The main component of the **QUENCH test facility** is the test section with the test bundle (Fig. 1). The facility can be operated in two modes: a forced-convection mode (typical for most QUENCH experiments) and a boil-off mode. In forced-convection mode a superheated steam from the steam generator and superheater together with argon as a carrier gas for off-gas measurements enter the test bundle at the bottom. The system pressure in the test section is around 0.2 MPa absolute. The test section has a separate inlet at the bottom to inject water for reflood (bottom quenching). The argon, the steam not consumed, and the hydrogen produced in the zirconium-steam reaction flow from the bundle outlet at the top through a water-cooled off-gas pipe to the condenser where the steam is separated from the non-condensable gases. The water cooling circuits for bundle head and off-gas pipe are temperature-controlled to guarantee that the steam/gas temperature is high enough so that condensation at the test section outlet and inside the off-gas pipe is avoided.

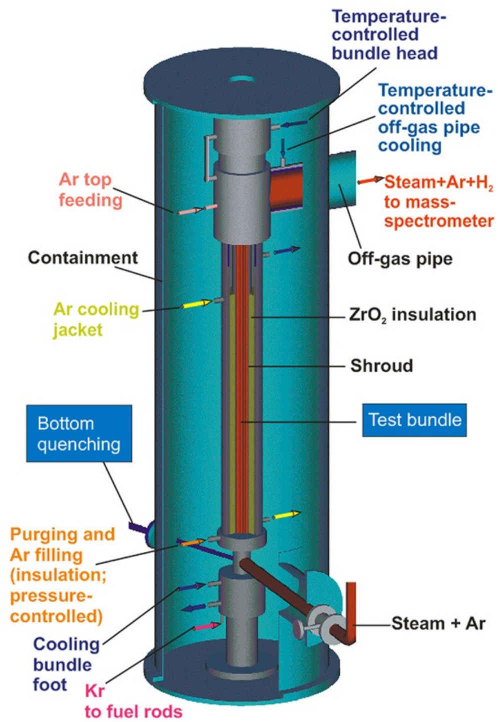


Fig. 1. QUENCH facility: containment and test section.

The test bundle is approximately 2.5 m long and is made up of 21, 24 or 31 fuel rod simulators (Fig. 2). The fuel rod simulators are held in position either by five grid spacers, four are made of Zircaloy-4 and the one at the bottom of Inconel 718, or (in the case of VVER bundle) by seven E110 spacers. For the bundle geometry with 21 rods all rods are heated except the central one. In case of 24 rods all rods are heated. In the case of 31 bundle rods 18 rods are heated and 13 unheated. Heating is electric by 6 (21 rods), 5 (24 rods) or 4 mm (31 rods) diameter tungsten heaters of length 1024 mm installed in the rod centre (lower edge of heaters corresponds to bundle elevation 0 mm). Electrodes of molybdenum (length 300 + 576 mm; Ø 8.6, 7.6 or 7 mm) and copper (length 390 + 190 mm; Ø 8.6, 7.6 or 7 mm) are connected to the tungsten heaters at one end and to the cable leading to the DC electrical power supply at the other end. The heating power (maximum 70 kW) is distributed between two groups of heated rods. The distribution of the electric power within the two groups of the bundle with 21 rods is as follows: about 40% of the power is released into the inner rod circuit consisting of eight fuel rod simulators (in parallel connection) and 60% in the outer rod circuit (12 fuel rod simulators in parallel connection). For bundles with 24 and 18 heated rods the power distribution is 50/50% between left and right rod groups. The tungsten heaters are surrounded by annular ZrO_2 pellets. All test rods are filled with Kr at a pressure of approx. 0.22 MPa absolute. The rods were connected to a controlled feeding system that compensated minor gas losses and allowed observation of the first cladding failure as well as a failure progression.

There are four (21 rods bundle), eight (24 rods bundle) or 6 (31 rods bundle) corner rods installed in the bundle. One half of them is made of a solid rod at the top and a tube at the bottom and are used for thermocouple instrumentation. The other half is particularly designed to be withdrawn from the bundle to check the amount of ZrO_2 oxidation and hydrogen uptake at specific times.

The test bundle is surrounded by about 3 mm thick shroud of Zircaloy-4, Zirconium 702 or E125 alloy with a 37 mm thick ZrO_2 fibre insulation extending from the bottom to the upper end of the heated zone and a double-walled cooling jacket of stainless steel over the entire length. The annulus between shroud and cooling jacket is purged (after several cycles of evacuation) and then filled with stagnant argon at 0.22 MPa absolute. The annulus is connected to a flow- and pressure-controlled argon feeding system in order to keep the pressure constant at the target of 0.22 MPa and to prevent an access of steam to the annulus after shroud failure. The 6.7-mm annulus of the cooling jacket is cooled by argon flow from the upper end of the heated zone to the bottom of the bundle and by water in the upper electrode zone. Both the absence of a ZrO_2 insulation above the heated region and the water cooling are to avoid too high temperatures of the bundle in that region.

The off-gas including Ar, H_2 and H_2O is analyzed by a state-of-the-art mass spectrometer Balzers "GAM300" located at the off-gas pipe ~2.66 m downstream the test section. The mass spectrometer allows also to indicate the failure of rod simulators by detection of Kr release.

The test bundle, shroud, and cooling jacket are extensively equipped with sheathed thermocouples at different elevations with an axial step of 100 mm. There are 40 high-temperature (W/Re) thermocouples in the upper hot bundle region (elevations between 650 and 1350 mm) and 35 low-temperature (NiCr/Ni) thermocouples in the lower "cold" bundle region (between –250 and 550 mm). At elevations 950 and 850 mm there are two centreline high-temperature thermocouples in the central rod, which are protected from oxidising influence of the steam. Some W/Re thermocouples isolated from steam are installed inside corner rods. Other bundle thermocouples are attached to the outer surface of the rod cladding. The shroud thermocouples are mounted at the outer surface of shroud. Additionally the test section incorporates pressure gauges, flow meters, and a water level detector.

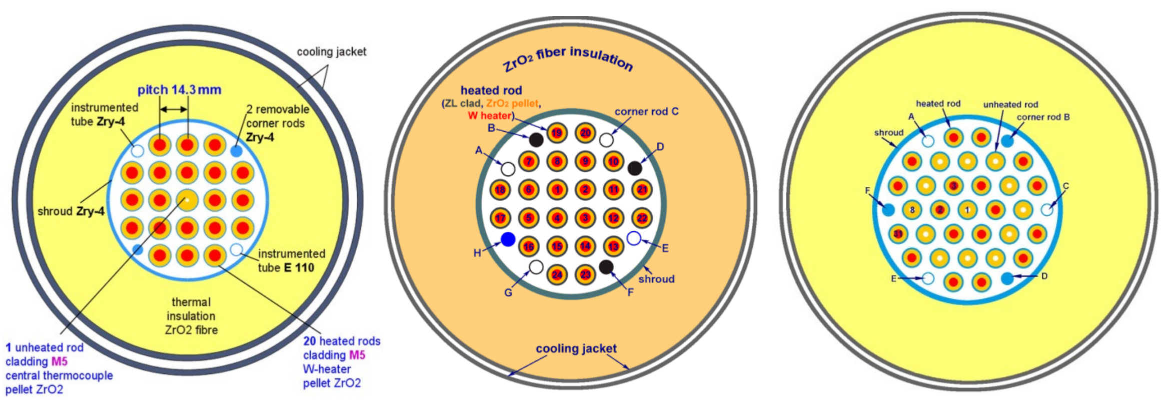
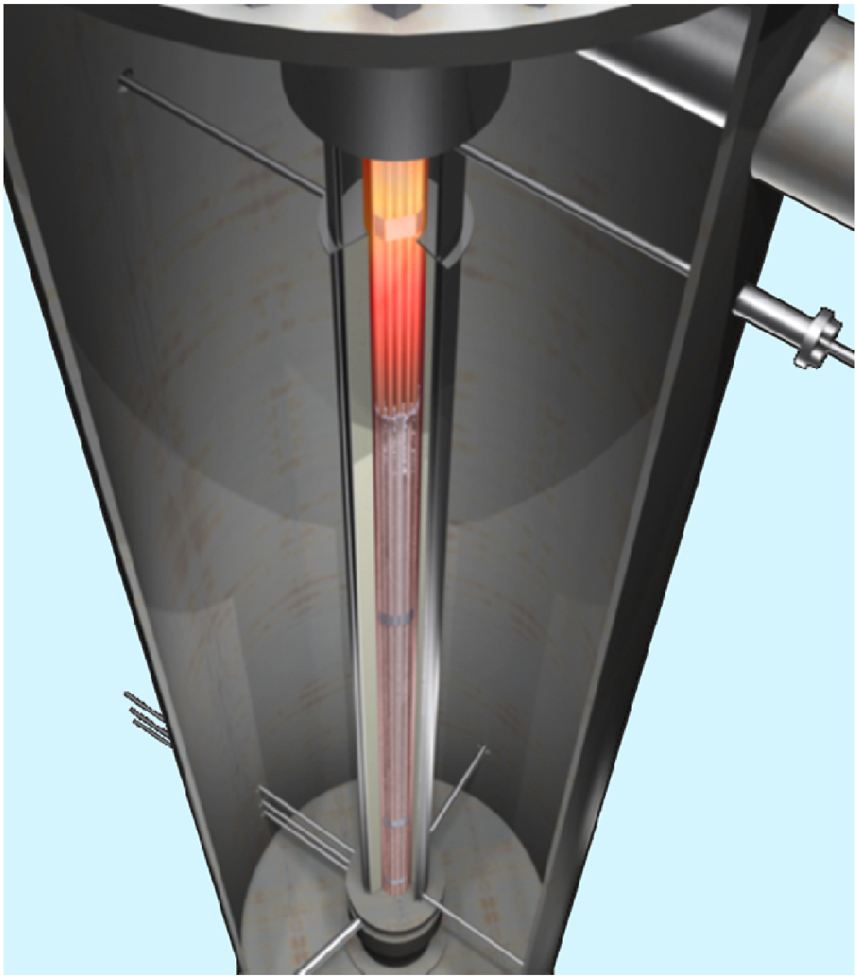


Fig. 2. Bundle cross sections with 21, 24 and 31 rods.



QUENCH facility with safety containment, shroud and hot flooded bundle