AREVA's accredited testing facility

AREVA's Thermo-Hydraulic Platform qualified as test and inspection body

Ingo Ganzman, Wolfgang Herr, Holger Schmidt, Willi Stecher, Dirk Walter, Klaus Umminger, Achim Beisiegel, Michael Wich, Phillipe Dolleans and Thierry Muller

Kurzfassung


Die maximalen Betriebsparameter der Versuchsanlagen der Thermo-Hydraulik-Plattform betragen bei Heizleistungen bis zu 22 MW, elektrischen Strömen bis zu 80 kA, Drücken bis zu 300 bar und Temperaturen bis zu 600 °C. Die Akkreditierung umfasst dabei Versuche und Bewertungen sowie sachkundige Konzeptbeurteilungen mit entsprechenden Unterstützungsprogrammen. AREVA bietet auch die dazugehörigen Vor-Ort-Untersuchungen im Kraftwerk beziehungsweise bei Herstellern an – zum Beispiel die Funktionsnachweise von Ventilen. Der vorliegende Beitrag gibt einen Überblick über das Arbeitsgebiet der Prüf- und Inspektionsstelle.

Introduction

AREVA NP GmbH has been operating a worldwide unique testing and qualification infrastructure for more than 30 years, which is mainly delegated to systems and components of light water reactors. With the upcoming renaissance of nuclear energy, the requirements regarding highly-qualified test capabilities have increased in such a way that it is not possible for all stakeholders to run their qualification programs at plant conditions within their own facilities. In addition, many facilities have been closed in the past decades for reasons of economic viability. Investments in new facilities or costs for a restart of old and closed facilities are far from reasonable financing. Therefore, AREVA has decided to open its Thermo-Hydraulic Platform for partners within the power plant industries, among which are authorities, research centres, component suppliers, utilities and/or engineering companies. To ensure our partners a high quality of test and qualification standards, AREVA has successfully applied for accreditation by the DAkkS GmbH (German accreditation body) as flexible test laboratory according to ISO/IEC 17025 and as independent inspection body according to ISO/IEC 17020. The International Laboratory Accreditation Cooperation (ILAC) has settled an almost worldwide cooperation agreement according to which the associated countries accept each others’ accreditations. According to this agreement, the accreditation of AREVA's Thermo-Hydraulic Platform is valid not only in Germany but also in almost all countries of the world, e.g. USA, Canada, India, China, Japan, Korea, Emirates, Russia and the EU. This article gives an overview of the general testing and inspection capabilities of AREVA in the field of thermal hydraulics and components testing.

Test and qualification range

The testing and qualification infrastructure is focused on flexible task solutions for power plant applications. Therefore, it is common practice to modify the existing testing infrastructure to fulfill the requirements of a qualification or an inspection task. To avoid new individual accreditations for each task, AREVA has successfully applied for a flexible accreditation based on which the general methods and applicable range of measurement have been certified (Table 1).

The methods are linked to the Thermo-Hydraulic Platform, which is the basis for tests and qualifications. This means the facilities will be used or the methods that have been proven at the facilities themselves. The applied methods can be concept inspections based on experiences supported by numerical analysis. In addition, the accreditation range covers on-site inspections and qualifications at power plant or component supplier sites. Some examples described in the following paragraphs indicate the range of the certification.

AREVA's Thermo-Hydraulic Platform

At sites in Karlstein and Erlangen (both in Germany), AREVA operates the Thermo-Hydraulic Platform with about 100 engineers and technicians. Therefore, AREVA is in the position to test all relevant components and systems of power plants.

"Primärkreislauf“ (PKL) – primary system loop

The most impressive example for a system test facility is the PKL loop, which represents...
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the system of a four loop pressurised water reactor (PWR) plant. Based on a reference plant, the German nuclear power plant Philippsburg 2, the facility was built in a 1:1 scale regarding height and 1:145 with respect to power and volumes. Figure 1 shows the scheme and the main components of the facility, which include the reactor pressure vessel (RPV), steam generators (SG), reactor coolant pumps (RCP), accumulators and pressuriser. The facility is also equipped with all relevant secondary-side components and other operational and safety systems, which are relevant for modelling of the total response of the entire system during accident situations – the main purpose of the PKL experiments.

Based on tests performed for more than 30 years, safety margins of operating and future nuclear plants have been demonstrated. The thermal hydraulic experiments encompass design basis accidents with and without loss of coolant (LOCA), as well as beyond-design-events. With more than 1,000 measuring sensors (much more than in the corresponding components of the PWR plants), the facility provides detailed information on the system behaviour of PWRs under accident situations. Nowadays, it is also used by utilities to train their staff.

Apart from the PKL facility – delegated to PWR activities – an additional facility is in operation dealing with boiling water reactor (BWR) tasks. It is called INKA and is described in [1 and 2]. The main component – the reactor pressure vessel mock-up – of INKA is also the core of the world’s biggest valve testing facility GAP.

**“Großarmaturen-Prüfstand” (GAP) – valve test facility**

The flow scheme of the GAP is shown in Figure 2. A very big steam accumulator with a volume of 125 m³ is connected to a BENSON boiler with a total power of 22 MW. It supplies steam with a pressure of up to 165 bar and a temperature of up to 360 °C. Depending on the test requirements, a test valve will be supplied with different conditions of water and steam – in case of a steam test, the valve will be connected to the top of the accumulator and for water tests to the bottom. In total, valves of diameters of up to 28” have been tested and qualified with blow rate flows of up to 2,000 kg/s steam and 4,000 kg/s steam/water mixture. The loop will be operated in an open mode where fluid flows through the test specimen, which is typically a valve, into a quencher pool, where the steam will be condensed. Due to the high flexibility of the test set-up, different other objects have been tested up to now, for example vent pipes, through which steam enters the quencher of a boiling water reactor, or insulation cassettes destroyed by a jet. In this case, the fragmentation has been analysed to obtain representative data for the qualification of sump sieves in front of injection pumps.

**SUSI – sump sieve test set-up**

For the qualification of sump sieves in consideration of the related transport phenomena, an own test set-up exists which has an open rectangular vessel of about 21 m³ as basic component. This vessel represents a section of the sump which is filled up with water in the case of a LOCA. Pre-tests have indicated that the overlay on a sieve formed of debris and insulation material destroyed by a hypothetical jet depends on the transport along the sump. Therefore, this facility is designed in such a way that the total flow path from the leakage through the sump sieve via a reactor pressure vessel section is covered as shown in Figure 3. The aim of the tests is to demonstrate the performance of the filtering systems and to show that an increased pressure drop due to deposition of debris will have no negative impact on the cooling of the fuel assemblies. Optional tests with a flow through a fuel assembly dummy can be performed to demon-

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**Table 1. Accredited measurement range of AREVA’s Thermo-Hydraulic Platform.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0 °C to 600 °C</td>
<td>± 0.3 K</td>
</tr>
<tr>
<td>Pressure</td>
<td>10 Pa to 40 MPa</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Volume flow rate</td>
<td>0.1 l/h to 100,000 m³/h</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Mass flow rate</td>
<td>Up to 4000 t/h</td>
<td>± 5 %</td>
</tr>
<tr>
<td>Force</td>
<td>Up to 10,000 kN</td>
<td>± 1 %</td>
</tr>
<tr>
<td>Momentum</td>
<td>Up to 50,000 Nm</td>
<td>± 1 %</td>
</tr>
<tr>
<td>Length</td>
<td>1 µm to 10 m</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Velocity</td>
<td>1 mm/s to 100 m/s</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Acceleration</td>
<td>0.5 to 1000 g</td>
<td>± 1 % Linearity</td>
</tr>
<tr>
<td>Electrical power</td>
<td>Up to 20 MW</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Active power</td>
<td>50 KW</td>
<td>± 1 %</td>
</tr>
<tr>
<td>Current</td>
<td>85,000 A</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Voltage</td>
<td>420 V</td>
<td>± 0.5 %</td>
</tr>
</tbody>
</table>

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**Figure 1. Flow scheme of the PKL facility (left), top view on PKL steam generators (right).**
AREVA’s accredited testing facility

strate the low impact on the downstream components in the case of an optimised filtering system.

"Komponentenprüfanlage" (KOPRA) – component test facility

For the qualification of RPV internals and valves, AREVA operates the multi-functional test facility KOPRA. The focus of this facility is on full-scale functional tests respecting nominal temperature, pressure and mass flow. Beyond that, for endurance testing to investigate long-term behaviour and wear effects, it is also possible to adapt the water chemistry. In general, the facility consists of four test loops with three recirculation pumps and pressurisers as shown in Figure 4. Main qualification tasks are focused on valves, safety valves with its pilots, pumps, RPV core internals as fuel assemblies and control rod drive mechanisms (CRDM).

In the “Armaturenprüfstand” (APS) – valve test section – (shown on the left side of Figure 4), different test objects (mainly valves) can be placed within different test sections of nominal diameters from 15 to 150 mm to measure pressure drops or determine the functional behaviour. Via the discharge line of the “Versuchsdruckhalter” (VDH) – test pressuriser – qualification tests for prototypes or functional and setting tests for safety valves have been performed. The in-service hot adjustment of a set of pilots of safety valves for PWR primary and secondary circuits with saturated steam is performed with the valve test array on top of the APS pressuriser. The advantage of these in-service hot adjustments in comparison to functional testing during the start-up, beside a shorter start-up phase, is an immediate maintenance and hot adjustment in the case of leakage. The “Regelstabprüfanlage” (RPA) – control rod drive mechanism (CRDM) test section – (shown on the right side of Figure 4) is designed to test CRDMs. Before installation, it is required to run factory acceptance tests over several hours under operational conditions to generate a magnetite layer on the sliding surfaces for serviceability and to ensure the functionality. The “Kernkomponentenversuchsanlage” (KVA) – core component test section – simulates the complete geometry of the central core position with a 1:1 scale. The fuel assembly is inserted in a fuel assembly channel in-between the lower support plate and the upper core plate. The control rod guide assembly is fixed by the upper support plate. The vessel head of the test channel corresponds to the RPV head with the CRDM adaptor and flange. Within this test set-up, functional tests to verify the adequate performance and endurance tests to demonstrate the proper functioning over the specified lifetime of the CRDM, mobile set and drop channel were performed. In addition, pressure drop characteristics over the fuel assembly were measured.

Test set-ups to qualify the functioning of fuel assemblies

To analyse the general thermal hydraulic behaviour of fuel assemblies, AREVA operates
special unique facilities for this purpose called Karlstein Thermal Hydraulic Test Loop (KATHY). With respect to the determination of critical heat flux as the basis for correlation developments the KATHY loop is in operation. Fuel assemblies are simulated by electrically-heated rods. The critical heat flux is identified based on a significant temperature increase at a certain power level. Two different test vessels are installed – one for BWR and one for PWR fuel assemblies. Apart from critical heat flux tests, this facility has also been used to analyse the flow stability in a BWR core including fuel assemblies under forced and natural circulation conditions [3]. The operational conditions are similar to those of the licensing process of fuel assemblies. The total electrical power is 20 MW.

Another set-up is focused on fluid-induced forces and possible vibrations. With advanced velocity measurement techniques like Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV) it is possible to analyse the flow pattern in the fuel assembly and potential consequences on the structure. For the measurement of the response of the structure itself laser triangulation sensors and laser vibrometers are installed in these facilities [4].

Loss of coolant (LOCA) qualification tests

All safety-related electrical components have to withstand LOCA conditions, even if they are in operation until they have reached their end of operation lifetime. For qualification over the entire lifetime spectrum, the test specimens will be artificially aged by considering the main degradation mechanisms which are radiation, thermal and mechanical aging. Therefore, the test specimens will be installed in front of a radiation source in such a way that the irradiation over a couple of days/weeks is representative to the degradation

Figure 4. Flow scheme KOPRA.

Figure 5. LOCA test, preparation of a motor drive.

Figure 6. Juliette test arrangement for the investigation of the lower plenum flow conditions in an EPR™ reactor.
during operation of the plant. Thermal aging will be performed in climate ovens in which the temperature is significantly higher than the operational temperature. The thermal aging time will be determined based on the Arrhenius law. Mechanical aging is also performed e.g. in the case of active components by simulating movements over the entire lifetime.

The artificially-aged specimens will be installed in a vessel where they have to withstand the loads of a LOCA. Depending on the defined conservative spectrum of the LOCA, a pressure and temperature time depending steam atmosphere will be injected in the vessel. After LOCA tests, further tests simulating post LOCA conditions have to be performed. Therefore, the specimens will be installed in a third vessel where they have to withstand lower pressures and temperatures than in LOCA conditions, but in addition to that, water chemistry and regular wetting are main degradation effects in this phase.

AREVA operates several vessels (Figure 5) to run the different stages of these qualification steps for test specimens of different sizes.

**Flow model and separate effect tests**

The Thermo-Hydraulic Platform is organised in such a way that test set-ups are standardised as much as possible but it also has to be as flexible as possible. In a lot of cases the tests will be run only once for one application. Therefore, in addition to the above-mentioned, AREVA’s facility park also has the infrastructure to run separate effect tests for water/steam applications and related flow model tests. Together with related flow modelling, they will be used to evaluate complex conditions. For example, the heat removing capabilities of an ex-vessel core-melt cooling scenario of a boiling water reactor was demonstrated in a multiple step approach [5]. In a first step, the flow behaviour around the RPV in the core melt experiment was investigated based on scaled water/air experiments. In a second step, the shape of a section was identified in such a way that it represented the flow conditions. In the third qualifying step, a 1:1 section model was installed in a high-pressure separate effect test facility of a power up to 2 MW and maximal operational conditions of 300 bar/600 °C. It is part of the competence of the expert staff to imagine all relevant scales aspects. In addition the expert staff are qualified to understand and to interpret thermal-hydraulics or fluid induced vibrations (FIV) phenomena.

The AREVA thermal-hydraulic testing and qualification tasks are completed with an infrastructure installed in Le Creusot (France). Examples for advanced flow model tests performed in France are tests regarding the flow distribution and the temperature distribution at the core inlet of AREVA’s EPR™ reactor. For this purpose, a transparent mock-up – called Juliette – scaled 1:5 was built (Figure 6). In addition to the RPV mock-up, this model included all main cooling lines. For the simulation of the pump rotations, swirl promoters with the same characteristics as a main coolant pump were installed. As a mock-up of the core, each location fuel assembly was represented by a Venturi meter to model a representative part of pressure drop and to measure the local flow rates. To understand the velocity field in the lower plenum, PIV and LDA measurements were performed. In addition to Juliette regarding the lower plenum, tests for the EPR™ reactor were run for investigation of the upper plenum behaviour mock-up at the same scale as Juliette (EPR RPV Lower plenum mock-up) and called ROMEO (EPR RPV Upper plenum mock-up) and for RPV internal fluid induced vibrations mock-up called Hydravib for FIV reason at 1:8 scale.

**Virtual test facilities and boundary condition setting**

For the proper design of test facilities or to evaluate concepts, computational fluid dynamics (CFD) methods and pipe system analysis programs are part of the field of activities and competence of the inspection body.

In addition, CFD is an essential tool for the understanding of the general flow conditions. It is a common process for complex flow conditions to optimise the test design including the measurement concept based on the understanding of flow conditions. Figure 7 indicates a case where it has been the purpose of the test to have a homogenous flow entering the test object. As real test set-ups have a limited size of homogenisation length a flow straightener has been installed in front of the test object itself. This design has been optimised with CFD methods. The homogenous flow distribution in front of the test object itself has been qualified with LDA measurements.

**On-site services**

In addition to the pure testing in the laboratories and related modelling, it is also part of the accreditation to perform diagnostics, tests and related inspections e.g. for valves on-site – at power plants or component suppliers. These on-site services as well as the laboratory activities are within the accredited measurement range.

As an example of the valve diagnostics and valve services activities mobile torque test benches (Mobiler Drehmoment Prüfstand, MDP) are designed, qualified and manufactured in the laboratory (Figure 8). The faulty operation of a valve often shows at an early stage through a change in the torque or switching behaviour of the actuator. It is therefore useful to determine the torques on a regular basis. Essentially, the MDP consists of an electromagnetic brake. Amperage is proportional to braking force. After switching off, the braking action is inhibited by the residual magnetism. In this way, a precise increase and decrease of the actuator braking torque can be ensured. Upon adjustment of the travel limit switch, the valve is ready for operation again. The MDP is also linked to the valve monitoring system “Armaturen Diagnose- und Auswert-Methode” (ADAM®). Whereas with ADAM® the function stand-by of the complete system ranging from power supply and control system to shutoff device of the valve is periodically being inspected and compared with the corresponding baseline measurement. The valve monitoring system is based on the proportionality of the active power of the actuator and the torque during valve operation. It ensures that all parameters relevant for valve and actuator performance are reliably monitored.
**Summary**

AREVA has a worldwide unique testing and qualification platform focused on thermal hydraulic tasks. To guarantee the high quality standards, AREVA GmbH positioned the related organisation in such a way that the DAkkS GmbH (German accreditation body) could accredit it as test and inspection body. Therefore, AREVA makes sure that persons involved in tests and inspection will not be influenced by any political, economic or social interests. Combined with the guarantee of a very high level of confidentiality, this ensures independency of the results. The accreditation also represents a qualified opening of the worldwide unique test and qualification infrastructure for component-suppliers, engineering companies, utilities and research centres. In case they have to run test or inspection programs, it is an advantage to avoid the costs for the construction of an own infrastructure. In this way, AREVA offers support to the partners in the nuclear community to guarantee high security standards which is in the joint interest of all participants.

**References**


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