Experimental study of reflooding heat transfer on Cr-layered cladding under atmospheric pressure

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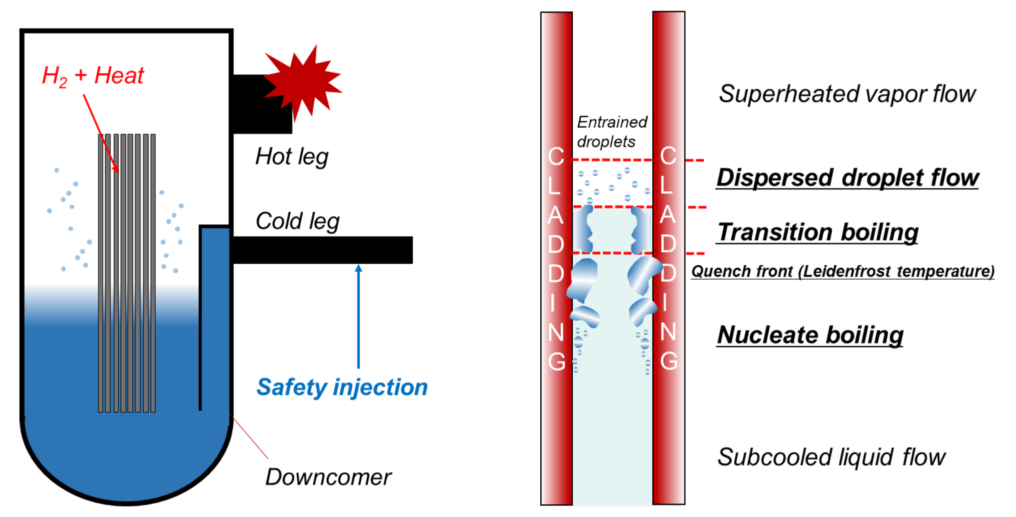
Introduction

● **Reflooding by Emergency Core Cooling System (ECCS)**



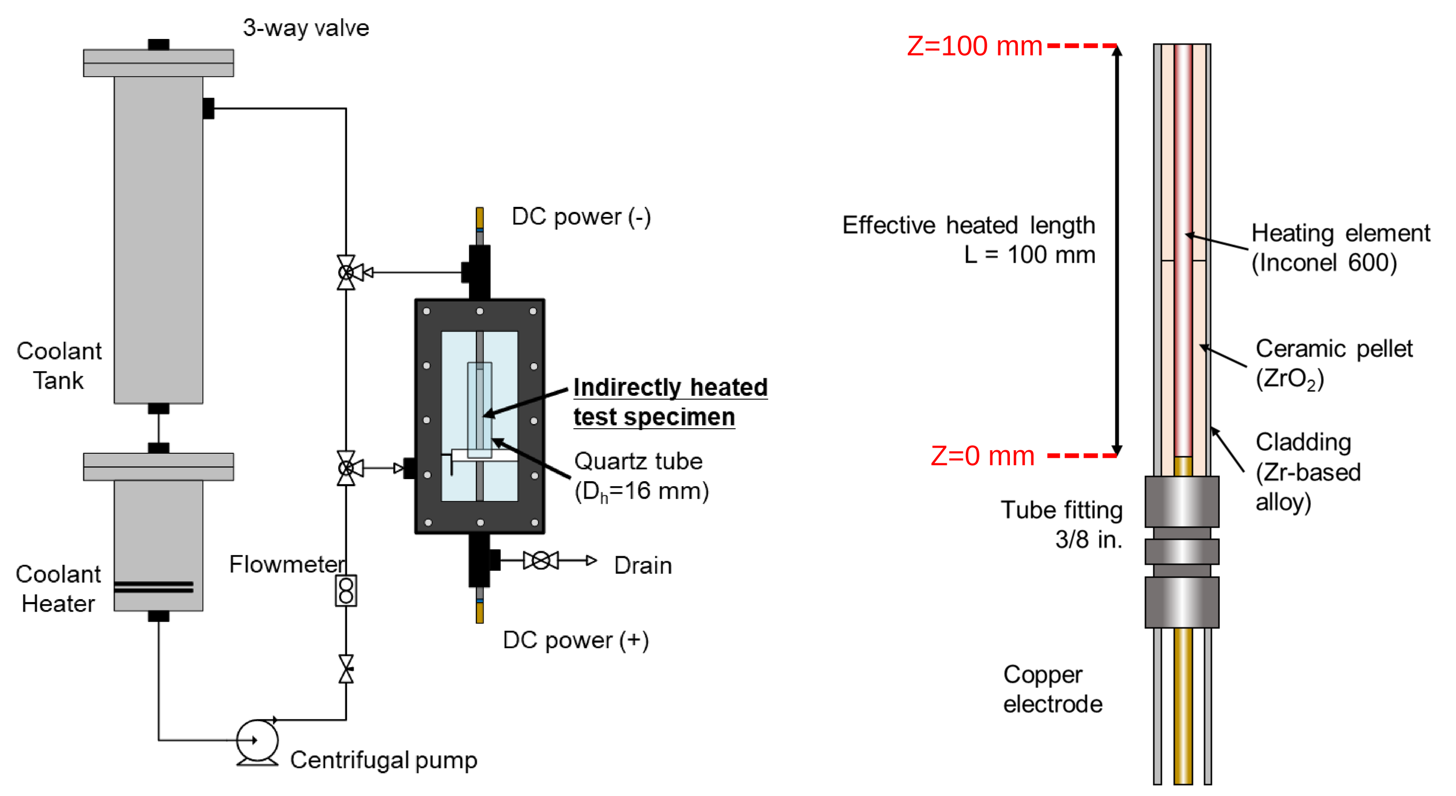
Various boiling regimes appears along the flow direction

● **Accident Tolerant Fuel (ATF) Cladding by Surface Coating**
- ✓ Oxidation resistant materials: **Cr** / FeCrAl / Mo / CrAl
- ✓ Coating layer successfully reduces oxidation of body material without significant changes in existing fuel cladding systems

● **Research Objective**
- ✓ To investigate the effect of Cr-layered coating on heat transfer during the reflood condition for single tube geometry

Experimental Setup

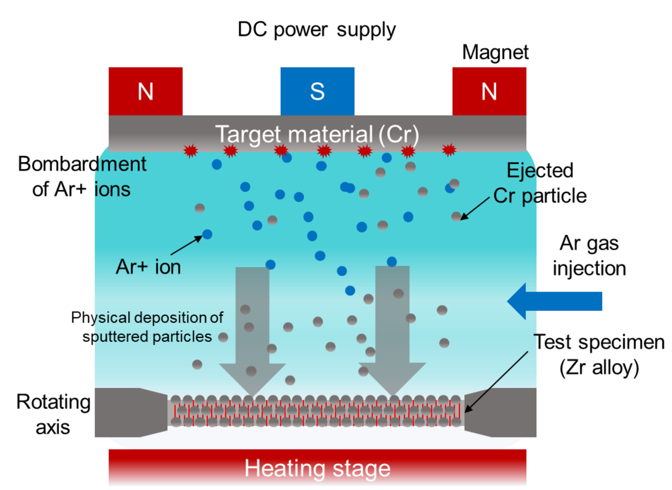
● **Experimental Apparatus**
- ✓ Decay heat simulation → Indirectly heated specimen
- ✓ Effective heated length: 100 mm
- ✓ Flow channel hydraulic diameter: 16 mm (ref. 12.53 mm in NPP)
- ✓ Specimen material: Zr-based alloy tube (Diameter: 9.53 mm)



● **Instrumentations**
- ✓ Two axial temperature measurements (z=20 mm / 60 mm)
- ✓ TCs embedded between the cladding tube and ceramic pellet

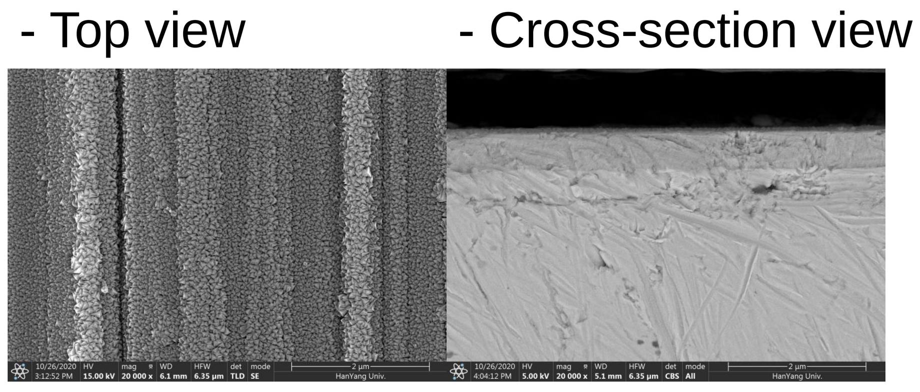
Test Matrix

● **Surface Preparation**
- ✓ Before depositing the Cr-layer, the cladding surfaces were initially grounded by sandpaper of grit number of 320 to achieve the same intrinsic surface roughness
- ✓ Micro-scratches were formed in circumferential direction
- ✓ Cr-coating was carried out by means of DC magnetron sputtering technique



<SEM images of Cr-coated specimen>

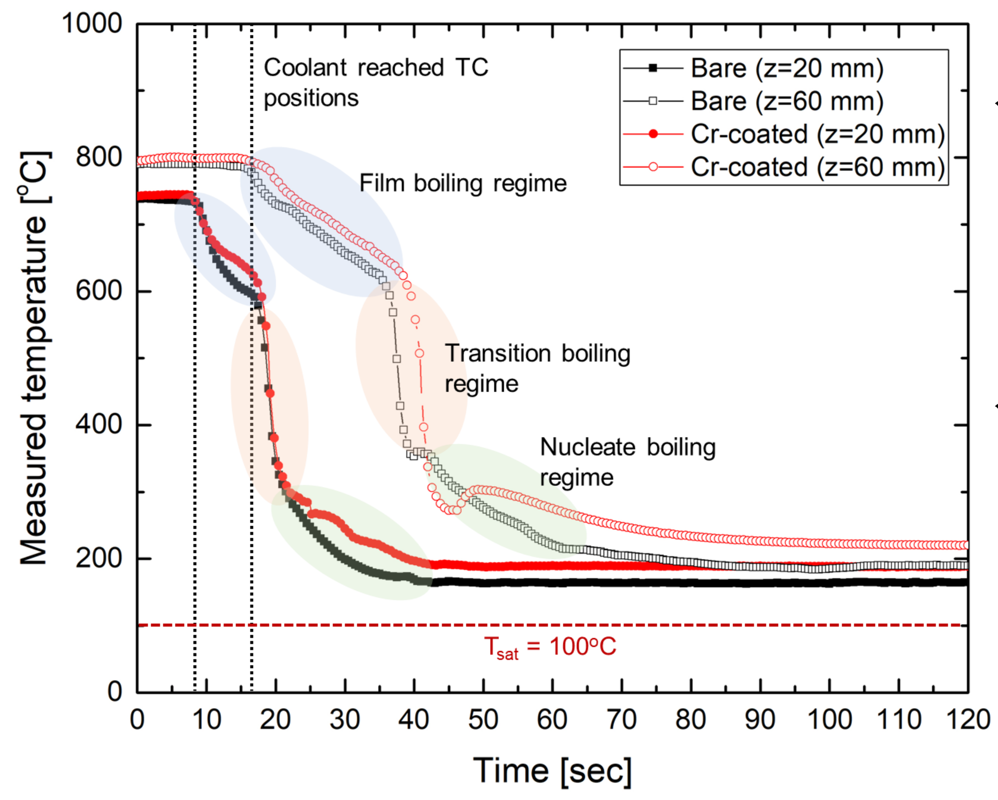
- Top view - Cross-section view



● **Test Conditions**
- ✓ Reflooding initiation: When temperature at z=60 mm reaches 780°C
- ✓ Reflooding rate: 6.6 mm/s
- ✓ Linear heat generation rate: 2.23 kW/m
- ✓ Coolant subcooling: 24°C

Results

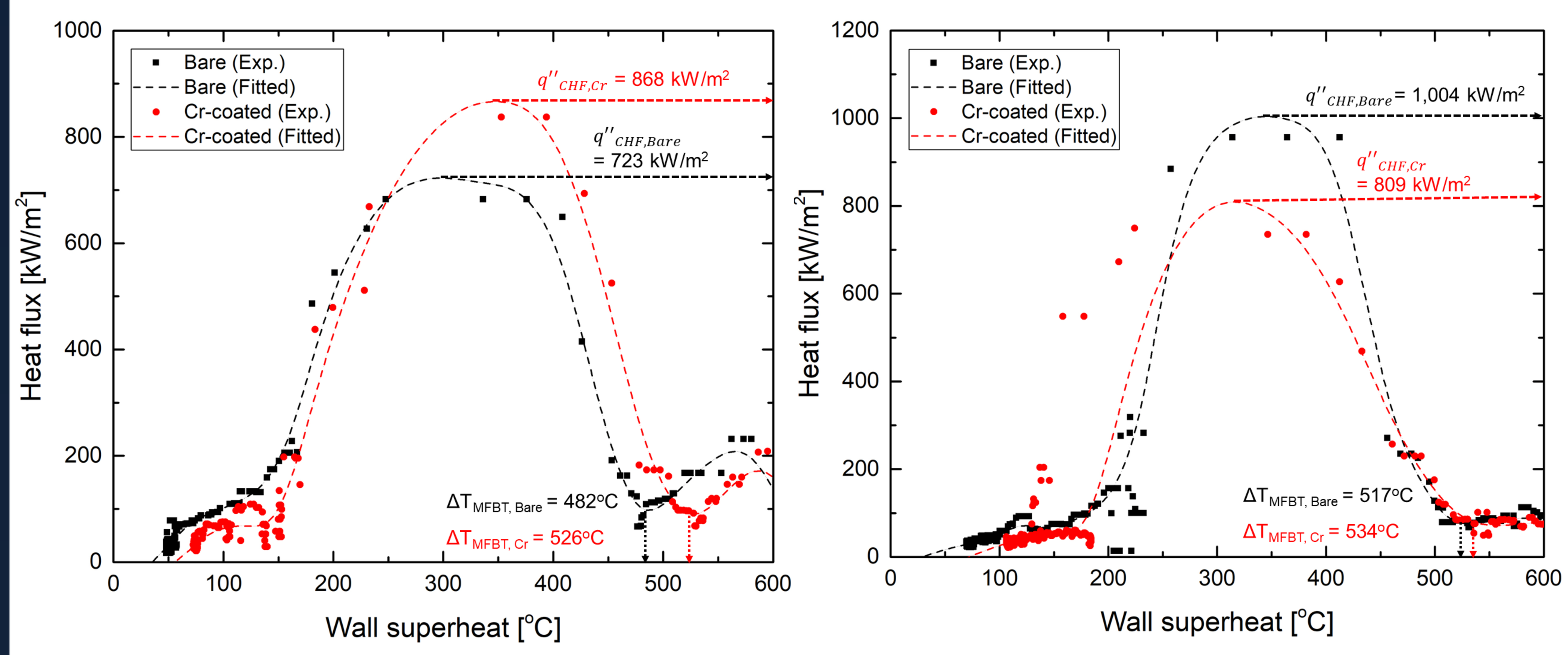
● **Temperature History**



- ✓ Distinct boiling regimes appear during the cooling process (Film → Transition → Nucleate)
- ✓ Due to continuous heat generation inside the specimen, the temperature measurements remains above the saturation temperature

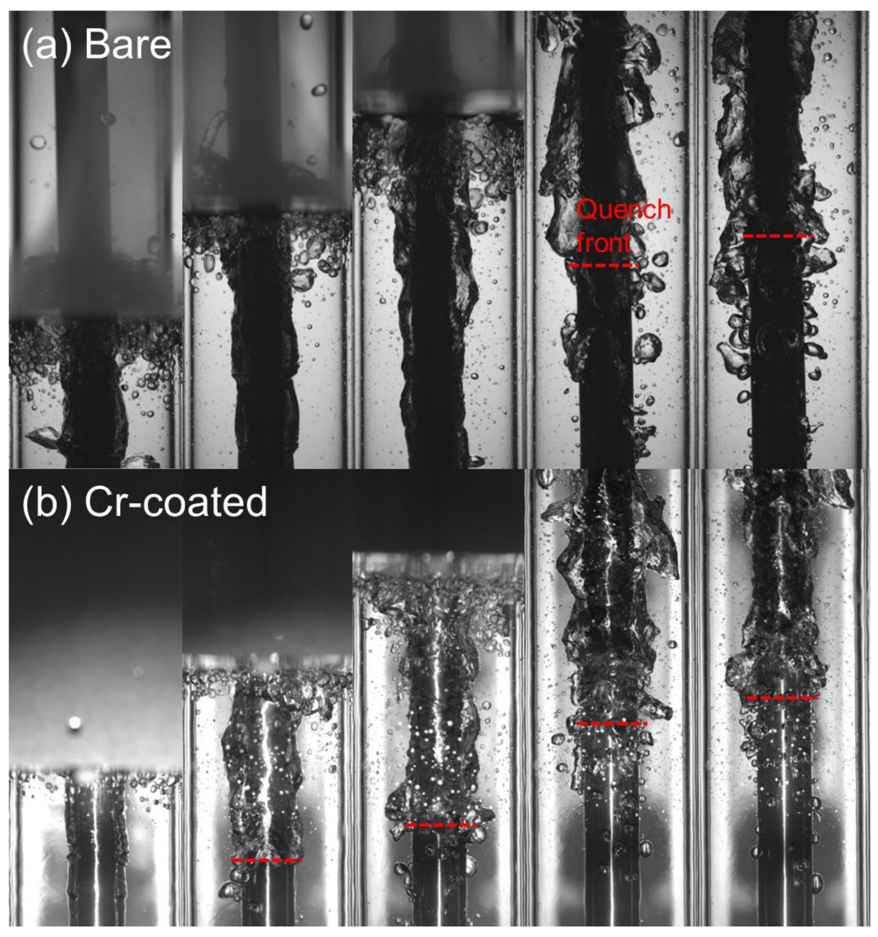
● **Boiling Curve Analysis (Inverse Heat Conduction)**

- z= 20 mm **- z= 60 mm**

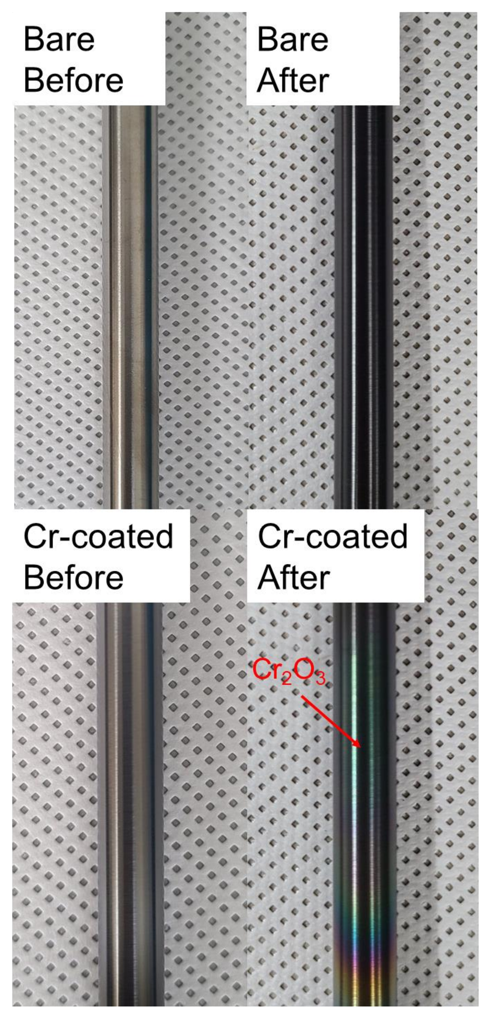


- ✓ At z=20 mm, Cr-coated surface showed better cooling performance in terms of both critical heat flux (CHF) and minimum film boiling temperature (MFBT)
- ✓ Due to slow reflooding rate, the rising bubbles generated from the bottom merged with vapor film affecting the quench phenomenon in elevated region
- ✓ Higher MFBT for both bare and Cr-coated surfaces were observed at z=60 mm than those of z=20 mm

● **High Speed Visualization**



Larger bubbles result in unstable and fluctuating vapor film at elevated region



- ✓ Larger bubbles are observed for the bare surface compared to the Cr-coated surface due to its superhydrophilic and nano-structured characteristics

Conclusion

- ✓ Cr-coating showed better cooling performance in terms of CHF and MFBT than the bare surface
- ✓ Enhancement in cooling performance was due to superhydrophilic and nano-structured surface characteristics of the Cr-coated surface
- ✓ Bubble generation at the bottom region affected the cooling process at the elevated region by inducing fluctuation in vapor film
- ✓ Smaller bubbles were generated for Cr-coated surface and showed less flow effect at the elevated region

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