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New nuclear advanced facilities at CVREZ

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ABSTRACT

Purpose: The goal of this paper is to present the facilities designed and built in the frame of the SUSEN program in the Centrum Výzkumu Řež, allowing research and development in the area of Generation IV and nuclear fusion reactors.

Design/methodology/approach: The coolants investigated are: supercritical water, helium and lead-bismuth. The SSD team is in charge to perform in hot-cells various kinds of mechanical tests on irradiated materials in the range from room temperature to 800°C (tensile test, creep test, tension-torsion test and fatigue test in different type of loading) and microstructure investigation with SEM and TEM.

Findings: SUSEN project allows at CVREZ to develop the facilities and instrumentations that institute has already had. This project allows also developing new facilities, buying new experimental machines and gives a wide range of investigation in different field in the research and development of Gen IV reactor.

Research limitations/implications: The different types of loops study the impact of media on the properties of structural materials. The behavior of media and the different type of mechanical tests in static and fatigue regime at different temperatures enable to extend the limit of knowledge about mechanisms of corrosion, mechanisms of degradations and improve the design and safety in nuclear power plant.

Originality/value: The SUSEN program is divided in four sub-programs and teams: Technological Experimental Circuits (TEC), Structural and System Diagnostics (SSD), Material Research (MAT) and Material Fuel Cycle (JPC). TEC team is in charge of the development large-scale experimental loops to improve the quality and quantity of data about the behavior of coolants used in the primary circuit and the corrosion of steel in contact with coolants.

Keywords: Mechanical test; High temperature; Corrosion; Loops

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MANUFACTURING AND PROCESSING

1. Introduction

Centrum Výzkumu Řež (CVREZ) is a research and development institute in the field of power engineering (mainly in the nuclear field). CVREZ is 100% a subsidiary of the UJV group; they both are located in the Czech Republic. Fundamental research in natural sciences using neutrons, research and development in nuclear energy related fields as corrosion processes, radiation induced damages in construction materials and research of development of radio-pharmaceuticals prepared by using nuclear reactors and design of new treatment procedures using neutrons are the different research activities at CVREZ. CVREZ is a nonprofit organization and its activities are restricted only for fundamental research and development.

With the support of the European Commission and the Ministry of Education, Youth and Sports of the Czech Republic, the implementation of the SUStainable ENergy (SUSEN) project allows to build a strong infrastructure for sustainable research and development activities. The SUSEN project permits the participation of the Czech Republic on the European effort in the investigations in the life extension for Generation II and Generation III technologies (Gen II and Gen III) and the investigation of materials which will be used for Generation IV (Gen IV) reactor concepts and fusion [1]. Material candidates for both technologies are similar. The SUSEN project is organized around four research programs: Technological Experimental Loops (TEC), Structural and System Diagnostics (SSD), Nuclear Fuel Cycle (JPC) and Material Research (MAT) [1]. In this paper MAT program is not presented because this research program is mainly linked to the TEC and SSD teams in the area of testing of non-irradiated materials for high temperatures applications and the development of new technologies for fusion welding of advanced materials for conventional and nuclear energy.

2. Technological experimental CIRCUITS (TEC)

The Generation IV international forum (GIF) defined eight technology goals to select the new reactor concept. These goals are gathered in four broad areas: sustainability, economics, safety and reliability, and proliferation resistance and physical protections [2]. Very-High-Temperature reactor (VHTR), Supercritical water-cooled reactor (SCWR), Molten-salt reactor (MSR), Gas-cooled fast reactor (GFR), Sodium-cooled fast reactor (SFR) and Lead-cooled fast reactor (LFR) are the reactor concepts meeting the eight technology goals. The TEC program in CVREZ is mainly focused on the construction of large-scale experimental facilities allowing research in the field of media present in Gen IV reactors and Fusion reactor. The following media are studied at CVREZ: supercritical water as medium for the primary circuit of SCWR, helium as medium for the primary circuit of VHTR and as coolant for the first wall of a fusion reactor [1]. Lead and lead-bismuth media are also studied in CVREZ for research on materials.

2.1. Supercritical water loop – fuel qualification test (SCWL-FQT)

The SCWL-FQT loop shall be used to test a small scale fuel assembly having the characteristic design features of the High Performance Light Water Reactor (HPLWR), i.e. the European concept of the SCWR. The test fuel assembly will be composed of four fuel rods with 8 mm outer diameter and with a wire wrapped around each rod as mixing spacer, and it will be placed in a pressure tube (irradiation channel) installed in the LVR-15 research reactor. The 4 fuel rods will contain UO_2 pellets with an enrichment of 19.7%, providing a power of more than 63 kW over an active length of 60 cm.

The coolant loop outside the pressure tube includes a recirculation pump, a coolant make-up system and a sampling system. A bladder type accumulator, partly filled with nitrogen, is helping to keep the system pressure stable. All these components are placed outside the reactor building. Inlet and outlet lines of the primary system are running inside a shielded duct through the reactor building to the primary block in a hall adjacent to the reactor hall. Safety systems are installed to ensure the integrity of the fuel cladding as well as the pressure tube at normal as well as accidental conditions.

The loop will be operated at 25 MPa pressure and at temperatures in the range between 385 and more than 500°C, which represent the operational conditions of the HPLWR.

2.2. High temperature Helium loop (HTHL)

The goals of HTHL (Fig. 1) are simulation of physical and chemical conditions of the GFR and VHTR simulation of clean up of the medium in operation mode of the reactor. HTHL is designed for testing of interaction of materials and gaseous atmosphere at high temperature, experiments aimed to helium coolant chemistry and purification are also possible. HTHL consists of two parts: active channel and helium purification, purity control and dosing system. Main projected parameters of the device are: maximum temperature in test section: 900°C, maximum gas pressure: 7 MPa, maximum gas flow rate: 0.01042 $kg.s^{-1}$. To minimize loss of helium during experiments, gas pressure during operation is usually maintained lower, typically 4-5 MPa.

The active channel was originally designed to be placed to the core of test reactor LVR-15, but later the decision was to use HTHL only for out-off pile experiments.

The section for specimens is approximately 500 mm long with diameter about 30 mm. Currently, the new loop for in-pile operation is built within the SUSEN project.

The purification system is similar to the real HTR reactor, the design was inspired by helium purification system of Chinese test reactor HTR-10 [4,5].

The experimental system is composed of five flow meters, eighteen pressure sensors and twenty nine thermocouples located in different loop sections. The loop is also composed of monitoring system of chemical composition of the gaseous medium, a hygrometer, and dosing device of gaseous additions.

Gas chromatograph with a helium ionization detector (GC-HID) is used to monitor the chemical substances present inside the helium gas. The following chemical substances are checked: CO, CO_2, H_2O, CH_4. HID detector principle: helium goes in the space between two electrodes; helium atoms are brought into excited state and form the helium plasma. When the helium returns in the gas state, photons are radiated and they ionize the sample. The ionized substances are those having a lower ionization potential than 17.7 eV. After the ionized molecules are attracted to the collecting electrode [6], GC-HID, with special chromatographic columns, allows a very low detection limits for gaseous substances determination.

To check humidity, an optical hygrometer Bartec 5673 is used; three sensors are placed in the loop. Locations of sensors are at the input and output of the purification circuit and behind the absorbers with molecular sieves. The principle of measuring the wavelength change of beam of infrared light is used by this type of hygrometer. This method is particularly accurate for determination of low humidity concentration (units, tens vppm). The low detection limit is 1 vppm. The hygrometer records and stores the experimental data every 10 minutes.

A dosing container is used for gaseous additions. Its vessel has a volume of 500 ml; it is filled with a gas or a gas compound. The composition and the pressure are defined. The content is flushed into the gas circuit of loop. First experimental results have been already published about the purification system and the behavior of impurities [5,7]. The first experience with dosing system during test operation of HTHL is not very good; the improvement of the system is under development.

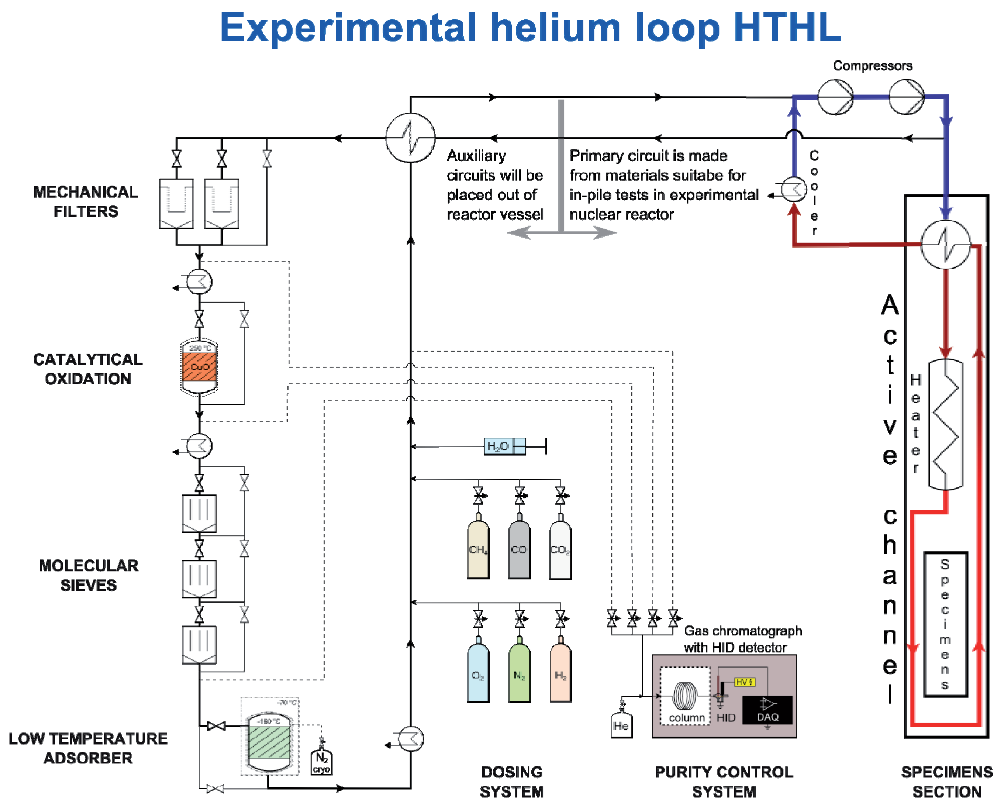

Fig. 1. Experimental helium loop

2.3. Lead/Lead-Bismuth loops

COLONRI I and II loops allow the monitoring of corrosion of material in lead-bismuth (Pb-Bi) and lead (Pb) respectively. They both are natural convection loops. Their design is based on convection loops allowing the measurement of corrosion evolution of structural materials in heavy and alkaline liquid metals [8]. Both loops are identical and have a mirror structure. The loops are made of an upper expansion tank, a high- (HT) and low-temperature sections (L), a heating (h) and cooling (c) legs (Fig. 2). The loops are wrapped by resistance wires to heating the system. During the test, the temperature is maintained constant and controlled by thermocouple with an accuracy of ± 1°C for experimental sections and ± 3°C in the expansion tank. The two experimental sections work at different temperature, with a temperature difference up to ΔT=150°C.

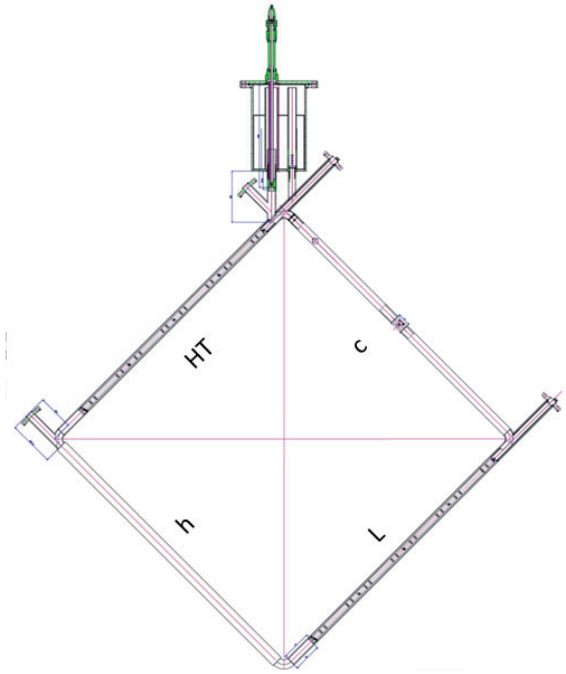

Fig. 2. Lead/Lead-Bismuth loop sketch

The loops were manufactured from austenitic stainless steel AISI 321. The inner surface of the tube working at the highest temperature (h) was covered with a molybdenum plate. Specimen holders, four for each leg, have a capacity of three rows of specimens, for a total length of around 2000 mm (Fig. 3). The upper expansion tank allows a partial derivation of fluid and as well to have a chemistry controlled of the medium. The chemistry of liquid metal is controlled by dosing gases (Ar, ArO_2, ArH_2, H_2) and monitored by electrochemical oxygen sensor. Up to five oxygen sensors can be placed in each loop. Sensors are electrochemical galvanic cells and manufactured in the CVREZ laboratories. The sensor is an yttrium stabilized zirconium ceramic tube, which is the solid electrolyte, and the reference system used is Bi/Bi_2O_3 [9]. The maximum operating temperature for Pb-Bi and Pb are respectively 550°C and 650°C, for a flow rate of 2 $cm.s^{-1}$ and each loops contains about 1.7 l of liquid metal.

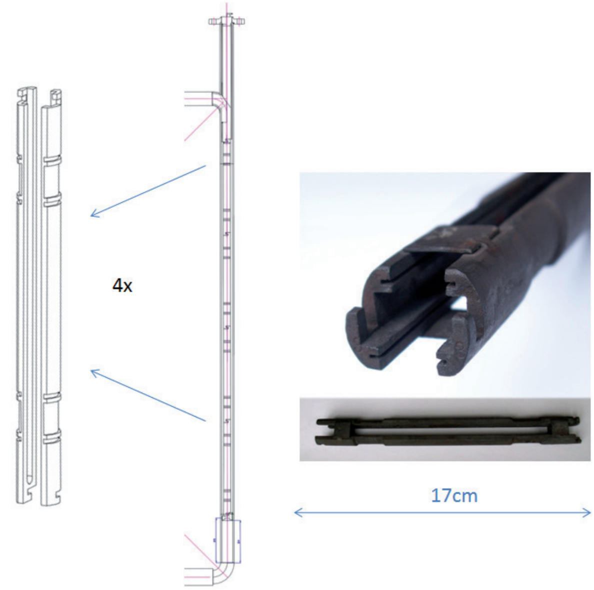

Fig. 3. Holder and test section

Several types of materials were tested in the COLONRI loops. Ferritic/martensitic steel T91 and austenitic 316 L were extensively tested in the loops [10], because they were selected as candidate materials for LFR construction materials. However, a large amount of work was also focused on ODS materials, coatings and other stainless steels evaluated for applications in Heavy Liquid Metals environments.

3. Structural and system diagnostic (SSD)

This program is focused on structural and system diagnostics of Gen II, Gen III and Gen IV nuclear power plant. The following tests will be performed in hot-cells at CVREZ, tensile testing, impact testing, fracture toughness testing, crack growth rate testing at cyclic loading, small-cycle fatigue testing, creeping tests for irradiated materials from room temperature to 800°C [1].

3.1. Static and dynamic confinement

Preparation and testing of irradiated materials require a confined area to be manipulated and protect persons working with these active materials. Thanks to the program SUSEN ten hot-cells and one semi-hot-cell are under construction (Fig. 4). The Hot-cells Hall is divided in 4 spaces, as show in Fig. 5. There are hot-cells in blue, operator hall, basement and ceiling. The maximum source activity from hot-cells will be up to 300 TBq ^{60}Co. Dose equivalent rate (DER) received in operator hall, basement and ceiling will be 1.38 µSv/h, 2950 µSv/h and 54 µSv/h, respectively.

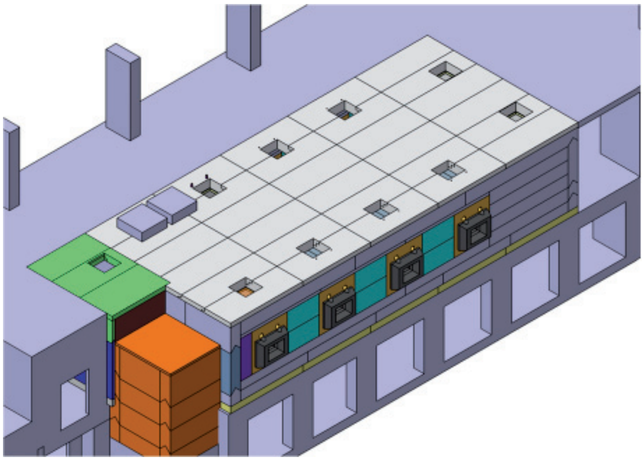

Fig. 4. Hot-cells overview

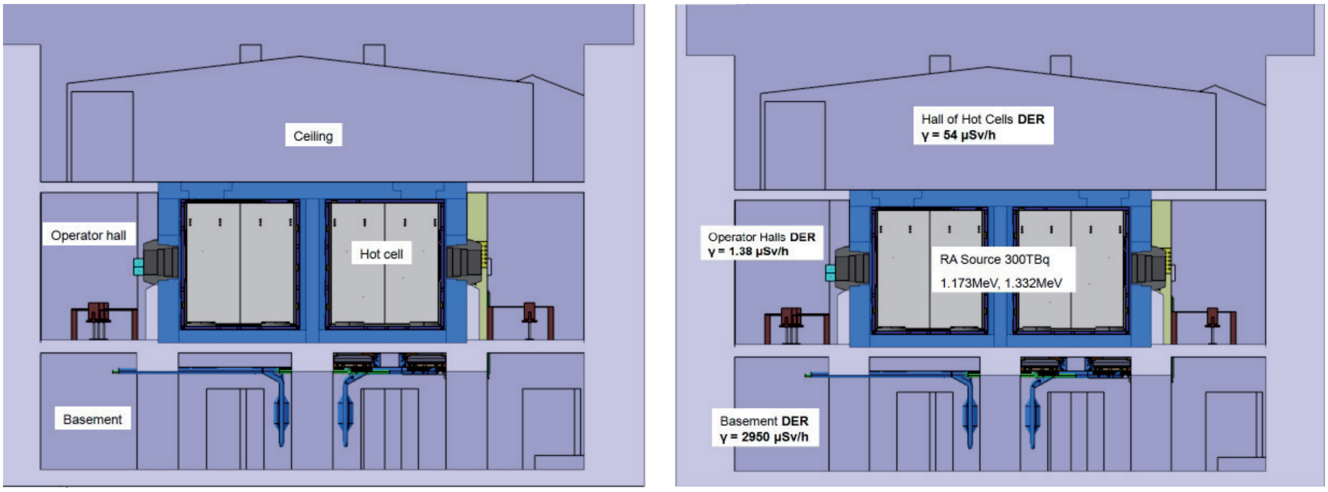

Fig. 5. Cross section of Hot-cells Hall

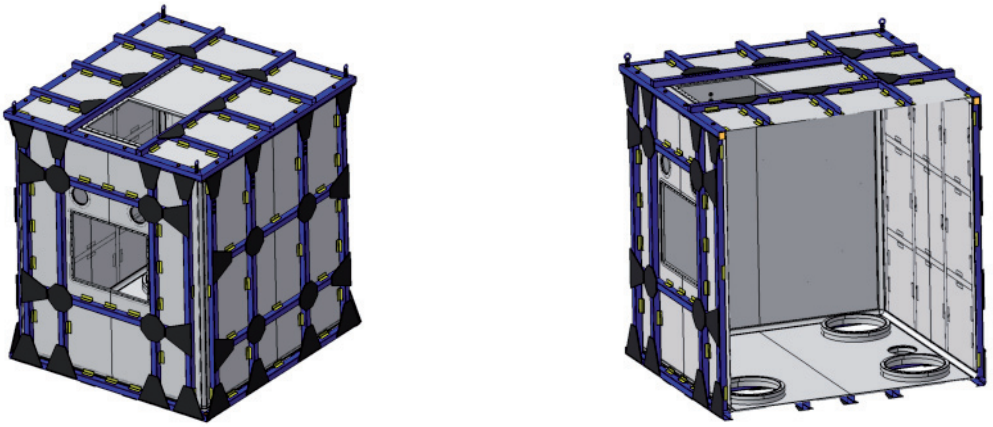

Fig. 6. Steel box with holes for windows, manipulator and entrance for specimens

The level of dose received determines the thickness of shielding. Stainless steel was chosen to be the shielding material. The thickness of side wall, wall between hot-cells, the ceiling shielding and floor shielding are 500 mm, 300 mm, 300 mm respectively. All hot-cells will be equipped by a hermetic, removable box made in stainless steel (Fig. 6). This approach of facility management allows at CVREZ, for any reason, to change the instrumentation inside the box and simply pull out the box and put new inside with new instrumentation without any delay.

The shielding of the hot-cells and the steel box are the static confinement part. The dynamic confinement is made by ventilation. The air from hot-cells passes through three sets of filter before to go in the air. Also inside the box will be active waste piping, LED light system for illumination of work space, numerous sensors (temperature, pressure, radiation level, etc.) and cameras for better control of the device inside. Each hot-cell will equip of set of manipulator to handle the sample, preparation machines, testing machines etc.

3.2. Equipment inside hot-cell

Electrical discharge machine (EDM) is used to manufacture sample (cutting and machining) at the desired shape without thermal and mechanical damage in the surrounding area of the cut. The maximum weight of work piece is 30 kg and the dimension of traversing table is 600 x 400 mm.

Electron beam welding machine (EBW) uses a high-velocity electrons beam which melts and flow two materials together under vacuum. The maximum dimension of work piece is 170 x 170 x 230 mm, the accelerating voltage is 20-60 kV and vacuum condition is 10^{-5} Pa.

Computer numerical control (CNC) is numerical machine to perform grinding, machining and drilling. The maximum weight of work piece is 15 kg for a maximum length of 200 mm.

For tensile test, fracture toughness test, low cycle fatigue and combined loading a universal tensile machine will be used. The loading cell is 250 kN maximum for a range of temperature from -150°C to 1000°C.

High frequency resonance pulsator is a device to test mechanical properties at high frequencies. Combination of static and dynamic loading is 50 kN maximum for a frequency of 250 Hz maximum for a range of temperature from room temperature to 800°C. CVREZ will use this machine for high cycle fatigue and pre-cracking of compact tensile sample.

Electromechanical creep machine will test the creep behavior in static and fatigue regimes at elevated temperatures. The loading cell is 50 kN maximum.

Autoclave with water loop is device for testing materials in control environment (water, high pressure, and high temperature). The loading cell is 50 kN maximum with maximum testing temperature at 350°C with control of chemical composition of water. With this device, it is possible to test the mechanical properties and corrosion resistance properties.

For the microscopy investigation a scanning electron microscope and light optical microscope will be present in a hot-cell.

4. Conclusions

SUSEN project allows at CVREZ to develop the facilities and instrumentations that institute has already had. This project allows also developing new facilities, buying new experimental machines and gives a wide range of investigation in different field in the research and development of Gen IV reactor. The different types of loops study the impact of media on the properties of structural materials. The behavior of media and the different type of mechanical tests in static and fatigue regime at different temperatures enable to extend the limit of knowledge about mechanisms of corrosion, mechanisms of degradations and improve the design and safety in nuclear power plant.

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