Studsvik

Accident Tolerant Fuel

FUEL & MATERIALS TECHNOLOGY

Fuel Qualification for Accident Tolerant Fuel

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Introduction

When a new nuclear fuel design is introduced to the market an extensive set of tests and analyses is required in order to demonstrate the fuel meets internationally accepted safety standards. Generally this evaluation is termed "Fuel Qualification".

If performed properly this testing and analyses can easily take several years to complete. However, any mistakes due to improper testing techniqes can waste several years investment (for example fuel that has been irradiated for several years and then deystroyed during testing due to improper techniques). Studsvik's long history of successfully developing Fuel Qualification techniques as well as the actual performanc Fuel Qualification for a variety of fuel designs for multiple organizations throughout the world helps fuel vendors mitigate this risk of cost overruns due to improper testing techniques.

Additionally, having the proper facilities is also a significant part of providing state-of-the-art Fuel Qualification. Studsviks has its own Hot Cell Laboraty facilities as well as microscopy, water chemstry, and mechanical examination laboratories, as well as facilities to develope unique testing equipment required during Fuel Qualification.

Studsvik's experience with Fuel Qualification uniquely positions Studsvik as valuable resource in the mission of developing ATF Roadmap. The ATF roadmap is to develop the next generation of LWR fuels with improved performance, reliability, and safety characteristics during normal operations and accident conditions and with reduced waste generation.

Significant out-of-reactor testing will be required to fully characterize the mechanical, physical and chemical properties of the ATF fuel. New PIE (Post Irradiation Examination) capabilities will have to be developed to meet new requirements of advanced design aspects of ATF fuel.

Studsvik has extensive experience in developing test equipment, as well as examining and testing light water, and advanced gas cooled reactor fuel, under a variety of operating conditions (real and simulated normal operation and anticipated transient conditions). Studsviks capabilities are based on well-developed experimental techniques and state-of-the-art competence within this area, especially with respect to cladding performance under mechanical load during power ramps as well as under reactivity initiated accident and loss-of-coolant accident conditions.

This document provides a brief overview of Studsvik's facilities and capabilities available to address the issue of ATF Fuel Qualification.

The Studsvik Hot Cell facilities

Hot Cell Laboratory

The Studsvik Hot Cell Laboratory (HCL) with 7 concrete cells, of which two are large enough to allow reception and handling of full length LWR fuel assemblies and pins, is used for fuel investigations, failure analyses, material studies and corrosion-related work as well as for refabricating test fuel rods. There is a chemical analysis laboratory close to the concrete cells. The facility has microscopy facilities with cells dedicated to sample preparation, a special cell for Light Optical Microscopy (LOM) work and an advanced Scanning Electron Microscope (SEM) with a Focused Ion Beam (FIB).

Figure 1
The Studsvik hot cell laboratory.

Active Metals Laboratory

The Active Metals Laboratory (AKL), with 11 lead cells and 8 steel cells, is used for mechanical testing of defueled cladding and structural materials. The laboratory disposes of a wide range of test methods, including determination of mechanical material properties of cladding as well as simulation of transient or accident conditions. In addition to standard techniques like axial and ring tensile tests, ring compression tests, burst and creep tests, crack growth rate and crack initiation measurements, etc., several special techniques have been developed.

Figure 2
The Studsvik active metals laboratory.

Experimental techniques

The experimental techniques employed at Studsvik fall into two main areas: out-of-pile testing of irradiated cladding and fuel and post-irradiation examinations (PIE) of fuel rods. Studsvik also collaborates with the Halden reactor for in-pile power ramp tests. The combination of these techniques offers a powerful tool to investigate cladding integrity issues. The mechanical testing techniques have helped to identify and quantify some important aspects of cladding performance under various load con¬ditions. Detailed post-irradiation examination is essential to analyse clad¬ding fractures induced by pellet-cladding mechanical interaction (PCMI).

Studsvik also works closely with external laboratories and universities for performing high resolution Transmission Electron Microscopy (TEM), Atom Probe Tomography (APT) and other experimental tech¬niques which are at the moment not available in Studsvik.

Non-Destructive Examinations (NDE)

The following NDE can be performed:

- Visual inspection and length measurements
- Profilometry
- Eddy current defect and oxide thickness measurements
- Axial and circumferential gamma scanning
- Burnup determination using axial gamma scanning

Destructive Examinations (DE)

The following DE can be performed:

- Puncturing and measuring of fuel rod internal volume and pressure
- Cutting and sample preparation of different sizes. Fission Gas Release measurements
- Light Optical Microscopy
- Pore Size Distribution and Porosity Evaluation
- Grain Size Measurements
- Hydrogen analyses by hot vacuum extraction
- Hydrogen determination by SEM image analyses
- Field Emission Gun Scanning Electron Microscopy
- Focused Ion Beam
- Inductively Coupled Plasma Mass Spectrometry Combined with High Performance Liquid Chromatography
- Laser Ablation Combined with ICP-MS
- Burnup determination using chemical analyses LOCA Testing
- Furnace Fuel Heating Tests
- Sieve Analysis
- Fuel rod four point bending test
- Clad Axial Tensile Test
- Clad Ring Tensile Test
- Clad Ring Compression Test
- Clad Creep Testing
- Mandrel Testing

Customized build tests and test equipment

Studsvik has the experience and capability of designing and building a state-of-the-art equipment depending on experimental need. An example of this type of equipment is the Studsvik LOCA Test Rig.

Studsvik LOCA Test Rig

Method description

The first LOCA test rig at Studsvik was built on behalf of the USNRC in order to perform the same type of LOCA testing as earlier done at the Argonne National Laboratory. The apparatus was designed to externally heat a 30 cm long fuel segment up to 1200 °C by infrared (IR) radiation. The test segment temperature is measured with a thermocouple attached on the rod approximately 50 mm above the axial mid plane. The test segment is pressurized with helium or argon and placed in a quartz glass chamber in a flowing steam environment. An air or inert gas (argon) at¬mosphere is also possible. Identical pressure transducers are used both at the bottom and at the top of the apparatus.

A front view picture of the LOCA apparatus is shown in Figure 3. This photo was taken when the rod was heated up to 1200 °C.

In a typical integral LOCA test, the fuel segment is internally pressurized to 50 – 100 bar and heated with a 5 °C/s heat-up ramp. At 650 – 800 °C, the rod balloons at mid-height and ruptures. Heating continues to 1100 – 1200 °C, where the temperature is held for a predetermined time period. Afterwards, the rod is cooled down to a preselected quench temperature, typically at 700 – 800 °C, before the test chamber is filled with room temperature water. The transient parameters, e.g. ramp rate, maximum temperature, oxidation time at peak temperature, quench temperature and rod inner pressure, are all controlled and can be chosen according to the test objective.

After the test, the segment may be studied by techniques such as profilometry, 4-point bending, gamma scanning, etc. The fuel loss can be determined and the oxidation of the cladding may be evaluated by means of metallographic examinations. The content of hydrogen in the cladding can be analysed, e.g. with hot vacuum extraction (HVE). Post-test characterisation provides information on, amongst others, cladding strain, ballooning and burst, fuel fragmentation, cladding oxidation, hydrogen pickup, and transient fission gas release. Rod inner pressure and cladding outer temperature are recorded during the test.

LOCA apparatus during a test.

New equipment was designed and built in the framework of SCIP III, Task 1, taking into account experience with the first Studsvik LOCA test rig. As an additional function, axial load can be applied and rod axial elongation can be measured. Modular design facilitates maintenance and repair. The specifications were as follows:

- Axial load up to 1000 N
- Axial displacement
- Rod internal pressure up to 20 MPa, online logging
- Temperature of specimen up to 1200 °C
- Environment control (steam, air, steam and air, argon)
- Quench
- Collection of dispersed fragments for analysis.

Figure 4 shows the equipment and its modular principle.

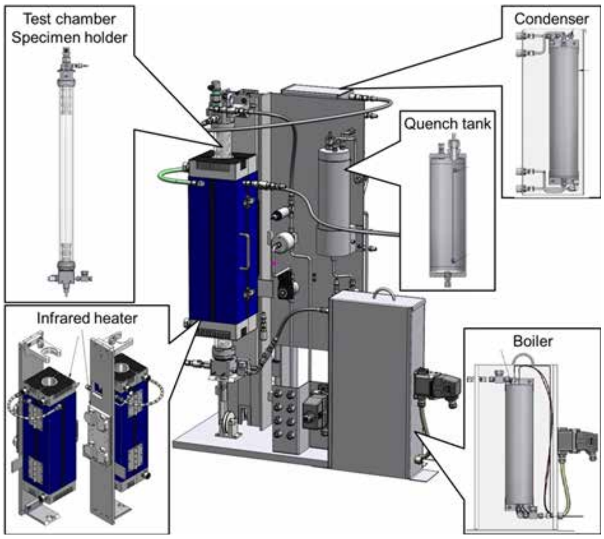

Figure 4
New Studsvik LOCA test rig

Key highlights

- Fuel Testing, Inspection, and Surveillance Post Irradiation Examination.
- World leading test capabilities of LWR materials the majority of which could be implemented for the ATF.
- Global experience covering BWR, PWR, VVER, AGR and GEN IV technology.
- Extensive knowledge of in-pile testing of various fuel types and material.
- Operating agent of OECD/NEA international program SCIP for 13 years

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