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In-Research Reactor Tests for SCWR Fuel Verifications

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1. Introduction

The Supercritical water cooled reactors (SCWRs) are essentially light water reactors (LWRs) operating at higher pressure and temperature. The SCWRs achieve high thermal efficiency (i.e., about 45% vs. about 35% efficiency for advanced LWRs) and are simpler plants as the need for many of the traditional LWR components is eliminated. The SCWRs build upon two proven technologies, the LWR and the supercritical coal-fired boiler. The main mission of the SCWR is production of low-cost electricity. Thus the SCWR is also suited for hydrogen generation with electrolysis, and can support the development of the hydrogen economy in the near term.

In this paper, the SCWR fuel performance verification tests are reviewed. Based on this review results, in-research reactor verification tests to be performed in a fuel test loop through the international joint program are proposed. In addition, capsule tests and fuel test loop tests to be performed in HANARO are also proposed.

2. SCWR Fuel Design Status

It is generally known that the SCWR has the following characteristics; high thermal efficiency up to 44%, direct cycle, lower coolant mass flow rate (about 1/10 of PWR), no steam generator and pressurizer, small coolant inventory, no phase change, and low average coolant density. Table 1 shows the design differences between SCWR and APR1400.

Table 1. Comparison of SCWR and APR1400 Design

Item	SCWR	APR1400
Pressure (MPa)	25	15
Temperature (^{o}C)	290~550	290~320
Efficiency (%)	44	34
Coolant	Water	Water
CHF Occurrence	No	Yes
Flow Rate	1	10
Cycle	Direct	Indirect
Pressurizer/SG/RCP	No	Yes
Containment	Small	Large

The reference SCWR fuel assembly designs proposed by university of Tokyo and KAERI are shown in Figure 1. University of Tokyo has developed the 25x25 fuel assembly that consists of 300 fuel rods, 16 guide tubes with 16 control rods, and 3x3 rectangular water flow holes with down flow, whereas KAER has developed the 21x21 fuel assembly that consists of 316 fuel rods, 25 guide tubes with 24 controls rods and 1 instrumentation, and cruciform ZrH_2 solid moderator.

The fuel rod dimensions are typical of 17×17 PWR fuel assembly rods, with the exception of the plenum length and fill pressure. The rod pitch is considerably smaller than the pitch used in LWRs. The U-235 enrichment, the Gd2O3 loading, and the fuel burnup are typical of the values used in high burnup LWR fuel, although their distribution within the fuel pin, within the fuel assembly and throughout the core are yet to be determined.

Candidate materials of the SCWR fuel have been identified by the ORNL materials experts for all the components of the fuel assembly. The structural materials recommended re primarily ferritic-martensitic steels (e.g., T91, A-21, NF616, HCM12A), and low swelling variants of the austenitic stainless steels (e.g., D-9, PNC). Among the more advanced materials oxide-dispersion strengthened ferritic steels (e.g., MA-957) and ceramic composites (e.g., SiC-SiC) should also be explored given their potential for superior high-temperature strength. Many of these materials have been selected based on satisfactory unirradiated properties and/or proven performance under irradiation. However, a more out-of-pile and in-reactor verification tests for suitable materials selection are to be performed.

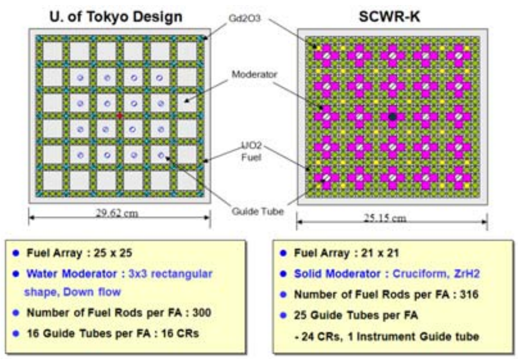

Figure 1. SCWR Fuel Assembly Designs

3. Verification Tests for SCWR Fuel

In order to supply the SCWR fuel to the SCWRs, the following performances are to be confirmed;

- the fuel system is not damaged as a result of normal operation and anticipated operational occurrences,
- fuel system damage is never so severe as to prevent control rod insertion when it is required,
- the number of fuel rod failures is not underestimated for postulated accidents,

- the reactor coolability is always maintained.

Various out-of-pile, capsule, in-research reactor and in-reactor tests are to be performed to meet the requirements mentioned above.

3.1 Materials Out-of-Pile Verification Tests

Simulating the SCWR normal/transient and accident conditions, the out-of-pile verification tests such as corrosion tests at high temperature and pressure, creep tests, mechanical and rupture tests, fatigue tests, thermo-physical characteristic tests, microstructure tests, LOCA and RIA tests are to be performed.

3.2 FA and Components Out-of-Pile Verification Tests

Simulating the SCWR normal/transient and accident operation conditions, the out-of-pile verification tests for fuel assembly components such as impact tests, fluid-induced vibration and fretting wear tests, pressure drop tests, critical heat flux tests, and mechanical tests are to be performed. In addition, simulating the SCWR normal/transient and accident operation conditions, the out-of-pile verification tests for fuel assembly such as lateral and axial stiffness tests, twist tests, tilt tests, lateral and axial vibration tests, pressure drop tests, liftoff tests, fluid-induced vibration and fretting wear tests, Lateral impact tests and axial drop tests simulating LOCA and seismic conditions, and drop tests simulating handling accidents are to be done.

3.3 In-Research Reactor Verification Tests

In-research reactor verification tests are composed of capsule tests and fuel loop tests. The capsule tests include materials corrosion tests, creep tests, fatigue tests and mechanical tests, fuel fission gas release tests, densification/swelling tests, materials irradiation-induced growth tests, etc. The fuel loop tests cover materials corrosion tests, creep tests, fatigue tests and mechanical tests, fuel temperature tests, PCI tests, SCC tests, power ramp tests, water chemistry tests and fuel rod behaviors simulating LOCA and RIA conditions.

3.4 In-Reactor Verification Tests

In-reactor verification tests are composed of pathfinder rod tests, fuel assembly components test, lead assembly tests and commercially-supplied fuel assembly performance surveillance. The pathfinder rod tests are performed to verify in-reactor behaviors of newly-developed materials, while the fuel assembly components tests are done to verify in-reactor behaviors of newly-developed fuel assembly components such as top and bottom nozzle, spacer grids, guide thimble tubes, etc. The lead assembly tests are carried out to investigate an integral effect of newly-developed materials and components on in-reactor behaviors of fuel assembly.

3.5 HANARO Verification Tests

The in-research reactor verification tests can be performed at HANARO and/or foreign research reactors. Considering that HANARO has not have test facilities simulating the transient and accident conditions yet, however, only some verification tests can be performed at HANARO.

Some capsule and fuel loop tests are proposed to be carried out at HANARO. The capsule tests proposed at HANAO may cover corrosion tests, creep tests, fatigue tests, mechanical tests, irradiation-induced growth tests for ferritic-martensite steels(T91, A-21, NF616, HCM12A), low swelling austenitic steels(D-9, PNC), oxide-dispersion strengthened ferritic steels(MA-957) and ceramic composite (SiC-SiC) that are candidates for the SCWR materials. The fuel loop tests proposed at HANARO under normal operating conditions may include corrosion tests, creep tests, fatigue tests, mechanical tests, irradiation-induced growth tests, spring force relaxation tests, fuel temperature tests, fission gas release tests, fuel densification and swelling tests, pellet-clad interaction tests, etc.

4. Summary

The out-of-pile tests for materials, fuel assembly and its components are reviewed. Also in-research reactor and in-reactor verification tests for materials, semi-fuel bundle and/or fuel assembly are reviewed. Some capsule and fuel loop tests are proposed to be carried out at HANARO, which may be economical and timely performed, compared with foreign research reactors..

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