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Advanced instrumentation options for cogeneration HTGR

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Summary

The structures of the measuring and control systems are near by the same for all former HTR projects and have been adopted in this form also for the newest project in China (HTR-PM). For the GEMINI HTR plant the measuring and control systems should be based on these experiences. This approach ensures that state of art can be used, and therefore uncertainties are reduced during licensing. As far as measurement systems are concerned, the result looks a bit different. Therefore, the main factor using tried-and-tested measurement technology approved in nuclear applications for the GEMINI HTR is reducing R+D and uncertainties during licensing. In the literature a lot of innovative measurement systems are described, but these new measurement systems are not installed in Nuclear Plants in the last 30 years since AVR in Germany, THTR300 in Germany, Fort St. Vrain in USA, HTTR in Japan, HTR-10 in China und HTR-PM in China were commissioned or operated. Nevertheless, two new measurement systems will be interested: - flow measurement systems with ultrasonic - level and physical data measurements with TDR The ultrasonic measurement system from KROHNE in Germany was installed for measuring the feedwater flow in the steam generator at Ol3 in Finland. The TDR measurement systems (a not guided system) were installed for level measurement of the fuel pools at Ol3 in Finland.

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Abbreviations

HTR	High Temperature Reactor
HTR-10	High Temperature Pebble Bed Text Reactor in China with $10MW_{th}$
HTR-PM	High Temperature Pebble Bed Reactor (twin Pant) in China with $2x250MW_{th}$
AVR	High Temperature Pebble Bed Reactor in Germany with $50MW_{th}$
THTR300	High Temperature Pebble Bed Reactor (Thorium) in Germany with $300MW_{el}$
HTR-MODULE	High Temperature Pebble Bed Reactor (twin plant) in Germany with $2x200MW_{th}$
TDR	Time Domain Reflection
Ol3	European Pressurized Water Reactor in Finland with 1.700 $MW_{elec.}$
HTR NPP	High Temperature Reactor Nuclear Power Plant
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
SG	Steam Generator

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Introduction

The structures of the measuring and control systems are near by the same for all former HTR projects and have been adopted in this form also for the newest project in China (HTR-PM).

For the GEMINI HTR plant the measuring and control systems should be based on these experiences. This approach ensures that state of art can be used, and therefore uncertainties are reduced during licensing.

As far as measurement systems are concerned, the result looks a bit different. Therefore, the main factor using tried-and-tested measurement technology approved in nuclear applications for the GEMINI HTR is reducing R+D and uncertainties during licensing.

In the literature a lot of innovative measurement systems are described, but these new measurement systems are not installed in Nuclear Plants in the last 30 years since AVR in Germany, THTR300 in Germany, Fort St. Vrain in USA, HTTR in Japan, HTR-10 in China und HTR-PM in China were commissioned or operated.

Nevertheless, two new measurement systems will be interested:

- flow measurement systems with ultrasonic
- level and physical data measurements with TDR

The ultrasonic measurement system from KROHNE in Germany was installed for measuring the feedwater flow in the steam generator at Ol3 in Finland.

The TDR measurement systems (a not guided system) were installed for level measurement of the fuel pools at Ol3 in Finland.

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PART 1: Instrumentation for GEMINI HTR

1 Instrumentation and Control Equipment

The instrumentation and control equipment consist of electronic devices, modules and systems which are involved in measuring, monitoring and control in the conduct of operations in GEMINI HTR.

With regard to safety, the instrumentation and control equipment is subdivided into:

- Reactor protection system
- Operational control systems
- Open and closed-loop control systems
- Limitation systems
- Accident monitoring systems

and also

- Equipment only for the commissioning phase
- Equipment only for the demonstration plant (first of kind)

1.1 Reactor Protection System

The reactor protection system with separate instrumentation and separate control equipment serve to prevent unacceptable loading on important components and systems and to minimize the effects of accidents upon the environment. The equipment of reactor protection system is designed to ensure automatic protection of important equipment units and takes priority over open and closed loop and manual actions. The design of the reactor protection system is governed by the principles of the given criteria and rules which are applied to the HTR in a manner consistent with their intent as appropriate to the plant's special characteristics.

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One of these special characteristics is to regulate the plant in such a way that a shutdown to temperature nearby cold gas temperature is not necessary because the numbers of shut down trips are limited.

The HTR plant has an independent and dedicated reactor protection system.

The reactor protection system (RPS) is required to monitor and process variables essential to the safety of reactor and the environment, to detect accidents and to automatically initiate protective actions. In the event of an accident, the reactor protection system shuts down the reactor and actuates the protective actions required for mitigation. The RPS has separate and redundant channels configured in such a way as to satisfy physical and electrical independence and separation requirements.

The monitored process variables, derivation of suitable initiation criteria and the generation of actuation signals for protective actions are performed based on the accident analyses.

In case of abnormal events, the reactor protection system implements the automatic and manual actuation of safety systems and the relevant monitoring functions necessary to reach a controlled state by initiating reactor trip and starting the safety systems:

- Reactivity control;
- Residual heat removal;
- Limitation of radioactive releases at the site boundary to an acceptable limit and maintaining integrity of the primary and secondary systems.

The RPS of the plant includes the data acquisition and automation of the:

- Reflector rods:
- Main circulator;
- Primary system isolation valves;
- Secondary system isolation valves;
- Steam generator relief valves

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The RPS is designed to ensure that fulfilment of its safety functions is assured in the event of accidents occurring simultaneously with a postulated equipment failure or unavailability due to maintenance.

The reactor protection system is designed such that flooding, lightning, storms or earthquake cannot cause failure of subsystems.

Table 1: Reactor Protection System - Process Variables

Process variable	Measuring point
Intermediate-range Neutron flux	Guide tubes in concrete of reactor cavity structure (or on the surface of)
Power-range Neutron flux	
Hot gas temperature	hot gas plenum ahead of steam generator tube bundle inlet
Cold gas temperature	Steam generator pressure vessel (cold gas plenum)
Primary coolant mass flow	Area: primary gas blower
Feedwater mass flow	Ahead of steam generator tube bundle
Primary system pressure	Steam generator pressure vessel (cold gas plenum)
Moisture in primary system	Bypass to primary gas blower
Pressure in secondary system	Ahead of steam generator (feedwater side)

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1.2 Operational Control System

The operational control system consists of process supervisory and control equipment for normal plant operation. Functions of operational control include plant power and load management, balance of plant and auxiliary subsystems control, energy control and general plant indication in both the control room, remote shutdown station and at local stations where appropriate.

Operational control is comprised of distributed control systems and subsystems such as fire protection, plant data and equipment monitoring.

1.3 Open and Closed-Loop Control

The open and closed-loop controls serve to control process steam and power generation by nuclear heat during normal operation (start-up and shutdown, power operation) by ensuring that process variables and chronological sequences are as prescribed.

The six manipulated variables which are available to control the GEMINI HTR are:

- Turbine throttle valve
- Primary gas blower
- High pressure feed pump
- Turbine extraction stem pressure
- Control rods
- Cogeneration splitting valve.

Most of the open and closed-loop control equipment is assembled from a mutually compatible electronic modular hardware system. Exceptions are dedicated controls provided especially for components of HVAC and compressed air systems, for example.

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High reliability of the equipment is ensured by extensive preventive measures and monitoring, such as short circuit-proof outputs, fault monitoring and time-out monitoring.

1.4 Limitation Systems

Limitation systems are provided which serve to limit initial values of the accidents to be regarded.

The limitation systems of the HTR are limitations of states which ensure that output parameters are kept for analysis of accidents.

1.4.1 Reflector Rod Insertion Limitation

In order to be always able to perform the shutdown function a minimum required lift in direction to shutdown has to be available. The possibly occurring changes of reactivity during different operating modes are higher than those which can be compensated by the reflector rods. The automated control tries to set the overall reactivity to zero in steady-state condition. It has to be prevented that the automated controls decrease the lift of shutdown. This is performed by an automated control which has priority against the thermal power control.

Each rod has its own control circuit of reactor rod position. A constant set value of the lift related to the lower end position is assigned to the control circuit. This constant set value is linked with the variable set value which is pretended automatically or manually via a selection of maximum values. If the variable set value becomes lower than the constant set value than the set value gets priority and the reflector rod remains in its minimum required lift.

The redundancy is given by the individual control of the rods.

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1.4.2 Power Limitation

The power of the HTR shall not exceed a value of 105% in the long run (range of hours).

In order to prevent overload a power limitation is performed which operates automatically. It consists of a control circuit variable which is the thermal power of the primary circuit and which acts on the control circuit of the rotational speed of the primary gas blower. The set value of this control circuit is approx. 103%. Therefore, this control circuit is not operating during normal operation. In case of overloads which exceed the set value at the inlet a negative control deviation occurs. This control deviation is integrated for hours and in this way the output signal of the integrator is reduced. This output signal is linked with the set value selection. In this way the minimum value becomes effective.

After a time period of overload, the power limitation system becomes effective and the rotational speed of the primary gas blower will be reduced until the power is below the set value of overload.

1.5 Accident Monitoring System

The design of the accident monitoring system ensures that adequate information and documentation is provided on plant conditions and on effects upon the plant and the environment during and after accidents and beyond-design basis event sequences (design extension conditions).

Measuring points installed in the plant for the accident monitoring system supply during and after an accident

Sufficient information on the condition of the plant to enable additional measures to be taken if required

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- An overall view over the effectiveness of automatically or manually initiated protective actions
- Information for assessment of radiological effects upon the environment
- Facility for recording the accident sequence and its reconstruction
- Information for drawing conclusions on the loading sustained and on the continued serviceability of important components

The accident monitoring system consists of accident indication and recording equipment. The accident indication equipment is subdivided into accident surveillance, accident detail and wide range indication equipment.

1.5.1 Accident Surveillance Indication Equipment

The accident surveillance indication equipment primarily presents data measured by the reactor protection system which indicates the type of accident and the plant condition.

Other variables, which permit the assessment of radiological effects and identification of additional damage mitigating measures which can be taken to protect the plant and the environment, are also displayed.

Where the instrumentation is part of the reactor protection system, it is of redundant design. Where measurements are non-redundant, either other variables giving equivalent information are available or alternative measurements can be used.

Reliable, low-maintenance devices suited for the particular application are used in the accident surveillance indication equipment. Function tests are possible without modifications having to be made to the wiring.

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The devices used in the accident surveillance indication equipment are so designed that they remain operational during the accidents which they are intended to detect and under the associated environmental conditions.

The indicators can be read clearly in emergency lighting. They stand out from other annunciation equipment by virtue of suitable arrangement or identification.

Important data are also indicated in the remote shutdown station.

On loss of auxiliary power, the devices are fed from the uninterruptible backup power supply.

1.5.2 Accident Detail Indication Equipment

The accident detail indication equipment serves to monitor the various systems and components used for accident control and damage mitigation. It provides detailed information for the diagnosis of accidents, on the accident sequence and for reconstruction of accident sequences.

The operational instrumentation is used for the accident detail instrumentation. No redundant indications are provided.

The design requirements for the instrumentation are governed by the systems and components which it is intended to monitor.

1.5.3 Wide-Range Indication Equipment

The wide range indication equipment gives information on plant parameters approaching or exceeding the design limits of activity barriers.

In the GEMINI HTR such indications are largely covered by the accident surveillance indication equipment without extension of measuring ranges being necessary.

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The variables handled by the wide-range indication equipment are displayed in the central control room and a selection thereof in the remote shutdown station.

The instrumentation is connected to an uninterruptible backup power supply.

1.5.4 Accident Recording Equipment

The accident recording equipment records data which enable reconstruction of the accident, assessment of the radiological effects, identification of the accident cause and permits assessment of the loadings sustained by important components and their continued serviceability.

Accident recording equipment is installed both in the central control room and in the remote shutdown station.

The accident recording equipment in the central control room includes:

- the variables measured by the accident surveillance indication equipment
- the variables measured the wide-range indication equipment
- variables measured by the accident detail indication equipment
- selected variables measured by the operational instrumentation equipment
- selected information from the reactor protection instrumentation
- selected information from the radiological protection instrumentation

The accident recording equipment in the remote shutdown station includes:

- the variables displayed by the accident surveillance indication equipment in the remote shutdown station
- the variables displayed by the wide-range indication equipment in the remote shutdown station

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Recording is such that all measured data can be related to real time.

The design of the accident recording equipment in the central control room is such that sufficient information remains available in the event of a single failure.

Power is supplied to the devices in the accident recording equipment from the associated uninterruptible back up power supply.

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2 Instrumentation / Measurements

2.1 Neutron Flux Instrumentation

Neutron flux density instrumentation is used for monitoring the HTR in every operating condition. Measurements cover a range of approx. 10-11 decades from the reactor subcritical cold condition to accident-specific overload.

The principal task of this instrumentation is to measure the mean flux density of the core as well as the transients of the flux density.

The sensors are physically arranged in such a way to enable assessments to be made of the axial and azimuthally distribution of the power density of the HTR from comparison of the signals.

The signals from the instrumentation are used as inputs to automatic systems such as the reactor protection system and plant controls, and also for the annunciation of operating and alarm conditions, display and recording.

The neutron flux instrumentation contains a number of channels for the following ranges:

- Source range
- Intermediate range
- Power range

This segmentation is used for reasons relating to instrument hardware, signal processing, layout and redundancy

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The detectors of neutron flux are located in metal tubes in the walls of the primary cavity or between the KAA-System (RCCS) and the cavity wall.

The detectors in each guide tube are installed in slides which are linked to form a container chain which can be raised or lowered within the probe guide tubes into the operating position on ropes.

Source range

The source range covers the five to six lower decades of the neutron flux density scale. Instrumentation is duplicated so that dissimilar readings would indicate a fault.

Normally BF3 counter tubes are used.

After pre- and main amplification, the pulse signals are led to a logarithmic amplifier whose output signals are proportional to the logarithm of the count rate and proportional to the logarithm of the neutron yield. Differentiating the signal with respect to time produces a magnitude representing the rate of change of flux density relative to its momentary value. This is equivalent to the inversely proportional reactor period and characterizes the dynamic behaviour featured during start-up operation.

The signals thus obtained are used for indicating, recording and alarm signalling purposes. In the shutdown condition the neutron flux density must be above a threshold to ensure safe start-up.

Intermediate range

The two operational instrumentation channels get a logarithmic measuring range. Differentiating the signal with respect to time produces the rate of change of flux density

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relative to the momentary value for flux density (inverse reactor period). This represents the safety margin during reactor start-up and is transmitted to the reactor protection system. The measuring range overlaps the upper section of the source range by at least two decades and extends to a value approx. 100 % above nominal power.

The upper part of the range is used for the acquisition of short-term accident-specific overload data. One of the three instrumentation channels is used for indications in the remote shutdown station. Linear amplification is applied to the detector signal for this purpose. The required measuring range is obtained by decade switching of the amplifier.

Gamma-compensated ionization chambers are used as detectors.

<u>Power range</u>

The power range covers the at least two upper decades of neutron flux density, plus around 25 % of the nominal power to allow for transients. Linear signal amplification is used.

The power range signals, after thermal correction, constitute one of the most important input variables for the reactor protection system. Installation of the equipment in triplicate and physical separation not only satisfies safety requirements but also gives information on azimuthally flux density distribution.

The coarse resolution required for axial flux density distribution is obtained by providing each probe guide tube with four detectors distributed over the height of the core.

Non-compensated ionization chambers are used as detectors.

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Measurement during refuelling

To control the reactor in refuelling mode three high sensitive in vessel ionization chambers of are used which are inserted in the permanent side reflector. During power operation these chambers are removed beyond the core limits.

The above-mentioned instrumentation means are used also to control a neutron power doubling time.

2.2 Burnup Measurement

In HTR plants with block fuel elements the burnup measurement of fuel element can only be taken place during refueling.

The burnup is determined by core calculations. For each block the calculated burnup will be documented to the assigned fuel block number.

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3 Instrumentation Equipment Inside/Outside the RPV

Measurement of the most significant operational variables in the GEMINI HTR provides information for the control room personnel and also for reactor protection, open and closed loop control functions. Such measurements are crucial to satisfactory operation of the plant.

As a rule, the sensors used for the operational variables convert the measurement into an electrical signal.

Redundant instrumentation channels are physically and electrically separated. There are no interconnections.

The physical layout of the transducers is guided by the following criteria:

- Housing of transducers in transducer compartments in which environmental conditions suitable for electronic equipment prevail
- Separate transducer compartments for each redundancy
- Short, non-intersecting cable routing between measuring points and transducer compartments observing the redundancy principle

Penetrations in the upper part of the reactor pressure vessel for instrumentation cables for:

- Small ball shutdown unit storage vessel instrumentation
- Reflector rod drive mechanism instrumentation
- Instrumentation in ceramic core internals

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Cables for the instrumentation for the primary gas blower drive unit and the flap valve and the piping for mass flow measurements in front of the flap valve are run to the outside through penetrations in the blower pressure vessel.

The penetration nozzle in the upper section of the steam generator vessel accommodates the temperature measurements inside the SG and a branch for moisture measurement.

The penetration nozzle in the middle section of the steam generator vessel accommodates connections for pressure sensing lines and the thermocouples for cold gas temperature measuring instruments.

The penetration nozzle in the lower portion of the steam generator vessel accommodates the connections for the thimbles for the hot gas temperature measuring instruments and one branch for moisture measurement.

The instrument lines are run from the penetration nozzles in the steam generator pressure vessel through the wall of the primary cavity to the measuring instruments and thermostats in the transducer compartments.

The piping is uniformly 10 mm in diameter or less. Downstream of the penetrations in the primary cavity walls instrument lines are each fitted with two isolation valves. These and all subsequent valves are sealed to the outside by means of bellows.

<u>Prestressed glass</u>

To minimize operational disturbances caused by leakages, primary coolant-carrying components in the transducer compartments (transducers, valves, etc.) are housed in sub compartments which are monitored for pressure and temperature rises. In the event of a pressure or temperature rise the isolation valves can be closed. Transducers whose output

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signals are indicated in the remote shutdown station are housed in separate sub compartments.

Because of the complex structure of the moisture instruments, the helium concentration in the atmosphere in the pertinent sub compartments is also monitored.

Normally all penetration nozzles for instrumentation include a prestressed glass.

3.1 Hot Gas Temperature

The temperature of the hot gas flow entering the steam generator is measured. NiCr/Ni sheathed thermocouples are used as sensors. These are located in thimbles which penetrate the central pipe of the steam generator from below.

The measuring instrument protrudes far enough into the hot gas plenum to avoid interference due to conduction.

The thimbles are anchored by welded joints on the central pipe and by a nozzle in the lower part of the steam generator pressure vessel.

Gastight attachment of the thimbles to the instrumentation nozzle of vessel permits replacement of temperature sensors without opening the primary system.

Double thermocouples are fitted in every thimble. Spare thermocouples are fitted so that defective temperature sensors can be replaced simply by changing connections in the transducer compartments.

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The temperature sensors can be regarded as having a long-life expectancy since rugged thermocouples are used and since neutron flux in the area of the measuring point is low.

Routing of the instrument lines and processing of the signals comply with the usual methods and for temperature instrumentation.

3.2 Cold Gas Temperature

The temperature of the cooled primary gas in the steam generator is measured in the middle section of the steam generator pressure vessel before the coolant flows through the primary cold gas channels to the primary gas blower.

Measurements are carried out by thermocouples housed in thermo-wells.

Defective temperature sensors can be changed by reconnecting and replacing spares.

3.3 Temperature Measurement in the Ceramic Internals

The temperature of the coolant at the bottom of the core is measured by means of thermocouples. This gives an overall view of the temperature distribution in the primary coolant flow under various operating conditions and for different manoeuvring patterns of the rods. Moreover, differences between this measurement and the hot gas temperature at the steam generator inlet could indicate flow bypass conditions in the hot gas area, whereas identical measurements would indicate that flow channels are intact.

The latter condition is essential for determining quantitative relationships between reactor output, primary coolant mass flow, reflector rod position and primary coolant temperatures, which is carried out in the first few years of operation. Since the temperature sensors at the bottom of the core cannot be replaced in the event of failure (their mean life expectancy is a

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few years), the quantitative data on the relationship between the most important operational variables is used for detecting possible bypass flow conditions later on in the life of the plant.

Metal sheathed thermocouples are used as sensors.

These thermocouples are located in slots between the graphite blocks, protruding far enough into the hot primary coolant flow to prevent interference with readings due to thermal conduction. To enable construction of a temperature map one or two sensors are provided in each square meter, for instance.

Wires from the thermocouples are run out of the upper portion of the reactor pressure vessel through prestressed glass penetrations.

The top reflector is similarly provided with temperature sensors which serve the purpose of design verification as regards temperature redistribution during residual heat removal by the cavity cooler.

3.4 Pressure Vessel Unit Surface Temperatures

The temperature of the outer surface of the pressure vessel unit (RPV, Cross Duct Vessel, SG-Vessel) is monitored over a large area and at points of particular interest.

Surface thermocouples sensors are used. The sensing tips are held against the vessel surface by clamps and spring pressure. Failed measuring points can be repaired by opening up the clamping fixture and replacing the defective thermocouples.

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3.5 Moisture

The primary coolant is monitored for moisture. The method employed relies on the change in properties of an electrical capacitance due to the moisture contained in the helium. Since the instrument is required for the detection of large steam generator tube leakages, its sensitivity for measuring operational moisture content is relatively low.

Precise operational moisture monitoring is performed by gas analysis in the helium purification system. Since no other process variables suitable for the detection of tube leaks are available for use in the reactor protection system, a high-grade engineering design is envisaged for this instrument loop.

The measuring chamber and the associated components are located outside the primary cavity. Coolant is extracted via an instrumentation nozzle from the discharge side of the running primary gas blower and returned to the suction side in the lower portion of the steam generator pressure vessel so that the primary coolant is propelled through the instrument loop by the differential pressure of the primary system. If the primary gas blower is not running a small blower operating in the reverse direction is used for this purpose.

A controller maintains constant flow through the loop.

The measuring chamber is protected from overheating by a thermostatic shut-off value.

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3.6 Flow

3.6.1 Primary Gas Flow and Other Gas Flow

The primary coolant, after cooling in the steam generator, passes through a number of cold gas channels from the cold gas plenum to the primary gas blower. These lines are long enough to accommodate standard upstream and downstream sections for standard venturi tubes, thus enabling differential pressure measurements to be made.

All other gas flow will be measured also by standard venturi tubes.

3.6.2 Feed Water Flow and Other Liquid Flow

For feedwater flow measurements the venturi principle can be used. This measurement system must be calibrated and arranged with small pipes from the venturi nozzle to the measurement conductor.

All other liquid flow will be measured also by standard venturi tubes.

3.6.3 Steam Flow

For steam flow measurements the venturi principle can be used. This measurement system must be calibrated to one steam condition (pressure and temperature) and arranged with small pipes from the venturi nozzle to the measurement conductor.

Because the calibration can not be changed the steam flow measurement by changing the steam conditions is not very precise.

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3.7 Pressure Measurement

The value measured is the static pressure with standard Barton cells. The measurements for the RPS are situated in the cold gas filled portion of the steam generator pressure vessel for the primary gas and in the feedwater line for the secondary cycle.

3.8 Position of Reflector Rods

The position of the reflector rods is measured continuously to supplement the binary signals for limit position monitoring and fault indication. The measurements serve to inform the operating personnel and provide actual values for the rod position control.

Additional sensors used for rod insertion limitation ensure that during power operation a maximum rod insertion is not under-run. This ensures that there is always sufficient shutdown reactivity available.

The wiring is run out of the upper portion of the reactor pressure vessel via a prestressed glass penetration.

3.9 Level Indication

3.9.1 Level Indication Small Ball Shutdown System

In addition to providing binary check back signals giving the status of the storage vessel closure, the level of small ball shutdown elements in the storage vessels is continuously measured.

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The measurement method relies on the determination of an electrical capacitance which is proportional to the level. The central tube in the storage vessel and the bed of small ball shutdown elements form the two plates of the capacitor. A thin layer of insulation on the central tube acts as the dielectric.

The capacitance is determined by the balance of an AC bridge circuit.

The wires are run out of the upper portion of the reactor pressure vessel via prestressed glass penetrations.

3.9.2 Level Indication for Liquids

The level indication systems are based on swimmer systems or on stand-by-pipes with optical indication systems.

3.10 Leak-Tightness and Leakage Monitoring

3.10.1 Leak-Tightness

As a rule, the pressure vessel unit and all adjoining piping systems are welded leak-tight. Flanged connections on the steam generator pressure vessel are provided with welded-lip seals or metal ring gaskets. The flanged connections of the RPV closure head and the circulator cover are sealed with double metal ring gaskets. Leak tests are conducted after every assembly to ensure that the system is leak-tight.

3.10.2 Leakage Monitoring of the Pressure Vessel Unit

During power operation, the air in the primary cavity is monitored which would indicate the presence of leaks in the vessels. The measured variable is in thermal conductivity which

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Helium measurement differs between helium and air. A gas mixture is constantly extracted from the exhaust air duct of the sub atmospheric pressure system and conveyed to a monitor. Because the air change rate in the primary cavity is low, even small leaks (corresponding to leak cross-section of 1 mm^2) produce a relatively high concentration of helium; conventional measuring instruments are therefore sufficiently precise. Convection in the primary cavity during power operation causes thorough mixing of the gas, with the result that the helium concentration at the measurement location follows that of the primary cavity after a delay.

3.11 Steam Conditions

The pressure and the temperature can be measured with pressure sensors and with thermocouples inside the steam flow. But the steam density must be calculated.

This system is not very precise. Therefore, the power of the plant will be calculated by the primary conditions and not with the secondary conditions.

3.12 Level Measurement Inside the SG

The SG will be a Helix-Tube-SG. Therefore, no level measurement can be installed inside the steam tubing.

The water level inside the SG will be calculated by pressure measurement system inside the inlet area (feedwater tube) and the outlet area (steam tube). This calculation is not very precise.

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3.13 Level Measurement without Electricity

For some vessels, e.g. the water tank of the cavity cooling system, it can be very interesting to know the fluid level. During a longer station black out only safety relevant measurements will be supported by batteries.

3.14 Earthquake Measurement

For measuring continually the ground acceleration, a qualified measurement system will be installed at the area of the complete plant and inside the reactor building.

Additionally, several sensors for measuring acceleration inside the reactor building and on the reactor pressure vessel can be foreseen. Some of these sensors will be adapted into the reactor protection system.

3.15 Radioactive Measurement

Radioactive measurements are done in helium supporting systems (e.g. helium purification system), liquid waste systems, in “heath physics”, in area monitoring (esp. controlled area), in ventilation systems (esp. the fluent to the vent).

All these instrumentations are standard and well know, as used in nuclear facilities.

This project has received funding from the Euratom research and training programme 2014-2018 under the grant agreement n°755478

4 Equipment for the Commissioning Phase

The equipment for the commissioning phase is commercial equipment. These measurement systems for pressure, temperature, flow, noise, difference pressure etc. will be removed or stay in place without any connection after the commissioning phase.

The used measurements must be calibrated and have to fulfil the customer rules and the special country regulations.

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5 Equipment only for the Demonstration Plant

During the detail planning phase, the erection phases and the licensing phases of a demonstration plant like the GEMINI HTR there will normally special items to be clarified in detail during operation of the plant.

Also, it can be necessary to get information by instrumentation of the cogeneration part or additional instrumentation has to be foreseen inside the cogeneration part.

The following table gives an overview of possible additional instrumentation for a demonstration plant.

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Table 2: Instrumentation for Demonstration Plant

Component/ System	Type	Description	Needed for
Core Internals	Temperature	measurement of temperature in several cross sections beginning at Hot Gas Duct midline level and ending at top level of side reflector	thermodynamic/termohydraulic code neutronics code
	Temperature	inside bottom reflector	thermodynamic/termohydraulic code neutronics code
	Temperature	inside top reflector	thermodynamic/termohydraulic code neutronics code
	Temperature	inside the lower RPV region (region of Shut-Down-Cooling-System)	thermodynamic/termohydraulic code neutronics code
	Temperature	outside of core barrel in several cross sections beginning with Hot Gas Duct midline level and ending at top level of side reflector	thermodynamic/termohydraulic code neutronics code
	Temperature	core barrel support plate	thermodynamic/termohydraulic code neutronics code
	Flow	flow measurement inside cooling holes of side reflector, at top and inside several cross sections	thermodynamic/termohydraulic code
	End position of Control Rods	control system: control rod at lowest position	neutronics code
Fuel Block	Burnup	measure burnup	burnup calculations, neutronics code
Block Fuel Columns	Temperature, Flow, Neutron	inside special cooling holes with lances	thermodynamic/termohydraulic code neutronics code
	Temperature, Flow, Neutron	at top of the last block fuel with a measurement spider lances	thermodynamic/termohydraulic code neutronics code
Reactor Pressure	Temperature	at all nozzles in the region vessel/nozzles	stress analysis, life time
Vessel	Temperature	at all flanges	stress analysis, life time
	Temperature	on all supports (mid-line Hot	stress analysis, life time

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		Gas Duct and top region with earthquake supports)	concrete life time
	Temperature	on all pressure tubes for Control-Rod-Systems and all Second-Shut-Down-Systems	stress analysis, life time
	Force	stretching forces on all nozzles and all flanges, special instrumentation on Hot Gas Nozzle, Control-Rod-Nozzle and Second-Shutdown Nozzle	stress analysis, life time
Hot Gas Duct	Temperature	inside the isolation system	stress analysis, life time, loss of power
	Temperature	outside at surface of support tube	stress analysis, life time, loss of power
	Force	stretching forces inside the gas liner	stress analysis, life time
	Force	stretching force inside thermo sleeves	stress analysis, life time
Connection Pressure	Temperature	at all flanges (if used)	stress analysis, life time
Vessel	Temperature	at the outside of the connection pressure vessel	stress analysis, life time
	Force	stretching forces inside the connection pressure vessel during start-up and shut down	stress analysis, life time
	Moving	measure the moving of the pressure boundary at start-up in direction to the steam generator	stress analysis, life time
Steam Generator Internals	Temperature	at all steam tube outlet side	stress analysis, life time, asymmetry of hot gas temperature in inlet area
	Temperature	outer shell on several cross sections	stress analysis, life time
	Temperature	an all 6 cold gas tubes 150 mm above SG-cover plate	stress analysis, life time
	Temperature	on metallic internals of the blower	stress analysis, life time
	Flow	in all SG tubes at the steam outlet	stress analysis, life time, asymmetry of steam flow
	Force	on all feed water inlet tubes	stress analysis, life time, asymmetry of feed water flow

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	Force	on all steam outlet tubes	stress analysis, life time
	Force	on all shrouds for helical tubes	stress analysis, life time
Steam	Temperature	at all nozzles in the region vessel/nozzles	stress analysis, life time
Generator	Temperature	at all flanges	stress analysis, life time
Pressure Vessel	Temperature	on all supports (mid-line Hot Gas Duct and upper region with earthquake supports)	stress analysis, life time, concrete life time
	Force	stretching forces on all nozzles and all flanges, special instrumentation on Hot-Gas-Nozzle	stress analysis, life time
	Force	stretching forces on feed water tube	stress analysis, life time
	Force	stretching forces on feed steam tube	stress analysis, life time
Primary Blower Internals	Temperature	at all cooling tubes inside blower pressure vessel (water, Oil, Helium)	controlling cooling of blower, design of cooling systems
	Temperature	at all electrical penetrations	stress analysis, life time
	Temperature	inner temperature on several locations	stress analysis, inner convection of the helium inventory
	Temperature	on upper blower plate behind insulation	stress analysis, life time
	Temperature	on all sealings, inside electrical motor	stress analysis, life time
	Speed	directly on shaft	stress analysis, life time, safety function
	Irradiation	level measurement on several points	stress analysis, life time
	Force	stretching forces on upper blower plate	stress analysis, life time
Primary Blower	Temperature	at all nozzles in the region vessel/nozzles	stress analysis, life time
Pressure	Temperature	at all flanges	stress analysis, life time
Vessel	Force	stretching forces on all nozzles and flanges with a special instrumentation on the flange to the SG-pressure vessel for vibration	stress analysis, life time
	Force	stretching forces on cooling water tubes	stress analysis, life time
	Force	stretching forces on oil	stress analysis, life time

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		tubes	
Control Rod System	Temperature	on all electrical components including penetrations	stress analysis, life time
	Vertical Moving	alternative measurement system for moving control rod in vertical direction including speed analysis for moving	neutronics code, safety
	Function connection system	measurement system for connect/disconnect control rod and control rod drive mechanism	neutronics code, safety
	Irradiation	level measurement on several points	stress analysis, life time
	End Position	alterative end position measurement system inside control rod system	safety
Second Shutdown System	Temperature	on all storage components and all electrical insertions including feed troughs	stress analysis, life time
	Mass of small balls	weight of small balls in each storage tank	safety
	Irradiation	level measurement on several points	stress analysis, life time
	Position valve	alternative measurement system for measure the position (closed/open) of the valve	safety
Shutdown Cooling System	Temperature	additional measure on all parts of the system inside RPV, special instrumentation on the heat exchanger	stress analysis, life time
	Flow	flow of cooling water (cold and hot leg) directly outside the RPV with ultrasonic measurement system to get no pressure drop	controlling system function
Cavity Cooling System	Temperature	additional measurement on all parts of the system inside primary cell, special instrumentation on the header	stress analysis, life time
	Temperature	measure the concrete temperature behind the	stress analysis and life time for concrete

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		cavity cooling tubes, special instrumentation at the supports for the cavity cooling system	
	Temperature	for cooling water in all tubes (clod and hot leg) from the storage tank to the header	controlling system function
	Force	stretching forces on header	stress analysis, life time
	Level	level measurement inside the water storage tank for the cavity cooling system	controlling system function
	Flow	flow of cooling water (cold and hot leg) in each system with ultrasonic measurement system to get no pressure drop	controlling system function
	Flow	flow of cooling water in all tubes (clod and hot leg) from the storage tank to the header	controlling system function
Helium Purification System	Temperature	additional measurement on all parts of the system, special instrumentation on all components	stress analysis, life time, function control
	Flow	flow control at all gaseous and liquid mediums with ultrasonic measurement system to get no pressure drop	function control
	Irradiation	level measurement on several points	stress analysis, life time
Fuel Handling System	Temperature	additional measurements on all parts of the system, special instrumentation on all components inside the RPV	stress analysis, life time
	Irradiation	level measurement on several points	stress analysis, life time
	Burnup	measure burnup of block fuels	calibration the burnup calculating code
HAVC Systems	Temperature	additional measurement on all parts of the HAVC systems inside the Reactor Building	stress analysis, life time, function control
	Flow	flow control in all HVAC systems with ultrasonic	stress analysis, life time, function control

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		measurement system to get no pressure drop	
	Pressure	special pressure instrumentation inside the HAVC pipe system (stream direction control)	stress analysis, life time, function control
Turbine	Temperature	additional measurement on all parts of the system, special instrumentation on the turbine inlet/outlet and on the condenser	stress analysis, life time, function control
	Flow	flow control at all steam and water pipes with ultrasonic measurement system to get no pressure drop	stress analysis, life time, function control
Steam/Feedwater System	Temperature	additional measurement on all parts of the system, special instrumentation on the SG inlet/outlet	stress analysis, life time, function control
	Flow	flow control at all steam and water pipes with ultrasonic measurement system to get no pressure drop	stress analysis, life time, function control
Start-Up and Shutdown System	Temperature	additional measurement on all parts of the system, special instrumentation on all heat exchangers	stress analysis, life time, function control
	Flow	flow control at all steam and liquid mediums with ultrasonic measurement system to get no pressure drop	stress analysis, life time, function control
	Force	stretching forces on critical components during transients	stress analysis, life time
Cogeneration Splitting System	Temperature	additional measurement on all parts of the system, special instrumentation on the valves	stress analysis, life time, function control
(valve station to split steam for cogeneration and steam turbine)	Flow	flow control at all steam pipes with ultrasonic measurement system to get no pressure drop	stress analysis, life time, function control
	Force	stretching forces on critical components during transients	stress analysis, life time

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Reboiler/Condenser/ Condensate Tank	Temperature	additional measurement on all parts of the system, special instrumentation on reboiler inlet/outlet, the condenser and the condensate tank	stress analysis, life time, function control
	Flow	flow control at all steam and water pipes with ultrasonic measurement system to get no pressure drop	stress analysis, life time, function control
	Level	additional level control inside the condensate tank	stress analysis, life time, function control

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PART 2: Possible Innovative Instrumentation Systems

Neutron Flux Instrumentation

All measurements systems for neutron flux used in former times were proofed, tested and have been licensed for NPP. Also, special regulations have been taken into account. Therefore, no innovated measurement system can be specified today.

Penetrations for Electrical and Electronically Signals

Normally all penetration nozzles for instrumentation or electrical power include a prestressed glass feed. Modern feed penetrations using ceramic materials like Al_2O_3 or Si_3N_4. These special materials can be manufactured in a combination with metal and the sealing is easier.

Hot Gas Temperature

For measuring the hot gas temperature no innovative measurement system is available.

An alternative option is also available (Appendix A).

Cold Gas Temperature

For measuring the cold gas temperature no innovative measurement system is available. An alternative option is also available (Appendix A).

Temperature Measurement in the Ceramic Internals

For measuring the ceramic internal temperature no innovative measurement system is available. An alternative option is also available (Appendix A).

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Pressure Vessel unit Surface Temperatures

The region of the pressure vessel for a temperature measurement system is the not insulated area of the reactor pressure vessel. Innovated measurement system uses the infrared measurement. This measurement is not located on the surface of the pressure vessel and therefore no clamps are needed. The use of conventional systems, available at the market, must be discussed with the customers and the regulators.

Moisture

It may be possible to detect the moister inside the primary helium with special TDR measurement system. This innovated measurement system has to be discussed with the manufacturers, customers and the regulators.

Flow

Primary Flow

The traditional arrangement of venturi tubes inside the six tubes between the outer cold gas cap of the SG and the inlet structure of the gas blower (with the flap valve) is complicated because the differential pressure tubes must be arranged inside the SG bundle and ending in nozzles at the pressure vessel of the SG.

New measuring and electronic equipments allows today arranging the venturi measurement inside the inlet structure of the gas blower with a calibration during end test by the manufacturer.

The differential pressure tubes ending inside the gas blower housing and inside this region the needed electronic systems can be installed.

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An innovative option using ultrasonic flow meter can be used (Appendix B).

Liquid Flow

Innovative flow measurement systems based on ultrasonic systems. The ultrasonic head can be arranged inside nozzles but a clamp on system is also available (Appendix B).

Pressure Measurement

Today Piezo ceramic pressure sensors can be used directly at the pressure vessels because the irradiation resistance of special sensors is good enough (Appendix E).

Position of Reflector Rods

The measurement of the position of the reflector rods are integrated in the design and the construction of the rods by the manufacturer. Normally the manufacturer had a license for these rods. Therefore, it’s no need for an innovative measurement system.

Level Indication

Level Indication Small Ball Shutdown System

This measurement is integrated in the design and the construction of the small ball system by the manufacturer. Normally the manufacturer had a license for this system.

It seams to be possible to measure the level of the small balls inside the storage tank with an TDR system (Appendix C).

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Level Indication for Liquids

In the last 10 years a lot of manufacturers had qualified a level system by TDR. These systems measure the time of a pulsed electromagnetic wave from the start up by the reflection. With an electronic system the distance between any reflection and the start point and also the distance between any reflection can be calculated. The systems are very precise, because the physical parameter time can be measured very precise (Appendix C).

Steam Conditions

Following data for the steam leaving the steam generator are necessary for a real power control over the steam generator:

Secondary Side

- Steam/Water pressure
- Steam/Water temperature
- Steam/Water flow
- Steam/Water density

Primary Side

- Helium pressure (inlet/outlet)
- Helium temperature (inlet/outlet)
- Helium flow (inlet/outlet)
- Helium density (inlet/outlet)

For the steam flow and the steam density the TDR measurement is available. All other parameters will be measured with conventional systems (Appendix C).

Level Measurement inside the SG

The SG will be a Helix-Tube-SG. Therefore, no level measurement can be installed inside the steam tubing.

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It is possible a corresponding straight tube to install inside the inner part of the SG-bundle beginning at the feed water nozzle and ending at the steam nozzle. Inside this straight tube a TDR level measurement system can be installed and an important information “water level inside the SG” can be produced (Appendix C).

Level Measurement without Electricity

During a station black out only safety relevant measurements will be supported by batteries (e.g. level in the water tank of the KAA system (RCCS)) .

For long time station black out a simple system can be installed during commissioning and only with a compressed air bottle the level can be measured with the air bubbling method. To have this option only a small bubbling pipe (10mm) has to be assembled inside the tank and outside the tank a rota meter and a pressure reducer is available. The flow rate of the air is corresponding to the level inside the tank.

Earthquake Measurement

All measurements systems for earthcake measurements used in former times was proofed tested and have been licensed for NPP. Also, special regulations have been to take to account. Therefore, no innovated measurement system can be specified today.

Radioactive Measurement

All measurements systems for radioactive measurements used in former times were proofed tested and have been licensed for NPP. Also, special regulations have been to take to account. Therefore, no innovated measurement system can be specified today.

This project has received funding from the Euratom research and training programme 2014-2018 under the grant agreement n°755478

Literature

Lit-1

IAEA Specialist Meeting on gas-cooled rector core and high temperature instrumentation

15 – 17 Jun 1982

Instrumentation of Steam Cycle HTR´ s up to 900 MWe

Lit-2

Design of High Temperature Engineering Test Reactor HTTR)

JERI 1332, 1994

Lit-3

Instrumentation and control system design

Nuclear Engineer and Design 233 (2004) 125-133

Lit-4

Nuclear Power Plant Instrumentation and Control (2012)

H.M. Hashemian

Analysis and Measurement Services Corp.

United States, www.intechopen.com

Lit-5

HTR Measurements and Instrumentation Systems

Oak Ridge ORNL/TM-2012/109

Lit-6

Instrumentation and Control Systems for Advanced Small Modular Reactors

IAEA Nuclear Energy Series No. NP-T-3.19 (2017)

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Lit-7

Accident Monitoring Systems Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.16 (2015)

Lit-8

High temperature ultrasonic sensors for fission gas characterization in MTR harsh environment

EPJ Web of Conferences 170, 04008 (2018) ANIMMA 2017

https://doi.org/10.1051/epjconf/201817004008

Lit-9

Nuclear instrumentation and measurement: a review based on the ANIMMA conferences

EPJ Nuclear Sci. Technol. 3, 33 (2017), DOI 10.1051/epjn/2017o23

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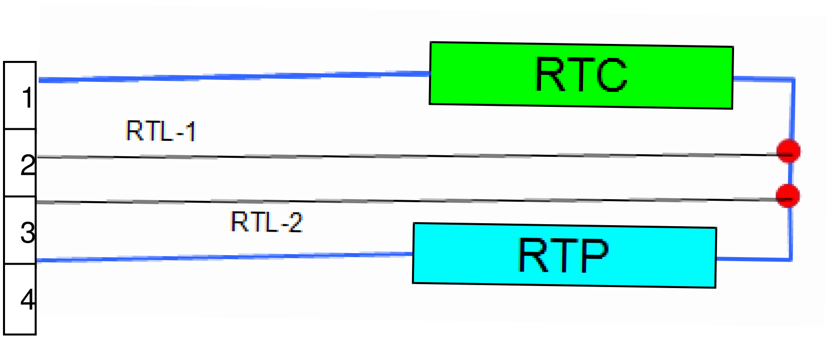
Appendix A: Special Resistance Thermometer

In the past for temperature were thermocouples used. These thermocouples from Type NiCr/Ni were arranged in a metallic tube therefore no measured medium was in contact to the thermocouples.

The same principle where used for resistance thermometer but the transformers were much more expensive than thermocouples.

With the new electronic components, the negative issue for resistance thermometer is not longer an argument to use this measurement.

With the following electrical circuit arrangement, a temperature measurement with high accuracy (fault +/- 0.1°C) and a compensation of the drift during lifetime (irradiation) can be created.



RTC= resistance with specified changing his ohmic resistance data with the temperature and a known Ohm changing during irradiation

RTP= resistance with specified ohmic resistance data without changing the Ohm data with the temperature and the same ohmic resistance changing during irradiation as RTC

RTL= resistance of the wire between transformer and RTC

Measurement between 1 and 2: Local temperature

Measurement between 3 and 4: Changing resistance from irradiation for correction the calibration curve of temperature

Measurement between 2 and 3: resistance of the wire between RTC/RTP and transformer

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Appendix B: Ultrasonic Level Measurement

Possible Solution 1, US immersion shell

➔ **Built in DN25 nozzles and measure directly to the fluid level**

➔ **US system is contact with the fluid with an immersion shell**

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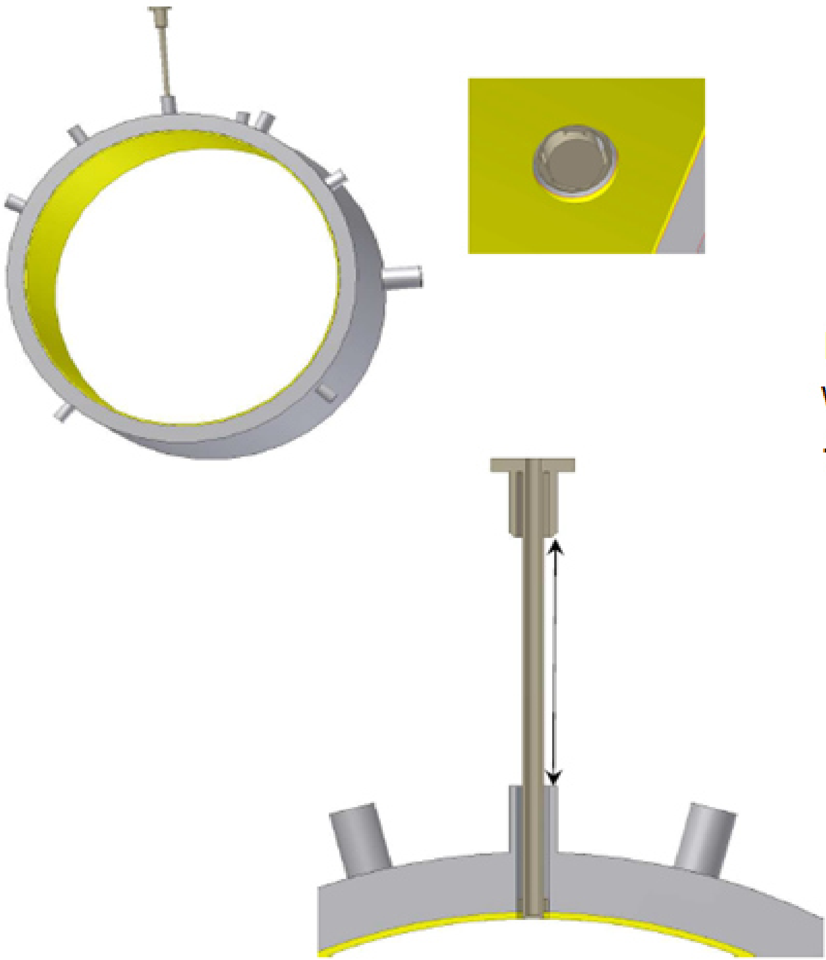
Appendix B

Ultrasonic Level measurement



- Ultrasonic Level Measurement with immersion shell
  → weld-in instrument well

Appendix B

Ultrasonic Level and flow measurement

Possible Solution 2, High-temperature Clamp On:

High temperature ultrasonic transducer for water level detection in PWRs during operation with clamp on:

- Framatome GmbH is using ultrasonic sensors for level measurements during Mid-Loop-Conditions inside PWR for sensor up to 550 °C.
- With these sensors and the clamp-on-technology Framatome GmbH together with KRONE is designed flow measurements for nuclear facilities.
- The development is based on evaluations of the University Dresden

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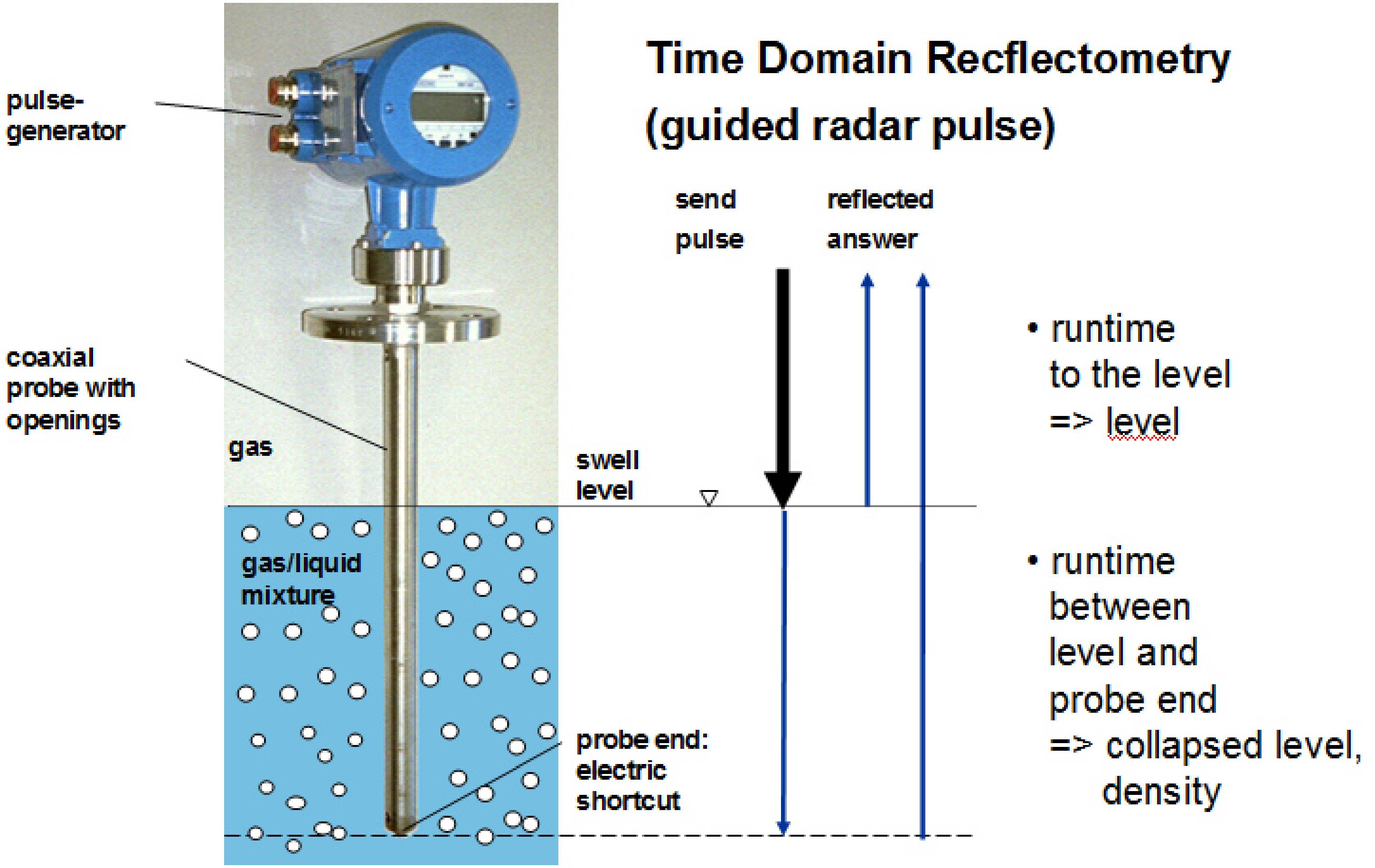
Appendix C: TDR – Level Probe: Continuous Level Measurement



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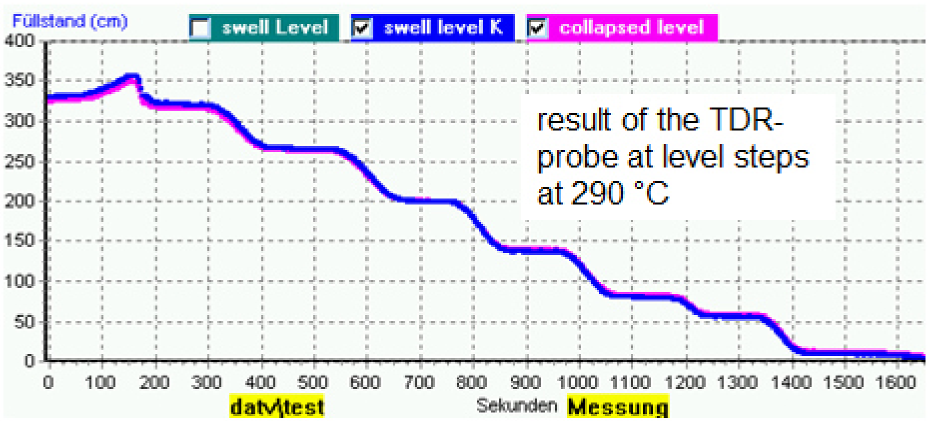
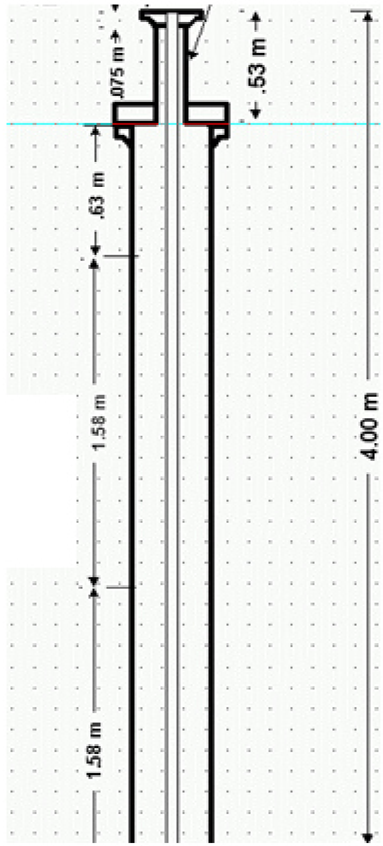
Appendix C

TDR - level probe: tests with water steam



Level steps with Deionat 20°C,180°C, 240°C, 290°C range 0 to 4 m



TDR - level probe in the test pressure vessel

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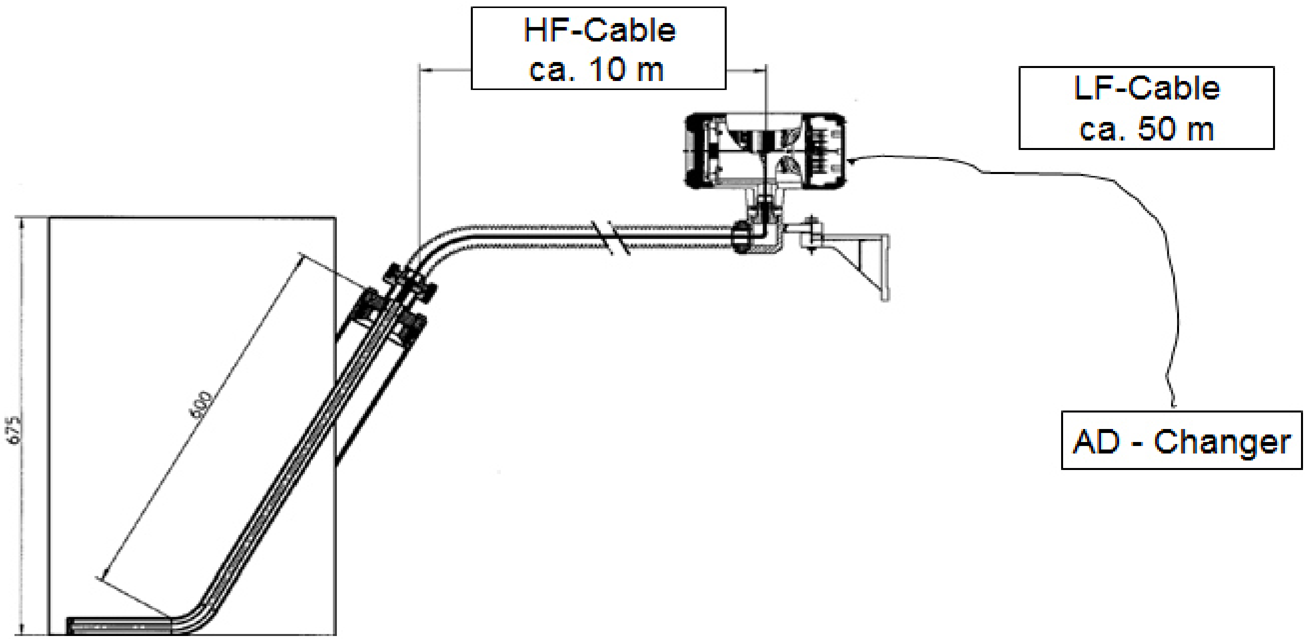
Appendix C

TDR - probe: In oil tank of main cooling pump



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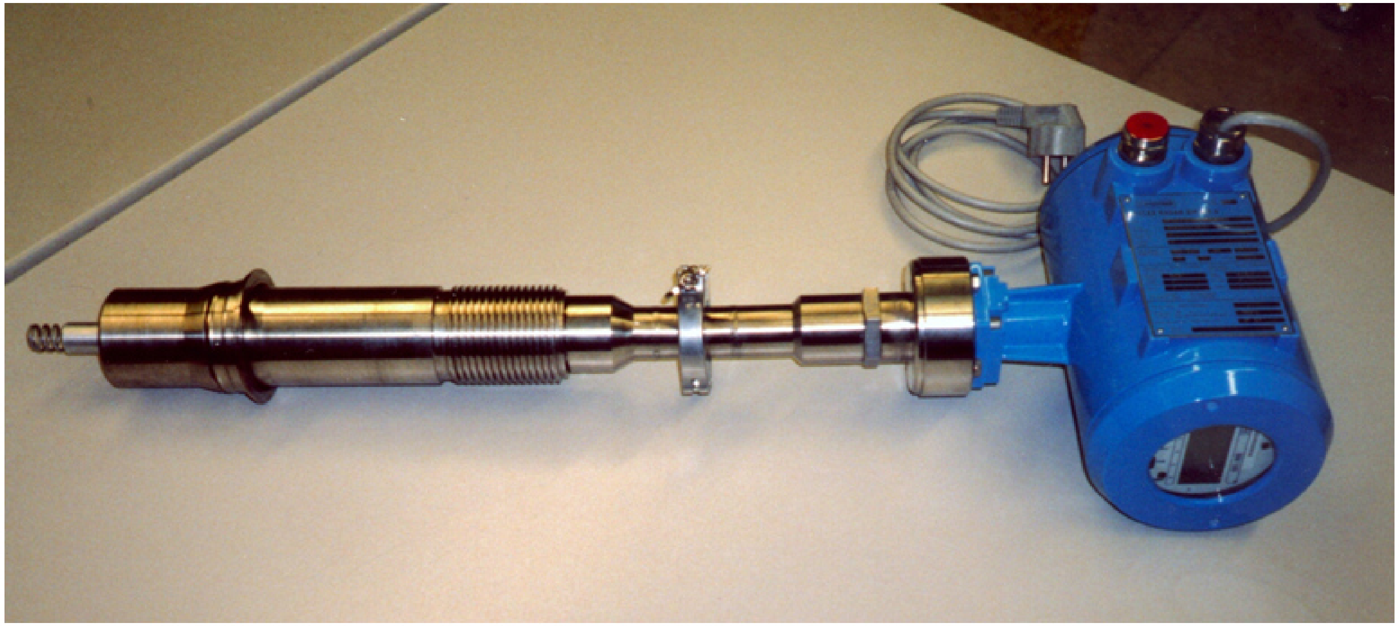
Appendix C

TDR - probe: high pressure probe head



TDR - probe: high pressure probe head for existing RPV nozzle. Layout 230 bar. Probe tube, same diameter like existing Probe (51 mm) , easy Backfitting in existing guide tube. Probe length 5 m.

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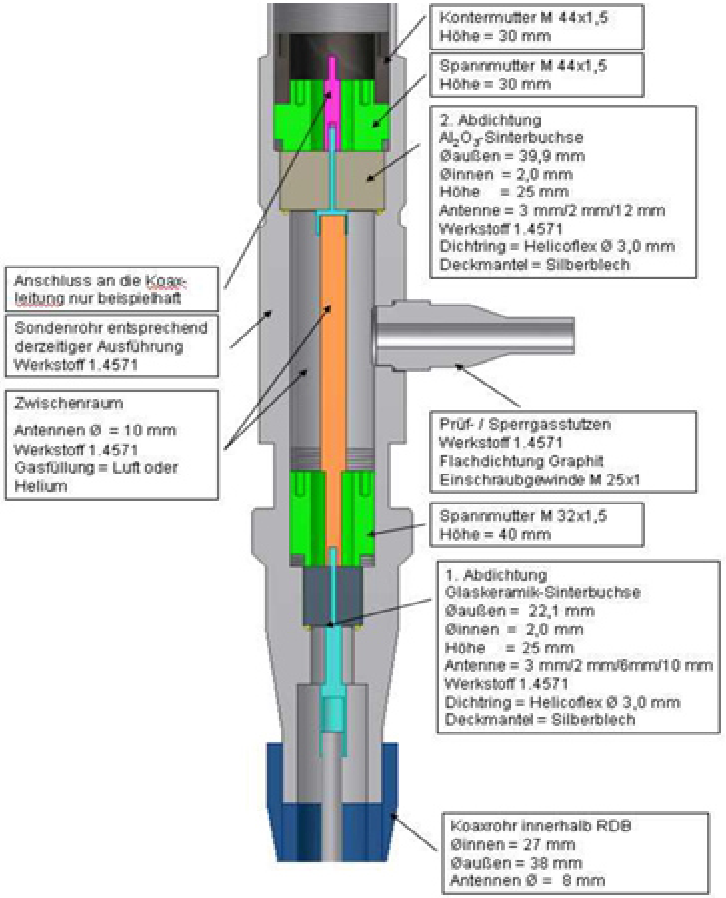
Appendix C

TDR - probe: high pressure probe head



Successful Tests with Prototype Probe Head of AREVA:

Level and pressure transients with steam/ deionat up to 170 bar / 350°C

According experience of prototype tests, Final design evaluated in 2011

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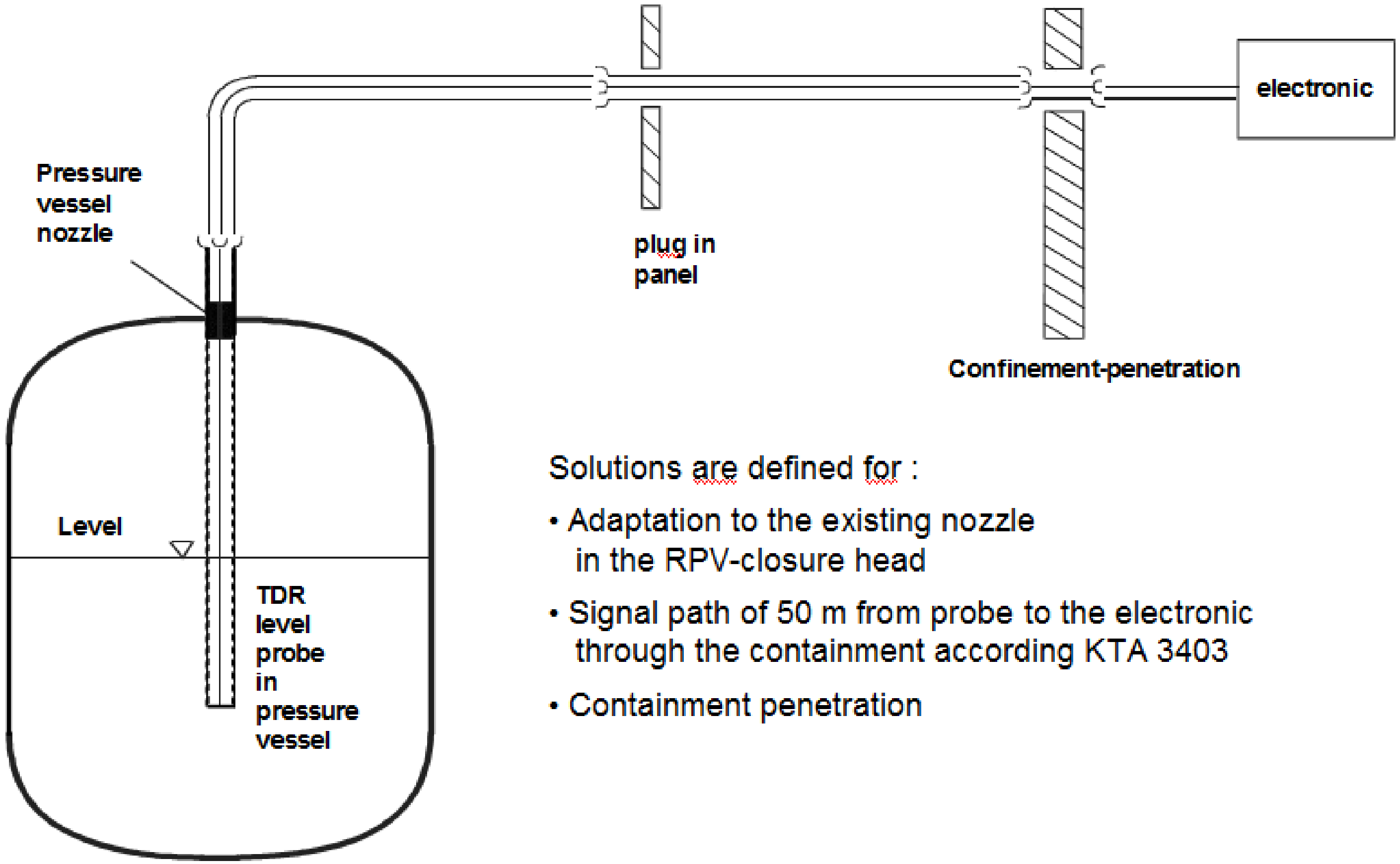
Appendix C

TDR - level probe : Configuration with electronic out of confinement



Solutions are defined for :

- Adaptation to the existing nozzle in the RPV-closure head
- Signal path of 50 m from probe to the electronic through the containment according KTA 3403
- Containment penetration

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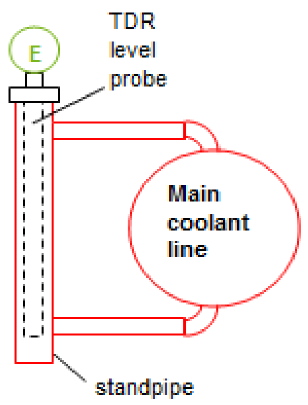
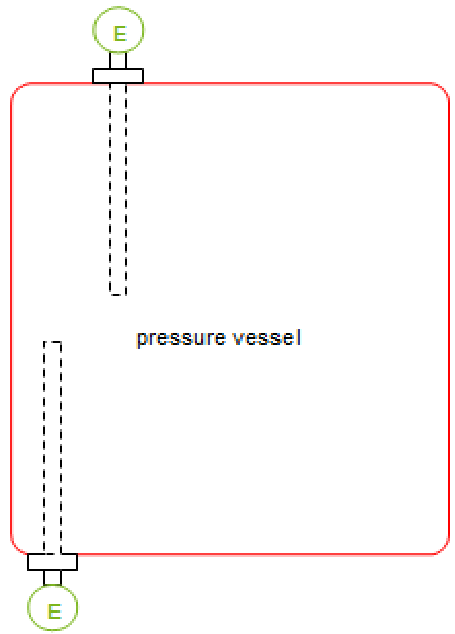
Appendix C

TDR - level probe: variants of arrangement

Probe = coaxial tube with no working parts.
Must not be replaced, can be permanently installed.



In a standpipe beneath a vessel (Main coolant line or RPV of BWR)



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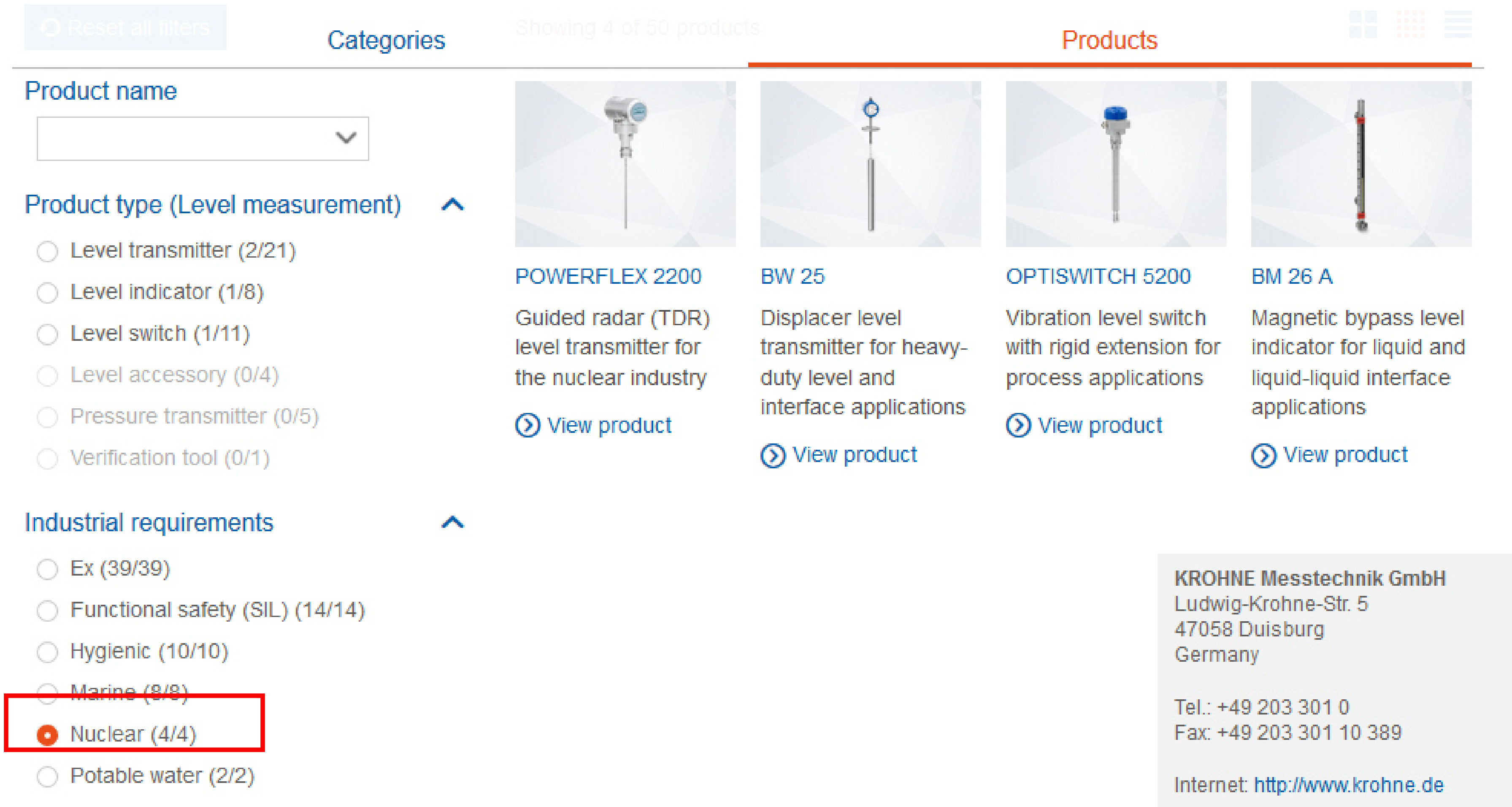
Appendix C: TDR Level Probe by KROHNE for Nuclear Plants



Appendix D: Nuclear qualified Temperature Sensors

Nuclear qualified instrumentation - Ultra Electronics Nuclear Sensors & ... https://www.ultra-nspi.com/products/nuclear-qualified-instrumen

Shipping / Street address

Ultra Electronics
NUCLEAR SENSORS & PROCESS INSTRUMENTATION
707 Jeffrey Way
Round Rock, TX 78665-2408
USA

Products | Information Central | Company | News | Contact Us | Store | Search

Nuclear qualified temperature sensors

Temperature sensor N9004

Fast Time Response RTD

Thermowell mounted with a temperature range from 0-750° F. Guaranteed for 40 years, this temperature sensor has a response time of less than 4 seconds.

Learn more

NSPI has been supplying nuclear qualified temperature sensors, thermowells and transmitters, pressure transmitters and fiber optic modems for more than three decades. NSPI is recognized as a global leader in the technologies we supply, in part because of our intense focus on quality and reliability.

Today, over 80% of all North American reactors rely exclusively on NSPI temperature sensors for critical reactor coolant monitoring. NSPI's nuclear qualified pressure transmitters are used for safety related and BOP measurements at over 20% of US nuclear power plants. NSPI products have been qualified for use in all of the leading reactor technologies, including PWR, BWR, CANDU (PHWR), and APWR.

Temperature sensors

Overview NSPI is the world's largest supplier of nuclear qualified RTDs and thermocouple temperature sensors. Qualifications are to IEEE, RCC-E and NUREG standards. Most of...

Temperature transmitters

Overview NSPI nuclear temperature transmitters are qualified to IEEE-344 and can be used with either RTDs or thermocouples. They are capable of withstanding up to...

Thermowells

Overview NSPI manufacturers a wide variety of nuclear qualified thermowells in virtually any style or material. While NSPI's standard thermowells are fabricated from stainless steel,...

Pressure transmitters

Overview NSPI supplies one of the broadest ranges of pressure transmitters for nuclear qualified applications. Most of the instruments are qualified to IEEE-323/344 and versions...

Fiber optic networking

Overview Fiber optic signal transmission for process monitoring and control has been progressively adopted in recent years. In critical applications with very high requirements for...

Commercial Grade/Non-Safety (BOP)

Overview Ultra Electronics, Nuclear Sensors & Process Instrumentation (NSPI) is recognized as a global leader in our industry, with over 35 years experience in the...

ASME Division 1, Class 1, 2 & 3 Vessels, Partials, Supports and Materials

Certification Details Ultra Electronics, NSPI has successfully completed the certification process from the American Society of Mechanical Engineers (ASME) for design and manufacture of pressure...

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Appendix E: Dynamic Pressure Sensors

SENSORS FOR MACHINERY HEALTH MONITORING | INDUSTRIAL |

Models **176AXX and 176MXX**

DYNAMIC PRESSURE SENSORS WITH CHARGE OUTPUT FOR ON-TURBINE COMBUSTION INSTABILITY MONITORING

- Detect dynamic pressure fluctuations in high static pressure environments
- Prevent high-cycle fatigue of components within and downstream of the combustion chamber
- Withstand extreme temperatures with UHT-12™ crystal and hermetically-sealed, nickel alloy housing
- Connect easily to existing combustion dynamics monitoring system

Typical Applications

- Condition Monitoring of Power Generation Turbines
- Condition Monitoring of Aviation Turbines
- Combustion Instability Measurement

CE IECEx

All products except Model 176A04

Provide Stable Sensitivity at Extreme Temperatures

Most of IMI Sensors' 176-Series pressure sensors utilizes a UHT-12™ element that provides a consistent sensitivity over a wide temperature range. The element does not experience pyroelectric noise spikes at very high temperatures nor does it require oxygen for operation.

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