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Preliminary I&C Design for LORELEI

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INTRODUCTION

The LORELEI (Light water One Rod Equipment for LOCA Experimental Investigation) device is one of the experimental platforms designed for the Jules Horowitz Reactor (JHR). It is dedicated to reproduce thermal-mechanical conditions of Light Water Reactor (PWR, BWR and VVER) in LOCA (Loss Of Coolant Accident) accident situations. The preliminary design of power, instrumentation and control for LORELEI experiment defines a conceptual I&C architecture with configuration of the control systems and the interfaces to JHR power supply networks(1). Conceptual Configuration of LORELEI's safety and service systems is established as well.

Temperature and position closed loop control rules were determined considering interfaces to displacement device. The automatic control rules are limited to predefined error ranges of temperature and displacement device's position. In any case the operator can intervene and take control of the experiment. The hot spot temperature and thickness of oxidation layer are essential parameters in LORELEI experiment. However, hot spot temperature cannot be measured directly and oxidation layer thickness can be calculated using adequate mathematical models only. Therefore, it is proposed to predict them in real time. Real time prediction can be performed by the proposed Computer Aided Operator Decisions System (CAODS). During the experiment CAODS predicted values will support the operator to take the proper actions. Furthermore, some predicted out of range parameters can be used for prevention or safety functions.

A hybrid simulation system comprising both virtual and real hardware will be developed for LORELEI verification. It will perform both integration cold tests with a partial hardware loop in JHR experimental area and virtual tests for the final I&C design. Additional hardware and software components will be used for simulation of external cooling channel and interfaces to safety systems. The simulator will comply with verification procedures mentioned in IEC 62138(2) regarding software aspects for computer based systems category performing B or C functions.

The preliminary design describes considerations regarding appropriate safety and service instrumentation and their technological characteristics (3). Preliminary electrical power design was conducted for force and I&C power supply. It determines LORELEI's expected power consumption for service and safeguard and methods for power control of Lorelei's heaters.

METHODS

Remote measurement of hot spot temperature

The study of the first LORELEI experiment will focus on 150mm and 250 mm flattened power profile section and their corresponding clad ballooning. The temperature objective of the hot spot is set to 1200°C while several requirements are dedicated to temperature thresholds or values of the hot spot. Since optical technology for non-contact hot spot temperature measurement is not expected to be available for the first experiment, thermocouples will be used for temperature measurement. The thermocouples should be assembled out-of the hot spot region in order to not interfere with the thermo mechanic phenomena. Moreover the measured temperatures should follow the hot spot temperature as close as possible. Initial position of thermocouples location attached to clad is set to $\pm$ 5 cm out of the expected ballooning zone. The clad temperature measurement in this case is limited to 940-1140^{0}C due to eutectics of the TCs sheath. The TCs will be attached to the clad with bands without welding. Another option is to use TCs placed on the coaxial heater to overcome eutectics. The overall temperature range to be covered up to 1200°C will be divided in to two sub ranges. In range up to about 900°C the TCs attached to clad will be taken in to account because they are reliable and available. Beyond this temperature range the TCs of coaxial heater will be available. They will not be used in the first range because the heater will be in operation and remote hot spot temperature measurement will be complicated. TC switching between the ranges should be bump-less. Hot spot temperature measurement for safety is also monitored remotely by TCs, therefore their thresholds should be adjusted properly.

CAODS for real time prediction of hot spot temperature

The hot spot temperature should be monitored and controlled continuously in the LORELEI experiment. However the hot spot temperature cannot be measured directly, it should be predicted using a Computer Aided Operator Decisions System (CAODS). CAODS will be based on prediction algorithms using real time measurements, which will be collected by control system. The prediction algorithms will be obtained by using data from numerical simulations. They will cover the most probable case and at least the extreme cases of ballooning. The data will include time depended thermal responses produced by wide range profiles of electrical and nuclear power (displacement device positions). The thermal responses include hot spot, remote temperature measurements equivalent to clad, coaxial heater and safety TCs. Several algorithms will be considered for prediction such as mathematical relationships, neural networks or fuzzy logic. Validation of each algorithm will related to numerical simulations and real time electrical rod experiments. Best performance algorithm will be applied in programmable automation controller (PAC).

CAODS for real time prediction of oxidation layer thickness

Oxidation layer thickness is critical since it affects the thermo-mechanic properties of the clad and changing its dynamic behavior. Kinetics of non iso-thermal zirconium oxidation reaction caused by water fumes in LOCA scenarios can be described by Baker-Just correlation. The decision to end oxidation phase in LORELEI experiment can be computer aided using CAODS. It will calculate equivalent cladding reacted based on Baker-Just correlation.

Hybrid simulator for LORELEI verification

The hybrid simulator will rely on instrumentation, control systems and electrical cabinets designed for the LORELEI experiment. In order to perform integration cold tests, additional hardware and software components will be used for simulation of external cooling channel and interfaces to safety systems. The hybrid simulator will verify only part of LORELEI loop equipment. Some of the experiment's phases will be

verified by real I/O interfaces related to hardware elements such as peripheral heater and steam generator. The uninstalled equipment will be tested functionally by the programmable automation controller (PAC) using virtual I/O. PAC program sections will simulate virtual l/O in software. Both virtual and real I/O will be resolved simultaneously. Dynamic behavior, such as time delays of valve actuation, can be also implemented within the virtual I/O. Virtual I/O will be used for verification of the remaining phases using experiment's transfer functions. The transfer functions will first be identified from thermo hydraulic calculations.

Temperature regulation for adiabatic heating

LORELEI experiment will simulate the heating resulting from a LOCA accident. In this case the clad should be heated adiabatically with a predetermined heating rate of 5^0C/s up to 20^0C/s and the coaxial heater should follow clad's temperature simultaneously. This phase can be achieved automatically by closed loop control in two steps. Initial positioning determination of the displacement device such that it maintains the desired heating rate. The adiabatic heating requirement will be maintained by controlling, in closed loop, the coaxial heater to follow the clad's heating rate. It is very important to reach the desired requirement as fast as possible due to mutual heating affects and sluggish thermal responses.

CONCLUSIONS

This document summarizes the preliminary I&C design for LORELEI experiment The preliminary design deals with considerations regarding appropriate safety and service instrumentation. The determined closed loop control rules for temperature and position will be implemented in the detailed design. The Computer Aided Operator Decisions System (CAODS) will be used for prediction of hot spot temperature and thickness of oxidation layer using Baker-Just correlation. The proposed hybrid simulation system comprising of both virtual and real hardware will be in-cooperated for LORELEI verification. It will perform both integration cold tests for a partial hardware loop and virtual tests for the final I&C design.

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