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Development of procedures for local void fraction measurements

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ABSTRACT

AREVA operates a world-wide unique thermal hydraulic platform to ensure high safety standards in the nuclear industry. This platform is operated as an accredited test and inspection body according to ISO 17025 and 17020 to grant high and independently confirmed quality standards. The aim of the tests is to demonstrate the reliability of components and systems, mainly under operational or accidental conditions. In addition to that it is also the aim of the tests to increase the understanding of the fluid dynamic processes. Especially under operational conditions it is very difficult to gain local measurement data. As an example for AREVA's strategy in the field of advanced two-phase flow measurement techniques, this paper gives an overview on the current activities regarding the development of these measurement procedures focused on the local void fraction measurements under two-phase flow conditions in an annulus.

With increasing requirements with respect to the local resolution, the efforts for measurement techniques increase as well. For that purpose AREVA has built up a specific test loop to develop adequate measurement techniques and corresponding validation processes. This loop allows the adjustment of water/steam properties representative of operational and accident conditions of LWRs and has been used to develop a procedure to measure the void fraction distribution in an annulus representing the hydraulic diameter of a typical LWR core sub-channel by means of a gamma tomography system. This paper describes the process, which has been established to reach a reliable high special resolution measurement. Further steps planned to increase the validity of the measurement procedure will also be discussed.

1. Introduction

AREVA has been operating a worldwide unique testing and qualification infrastructure for more than 35 years, which is mainly dedicated to systems and components of light water reactors (Ganzmann et al., 2011). This Thermo-Hydraulic Platform has been opened for partners within the power plant industries, among which are authorities, research centers, component-suppliers, utilities and/or engineering companies. To ensure a high quality of test and qualification standards AREVA's platform is accredited as a flexible test laboratory according to ISO 17025 and as independent inspection body according to ISO 17020. The International Laboratory Accreditation Cooperation (ILAC) has set-up an almost worldwide cooperation agreement, according to which the associated countries accept each other's accreditations. According to this agreement, the accreditation of AREVA's Thermo-Hydraulic Platform is valid not only in each of the countries with AREVA laboratories (which are France, Germany and USA) but also in almost all countries of the world e.g. Canada, India, China, Japan, Korea, Emirates, Russia and all countries of the EU.

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 the applicable range of measurement have been certified, which are given in Table 1.

Within a continuous improving process new measurement methods are under development to ensure that the test capabilities are going to fulfill the requirements of the customers. With increasing relevance of computational fluid dynamics there are clear indicators that local two-phase flow parameters are of increasing relevance. In the frame of the approach that AREVA operates several facilities under original operating conditions, it is also required to develop such measurement techniques for high pressure and temperature conditions. This paper focuses on the development of a local gamma void measurement system and outlines how to bring it on the level of an accredited measurement technique.

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

Parameter	Range
Temperature	0 °C–1000 °C
Pressure	10 Pa–40 MPa
Volume flow rate	0,1 L/h–100,000 m^3/h
Mass flow rate	Up to 4000 t/h
Force	Up to 10.000 kN
Momentum	Up to 50.000 Nm
Length	1 µm–10 m
Velocity	1 mm/s–100 m/s
Acceleration	0,5–1000 g
Electrical power	Up to 20 MW
Active power	Up to 50 KW
Current	Up to 85,000 A
Voltage	Up to 420 V

2. Motivation and background for local void measurements

Local void measurement techniques are relevant for nuclear but also for non-nuclear applications. For example, in the development of coal fired power plants based on Siemens's BENSON license, it can be of interest to know the local void fraction distribution in so called riffled boiler tubes to understand the mechanisms of the heat transfer and to provide information for possible further heat transfer improvements. For that purpose, extensive test campaigns have been performed at the BENSON facility shown in Fig. 1 (Schmidt et al., 2000; Schmidt and Herbst, 2012).

A riffled tube (a cross section of such a tube is shown in Fig. 2) has been installed as a vertical test section in the BENSON loop. The loop itself has been used mainly to gain critical heat flux data, therefore, the tube has been directly electrically heated.

Fig. 2 (right side) depicts an example of the measurements of this void fraction distribution in a riffled tube based on gamma densitometry as described in Schmidt et al. (2000). The line-averaged void fraction over the cross section of the riffled boiler tube was measured by means of a gamma densitometer consisting of a radiation source and a gamma detector, both mounted on a plate and movable in a traverse direction (the measurement principle is explained in more detail in chapter 3, see also Fig. 5). The measured void fraction distribution appeared to be reasonable, but it became also evident that it is very time consuming and the required calibration steps and the corresponding preparation work is rather complex.

In this context, it is foreseen to install this measurement technique also in other large test facilities such as INKA and PKL operated at AREVA for system investigations on the accidental behavior in BWR and PWR plants respectively. The measurement of the void fraction with high special resolution provided by the measurement principle is also suitable for code validation (CFD as well as thermal hydraulic system codes).

The KATHY loop (Kreuter et al., 2004) is used to measure the critical heat flux in fuel elements (the loop is shown in Fig. 3, left). This loop can be operated in forced circulation or in natural circulation (right part of test loop in Fig. 3) mode. The loop itself was designed in such a way that the rods installed in the test channel (see right-hand top photo of Fig. 3) can be electrically heated. Based on related temperature measurement it is possible to detect the critical heat flux.

Another possible position for a local void fraction measurement could be in the PKL loop (Umminger et al., 2002), shown in Fig. 4. PKL is a system test facility representing a 1300 MW PWR, scaled 1:1 in heights and 1:145 in volume (cross sections) and power.

The core is modeled by electrically heated rods, whereas the rod geometries and spacer represent original geometries. The steam generator comprises U-tubes representing the different heights of original U-tubes in the scale 1:1.

The loop has more than 1500 measurement positions, which are mainly robust temperature, pressure, pressure drop and flow rate measurements. Different accident scenarios have been and will be investigated. Test objectives are, for example, the investigation of the effectiveness of counter measures in case of various accident scenarios, gaining general information on the transient phenomena and providing a data base for code validation. For that purpose, it could be of advantage to have advanced high pressure resistant measurement techniques to get a deeper understanding of the relevant phenomena.

3. Development process to validate the local gamma measurement technique

In order to optimize the measurement process for void fraction detection outside the large test facilities, a separate test and calibration loop has been built. Focus of the development was on the local near wall boundary layer. Therefore, this method has been developed for an annular configuration, because of its relevance for nuclear fuel elements. In general, it was the aim to use the known measurement techniques of gamma densitometry and to approve a measurement and evaluation process (Schmidt and Herbst, 2012). Therefore, the applied method is in general also transferable to other geometries like circular pipes. Fig. 5 shows a scheme of the loop including the applied gamma void measurement technique.

The loop was designed in such a way, that water is pumped via a piston pump into the heater, where it is evaporated and superheated. The superheated steam enters the test channel from the bottom. This

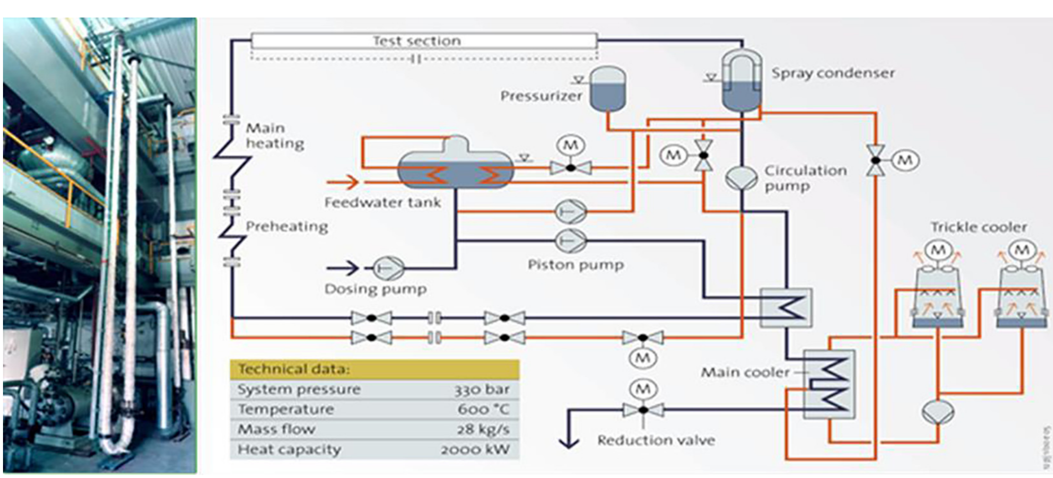

Fig. 1. BENSON Test rig scheme and a photo with integrated test tube.

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