LOCA TEST EQUIPMENT AT STUDSVIK HOT CELLS

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ABSTRACT

Since 2010 Studsvik has performed LOCA (Loss Of Coolant Accident) tests both on un-irradiated cladding as well as irradiated fuel rod samples. The LOCA equipment is based on a machine from Argonne National Laboratory and was a central part of a fragmentation study on high burnup fuel sponsored by NRC and performed by Studsvik. This first equipment is still in operation and has been used in a number of other projects such as on-line rod internal pressure measurements during LOCA transients (Swedish Program Group for Fuel) and other tests within the SCIP III (Studsvik Cladding Integrity Project) programme.

A second equipment for LOCA tests is currently being constructed at Studsvik. In this paper the differences in design between the first and second equipment as well as test capabilities will be presented with particular attention to Hot Cell adaptation.

For the LOCA sequence the sample is positioned inside a chamber made out of a quartz tube. An infrared furnace surrounds the chamber and creates the LOCA-like temperature conditions for the specimen. A number of different environments can be obtained inside the chamber such as inert environment (noble gas) or oxidizing environment (air or steam).

1. Introduction

In order to study the LOCA effect of transients on fuel rod segments and to meet requested test conditions, test volumes and to limit the cost of each test, an equipment that replicates Loss Of Coolant Accident (LOCA) conditions in Hot Cell was designed, fabricated and commissioned in the Hot Cells of Studsvik Nuclear AB.

The first test programme on irradiated fuel rod samples began on behalf of the USNRC (NRC LOCA program). This was primarily meant to investigate the effects of LOCA transient conditions on high burn-up cladding – which turned out successful – but as other observations on fuel behaviour were made, the topics of fuel fragmentation, fuel relocation and fuel dispersal became more and more interesting.

Today the SCIP III (Studsvik Cladding Integrity Project) programme main focus is on the causes and effects of these mechanisms. As a consequence, the need to refine and improve the LOCA test significance, as well as to accommodate a larger number of tests, brought Studsvik to design and build a second LOCA equipment with which new test expanded conditions can be obtained.

2. First LOCA equipment: description and test procedure

The first LOCA test equipment is shown in Figure 1. The sample (a 300 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 cladding. High pressure couplings are then mounted to the plugs and the sample holder (consisting of a top sample holder, the fuel segment sample and a bottom sample holder) can be assembled. The sample holder 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 holder is then mounted 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. The internal pressure of the sample can be monitored with two pressure transducers placed at the top and at the bottom of the sample holder.

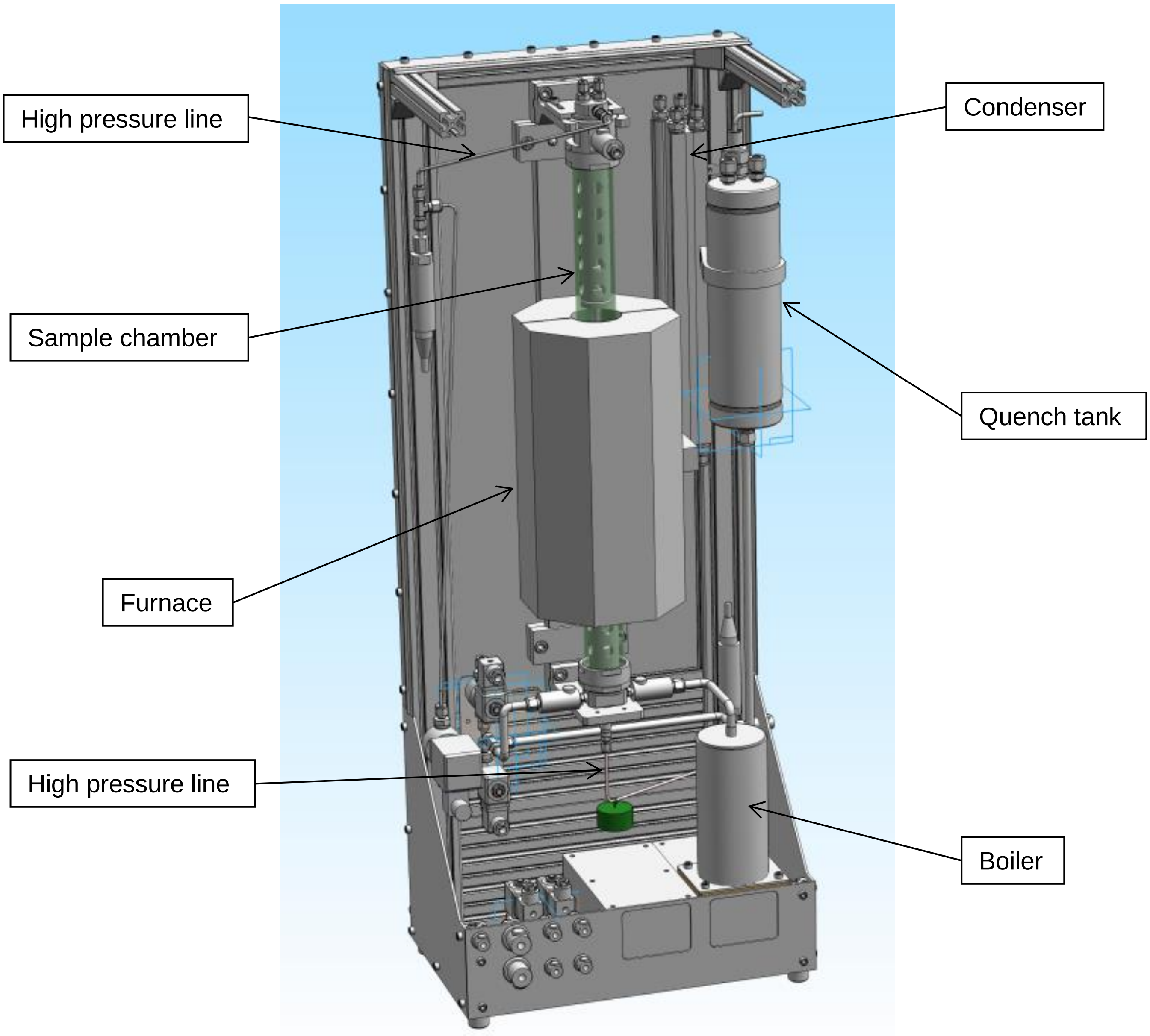

Fig 1. Schematic view of the first LOCA equipment showing the main parts

The sample chamber isolates the sample from the cell environment making it possible to run the LOCA test sequence in an inert atmosphere (Argon) or in an oxidizing atmosphere (steam or air). 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 (~2 litres) is processed separately.

After completion of the building phase of the first LOCA equipment, a number of tests on un-irradiated cladding samples were performed out of cell in order to obtain temperature calibrations as well as characterize the furnace’s axial heating profile. Different methods were used for the latter: a series of thermocouples were first welded to the cladding tube at first. This method could though not be used on irradiated fuel samples later for in-cell tests, therefore the validation of a new way of fixing the thermocouple on the sample with an elastic clamp was obtained.

This “un-irradiated” test phase was also used to optimize other important parameters for the LOCA transient simulation: the cooling water flow to furnace and condenser was optimized both from an energetic and waste point of view, the water flow to the steam generator was established, the parameters for the input power regulation of the boiler were therefore obtained, finally the optimal pressure for the quench tank was obtained as a function of the “filling speed” in the sample chamber.

After completion of the “un-irradiated” test phase, the equipment was installed in-cell. A few more tests on un-irradiated material were performed in order to assess functionality for all systems, including media, signal and power communications through the cell wall.

A typical LOCA test sequence is shown in Figure 2 (courtesy of NRC) [1]. A preconditioning step (300 °C) is normally present at the beginning in order to achieve stability of steam flow as well as sample internal pressure. The pressure is manually adjusted before start of the heat ramp. The heat ramp rate is normally 5 °C/s and continues to Peak Cladding Temperature (PCT). During the heat ramp the rod, if pressurized, normally ruptures. A constant temperature step (at PCT) usually follows to reach the desired Equivalent Cladding Reacted (ECR) value at which point a cooling ramp starts, normally by 3 °C/s until 800 °C is reached. At this point a quench step may or may not be initiated (in Figure 2 the quench step was performed).

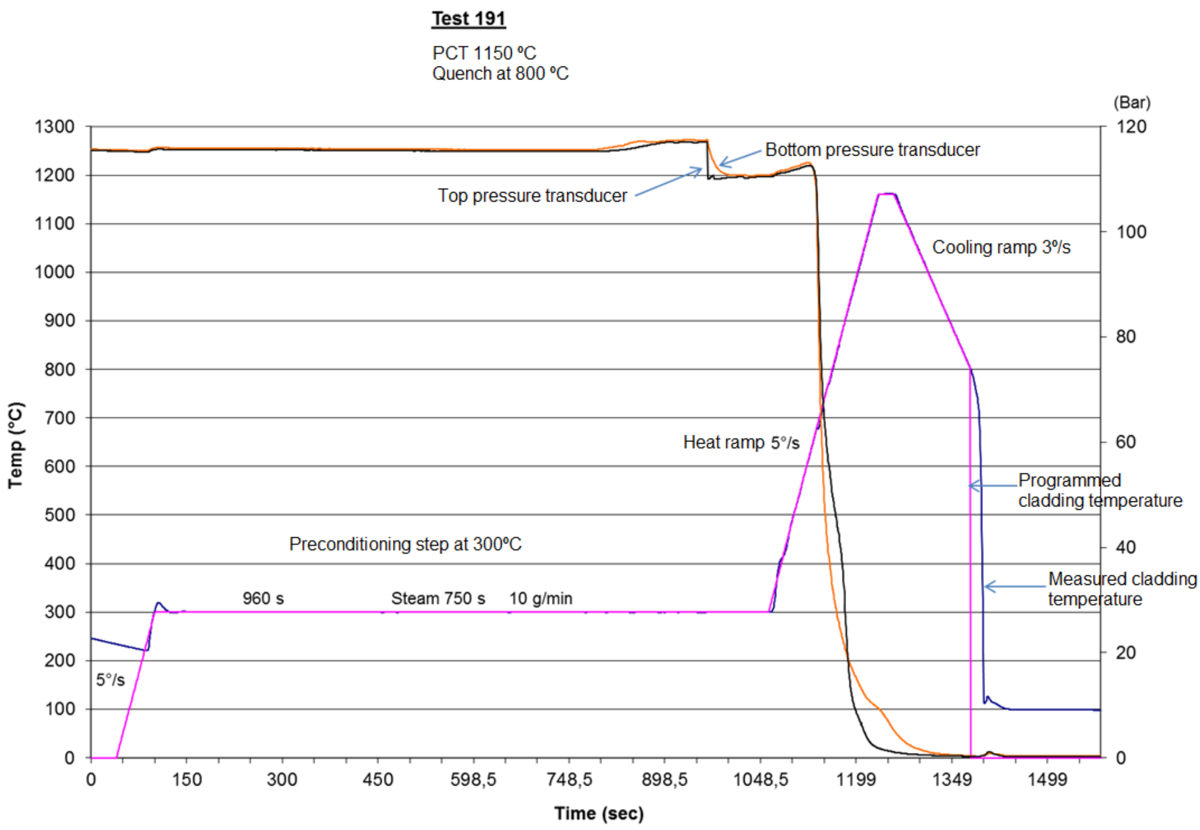

Fig 2. A typical LOCA test sequence, [1]

There are of course a few compromises to accept when testing fuel in an out-of-pile equipment instead of performing tests in a test reactor: the most obvious is the temperature gradient along the radius of the fuel rod which becomes the opposite with respect to in-core test, where the fuel itself is an active part in the generation of heat rather than being a "passive" heat absorber. On the other side, planning of in-core LOCA tests depends upon reactor shutdown schedules and the costs per test are considerably higher.

Post-test examinations of the sample usually include visual inspection, photographing, weighing, diametrical strain measurement, 4-point-bend testing, "shake test", sieving of fuel fragments, metallography and Hydrogen measurements. Some tests, aimed to the study of fission gas release during LOCA transients, require on-line monitoring of internal pressure and collection of gas samples from the test rod. These gas samples are then analysed by gas mass spectrometry in order to identify and quantify the isotopic composition.

3. Second LOCA equipment: description

A second LOCA test equipment is currently under construction at Studsvik. Changes in design are made in order to accommodate a larger number of tests, solve the "lessons learned" issues from the first equipment and add some features in order to open new test possibilities.

3.1 Improvements and additional functions

The main improvement is the modular concept. 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. These parts are mounted in a way that they cannot be easily removed (if not removable at all) in the first LOCA concept. This, of course, makes approaching the equipment impossible for a person and all the maintenance needs to be done in-cell by remote handling (Master-slave manipulators).

The concept for the second LOCA equipment is modular based, making it possible to easily remove high activity parts in order to achieve low activity levels and this simplifies the maintenance issues. The modular concept also allows fast replacement of vital parts in-cell.

A schematic of the new LOCA equipment is shown in Figure 3 (front view) and Figure 4 (rear view). The basics of the test sequence and working concept are the same as for the first LOCA equipment.

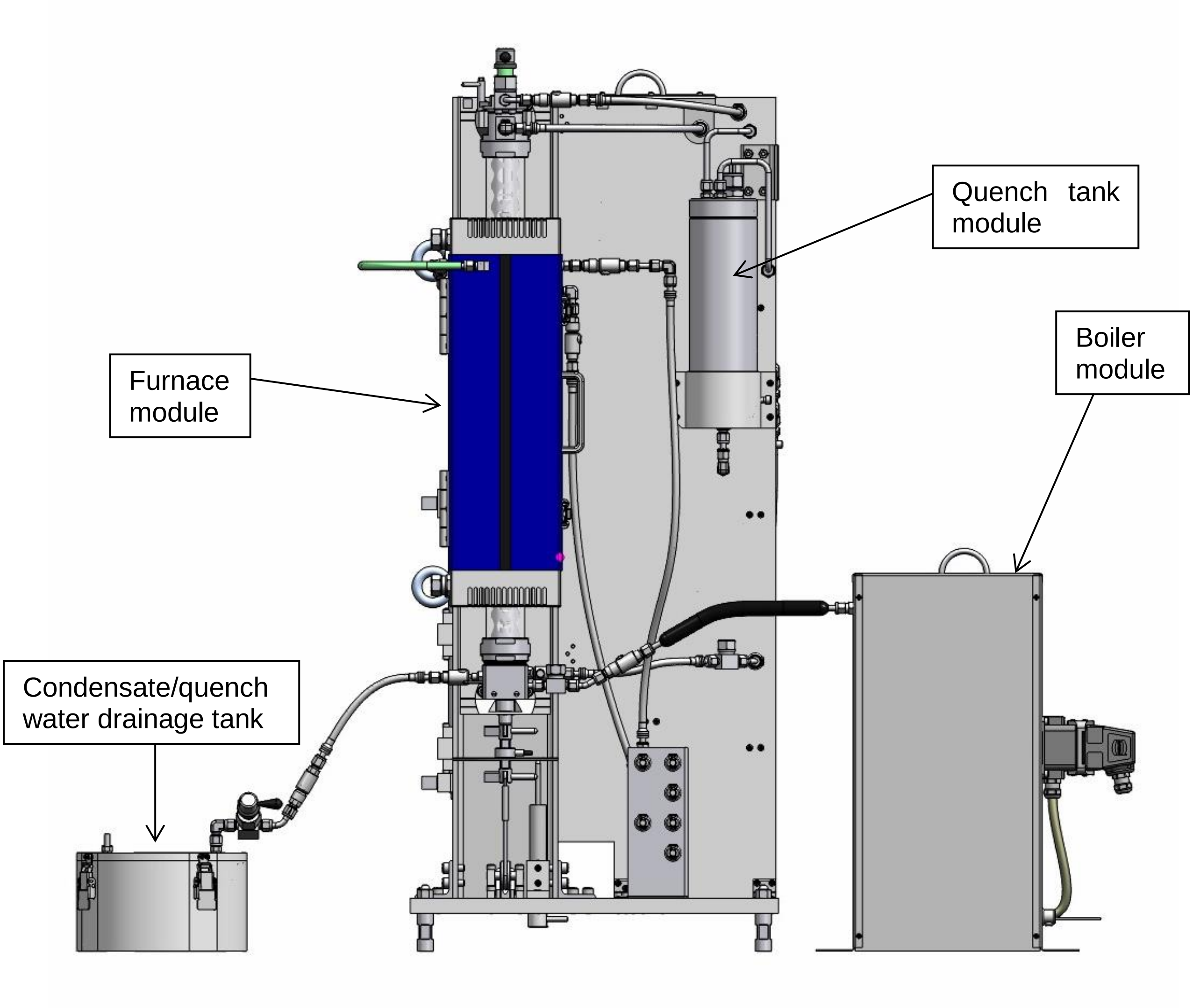

Fig 3. Second LOCA equipment, front view

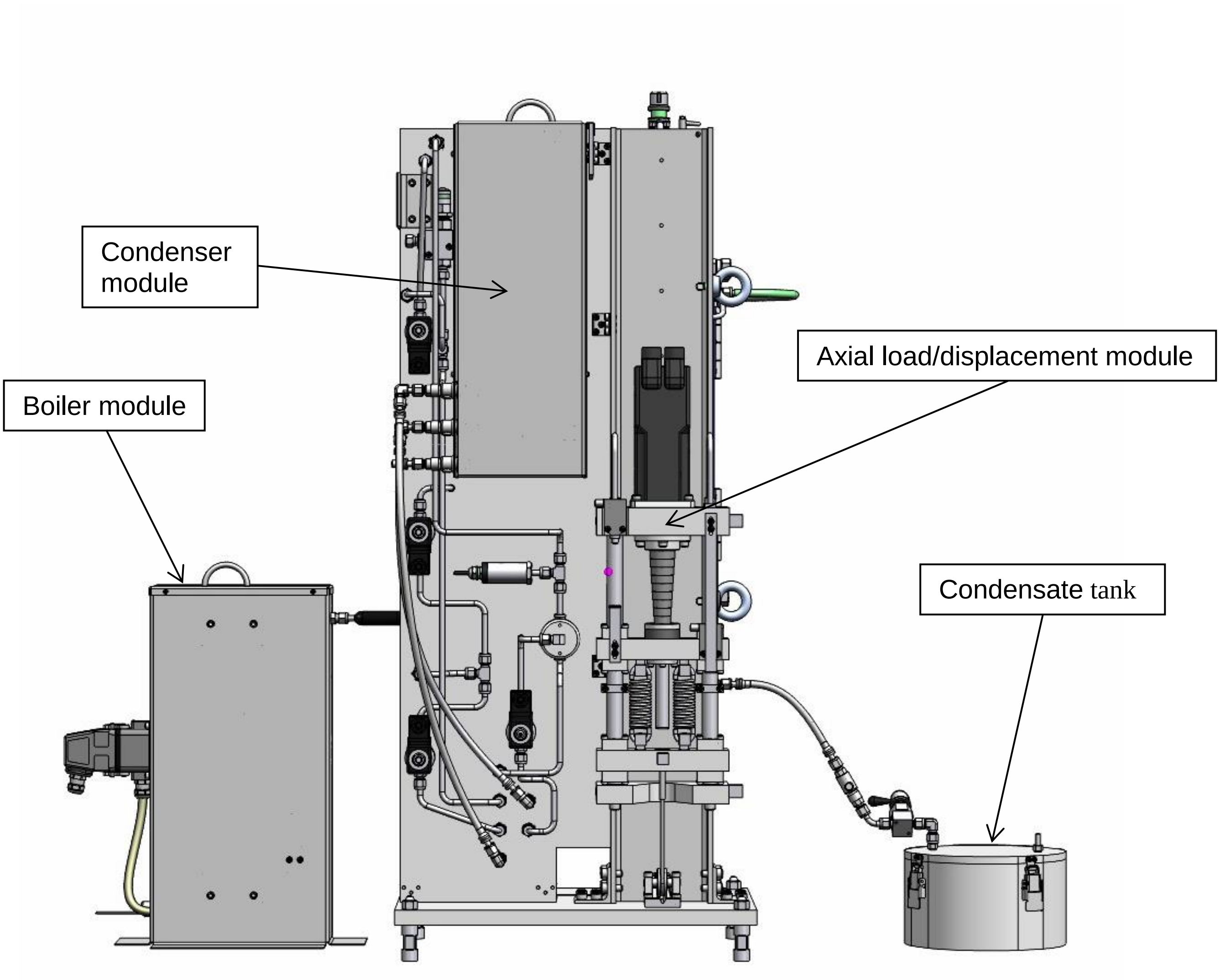

Fig 4. Second LOCA equipment, rear view

Another improvement is the increased length of the furnace which makes possible to test samples with fuel stack lengths up to 400 mm. This creates also a somewhat flatter axial temperature profile. Concerning the additional functions, two features are added in the new equipment: an axial load device (ALD) and an over-heater for the steam generator (OSG). The ALD will allow testing of the sample's structural properties at different stages of the LOCA sequence. This new system includes a load transducer and a displacement transducer and can be regulated to follow a predisposed load sequence. The OSG will allow new test chamber environments such as dry steam only or a steam-air mixture.

3.2 Other parts of the system

So far, a presentation of the LOCA test equipment has been given for those components that are placed inside the cell. In addition to this a number of other components are needed to run the equipment.

The regulators for furnace input power, boiler power and axial load unit resides in a control box outside the cell. The operator configures the test sequence and parameters through a LabView based interface. The control box unit also contains the pump for the primary cooling circulation and the heat exchanger.

Communication between the control box and the LOCA equipment is fed through four cell wall plugs, each one dedicated to a specific task in order to avoid disturbances: power (i.e. furnace, boiler and heaters inputs), signal (i.e. pressure, load and elongation transducers), temperature measurement (i.e. sample temperature, steam temperature and furnace shutdown), media (i.e. high pressure gas, water to steam generator, cooling water to furnace/condenser).

4. Summary

The LOCA test programme at Studsvik has been on-going since 2008. A first LOCA equipment has been used until today within different projects. A second LOCA equipment is currently being qualified in order to accommodate a larger number of 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. New features are added to the second LOCA equipment in order to increase the test's significance and capabilities.

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6. References

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