate non-structured layer on the fuel rod model such as CRUD and debris with gap conductance, clad deformation and metal-water reaction models.

Revised MARS-KS version is also used for the assessment of Long-term cooling analysis methodology.

2. MARS-KS code modification for 4-layer fuel rod model

Current MAS-KS code have equipped with gap conductance, clad deformation and metal-water reaction models for fuel rod model and the number of material used in fuel rod heat structure is limited to 3 including fuel, gas gap and clad.

Considering layers such as CRUD and Debris are non-structural material. And fuel deformation model is calculate thermal expansion and contraction of fuel and clad layer and strain by the hoop stress of the fuel clad. But conduction equation solver should include the added layer. Therefore, modification was done to exact assign these layer's thicknesses of fuel surface radius (added layer outer surface) and clad inner and outer surface radius to the related models.

Current fixed layer location (1st for fuel pellet, 2nd for gas gap, 1st outer for clad) in the code were revised as the number of layers. For example, outer clad surface is defined as 3rd material outer from the center of the fuel rod for 4 and 5-material layer fuel rod model. And conduction equation calculates the added multi-layer temperature.

2.1 Verification with 3-layer model

Steady-state radial temperature distribution of 3-layer fuel rod model was compared for MARS-KS v.1.4 and revised code as Fig. 1. The revised code predicted same radial temperature distribution of fuel rod 3-layer fuel rod model. It means previous inputs can be used with the revised code.

2.2 Verification with 4-layer model

4-layer model with identical material properties with different material number on the clad region was compared with 3-layer model. Calculation result showed that revised code calculated identical clad mesh point temperatures.

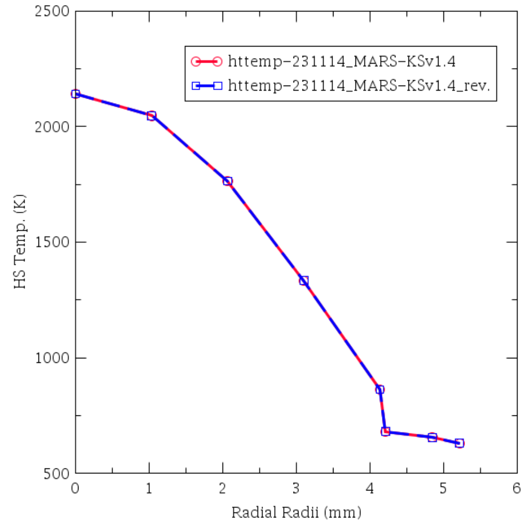

Fig. 1. Steady-state radial fuel rod temperature distribution for MARS-KS v.1.4 and the revised code.

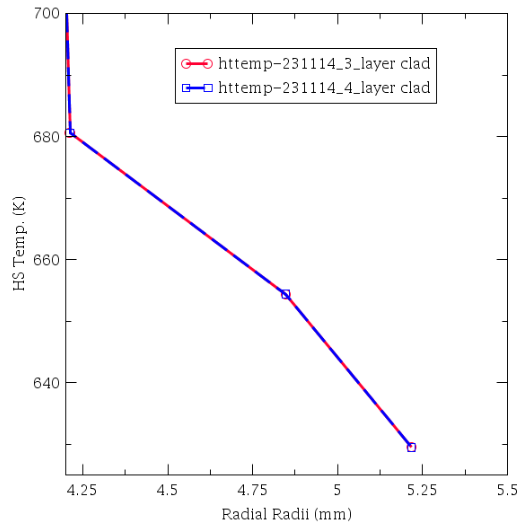

Fig. 2. Clad mesh point steady-state temperatures for one clad material case and two clad materials (identical properties) case

Cases that 4th layer conductivity is doubled and decreased to half than the normal clad were comparted with normal 4-layer model in Fig.3. Clad temperature calculation was reasonable that the half 4th layer conductivity case (H_con) showed higher temperature difference within 4th layer only as sown in Fig. 3 and vice versa.

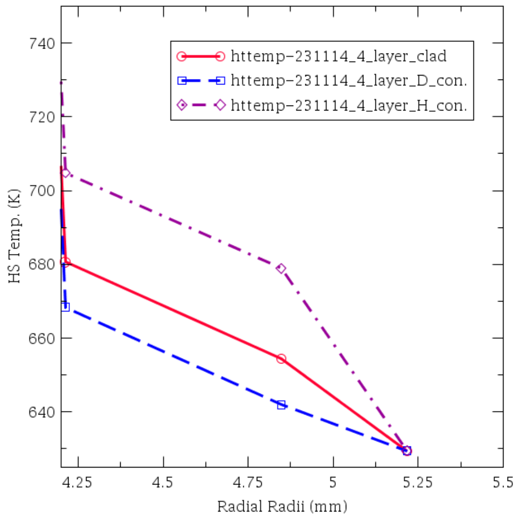

Fig. 3. Clad mesh point steady-state temperatures for various conductivity 4th layer cases (D_con.: double conductivity case, H_con. : half conductivity case)

3. Re-assessment of the post-LOCA long-term cooling response with in-vessel downstream effect of debris

Earlier method for the assessment of downstream effect of debris for post-LOCA long term cooling is as below.[3]

(1) Modeling the 4th layer with clad thermal properties and debris thickness during steady-state calculation.
(2) 4th layer thickness is set 16.7mils by the calculation result of LOCADM
(3) Transient calculation is separated by the debris accumulation point, after the restart point, 4th layer thermal properties is modified for debris.
(4) Before the restart point, the thermal conductivity of the 4th layer should be increased not to increase conductance of the 4th layer and after the restart point 0.5W/m-K of the conductivity for the 4th layer should be applied.
(5) Combined effect of the 4th layer modeling and neglecting gap conductivity model could be compensated with decreased gap-width. Degree of gap-width modification should be within the thermal response of the 3-layer model case. Note that this method is not precise, but could calculate the conservative cladding surface temperature.

With the revised MARS-KS code for 4-layer fuel rod modeling capability, above procedure can be simplified as below

(1) Modeling the 3-layer rod model with clad thermal properties and thickness during steady-state calculation. Note that clad layer

should be composed of two or more intervals for the transient 4th layer modeling.

(2) Transient calculation is separated by the debris accumulation point, after the restart point, 4th layer is modeled by debris material is defined at the steady-state outermost interval.

(3) Debris layer thickness is set 16.7mils by the calculation result of LOCADM and 0.5W/m-K of the conductivity should be applied for the 4th layer.

3.1. Before debris accumulation

Steady-state calculation result of the original 3-layer rod model in terms of the hottest rod radial temperature distribution showed identical for the both of MARS-KS 1.4 code and revised code version as verified as in Fig. 1.

LOCA transient clad surface temperature for the hottest rod was also compared in Fig. 4. During transient calculation, estimated cladding temperature with both code version was identical.

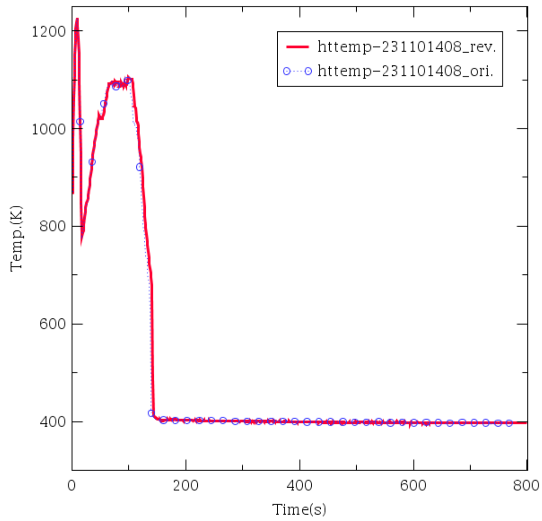

Fig. 4. Hottest rod clad surface temperature response with MARS-KS 1.4 original and revised version.

3.2. Debris accumulation transient

Restart calculation have done for post-LOCA downstream effect and debris accumulation effect on long-term cooling.

Restart input was prepared with modification of fuel rod heat structure for addition of 4th debris layer and clad interval adjustment complied with the end of first transient calculation.

Clad surface temperature during the second transient calculation is shown in Fig. 5. Other cases that the debris thickness is varies from 0.1 μm to 4.24e-4m (16.7 mils) are also compared.

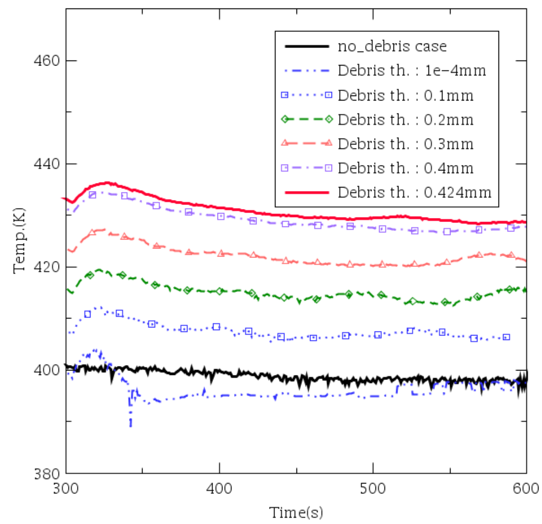

Fig. 5. Clad temperature response of the hottest rod with various debris thickness during the second restart calculation.

Calculated clad temperatures during the second transient showed different restart initial temperatures due to the clad geometry change and additional debris layer.

Nevertheless the initial clad surface temperatures, clad surface temperature was not increased sharply during the core inlet blockage simulation periods from 300.0s to 400.0s. Fig. 6 showed fuel rod radial temperature distributions at 327s at which the highest clad temperature was estimated during 2nd restart calculations. In the figure, temperature distributions are calculated reasonably with relatively lower thermal conductivity of the debris layer 0.5W/m-K than the clad material.

Estimated clad surface temperature was 436.3K (325.67 ˚F)

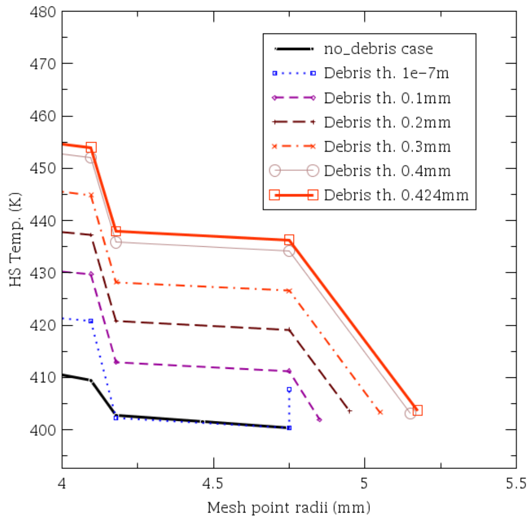

Fig. 6. Radial clad temperature distribution of the hottest rod with various debris thickness at 327s of the second restart calculation.

5. Conclusions

MARS-KS version 1.4 code was revised to model 4-layer fuel rod model considering gap conductance, clad deformation and metal-water reaction models.

With the help of the revised 4-layer fuel rod capability code, the method for the assessment of downstream effect of debris for post-LOCA long term cooling was simplified with three steps.

Application result of the newly introduced assessment method for the post-LOCA long-term cooling response with in-vessel downstream effect of debris showed that the clad surface temperature the debris accumulation on the surface fuel clad during the post-LOCA long-term cooling period was 325.67˚F which is far below than the acceptance criteria of 800˚F.

It is also re-confirmed that the licensee's calculation result of 468˚F with 16 mils debris layers[5] still valid conservatively as well as earlier assessment result.

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