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Transient Analysis of Corium Coolability Considering Water Ingression into Debris and Corium-to-Vessel Gap

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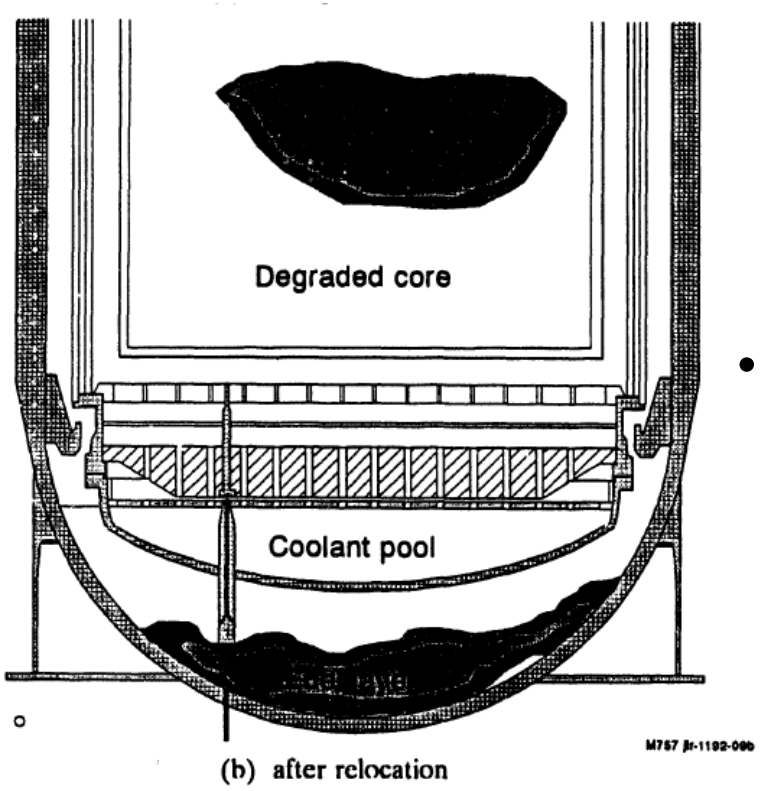
Presented by Moon Won SONG

TMI-2 Vessel Investigation Project

- **Main results of TMI-2 Vessel Investigation Project (VIP*)**

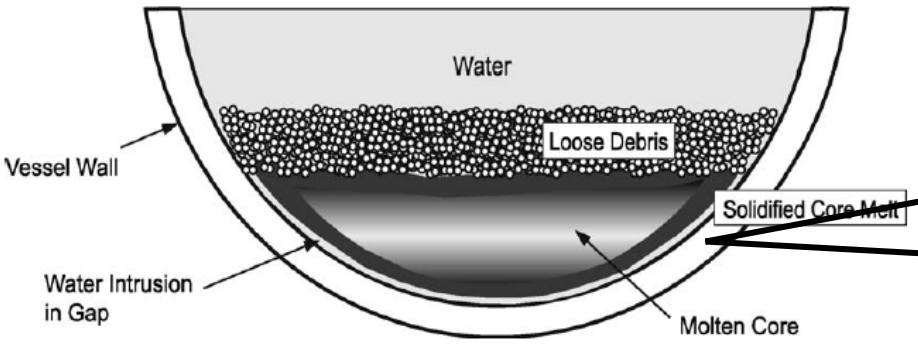


(b) after relocation

- **Observation:**
  - **No substantial thermal attack of the reactor vessel**
  - **Virtually no adherence of the corium to the lower head wall could be detected during defueling (VIP)**
- **Thermal/Metallurgical Analysis:**
  - **An unexpected phenomenon showed up that could not be predicted: A hot spot of almost 1400K formed for about 30 min and then disappeared (Muller, 2006).**
  - **The results indicated that the cooling mechanisms (gap/debris cooling) were needed to be consistent with metallurgical examined data (VIP)**

*** Participants: Belgium, Finland, France, Germany, Italy, Japan, Spain, Sweden, Switzerland, United Kingdom and United States.** *** Project Period: 1 Jan. 1988-31 Mar. 1993** *** Budget: USD 9 million**

Research Question and Significance



I. Gap Formation
II. Water Penetration
III. Thermal Behavior

- **Can we predict thermal behavior of the TMI-2 vessel by analysis of water penetration into gap/debris ?**

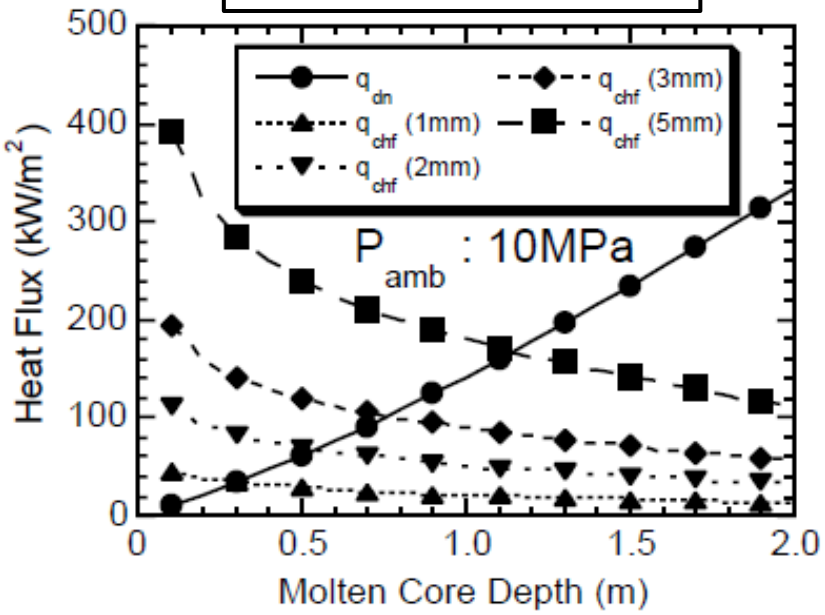
  : No substantial thermal attack of the reactor vessel
  (A hot spot of almost 1400K, 30 minutes)
  : Effect of pre-existence of water in lower plenum
  : Safety limits for maximum corium mass at the given decay heat level

- **Significance**

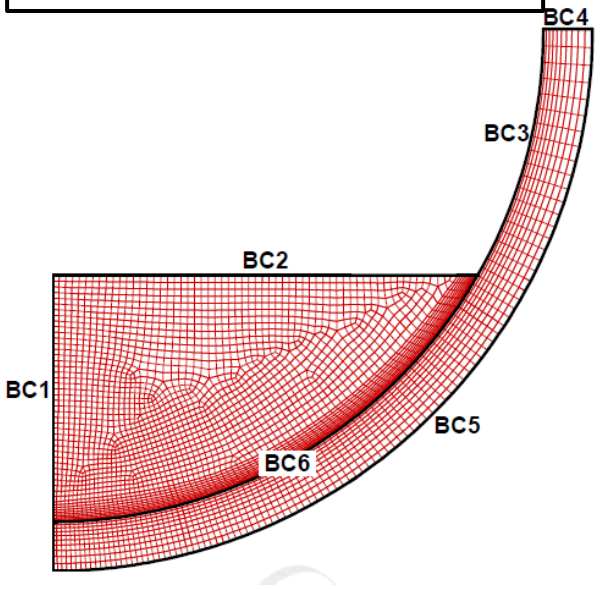
  : Validation of pre-flooding strategy in the vessel on SAMG
  : Reducing uncertainties of in-vessel phenomena

Existing Gap Cooling Analysis

Steady Analysis

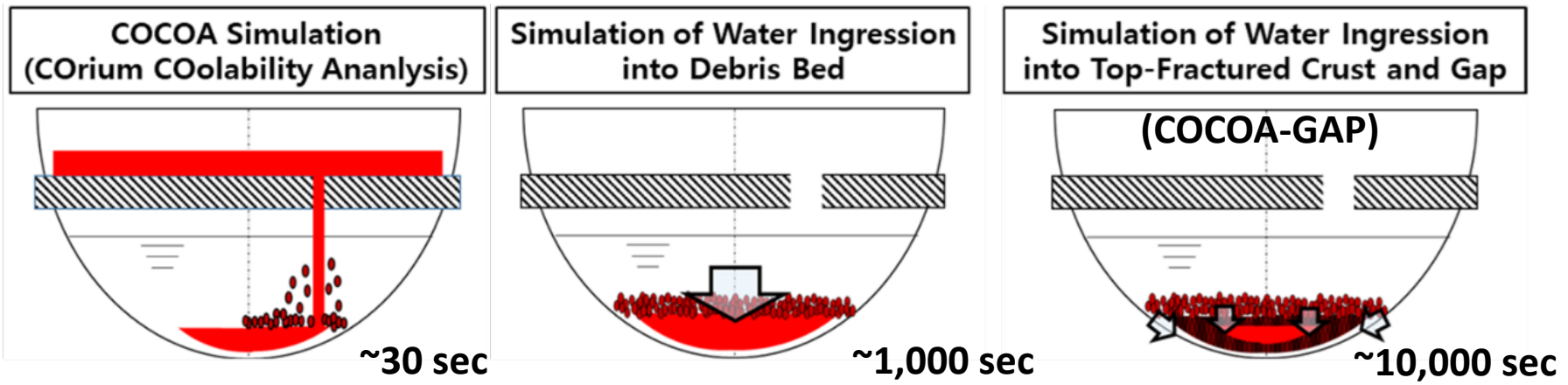


Transient Analysis



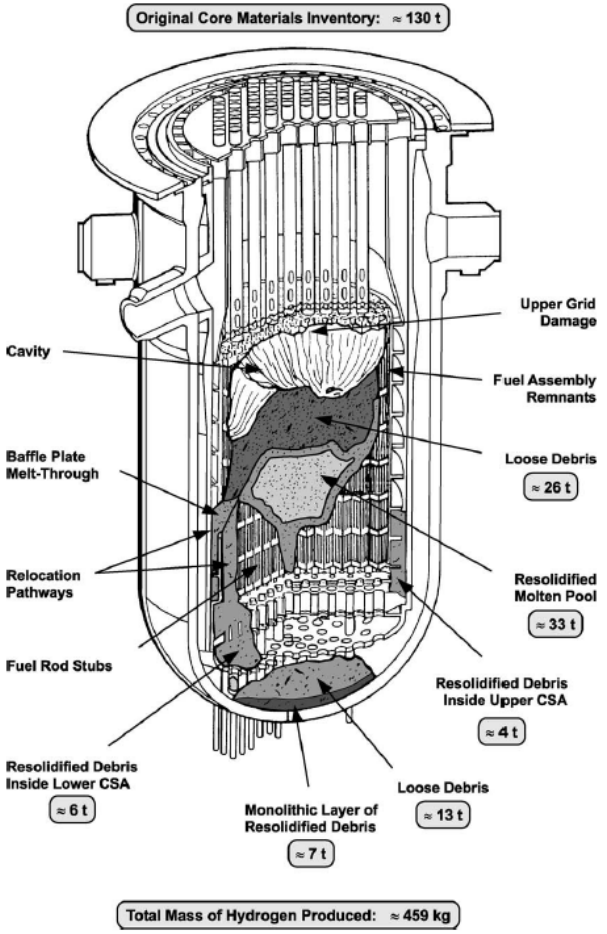
- **Limitations:**
  - **Lack of understanding of gap formation mechanism**
  - **No validation of large melt mass experiments**
  - **Application: no TMI-2 analysis**

Integrating Tools for In-vessel Corium Coolability with Consideration of Water Penetration



	Common input variables	Individual input variables
I. Inputs of COCOA simulation	- initial melt superheat - initial melt mass - system pressure - water mass - initial water temperature	- cavity volume - mean particle diameter - jet nozzle diameter
II. Inputs of water ingression in to particulate debris bed		**- accumulated area of the corium*** **- thickness of particle bed/melt*** - porosity of particle bed **- temperature of particle bed*** - T_{MFB}
III. Inputs of COCOA-GAP		**- water ingression time of particle debris bed*** - T_{MFB} - vessel geometries - initial conditions for melt

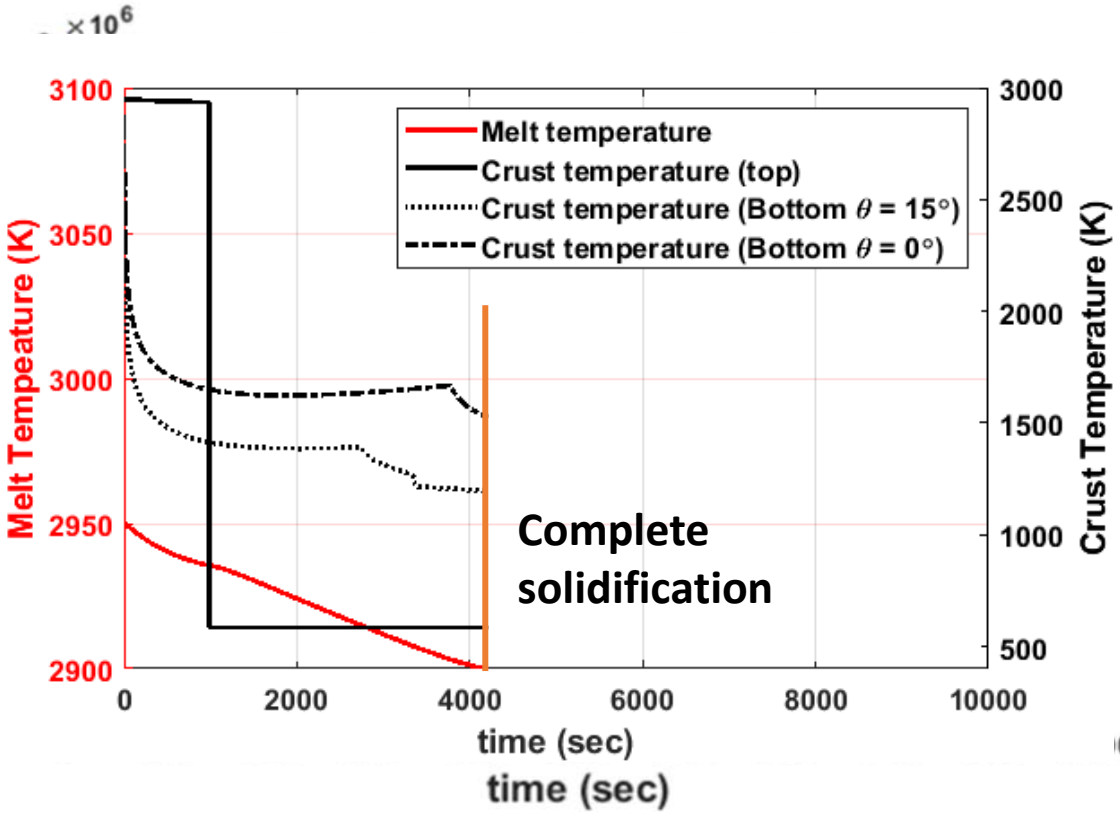
Simulation Conditions (TMI-2 Accidents)



	Lower bound of TMI-2 accident
Decay heat level	**0.75 [MW/m^3] (Nominal 1.0 [MW/m^3])**
Initial corium mass	20,000 [kg]
Particulate debris mass (from COCOA simulation)	12,481 [kg]
Melt mass	7,519 [kg]
Initial melt superheat	50 [K]
W.T. fraction of UO_2 and ZrO_2	80% UO_2 and 20% ZrO_2
System pressure	100 [bar]
Subcooling	10 [K]
Vessel thickness	0.127 [m]
Vessel radius	2.2 [m]

No substantial thermal attack of the reactor vessel
(A hot spot of almost 1400K, 30 minutes)

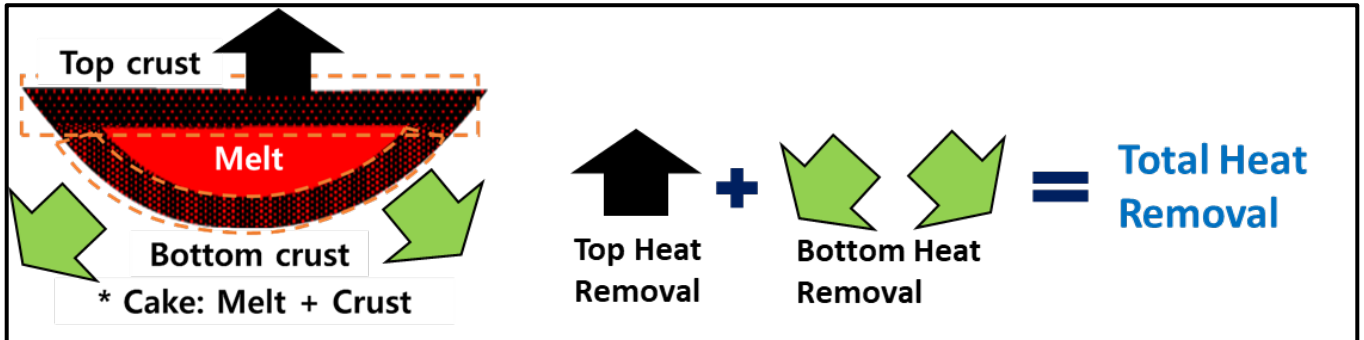
Results of TMI-2 Simulation



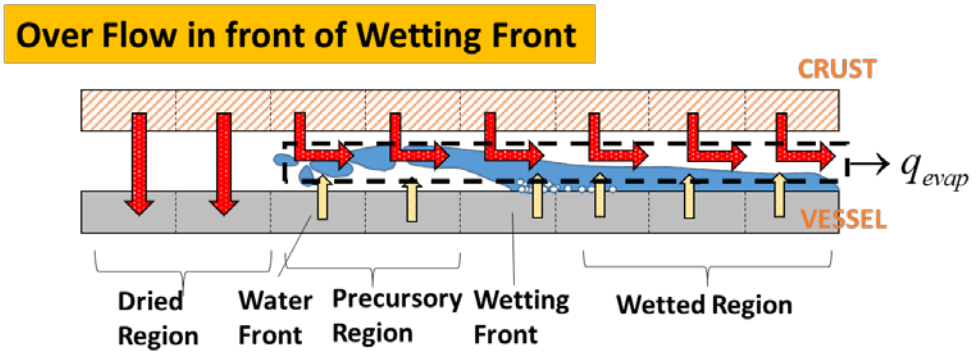
* Total heat removal (blue)
  > Total heat generation(red)
(decay +solidification)

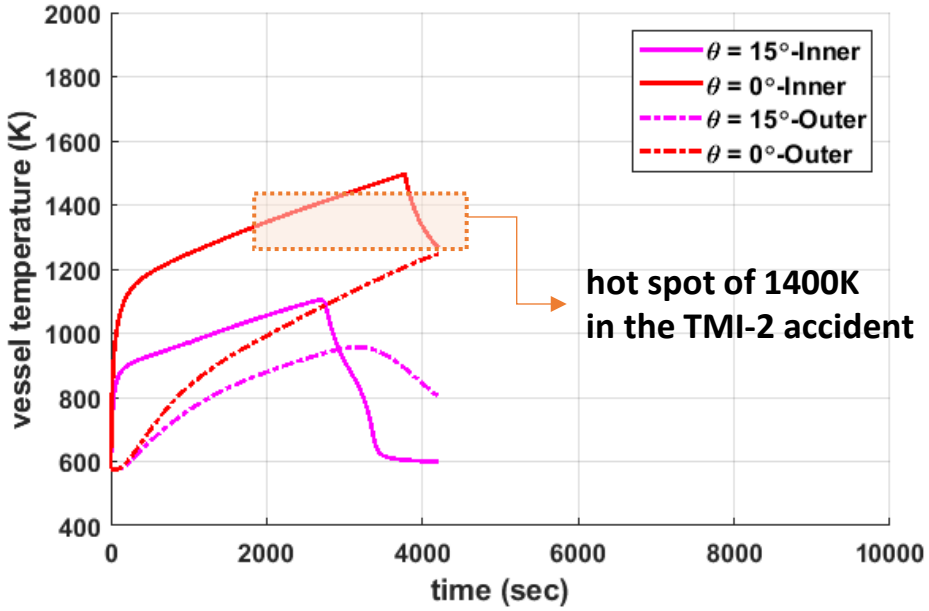
* Heat removal on the top (black)
  > Heat removal on the bottom (green)

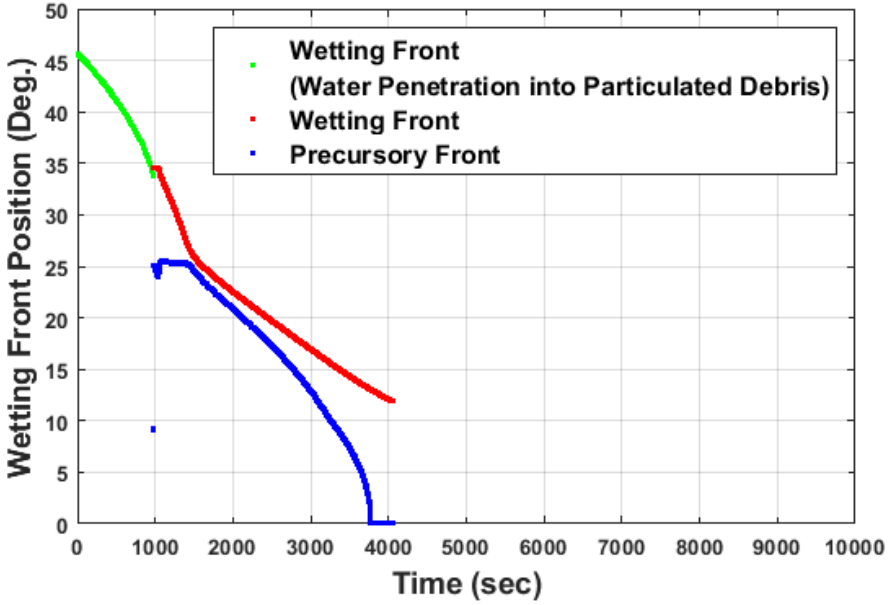
* Melt and crust can be stable.



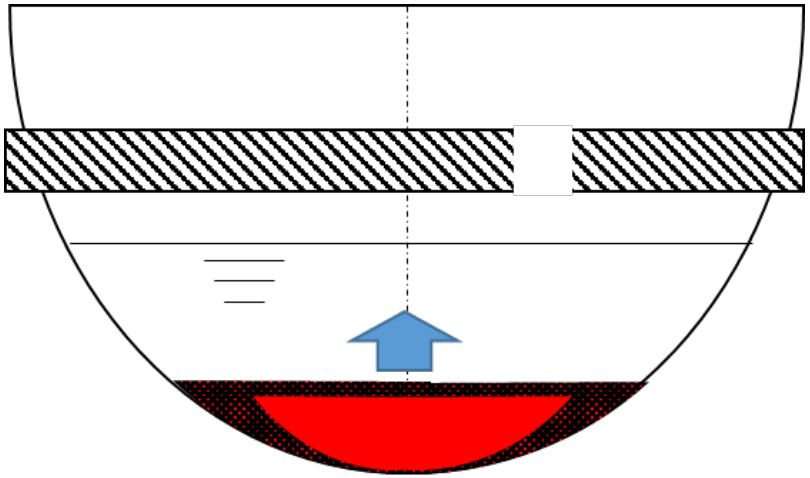
Results of TMI-2 Simulation

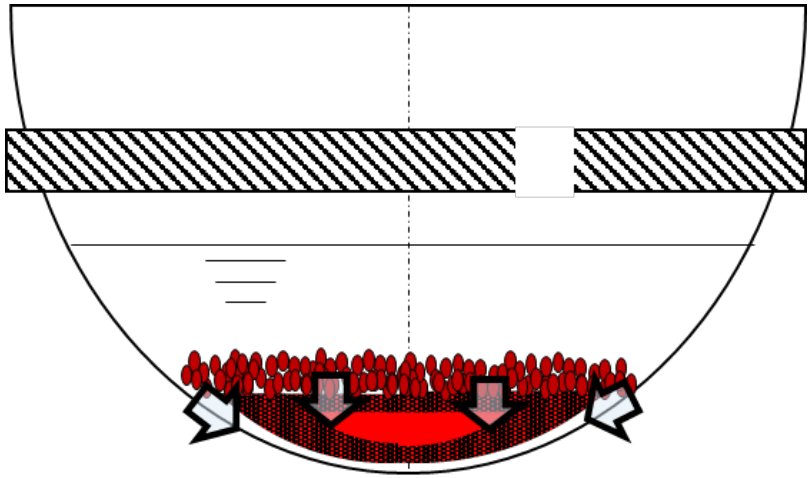






Evaluation of Water Penetration Effect



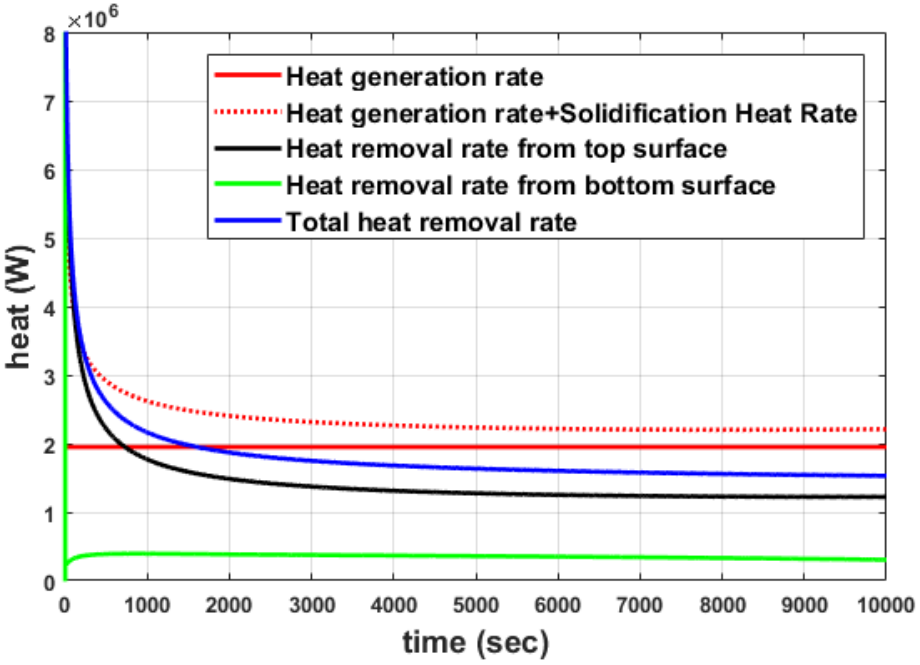


I. No Water Ingression
(Direct contact with vessel/film boiling on the bottom/top)

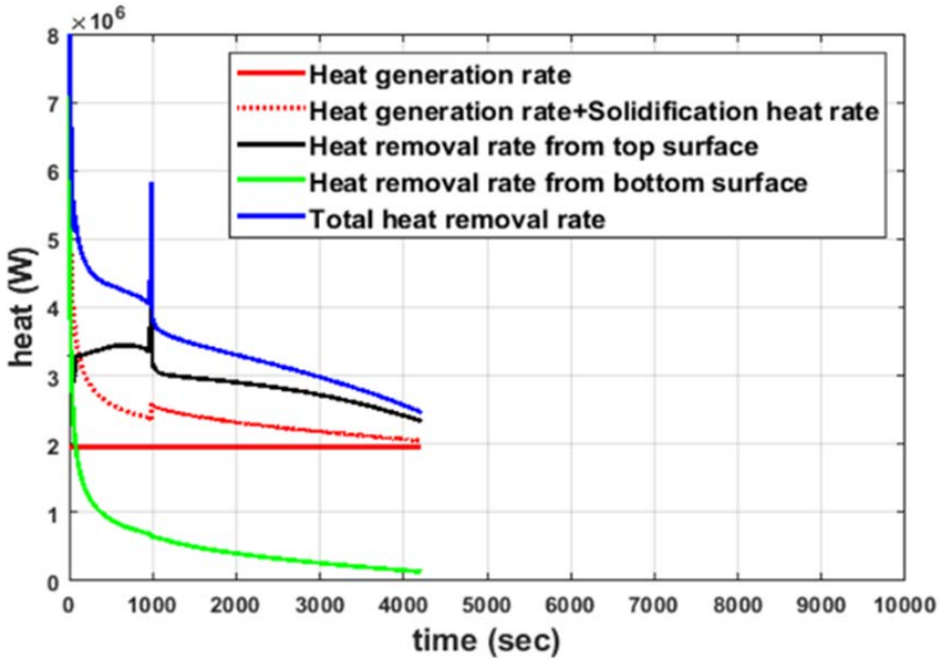
II. Water Ingression into gap and particulate debris/fractured-top crust
: Integrated tool developed in this study

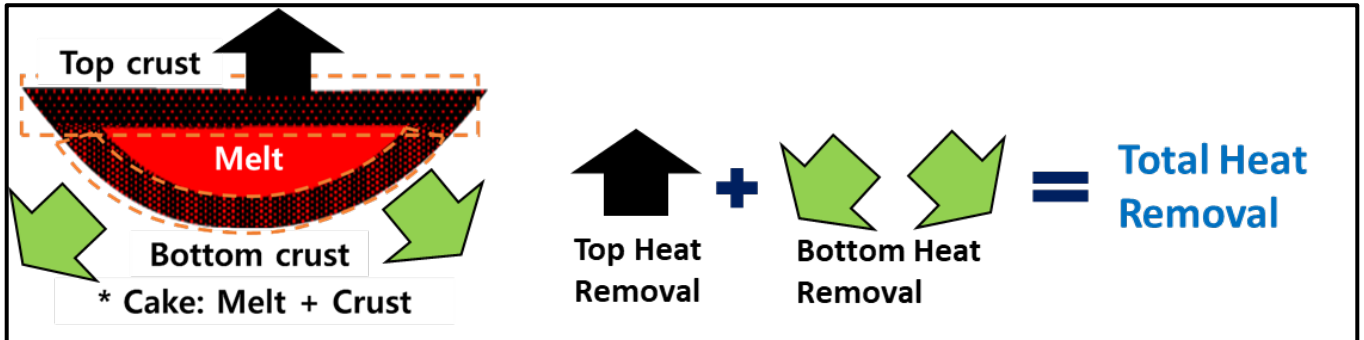
Comparison with No Water Penetration

No Water Penetration



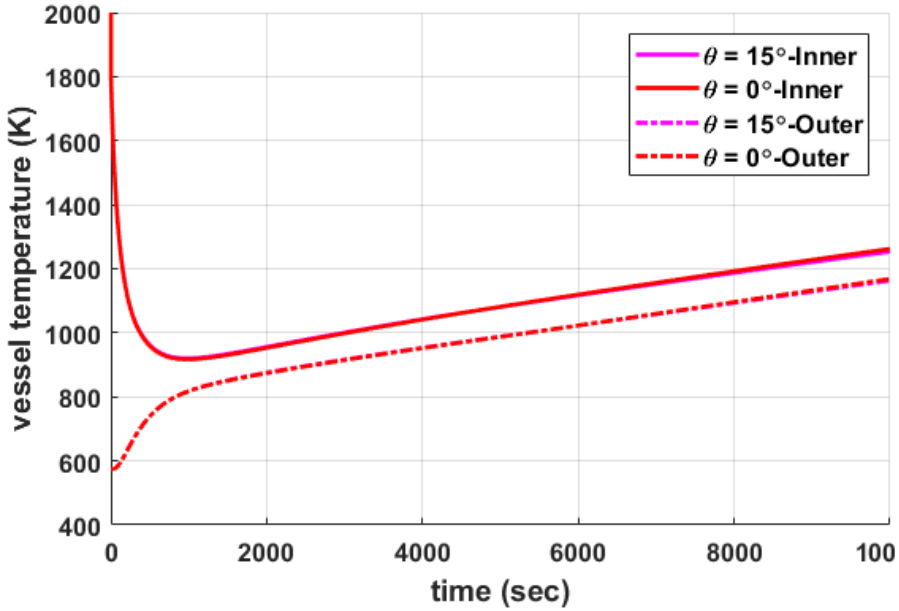
Water Penetration into gap/debris



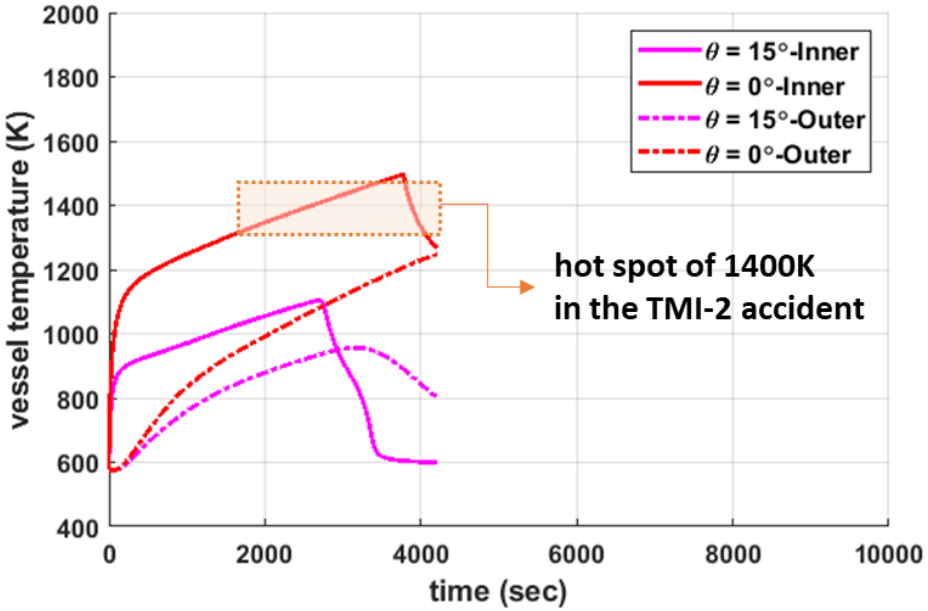


Comparison with No Water Penetration

No Water Penetration

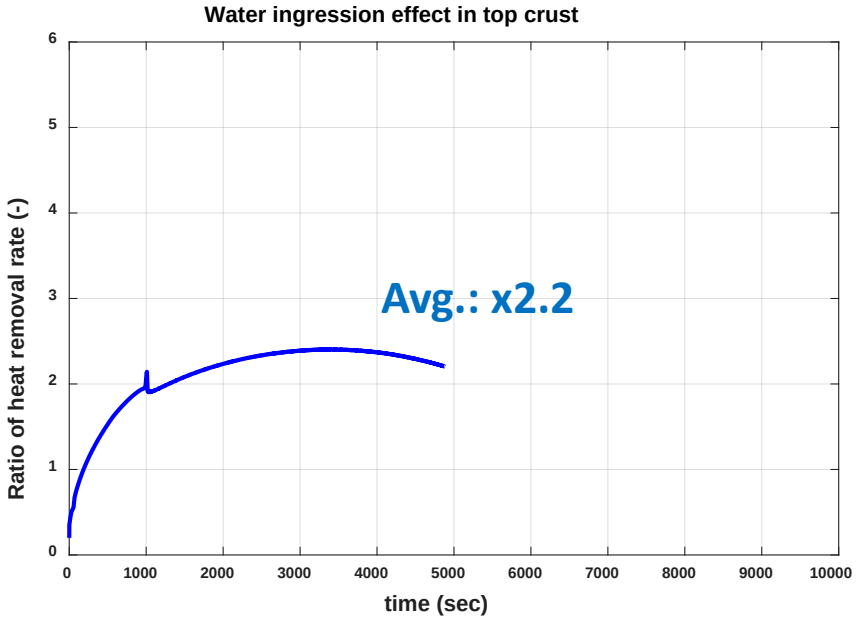


Water Penetration into gap/debris

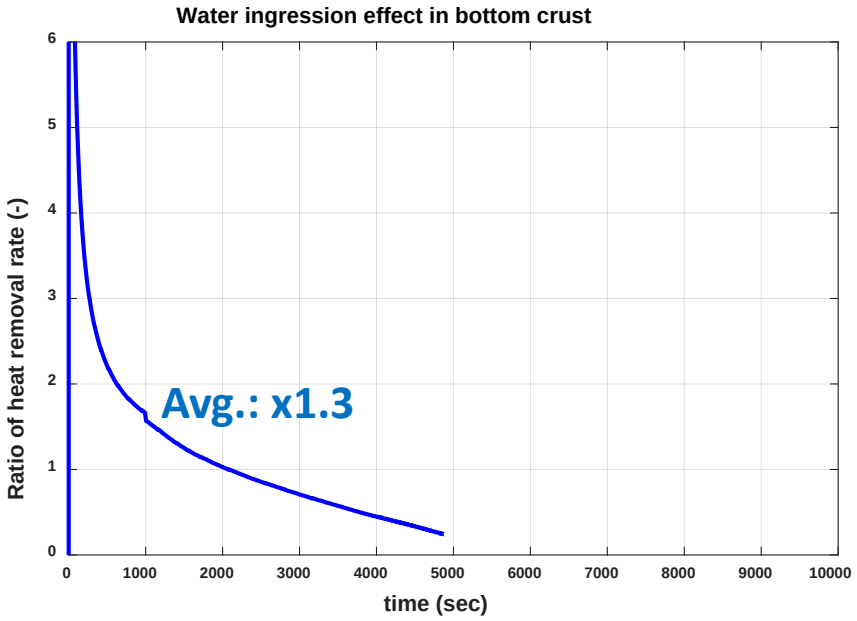


Quantitative Evaluation of Water Penetration Effect

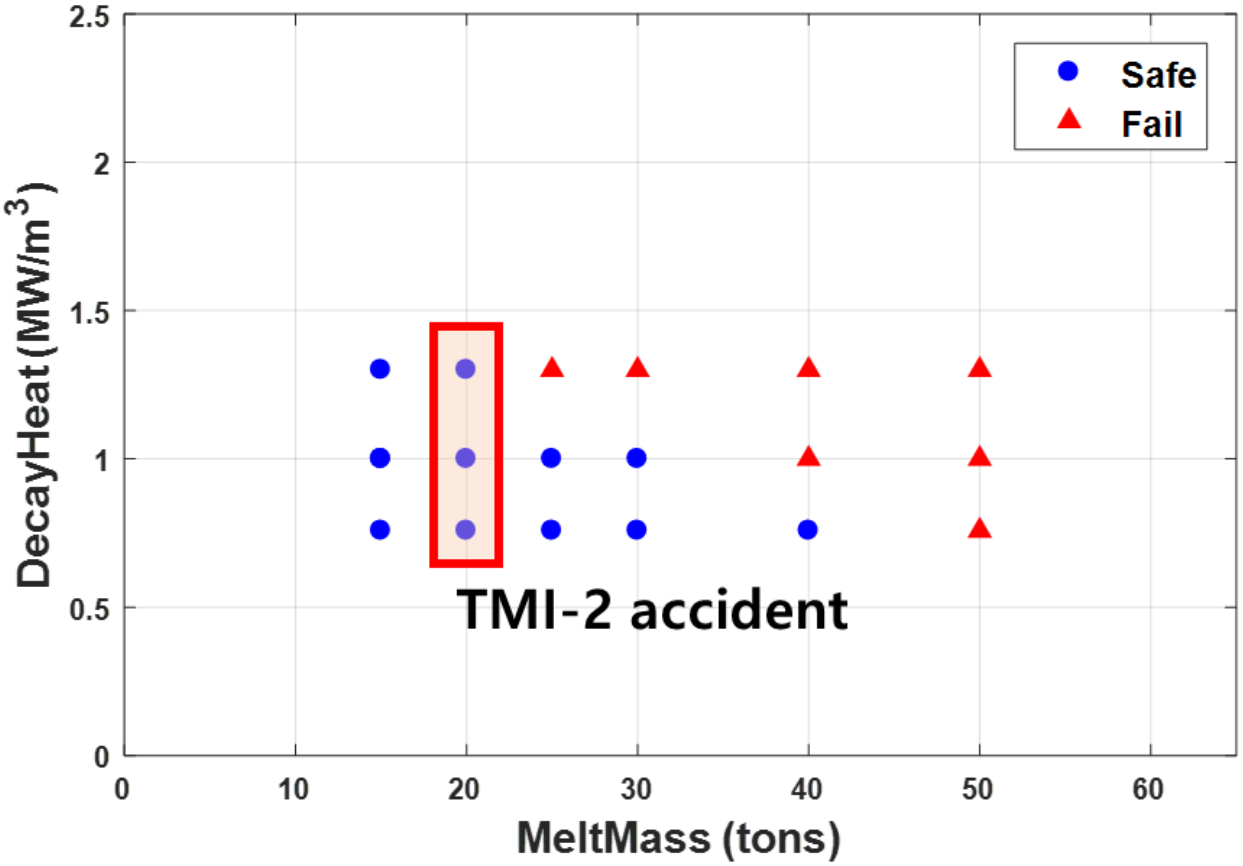
Top Water Ingression Effect



Bottom Water Ingression Effect



Safety Limits for TMI-2 Reactor Vessel



Conclusions

- **COCOA-GAP tool was extended through integrating with tools of the fuel-coolant-interaction analysis and water penetration into particulate debris bed.**
- **The gap cooling and 1400K of a hot spot were successfully simulated.**
- **The heat removal from the upper and lower crust was increased by 2.2 and 1.3 times than the ones predicted with the assumption of no water penetration, respectively.**
- **Safety limits for maximum corium mass was proposed at the given decay heat level.**

Appreciate Your Attention
Any Advice Welcome

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