# 2. NEUTRON SOURCES

## 2.1. THE IBR-2 PULSED REACTOR

In 1997, the reactor operation for physical experiments on extracted neutron beams was continued. Detailed information on the operation of the reactor is presented in Tables 1 and 2.

On June 12, 1997, the reactor was shut down to repair a malfunction in the prompt emergency shutdown (PES) system (the system could not be set in the operative position, connected with a decrease in the travel range).

In accordance with the characteristics of the control and emergency system (CES) and methods of providing safety accepted for the IBR-2 reactor, in response to the alarm signal the 1PES and 2PES systems shut down the reactor (efficiency – $0.36\pm0.02$ $\beta_{eff}$ and $0.49\pm0.03$ $\beta_{eff}$, respectively) for less than 0.02 s.

The measurement of the efficiency and speed of response of 1,2PES with the decreased working strokes of the PES units on July 11-16, 1997 demonstrated that on retention of the speed of response less than 0.02 s the efficiency of CES units was 0.21 $\beta_{eff}$ for 1PES and 0.35 $\beta_{eff}$ for 2PES, respectively.

In places accessible to observation (using a remotely controlled tool and photographing and filming) the elements which can affect the technology of setting PES system in the operative position were examined by stages. This made it possible to detect a worn spot on the upper front surface of the 1PES unit. This spot is direct evidence that the 1PES unit in the operative position came in contact with the case of the stationary reflector.

So, the provided clearance disappeared, and this prevented the setting of the 1PES unit in the operative position. A visual inspection of the 1PES unit and the places of the construction of the 1PES channel accessible to observation testified that all elements are intact (see Fig.1 and 2). When examining the mechanism of the rod of 1PES, the vertical backlash of the lower end of the rod was detected, which is a result of the wear while in service.

Taking into account that the efficiency of the PES units is practically independent of (within the travel range) the location of the point of the operative position of units, and depends on the travel range itself, it was decided to move the construction of 1PES 12mm away from the active zone and to fix it in that position, as well as to replace the water moderator by a newly manufactured one with geometry which ensures the absence of contact between 1PES and water moderator within the full travel range.

The results of the repairs are illustrated in Table 3.

The repairs, which proceeded under difficult radiation conditions, were completed in October 1997, and on November 11, 1997, the reactor was put into operation.

Positive experience in operating two movable reflectors of the IBR-2 reactor, which have worked out their service life: the first one – 13000 hrs. and the second – 20000 hrs, made it possible to redetermine the limit values for the levels of vibration for the third generation reflector (PO-2R) now in service. These levels are used as a basis to control the operation of the reflector. In addition, vibration diagnostics is carried out to detect malfunctions of the movable reflector early in their development using different algorithms of static analysis of vibration signals, which make it possible to identify the origin of changes in this or that parameter of vibration signals.

*Table 1*

**IBR-2 reactor operation characteristics for 1997**

| № cycle | Start and completion dates of cycles | Operation time for physical experiments, $T_{ph.e.}$ | MR operation time, $T_{MR}$ | Number of emergency shutdowns, $N_{ES}$ | Causes of emergency shutdowns (malfunction classification according to RD-04-10-94) | | | | | | Number of operating beams |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Voltage drops (MR8) | Equipment breakdowns (MR7) | Electronic equipment breakdowns (MR7) | Personnel errors (MR5) | Scheduled emergency shutdowns | Malfunctions of safety systems (MR4) | |
| 1 | 20.01 - 01.02 | 250 | 284 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 12 |
| 2 | 10.02 - 21.02 | cancelled by order of the FLNP Directorate | | | | | | | | | |
| 3 | 10.03 - 25.03 | 263 | 328 | 5 | 3 | 0 | 0 | 0 | 0 | 2 | 12 |
| 4 | 07.04 - 18.04 | 252 | 273 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 12 |
| 5 | 19.05 - 30.05 | 242 | 273 | 4 | 1 | 2 | 1 | 0 | 0 | 0 | 12 |
| 6 | 9.06 - 12.06* | 54 | 92 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 12 |
| 7 | 10.11 - 26.11 | 367 | 441 | 5 | 1 | 0 | 2 | 1 | 1 | 0 | 12 |
| 8 | 8.12 - 26.12 | 403 | 427 | 6 | 0 | 1 | 5 | 0 | 0 | 0 | 12 |
| | **Total:** | **1831** | **2118** | **26** | **6** | **4** | **9** | **1** | **2** | **4** | |

* the reactor was shut down because of a malfunction in the prompt emergency shutdown systems (1,2PES)

*Table 2*

**IBR-2 operational parameters as on November 1, 1997**

| № | Parameter | Achieved | Allowed |
|---|---|---|---|
| 1 | Total operation time for physical experiments, hrs. | 32143 | |
| 2 | Total generated energy, MW/hrs. | 60970 | 85000 |
| 3 | PO-2R total operation time, hrs. | 6392 | 18000 |
| 4 | Maximum fluence on the reactor jacket at the centre of the active core ($10^{22}$ n/cm$^2$), for $E_n > 0.1$ MeV | 2.68 | 3.72 |
| 5 | Maximum fuel burning, (%) | ~ 4.9 | 6.5 |
| 6 | Total number of emergency shutdowns | 380 | 550 |

*Table 3*

**Efficiency, speed of response and full travel range of 1,2PES units in the previous and new working positions**

| Characteristics | Previous value | Value in a new working position |
|---|---|---|
| Full efficiency of 1PES, $\beta_{eff}$ | 0.36±0.02 | 0.37±0.02 |
| Full efficiency of 2PES, $\beta_{eff}$ | 0.49±0.03 | 0.37±0.02 |
| Speed of response of 1PES, s | less than 0.02 | less than 0.02 |
| Speed of response of 2PES, s | less than 0.02 | less than 0.02 |
| Full travel range of 1PES, mm | 23.5 | 24 |
| Full travel range of 2PES, mm | 23.5 | 17.5 |

The diagnostics of the current state of PO-2R is performed using the vibration monitoring program, the basis for which is the construction of base spectrum "mask" from data of vibration measurements in i-th cycle (operation time of the reflector in one cycle is ~ 280 hrs). This cycle is chosen as stationary from the viewpoint of constancy of characteristics of vibration signals picked up from the bearing supports of PO-2R following its running-in. The allowable limit values of vibration levels are established for each subrange of spectrum characteristics (low-frequency, medium and high-frequency). The position of current spectra relative to the base mask characterizes the current state of the movable reflector. The analysis of the trend curve, constructed from the results of measurements of vibration-acceleration as a function of the number of operation cycles taking the statistical spread of readings into account, allows us to evaluate the residual service lifetime of PO-2R.

In addition, to evaluate the degree of wear of rubbing parts of the movable reflector—radial and radial thrust bearings, spur and cone gears, journals of the shaft of the reflector—and to establish a correlation with the parameters of vibration signals, the method of neutron activation analysis of samples of oil of the lubrication system of PO-2R was proposed. This method makes it possible to determine the content of the wear products on the basis of analysis of spectral presentation of nuclides of activated metal impurities. The nuclide content in oil samples, radiation energy in keV, and pulse area following the operation of PO-2R for 21 cycles (6000 hrs) are presented in Table 4.

*Table 4*

**Spectral content of metal impurities in oil samples following the operation of PO-2R for 6000 hrs.**

| Element No. | Energy, keV | Pulse area | Resolution in keV | Nuclide |
|---|---|---|---|---|
| 1 | 135.95 | 350 | 1.84 | Se-75 |
| 2 | 192.45 | 174 | 1.88 | Fe-59 |
| 3 | 264.51 | 386 | 3.73 | Se-75 |
| 4 | 279.36 | 208 | 1.66 | Hg-203, Se-75, Pb-203 |
| 5 | 320.02 | 789 | 2.38 | Cr-51 |
| 6 | 336.14 | 264 | 2.57 | In-115m |
| 7 | 411.95 | 165 | 2.77 | Au-198 |
| 8 | 528.20 | 156 | 1.91 | Cd-115 |
| 9 | 563.74 | 146 | 4.75 | Cs-134, Sb-122 |
| 10 | 602.73 | 789 | 2.08 | Cs-134, Sb-124 |
| 11 | 646.33 | 115 | 4.80 | Sb-124 |
| 12 | 723.27 | 163 | 2.83 | Sb-124 |
| 13 | 765.14 | 140 | 2.76 | Nb-95 |
| 14 | 834.61 | 220 | 6.51 | Mn-54, Ga-72 |
| 15 | 1099.17 | 770 | 2.69 | Fe-59 |
| 16 | 1115.44 | 4757 | 3.26 | Zn-65 |
| 17 | 1173.06 | 1373 | 3.13 | Co-60 |
| 18 | 1291.18 | 481 | 2.78 | Fe-59 |
| 19 | 1332.23 | 1267 | 4.37 | Co-60 |
| 20 | 1460.27 | 275 | 4.19 | K-40 |
| 21 | 1689.75 | 99 | 1.45 | Sb-124 |

Qualitative and quantitative changes in mass of the wear products in oil in the further stages of the operation of PO-2R together with the results of vibration diagnostics will allow us to detect more precisely the starting moment of the progressing wear of the rubbing parts under study.

The experimental investigations into the dynamic properties of the IBR-2 reactor have been carried out. The main result of these studies is as follows: after the second reloading (1996) the reactor operates steadily over a whole range of power (up to 2 MW) and at a sodium flow rate of 80-120 $m^3/h$.

Work to manufacture a cryogenic moderator (CM) has been completed in the main. However, the factory endurance tests have revealed that significant modifications in the construction are required to ensure reliability of CM, which will delay the ultimate date of manufacture until the middle of 1998.

Work to modernize the circulating water supply system has been performed. This makes it possible to set a more economical regime of water supply when the reactor does not operate.

The reserve power supply of IBR-2 from the Ivankovskaya hydroelectric power station in case of emergencies at the GPP-2 reserve control desk has been improved.

The financing of theme 0851 was low and unstable as before. For eleven months the contract payment amounted to 806 million rubbles (~140 k$) as compared to the annual plan of 1620 k$. For this reason, work on the projects for the modernization of IBR-2 and the production of TVELs has not been carried out. The debts for work executed in 1996 have not been redeemed either.

*Table 5*

**Financing of theme 0851 (IBR-2) in 1997 (in k$) (as on November 1, 1997)**

| | STE | CM | MR-3 | TVEL | Main Equipment | Total |
|---|---|---|---|---|---|---|
| January | – | – | – | – | – | – |
| February | – | – | – | | – | – |
| March | – | 9 | – | – | – | 9 |
| April | 8.5 | 6 | – | – | 7 | 21.5 |
| May | 8.3 | 13.1 | – | – | – | 21.4 |
| June | – | – | – | – | – | – |
| July | 2.6 | – | – | – | – | 2.6 |
| August | 24.5 | 3.7 | – | 30.1 | – | 58.3 |
| September | 1.0 | – | – | – | 2.6 | 3.6 |
| October | 2.7 | – | 20.6 | – | – | 23.3 |
| **TOTAL:** | **47.6** | **31.8** | **20.6** | **30.1** | **9.6** | **139.7** |

## 2.2. THE IREN PROJECT

The project status. Following the recommendations of the JINR Plenipotentiary Committee (March 1993) the JINR Directorate adopted the decision, approved at the 76th Session of the JINR Scientific Council June 1994), to construct the new modern source of resonance neutrons for investigations in fundamental and applied nuclear physics. The completion date (physical startup date) was the end of 1997. The IBR-30 analogous scheme, i.e., the combination of a powerful linear electron accelerator and a subcritical multiplying target, was chosen for the new neutron source. The new IREN facility will permit the neutron energy resolution to be increased an order of magnitude at a double increase in luminosity.

In 1997 financing of the work on the IREN project became lower than in 1996 (30 K$ per year) and only extraordinary efforts of the project management allowed to preserve validity of the key contracts ensuring construction of the main IREN systems. So to the initial completing date of the IREN project established at the official beginning of the project in 1994 we have at least two years delay. To the end of 1997 in the frame of the project implementation it was invested 870 K$ and the total cost of the signed contract achieved 2700 K$. In spite of lack of financing minor progress took place in design and construction of the electron gun (at LHE and LPP), the RF system of the LUE-200 and the full scale stand for testing the accelerating systems of the linac (at FLNP). The first variant of the control system for the IREN was created and will be tested during 1998 at the IBR-30.

The situation with implementation of the IREN project was considered by the special expert committee formed by the JINR Directorate and by the 7th session of the Program Advisory Committee for nuclear physics. Both committees strongly recommended the JINR Directorate to seek possibilities for completing the project in 1999-2000.