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INVESTIGATION OF FISSION PRODUCT RELEASE FROM HIGH BURN-UP FUEL ANNEALED UNDER OXIDIZING AND REDUCTION CONDITION

VERONIKA

(VVER Experiments on Release due to Over-heating: Normalization and Knowledge Augmentation).

Project Proposal

RIAR (Dimitrovgrad), IBRAE (Moscow)

Objectives of VERONIKA Project

- ***To obtain detailed experimental data on fission products release from highly irradiated VVER fuel along with fuel micro-structure evolution under severe accident conditions***

- ***To use these results for the development (and validation) of the physical models and numerical codes describing fuel behaviour and fission products release***

MFPR Code Features

Development

IBRAE-IRSN co-operation (1995-2006)

Mechanistic description

of FP behavior in irradiated UO_2 with intact geometry

- ***in irradiation regime : steady state and transients***
- ***in annealing regime : steady state and transients***
- ***in accidental conditions: LOCA, severe accidents***

Two kinds of mechanistic models

- ***Fission gases and gas bubbles***
- ***Chemically active elements***

And also…

- ***Interaction between the two models***
- ***Fuel oxidation/vaporisation in steam/hydrogen/inert mixtures***
- ***Evolution of fuel microscopic defect structure***

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Tasks of VERONIKA Project

- ***To obtain new detailed experimental data on fuel microstructure, FP release and behaviour under the insufficiently investigated conditions for VVER high burn-up fuel***
- ***Basing on results of the new experiments, to obtain data missing for FP release modelling and code development***
- ***To improve existing physical models, to develop and validate the codes predicting FP release under severe accident conditions basing on newly obtained data for VVER fuel***

Scope of VERONIKA Project Tests

- ***Investigation of fission products release from fuel with burnup of 60 MW*d/kgU in oxidizing and reducing environments in the temperature range of 1400 - 2300°C***
- ***Investigation of the release of a wide list of fission products including short living isotopes: ^{85}Kr, ^{133}Xe, ^{131}I, ^{137}Cs, ^{134}Cs, ^{106}Ru, ^{103}Ru, ^{144}Ce, ^{99}Mo, ^{140}Ba, ^{95}Zr and other. That will be provided by pre-irradiation of the specimens in the research reactor***
- ***Accurate representation of evolution of high burn-up fuel microstructure under tests conditions (by pre- and post-test microanalysis of samples)***

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Main Test Procedures

- *Manufacturing of the experimental rig*
- *Initial fuel rod examinations*
- *Preparation and certification of fuel specimens (fuel pellets and fragments of fuel rods)*
- *Fuel pellets and fuel rod fragments encapsulation*
- *Preirradiation of the capsule*
- *Fuel specimen withdrawal from the capsule*
- *FP release tests*
- *Post-test examinations*

Initial fuel rod examination

Objectives:

- *Selection of the typical spent fuel rod*

Test procedures

- *Y-scanning*
- *Plenum gas analysis*

Fuel and cladding structure characterization

Metallography – *Pellet crack pattern, fuel-cladding interaction/gap, fuel porosity, fuel grain size measurement.*

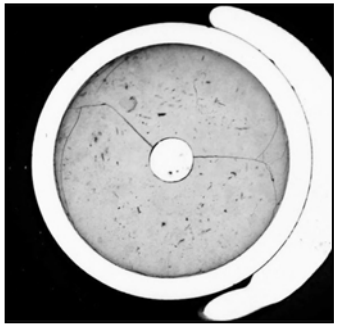
SEM - *(polished surface and fractography) porosity, intra- and intergranular bubbles pattern.*

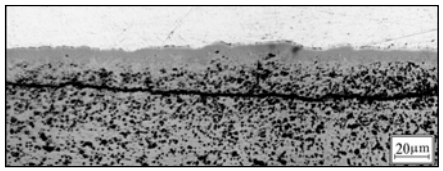
EPMA – *Fission product distribution, precipitates composition.*

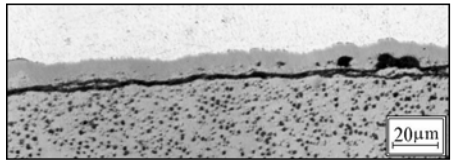
Specimen preparation

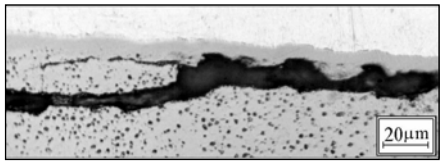
Bare fuel pellet extraction

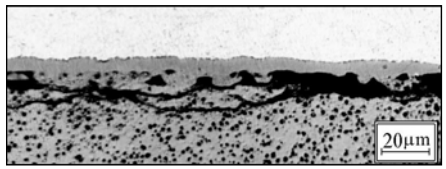
Radial and contraction cracks in the fuel



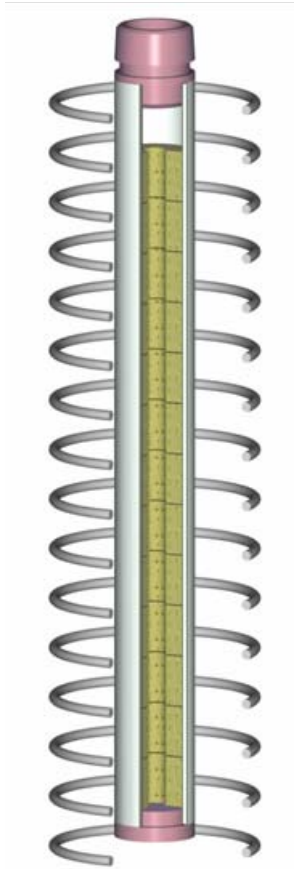


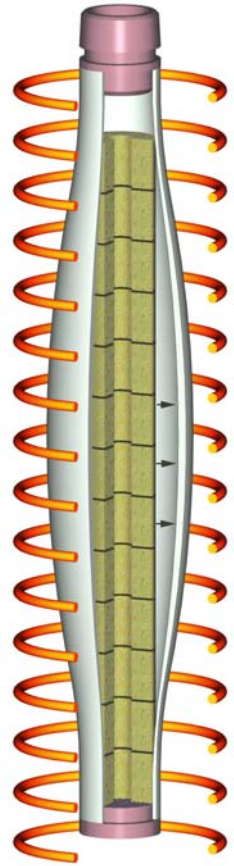






Pellet-clad separation by heating the pressurised rods up to 700°C



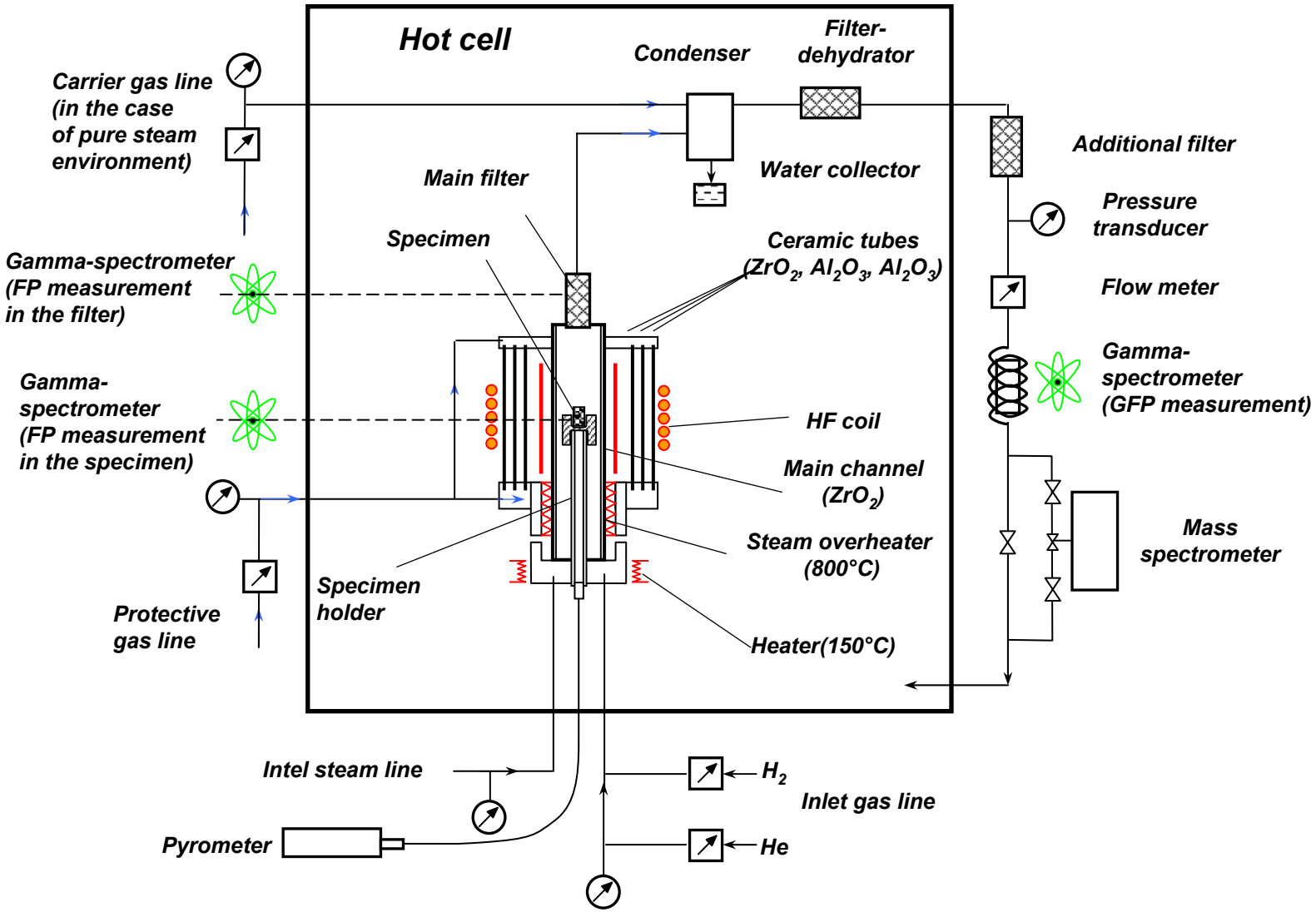


Refabricated fuel irradiation

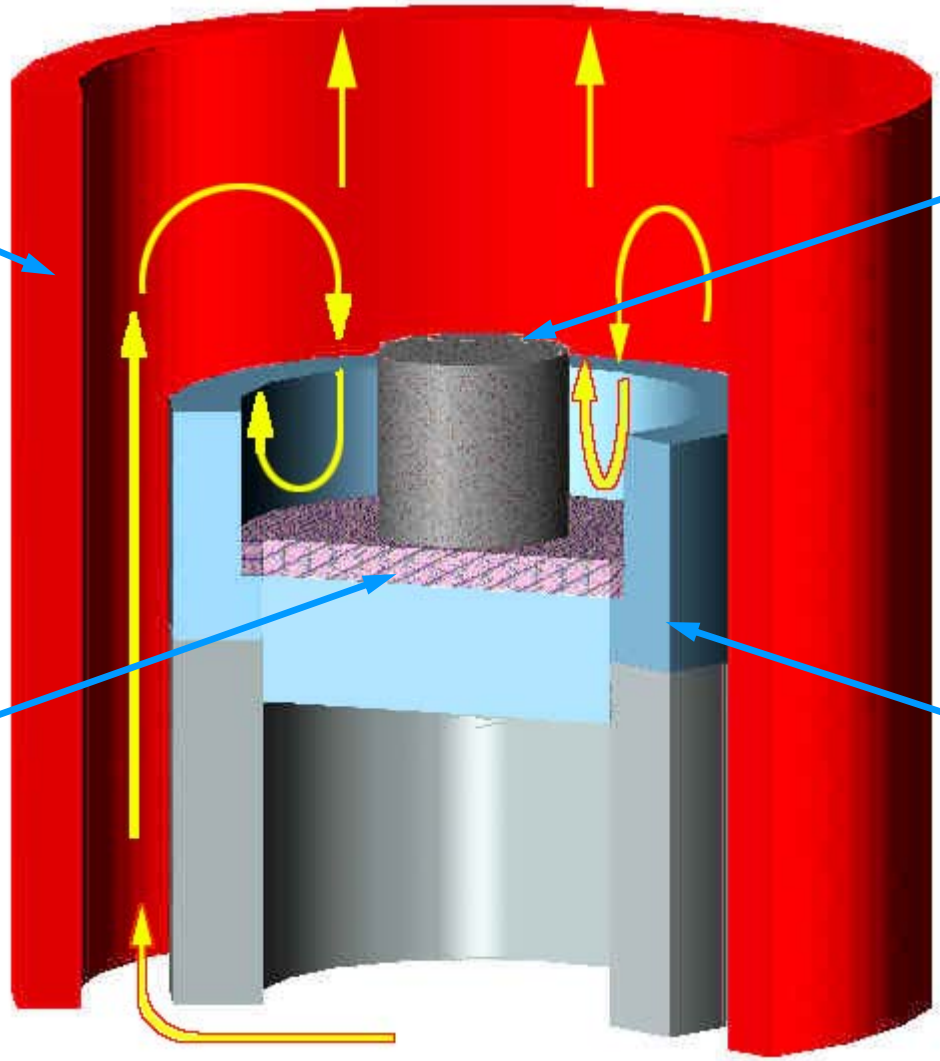
- Low power (30-50 Wt/cm)
- Low temperature (below 400°C)

Objective: accumulation of the short-lived isotopes in the solid solution; prevent any fuel structure transformation

Test Rig


Hot cell
Condenser
Filter-dehydrator
Carrier gas line (in the case of pure steam environment)
Main filter
Water collector
Additional filter
Pressure transducer
Specimen
Ceramic tubes (ZrO_2, Al_2O_3, Al_2O_3)
Gamma-spectrometer (FP measurement in the filter)
Flow meter
Gamma-spectrometer (GFP measurement)
Gamma-spectrometer (FP measurement in the specimen)
HF coil
Main channel (ZrO_2)
Mass spectrometer
Steam overheater (800°C)
Specimen holder
Protective gas line
Heater(150°C)
Intel steam line
H_2
Inlet gas line
Pyrometer
He

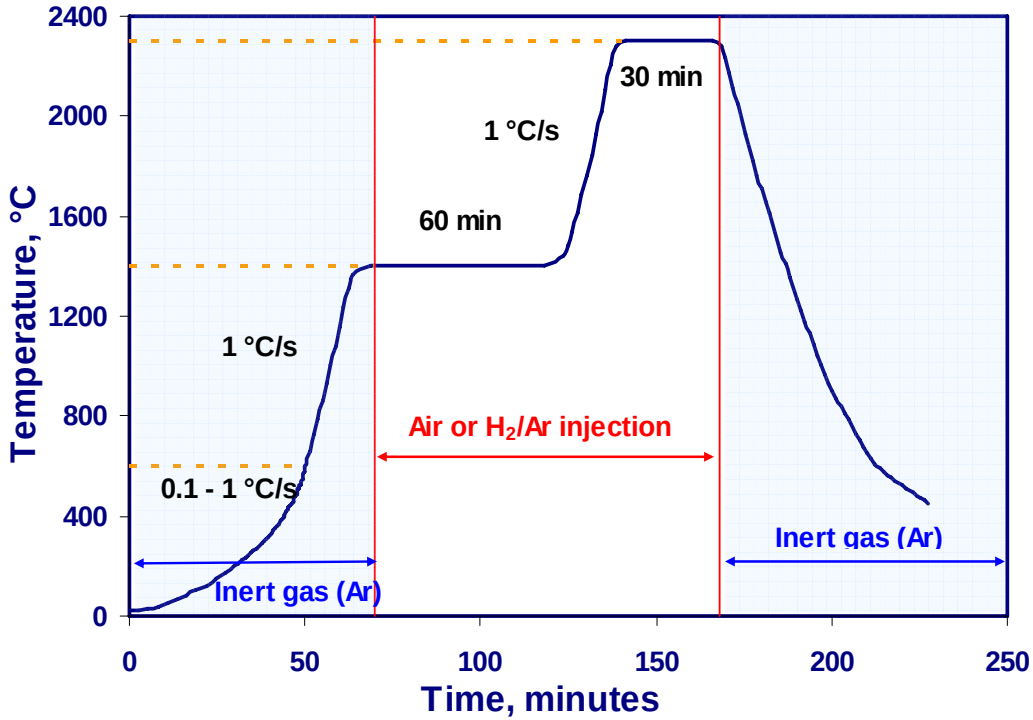
Crucible materials



Test Regime

Test temperature

- *heating in the inert atmosphere up to the temperature of 600 °C*
- *heating from 600 up to 1400 °C with a rate of 1 K/s*
- *annealing at 1400 °C during 1 hour*
- *heating with a rate of ~ 1 K/s up to the specified temperature (1700 or 2300 °C)*
- *annealing during 30 minutes*
- *end of heating*



Test matrix

Test number	Sample type	Gas phase	Test temperature (°C)
1	Bare fuel	H_2O/Ar	1700
2	Bare fuel	H_2/Ar	1700
3	Bare fuel	H_2O/Ar	1400
4	Bare fuel	H_2O/Ar	Above 2000
5	Bare fuel	H_2/Ar	1400
6	Bare fuel	H_2/Ar	Above 2000
7	Bare fuel	Air/Ar	1400
8	Bare fuel	Air/Ar	1700
9	Fuel rod segment	H_2O/Ar	1700
10	Fuel rod segment	Air/Ar	1700

Test Performance

Parameters to be measured during the test

- ***intensity of GFP in the delaying coil***
- ***intensity of FP in a fuel specimen***
- ***intensity of FP on the main filter***

Results to be obtained

- ***relative FP release***

Post-Test Examinations

1. **Optical metallography**
   - *grain size*
   - *porosity*
   - *gas swelling*

- **EPMA and SEM analysis**
  - *local content and radial distribution of fission products*
  - *elemental content of precipitates in the fuel*

Part B. MFPR
(Model for Fission Products Release)

Objectives

On the base of new experimental results:

- ***to develop theoretical models of fission products and irradiated VVER fuel behaviour under conditions of severe accidents***
- ***to improve and to adapt physical models and codes developed for PWR fuel to VVER fuel***

MFPR Tasks in VERONIKA Project

- ***Pre-test calculations of new experiments for determination of parameters and conditions of the tests***
- ***Processing and analysis of results of new experiments***
- ***Development and improvement of the physical models on fission products release and high burnup VVER fuel behaviour under conditions of severe accident***
- ***Implementation of the developed and improved models in the MFPR code***
- ***Verification of the MFPR code against the new experimental database and other new available data at the end or during the program***

Project Costs

The first stage

(3 years duration, 960 000 $) :

- $T_1 0$ – beginning of the work under the project;
- $T_1 0$+1.5 year – manufacturing and testing of the experimental rig;
- $T_1 0$+1 year - adaptation of the MFPR code to the new experimental rig, pre-test calculations;
- $T_1 0$+3 years – first series of tests (10 tests);
- $T_1 0$+3,0 years – theoretical analysis of the obtained experimental data, development of models and codes.