Power ramp test preparation of HANA-6 cladding

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1. Introduction

The increased risk of Pellet-Cladding Interaction (PCI) failure during load-following operations requires revising current power maneuvering guidelines based on empirically defined PCI limits[1]. HANA is nuclear fuel cladding material for which KEPCO Nuclear Fuel(KNF) has independent technology ownership. For HANA cladding, establishing these limits requires power ramp testing. KNF plans to execute five such tests by 2030; accordingly, this paper presents the experimental design results for the first two tests.

2. Overall power ramp test procedure

The power ramp test procedure consists of initial characterization, refabrication of fuel segments into testable rodlets, transportation, test execution, and targeted PIE depending on whether the specimen breached or remained intact. Securing reliable fabrication capabilities and an appropriate testing reactor are paramount. For specimen preparation, KNF commissioned Studsvik, where the fuel segments were securely stored[2], to perform the refabrication, thereby guaranteeing high quality based on Studsvik's extensive international PIE and testing experience. Although global ramp testing capabilities have been severely constrained since the shutdown of the Studsvik R2 (2006) and Halden (2018) reactors, BR2 at SCK CEN was identified as having the fully operational infrastructure required for this campaign.

3. Power ramp test specimen and test design

3.1. Specimen Characterization

The first and second tests will utilize rodlets refabricated from the R16 parent fuel rod. The gamma spectroscopy results are presented in Fig. 1[3]. The specimens were specially fabricated so that the flat region of the gamma profile aligns with the peak power position when loaded into the research reactor. The local burnups of the test sections were 45 GWd/MTU. Beyond burnup, pre-test characterization included cladding outer diameter (via profilometry), oxide thickness (via eddy current testing), and pellet-cladding gap measurements. These baseline data directly inform both rodlet refabrication and experimental design.

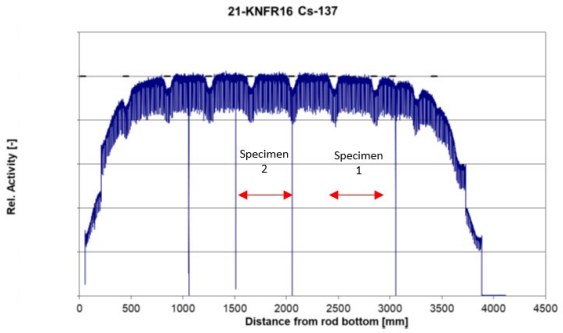


Fig. 1 Gamma spectroscopy result on parent rod(R16)

3.2. Rodlet refabrication

To ensure continuity in fuel behavior, helium gas was injected during refabrication to closely match the internal pressure of the parent rod, which had been measured at the hotcell facility in Studsvik. Following the welding assembly, laser marking was applied to each rodlet to ensure traceability. Upon completion of the refabrication, visual examinations were conducted within a hot cell environment, as depicted in Fig. 2. Subsequent leak testing, verifying the structural integrity and successful preparation of the specimens.

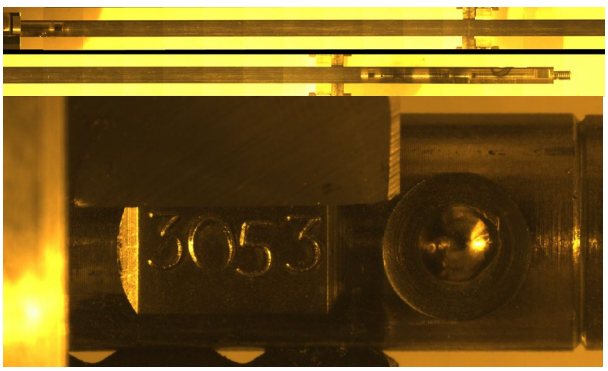


Fig. 2 Visual inspection of refabricated rodlet and its marking near welding point

3.3. Ramp test simulation and parameter determination

The design of a power ramp test is established by defining four parameters: conditioning power, ramp rate, terminal power, and hold time. Since the ramp rate and

hold time are generally fixed based on extensive prior research, the experimental design practically relies on determining the conditioning and terminal powers. Simulations were conducted using the commercial fuel performance code ROPER[4], inputting manufacturing geometry specifications, the targeted ramp power variations, and the commercial reactor irradiation history. By incorporating the axial power distribution during its irradiation as a Lead Test Rod (LTR), the power history for Specimens 1 and 2 was applied. A distinct feature of this history is the low power level during the third cycle. If this third-cycle power were directly applied as the conditioning power, pellet-cladding contact might not occur during the conditioning phase, potentially leading to an underestimation of the test results. Therefore, the conditioning power was adjusted to induce partial contact, ensuring adequate stress application to the cladding during the power ramp.

3.4. Power ramp test design result

Ramp test simulations confirmed that the predicted maximum stress, intended to serve as the PCI limit, is primarily governed by the terminal power. To precisely define the failure threshold, the first specimen was designed to remain intact, while the second was designed to carry a partial risk of damage, rather than guaranteed failure [5]. These outcome predictions were grounded in previous mandrel test data for HANA [2].

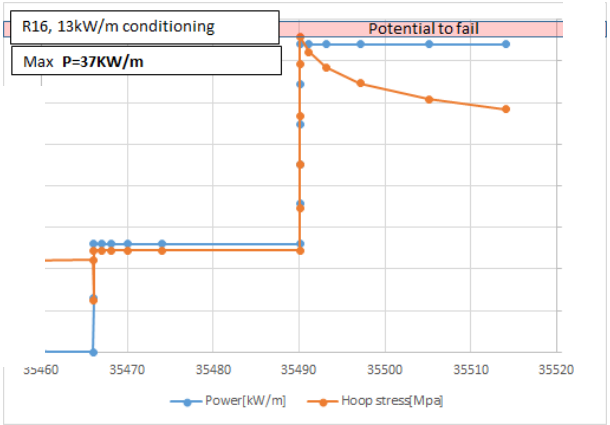


Fig. 3 HANA ramp test design result for the first ramp test

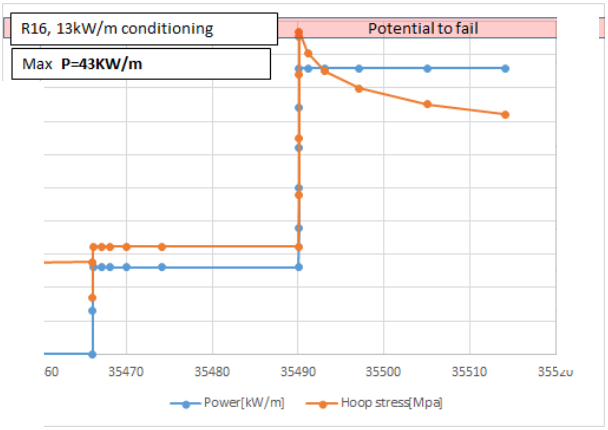


Fig. 4 HANA ramp test design result for the second ramp test

4. Conclusion

The design for the initial two power ramp tests has been successfully established, and the tests will be conducted accordingly in later 2026. The outcomes of these initial two tests will determine the design direction for the subsequent three ramp tests. Upon completion of all power ramp tests, the post-test evaluation will be performed to verify the currently established PCI limits for HANA-6

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