LOW-TEMPERATURE VERTICAL CHANNELS OF THE IRT-2000 REACTOR

L. A. Vadachkoriya, Dzh. G. Katsitadze,
Sh. A. Mumladze, I. A. Naskidashvili,
G. P. Tavkhelidze, L. S. Topchyan,
and A. A. Chipashvili

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Two types of low-temperature vertical channels are described, of the IRT-2000 reactor with circulating helium as the heat transfer agent and liquid nitrogen as refrigerant, designed for intra-channel investigations of the physico-mechanical properties of materials at low-temperatures during irradiation.

When investigating the kinetics of generation of radiation defects in solids, irradiation of the samples being studied at low temperatures is of paramount importance, when structural defects which have originated as a result of irradiation are relatively fixed [1, 2]. For this purpose, the irradiation of samples usually is carried out at liquid nitrogen, neon, hydrogen or helium temperatures. Because of this, it is becoming necessary to equip research reactors with low-temperature channels; in so doing, in addition to the usual low-temperature problems, additional difficulties arise, associated with heating from the radiation which penetrates the samples, the measurement sensors and units of the equipment, and also with the specific characteristics of intrareactor investigations of the properties of a solid.

The most widely used method of cooling the samples being investigated and irradiated in the reactor channels and also the measurement sensors, is cooling by means of a circulating gaseous coolant. Facilities operating on this method are a closed circuit, in which the circulating heat-transfer agent, cooled by a liquid refrigerant outside the irradiation zone, cools the object being studied in the irradiation zone. At present, there are facilities with natural circulation of the heat-transfer agent [3, 4] and also with forced circulation of the heat-transfer agent [5, 6, 7]. It should be noted that in certain facilities, the circulating heat-transfer agent during cooling is condensed and passes into the liquid state in the irradiation zone [3, 4, 5].

Gases with a low neutron absorption cross-section, low erosion and corrosion activity relative to structural materials and with high thermophysical properties are used as heat-transfer agents. One heat-transfer agent which satisfies these requirements is helium, although in individual cases neon and nitrogen are used.

In 1964, in the nuclear reactor of the Institute of Physics of the Belorussian SSR, a low-temperature vertical loop was constructed, designed as the basis for intrachannel investigations of the mechanical properties of materials over the temperature range from liquid nitrogen to room temperature. Helium is used here as the heat-transfer agent and liquid technical nitrogen as the refrigerant. The channel-cryostat of this facility, with a length of 7.5 m, has a working chamber with a diameter of 70 mm, cooled in the irradiation zone to a height of 1 m. Figure 1 shows a schematic diagram of this facility.

The helium, which is circulated by means of the membrane compressor 1 (MK-10/6, with an output of 10 m^3/h), passes directly through the counter-flow heat-exchanger 2 and the coil heat-exchanger 3 located in a bath of liquid nitrogen. The helium, cooled to 80°K, reaches the working chamber 6 through the

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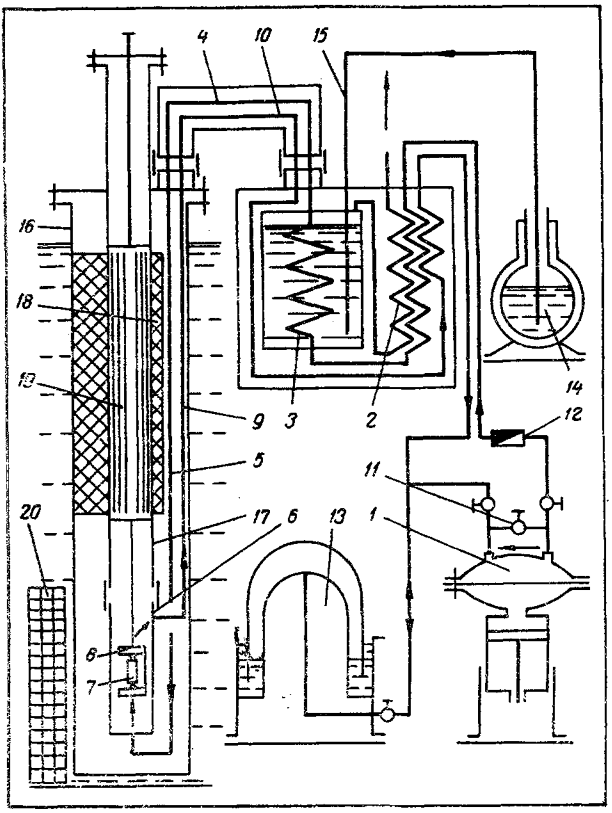

Fig. 1. Schematic diagram of the first type of facility: 1) compressor; 2) counter-flow heat-exchanger; 3) refrigerator; 4, 5) feed pipes; 6) working chamber; 7) sample; 8) measurement sensor; 9, 10) outlet pipes; 11) valve; 12) flowmeter; 13) gas-holder; 14) Dewar flask; 15) overflow; 16) reactor channel; 17) loading channel; 18) radiation shielding block; 19) radiation shield plug; 20) active zone.

feed tubes 4 and 5. On passing through the working chamber, the helium cools its walls, the sample 7 and the measurement sensor 8, thus reducing the intensity of heating from the penetrating radiation. From the working chamber, the helium returns to the compressor through the outlet pipes 9 and 10 and the heat exchanger. The change of temperature of the sample from the low temperature produced to room temperature produces a change in the feed rate of the circulating helium. The change and control of the feed rate of the helium is effected by means of the bypass valves 11 and the flowmeter 12.

In the circulatory system, the helium starts from the gasholder 13 which, during operation, serves as a buffer tank and, from the Dewar flask 14 through the overflow 15, liquid nitrogen is fed into the bath according to requirement. The aluminum channel of the reactor 16 serves as a vacuum jacket channel-cryostat and the channel 17 serves for loading the sample and measurement sensor into the working chamber. The block 18 and plug 19 prevent the penetration of radiation into the reactor room. The thin-walled working chamber and conduits are made of stainless steel and the heat-exchanger elements of the cooling system are of copper.

A facility of this design has been operated successfully over several years under conditions when the channel-cryostat passes tangentially to the active zone, where the average unit intensity of heating from the radiation penetrating the working chamber did not exceed 0.05 W/g. Under these conditions, the samples were cooled to 85-100°K, depending on the total mass of the object being irradiated and the intensity of the radiation.

Subsequently, when the channel-cryostat was positioned in the active zone, where the intensity of the radiation heating in the working chamber with a reactor power of 1 MW, was increased to 0.2 to 0.3 W/g, these facilities were found to be of little use because of the low efficiency of cooling of the sample — the sample temperature, on the average, was increased by 50°.

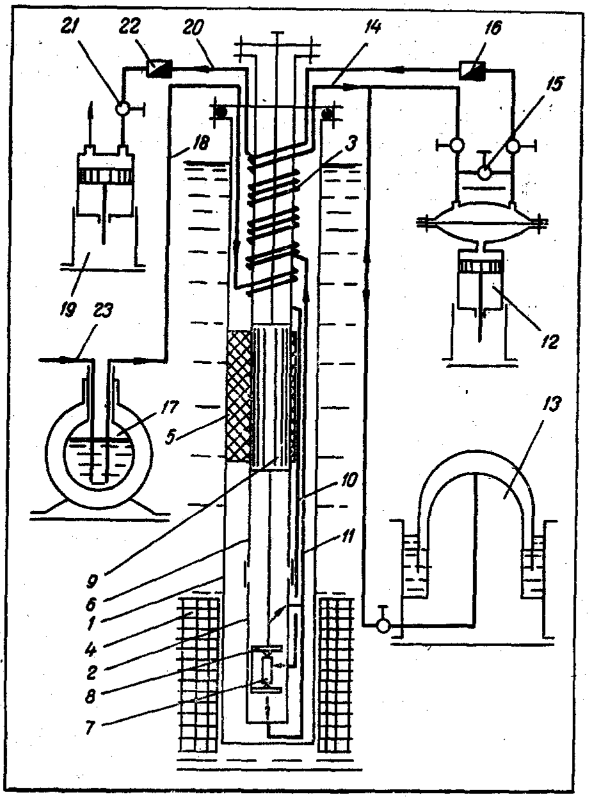

Fig. 2. Schematic diagram of the second type of facility: 1) reactor channel; 2) working chamber; 3) heat exchanger; 4) active zone; 5) radiation shielding block; 6) loading channel; 7) sample; 8) measurement sensor; 9) radiation shield plug; 10) feed pipe; 11) outlet pipe; 12) compressor; 13) gas-holder; 14) conduits; 15) valve; 16) flowmeter; 17) Dewar flask; 18) overflow; 19) pump; 20) conduit; 21) valve; 22) flowmeter; 23) overflow.

The sample cooling efficiency is determined by the performances of the cooling system, the flow-rate and specific heat of the heat-transfer agent, the heat flux externally through the heat insulation into the feed pipes and the working chamber, the intensity and the spectrum of the heating from the penetrating radiation, the mass distribution of the object being studied and elements of the facility in the irradiation zone and in the circulating coolant flow, etc.

In order to increase the sample cooling efficiency and make possible a temperature change over the range from low to room temperature, by varying the flow of liquid nitrogen at a constant flow rate of the circulating helium (the necessity for which arises during operation by a single compressor of a line of several installations), in 1969 a new facility was developed in the reactor of the Institute of Physics of the Academy of Sciences, Belorussian SSR; the schematic diagram of this facility is shown in Fig. 2.

In the reactor channel 1, the working chamber 2 and the heat exchanger 3 in which the complete cycle of cooling of the circulating helium takes place, are arranged in such a way that the working chamber is located in the active zone 4, and the heat exchanger is shielded from radiation by the block 5. Just as in the previous case, the channel 6 serves for loading the sample 7 with the measurement sensor 8 into the working chamber and the plug of the radiation shield 9 closes the channel 6.

By placing the cooling system in the channel-cryostat, the path of movement of the cooling helium up to entry into the working chamber was found to be considerably shortened. This, in its turn, defined the reduction of heating of the helium on reaching the sample and, as the final result, also the increase of its cooling efficiency.

The feed pipes 10 are jointed to the working chamber at the level of the center of the active zone, opposite from the sample position, and to the heat exchanger — at its coolest part and at the level of the

TABLE 1. Dependence of Sample Temperature on Reactor Power, in Both Types of Facility (Unit intensity of radiation heating is 0.2 W/g at a reactor power of 1 MW; total weight of sample with sensor is 325 g; flow rate of circulating helium 0.25 g/sec)

Reactor power, MW	0	200	400	600	800
Temperature of sample in facility of first type, °K	89,2	100,5	112,3	124,5	137,2
Temperature of sample in facility of second type, °K	84,4	87,7	91,1	94,8	98,6

liquid nitrogen input. The outlet tube 11 from the working chamber is connected with two openings at its upper and lower ends and with the heat exchanger — at the point of the corresponding temperature level for utilizing the residual cold of the circulating helium reverse flow.

This defined the efficiency increase of the sample cooling, due to cooling initially of the sample by the circulating helium and then the walls of the chamber and the elements of the measurement sensor. Here, the sample is found to be at the coldest and most intensely irradiated part of the working chamber.

The forced helium circulatory system of this facility also consists of the compressor 12 and gasholder 13, connected to the pipelines 14, valve 15 and flowmeter 16.

This facility is provided with the possibility for varying the temperature of the sample by varying the liquid nitrogen feed. The liquid nitrogen feed system comprises the Dewar flask 17, connected to the channel-cryostat by the overflow 18 and the pump 19 for pumping out nitrogen vapor from the heat exchanger connected to the channel-cryostat by the pipeline 20. Here, during operations, the liquid nitrogen is fed directly into the heat exchanger and, if necessary, its supply is varied and controlled by the valve 21 and the flowmeter 22. The overflow 23 serves to fill the flask 17 with liquid nitrogen, according to requirements.

Tables 1 and 2 show the temperature dependence of the sample on the reactor power in both facilities. These data have been taken under working conditions, when experiments were being carried out in the facilities.

Identical samples with sensors were loaded into the channel-cryostats of both facilities, which were under identical conditions of irradiation and with an average intensity of heating from penetrating radiation at a reactor power of 1 MW in the working chamber of 0.2 W/g. The weight of the sample was 66 g and the total weight of the sample with sensor was 325 g. The temperature was measured by attaching copper-constantan thermocouples to the samples. The helium, circulating from a single MK 10/6 compressor, passed through both facilities in succession, which ensured identical flow-rates of the heat-transfer agent in them. The helium flow rate was constant during the entire experiment and amounted to 5 m^3/h (0.25 g/sec). The data given in Table 1 were obtained during 100 hours of irradiation.

It is obvious that the difference between the sample temperatures (4.8°K) in these facilities with zero reactor power, is determined by the greater amount of heating of the cooled helium in the feed pipes of the first facility than in the second facility because of their greater length. Further increase of the difference between the sample temperatures with increase of the reactor power is determined increasingly by the increased heating of the walls of the working chamber by penetrating radiation and the elements of the measured sensor which cool the circulating helium in the first facility before reaching the sample.

TABLE 2. Dependence of Sample Temperature on Reactor Power in a Facility of the Second Type (Unit intensity of radiation heating 0.2 W/g at a reactor power of 1 MW; total weight of sample with sensor 2 kg; flow rate of circulating helium 0.375 g/sec)

Reactor power, MW	0	1,0	1,5	2,0
Sample temperature, °K	83,2	104,5	109	118 5

At the end of the experiment, a smooth change of sample temperature from 98.6 to 270°K was obtained in the second facility and conversely during irradiation by changing the liquid nitrogen flow rate from 8 to 0.5 liter/h and conversely.

Table 2 shows the temperature dependence of the sample on the reactor power, taken in the second facility in an experiment with a bulky measurement sensor — an apparatus for stretching microsamples [8]. Eight samples were mounted in the drum of the sensor and their total weight, together with the drum, amounted to 40 g; the total weight of the measurement sensor with samples was 2 kg. The temperature was measured with a copper-constantan thermocouple attached to the drum. The flow-rate of the circulating helium during a 50-hour irradiation was constant and amounted to 7.5 m^3/h (0.375 g/sec).

The results of operating these facilities show that they can be used for intrachannel investigations of the physico-mechanical properties of materials at low temperatures during irradiation. It should be noted, however, that facilities of the second type are characterized by a higher sample cooling efficiency and make it possible to vary the sample temperature, both by varying the flow-rate of the circulating heat-transfer agent and also the flow-rate of the liquid refrigerant — when possible, preference should be given to it, especially in the case of high thermal loadings and for operation on a single compressor line of several facilities.

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