NEW LOCA TEST EQUIPMENT AT STUDSVIK HOT CELLS

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ABSTRACT

Loss Of Coolant Accident (LOCA) simulations using irradiated fuel segments have been ongoing at the Studsvik Hot Cell Laboratory since 2009.

At the HotLab conference in 2015, the first LOCA equipment was presented together with example results. The concept for a new equipment with higher test flexibility as well as new features was also briefly introduced.

This equipment is now completed and a number of tests on unirradiated cladding samples has been performed within the qualification process, including e.g. ramping and regulator settings, quenching, axial load tests and axial temperature profile characterization.

In this work the new equipment will be described and the qualification results shown. Furthermore the installation into the hot cell is described including the media throughputs for water, gas and electricity for power and measurements. Maintenance and quality check routines will also be discussed.

1. Introduction

A new integral LOCA test device (LOCA 2) has been developed at Studsvik within the OECD/NEA SCIP III project in order to study the effects of transients (such as fuel fragmentation, fuel relocation and fuel dispersal) on irradiated fuel rods segments in a hot-cell.

The equipment can accommodate a sample up to 400 mm long which can be heated up to 1200 degrees C by an infrared (IR) furnace placed around the fuel segment. During the test sequence the sample can be pressurized internally up to 190 bar and a number of different environments can be produced around the segment inside the so called sample chamber. In addition, the new device also has the possibility to apply an axial load to the segment before, during and after the test sequence in order to study structural integrity properties. Furthermore the axial elongation of the sample during the test can be measured.

Before installation of the equipment in the hot-cell, an extensive qualification and verification programme has been performed in order to gain essential informations for future experimental setups and measurements.

2. LOCA 2 device: description and test procedure

A schematic view illustrating the modular concept of the LOCA 2 test device is shown in Figures 1 and 2. The sample (a 400 mm irradiated fuel rod segment) is prepared according to one of Studsvik's refabrication procedures, which allows the welding of new end plugs to the irradiated fuel rod segments. High pressure couplings are then mounted to the plugs and the sample holder (consisting of a top sample holder, the fuel segment and a bottom sample holder) can be assembled. The sample holder at the top offers gas communication all the way through, making it possible to pre-pressurize the sample at cold conditions while fine hot condition adjustments of the sample internal pressure can be performed later. The sample pressure can be monitored on-line during the LOCA sequence and released fission gas aliquots can as well be collected after the test. After connecting the sample to the sample holder the whole test train is then inserted into the test chamber consisting of a quartz glass tube running through the infrared furnace. High pressure gas lines are connected in order to pressurize the sample and the axial load / axial elongation device is connected to the bottom sample holder.

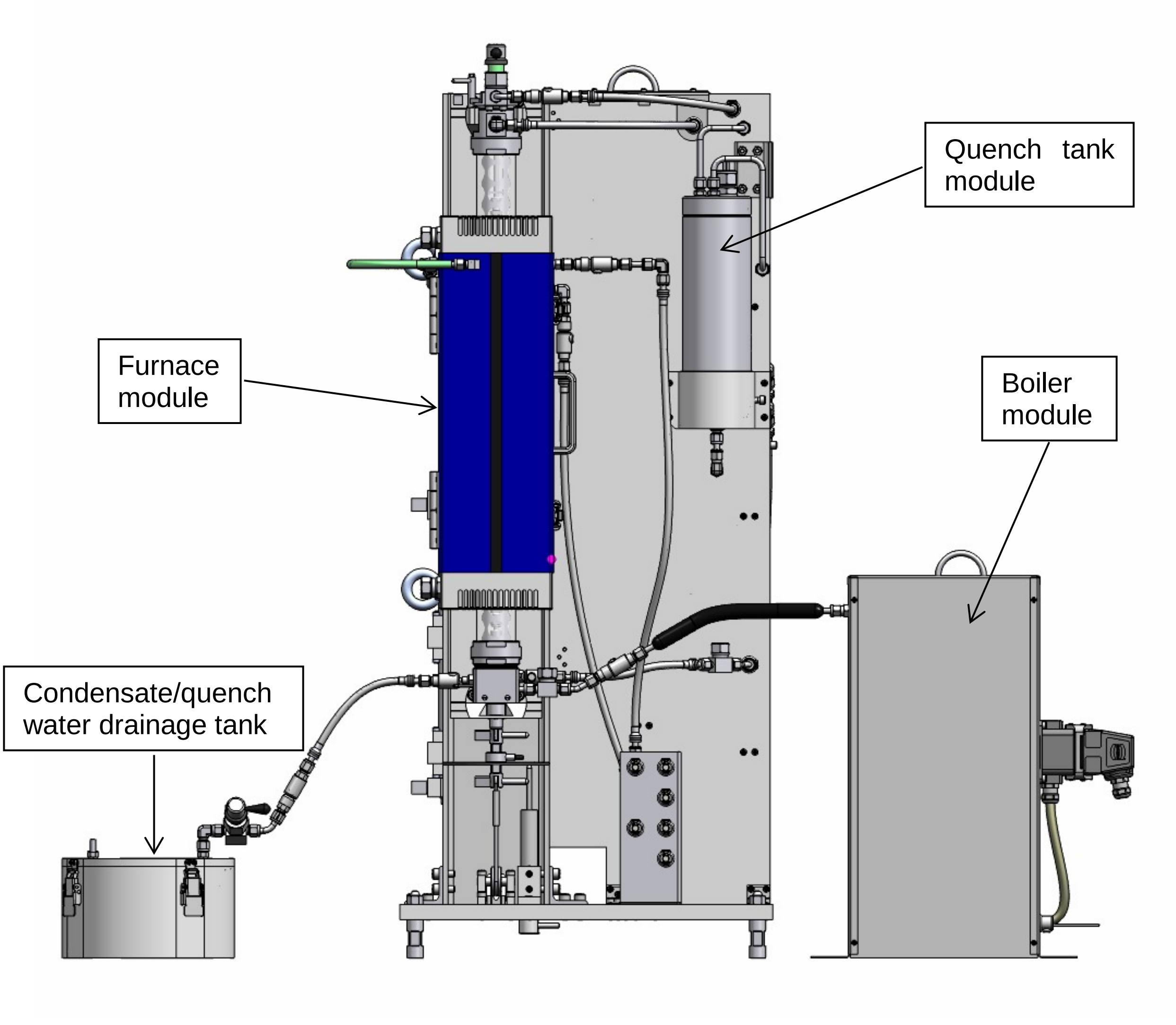

Fig 1. Schematic view of the LOCA 2 device showing the main parts (front view)

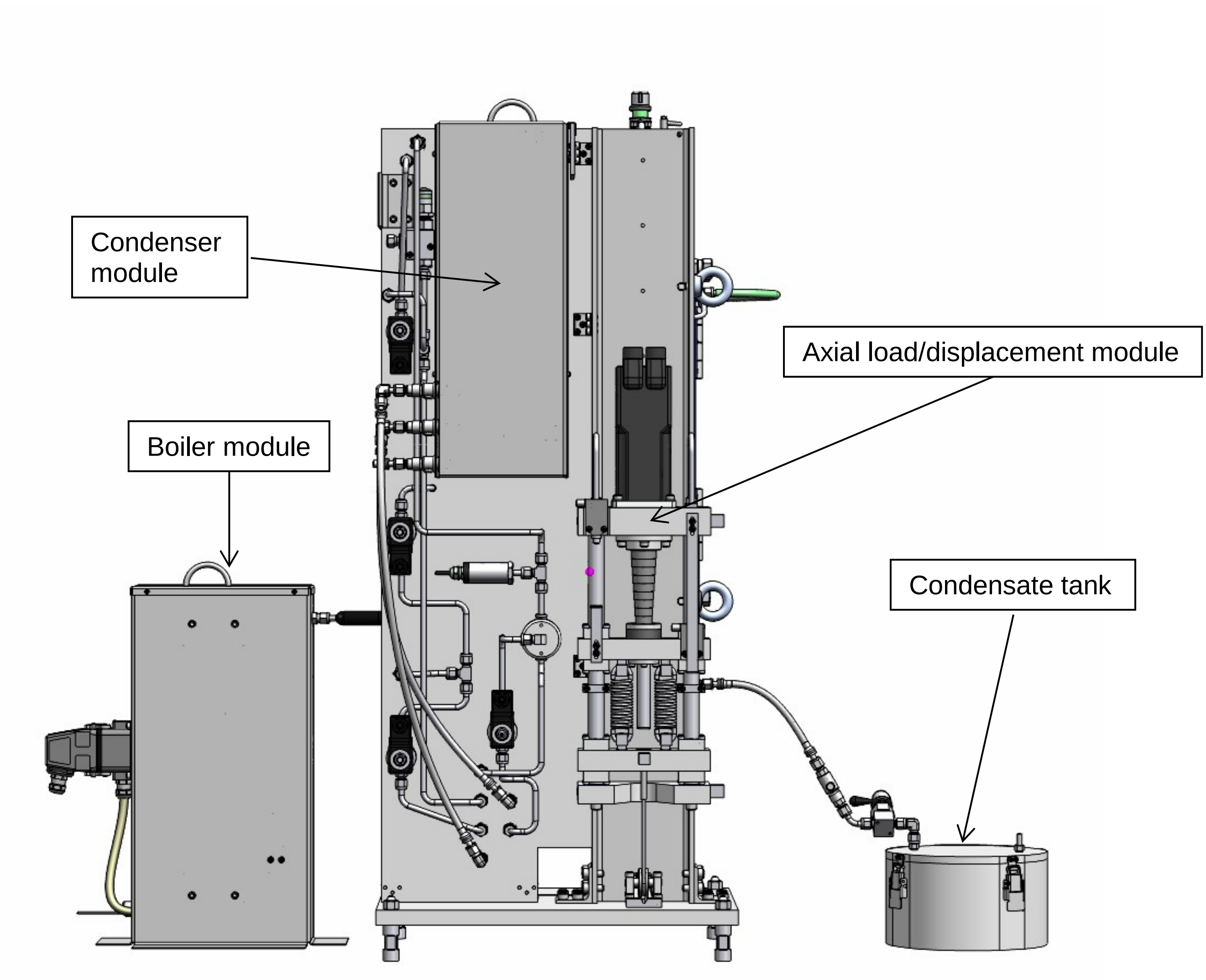

Fig 2. Schematic view of the LOCA 2 device showing the main parts (rear view)

The sample chamber isolates the sample from the cell environment making it possible to run the LOCA test sequence in a number of different environments such as flowing saturated or dry steam, air, Argon or in combinations such as air and steam. Furthermore, the sample chamber can be flooded with water at a certain stage of the test sequence to simulate quenching of the fuel rod. A constant flow of steam is produced in the boiler. After passing the test chamber the steam goes through a condenser, which brings it back to liquid phase, and this is then led to a condensate tank.

Heat removal from the furnace and the condenser is ensured by a primary water flow circulating in a closed loop. This closed loop (possibly contaminated) is in turn cooled in a heat exchanger through which a secondary flow of ordinary faucet water (open loop) runs, thereby removing the heat. The primary and secondary flows are at all times separated from each other. This ensures that no activity limit is exceeded in the sewage system for process water. The water from the closed loop is processed separately.

During LOCA tests a relatively large amount of activity will be carried by some media (i.e. quench water) and deposited in some parts of the equipment due to fuel dispersal. The modular concept for the LOCA 2 equipment gives the possibility to easily remove high activity parts in order to allow maintenance by hand and replacement of vital parts in-cell.

3. Qualification

Being a completely new device with new components, features and functions, the LOCA 2 equipment has undergone an extensive qualification process prior installation in hot-cell. A number of out-of-cell tests on un-irradiated cladding samples was performed for this purpose. In Table 1 the qualified and verified performance specifications are showed.

Table 1. Test device specifications (qualified).

Parameter	Value	Comments
Heating rate	Up 10 C/s	Faster is possible at lower temperatures.
Temperature	1200 °C	Higher temperatures can be achieved for low heating rates
Cooling rate	0.5 to 10 °C/s	Depends on the temperature range
Load	1000 N	-
Maximum loading rate	150 N/s	-
Controlled loading rate	Up to 15 N/s	-
Elongation	50 mm	Range of LVDT
Pressure	190 bar	-
Quench rate	Up to 37.5 mm/s	
Steam flow	Up to 1.2 l/h	-
Specimen length	Up to 400 mm	

The temperature values for test data sampling as well as for temperature control are obtained by mounting a thermocouple on the sample. The temperature axial profile at different conditions has been assessed under the qualification process and is shown in Figure 3.

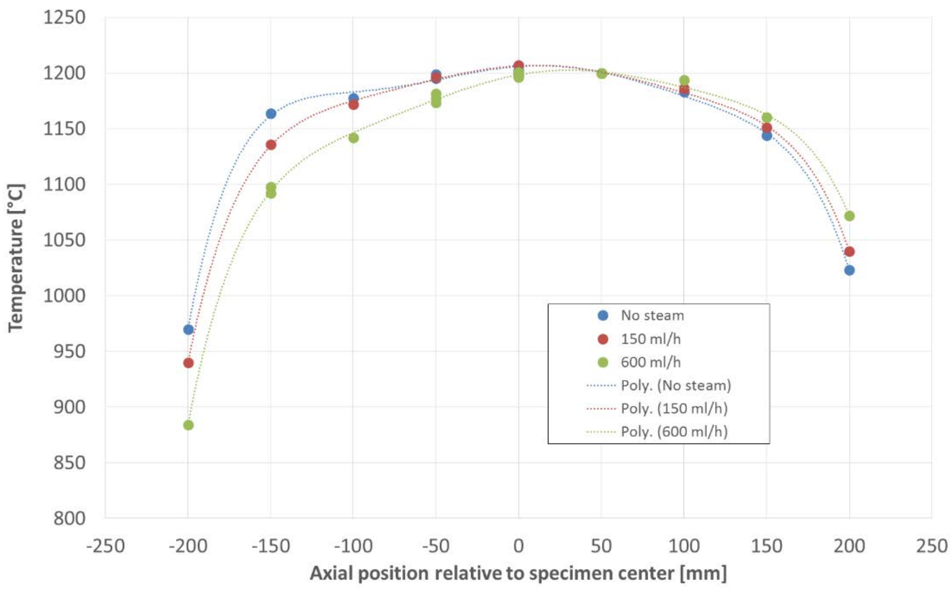

Fig 3. Axial temperature profile with specimen centre temperature 1200 degree C and steam flow in the direction from bottom to top (left to right in the plot)

As for the axial load, the loading rate was assessed both as a function of the maximum motor output (shown in Figure 4) and by controlled loading rate.

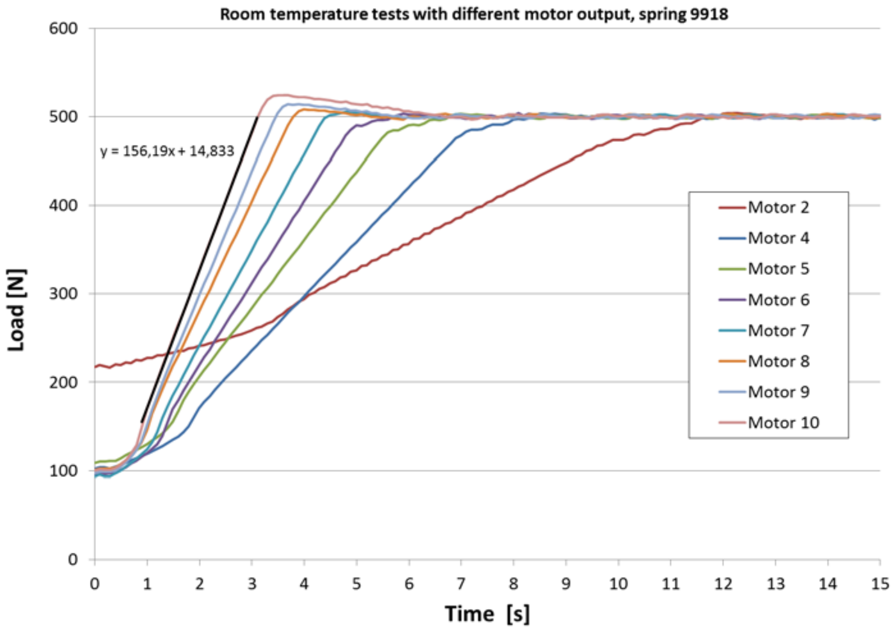

Fig 4. Loading rate as a function of maximum motor output.

An LVDT connected to the bottom sample holder gives the sample elongation. This is measured online during the test sequence. A typical appearance for the axial elongation of a sample tested to burst and followed by quenching can be seen in Figure 5.

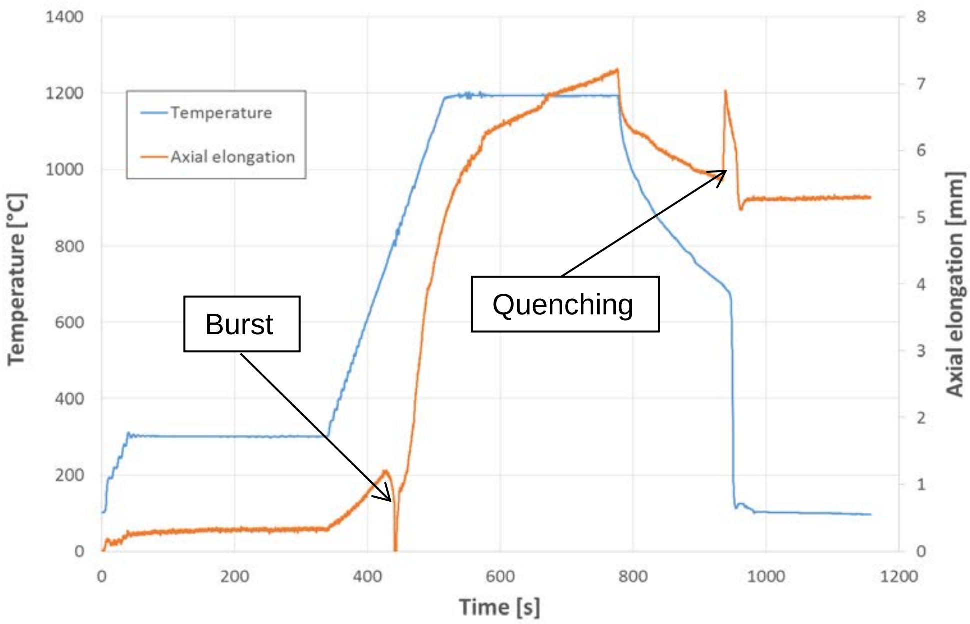

Fig 5. Axial elongation of a 40 mm specimen during a test transient.

Other features included in the qualification process were the temperature control system, heating rates and overshoot, the cooling rate, pressure lines and pressure transducers, test environments (argon, saturated and dry steam, air and mixtures), quench and quench rates, plenum volumes and temperatures during test as well as uncertainties for the measurement systems.

As PID controllers are employed to control different components (such as IR furnace, steam generator and axial loading module), different parameter sets have been achieved for classes of test sequences as well as for specific parts of the sequence itself.

Furthermore a series of out-of-cell tests were dedicated to integral qualification tests to show that ballooning can be induced at predictable temperatures, pressure and at a valid location and to confirm that test operations can be performed without complications in the hot-cell.

3.1 Calibrations and verifications

Due to the difficulties involved in calibration of measurement components once the equipment is in the hot-cell, a series of methods to verify the functionality of these components has been developed. In the event that the functionality and measurement results should fail to be within the acceptance range, the specific component will be replaced with one which is new and calibrated.

4. Facility modifications

Being the LOCA 2 device more complex than the old LOCA device used until today, it required construction and installation of new cell wall throughputs including one power, one signal and one thermocouple cell wall plugs. The power and signal throughputs had to be designed in a way so that they cannot be wrongly coupled to the control and power unit outside the cell thereby eliminating the problem of equipment damage.

5. Summary

The LOCA test programme at Studsvik has been on-going since 2008. A first LOCA equipment has been used until today within many different projects. A second LOCA equipment (LOCA 2) has now been built and qualified in order to accommodate a larger number of more advanced tests. This new equipment is based on a modular concept. This simplifies replacement of vital parts and respects the ALARA philosophy (As Low As Reasonably Achievable) for what concerns maintenance operations. The new features of LOCA 2 equipment have now been verified and the equipment is ready for installation in the hot cell.

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7. References

[1] P. Askeljung, J. Flygare, D. Minghetti: ”NRC LOCA testing program at Studsvik, recent results on high burnup fuel”, TOPFUEL2012-A0117.