LVR-15 Reactor Application for Material Testing

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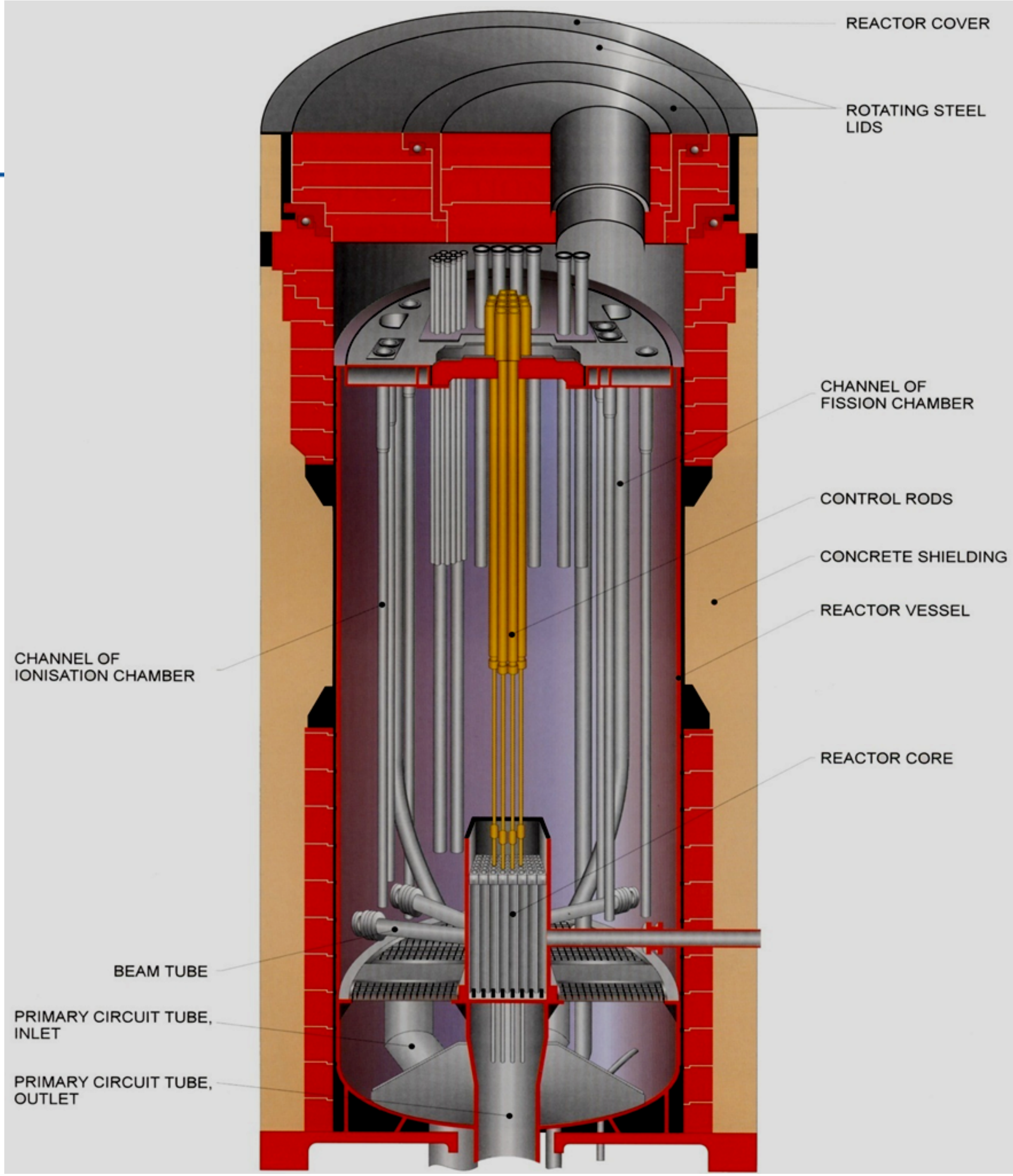
Contents

Research Reactor LVR-15

- Light-water moderated and cooled tank nuclear reactor with forced cooling,
- Maximum thermal power of 10 MW,
- The fuel type IRT-2M enriched to 36%,
- Combined water-beryllium reflector,
- 5 kg of ^{235}U,
- 28 to 31 fuel elements.

LVR-15 cross section



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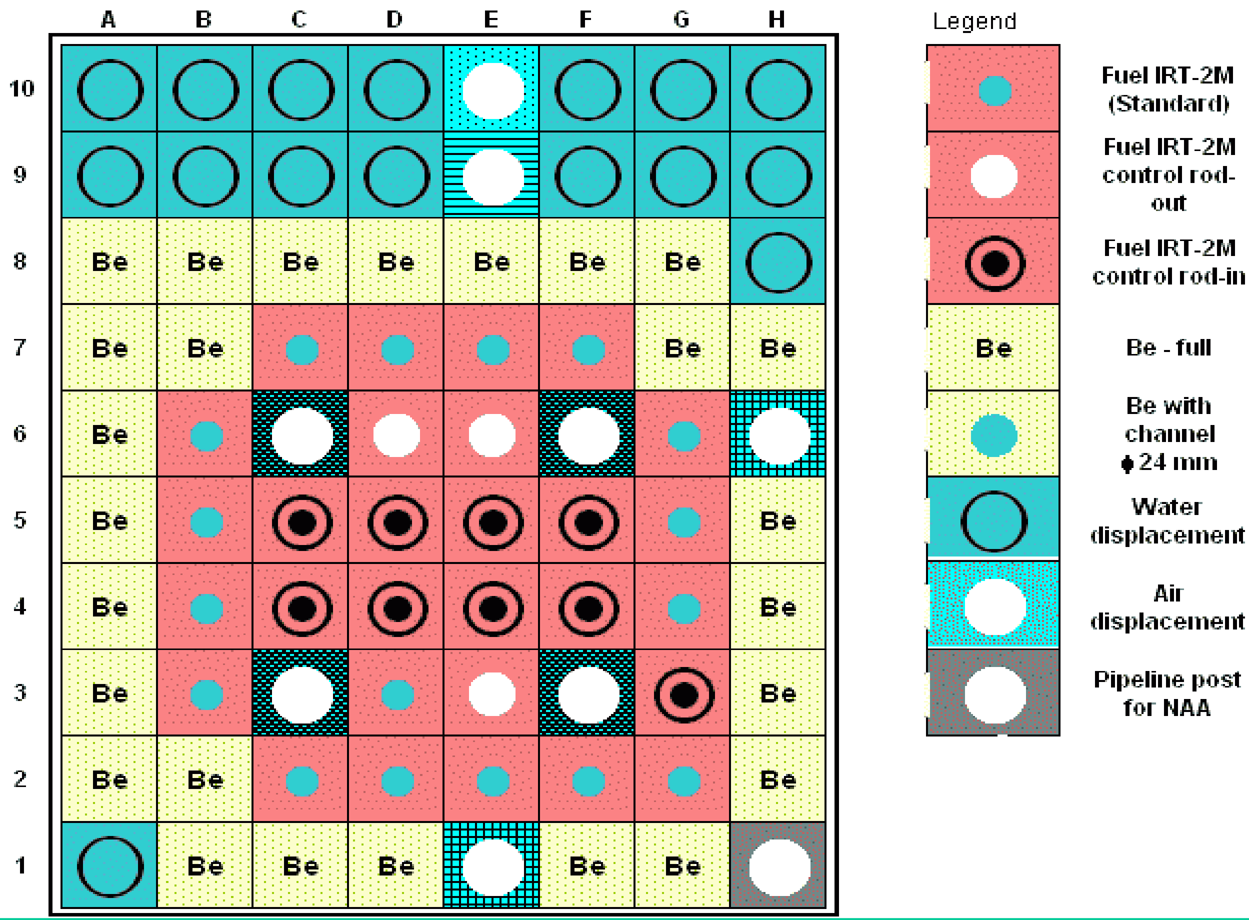
LVR-15 - Core cross section

LVR 15 standard core configuration

Fluence rate, dpa and gamma heating characterise the irradiation facilities (at 10 MW)



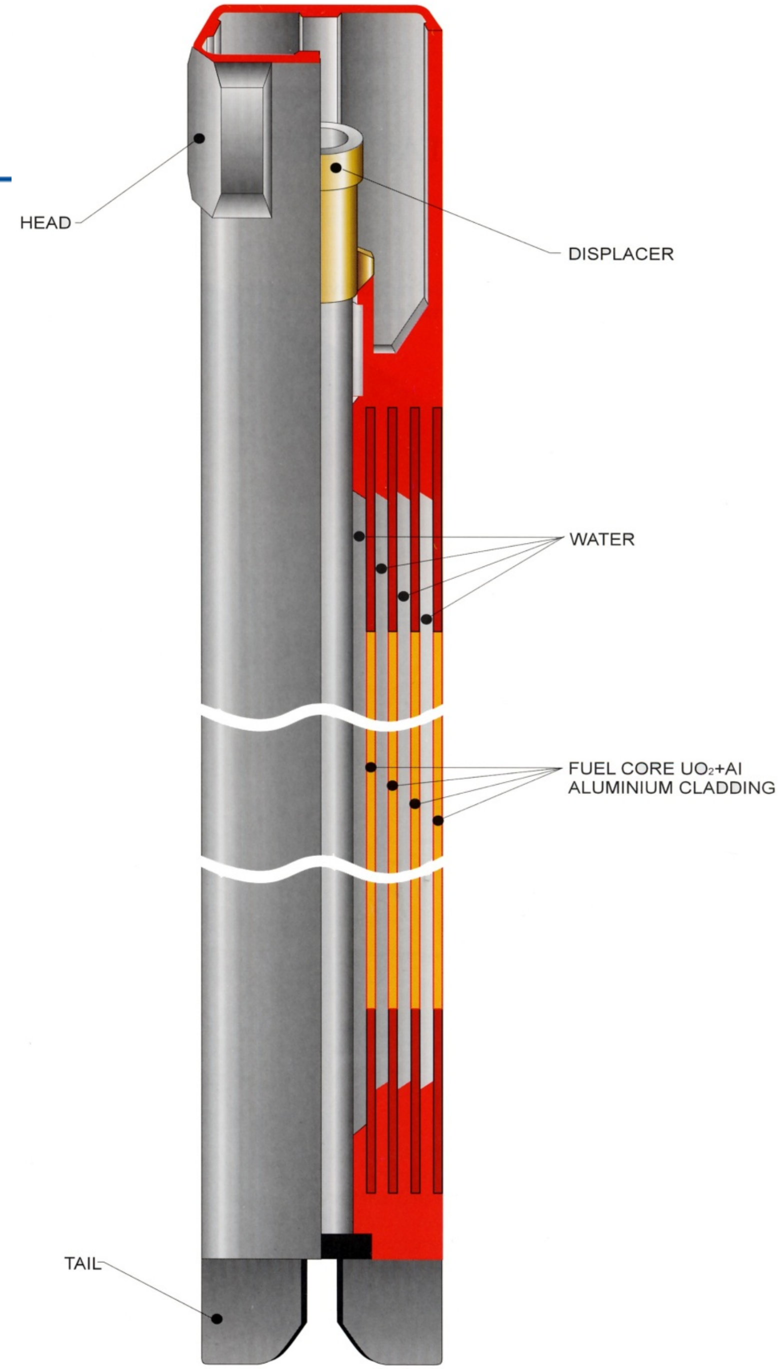
Irradiation channel	Fluence rate E>1.0 MeV ($m^{-2}s^{-1}$)	dpa rate (s^{-1})	Gamma heating in steel (W/g)
	1.60E+16	2.26E-09	0.7
	3.20E+16	4.53E-09	1.2
	1.70E+17	2.41E-08	1.9
	4.38E+17	6.20E-08	3.2

Reactor Characteristics

maximum reactor power	10 MW
maximum thermal neutron flux in the core	$1.5x10^{18}$ n/m^{2}s
maximum fast neutron flux in the core	$3x10^{18}$ n/m^{2}s
thermal neutron flux at the end of the horizontal beam tube	$1x10^{13}$ n/m^{2}s
thermal neutron flux in irradiation channel in fuel	$1.2x10^{18}$ n/m^{2}s
thermal neutron flux in irradiation channel in reflector	$9x10^{17}$ n/m^{2}s

Fuel Element (1)

total length	882 mm
active length	580 mm
section square	71,5 x 71,5 mm
mass of the assembly	3,2 kg



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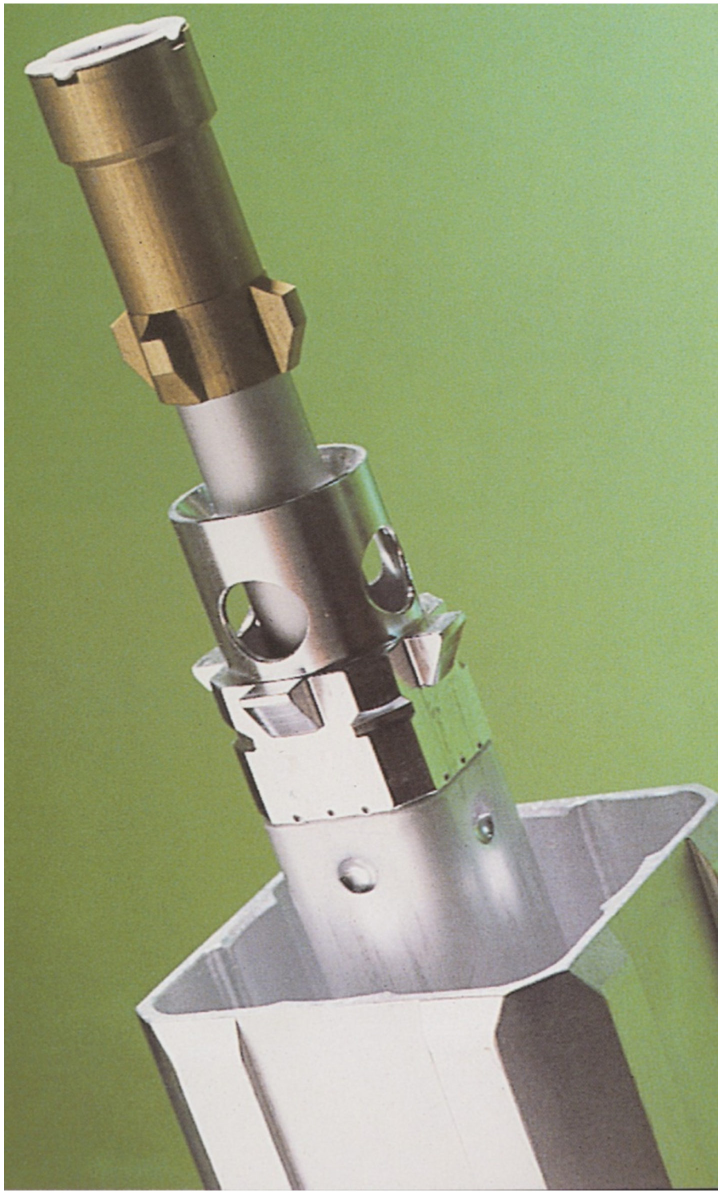
Fuel Element (2)

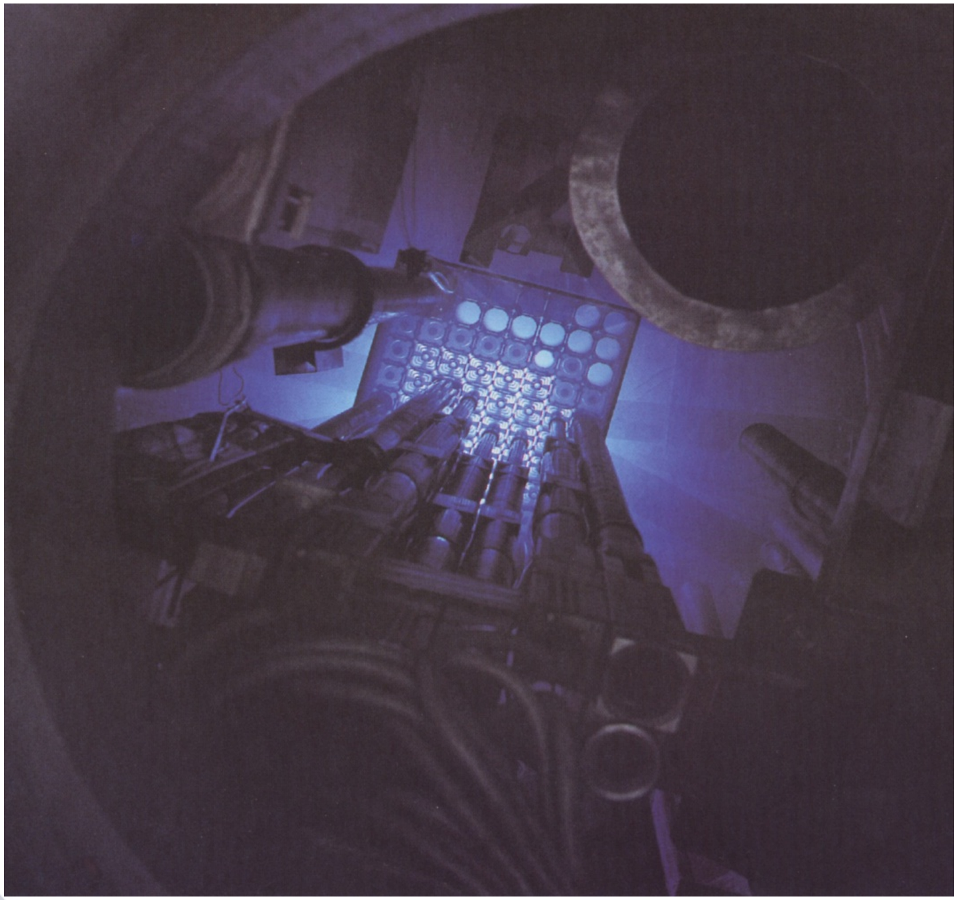
tube wall thickness	2 mm
cladding thickness	min.0,4 mm
fuel material	UO_2 – Al
mass of ^{235}U	230 g
^{235}U enrichment	36%



The Reactor Serves as a Radiation Source for:

- Material testing experiments in water loops and irradiation rigs
- Activation analysis with the pneumatic rabbit system
- Experiments at beam tubes in the field of nuclear and applied physics
- Irradiation of iridium for medical purposes
- Irradiation for radio-pharmaceuticals production
- Irradiation of silicon mono crystals
- Neutron capture therapy project

Experimental Facilities



- High-pressure water loops
- Vertical channels for material testing (rigs)
- Vertical irradiation channels
- Pneumatic rabbit system for short-time irradiation
- Nine horizontal channels (beam tubes)
- BNCT facility
- Hot cells

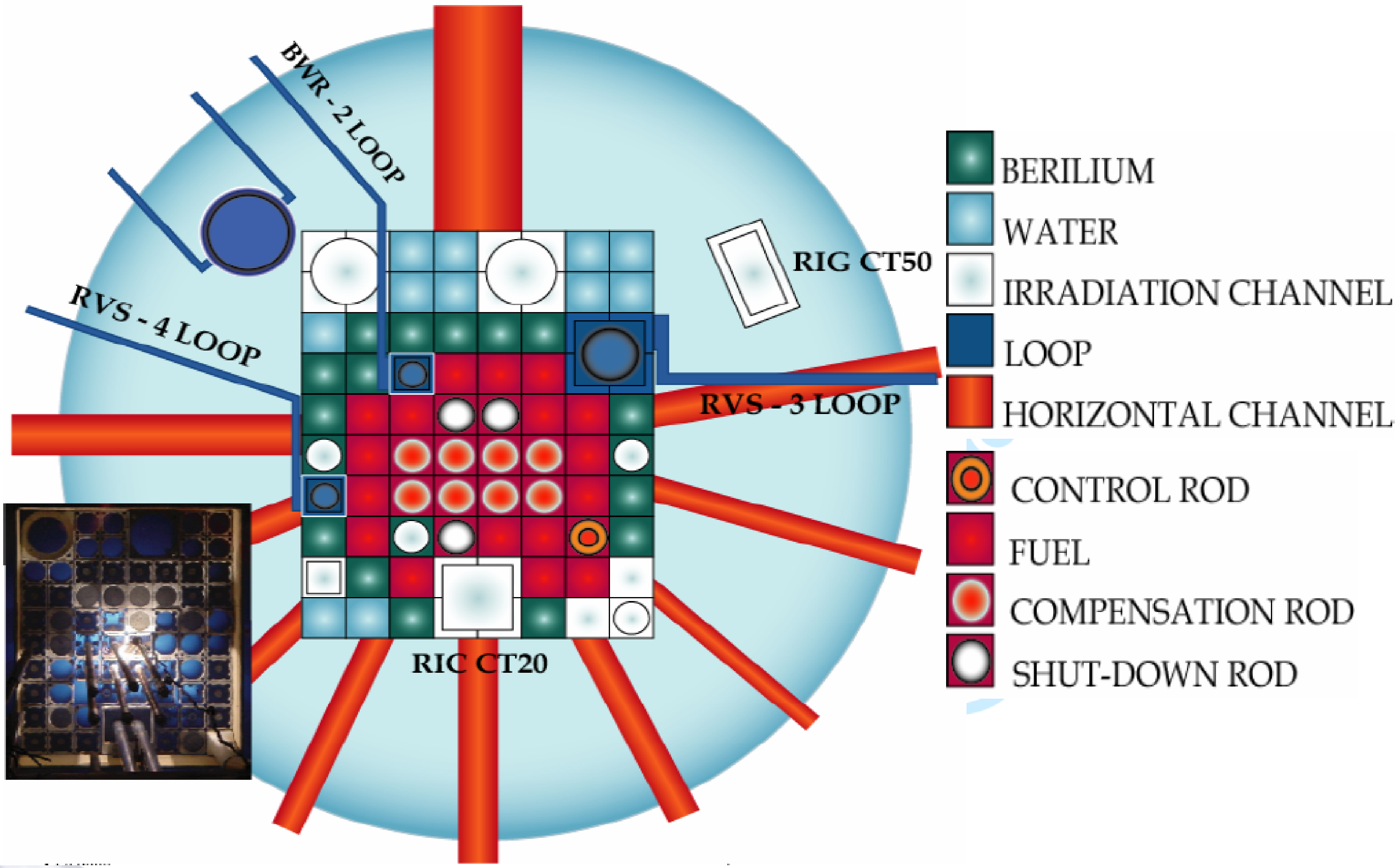
Experimental Parameters for materials testing in loops

1. As close as plant coolant chemistry:
   - high flow rate
   - water of very high purity ($\kappa \sim 0.1\ \mu S/cm$)
   - radiation effects (radiolysis)
   - gas dosing system
2. Chemistry control:
   - gasses, conductivity: on-line measurement
   - ions, pH, etc.: off-line (sampling system)
3. Instrumentation
   - electrically heated rods
   - SCC hydraulic loading system
   - SSRT

High Pressure Loop Parameters

Loop	Water chemistry	Temperature [ºC]	Pressure [MPa]	Flow Rate [t/h]
RVS-3	VVER/PWR	345	16.5	3 - 10
BWR-1	BWR	300	10	2
BWR-2	BWR	300	12	8
ZINC	PWR	320	15.5	0.8 - 1
RVS-4	VVER	322	15.7	2

Location of loops and rigs in LVR-15 reactor



Reactor Dosimetry

- According to the type of experiment different demands on reactor dosimetry are expected. Neutron spectra, thermal and fast neutron flux densities and their changes during the irradiation, final neutron fluences, gamma radiation heating and absorbed doses are to be measured. To fulfil these demands, several measures are taken:

- irradiation position assessment
- instrumentation design
- mock up experiment
- radiation monitoring
- post-irradiation evaluation

RVS–3 Loop (1)

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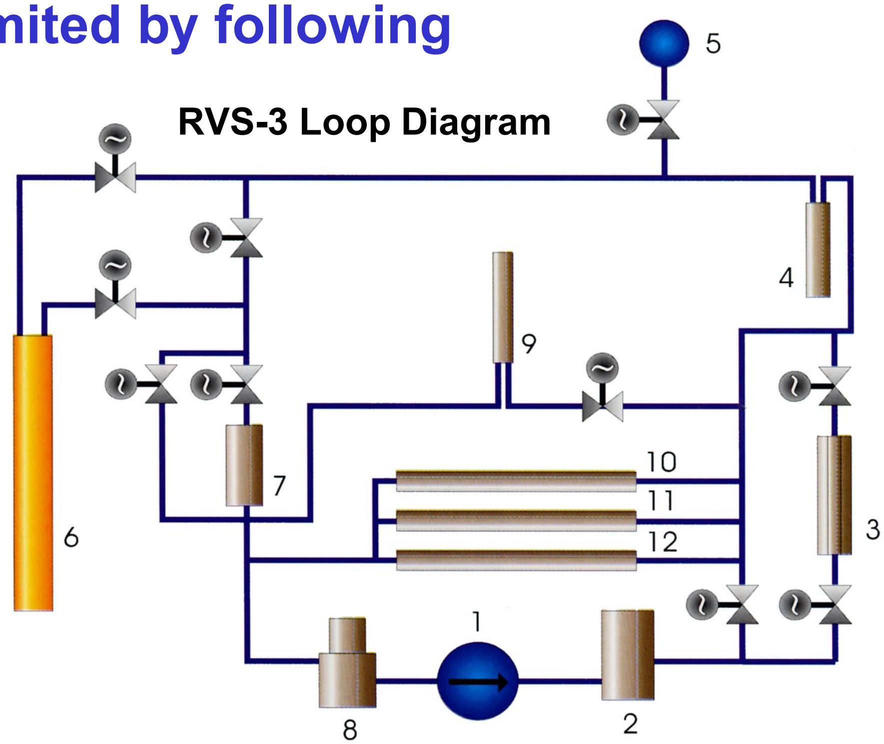
The loop is designed for material and radioactivity transport investigation under PWR/VVER conditions. The RVS-3 loop facility enables to perform irradiation experiments in wide range of operational parameters limited by following maximum parameters :

- **Pressure 16.5 MPa**
- **Temperature 345°C**
- **Water flow rate 10 000 kg/h**
- **Neutron flux ~1x10^{18} n/m^{2}s**
- **Electrical heating capacity 100 kW**

RVS-3 Loop Diagram

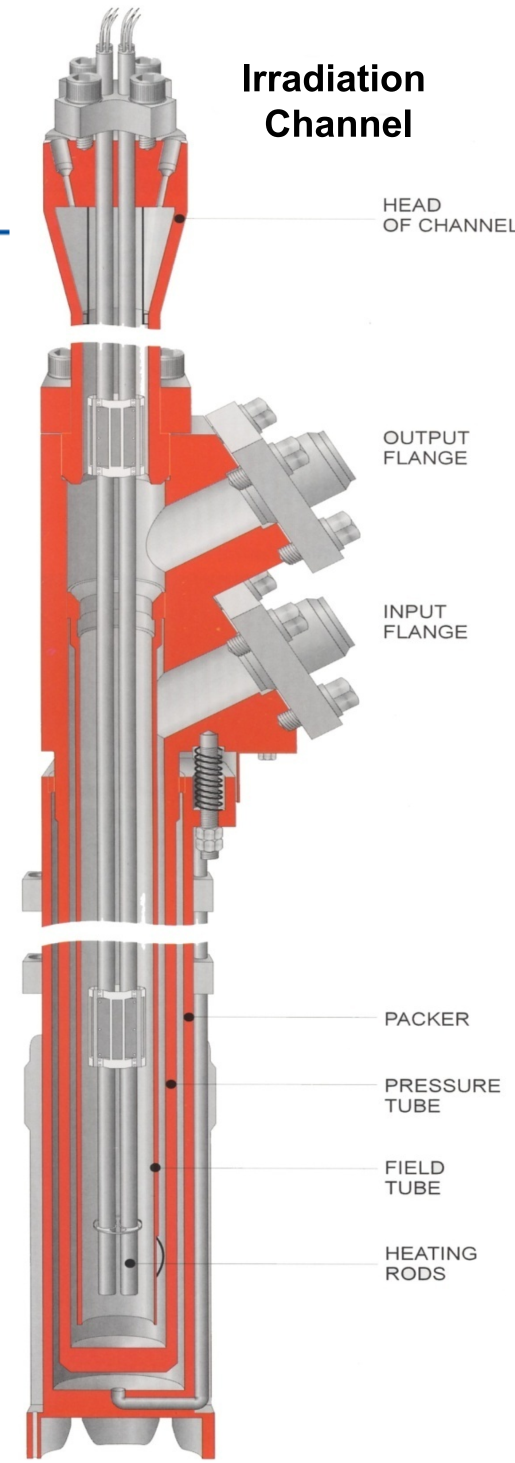


1 main circulating pump
2 electrical heater
3 out-of-pile test section
4 comparative channel
5 volume compensator
6 active channel
7 cooler
8 degasser
9 pressurizer
10 filtration circuit
11 cold measuring circuit / autoclaves /
12 hot measuring circuit / autoclaves /

RVS–3 Loop (2)

- Investigation of structural materials mechanical properties degradation and corrosion behaviour under irradiation and PWR/VVER water chemistry and thermal-hydraulic conditions
- Investigation of behaviour (corrosion, hydriding) of fuel cladding materials under influence of irradiation, thermal flux and water chemistry conditions
- Investigation of radioactivity transport and behaviour under PWR/VVER conditions (e.G. Influence of water chemistry, pHT regime, zinc injection ammonia, etc.)
- Testing of high-temperature, high pressure sensors for water chemistry monitoring.

Irradiation Channel



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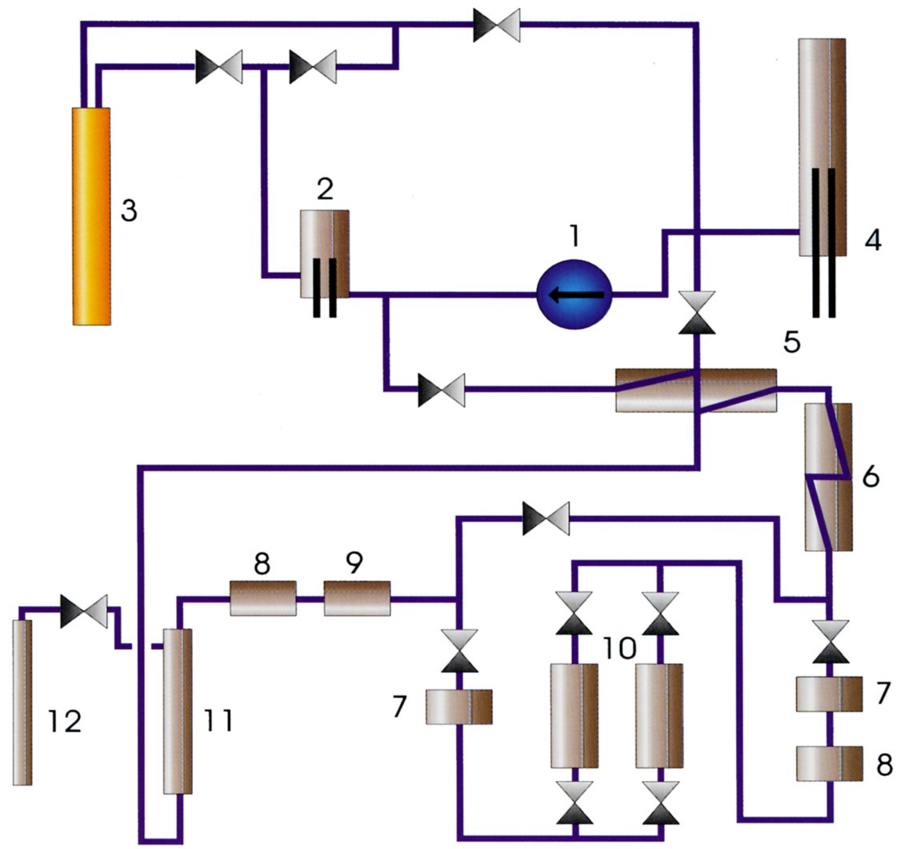
BWR–1 Loop (1)

- The loop is designed for investigation of structural materials behaviour and radioactivity transport under BWR conditions.
- The BWR-1 loop facility enables to perform irradiation experiments in wide range of operational parameters limited by the following maximum parameters:
  - **Pressure 10 MPa**
  - **Temperature 300°C**
  - **Water flow rate 2 000 kg/hr**
  - **Neutron flux ~1x10^{18} n/m^{2}s**

BWR-1 Loop Diagram



1 circulation pump
2 heater
3 active channel
4 pressurizer
5 heat exchanger
6 cooler
7 mech.filter
8 cond.measurement
9 H_2, O_2 measurement
10 mixbed filter
11 H_2, O_2 dosing
12 pressure gas bottle

BWR–1 Loop (2)

- Investigation of materials mechanical properties degradation and corrosion behaviour under irradiation and BWR water chemistry conditions.

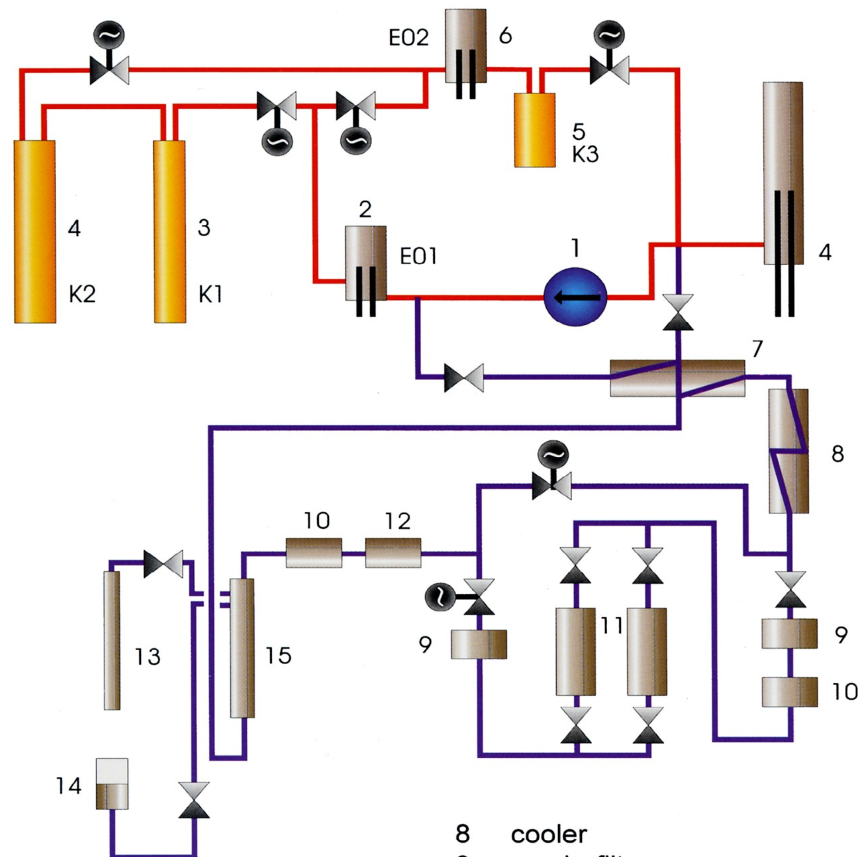
- Investigation of radioactivity transport and behaviour under BWR conditions (e.g. Hydrogen water chemistry, zinc injection, etc.).

- Testing of high-temperature, high pressure sensors for water chemistry monitoring.

BWR–2 Loop (1)

- The experimental water loop shall be used for the material research of BWR reactors under conditions simulating the operation of BWR reactors (pressure, temperature, radiation, fluid analysis).
  - Pressure 12 MPa.
  - Temperature 300°C.
  - Water flow rate 8 000 kg/h
  - Force applied to the specimen 150 kN.

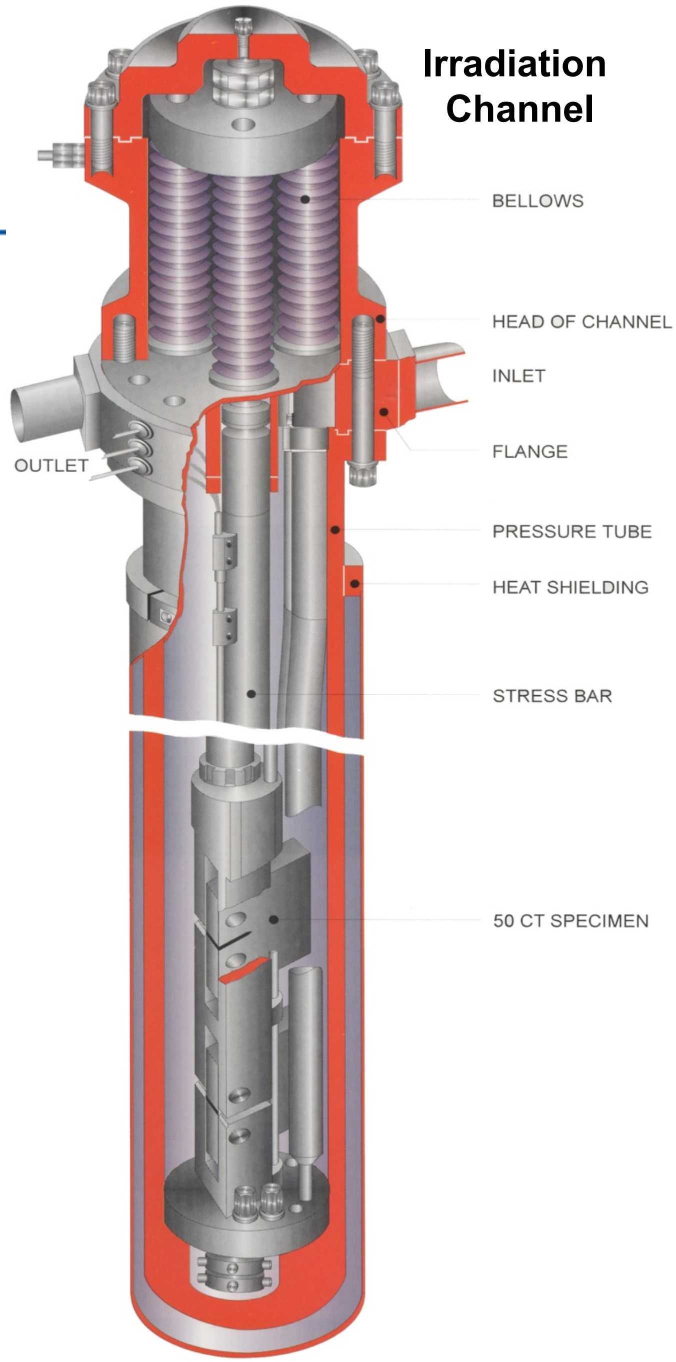
BWR-2 Loop Diagram



1 circulation pump
2 heater E01
3 generation channel
4 irradiation channel
5 out-of-pile channel
6 heater E02
7 regen. cooler
8 cooler
9 mech. filter
10 conductivity meassurement
11 mixbed filters
12 H_2,O_2 measurement
13 pressure gas bottle
14 reagents vessel
15 H_2,O_2 dosing

BWR–2 Loop (2)

- IASCC of RPV and core internals
  - 2CT & 1CT specimens,
  - hydraulic loading
    – cycling/constant load 20-75 MPa√m,
  - ferritic & austenitic steels, BM, HAZ



BWR-2 Loop (3)

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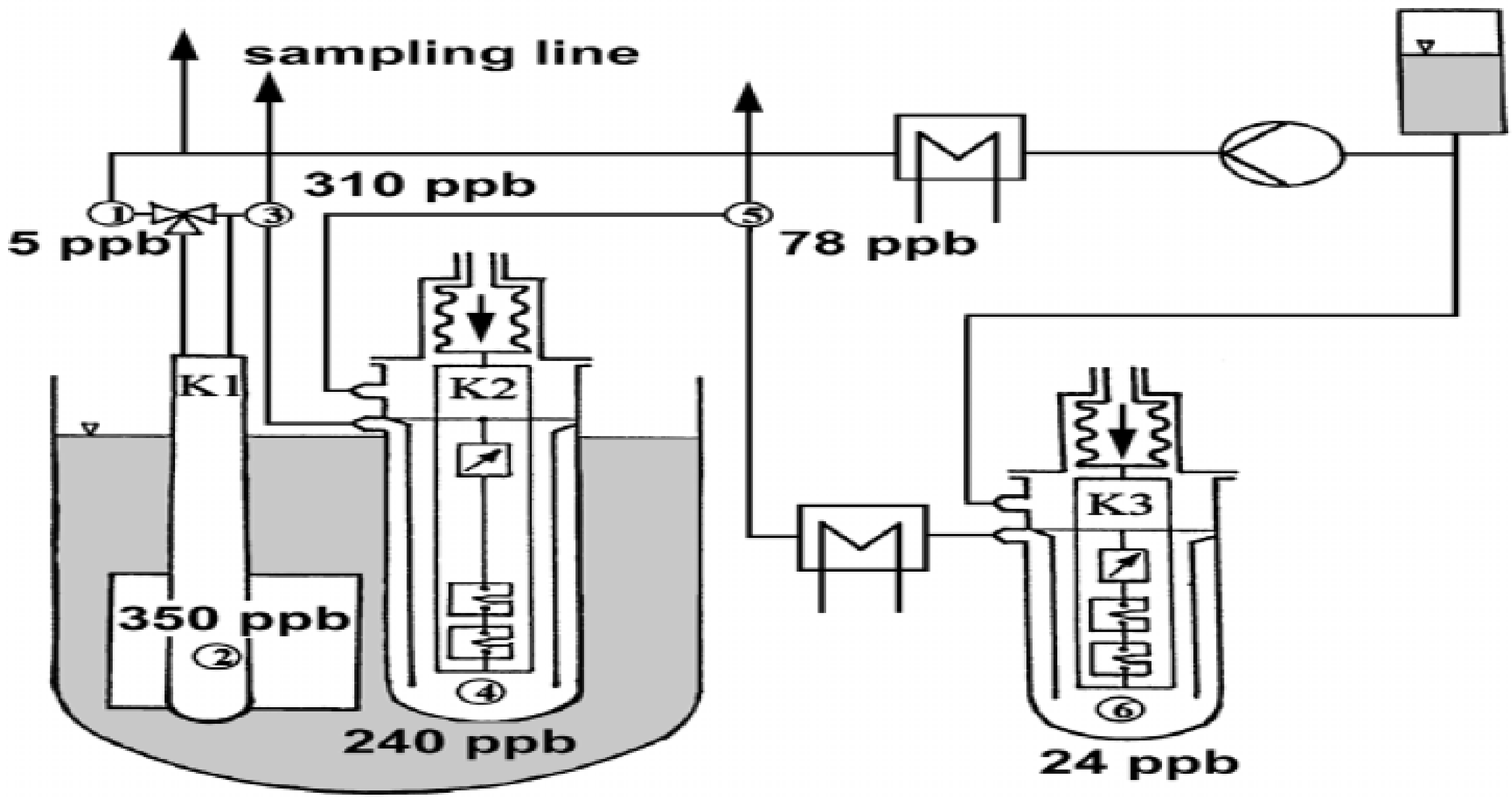
BWR-2 Loop with Hydrogen Peroxide Measurements



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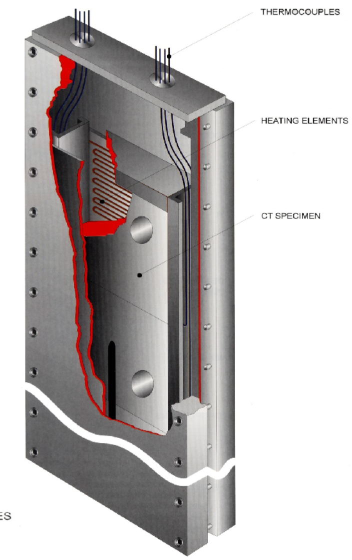
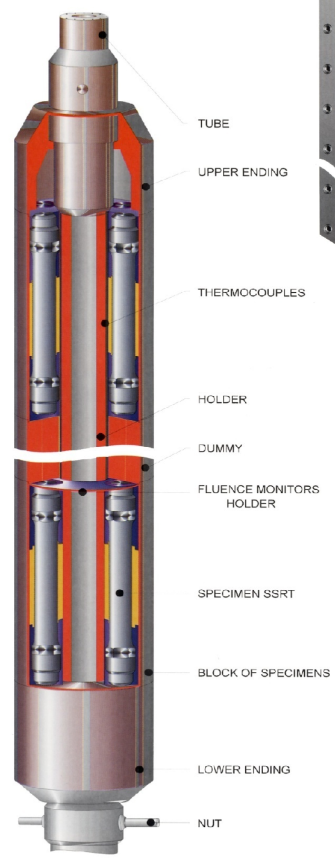
Irradiation Rigs

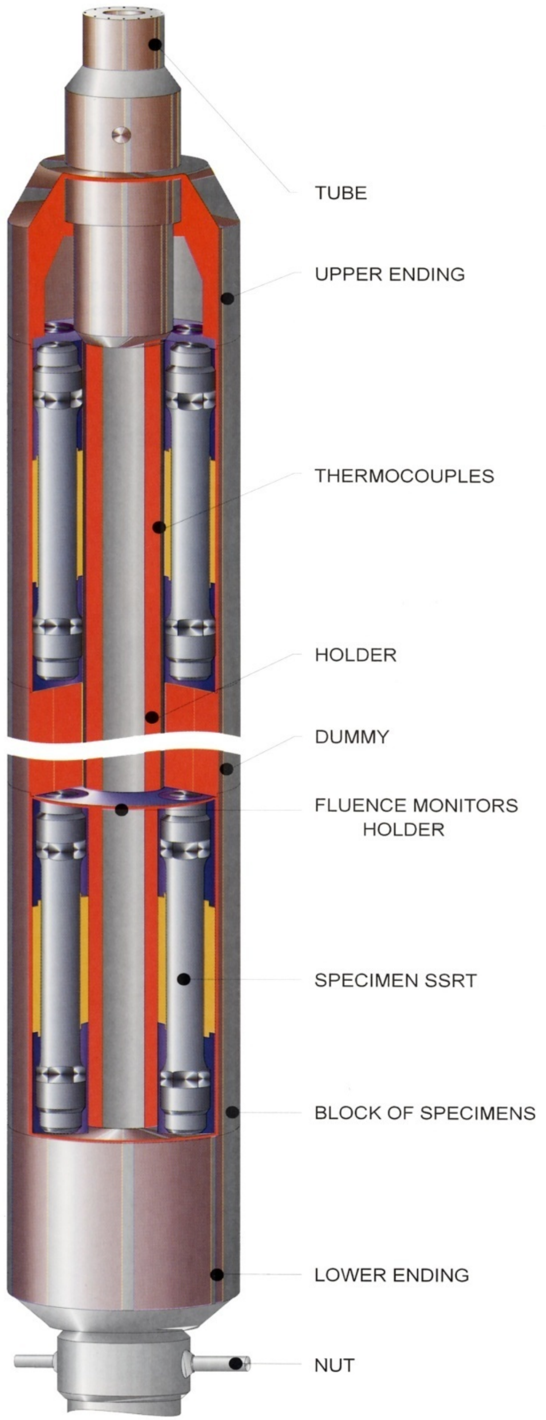
- ❑ **Cylindrical, flat**
- ❑ **Full temperature control**
- ❑ **Four types of specimens:**
  - **Tensile specimen**
  - **CT specimen**
  - **Round CT specimen**
  - **Charpy-V specimen**





CHOUCA Irradiation Rig

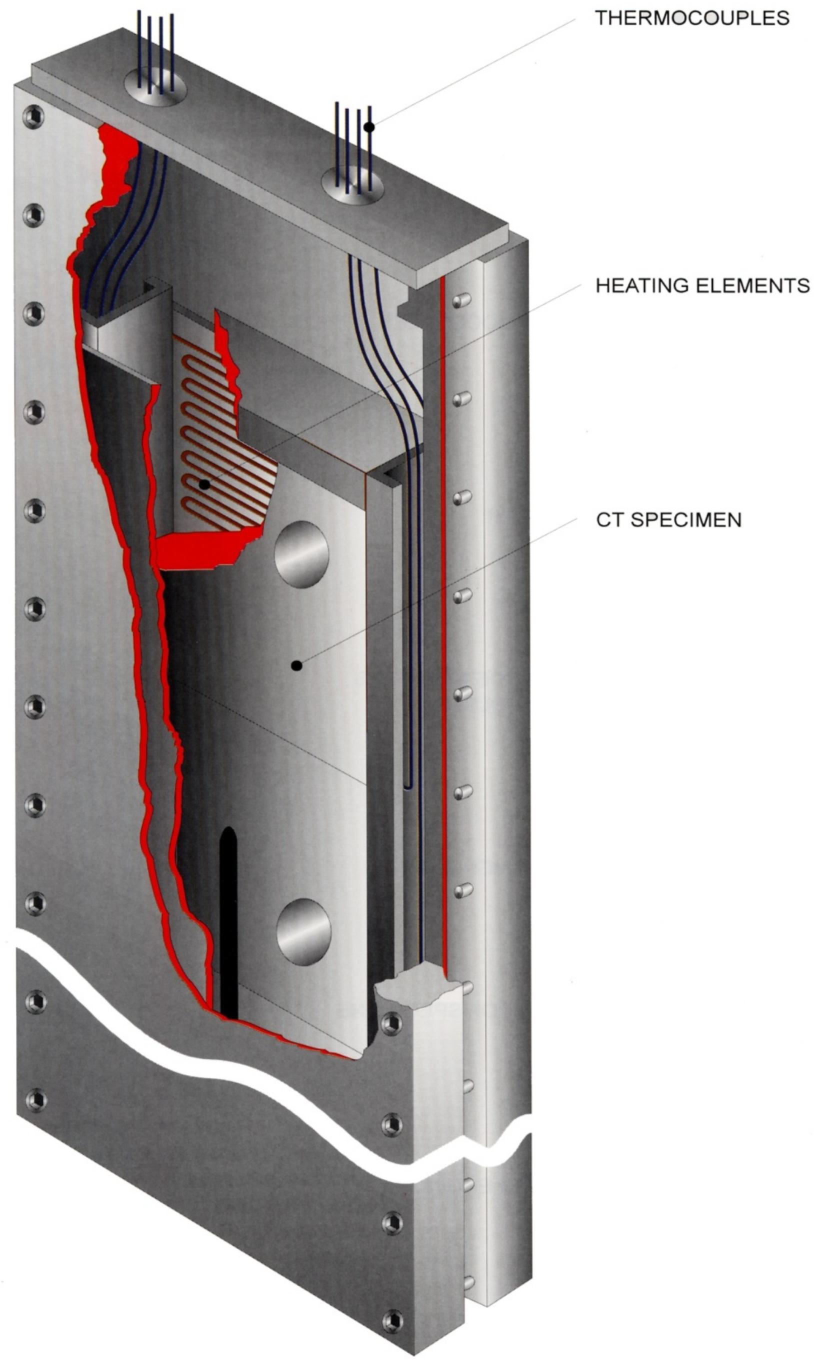
- Independent and controlled heating in sections
- Thermocouples
- Neutron monitoring



Flat Irradiation Rig

- Independent and controlled heating in sections
- Thermocouples
- Neutron monitoring

  - Rig cross-section
    - ❑ 70 x 70 mm^2
    - ❑ 140 x 70 mm^2
  - Sample cross-section
    - ❑ 60 x 60 mm^2
    - ❑ 120 x 60 mm^2



SCWR and VHTR Experimental Base for In-Reactor Material & Chemistry Studies

- **Experience based on long-term research in material, water chemistry and radiolysis tests for PWR/VVER and BWR**
  - **In the case of SCWR: advantage taken from practical experience in water chemistry and materials testing in PWR/VVER and BWR loops.**
  - **In the case of He systems, experience is partly based on former CO_2 in-reactor loop for GCHWR systems and on material irradiation for ADTT and big samples (CCT) irradiation of RPV.**

Mechanical Tests In-pile for BWR and PWR

- SCC tests were performed in BWR
  - Reactor water loop BWR-2: 8 t/h flow rate, 0.4 t/h purification rate, 9MPa, 288 ^{o}C, NWC/HWC, on-line ECP
  - Constant load or cycling was applied to 1CT/2CT specimens
  - Potential drop measurement (DCPD) of crack growth rate was applied
- In-pile SSRT was performed on highly irradiated core internals of PWR
  - Reactor water loop RVS-3 with PWR water chemistry conditions; flow rate 8 t/h

SCWR Loop for materials testing and water chemistry optimization

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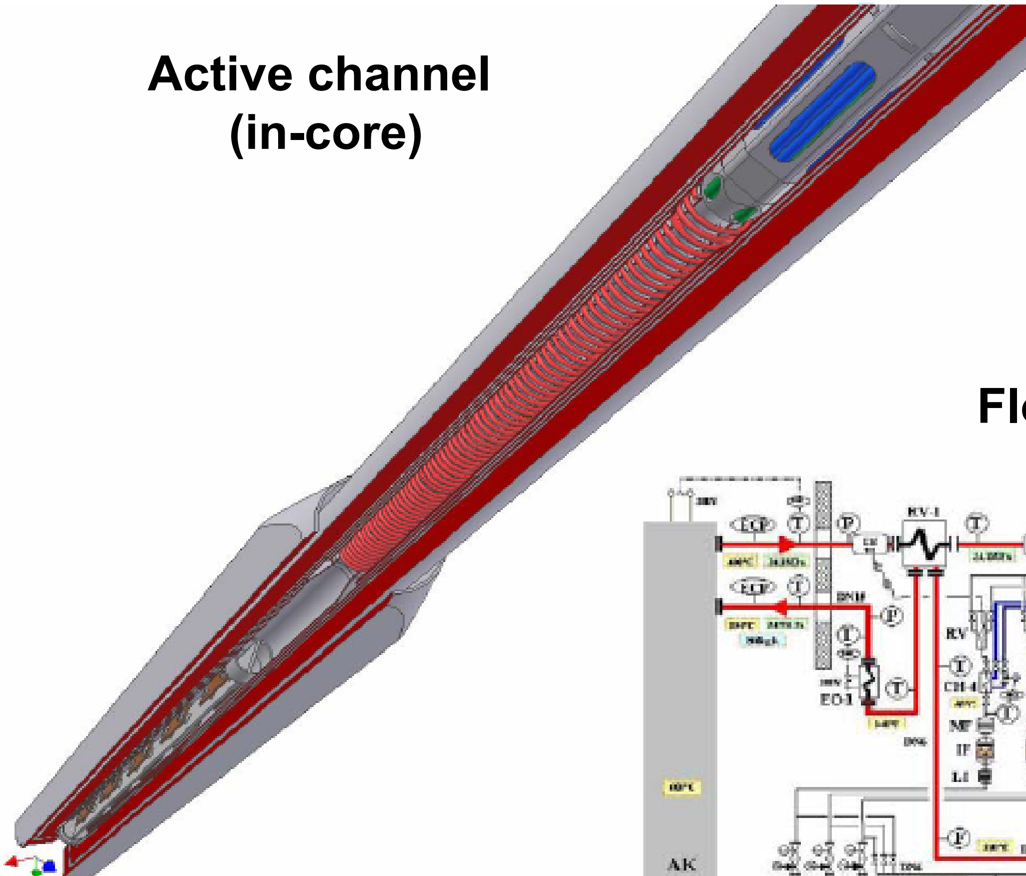
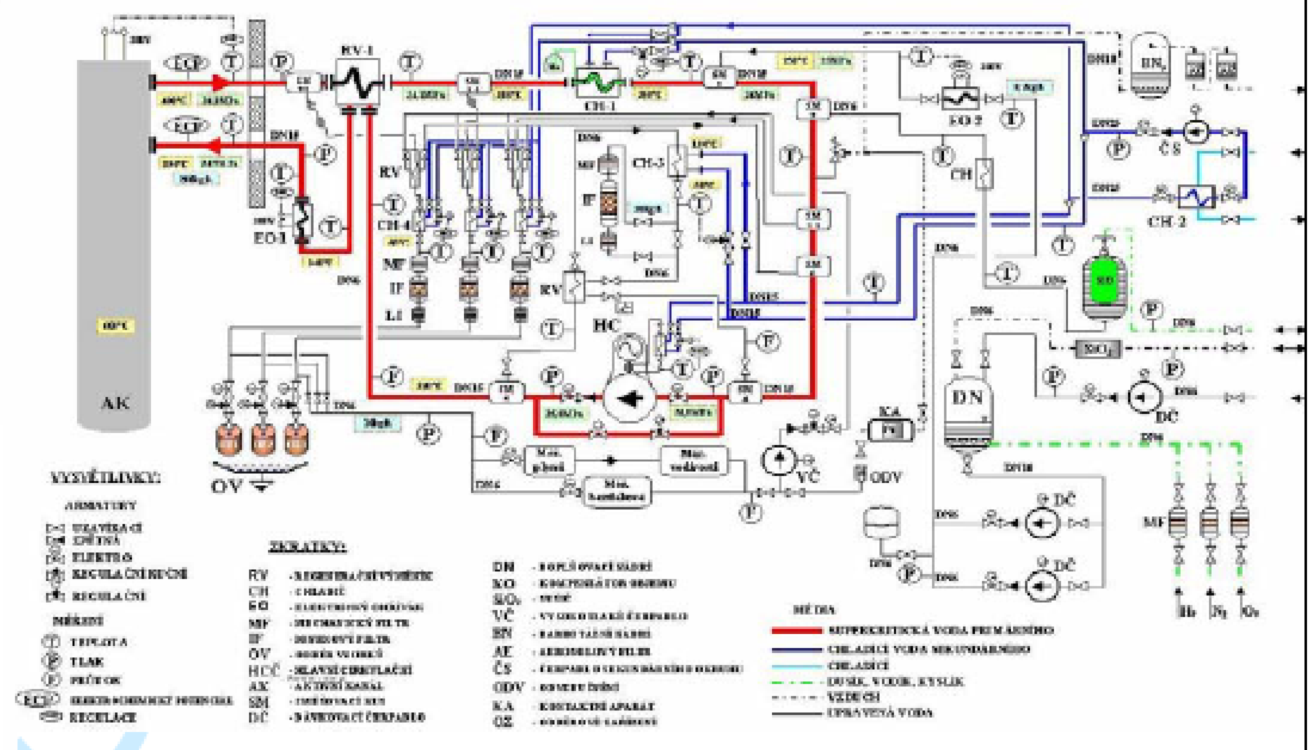
- Parameters
  - 600 °C, 25 MPa in the active core
  - 350-400 °C in the primary circuit
  - Flow rate 200 kg/h
  - Purification: molecular sleves; 5-10% of the main flow
- Objectives of the loop:
  - Testing of candidate materials
  - To study in-core radiolysis
  - To test and optimize water chemistry
  - Attempts to install a redox potential sensor (and/or ECP sensor, although it currently looks quite troublesome)
  - Instrumentation with a loading system is a future task (It will probably require a different design of the active channel internals

SCWR Loop

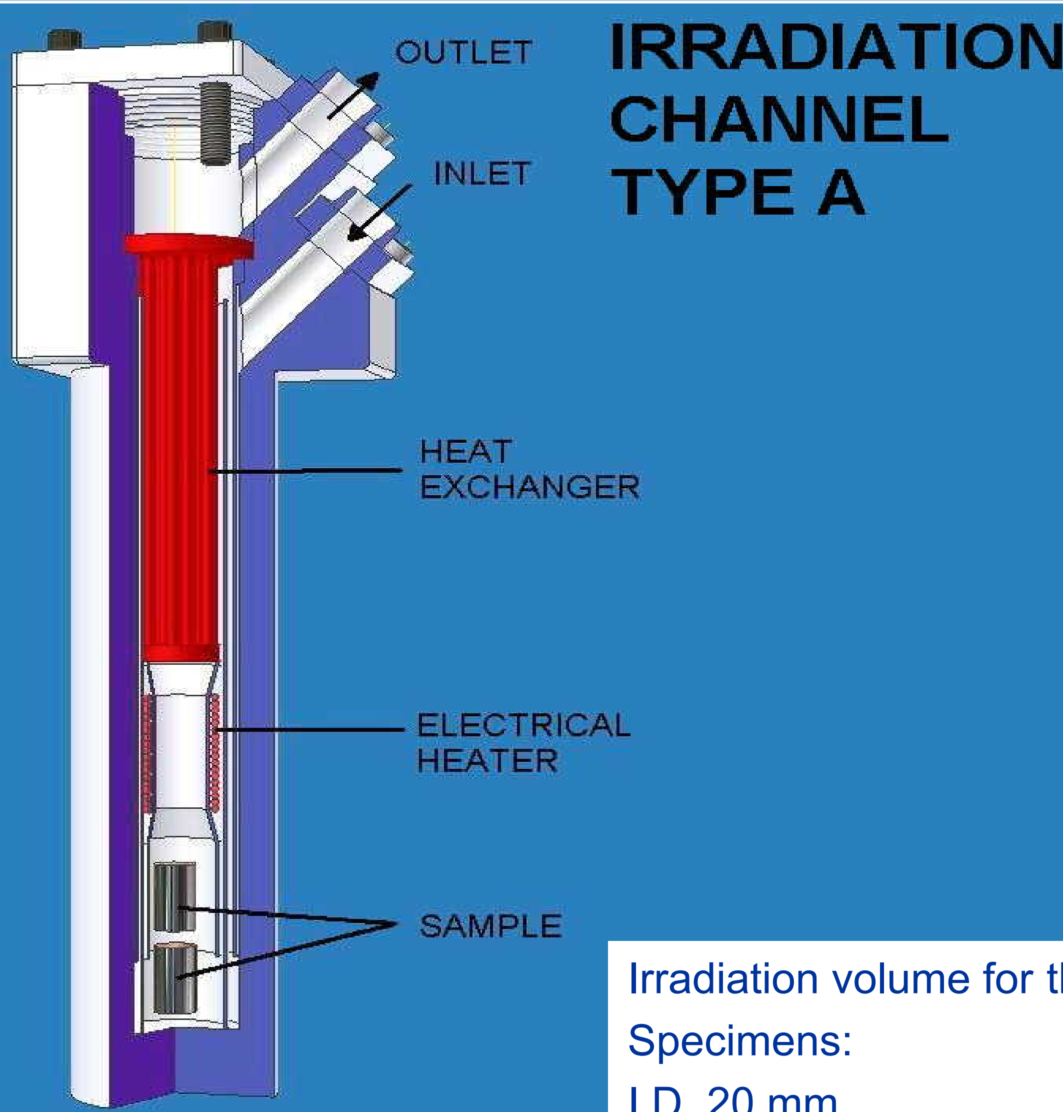
Active channel (in-core)



Flow chart of auxiliary circuits



SCWR Loop



Irradiation volume for the Specimens:

I.D. 20 mm,

Length 500 mm

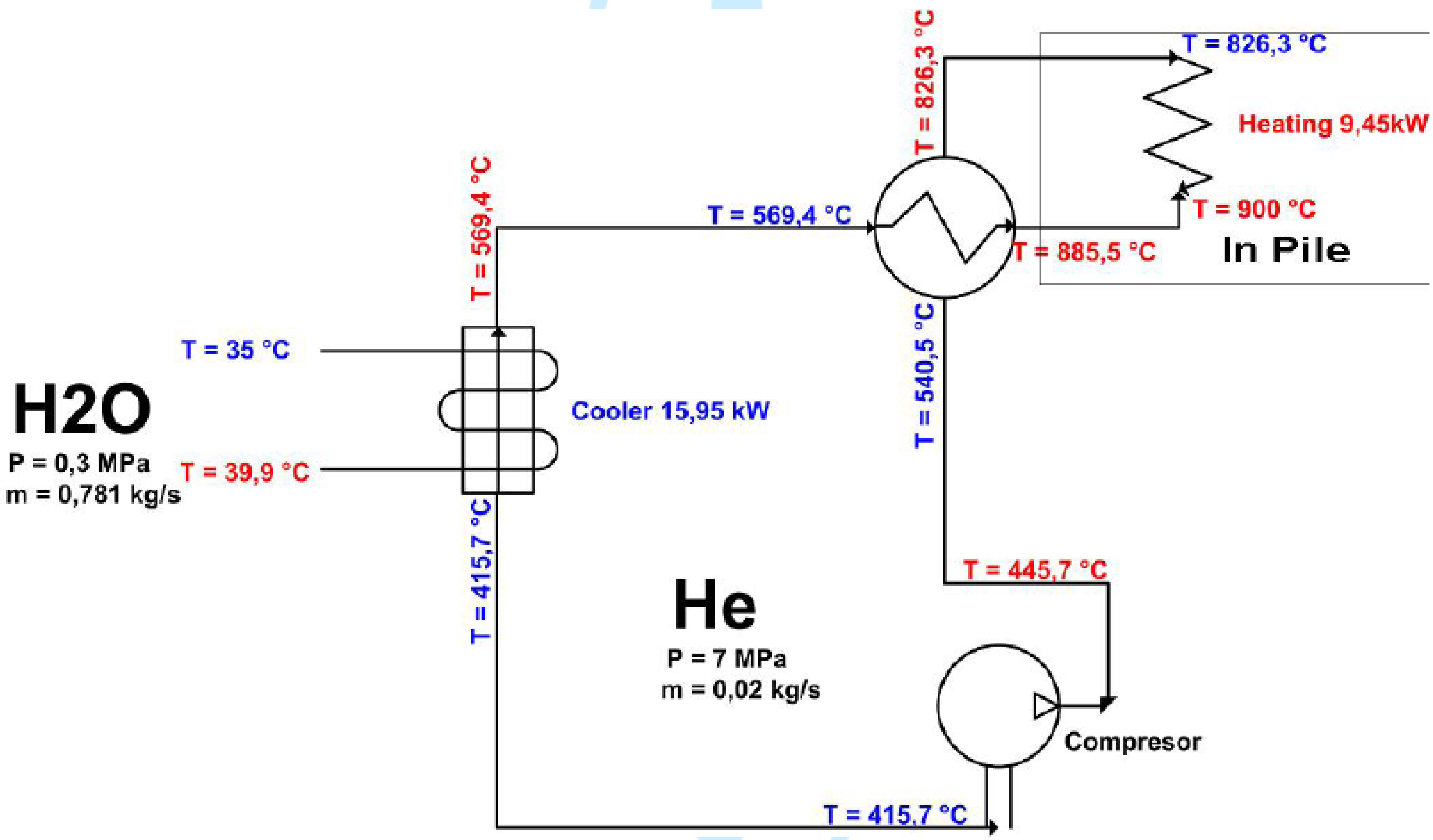
SCWR Instrumentation

- Attempts to install redox potential and/or ECP sensors in-core to monitor conditions of environment and material samples.
- Limited experience from the past, many technological constraints.
- First proposal – platinum electrode for redox potential monitoring (simple design) and a lead-through for a reference electrode (not available yet).
- First trial electrodes tested in autoclave for durability of the ceramic and the joint

Helium Loop for materials testing and purity control

- Parameters
  - 7 Mpa, 900 ºC
  - Flow rate 36 kg/h
  - Purification: molecular sleves; 5-10% of the main flow
- Testing of reactor component materials:
  - Nuclear graphite
  - Reactor pressure vessel internals
- Effect of impurities present in He on oxidation of materials
- Impurities control and analytical methods for their evaluation
- In 1st stage, material irradiation w/o mechanical load shall be performed
- In 2nd stage, creep and fatigue tests are considered

HTHL Flow Chart



Active channel with in-pile compressor

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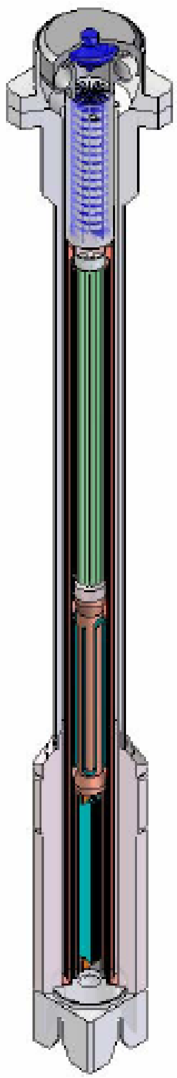
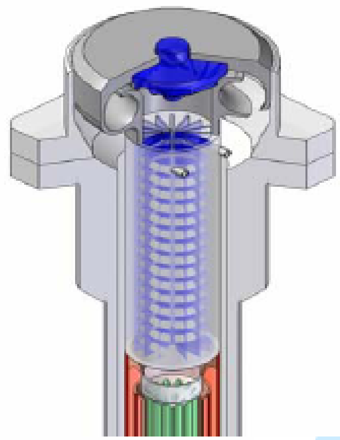
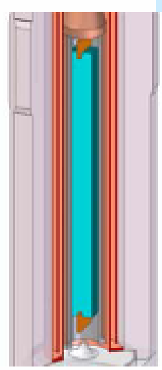
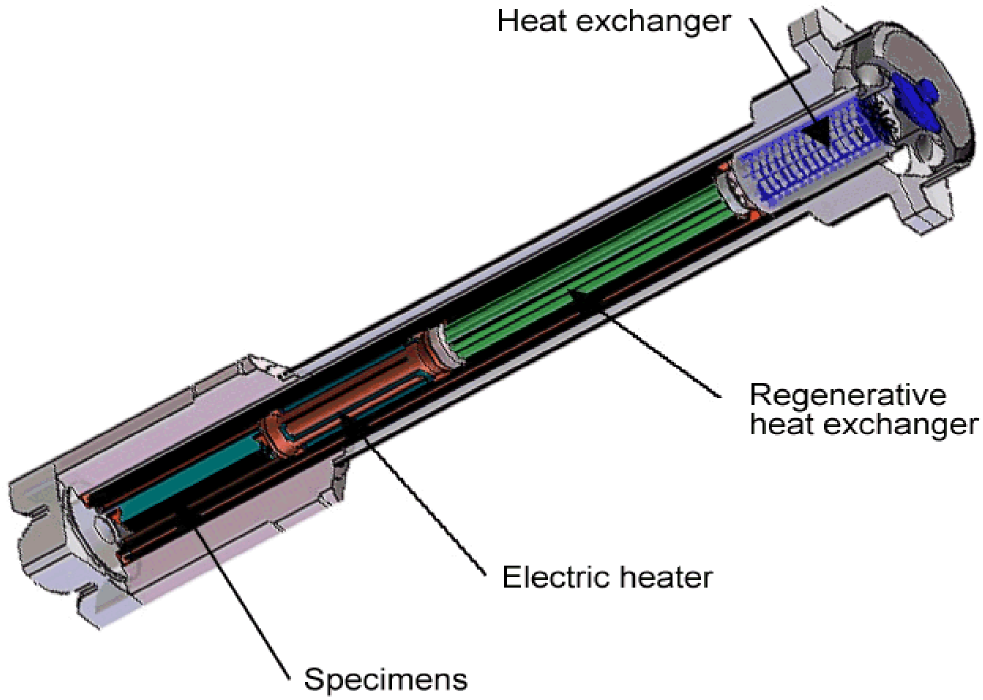


Head with compressor



Space for samples

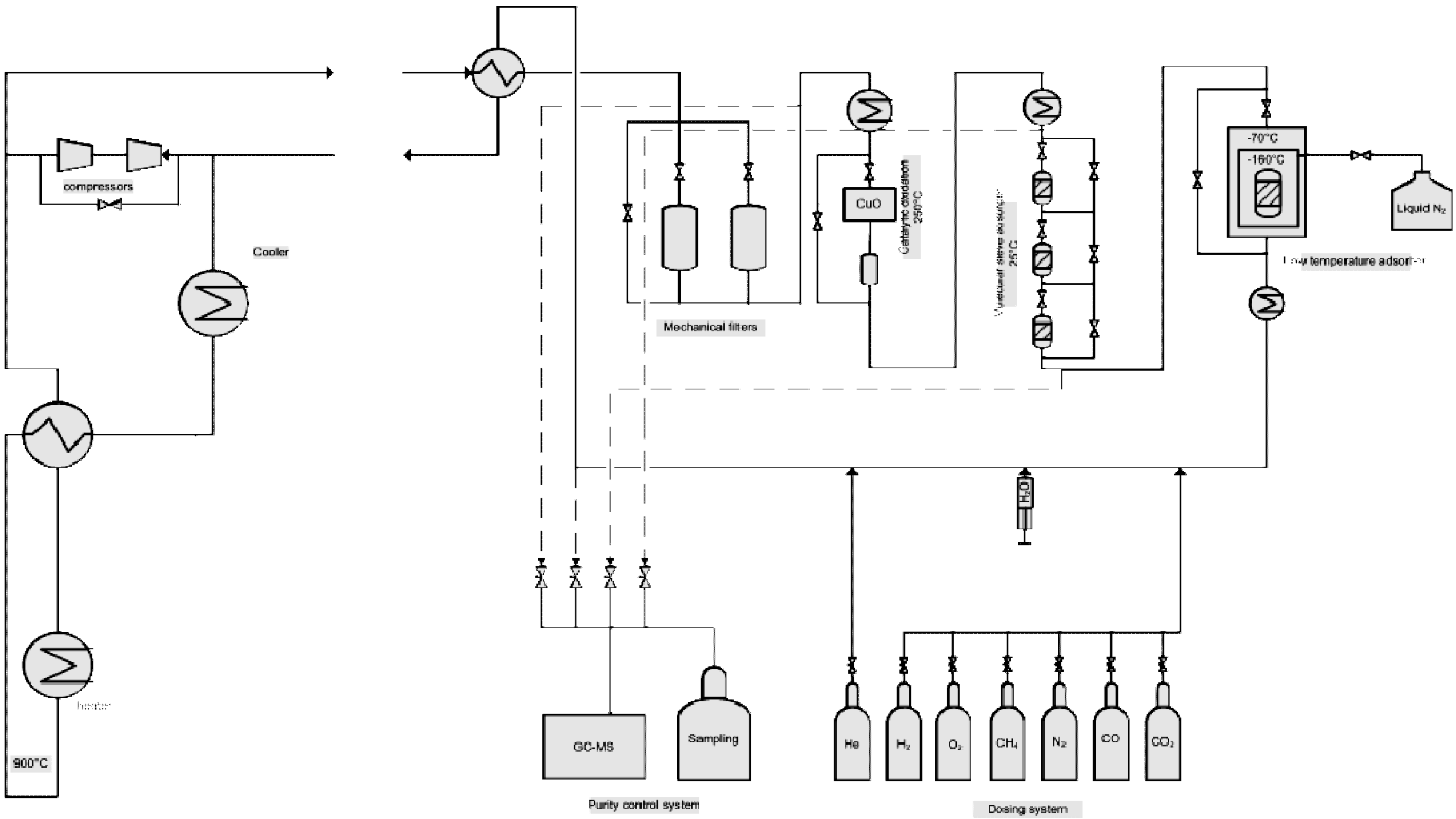




Space for samples: 30 x 570 mm

Sample size: 4 x 40 mm

High Temperature Helium Loop (HTHL)



Active channel

Dosing and helium purification system

HTHL: Dosing and Purification System

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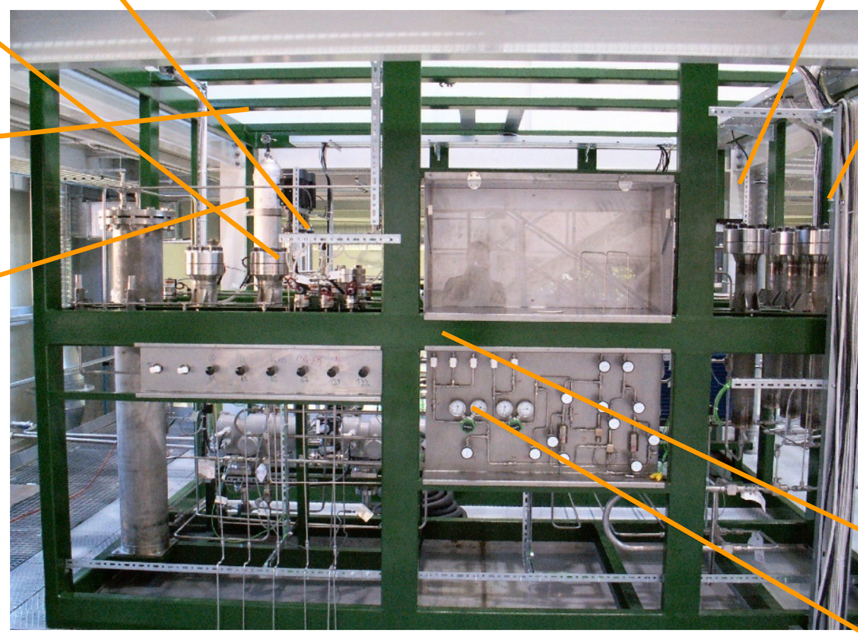
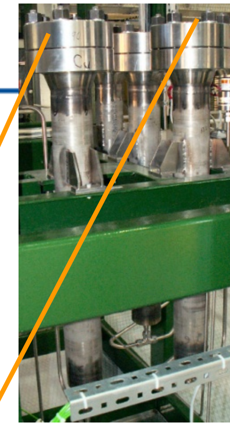
Frame dimensions: 3,5 x 3,4 x 2,7m^3

Dosing system

Volume compensator and water pumps





Adsorbers

Low temperature adsorber

Sampling system

HTHL: Main Parts

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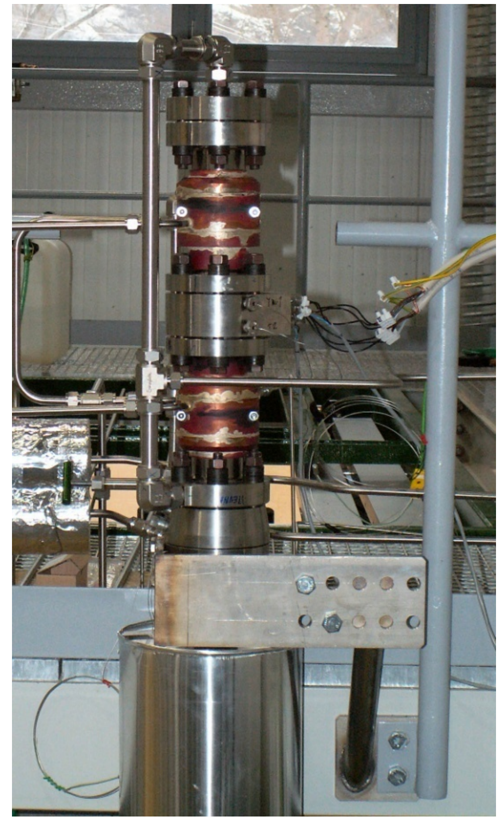
Active channel with compressor

Compressor

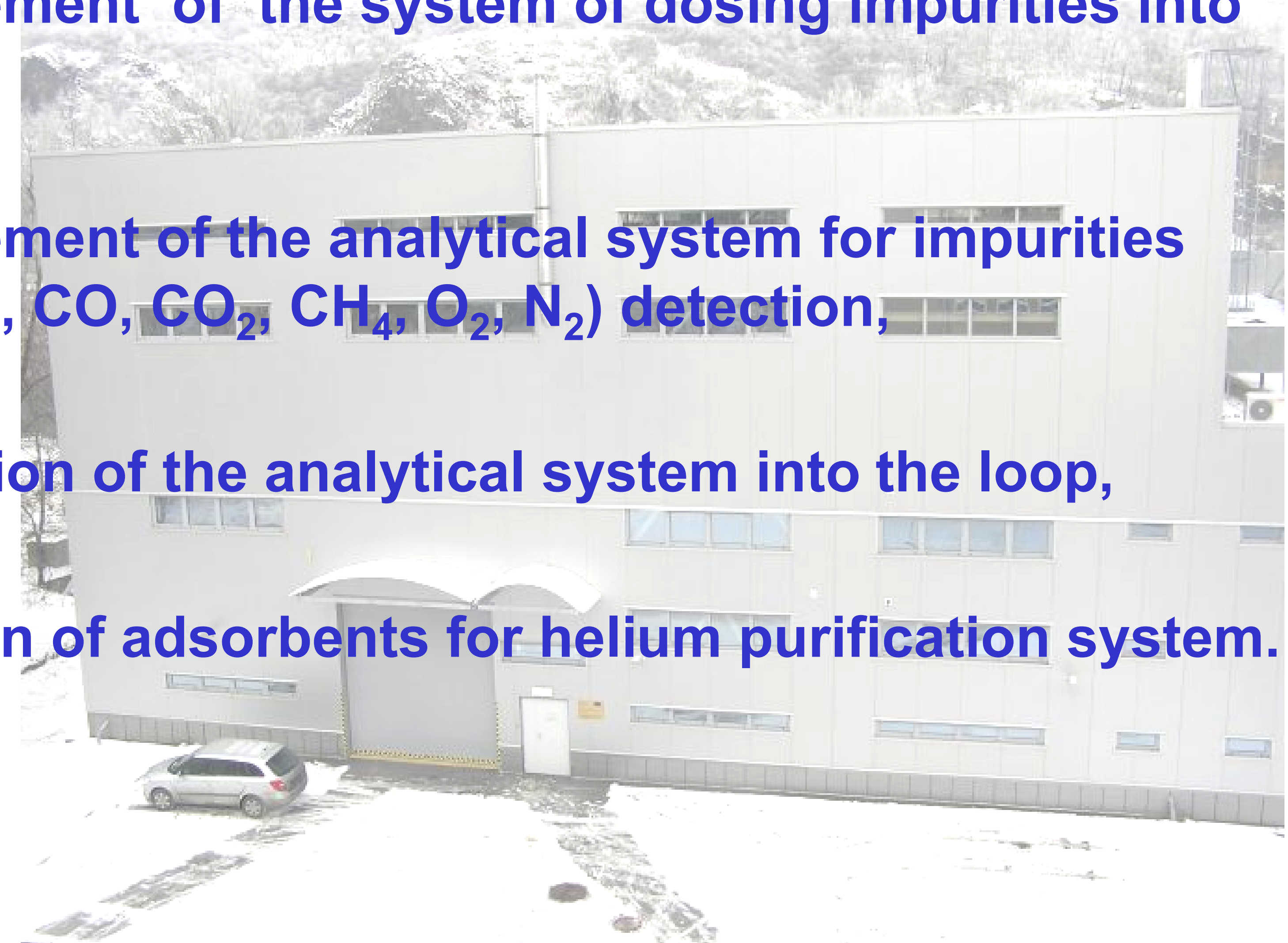


HTHL: Current Status

- Current status of HTHL
  - HTHL has been set together in the hall,
  - First test of HTHL have been started,
  - Manufactural inaccuracies are being corrected.

HTHL: Next Steps

- Improvement of the system of dosing impurities into helium,
- Improvement of the analytical system for impurities (H_2, H_2O, CO, CO_2, CH_4, O_2, N_2) detection,
- Integration of the analytical system into the loop,
- Selection of adsorbents for helium purification system.



Irradiation Examination (1)

- Dismantling in the reactor hot cells – some simple PIE may be performed in these cells;
- For specialized PIE (fracture toughness and tensile tests, preparation of cross-sections for SEM and TEM investigation, etc.), specimens are transported to hot and semi-hot cells situated outside the reactor building.

Irradiation Examination (2)

- The following tests can be performed:
  - Static tensile tests,
  - Impact instrumented Charpy-V-notch type tests on standard and subsize specimens,
  - Static fracture toughness tests on standard and subsize specimens,
  - Crack growth rate in air, vacuum and BWR/PWR environments,
  - Stress corrosion tests in BWR/PWR environments
  - Slow strain rate tests.

- NRI can accept and export the irradiated materials.

Conclusions

- Experience gained with PWR and BWR loops will be used in supercritical light water and high temperature reactors in-core testing to study synergy effects of materials, coolant, chemistry, radiation and mechanical load;
- New experimental hall was built for out-of-pile loop tests before loading the facilities into the reactor core;
- SCWR loop and HTHL loops shall be completed during this year, installed in the hall and tested out-of-pile (tests shall be completed by 2009/2010);
- The future experimental program is in the line with EU partners and GIF members.

Thank you for your attention ...

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