

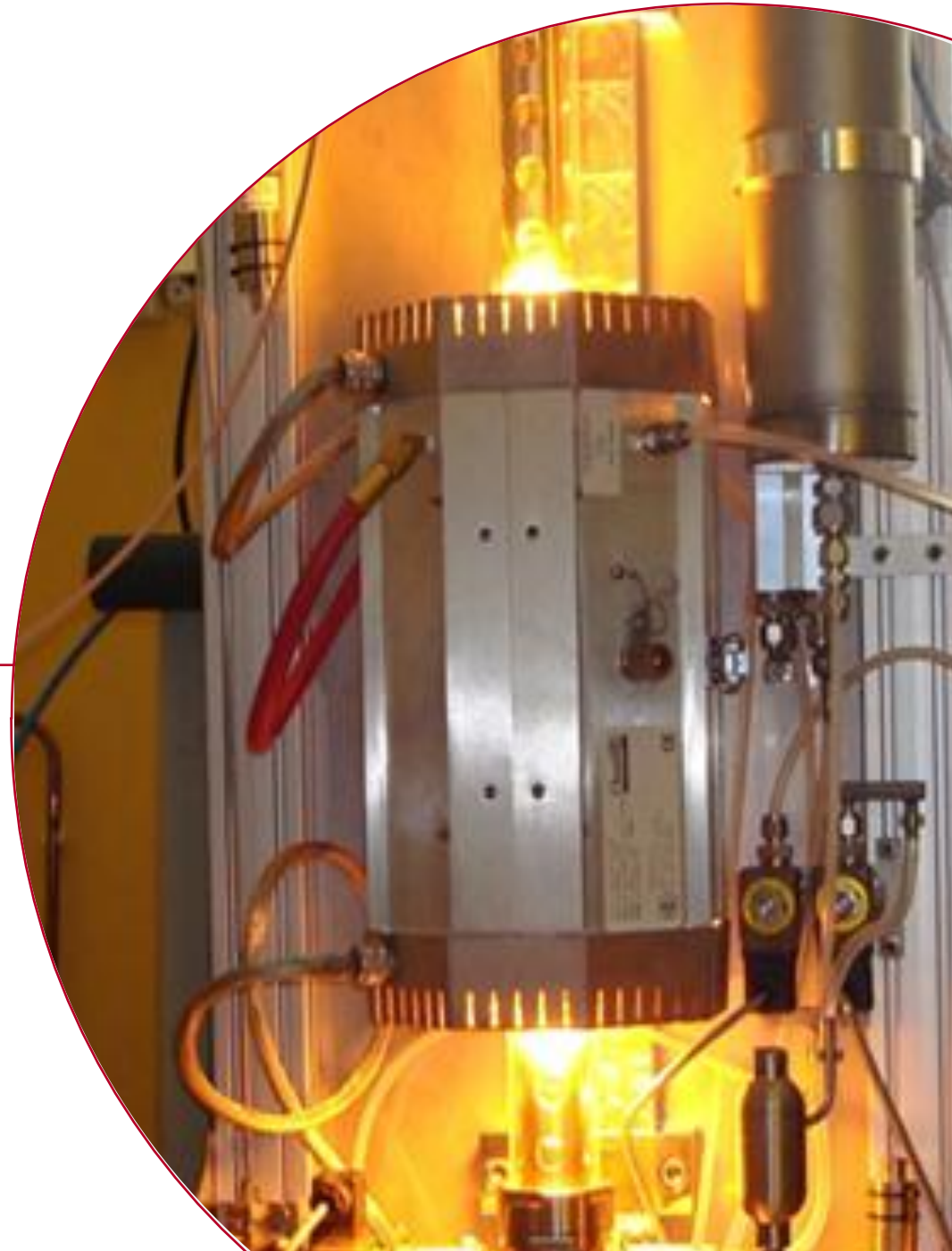
Studsvik

Loss Of Coolant Accident experiments at Studsvik's Hot Cell Laboratory

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Introduction

- The main phases of a Loss Of Coolant Accident (LOCA):
 - Consider the scenario:
 - Break
 - SCRAM
 - Reactor Coolant Pumps trip
 - Steam line isolation
 - Feed water isolation
 - No HPIS (High Pressure Injection System)

Introduction (Cont.)

- The reactor is scrammed BUT the decay heat power from the fuel is still substantial
- Low pressure in reactor vessel must be reached for LPIS (Low Pressure Injection System) to start working
- During this time the water level can drop under the top of active region of fuel rods
- Steam still generating at the lower region of the core has a much lower cooling capability (low heat capacity)
- Temperature in the fuel will begin to rise
- Cladding oxidation is much faster at temperatures above 600 degrees C
- High temperature will soften the cladding and as a result of fission gas pressure inside the fuel rod a balloon will start to form
- The balloon will, if allowed, burst releasing Fission Gases and fuel in the Reactor Vessel (fuel dispersal)
- Eventually the LPIS will start and restore the water level (quenching)

Introduction (cont.)

- At the last SCIP III meeting held in Studsvik a participant said: "There are so many variables during a LOCA that it is basically pointless to discuss a test scenario. Exactly like that it will never happen anyways".
- Why then focus on the topic?
- In 2008 Studsvik began the construction of the first LOCA equipment to perform tests on fuel commissioned by NRC.
- An interesting behavior by the fuel was observed, possibly correlated to the burn-up.
- Fuel fragmentation and fuel dispersal became the focus point of the project
- A number of tests have been performed until today and more are planned for the near future in order to investigate the presence of a set of "threshold" parameters that will explain these behaviors

LOCA Generation 1

- Functions:
 - IR-furnace with maximal temperature ramp rate of 5 °C/s
 - Active sample length \approx 300 mm
 - Possibility of testing the sample in air, inert gas or steam environment
 - Possibility to pressurize the sample internally
 - Possibility to quench the sample

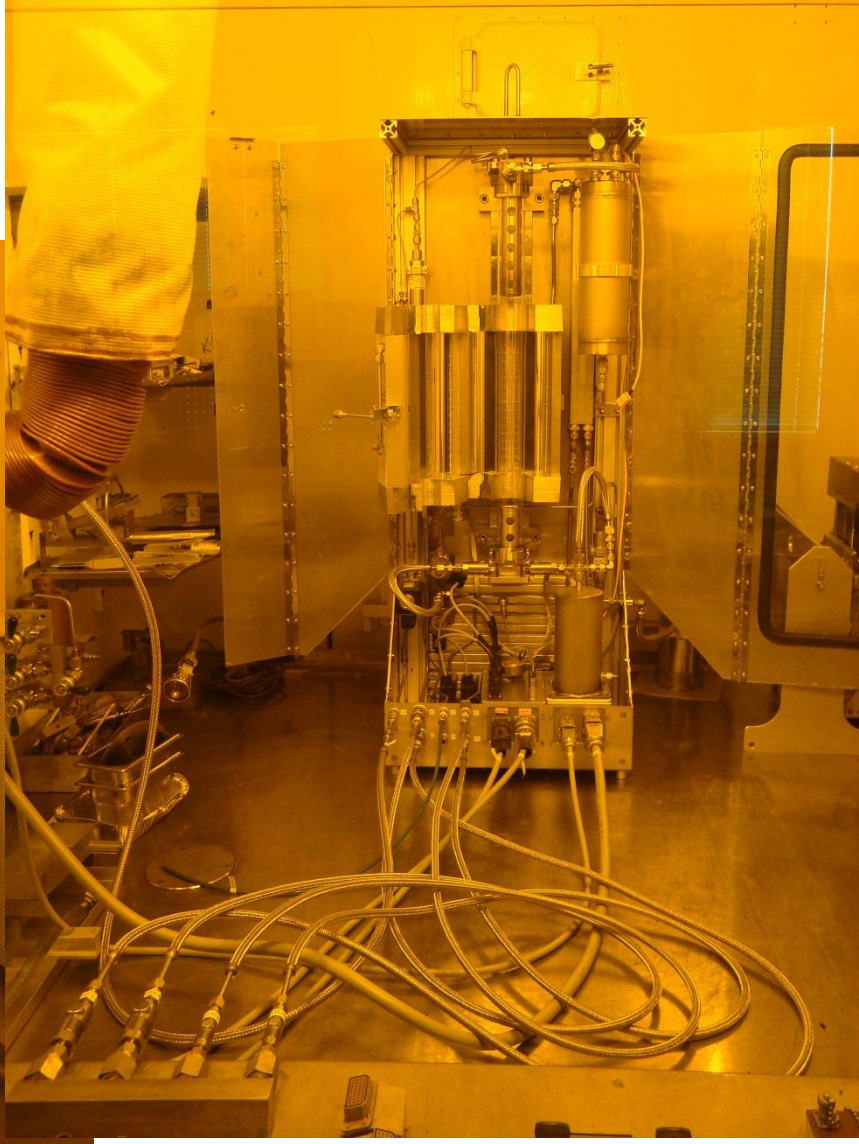
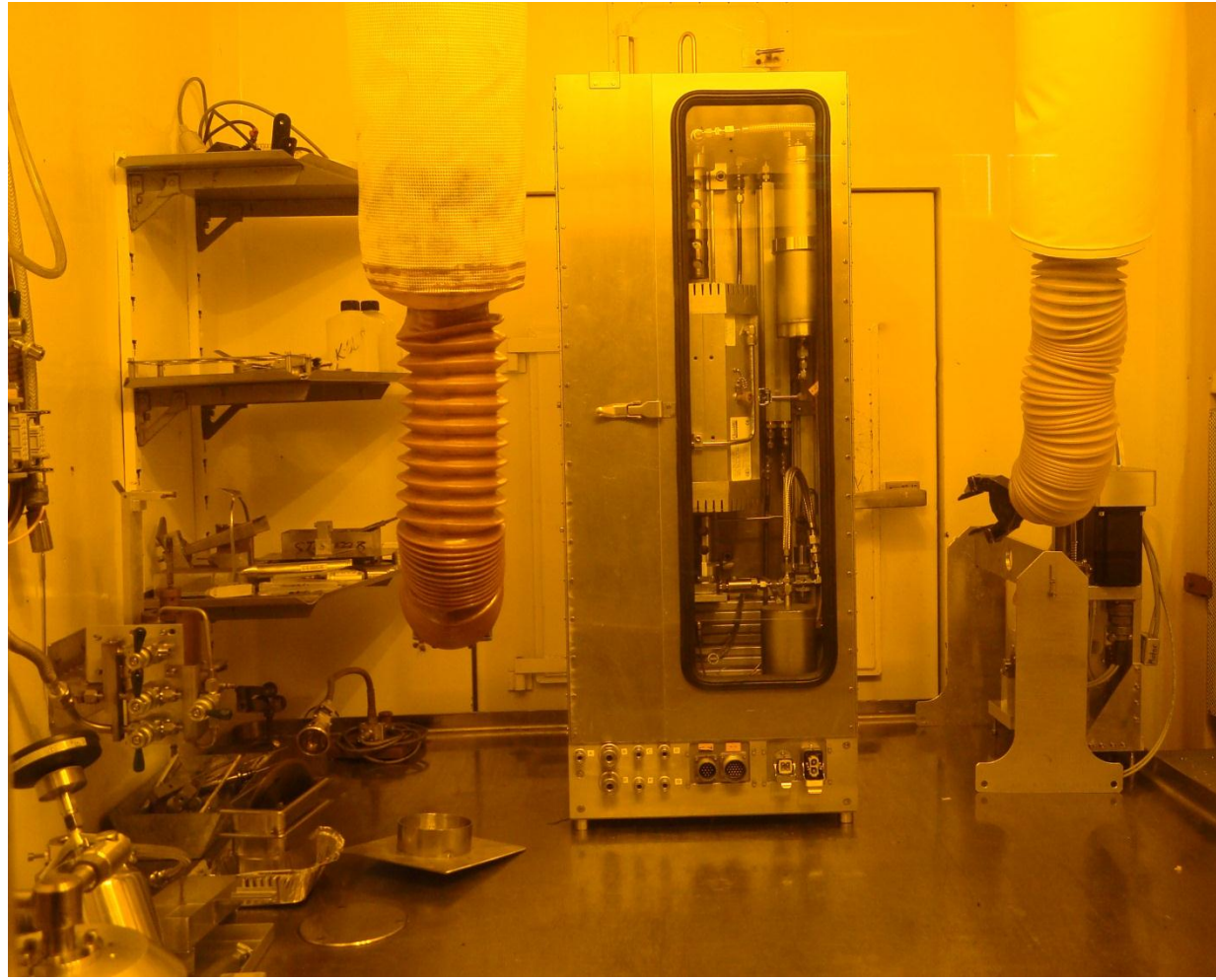


LOCA Generation 1 (cont.)

- Inactive tests – Qualification
 - Fresh cladding samples were manufactured to test functionality of systems and to collect information about the equipment such as axial temperature profile, optimal water flow to steam generator, optimal quench tank pressure.
 - A method for assembling the sample chain in-cell as well as for the mounting of the sample chain in the LOCA equipment was established under this step.
 - Final preparations for in-cell use included:
 - Choice of cable insulator material for cell environment
 - Installation of new power and signal cell plugs
 - Installation of new "media" cell plugs (furnace water cooling, water to steam generator, high and low pressure gas lines)
 - Containment box around the LOCA equipment to minimize spreading of fuel in case of sample chamber rupture

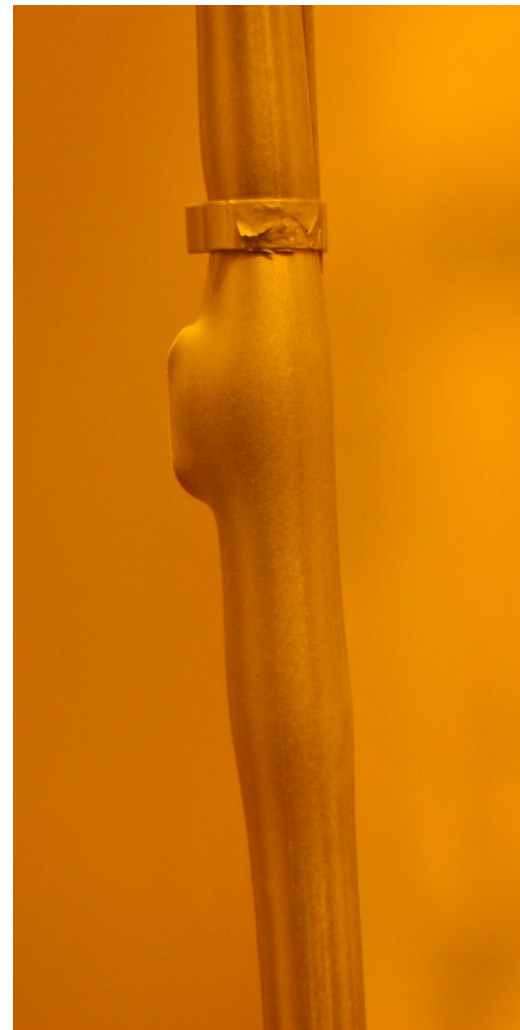
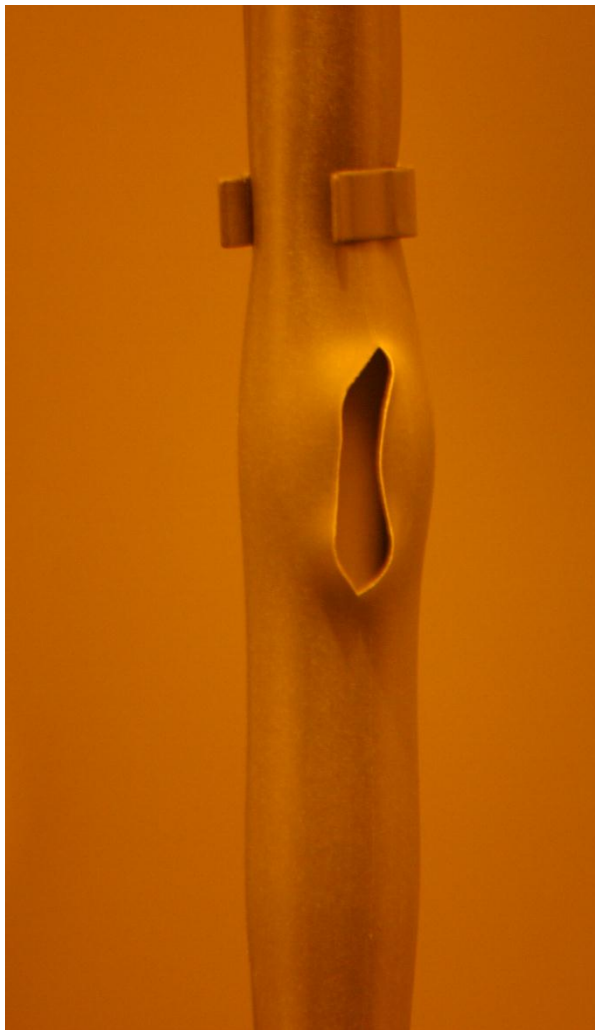
LOCA Generation 1 (cont.)

- Introduction of equipment in cell



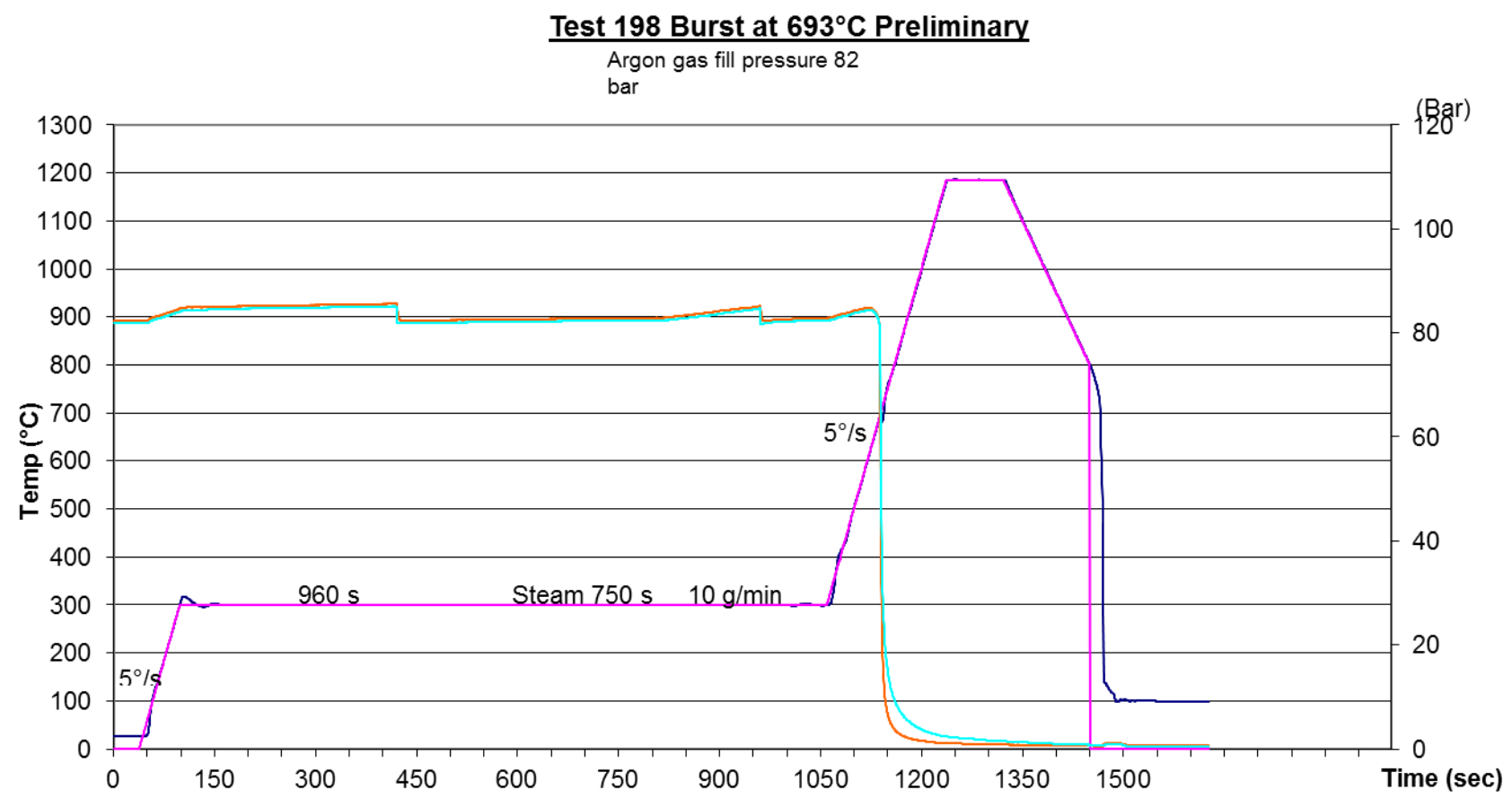
LOCA Generation 1 (cont.)

- In-cell inactive tests



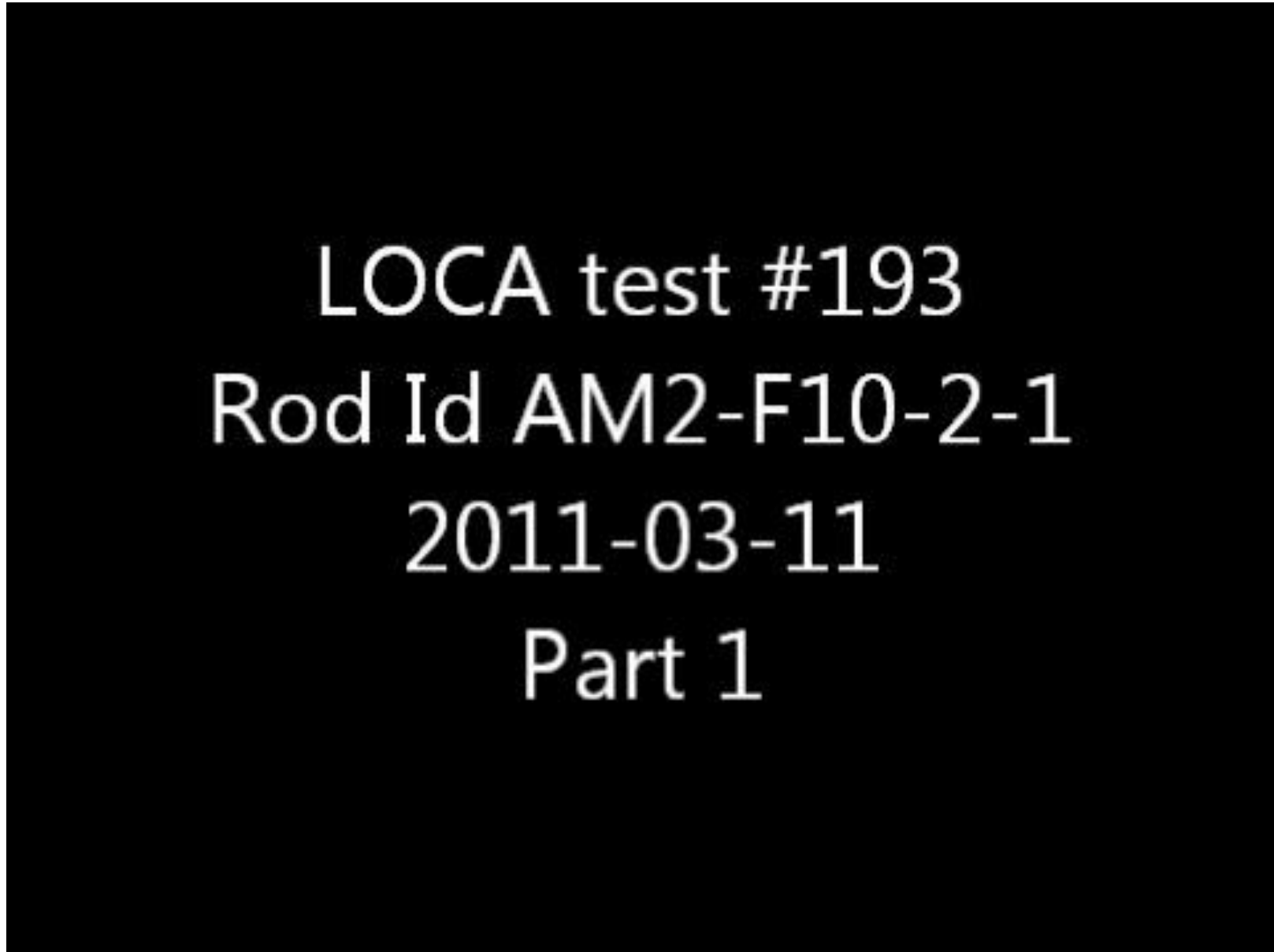
LOCA Generation 1 (cont.)

- A typical LOCA sequence (courtesy of NRC)

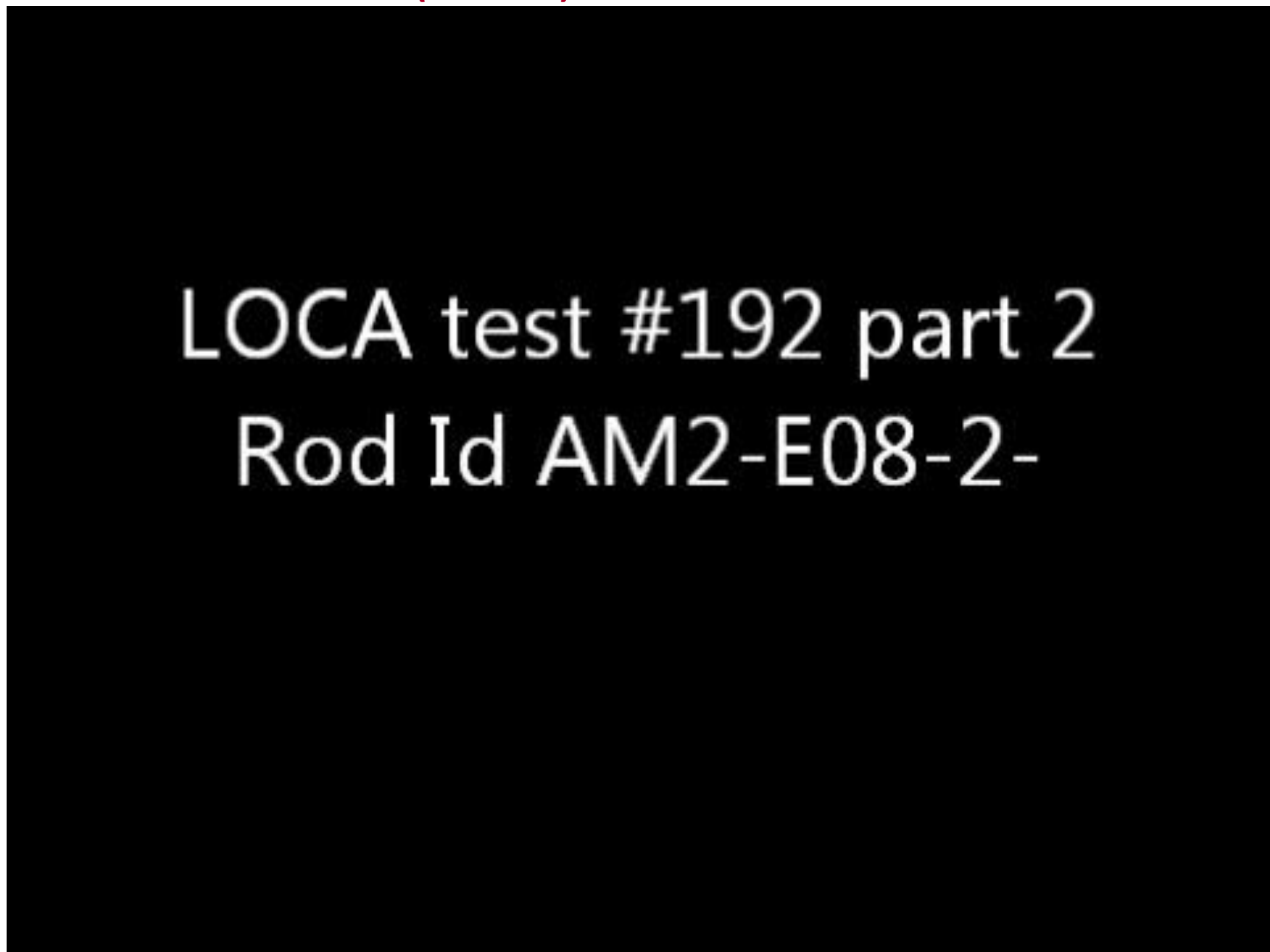


LOCA Generation 1 (cont.)

- Active tests on irradiated fuel (courtesy of NRC)



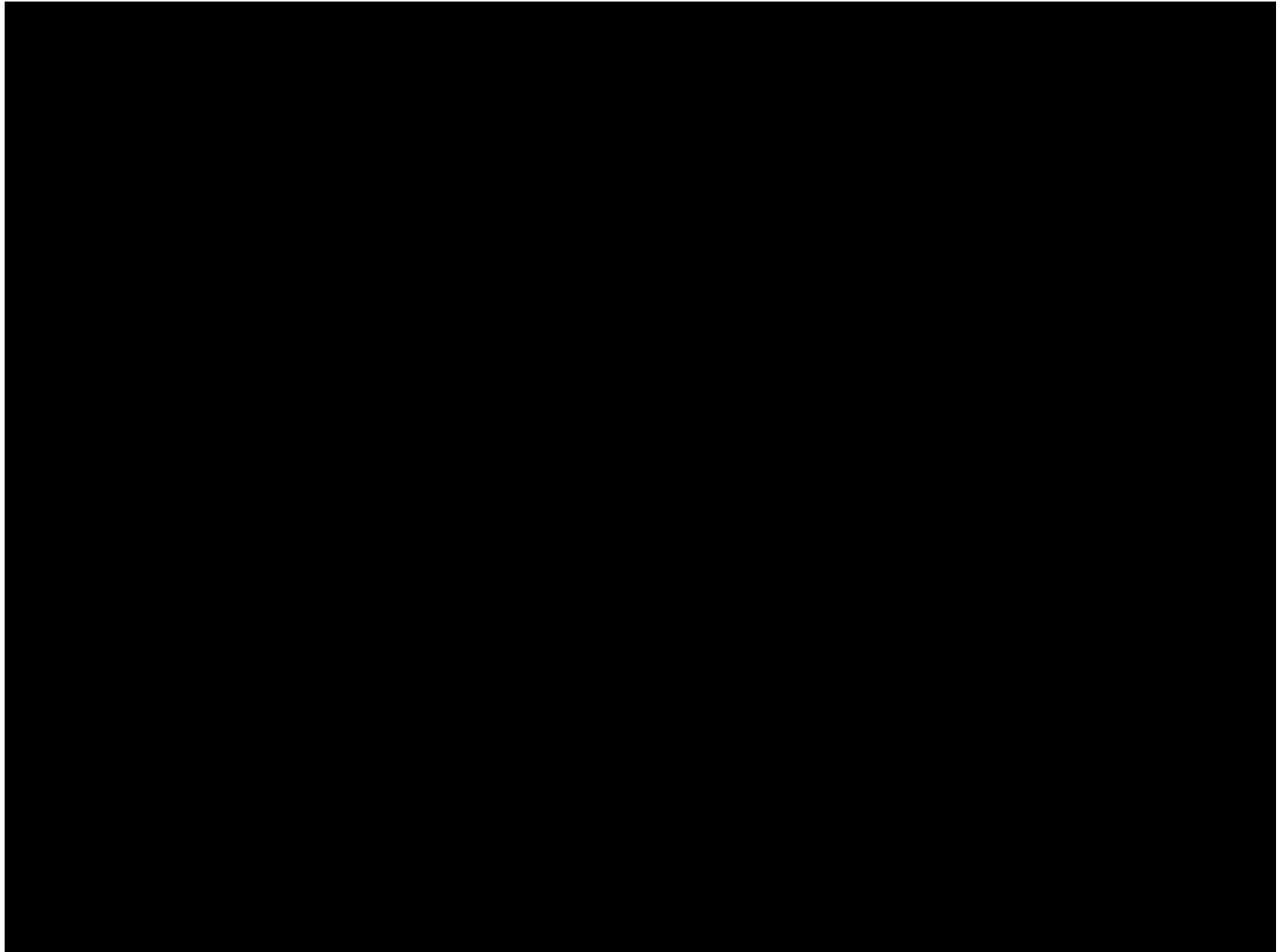
LOCA Generation 1 (cont.)



LOCA test #192 part 2
Rod Id AM2-E08-2-

LOCA Generation 1 (cont.)

- 4 point bend test after LOCA sequence



LOCA Generation 1 (cont.)

Shake test #193
Rod Id AM2-F10-2-1
2011-03-17
Top and bottom part

LOCA Generation 1 (cont.)

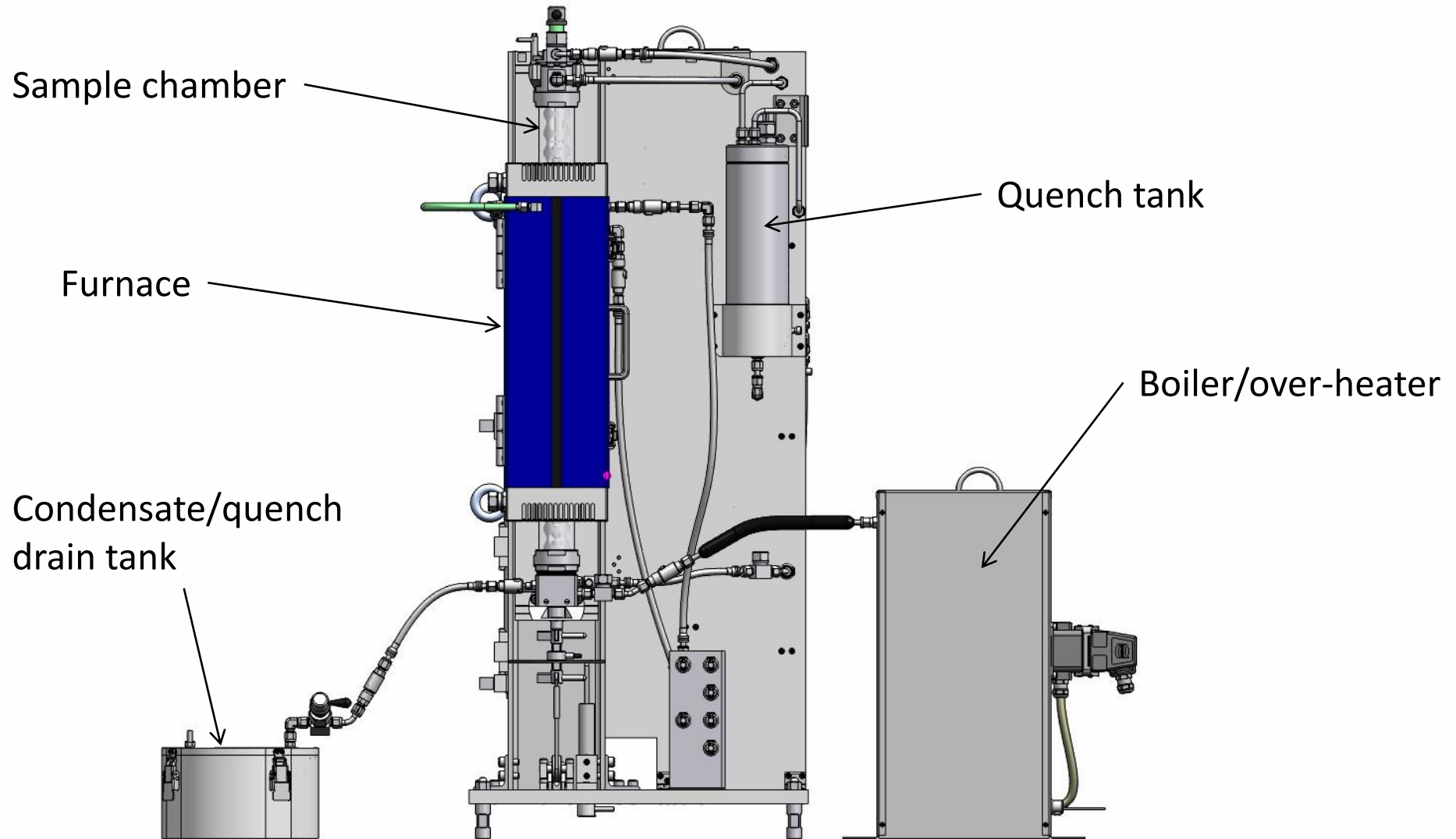
- In addition to standard Integral LOCA Tests the equipment was also used for:
 - Oxidation tests on un-irradiated cladding samples where the steam flow had to be guaranteed both outside and inside the sample
 - Investigation of Fission Gas Release during LOCA transients
 - On-line monitoring of internal pressure during transient
 - Internal volume increase
 - Collection of after-LOCA Fission Gas samples for Mass Spectrometry analysis

LOCA Generation 2 – current status

- Problems/limitations with the first equipment:
 - Not all the components are Master-Slave friendly, some steps are quite demanding and require long time
 - Equipment not designed for on-line monitoring of sample internal pressure, extra equipment was needed
 - Some components show blockage due to fuel fragments in the draining lines
 - Pronounced condensation of steam in the lower sample chamber holder (draining problems!)
 - The equipment is "fixed", accumulation of activity in parts of the system makes approaching it impossible
 - All service has to be done in-cell

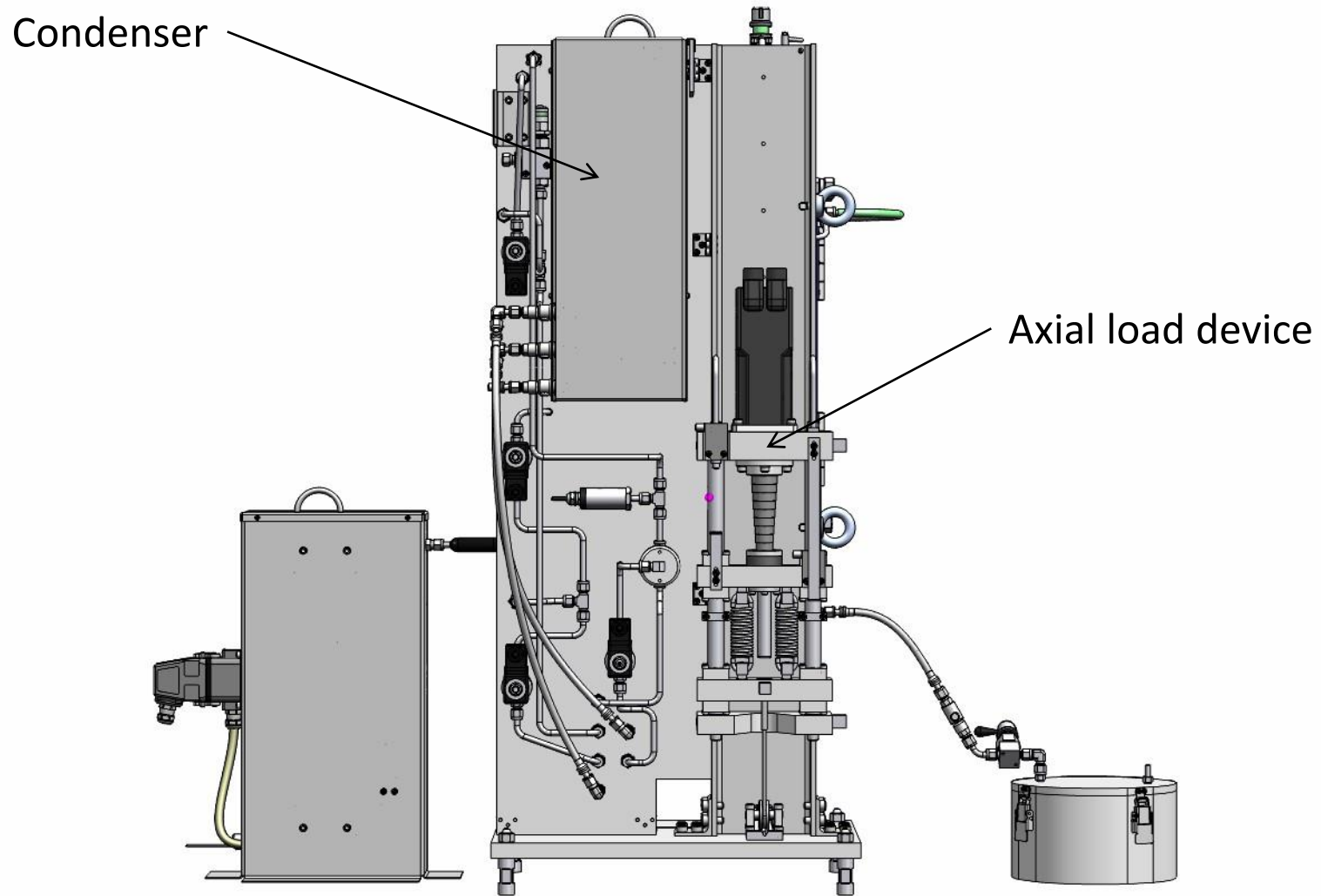
LOCA Generation 2 – current status

- Modular concept



LOCA Generation 2 – current status

- Modular concept

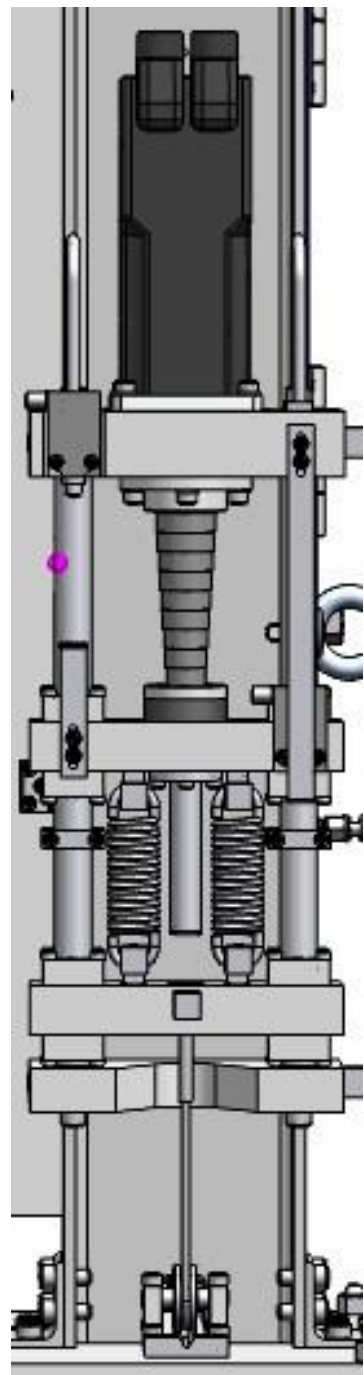


LOCA Generation 2 – current status

- Improvements:
 - The module based concept allows “easy” in-cell replacement of damaged/vital parts
 - Activity-accumulating parts can be removed from equipment before manual maintenance
 - Longer furnace → longer sample (≈ 400 mm active length) → flatter temperature profile at sample mid region
 - Built-in sample internal pressure monitoring and Fission Gas Release sample collection
 - Possibility of collecting dispersed fuel samples as well as condensate and drainage samples
 - Possibility of running test in saturated or overheated steam environment
 - Heated lower sample chamber holder to minimize condensation of steam

LOCA Generation 2 – current status

- New Features – axial load and displacement
 - Up to 1000 N
 - Programmable sequence:
 - Load-based regulation



Summary

- LOCA test program started 2008 (NRC)
- First generation LOCA equipment proved to be successful
- Interesting fuel behavior were observed (fragmentation and dispersal)
- New tests required improvement of the equipment
- Design of a new LOCA test equipment started in 2014
- New module-based concept, new features (dry steam, axial load, sample pressure monitoring)
- The machine is now built and the qualification test program is ongoing
- The new machine will be operative in cell in the beginning of 2016

Acknowledgments

- The following persons, institutions and groups are acknowledged for their contributions:
 - NRC
 - EON
 - SSM
 - PGB (Swedish Program Group for Fuel)
 - OECD/NEA
 - EPRI
 - SCIP III open program proposal
 - Peter Askeljung (Studsvik Nuclear AB)
 - Fredrik Nisserud (Studsvik Nuclear AB)

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