METHODS OF PERFORMING THE POWER RAMPING EXPERIMENTS WITH VVER FUEL RODS AT DIFFERENT BURNUPS

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Abstract

In the present report an engineering of experiments "power ramp", realized in RIAR till 1995 is considered. Included are methods and program of some experiments, scheduled for 1995.

TEST PROGRAM

The purpose: determination of safe linear heat generation rate (LHGR) at various burnup and safe speed of ramp.

Types of fuel rods:
- experimental (length 0.25-1 m)
  - cladding - Zr + 1 % Nb (110-alloy);
  - Zr + 1 % Nb + 1 % Sn + 0.5 % Fe (635-alloy);
- fuel - UO2 usual pellet;
- refabricated (length 1 m) and full-scale VVER-440 and VVER-1000 (length 2.5 and 3.8 m) at average and high burnup.

Main parameters:
- range LHGR ~ 150 - 700 W/cm;
- amplitude of ramps ~ of 200 %;
- time of power rise:
  "slow" ramps - 2 min. and more;
  "fast ramps" - 1-5 s;
- fuel rod burnup - 0-70 MW-day/kg U;
- parameters of a coolant correspond to VVER parameters.

Experimental equipment:
- MIR reactor;
- loops with water coolant (PVP-2, PV-1, PVK-2);
- special fuel rod rig and technological equipment.

The characteristics of the MIR reactor and its loop installations are indicated in tables 1,2. Chartogramm of a reactor core and arrangement of loop channels is shown in fig. 1. The arrangement
<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal capacity</td>
<td>up 100 MW</td>
</tr>
<tr>
<td>Maximum neutron flux (E&lt;0.68 eV)</td>
<td>$5 \times 10^{14}$ 1/cm² .s</td>
</tr>
<tr>
<td>(E&gt;0.1 MeV)</td>
<td>$2 \times 10^{14}$ 1/cm² .s</td>
</tr>
<tr>
<td>Moderator</td>
<td>Be, H$_2$O</td>
</tr>
<tr>
<td>Reflector</td>
<td>Be</td>
</tr>
<tr>
<td>Coolant</td>
<td>H$_2$O</td>
</tr>
<tr>
<td>Water pressure</td>
<td>1.24 MPa</td>
</tr>
<tr>
<td>Coolant temperature</td>
<td>40 - 83 °C</td>
</tr>
<tr>
<td>Campaign duration</td>
<td>30-40 days</td>
</tr>
<tr>
<td>Fuel assemblies</td>
<td>UO$_2$ - Al</td>
</tr>
<tr>
<td>Number of Fuel assemblies</td>
<td>48</td>
</tr>
<tr>
<td>Number of control rods</td>
<td>29</td>
</tr>
<tr>
<td>Number of movable Fuel assemblies with compensating rods</td>
<td>12</td>
</tr>
<tr>
<td>Number of loop channels</td>
<td>11</td>
</tr>
<tr>
<td>Core height</td>
<td>1 m</td>
</tr>
</tbody>
</table>

of channels permits to create neutron flux, distinguished in 5-10 times in various channels. It is provided by control facilities of reactor and loading burnup or new fuel assemblies of the MIR reactor about the loop channel.

The scheme of a loop is shown in fig. 2. For example, in the PVP-2 loop there are monitoring system of fuel rods tightness by activity of coolant, the system of coolant clearing, emergency cooling, disactivation, storage of active coolant and other. The loop has gauges of temperature on input and output from a channel, as well as gauges of heating, coolant pressure and flow rate.

For a example the scheme of realization of experiment is shown in fig. 3. The reading of loop gauges, results of determination of thermal losses and heat release in materials from gamma-radiation are used for determination of total power in fuel rods by a thermal balance method. Power distribution between fuel rods and along fuel rod is specified after post experimental gamma-scanning. In addition it is possible to use thermocouples and neutron detectors inside loop channel. The error of a linear power determination is 5-10 % depending on total power of fuel rods.
### TABLE II. CHARACTERISTICS OF LOOPBACK INSTALLATIONS (LI) AT THE MIR REACTOR

<table>
<thead>
<tr>
<th>Name LI</th>
<th>PV-1</th>
<th>PV-2</th>
<th>PVK-1</th>
<th>PVK-2</th>
<th>PVP-1</th>
<th>PVP-2</th>
<th>PG-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant</td>
<td>water</td>
<td>water, steam</td>
<td>water, steam</td>
<td>water, steam</td>
<td>helium, mixture of 2 gases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P, MPa</td>
<td>20</td>
<td>20</td>
<td>8.5</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N, KW</td>
<td>2000</td>
<td>2000</td>
<td>100</td>
<td>2000</td>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T, °C</td>
<td>340</td>
<td>340</td>
<td>500</td>
<td>500</td>
<td>550</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>1000</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Q, kg/h</td>
<td>16000</td>
<td>14000</td>
<td>675</td>
<td>1000</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>A, Bq/ kg</td>
<td>3.7 e10</td>
<td>3.7 e10</td>
<td>3.7 e10</td>
<td>3.7 e10</td>
<td>3.7 e10</td>
<td>3.7 e10</td>
<td></td>
</tr>
</tbody>
</table>

P - maximum pressure;
N - maximum capacity;
T - maximum temperature of a coolant;
Q - coolant flow;
A - maximally allowable activity of coolant.

**NOTE:**
1. Density of a flow of neutrons in channels
   \[ E < 0.68 \text{ eV} \quad (3 - 5) \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1} \]
   \[ E > 0.1 \text{ MeV} \quad (2 - 4) \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1} \]

2. Maximum internal diameter of water channels of loopback installations - 74 mm.

It is possible to receive some different types of power ramping such as: "slow" or "fast". Methods are shown in fig. 4. They are follows: by change of reactor power for "slow" ramps, turn of fuel rods about the absorbing screen or movement of fuel rods from above downwards about screens ("fast" ramps). At moving of fuel rod about the screen it is possible to increase the non-uniformity of a neutron flux by arrangement of reactor control rods.

The characteristics of six "slow" ramps realized till 1995 are presented in table 3. In this case the ramps were performed by change reactor power (R6), reactor rods position (R1), or combination of these methods.
### TABLE III. THE COMMON ITEMS OF INFORMATION ON THE R1-R6 EXPERIMENTS WITH VVER FUEL RODS ON THE MIR REACTOR

<table>
<thead>
<tr>
<th>Name</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place of tests</td>
<td>PVK-2</td>
<td>PVK-2</td>
<td>PVK-2</td>
<td>PVK-2</td>
<td>PVK-2</td>
<td>PV-1</td>
</tr>
<tr>
<td>Quantity of fuel rods in irradiation rigs</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>11+6</td>
<td>12</td>
</tr>
<tr>
<td>Length of fuel rods, mm</td>
<td>265</td>
<td>265</td>
<td>1075</td>
<td>265</td>
<td>265</td>
<td>1075</td>
</tr>
<tr>
<td>Burnup, MW·day/kg U</td>
<td>8.5-10</td>
<td>8-10.7</td>
<td>47</td>
<td>17</td>
<td>15-30</td>
<td>50</td>
</tr>
<tr>
<td>Amplitude of power ramp</td>
<td>1.9</td>
<td>2.8</td>
<td>1.9</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Duration of capacity increasing, min.</td>
<td>8</td>
<td>13</td>
<td>2.5</td>
<td>8</td>
<td>10</td>
<td>113</td>
</tr>
</tbody>
</table>

In the latter case at first stage a reactor power was decreased, and simultaneously fuel rods power was supported constant by control rods, then reactor power was increased. So it is possible to realize ramp for a time more than two minutes. The results six "slow" ramp are presented in fig. 5. They were realized at different burnup. For a burnup of ~ 50 MW·day/kg U the refabricated fuel rods were used. All fuel rods have saved tightness, no cracks detected on internal surface of a cladding after eddy current control and crosssection investigation.

These "ramps" were realized in dismountable fuel assemblies, enabling to replace fuel rods. The ramps with a short fuel rod were realized in a test arrangement, shown in fig. 6. For fuel rods of 1 m long a test assemblies were used (fig. 7 and 8). Replacement of fuel rods in subassembly was performed in the shielding chambers, located in the reactor building. After "ramp" and gamma-scanning the fuel rods were sent for researches in other building, where there is a research laboratory.

Up to the end of 1995 and in the beginning 1996 some experiments were prepared for realization. There are "slow" ramps with using refabricated and full-scale fuel rods at burnup of 30-60 MW·day/kg U, and one "fast" ramp for a time of 1-5 seconds with refabricated fuel rods (by turning about the screen) as well as "fast" ramp by moving of a fuel rod along screen. In the later case one can obtain the less depression of neutron flux with one fuel rod and the more linear power. In fig. 9 an assembly is shown, in which refabricated and full-scale fuel rods are placed together.
Chartogram of the MIR reactor

1 - channels of PV-1 and PV-2 water loops;
2 - channels of other experimental loops;
3 - reactor working channels with driving FA;
4 - control rods with fuel tails;
5 - control rods;
6 - reflector.
Fig. 2

Scheme of the first circuit PVP-2 loop facility: 1 - loop channel; 2, 3, 4 - bottles, pumps and tanks of the System Emergency Cooling (1, 2) correspondingly; 5, 16, 18 - sampling system; 6, 10 - mixers; 7 - separator; 8 - pipe to the system of the hydrogen burn-up; 9, 23 - main and regeneration heat exchange devices; 11 - volume compensator; 12 - distillat replenishment line; 13 - tanks for the long-term storage of the liquid radioactive waste (1, 2); 14 - drainage to the waste piping; 15 - heat exchange device of the purification system; 17 - ion-exchange filters; 19, 24 - gauze filters; 20, 21 - pumps; 25 - barbotage tank.
\[N_r, N_t - \text{energy of radiactivity heating and thermal losses;}\]
\[\Sigma N_{T1} - \text{total power of assembly;}\]
\[N_{T1} - \text{power of fuel rod (i);}\]
\[\Delta t, Q, T_{ex}, P - \text{coolant parameters;}\]
\[q_L = f(l) - \text{linear heat generation rate;}\]
\[A_i = f(L) - \text{i-spectrum of fuel rod (i);}\]
\[\text{ASNI - automatic system of scientific investigations.}\]

Fig. 3  Scheme of experiment's stages sequence and moving of information
Kind of tests

- "slow" power ramps
  - change of fuel rod power by change of reactor power.

- "fast" power ramps; prolonged tests with cyclic power change
  - turning of a rig about absorbing screen
  - moving of fuel rod through the generated area with high neutron flux

Fig. 4 Methods of power change during tests
Fig. 5  Power RAMP tests in reactor MIR
Fig. 6 The "TEST-1" irradiated rig
Fig. 7 Scheme of an irradiation rig accommodation in a loopback channel
Fig. 8 The KMT irradiation rig

1- base body of the rig
2- dismounting jacket
   (60 x 0.8: Zr-alloy)
3- fuel rod (12 rods)
4- simulator (12 rods)
5- fixation
6- coolant (water)
7- carrying tube
8- grid
9- upper grid
Fig. 9
Irradiation rig for test of refabricated and full-scale fuel rods:
1 - cowl; 2 - vessel; 3 - rod; 4 - leading grid; 5 - refabricated fuel rod; 6 - full-scale fuel rod; 7 - bed.
Fig. 10  The “GR” irradiated rig:
1 - body of channel; 2 - case of gauge; 3 - fuel rod with pressure transducer; 4 - casing; 5 - thermocouple(input); 6 - pusher; 7 - spring; 8 - support demountable; 9 - screw; 10 - rod; 11 - Zr - rod; 12 - emphasis demountable; 13 - fuel rods; 14 - rig; 15 - thermocouple (output); 16 - ring; 17 - core; 18 - fixing spring; 19 - coil; 20 - spring of core; 21 - direction screen; 22 - head of channel; 23 - joint.
The simultaneous experiment with refabricated and full-scale fuel rods can determine difference in their behaviour. The full-scale fuel rods of VVER assemblies are used after nondistuctive investigations of assembly in RIAR. In RIAR prepare the refabricated fuel rods are prepared from the same fuel rods.

The dismountable assembly with refabricated fuel rod is shown in fig. 10. The assembly has gauge of linear movement. The transducer of gas pressure into linear movment is located on the top of fuel rod. This assembly is used for several experiments. In this case the replacement of fuel rods is performed. Gas pressure and change of fuel rod length is simultaneously measured by this assembly. Thermocouples are located at input and output from assembly. The experiment with such assembly is scheduled to perform at the beginning 1996. VVER refabricated fuel rods will be tested at the burnup of 50-60 MW - day / kg U.

As follows from the paper the equipment permits to test several various fuel rods in one assembly simultaneously. It provides a good statistics with using a little number of experiments.

REFERENCE