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**USE of a METHOD of LOCAL COOLINGS  
FOR STUDY of a CONDITION IRRADIATED FUEL  
PINS  
of LMFR and VVER-type REACTORS**

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USE of a METHOD of LOCAL COOLINGS  
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Abstract.

In SSC RIAR are developed and are used at realization postirradiation examination in hot cells original methods of researches based on a principle of deep local cooling single fuel pins or fuel assemblies . The features of these methods and experimental devices focused on study of various radiating effects in single fuel pins and fuel assemblies multielement are described.

1. INTRODUCTION.

The SSC RIAR has a large research complex including:

- Research reactors on thermal and fast neutrons (CM-2, МИП, РБТ-6, БОР-60 etc.);
- Techniques and equipment for in-pile tests and measurements in these reactors;
- More 50 hot cells for study of a condition fuel pins and fuel assemblies, irradiated in own research reactors or in power reactors, taking place outside RIAR or Russia.

Large share of works which are carried out at hot cells, occupy PIE of regular and experimental full size fuel assemblies, irradiated in power reactors on thermal and fast neutrons BBЭP-1000 and БН-600. These assemblies have the large sizes and contain much pins. For example, length assembly BBЭP-1000 is close to 5 meters, in it is placed 317 pins. In assembly reactor БН-600 is placed 217 pins.

The detailed study by destroying methods of a condition everyone pin in such multielement assembly would require a lot of time and means. Therefore limited amount of pins gets out for destroying researches by results of non-destructive researches all pins. However, use of traditional non-destructive researches pins, such as profilometry, eddy current defectoscopy, gamma-scanning etc. can be insufficient for a choice pins with unusual anomalies in properties. Besides, the time necessary for the individual non-destructive control of each of pins multielement assembly, is inevitably great.

For overcoming similar difficulties in RIAR a series of original methods of the non-destructive researches based on a principle of local thermal influence on irradiated pins and assemblies was developed. As against a method of local heating, which was developed and is applied in RIAR for modeling emergency overheating of fuel rods and rod bundles [1, 2], in this case, pins and assemblies are exposed to deep local cooling [3-8]. At cooling pins or assemblies any design or emergency condition are not simulated and any additional changes to fuel or can condition to solid fission products are not burning. At the same time, the physical constituent of gaseous fission products has principal changes - they are condensed in a liquid or solid condition on the beforehand chosen site of pin, which is exposed to deep cooling.

In table 1 those physical properties of fission gases Xe and Kr are given which were used by development of methods and devices for deep local cooling irradiated fuel pins and assemblies.

Table 1

Physical properties Xe and Kr.

Gas	$T_{\text{melt}}, ^\circ\text{C}$	$T_{\text{boil}}, ^\circ\text{C}$	$\gamma_{\text{solid}}, \text{g/cm}^3$	Gas volume from 1 L Condensate, L
Kr	-157,3	-153,4	2,16 (at $-146^\circ\text{C}$ )	644
Xe	-111,9	-108,1	3,50 (at $-109^\circ\text{C}$ )	519

The cooling fuel pins and assemblies by liquid nitrogen ( $T_{\text{boil}} = -195,8^\circ\text{C}$ ) can be used for condensation fission gases Kr and Xe in a liquid or solid condition.

## 2. VARIANTS of USE of a METHOD of LOCAL COOLINGS.

### 2.1. Definition of tightness of a single fuel pin by measuring volume released fission gases.

The burning out of fuel in fast reactors fuel pins can reach and to exceed 10 % t.a. The release of fission gases from fuel can reach and to exceed 90%. Therefore amount of fission gases released under can, for example, BH-600-reactors fuel pin, can achieve and to exceed  $360 \text{ n.cm}^3$ . Height of a pole of a condensate of these gases in plenum can achieve and to exceed 23 mm. Under similar conditions height of a pole of a

condensate (Xe + Kr) in plenum of BOP-60 reactor fuel pin can achieve and to exceed 13 mm. Rather high density of a condensate ( $3,4 \text{ g/cm}^3$ ) and large distinction in meanings of density of a condensate and stainlesssteel cause an opportunity of visual «division» of these materials at viewing or photographing in x-ray beams cooled plenum.

The possible variations of this method are connected to use of different ways of registration of volume (height) (Xe + Kr) - condensate. Instead of fluerografy or photographing in x-ray beams actually (Xe + Kr) - condensate, such ways as, for example, eddy current defectoscopy, magnitometry, gamma-spectrometry can be used. For this purpose in fuel pin's plenum should be previously placed executed from a suitable material and having the appropriate form mobile indicator of a level (Xe + Kr) - condensate.

On fig.1, 2 are given the circuit and result of definition of tightness fuel pins, irradiated in fast neutrons reactor BOP-60. It is possible to note, that at such circuit the separate control single fuel pins, simultaneous control of group fuel pins, control fuel pins, driven on the conveyor can be realized.

In fuel pins of VVER, PWR, BWR- type reactors the value of burnup and gas release from fuel are much less, than in fast reactors fuel pins. Therefore height of a pole of a condensate (Xe + Kr) in fuel pin's plenum will not exceed 2-3 mm, that it is not enough for the sure measurements. The accuracy of results of measurements can be increased by changing the form of fuel pin's plenum.

## 2.2. Definition of a site untight fuel pins inside fuel assembly.

The individual, group and line (conveyor) control of tightness of fuel pins on the above described method is possible only after complete dismantling of fuel assembly and a lot of time requires.

Method of the simultaneous control all pins in the assembly without its dismantling therefore was developed. The following components of a method are important for its realization:

- The can of pins and the cover of assembly should be made from unferromagnetic materials (austenitic stainless steel, Zr-alloys);
- Mobile ferromagnetic indicator should be inserted in plenum of each fuel pin;
- Before cooling of the bottom part of assembly below the temperatures of xenon solidification ( $T < 112$  °C) indicators are lower should be raised upwards in a magnetic field of the included electromagnet;
- After xenon solidification the electromagnet should be switched - off, therefore the indicators will be lowered on a solid surface of xenon;
- The cooled part of assembly should be photographed in x-ray beams in two projections.

In case of replacement ferromagnetic rods-indicators on easy floats emerging in liquid xenon, disappears necessity for use of an electromagnet. Besides the restrictions on magnetic properties of can, cover and indicator are removed.

Use of the described method for the pins control in dismantling assembly will allow quickly to determine a site untight pins and to unload them from assembly without its complete dismantling.

On fig.3, 4 are given the circuit and result of use of a method with reference to assembly of fast reactor БОР-60. The assembly contained in a cover from austenitic stainless steel by thickness 1 mm 37 fuel pins with can  $d \times \delta = 6 \times 0,3$  mm from austenitic stainless steel. In lower plenum of each pin the coil - indicator from iron was placed. The fuel pins №№ 13, 19 have lost tightness at an irradiation.

### 2.3. Definition of single fuel pin tightness by measuring Kr-85 activity.

Measuring speed of the account the gamma-radiation Kr-85 with energy 514 keV in area of fuel pin's plenum, is possible to estimate concentration Kr-85 in unit of free volume of fuel pin and to make the conclusion about tightness of fuel pin. Low sensitivity and accuracy - basic lacks gamma-spectrometer of a method of definition of tightness of fuel pins by measuring of Kr-85 activity. In the greater degree these lacks are displayed at the control fuel pins, containing fuel with small burn-up, with low gas release, with large free volume.

Method of concentration all of Kr-85, released from fuel, in a local site of pin's plenum therefore was developed. Gamma-spectrometer of measurement will be carried out just on a site of local cooling fuel pin.

On fig.5, 6, 7 are given the circuit and results of use of a method with reference to fuel pins of БОР-60 and ББЭР-1000 reactors. In fuel pin of БОР-60-reactor the burn-up of oxide fuel was equal 2% h.a., thus

under can was released  $37 \text{ n.cm}^3$  fission gases. In fuel pin of BBЭP-1000 reactor the burn-up of oxide fuel was equal  $32,6 \text{ Mwt.d/kg U}$ , thus under a can was released  $40 \text{ n cm}^3$  of fission gases. The measurements of gamma-activity were carried out on distance  $2,5 \text{ m}$  from the pin. As it is visible from fig.6, 7, at such distance, small amount released fission gas, a large background the tightness of fuel pins could be determined only after condensation all of Kr-85 on a local site of plenum.

#### 2.4. Measurement of free volume in fuel pins.

The essence of a non-destructive method of definition of free volume in irradiated fuel pin consists in measurement of speeds of the account gamma-radiation Kr-85 on the same site plenum before its deep cooling. The relation of results of these measurements is proportional to value of free volume in pin. Factor of proportionality is determined from auxiliary experiments.

As have shown researches, the error of a method depends mainly on accuracy of measurement of speed of the account gamma-radiation Kr-85 before cooling plenum. Therefore for reduction of an error of measurements of value of free volume it is expedient to carry out measurements under the circuit represented on fig.8. In it, remote variant of the device the background radiation both distance between fuel pin and detector of radiation can be essentially reduced.



## 2.5. The control gas penetration through fuel column.

Radiating swelling of the fuel core, the transfer mass of fuel and solid fission products, chemical reactions between components of fuel pin with formation of reaction products with smaller density - all these phenomena and the processes can result in occurrence in fuel element «plugs», impenetrable for gases. The formation such «plugs» can be the reason premature rupture or increased plastic deformation of can.

The definition of presence and site disposition such plugs in of fuel pins of a container type with helium bonding can be made on a method, which block diagram is given on fig.9.

According to the circuit, the speed of the account gamma-radiation gaseous Kr-85 in one of not cooled plenums is measured during local cooling another plenum. The reduction of speed of the account testifies to outflow gaseous Kr-85 from a zone of measurement through impenetrable for gases a column of fuel in a zone of cooling and condensation liquid Kr-85. The constancy of speed of the account in a zone of measurement testifies to presence in a column of fuel impenetrable plug.

The site disposition of a plug in fuel pin find by consecutive local cooling of various sites pin during measurement of speed of the account gamma-radiation Kr-85 in both plenums.

## 2.6. Definition of gas pressure in fuel pin.

The known methods of measurement of gas pressure in fuel pin are based on short-term heating of a local site plenum with the subsequent registration of change of temperature outside of area heating. The change

of temperature of a can is connected gas and heat convection and sharp increase of pressure of gases in pin owing to temperature expansion of gases in a zone of heating.

The new method consists in replacement of local heating of pin on local cooling of pin. It is achieved by fast immersing of a part of pin plenum in liquid nitrogen (fig.10). The pressure in pin decreases originally owing to cooling gases, and then - because of their condensation. The fall of pressure in pin results in reduction of temperature of an environment outside of a zone of cooling in liquid nitrogen. The change of temperature of a can is registered by termocouple.

Owing to condensation of gases at deep pin cooling, fall of pressure and, accordingly, the maximal change of temperature of a can in some times is more, than at heating on the same difference of temperatures  $200^{\circ}\text{C}$  (fig.11). Due to this the error of measurement of pressure of gases in fuel pins was reduced.

### 3. THE CONCLUSION.

In SSC RIAR is developed and a series original in-cell non-destructive methods of study of a condition and measurement of some properties irradiated fuel pins and fuel assemblies for reactors on thermal and fast neutrons is realized. In a basis of all developed methods the principle of deep cooling of local parts pins or assemblies and condensation of fission gases Xe and Kr in a liquid or solid condition.

Use of the developed methods in hot cells facilitates the decision of a number of technical, scientific and ecological tasks. It concerns increase

of productivity of some control operations, increase of accuracy of some measurements, replacement of some destroying tests on not destroying.

The method of the collective control fuel pins inside of undismantled fuel assembly can be used not only in hot cells, but also on stands of inspection and repair fuel assemblies.

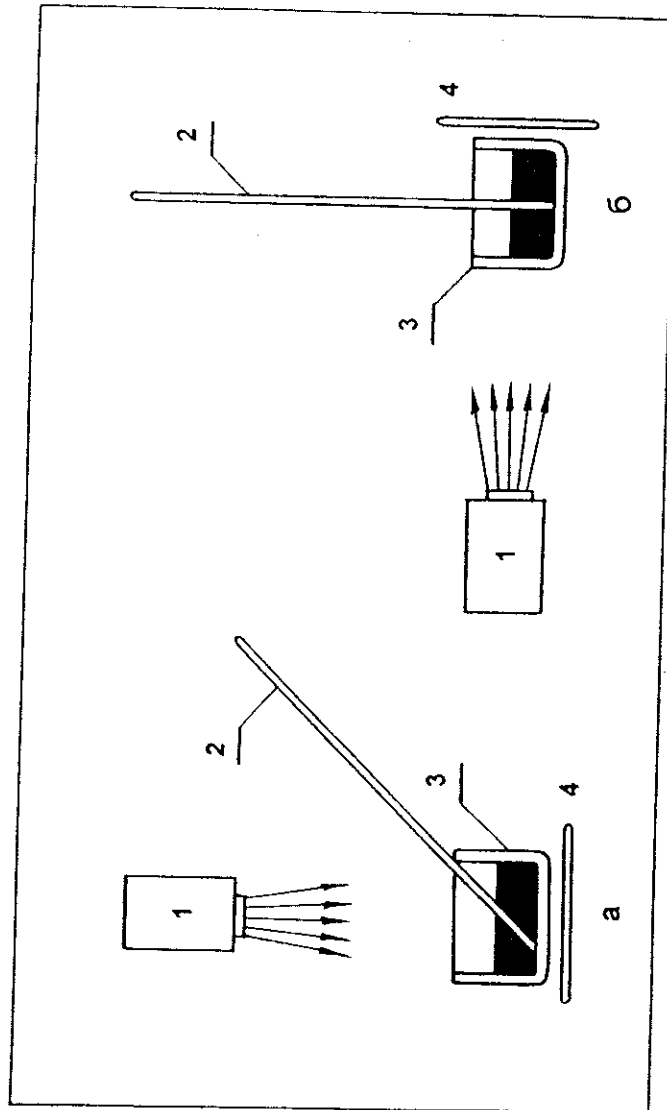
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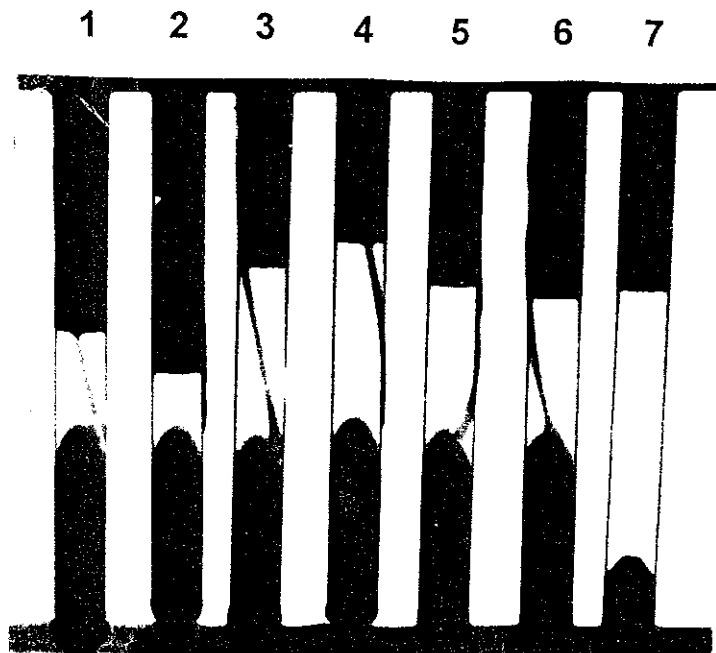
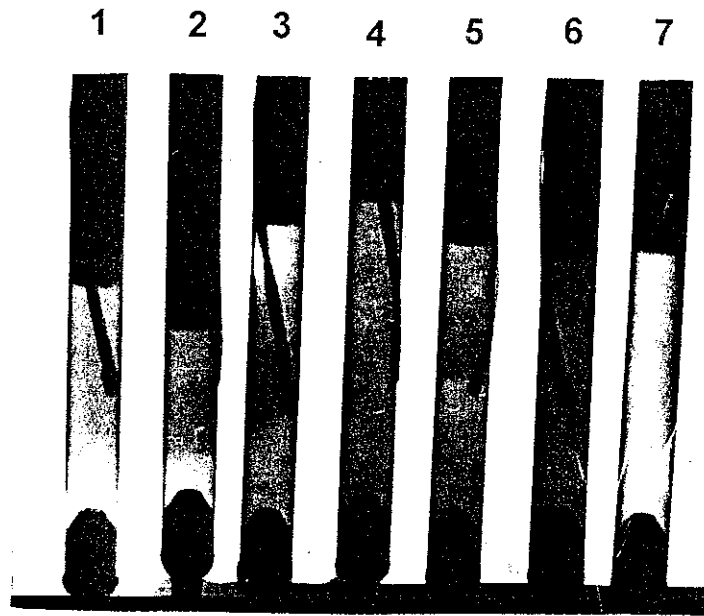
# Measurement of cladding-enclosed gas content by its condensate volume



a, b - X-ray apparatus 1 (horizontal and vertical position) in cell;  
2 - fuel pin;  
3 - cooling container;  
4 - X-ray film.

Fig.1

# X-ray pictures of fuel pin plenum

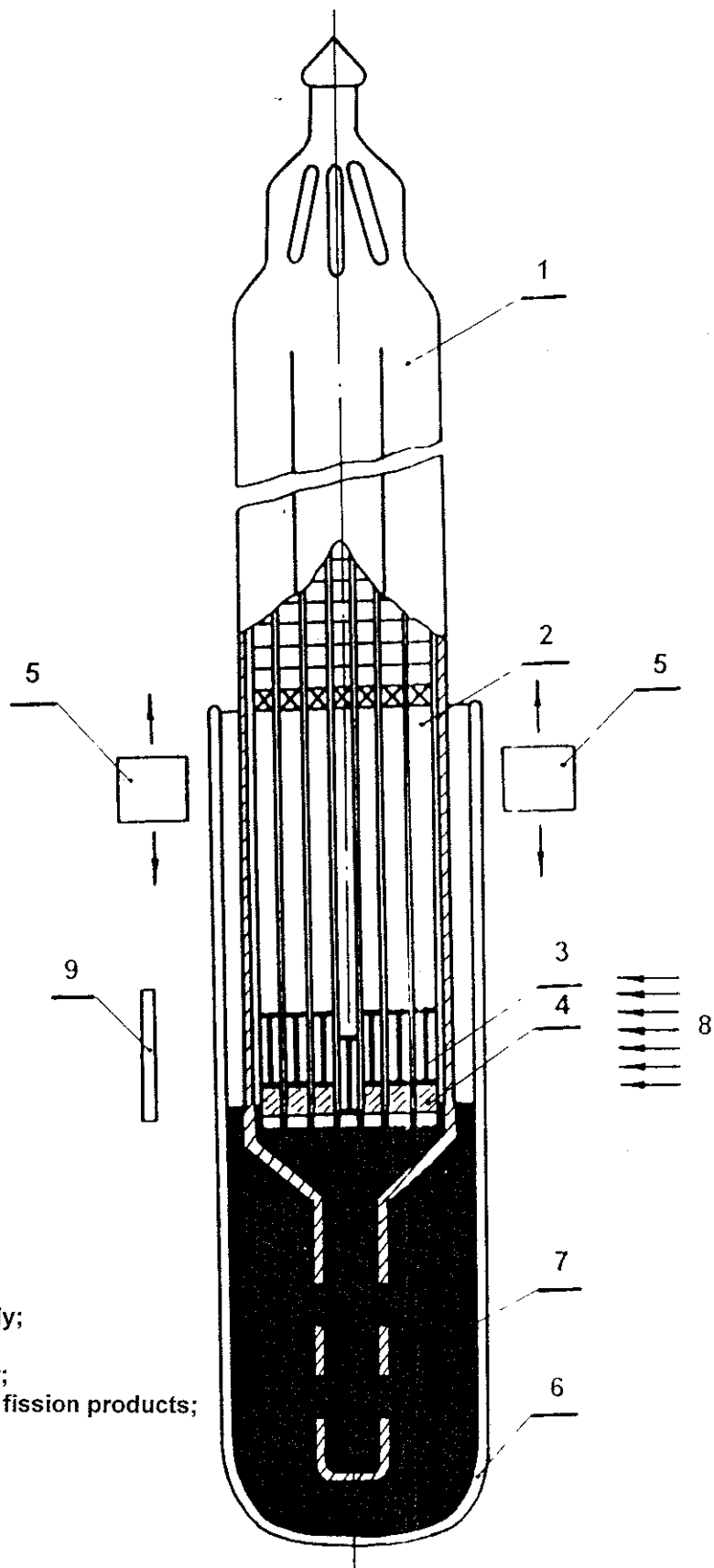


a- before cooling;  
b - after cooling.

Fig. 2

*fuel pin 7: did lose  
tightness under  
irradiation.*

# Checking of fuel pin tightness in spent FA of fast reactor

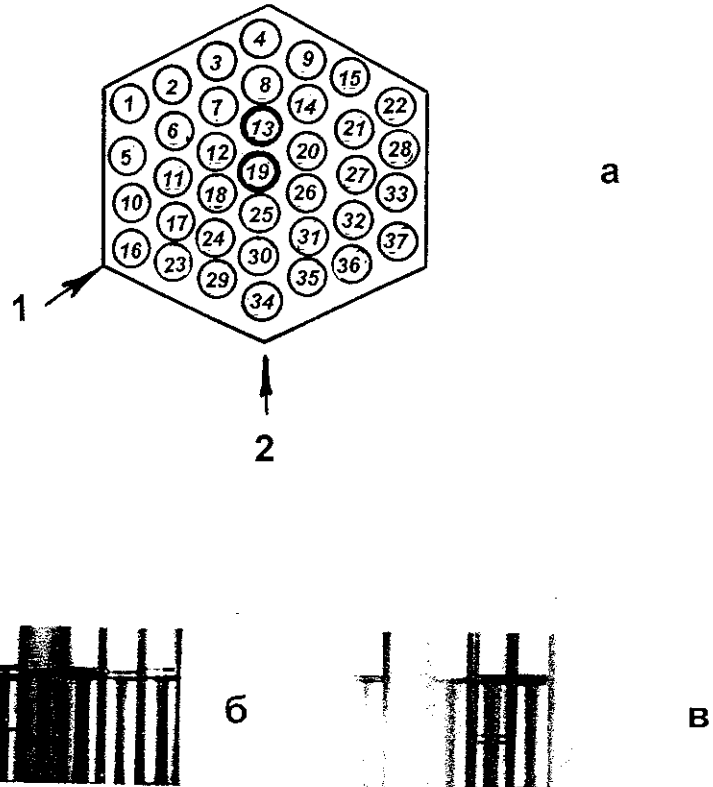


- 1 - fuel pin under study;
- 2 - fuel pin;
- 3 - tightness indicator;
- 4 - condensate of gas fission products;
- 5 - annular magnet;
- 6 - Devar flask;
- 7 - liquid nitrogen;
- 8 - X-ray radiation;
- 9 - film.

Fig.3



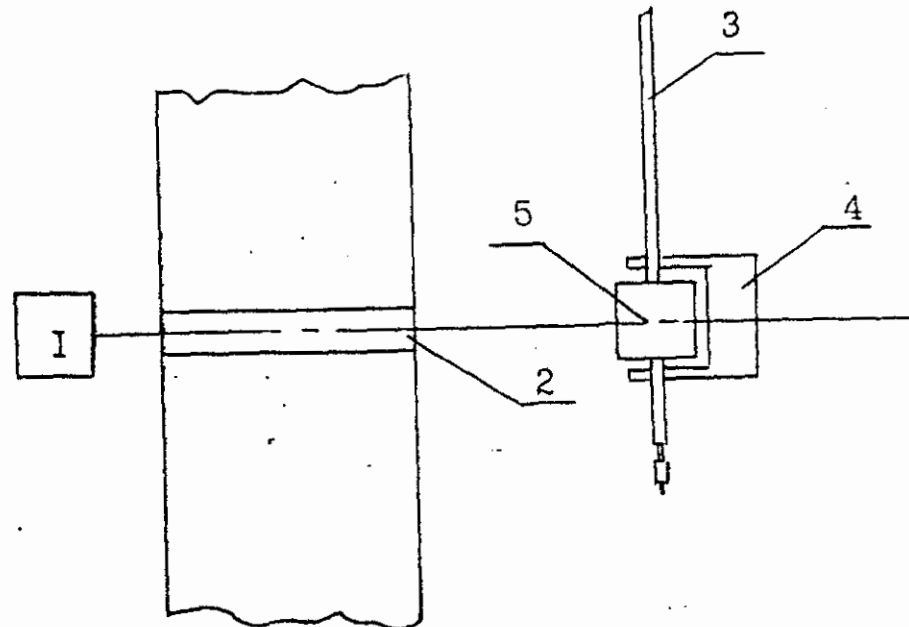
**Identification of unsealed fuel pins in BOR-60 reactor  
(fuel pin no 13 and 19 are unsealed)**



**a - location of fuel pins in assembly;  
b - X-ray picture for latent image  
of lightness indicator (arrow 1);  
c - X-ray picture (arrow 2).**

**Fig.4**

**In-cell device for gamma-spectrometric measurement  
of cladding-enclosed gas**



- 1 - Ge (Li) detector of gamma-spectrometer;
- 2 - collimator in wall of shielding chamber;
- 3 - fuel pin;
- 4 - mechanism of fuel pin adjusting;
- 5 - cooling assembly.

**Fig.5**

Gamma-spectra in plenum before (a) and after (b) fuel pin cooling

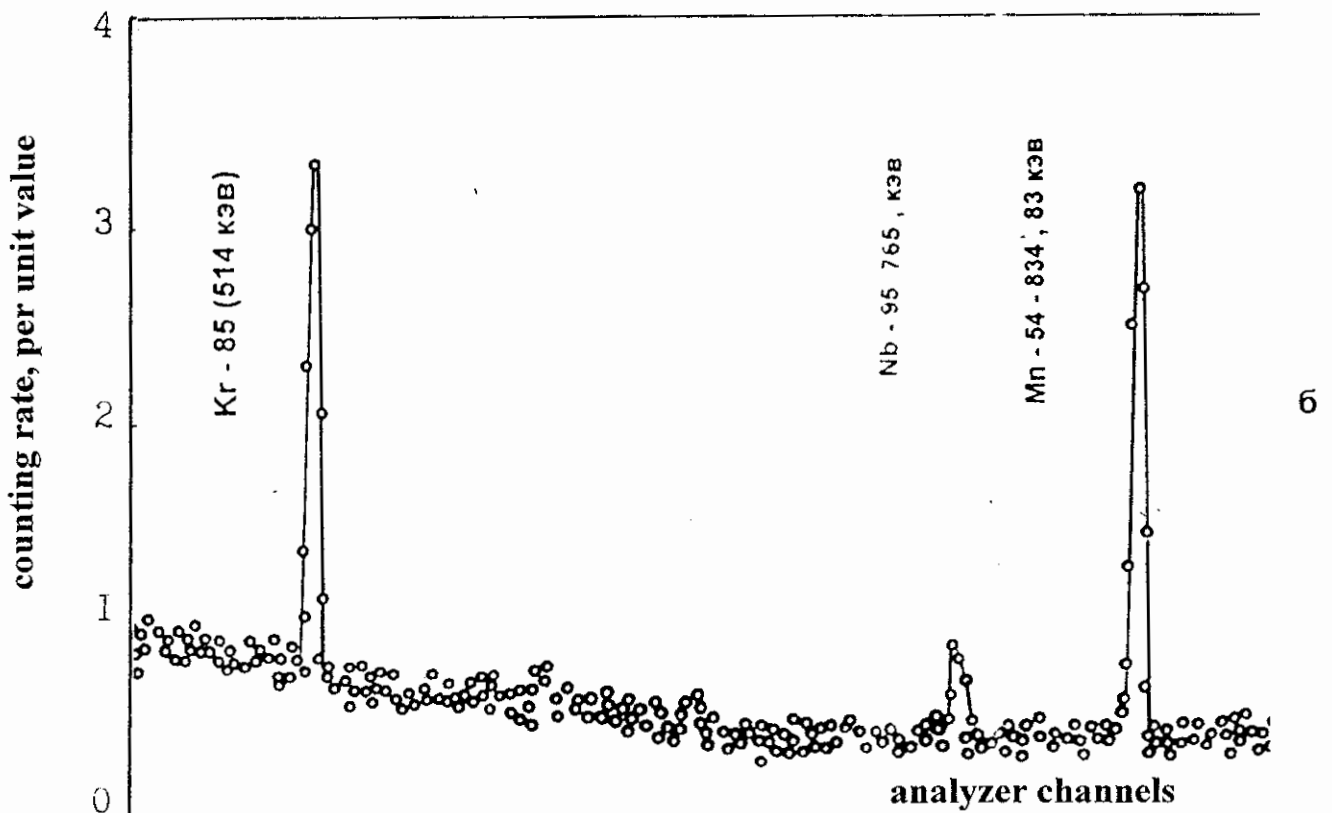
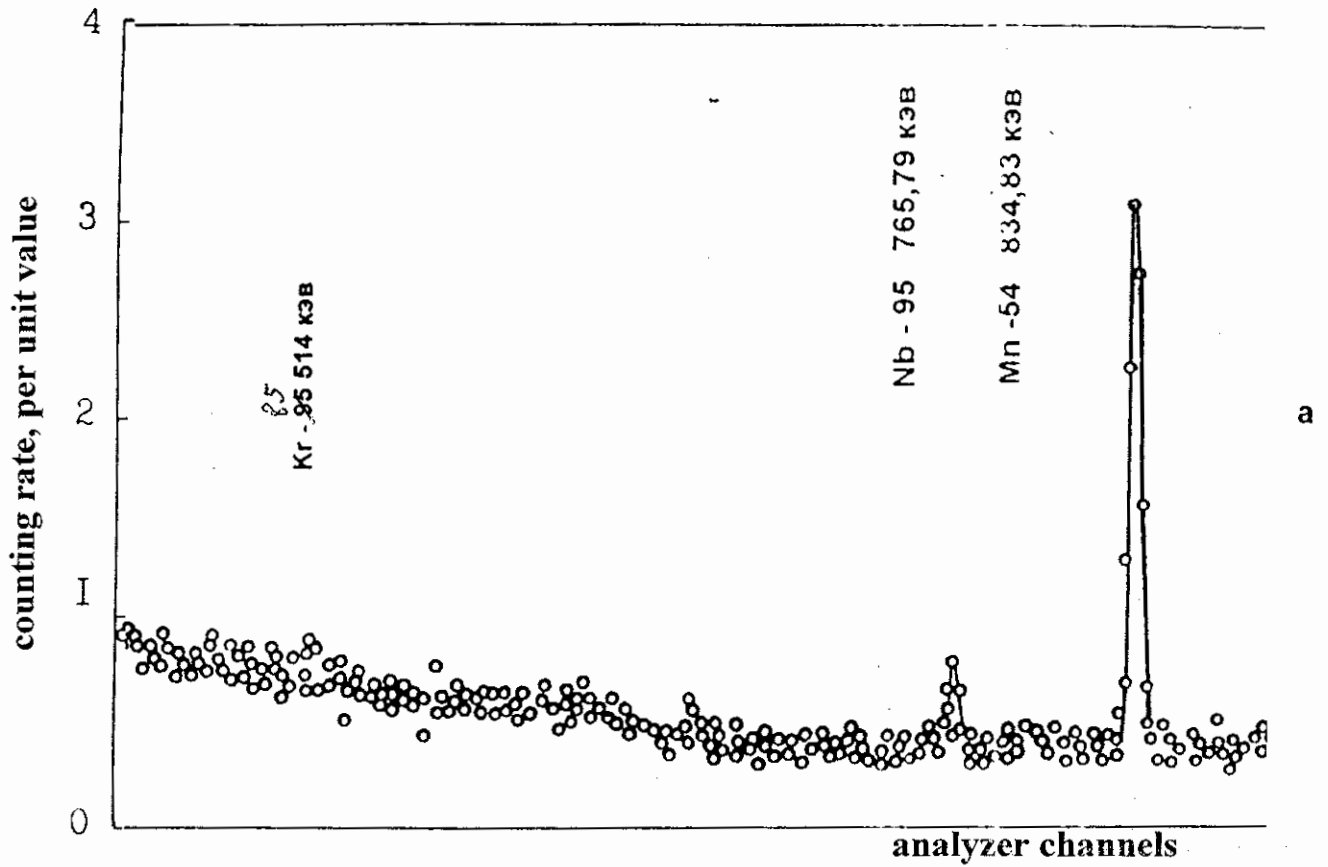
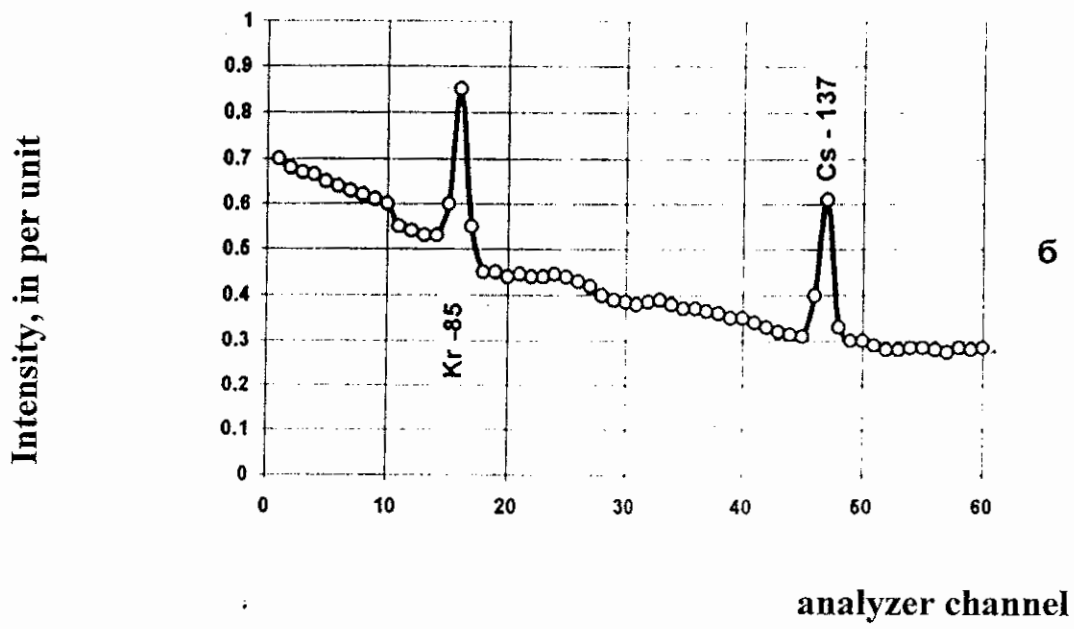
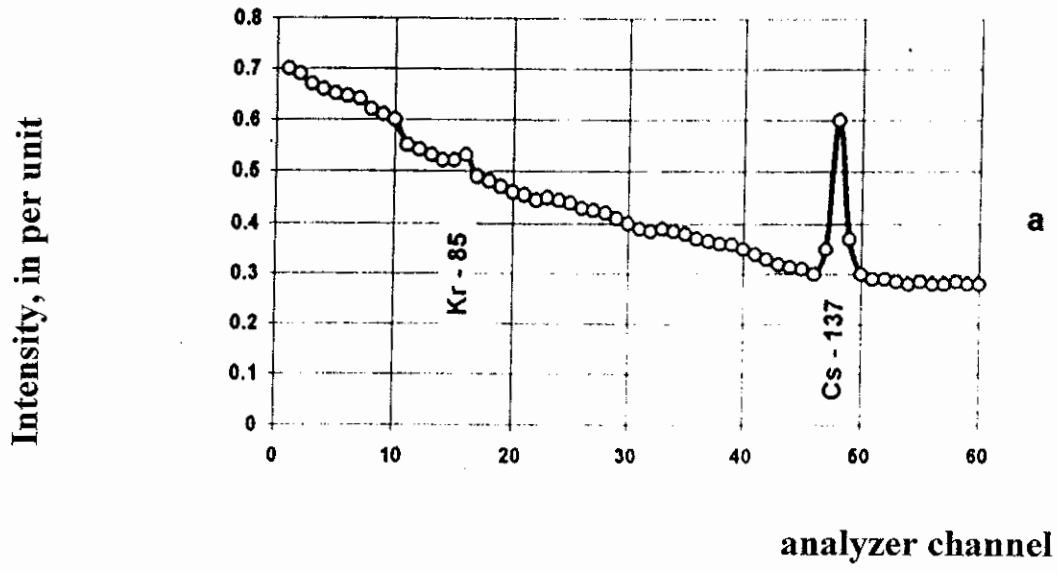


Fig.6

# Gamma-spectrum section in VVER fuel pin plenum

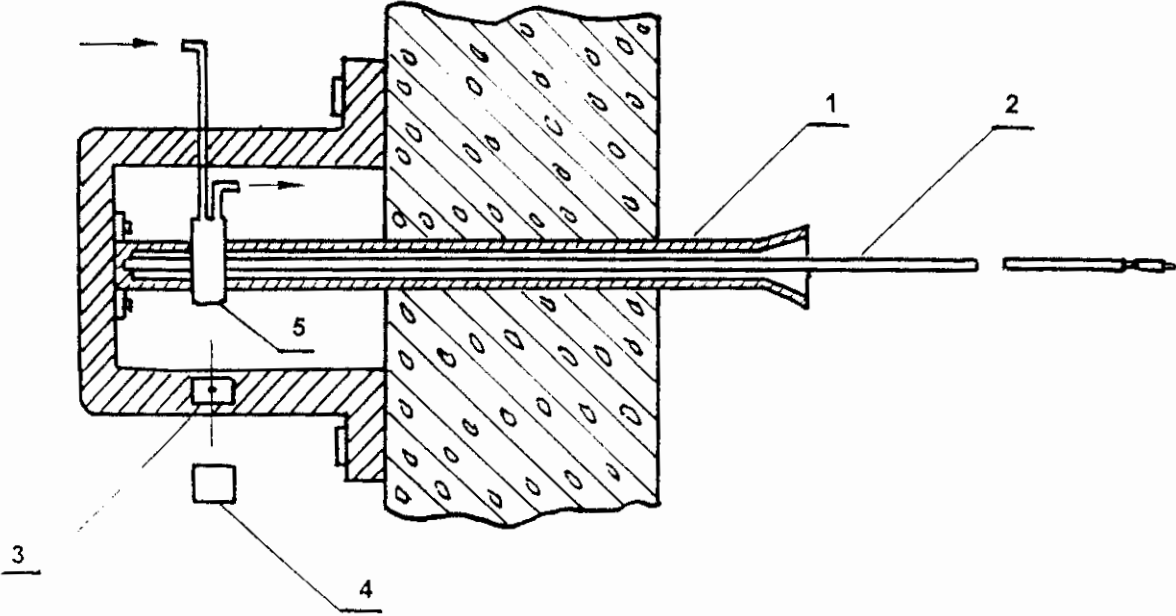


a - before cooling;  
b - after cooling of plenum.

Fig.7

Remote device for gamma-spectrometer measurement  
of gas parameters under fuel pin cladding

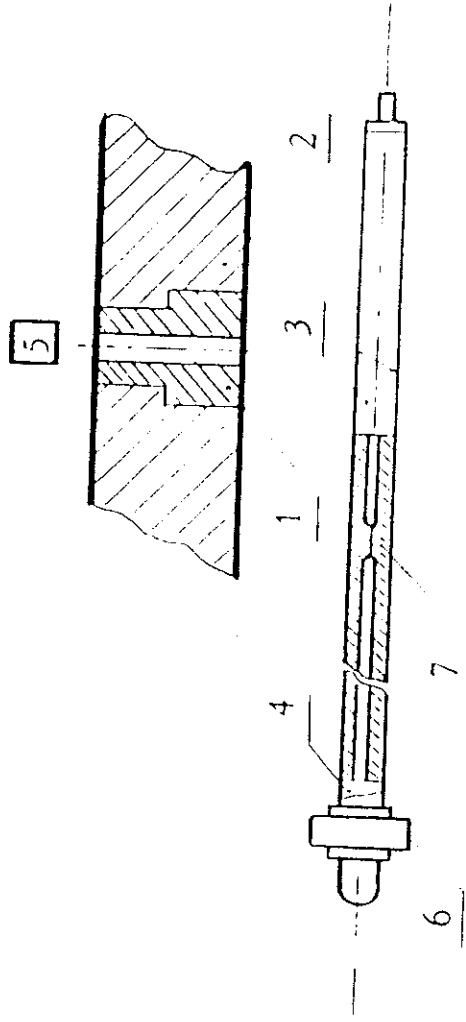
liquid nitrogen



- 1 - adjusting device;
- 2 - fuel pin;
- 3 - collimator;
- 4 - gamma-spectrometric detector;
- 5 - cooling device.

Fig.8

**Facility for determination of gas permeability  
in fuel pin column**

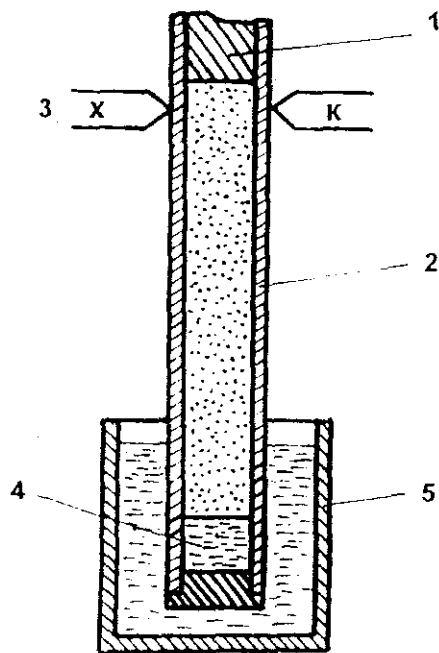


fuel pin bottom

- 1 - collimator
- 2 - shielding chamber wall
- 3 - bottom plenum
- 4 - upper plenum
- 5 - detector of gamma-spectrometer
- 6 - fuel pin cooling device
- 7 - gas-nonpermeable plug

**Fig.9**

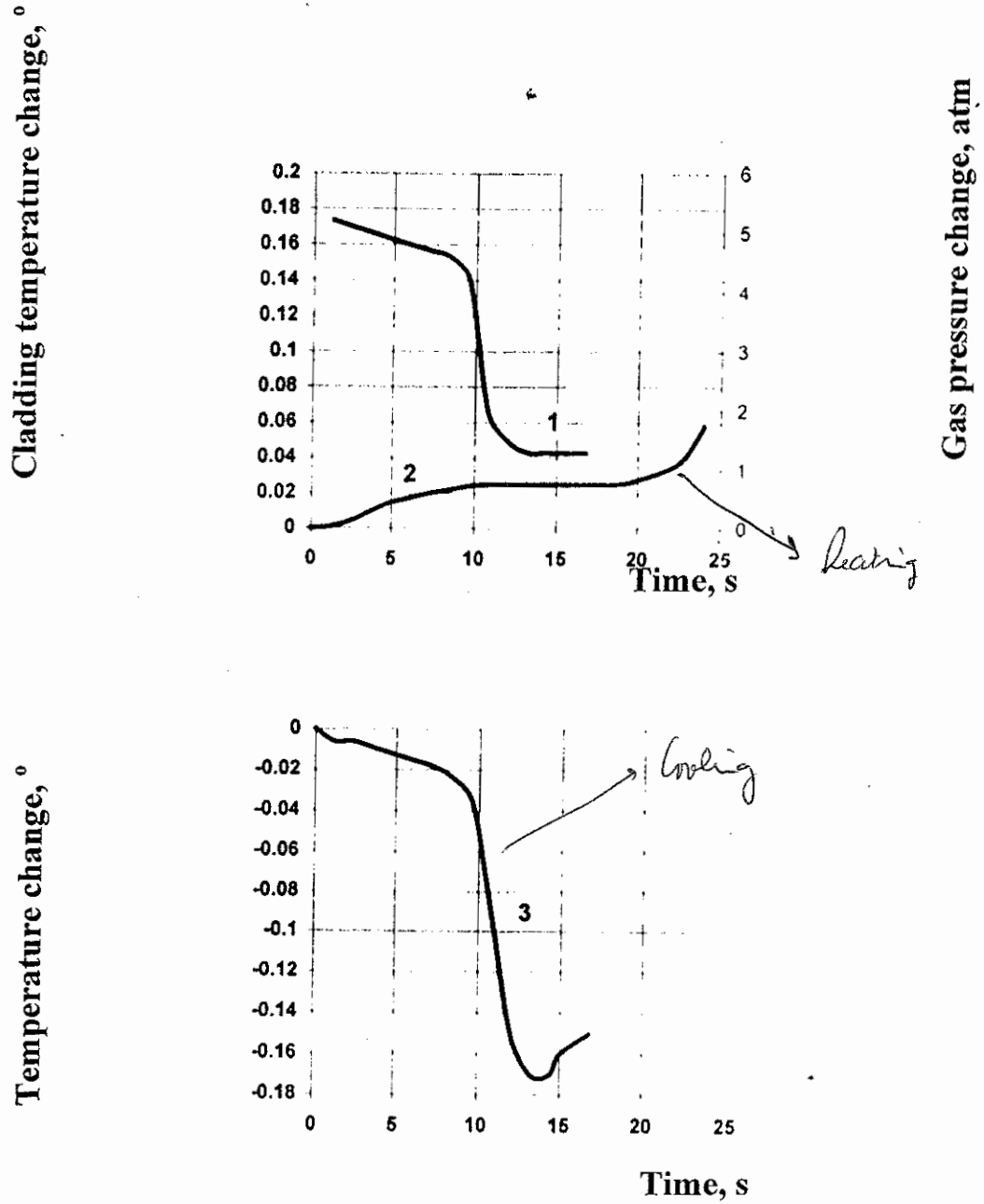
## Gas pressure measurement by thermocouple



- 1 - fuel pin core;
- 2 - gas plenum cladding of fuel pin;
- 3 - chromel-copel thermocouple;
- 4 - condensed gas;
- 5 - flask with liquid nitrogen.

Fig.10

**Change of gas pressure and cladding temperature on fast heating and cooling of fuel pin plenum**



- 1- change of gas pressure in cooling;
- 2 - change of cladding temperature on plenum heating by 200°;
- 3 - change of temperature in cooling with liquid nitrogen.

**Fig.11**