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The Integral Test Facility Karlstein – INKA

Stephan Leyer[1], Michael Wich[2] AREVA NP
63010 Offenbach, Germany
[1]*Tel:+49(0)6925571841 , Fax:* +49 (0)69 2557 1883 *, Email:* stephan.leyer@areva.com
[2]*Tel:+49(0)913190069231 , Fax: +49(0)9131900693091, Email:* michael.wich@areva.com

Abstract

The INKA (**IN**tegral Test Facility **KA**rlstein) test facility was designed and erected to test and demonstrate performance of the passive safety systems of KERENA™, the new AREVA Boiling Water Reactor (BWR) design. The experimental program within the KERENA™ development program included single component/system tests of the Emergency Condenser, the Containment Cooling Condenser and the Passive Core Flooding System. Integral system tests will be performed to simulate transients and LOCA (Loss of Coolant Accident) scenarios at the INKA test facility. These tests will test and demonstrate the interaction between the passive components/systems and demonstrate their ability to perform their design function. For the integral tests, the Passive Pressure Pulse Transmitter will be included.

The INKA test facility represents the KERENA™ Containment with a volume scaling of 1:24. Component heights and levels are full scale in order to match the driving forces for natural circulation. The reactor pressure vessel is simulated by the accumulator vessel of the large valve test facility of Karlstein – a vessel with a design pressure of 11 MPa and a storage capacity of 125 m^3. The vessel is fed by a benson boiler with a maximum power supply of 22 MW. The drywell of the INKA containment is divided into two compartments and connected to the wetwell (Pressure Suppression System) via a full scale vent pipe. Therefore, the INKA pressure suppression system meets the requirements of modern and existing BWR designs. As a result of the large power supply at the facility, INKA is capable of simulating various accident scenarios starting with the initiating event – for example pipe rupture. At INKA a full train of passive safety systems is available. INKA is also able to simulate the functions of active safety system such as containment heat removal. Therefore accident scenarios relevant to modern Gen III as well as for operating Gen II design can be simulated in order to validate system and containment codes.

Introduction

The KERENA^{TM} is a medium-capacity boiling water reactor (BWR). It combines passive safety systems with active safety equipment of service-proven design. The passive systems utilize natural forces, such as gravity and natural convection, enabling them to function without electric power or actuation by electric instrumentation and control (I&C) equipment. They are designed to bring the plant to a safe and stable condition without the aid of active systems. Furthermore, the passive safety features reduce the number of active systems, significantly reducing costs, while providing a safe, reliable and economically competitive plant design [1].
The INKA (**IN**tegral Test Facility **KA**rlstein) test facility was designed and erected to experimentally analyze the passive safety systems of KERENA^{TM}. Therefore all passive safety features necessary to simulated accident scenarios (loss of coolant accident [LOCA] and non-LOCA) are included in the design. The following section gives a brief description of these passive systems. The INKA setup simulates the KERENA^{TM} Containment in a volume 1:24 scale. Component heights and levels are full scale in order to match the driving forces for natural circulation in systems. The steam accumulator vessel of the large valve test facility in Karlstein represents the RPV.

At INKA, the systems can be tested individually to analyze their performance, and during integral tests to analyze the interaction between the systems and therefore the capability of the KERENA^{TM} passive systems performing their design function.

Even as KERENA^{TM} is the reference plant for INKA, other tests dealing with generic tasks for BWR plants or even other Light Water Reactor design could be performed. The detailed instrumentation concept also allows investigation of several single effect problems.
Within this paper, the design of the test facility and the potential of the test facility will be shown. The instrumentation concept will also be explained.

1. Passive Safety Systems at INKA

Figure 1 shows a section through the KERENA^{TM} containment with the passive safety systems Emergency Condenser (EC), Containment Cooling Condenser and the Passive Core Flooding System (PCFS), to be tested at INKA. The Passive Pressure Pulse Transmitter which is also included in the INKA design is not shown in figure 1.
The EC is a passive Emergency Core Cooling system with natural circulation flow. The CCC is a passive Containment heat removal system using also natural convection. Together with the EC the CCC represents the passive Cooling Chain connecting the heat source RPV with the heat sink Shielding/Storage Pool located above the Containment.. In the event of a LOCA the PCFS replenishes the RPV. The PPPT is a diverse system to the active reactor protection system and initiates passively reactor scram, reactor depressurization and Containment Isolation.
A detailed description of the operation principle of the KERENA^{TM} passive systems is given in [2].

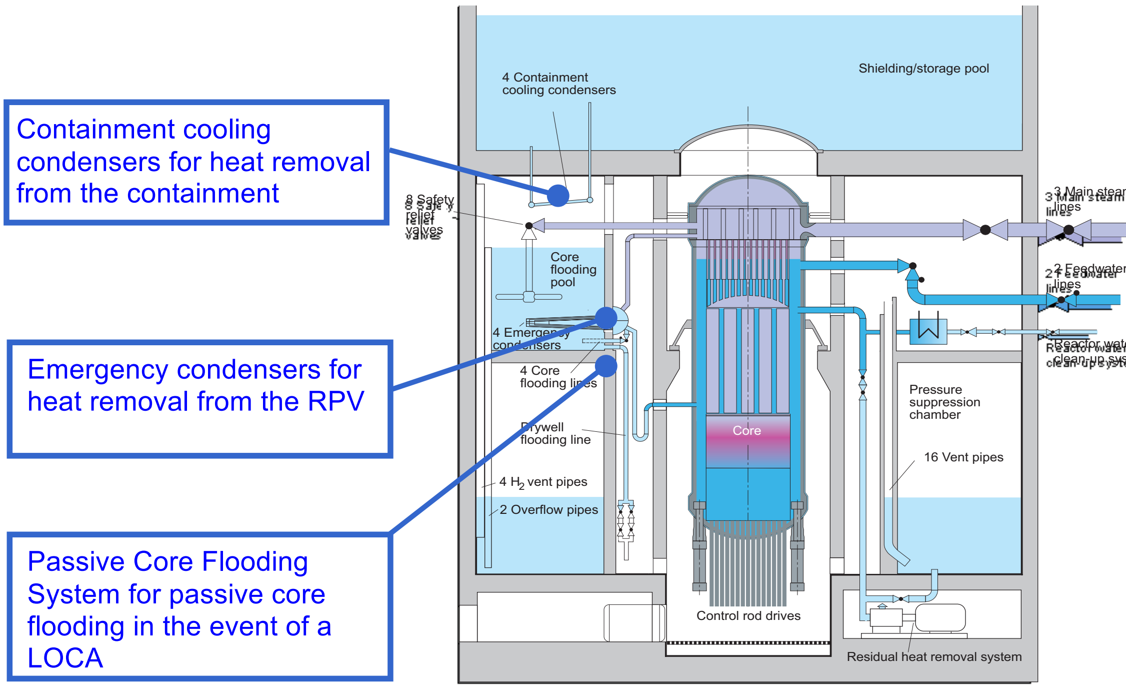

Figure 1: Section through KERENA™ containment with passive safety systems to be tested at INKA. (PPPT is shown in Figure 2)

2. INKA Test Setup

The INKA test facility has been designed for performing steady-state full-scale EC, CCC, PCFS and PPPT tests and for simulating transients/LOCA conditions in a smaller-scaled configuration. The PPPT is used to actuate the safety-relief valve during the tests. The Containment volumes are modeled to a volume scale of 1:24. The interconnecting piping is designed such that the pressure drops match those of a real KERENA™ plant. Instrumentation is provided to determine the heat transfer capacity of the components as well as the thermodynamic conditions in the vessels simulating the various KERENA™ containment compartments.

The vertical distances between components, water levels, floors and ceiling of the KERENA™ containment that are important for the performance of the tested components are simulated in full scale at INKA. Figure 2 is a 3-D computer image of the test facility. The vessel water and gas volumes result from downscaling of the KERENA™ volumes by a factor of 1:24. The volume of the vessels and the test facility height is given in Figure 2.

INKA is integrated into the Large-Valve Test Facility “GAP” ("Grossarmaturen-Prüfstand”) that has been in operation in Karlstein for many years. The GAP test facility consists of a steam accumulator (height: 21.7 m, volume: 125 m^3) fed by a 22-MW boiler. This accumulator (GAP Vessel) will supply the steam needed for the experiments and will replicate the RPV in the integral tests. An additional vessel with a water volume of about 50 m^3 is placed inside the GAP support frame at the top. This vessel simulates the shielding/storage pool and will therefore supply water for the secondary side of the CCC.

The containment will be simulated by three vessels. The Flooding Pool Vessel (FPV) contains the EC and the CCC. The PCFS connects the FPV with the return line of the EC. The PPPT is connected to the down comer line. The DryWell Vessel (DWV) simulates the residual gas volume of the drywell. The Pressure Suppression Pool is simulated by a third vessel (PSPV).

During tests of the individual passive components only the FPV is needed.
For the integral transient and LOCA experiments, all vessels and components are in use.

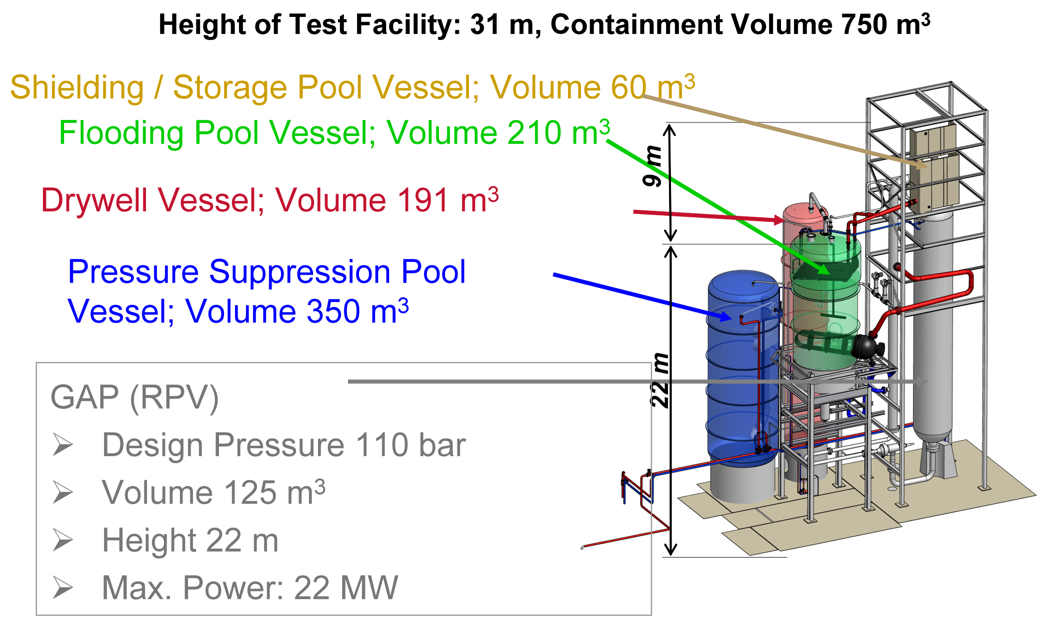

Figure 2: 3-D Image of INKA Test Facility at Karlstein

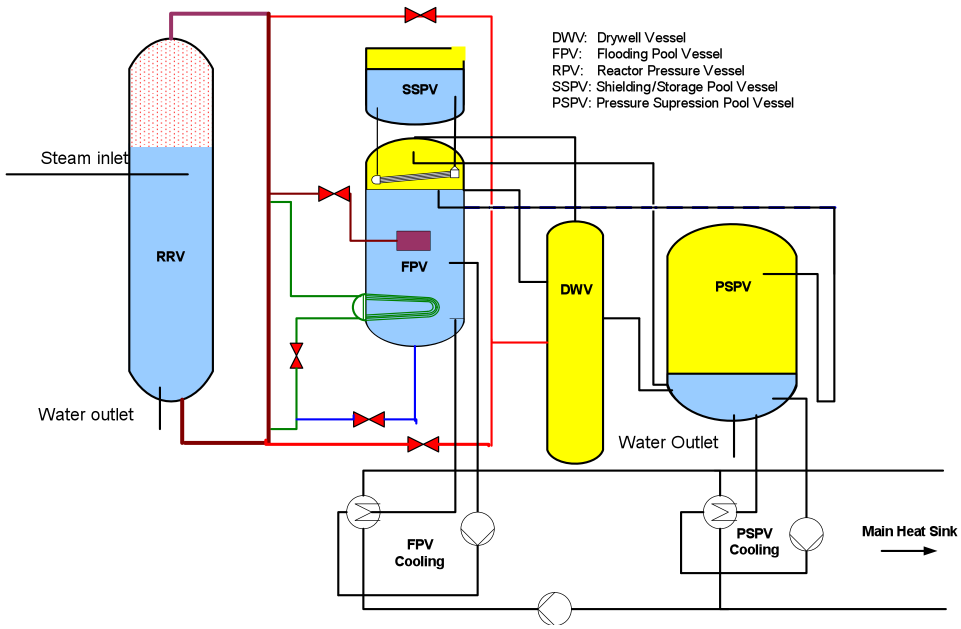

Figure 3: Simplified P&ID of the INKA Test Facility

Figure 3 shows a simplified P&ID of the INKA test facility with the containment vessels FPV, DWV, and PSPV. Two pipes connect the FPV with the DWV to represent the connections between the gas spaces of these compartments. The FPV is connected to the PSPV via the overflow pipe limiting the FPV water level. A second connection is the hydrogen overflow pipe used for pressure limitation during severe accident mitigation at KERENA™. The DWV and the PSPV are connected via a full scale vent pipe. Additionally, the function of the Safety and Relief valve is included in the design. The system is connected to the down comer line and goes into the FPV. For LOCA test scenarios two different lines enter the DWV - one for the simulation of breaks of a water line, the other for breaks of a steam line.

The water of the FPV and the PSPV can be cooled down via two pool cooling systems. These systems are used for the pre-conditioning of the test facility and can be used for the experimental simulation of active system accident management. At KERENA™, the active heat removal from the containment is done via the cooling of the Core Flooding Pools (CFP) and the Pressure Suppression pool. Active core cooling and flooding of the KERENA™ RPV is done via low pressure injection systems (LPIS) injecting water taken from the wetwell into the RPV. Currently no such LPIS is installed at INKA. The impact of this active system can be simulated be removing water from the PSPV and water introduction into the GAP vessel.

3. Instrumentation Concept

Figure 4 gives an overview of the sensors installed at the INKA test facility. Overall there are more than 300 sensors available at INKA. Most of them are conventional instrumentation like temperatures, mass flow measurements, pressures and differential pressure sensors. Additionally two phase flow instrumentation (Thermo Pin Probes and Gammadensitometer) in cooperation with Helmholtz Zentrum Dresden/Rossendorf (HZDR) is installed. The gas mixture in the vessels is by a mass spectrometer with a probe sampling system (Cooperation with Paul Scherrer Institut in Switzerland). In the Emergency Condenser condensate line the AREVA Fatigue Monitoring System (FAMOS) is tested under plant relevant conditions.

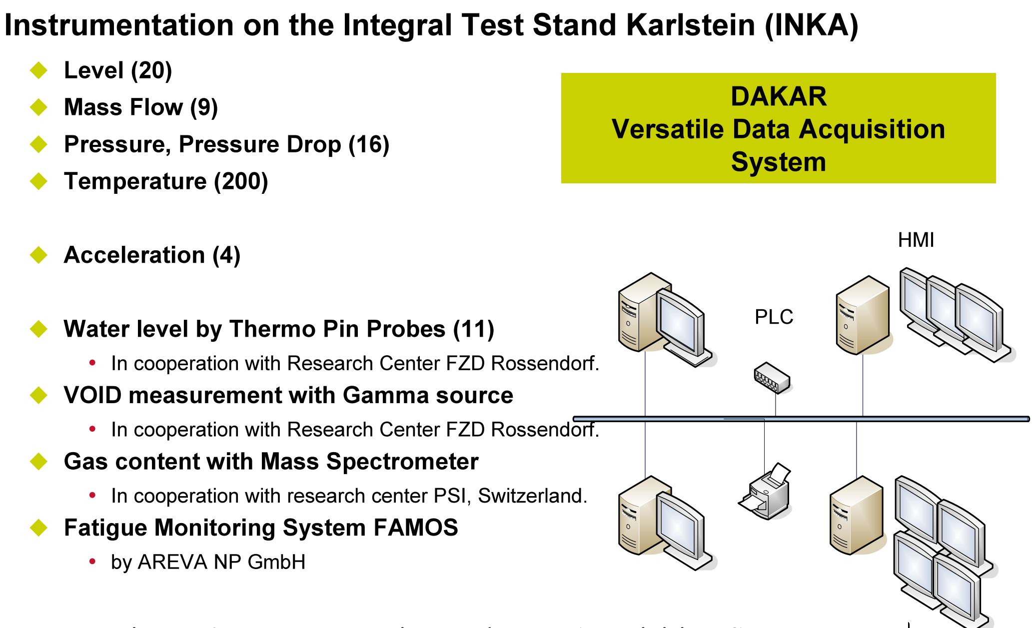

Figure 4: Instrumentation and Data Acquisition System

The data acquisition system DAKAR, which was developed by AREVA in Karlstein, is used. The system allows the time synchronized combination of fast and slow data recording.

3.1 Instrumentation of the Test Vessels

Figure 5 gives an overview of the instrumentation of the INKA vessels. The FPV has the highest sensor density due to the fact that this vessel contains the passive systems EC and CCC. The PSPV has thermocouples in the water volume at four different levels, located in three different radial locations. In the gas space of the vessel the temperature field is measured at five levels in the same three radial positions. At all levels in the gas space the thermocouples at the axis in the center line of the vessel is connected to a gas probe sampling sensor. Like in all other vessels the pressure and the water level is measured. In the DWV, the gas temperature is measured at six levels. The upper five levels are equipped with a probe sampling sensor.

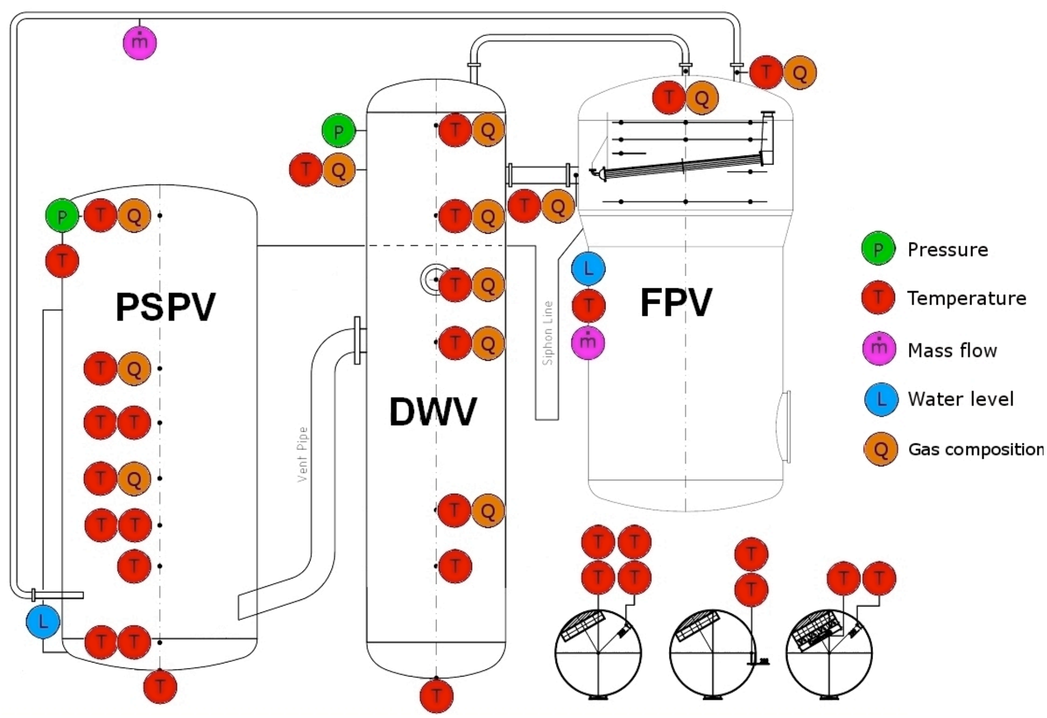

Figure 5: Drawing of the INKA vessel Instrumentation

The instrumentation of the FPV is shown in Figure 6. The temperature of the water space is measured at nine levels along the vessel axis and on a parallel chain outside the chimney of the EC bundle. Like in the other two vessels, the pressure and the water level are measured. In the FPV the water level cannot exceed the level of the inflow of the overflow pipe connecting the FPV with the PSPV. The gas space of the FPV is extensively instrumented with thermocouples and sampling probe sensors in order to determine the impact on gas compositions to the heat transfer capacity of the CCC and the influence of the CCC operation to gas and temperature stratification.

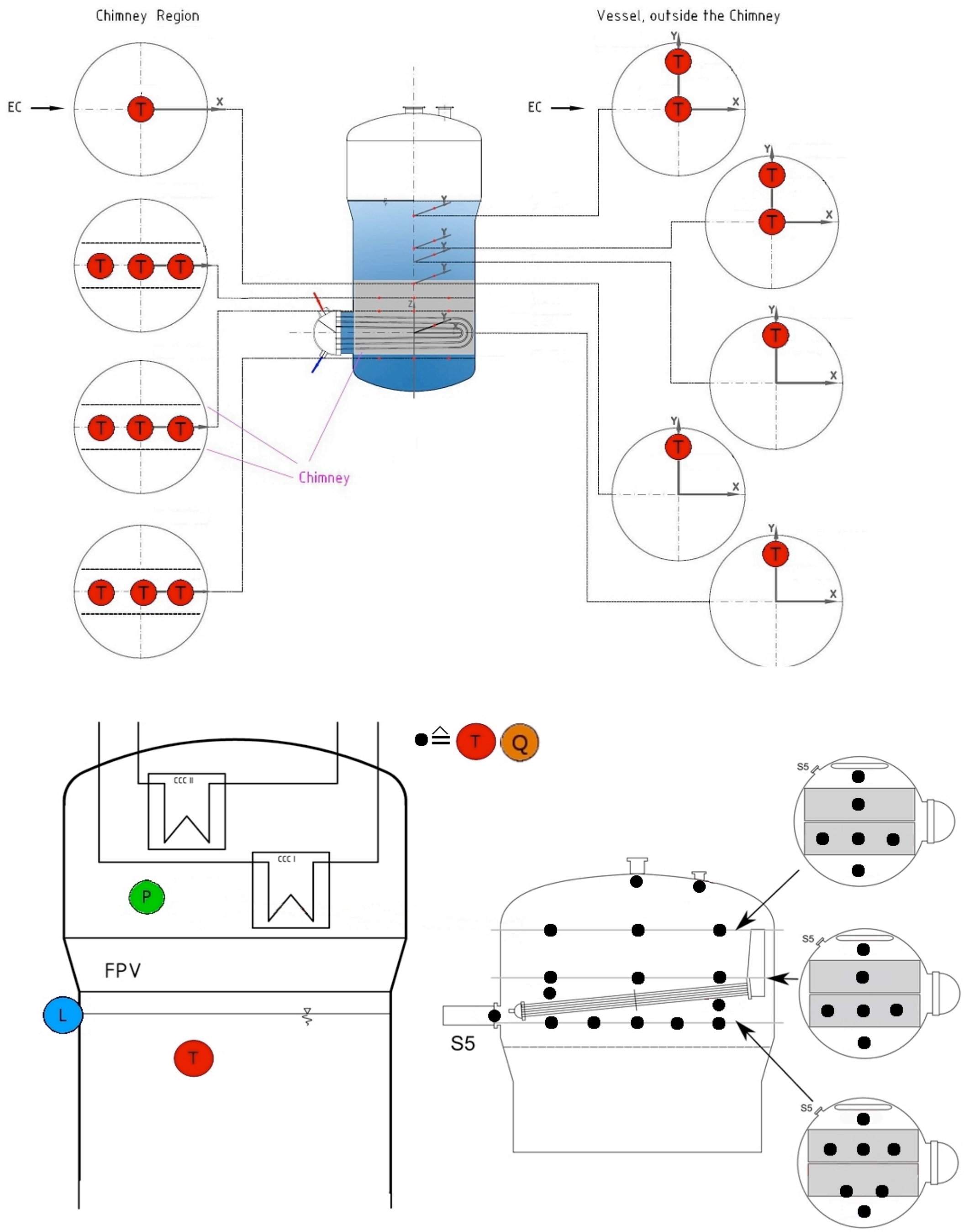

Figure 6: Instrumentation of the FPV

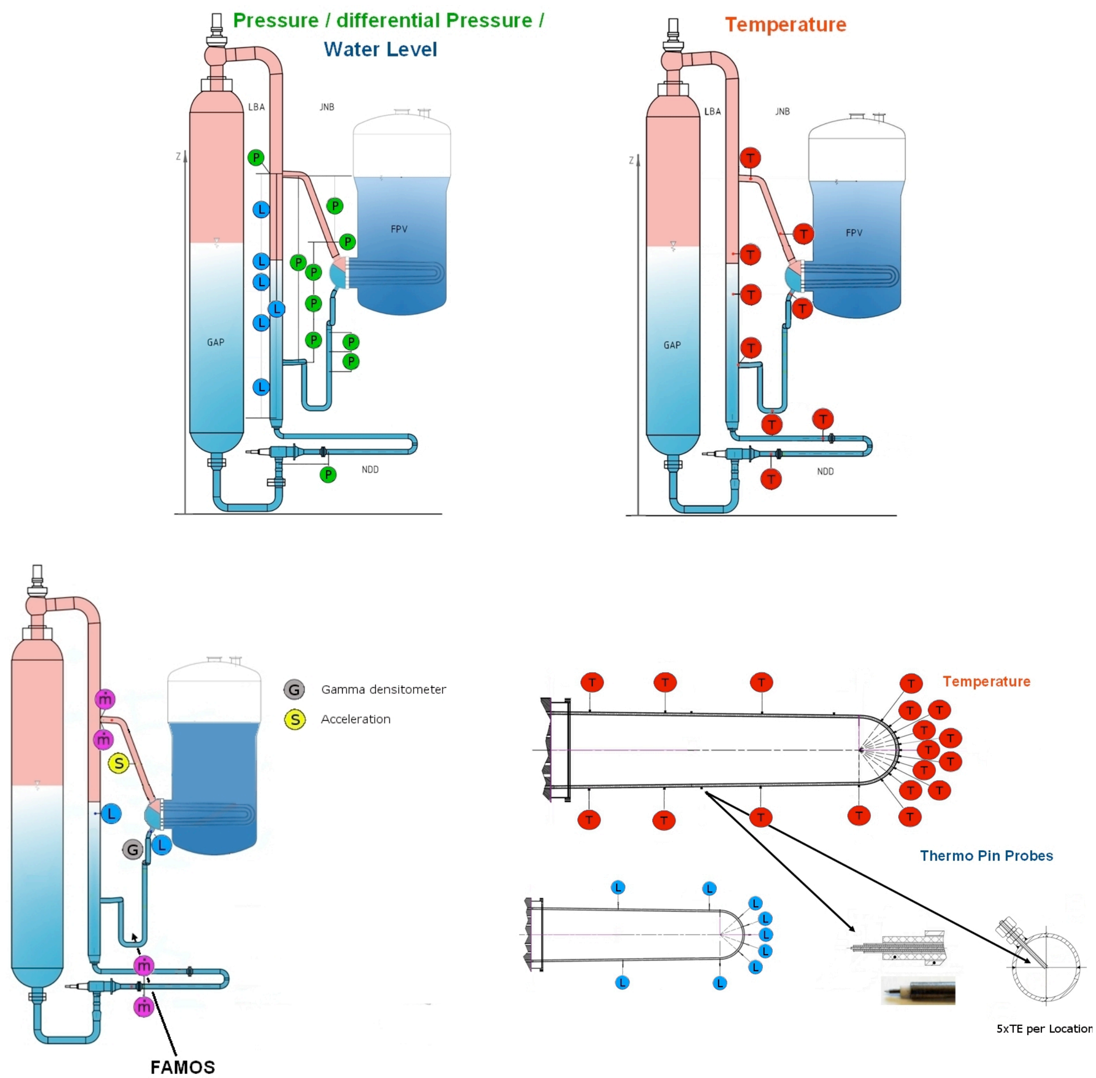

Figure 7: Instrumentation of the EC System

3.2 Instrumentation of the Systems

The EC system instrumentation is shown in Figure 7. The system is connected to the stand pipe of the large valve test facility which represents the down comer of the KERENA^{TM} RPV. In the GAP vessel itself the water and steam temperature, pressure, and water level is measured. In the down comer, the differential pressure and the temperature is measured at different elevations for determining the water level with sufficient accuracy. Above the water level the absolute pressure is measured. The inlet line, return line, and the EC component itself are equipped with several differential pressure transmitters. In the piping system the temperature is determined at different positions.

The right scheme of the lower part of Figure 7 highlights the mass flow measurements, the local void fraction measurement outside the EC component (Thermo Pin Probes in the EC outlet line and the down comer line), the acceleration measurements for the determination of vibrations in the system during operation, and the integral void measurement in the outlet line.
The operation principle of the latter measurement is also described in [3].
It consists of a radiation source and a detector array. The pipe in which the void fraction shall be determined is located in between. Based on the attenuation of the emitted radiation, the void fraction in the pipe can be determined.
Two of the outer heat exchanger tubes in the EC heat exchanger bundle are equipped with instrumentation- one with thermocouples and the other with nine thermo pin probes. At most of the locations indicated, the thermocouples are located in the tube axis. At three different positions there are four additional thermocouples at the inner side and the outer side of the heat exchanger tube wall. With the combination of the local void fraction measurements and the five thermocouples per location, the heat transfer and the type of two phase flow in the tube can be determined.
Figure 8 shows the instrumentation of the CCC system and component. The differential pressure of the inlet line, return line, and the component itself is measured. In the return line the pressure is measured. Thermocouples are installed at different locations in the piping system. In the return line several thermocouples are located at different position over the pipe cross section to identify stratification of the flow. In the case of two phase flow operation, the integral void fraction can be determined via a gammdensitometer located on the return line. The heat exchanger tubes are equipped with thermocouples along the tube axis to determine the heat up of the coolant.

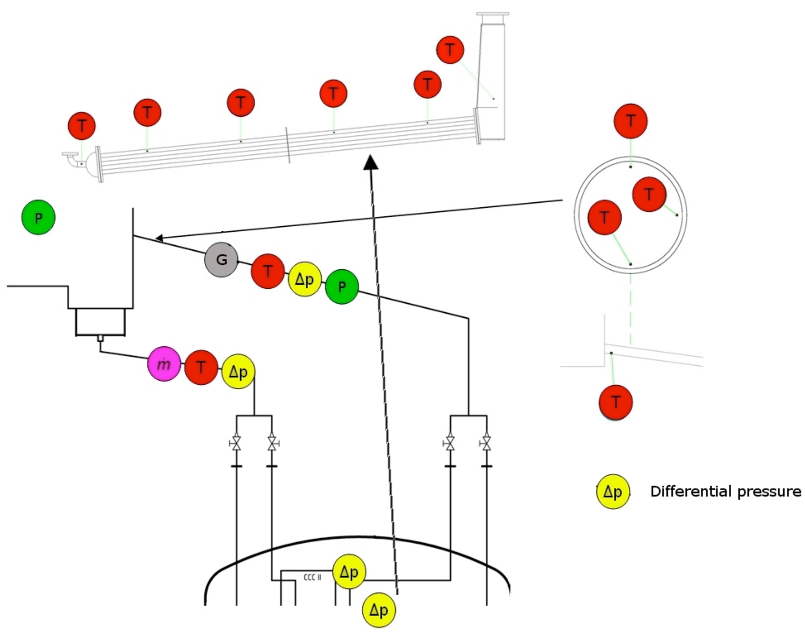

Figure 8: Instrumentation of the CCC System and Component.

For information of the instrumentation of the PCFS see [4].

4. Test to be run at INKA

INKA simulates a multi-compartment containment of a BWR, that meet the requirements of modern BWR systems. It has a scaling that is relevant of real plant conditions and is equipped with a high instrumentation density.
Because of the pre-conditioning capability of INKA and the option to operate all vessels and systems individually many single effect phenomena can be addressed.
The following list gives an overview about effects to be analyzed:

- Heat transfer on surfaces – Water surface Containment walls for example in the PSPV of INKA
- Heat transfer on the inside and outside of heat exchanger tubes and the impact on natural circulation systems – for example impact of sub cooling on the EC system
- Influence of non-condensable gases on the heat transfer – for example for the EC and CCC
- Temperature stratification in the water and gas space of compartments/vessels – for example INKA, FPV, and PSPV
- Gas compositions in the gas space of compartments/vessels – for example INKA, FPV, and PSPV
- Impact of natural convection on temperature stratifications and gas compositions in compartments or vessels – for example the influence of CCC operation on the FPV
- Gas concentrations in drywell and wetwell after blow down depending on the leak size
- Temperature stratification in the wetwell after blow down depending on the leak size

The integral test as well as the single effect tests can be simulated in a scaling close to real plant conditions. The instrumentation concept and the sensor density provides data for the validation of thermo hydraulic codes like RELAP or TRACE for example or containment codes like COCOSYS or GOTHIC. Nevertheless for special tasks the instrumentation concept can be easily upgraded. Also the installation of additional systems matching tasks of other reference plants can be realized.

5. Summary

The INKA test facility was build to test the passive safety systems of KERENA™. INKA simulates the KERENA™ containment in scaling of 1:24. The primary system is represented by the GAP vessel and the GAP main steam line representing the RPV down comer. The systems to be tested at INKA are constructed in full scale. Because of the possibility of INKA to pre-condition and operate all vessels and systems individually, integral testing such as the experimental simulation of BWR accident scenarios, as well as the analysis of single effects, can be performed. The large energy storage capacity and power supply of INKA allows the performance of tests in a scaling that is relevant for full scale commercial nuclear power plants.

REFERENCES

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[2] AREVA, SWR 1000 General Description

[3] U. Hampel et al., Review of Scientific Instrumentation **78**, 103704 (2007)

[4] S. Leyer and M. Wich; Integral Test Facilities and Thermal-Hydraulic System Cod