JOINT INSTITUTE FOR NUCLEAR RESEARCH

Laboratory of Neutron Physics

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IBR - PULSED REACTOR WITH INJECTOR

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The pulsed fast reactor (IBR) at Dubna has been operating from 1960. This reactor was made for performing time-of-flight investigations, and it has been successfully used up to the present time.

The operation principle, construction and main characteristics of the IBR were described in references/1-3/, therefore, these topics will be discussed in this paper only briefly paying more attention to the improvements that have been introduced for the last two years after the III Geneve Conference.

Increase of the Reactor Average Power

In March, 1964, the reactor average power was increased up to 3 kw, and since then it has been operating at this power instead of the designed power of 1 kW. This had been achieved by increasing the air flow rate that cools the stationary core of the reactor from 90 up to 170 nm^3/hr. Simultaneously the cooling of emergency rods was introduced. All of the reactor units being in good condition it was possible to increase the power, and in February, 1965, it was increased up to 6 kW which is the reactor operating condition at the present time. Its principal characteristics are given in table 1.

A subsequent increase of the reactor power is limited mainly by the cooling of the principal mobile core (PMC) that, besides thermal effects, undergoes large mechanical loads owing to centrifugal force. The protective covering of the PMC is in the same condition and is deformed owing to thermal and mechanical effects. Its deformation makes the heat transfer worse, and it is dangerous because there is a possibility for a blow onto the sta - tionary core that is 1.5 mm from the rotating disc.

At the present time the laboratory has prepared a design of increasing the reactor power up to 20-30 kW based on using two inserts of U^{235}. The second insert will be used in place of the counterweight of U^{238}. That enables to divide the power evenly between the two inserts. The complexity of realizing this design lies in the fact that at the coincidence of each insert with the stationary core the reactivity should not differ more than 10^{-3}%. (The accuracy of making the inserts, their fitting into the disc, the wobbling of the disc etc. are included into this number). In this case the pulses will not differ more than 10-20%.

Furthermore, the design provides an increase of the electron injector power.

The Operation of IBR with a Microtron

The disadvantage of the IBR as a pulsed neutron source for spectroscopy is the long burst duration. An electron accelerator (microtron) was used as an injector for shortening it. At that time the reactor operates in a subcritical state as a multiplier of fast neutrons /4/. The operation of the microtron began in the end of 1964. In fig. 1 the arrangement of the microtron and reactor are given, and in table II the principal parameters of the IBR microtron system that have been achieved up to the present time.

The start-up of the microtron is performed by a pulse connected with the rotating disc of the IBR, so the pulse of the microtron occurs at the moment of the maximum reactivity. The total number of neutrons in a neutron burst is : $N = S/|\varepsilon|$, where S - number of neutrons generated by the injector in one burst and ε - reactivity for prompt neutrons. The shape of the pulse is shown in fig.2. The leading edge has a duration T equal to the electron pulse duration, and the trailing edge presents a damped exponent with $\tau/|\varepsilon|$. The neutron average life time for the IBR is $\tau = 1.3 \times 10^{-8}$ sec. The operation condition at which $\tau/|\varepsilon| = T$ is optimal. In this case at $T = 2$ μsec. the prompt neutron multiplication is $1/|\varepsilon| \simeq 150$.

The essential difference of the pulse reactor-multiplier from the stationary one is the little multiplication of delayed neutrons between pulses. The PMC being removed from the reactor, the latters reactivity is-0.07 which corresponds to the multiplication of 14. For a stationary multiplier in the above mentioned conditions the delayed neutron multiplication is $\frac{1}{|\varepsilon + \beta_{eff}|} = \frac{1}{0.66 \times 10^{-2} - 0.3 \times 10^{-2}} = 280$, i.e. the background value will be 20 times larger. This makes it necessary to work at little multiplications, in an order of 10, as it is at the Harwell booster /5/.

The IBR - microtron system being put into operation enabled to essentially improve the resolution of the spectrometer that is now 3-4 n.sec./m for the flight path of 1000m.

Reactor Operation in Alternating Pulse Power

The constant component background is an essential interfering factor for some physical experiments. In such cases it is profitible to decrease the reactor pulse frequency at a constant average power which leads to an improvement of relations between the effect and background. Preparing to realize the infrequent pulse condition of reactor operation, at the Laboratory of Neutron Physics a thermophysical calculation was performed and a testing of the infrequent packet pulse condition of operation with raised power.

The essence of this operation condition is as follows. The IBR having its usual operation condition the power pulse develops in the moment of coincidence of the principal (PMC) and auxiliary (AMC) of the mobile cores in the center of the stationary core. Both cores are rotated simultaneously by one motor. In the new reactor operation condition the rotation of both of the inserts are carried out by independent motors, the AMC rotates considerably slower than the PMC,so that while the AMC passes the stationary core the PMC makes a few rotations. At this time a packet with a few pulses of different power appears depending on the position of the AMC. In fig. 3 there is a scheme demonstrating the alternation and pulse power in the usual reactor operation condition (frequency 5 pulses/sec) and in the alternating pulse power condition. In the latter case the rotation speed of the PMC and AMC discs are correspondingly 50 revs/sec. and 0.12 revs/sec. The reactor thermal power in both cases is 4 kW, the power of central pulses in the packet is approximately 7 times higher than the pulse power of the usual reactor operation condition.

The experimental start-up of the reactor in the new operation condition confirmed the correctness of the calculations, the reacto operation was stable and reliable. A farther improvement of this operation condition can take place in the rotation of the AMC with variable speed so that in the place of a pulse group there would be one pulse of total energy.

Choice of Optimal Moderator

The introducing of the microtron-reactor raised the resolution of the spectrometer and enabled to perform measurements in the neutron energy region up to tens of KeV. At the same time there appeared a necessity of defining more accurately the values and nature of the background in this region during the measurements of transmission. It was discovered that when using neutron lithium glass detectors and liquid methyl borate detectors, that are sensitive to gamma-rays, in the flight time region of 200 - 500 μsec a considerable part of the background (20-30%) depends upon the gamma-rays, the intensity of which decrease exponentially with the life time of about 80 μsec. This background component appears at the capture of thermal neutrons, coming out of the moderator, by a tungsten reflector. To decrease it there was a 0.4 g/cm^2 boron carbide screen placed between the moderator and reflector. This decreased the gamma background considerably as it is seen in fig.4 in which there are curves obtained in the reactor operating condition by transmission through 10 cm thick paraffin that completely removes the neutrons from the beam. However, at the same time the resonance neutron yield was reduced by 20-30% and the thermal - two times. In connection with this, in addition to the earlier performed measurements of neutron yield depending on the moderator thickness /6/ similar measurements were performed having a boron screen between the reflector and moderator to choose the optimal moderator thickness.

Measurements of the neutron flux were performed simultaneously on different beams. The thermal neutron flux on beam №1 was measured with the aid of an uranium fission chamber. The neutron flux in the resonance region was measured by boron counters on beam №6. The reactor power was 1 kW that was kept constant in all the measurements.

Fig.5 shows the thermal neutron yield depending on the thickness of water for a pure water moderator (curve 1) and for a moderator with a boron carbide screen (curve 2). It is seen that the boron screen reduces the thermal neutron flux and shifts the optimal thickness of the moderator (maximum yield is at 70 mm of water instead of 55 mm). The intensivity of resonance neutrons for a few moderators are shown in fig.6. The boron screen being between the moderator and core it reduces the neutron flux, it is the same for thermal neutrons. The increase of the water thickness from 40 to 55 mm reduces the neutron yield at an energy higher than 7 eV.

Thus, the preliminary performed measurements show that it is advisable to use, if possible, a special moderator for all kinds of work. In the future it is assumed to continue the started investigations in choosing optimal moderators and also investigate in more detail the background nature in the region near to the microtron pulse.

Experimental Devices and Beams of IBR

At the present time seven beams are used for physical experiments at the IBR. Their arrangement is shown in fig.7. The nuclear-physical work is discussed more throughly in reference /7/, therefore, this work is not considered in this paper. The work on solid physics is discussed somewhat more.

Beam №1 has a maximum flight path of 100 m with a gap in the vacuum pipe at 30 m. In the reactor operating condition with a microtron the investigation of gamma-ray spectra at resonance neutron capture is carried out on this beam and the investigation of reaction (n, α). In the reactor operating condition the investigation of neutron inelastic scattering on liquids and solids is carried out using the method of" inverse geometry" /8/.

Beams №№ 2,3,4,5 and 7 go into the experimental hall that is next to the reactor hall. Three of them (3,4 and 5) are lengthened now, and experiments can be carried out on these beams with flight paths of 50-120 m.

There is a device on beam №: 2 in the experimental hall for investigating slow neutron scattering at small angles (up to 10^0). At the present time measurements of coherent neutron scattering by solid and liquid metals at small momentum transfers are being carried out. There will be a report on this at the present symposium/9/

Beam №:3 is intended for work with polarized neutrons. The magnets, crystals and other equipment are in the experimental hall, the detector can be placed on flight paths of 17m 56m and 120m.

There was a device on beam 4 for investigating the phonon spectra of crystals. A monochromatic neutron beam was obtained by reflection from a single crystal of zinc and the energy of neutrons scattered on the sample was measured by the time of flight over a 10 m. path. The arrangement is shown in fig.8. Fig. 9 shows the spectrum of neutrons scattered on a bismuth single crystal that was obtained in 15 hours the reactor power being 2.5 kW /10/.

Beam 5 is intended for neutron-structural investigations by the time of flight method /11/. Fig. 10 shows the arrangement that enables to obtain neutron-diffraction patterns on powder samples at different angles of scattering. The spectrometer flight path was about 16 m.

At the present time the spectrometer is being reconstructed. This will essentially reduce the time of obtaining neutrons-diffraction patterns. Neutron-diffraction patterns obtained before the reconstruction are shown in fig.11 (top curve) and after reconstruction (lower curve) with a silicon sample in 12 hours.

Beam № 6, having the maximum flight path of 1000 meters, is intended for neutron spectroscopy. In the microtron operation condition measurements of total cross sections (distance to detectors L=500 and 1000 m) and cross sections of radiative capture (L = 500 m) are carried out. In the reactor operation condition with a 1000 meter flight path investigations with a liquid fission detector are being performed, 750m - with a detector of scattered neutrons

There is a device at 250 m. for investigating angular distributions of scattered neutrons in the energy region up to 25 Kev.

There is a device on beam 7 for measuring double differential scattering cross-sections of slow neutrons. A mechanical chopper synchronized with the IBR pulses is mounted 10 meters from the reactor and enables to obtain monochromatic neutron pulses with a duration of 50-100μsec. The spectrum of inelastic scattered neutrons is measured by the time of flight simultaneously for a few angles/3/.

The five years of IBR operation have shown that it is a source of neutrons convenient for investigations in the region of solid state physics, and using the injector - for neutron spectroscopy. It is assumed to improve the IBR by increasing its power in the reactor operation condition up to 20-30 kW, and in the reactor operation condition with an injector improve it by using a more powerful injector to increase the intensity and reduce the pulse duration.

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TABLE I

Principal Parameters of IBR

Parameter	Measurement unit	Parameter value
Thermal power	kw	6
Pulse repetition frequency	1/sec	5
Pulse duration	μsec	60
Maximum power in pulse	MW	20
Global neutron flux	n/sec	3.3×10^{14}
Global flux in pulse maximum	n/sec	1×10^{18}
Average thermal neutron flux in maximum of spatial distribution in a thick moderator	n/cm^2 sec	3.6×10^{11}
Average neutron flux with 100 eV energy at 100 meters from reactor	n/cm^2 sec eV	12

TABLE II

Principal Parameters of the IBR Microtron System

Parameter	Measurement Unit	Parameter Value
ectron energy	MeV	30
lse current	mA	60-70
ectron pulse duration	μsec	1.2-2.2
actor subcriticality for ompt neutrons		$5x10^{-3}$
lse repetition equency	1/sec	50
erage power	kW	1.0
er between pulses	W	40
ective width of power se	μsec	4
bal neutron pulse	n/sec	$5x10^{13}$

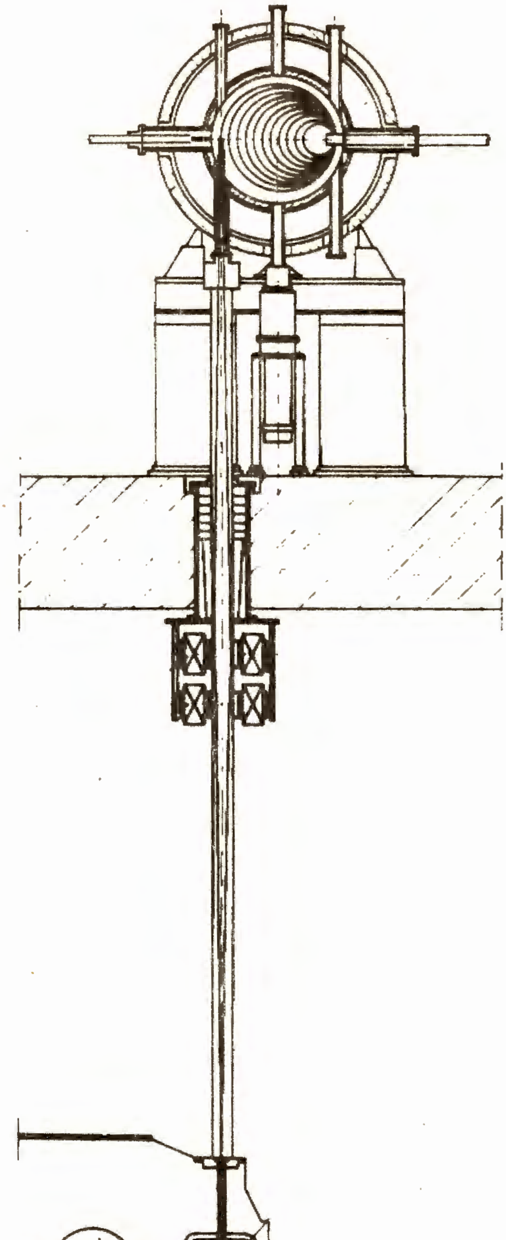

Fig.1. Arrangement of Microtron and Reactor IBR.

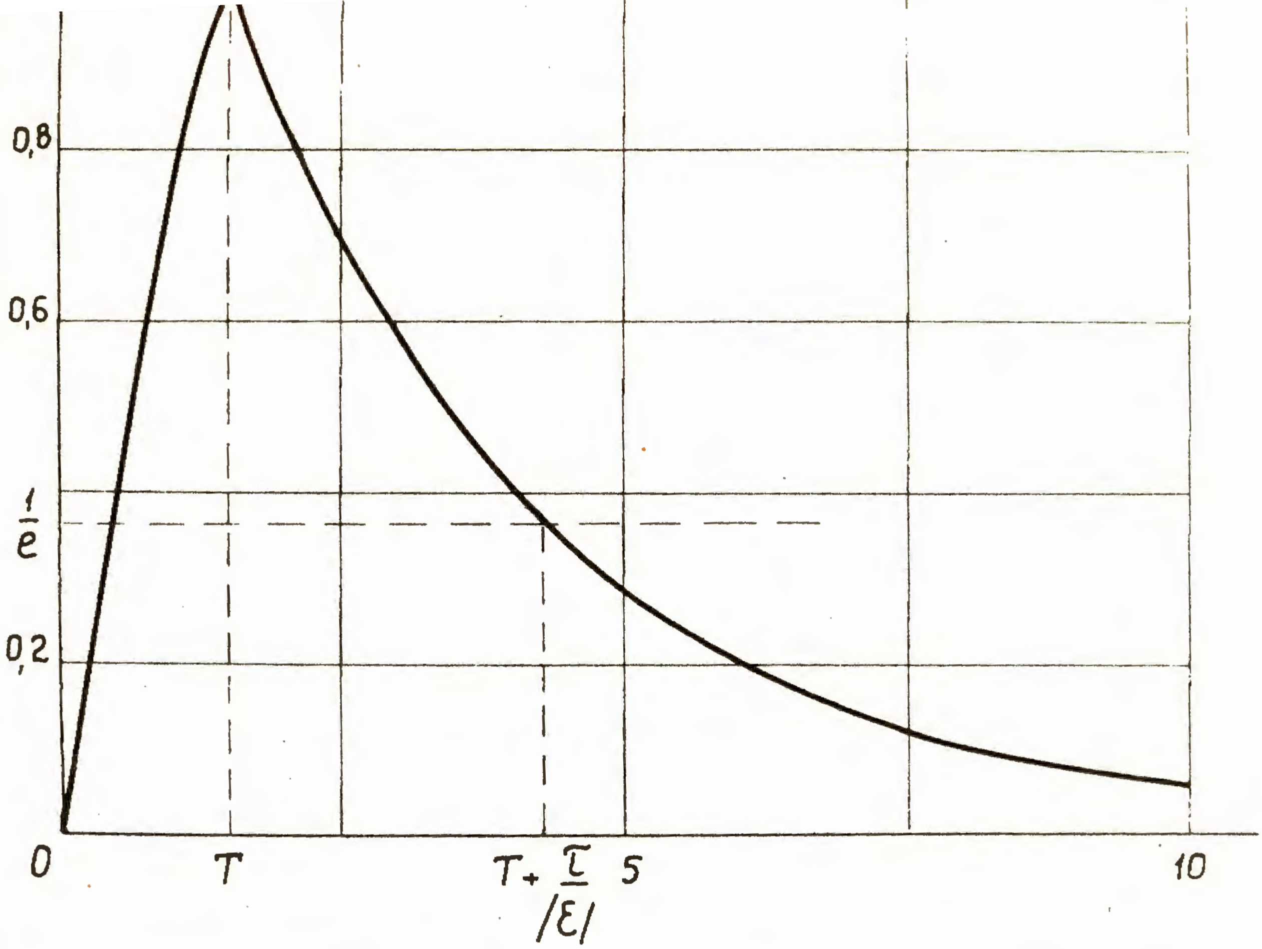

Fig.2. Design shape of IBR Pulses in Neutron Multiplication Conditions Generated in the Microtron Target. Microtron Pulse of Rectangular Shape; T = 1.5 μsec., Subcriticality $\varepsilon = -4.6 \times 10^{-3}$; $\tau = 1.3 \times 10^{-2}$ μ sec.

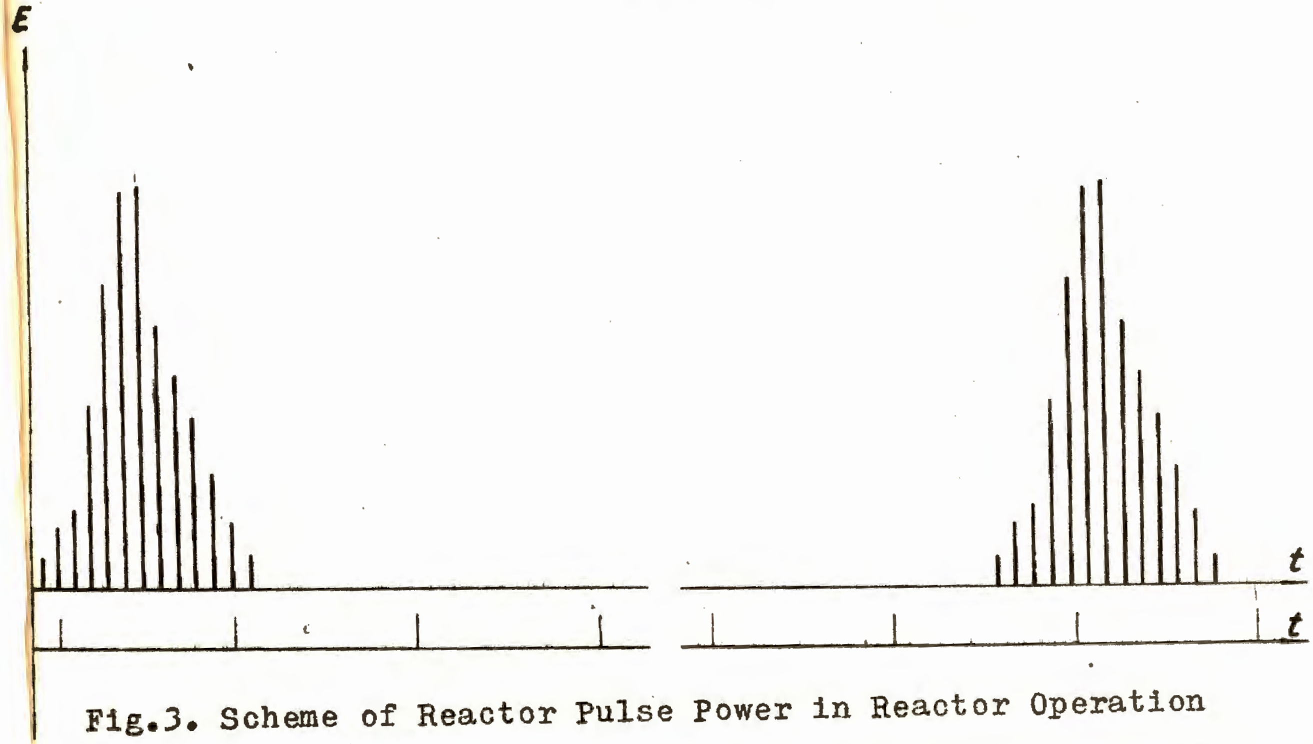

Fig.3. Scheme of Reactor Pulse Power in Reactor Operation Condition of Group Pulses and Usual Operation Condition of Permanent Pulses.

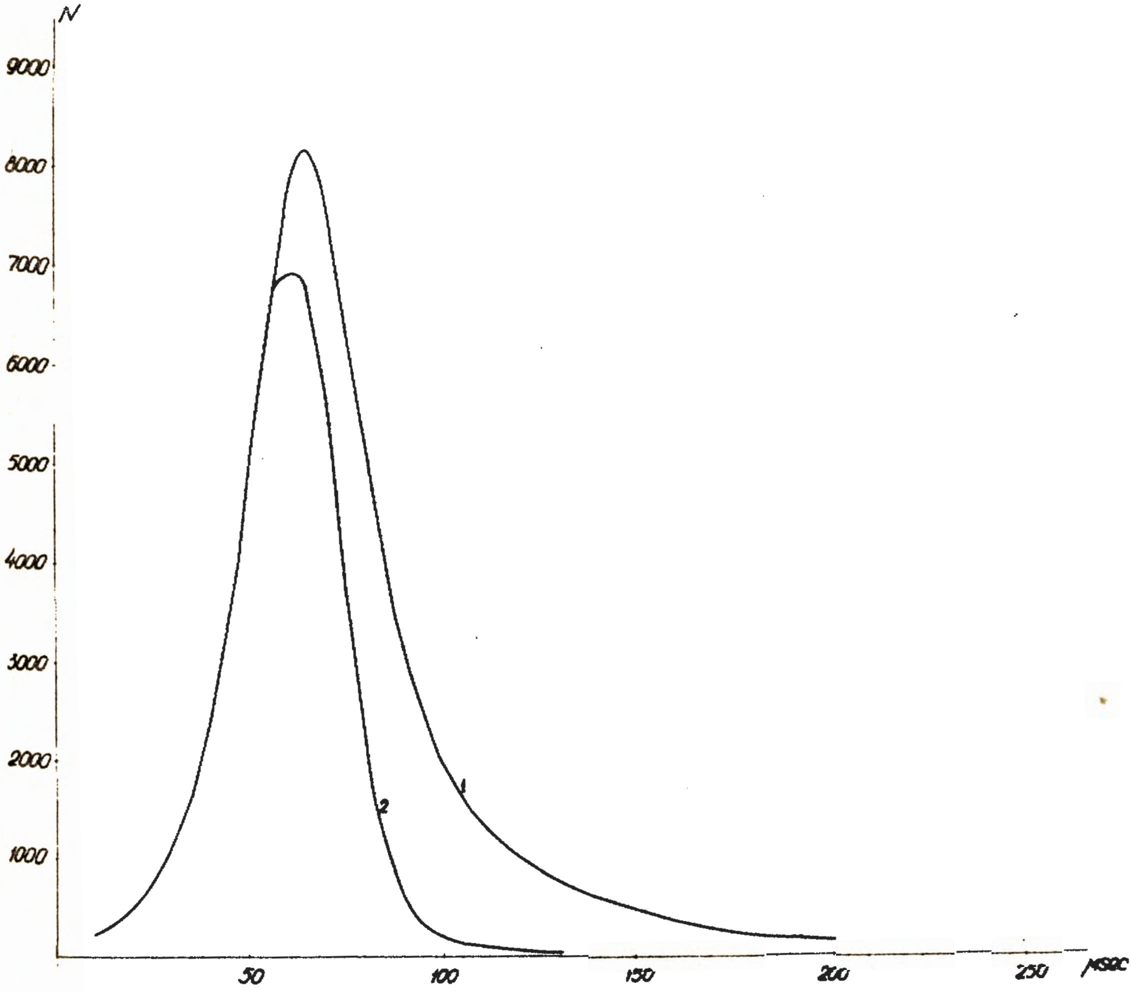

Fig.4. Reactor Gamma-Background Depending on Time for Moderator with Boron Carbide Screen (curve 1) and Water Moderator without Screen (curve 2).

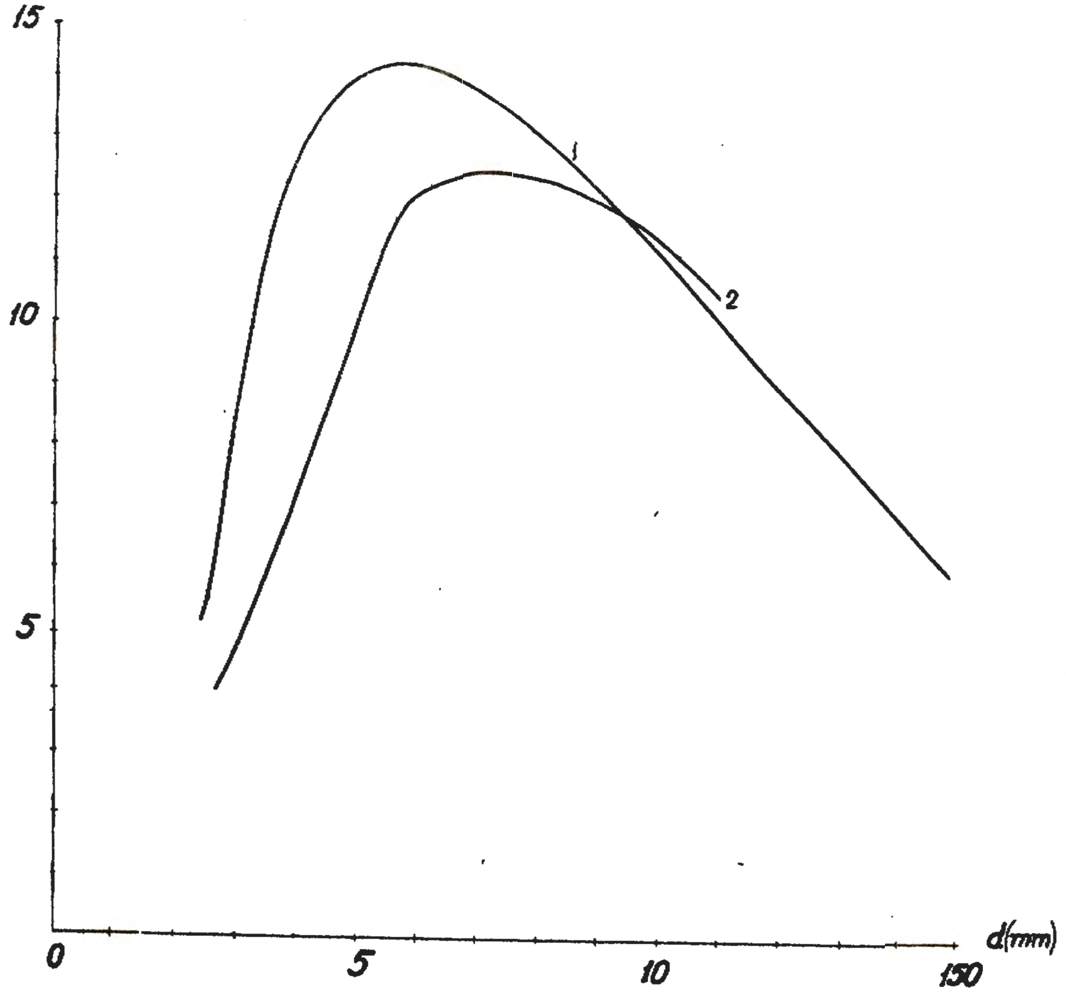

Fig.5. Relative Thermal Neutron Yield Depending on the Thickness d of Water Moderator (curve 1) and Moderator with Boron Carbide Screen (curve 2).

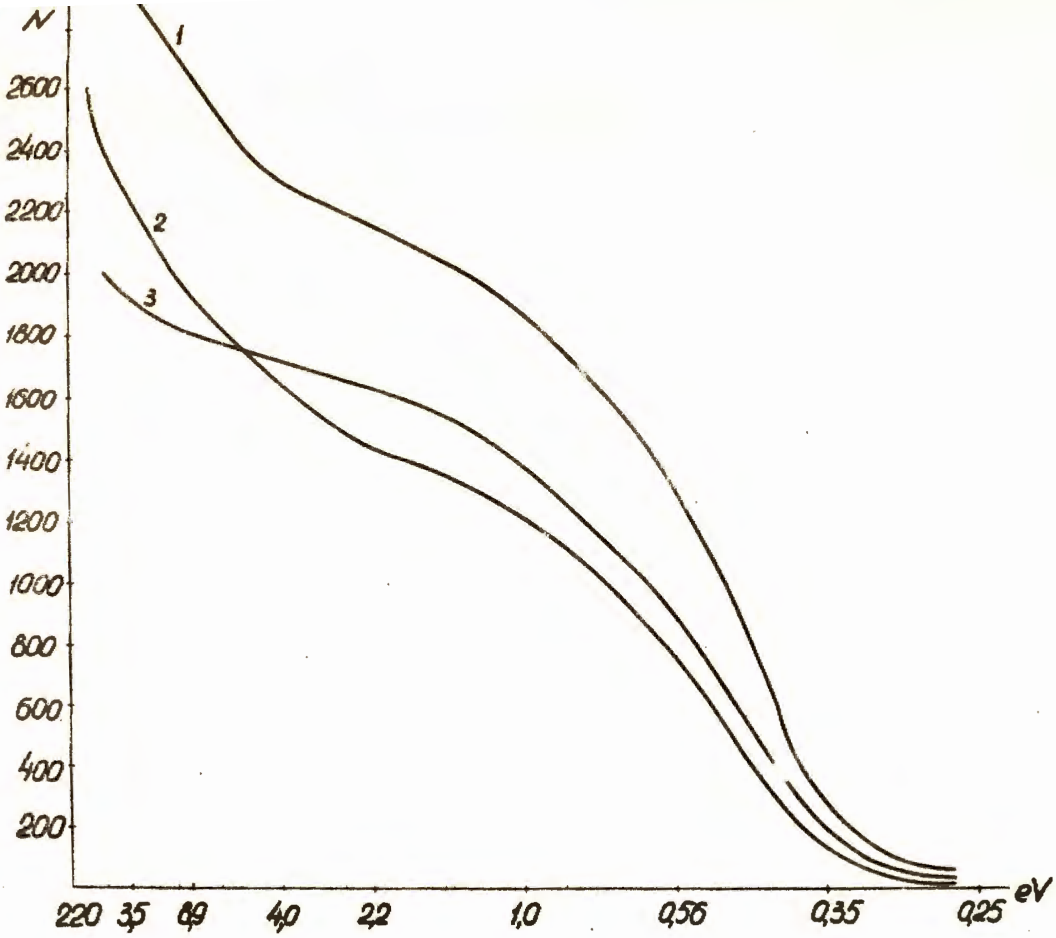

Fig.6. Intensity of Resonance Neutrons for Different Moderators

Curve 1 - 40 mm of Water

Curve 2 - 40 mm of Water with Boron Screen

Curve 3 - 55 mm of Water with Boron Screen

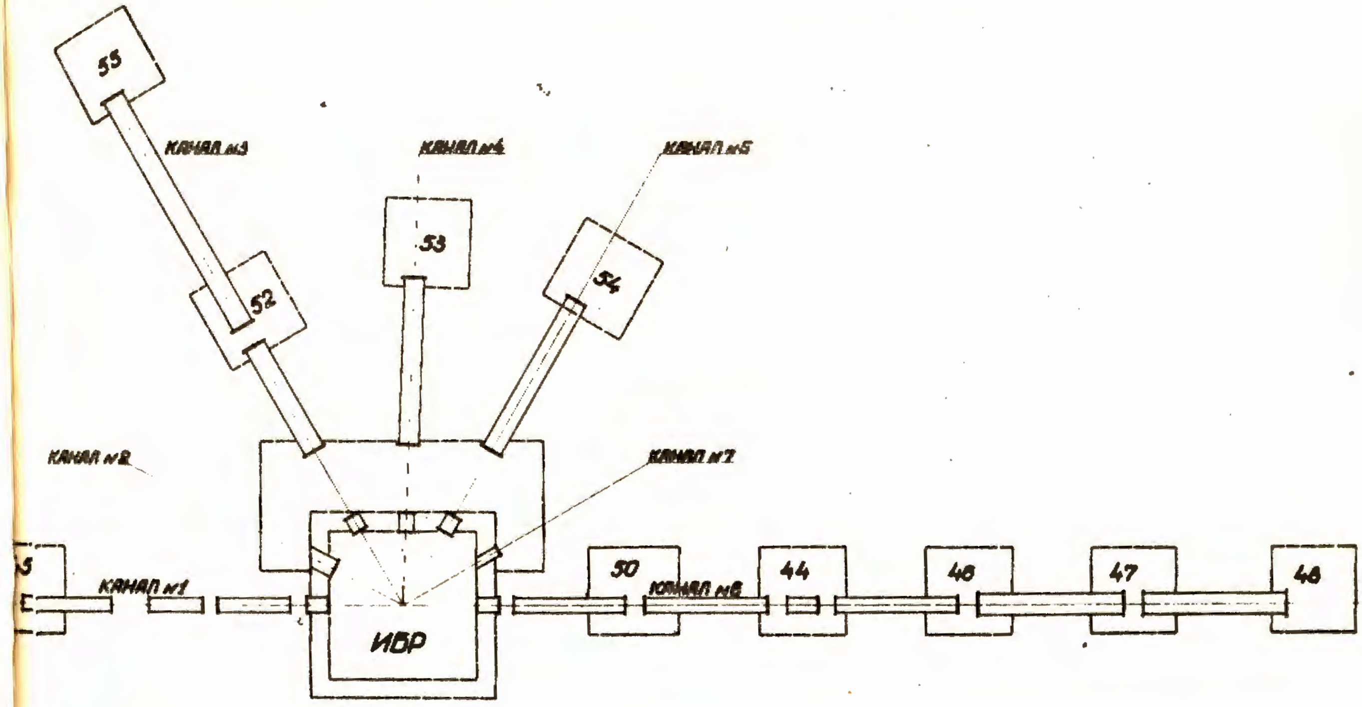

Fig.7. IBR Beams

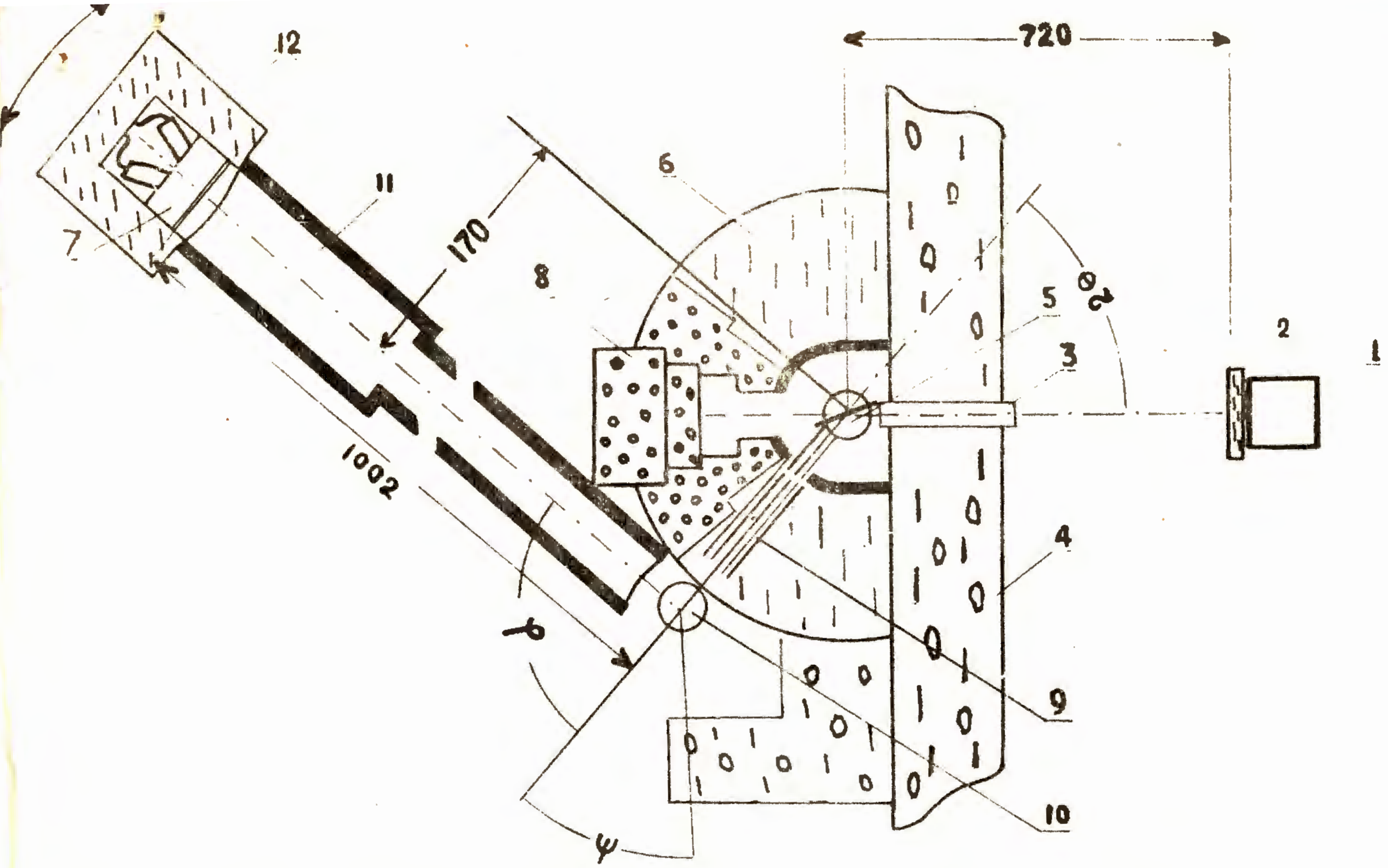

Fig.8. Arrangement for Investigating Crystal Phonon Spectra.

1 - Reactor, 2 - Moderator, 3,11 - Neutron Guide,

4,6,8,12 - Shielding, 5 - Single Crystal of Zinc,

7 - Detector, 9 - Collimator, 10 - Sample.

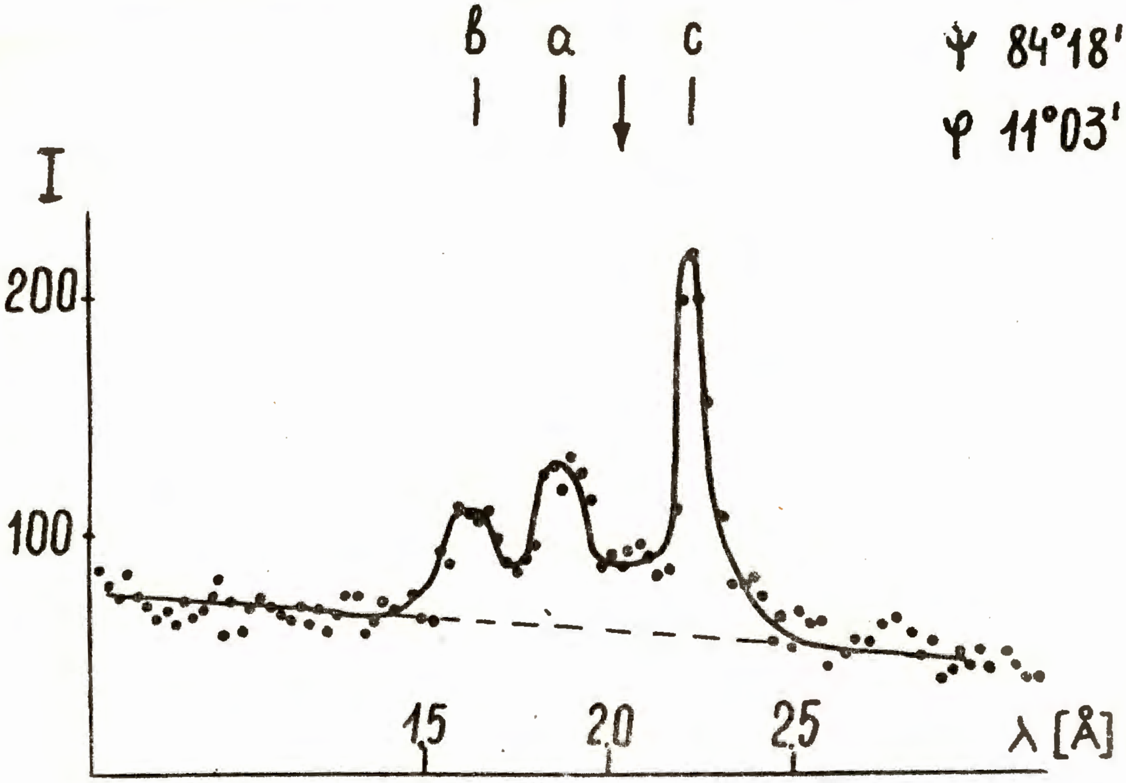

Fig.9. Spectrum of Neutrons Scattered in Single Crystal of Bismuth.

Arrow shows Neutron Wave Length Falling on Sample ( )

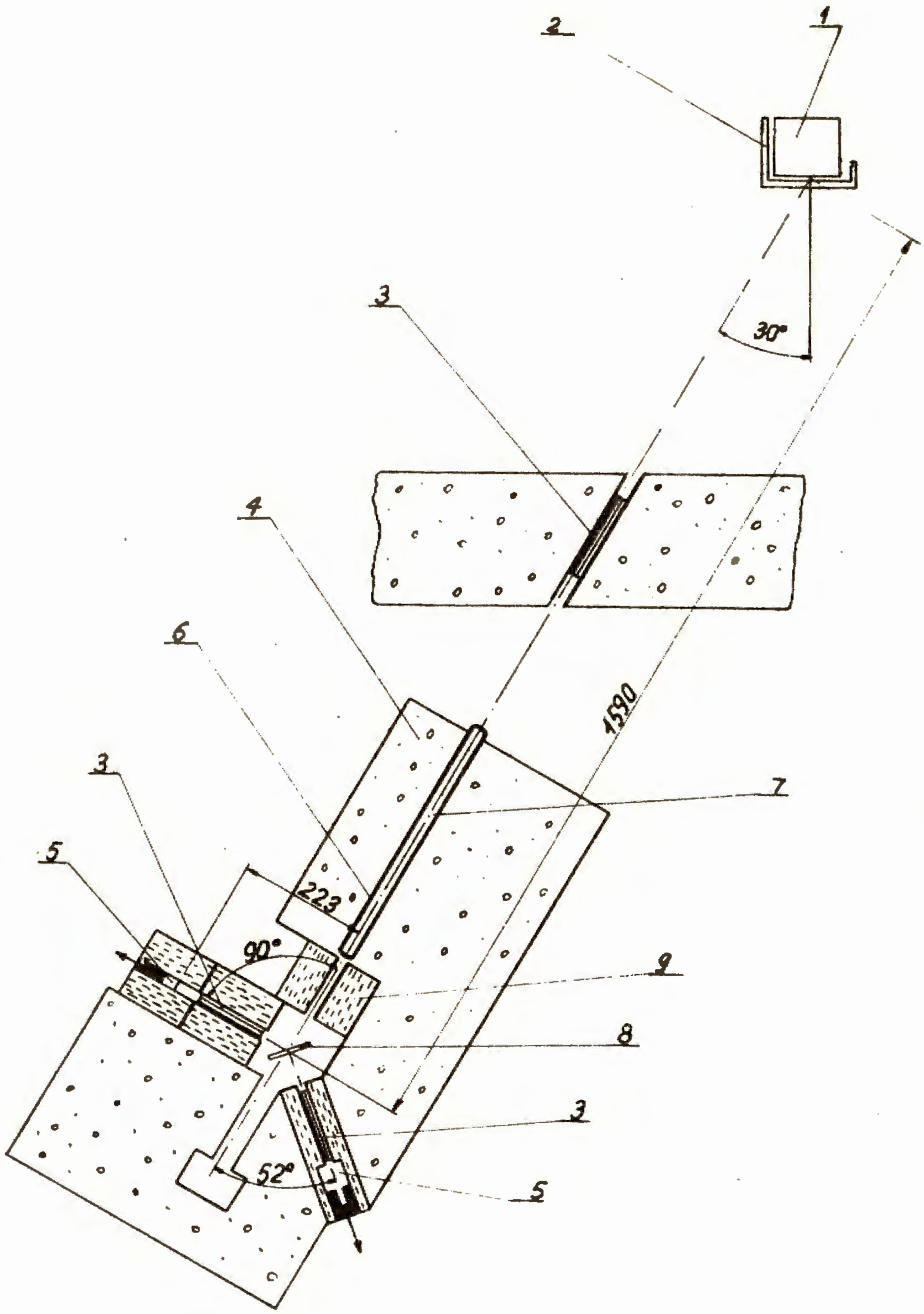

Fig.10. Arrangement for Obtaining Neutron-Diffraction Patterns by Time-of-Flight.

1 - Reactor, 2 - Moderator, 3 -Collimators, 4,9 - Shielding, 5 - Detectors, 6,7 - Vacuum Neutron Guide, 8 - Sample.

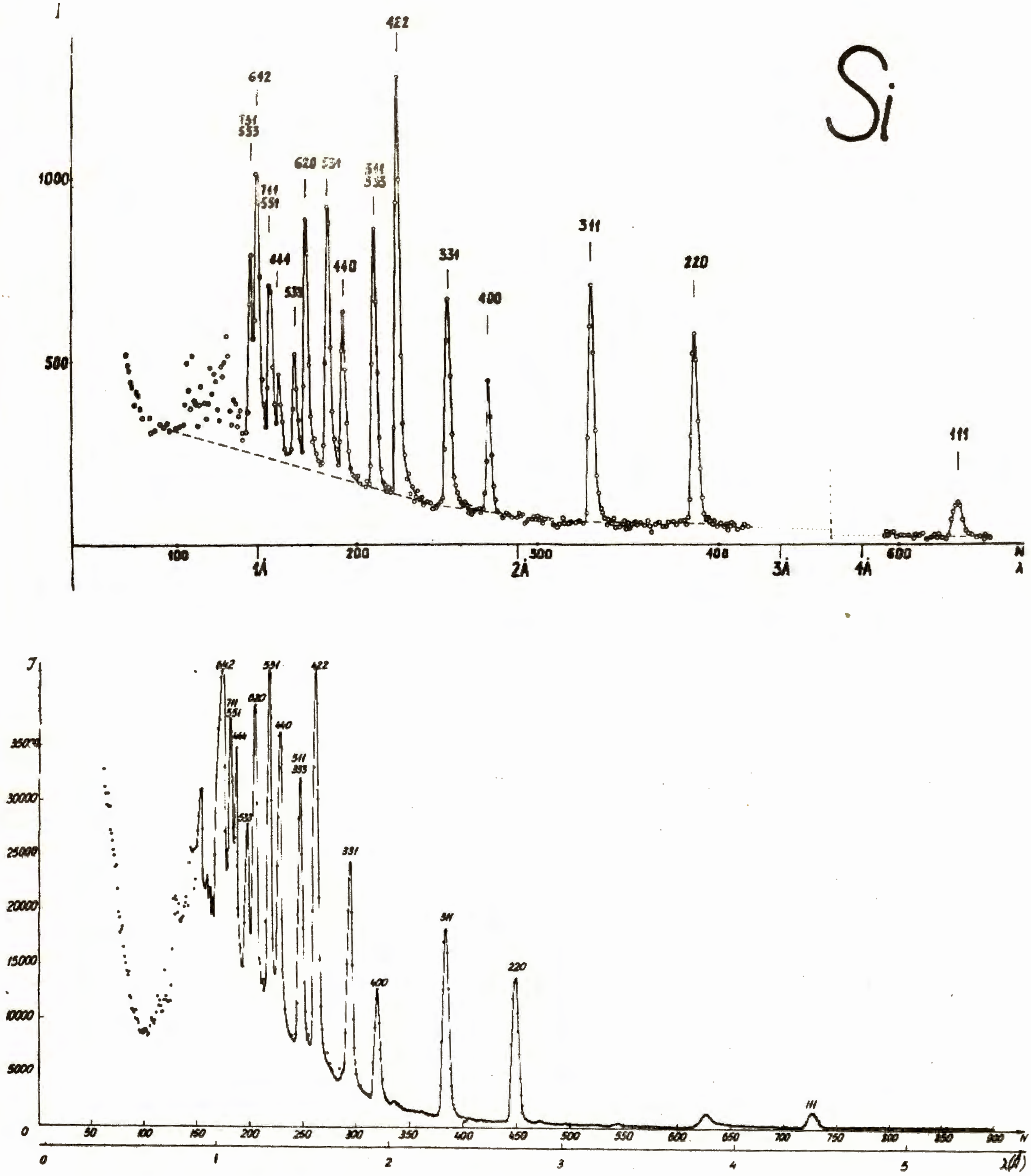

Fig. 11. Neutron-Diffraction Pattern Obtained before Reconstruction (top curve) and after Reconstruction (lower curve) with a Silicon Sample in 12 Hours.