# FEATURES OF SPHERICAL URANIUM-GRAPHITE HTGR FUEL ELEMENTS CONTROL

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Control features of spherical HTGR uranium-graphite fuel elements with spherical CFP are mainly determined by specificity of their construction and fabrication technology. The technology as known [1-3] is chiefly based on the methods of ceramic (fuel microspheres fabrication) and graphite (forming proper fuel elements) production.

In practice it is neccessary to deal with a lot of problems from the determination of raw materials characteristics to final fuel elements attestation. Parameters nomenclature and range of control methods and technical means of measurements, automatization degree of control operations and treatment methods of information obtained are non-constant and widely vary in dependence upon state-of-art.

The control operations and their succession are given in Fif.1. Some parameters characterizing initial materials state are subjected to an evaluation at the inlet control. Some parameters are specified from the point of view of physico-mechanical and thermalphysical properties of some fuel elements components. Attestation of shapes and fuel elements sizes, their mass, total content and uniformity of fission products distribution, thermal conductivity, surface and volume contamination etc. is advisable to carry out on every article.

Well developed and normalized standard methods were used at inlet control. These methods were used when some characteristics (for example chemical and phase composition) of fuel elements components were evaluated.

Sample selection and preparation which as it is seen from Fig.1, played an important role, were previously solved. Only correctly organized sample selection provided statistical extracts uniformity when the number of controlled objects was large (complectation of one fuel element consumes nealy $10^4$ coated fuel particles).

For selection of fuel microspheres and coated fuel particles (CFP) in principle various devices are good; conical three staged divider, permitting to single out 1/1000 part of the initial sample during some minutes is a model of such a device described in [4].

Flow samplers, the operation principle of which is multiple periodical discharge of small portions of particles from the common bunker into separate containers, are good for selecting portions of tens and hundreds of grammes. Similar devices quickly divided particles into gramme portions when revolution rate of particles was 60 r.p.m.

In a more universal batcher-normalizer, the scheme of which is shown in Fig.2, the known method of loose materials separation when a particle flows out from bunker through grid bottom with large quantity of the transport canals is realized. Equiprobability of the particles distribution in each of the containers is quaranteed when the inlets and outlets of the canals are arbitrarily connected. The bunker for loading was fixed at the top of a stand and the microspheres outflow was stimulated with a special vibrator. The device output was varied within a wide range changing regime, number and canals extension.

Among the main charateristics of the fuel microspheres and the coated fuel particles obtained on their base (with a various combination of pyrocarbon and carbide layers) first of all we pay attetion to the shape and sizes, density, thermal conductivity, strength, fissile substance content and in the case of CFP we pay attension to the surface contamination as well.

For the control of such characteristics as average diameters and coefficient of single objects non-sphericity and also their versions in separate lots, devices with various automasation degree trating photo or shadow objects image are used. In one of the known systems for example the information obtained while particles passing the fixed photodiodes or photomatrixes is an initial information.

To widen the possibilities of such devices and to reveal an inner CFP structure when controling CFP an operating model of the device is developed; this model is presented in Fig.3.

A microradiographical negative scanned when magnifying by special optico-mechanical device with solid-body converter of light image is initial.

Using such a converter it was possible to obtain information concerning outer CFP sizes and fuel core sizes and also concerning coatings thicknesses.

The device is supplied with a mini-computer which quickly treats measurements results and delivers averaged data both for single particles and for the groups of particles.

According to the data obtained knowing the total mass of group particles it's easy to determine averaged magnitude of geometrical density. As for this characteristic for individual objects the possibility of traditional sedimentometers improvement was investigated.

In one of the initial versions the known scheme was changed (Fig.4). When rate of particles sedimentation into liquid was stabilized, the position of particles was fixed in a definite time interval on a photoplate with a photoflash. Knowing lequid density, particles size and particle path, it's easy to determine their density.

Automatization of such devices does not meet principle difficulties. In one of such devices, for instance, we got the algorithm of density evalution accoding to rate of laminar gravitation particles sinking successively in two wetting them liquids, but these liquids do not wet each other.

Methods of revealing of coatings structure features and their anisotropy are in detail described in [5].
Another important characteristic of the objects considered is thermal conductivity the value of which as practice showed depends upon many factors.

$UO_2$ spheroidized particles conductivity for instance changed when their porosity increased (Fig.5). Such a type of changes (calculated curve was obtained supposing arbitrary distribution of pores unlinked among themselves in material bulk) indicates that begining with the definite moment the type of intergrain links influences greatly the materials properties.

Conductivity was determined according to the results of successive measurements of indium or tin specimens conductivity pre and post their filling arbitrarily with given amount of microspheres. Calculation was carried out using known Maxwell-Eken relation. An experimental check of the method on stainless steel calibrated balls revealed that the final result precision approached 15-20%.

Effective particles conductivity was increased after coating dioxide microspheres with thermoconductive pyrocarbon and carbide layers. In Fig.6 (conductivity of particles) is shown to be increasing when the number of pyrocarbon (density is about 1.7 g/cm$^3$) and carbide monolayers rises. Layer measurements on real CFP gave more complex picture (Fig.6, c) because of some differences of layers properties and thickness variations. Nevertheless the final values of $\lambda_{ef}$ of CFP with fivelayer coating were reproduced satisfactorily and were in the range of 28 and 35 Wt/(m.K) that was almost three times higher than the conductivity of initial $UO_2$ microspheres.

To control U-235 content and CFP surface contamination devices prototypes are developed (Fig.7). The analysis carried out by the authors indicated that in both cases measurements on objects monolayers are most expedient; monolayers are formed using special mechanical devices provided for instance with vibrators.

U-235 amount determined by the autoemission method is obtained in a digital form. The developed electron block carried out control of monolayer formation system besides detector signal treatment. The range of U-235 controlled amounts is 0.45...1.6g; the main measurements error is not more 2% (confidence probability is 0.95).

Explotation experience of such devices showed that after corresponding improvements on their basis a dosator may be developed providing the mentioned accuracy of CFP portions selection with the given U-235 amount.

CFP and fuel elements gas-tightness an a whole was judged according to the results of "weak" in-pile irradiation[6].

About CFP contamination one judges according to the intensity of $\alpha$-radiation registered by special detection blocks. In our case ZnS scintillator pressed into organic glass and joined with a photomultiplier were used. Sufficiently high (about 200g of particles per hour) output was provided when scintillator area was 150-200 $cm^2$. In each measurements cycle phone radiation and monolayer radiation were registered and compared 20-25% accuracy at threshold levels of controlled value from $2\ 10^{-9}$ up to $2\ 10^{-13}$ Kurie/$cm^2$ was provided at acceptable for practice calculculation time using methods of successive statistical analysis and a compact electron scheme.

While fuel elements attestative the determination of some of the parameters listed in Fig.1 offered no difficulty.These parameters are: mass, outer diameter, density, strength and others; their determination is connected with the destruction of the articles. More complex situation is in the case of undestructive control of quantity and uniformity of CFP distribution in fuel element, graphite shell thickness, its continuousness, thermal conductivity,surface contamination etc.

In Fig.8 for example the appearance of the device used by us to determine U-235 amuont in fuel elements according to self $\gamma$-radiation is shown. The device includes mechanism of article supply to detectors and the block of measuring signals treatment. Really achievable measurements accuracy was about 5% taking into consideration absorption in the shell material and self-absorption in CFP. Data concerning the distribution uniformity of the fissile components are obtained according to the angle variations of radiation intensity. The same problem was solved when weakening of collimated radiation beam from a source (for example Am-241) was determined. In this case all article volume was transilluminated when the fuel element was being successively turned around the centre and uranium mass was determined in different zones of the core taking into consideration the weakening coefficient core location from the outer surface of the fuel element and its graphite shell thickness were determined. In particular in the developed tomograph (Fig.9) the arrangement of which is described in detail in [7],about its inner structure the authors made judgement according to the results obtained in the eight sections of 2 to 8 mm thickness. The scanning automatic device moved simultaneuosly 4 fuel elements around Am surces of radiation fixed in the centre. Information was registrated by 8 detectors, treated in the electron block and then delivered to the computer where tomogramms were restored according to the special algorithm, then the tomogramms were delivered to the display and the printing device.

The device determined the zones of CFP distribution non-uniformity in the core, singling out about 1.0cm$^3$ volumes, differing according to CFP content by 10%, estimated uniformity and graphite shell thickness.

Considerable information concerning uniformity and other shell characteristics gave electrophysical methods, in particular eddy-current. Material density, thermal conductivity, different kinds of disturbances of pores, cavities, cracks etc. were determined, using these methods. Both the first and the second parameters for real graphites were correlated with their electrical conductivity. For electrical conductivity control by the pick-up transducers with end distribution of inductance coil in [8] a special form of a support with cone-type recess (Fig.10) was found. It was shown that while working with ball elements additional error because of a surface curvature does not exceed 2-3%.

As for continuousness disturbance its effect on the output signal of converters was estimated experimentally using simulators; the arrangement of the simulators is described in detail in [9,10], the simulators permitted to vary extension, width and depth of a defect deposition in a wide range.

CFP and surface fuel element purity was controlled according to $\alpha$-radiation intensity. In the real conditions the detection block was fabricated of two scintillators with semi-spherical surfaces that while being drawn together formed the cavety, geometry of which was about to $4\pi$. Contamination was controlled within 2 $10^{11}$-6 $10^{-14}$Ku/cm$^2$.

REFERENCES

1. D.Bedenig. Gas-Cooled High Temperature Reactors. M., Atomizdat, 1975.
2. L.E.Kostikov, V.V.Losovetskiy, V.V.Perevezentsev. State-of-art and Perspectives of Fuel and Fuel Elements Development for High Temperature Gas-Cooled Reactors. "Atommaya technika abroad", 1976, N9, p.17.
3. A.S.Chernikov, V.S.Kolesov, L.N.Permyakov et al. Construction and Main Characteristics of HTGR Fuel Elements. Report at the Conference of the Technical Committee IAEA on Gas-Cooled Reactors. Minsk, 12-16 October 1981, Bestsi Academy of Sciences, BSSR, N3, Minsk, 1982, p.77.
4. J.Holliday, M.S.Price et al. Methods of inspection and testing of HTR fuels. Nucl. fuel Perfom.- In. Proc. Int. conf. London, 1973 (13/1).
5. I.S.Alekseeva, A.A.Babad-Zahryapin, M.P.Glasunov et al. "Microstructure of Pyrocarbon Shells on Fuel Microelements". Atommaya energia, v.52, issue 4, 1982, p.266.
6. A.S.Chernikov, N.N.Ponomarev-Stepnoy, Yu.v.Koshelev et al. Spherical fuel elements and some results of their tests. Proc. conf. "Gas-cooled reactors to day", Bristol, 20-24 Sept., 1982, British Nuclear Soc., paper 87, p.35.

7. E.Yu.Vasilieva, B.G.Kirov, L.I.Kosarev, et al. Undestructive Control of HTGR Fuel Elements with Method of Computer-Tomography. The third International Conference on Undestructive Control, Moscow, 1982, v.6, p.153.

8. V.G.Vyakhorev, V.V.Fomenko. Pick-up Eddy-Current Transducer for the Control of Articles with Curved Surface. Author certificate. USSR N645071 1979 GOI N27/86, Invention bulletin N4, 1979.

9. V.G.Vyakhorev, V.S.Nikulshin, P.P.Oleynikov. Simulator for Electromagnetic Flaw Detectors Tooling Adjustment. Author certificate. USSR N926584 1980 class $MKU^3$GOI N27/90 Ivention bulletin N17, 1982.

10. V.G.Vyakhorev, V.S.Nikulshin, P.P.Oleynikov. Simulator for Electromagnetic Flaw Detectors Adjustment. Author certificate. USSR N926585 1980, class $MKU^3$ GOI N27/90, Invention bulletin N17, 1982.

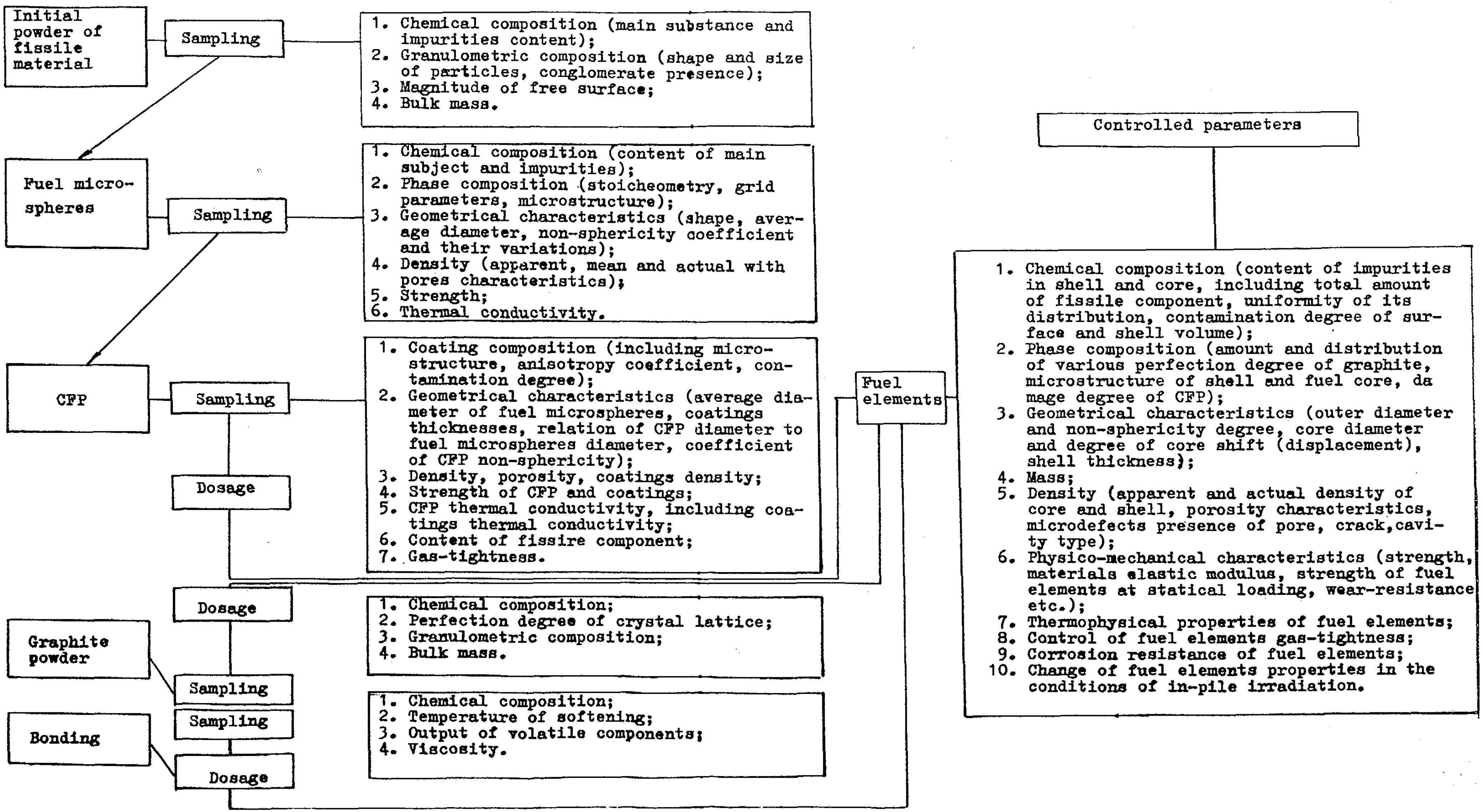


**Fig.1. Summerized scheme of HTGR sphere graphite fuel element control.**

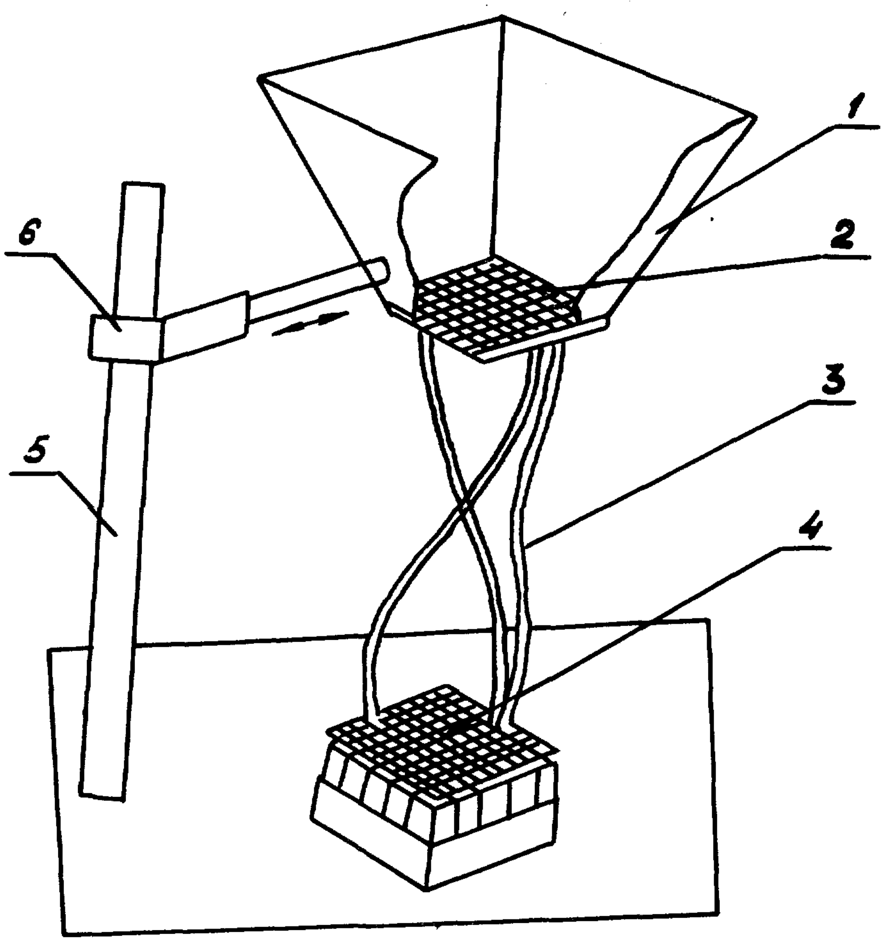


Fig.2. Device for dosage (division) and normalizing of kernels and coated fuel particles.

1 - bunker; 2 - grid foundation (bottom); 3 - transport canals; 4 - receiver (container); 5 - cell; 6 - vibrator.

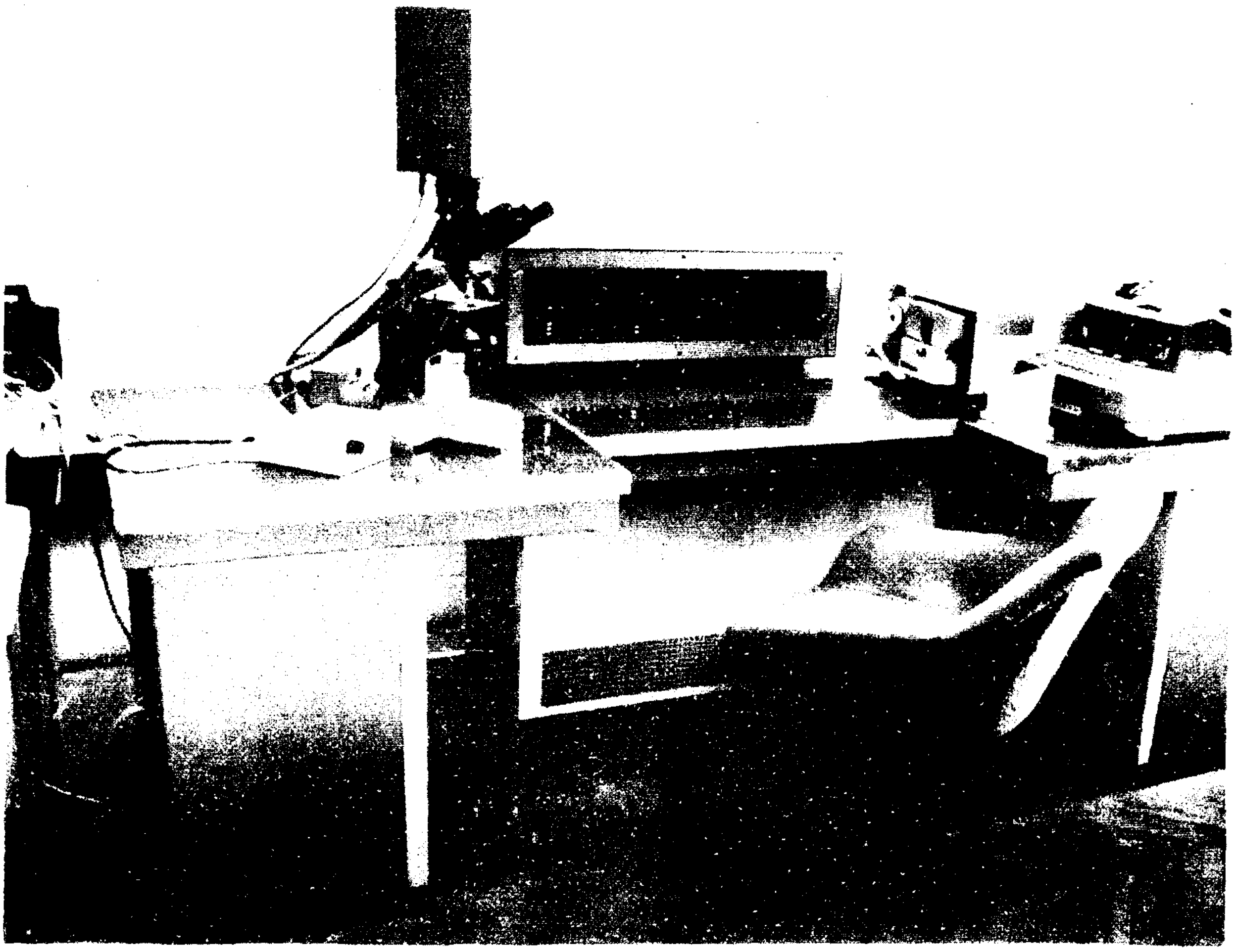

Fig.3. Appearance of device for control of CFP geometrical characteristics.

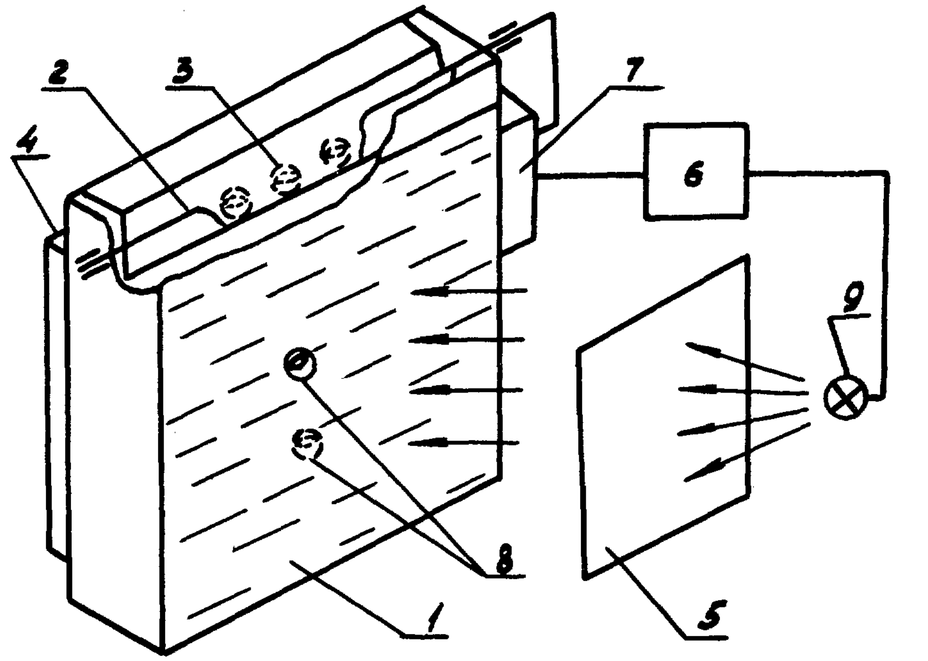


Fig.4. Scheme of device for determination of microspheres density

1 - vessel of liquid; 2 - slot bunker; 3 - controlled article; 4 - cassette with photoplate; 5 - light source; 6 - scheme of start; 7 - electromagnet; 8 - two successive positions of article during deposition.

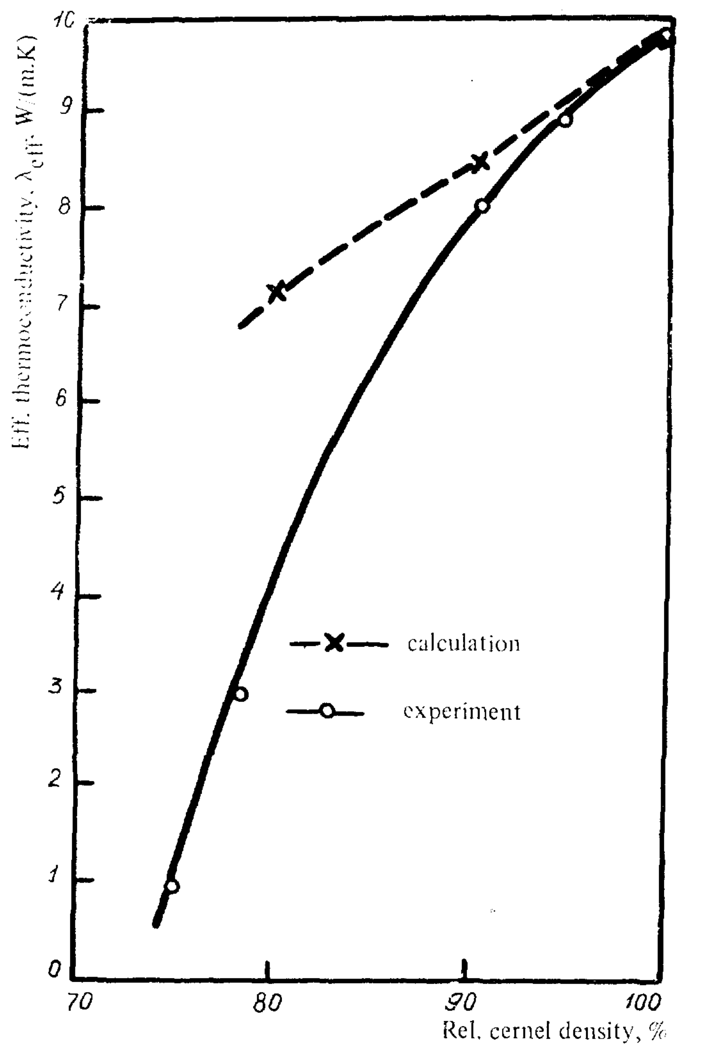


Fig.5. Dependence of kernel effective thermal conductivity upon density.

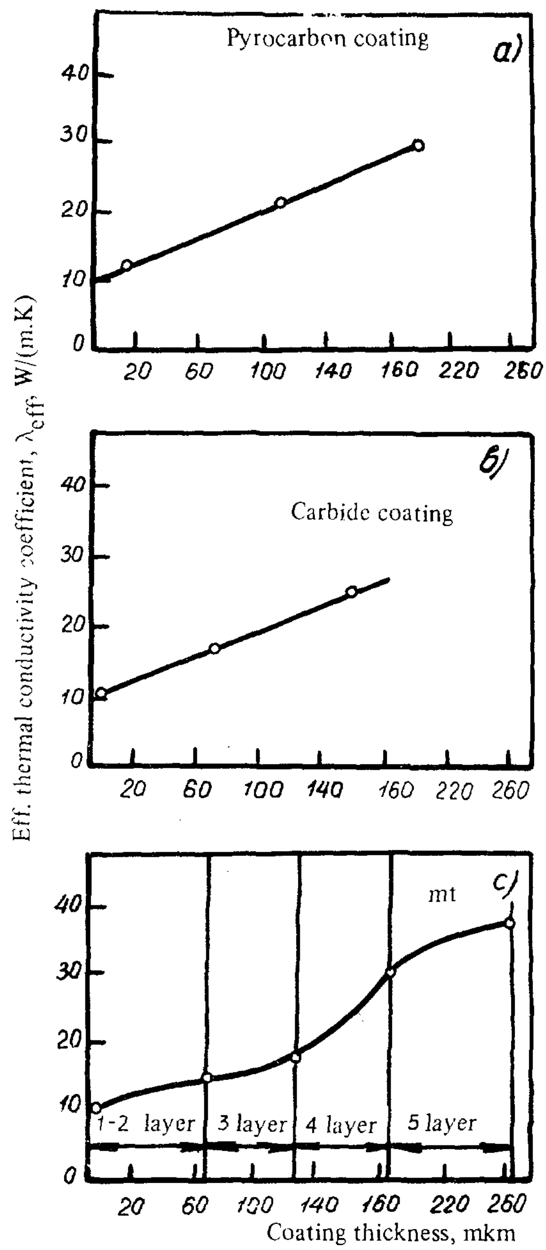


Fig.6. Change of effective thermal conductivity of fuel kernels when protective coating deposition

a) 1.7 g/cm$^3$ density pyrocarbon coating;

b) carbide coating;

c) CFP of fivelayer coating.

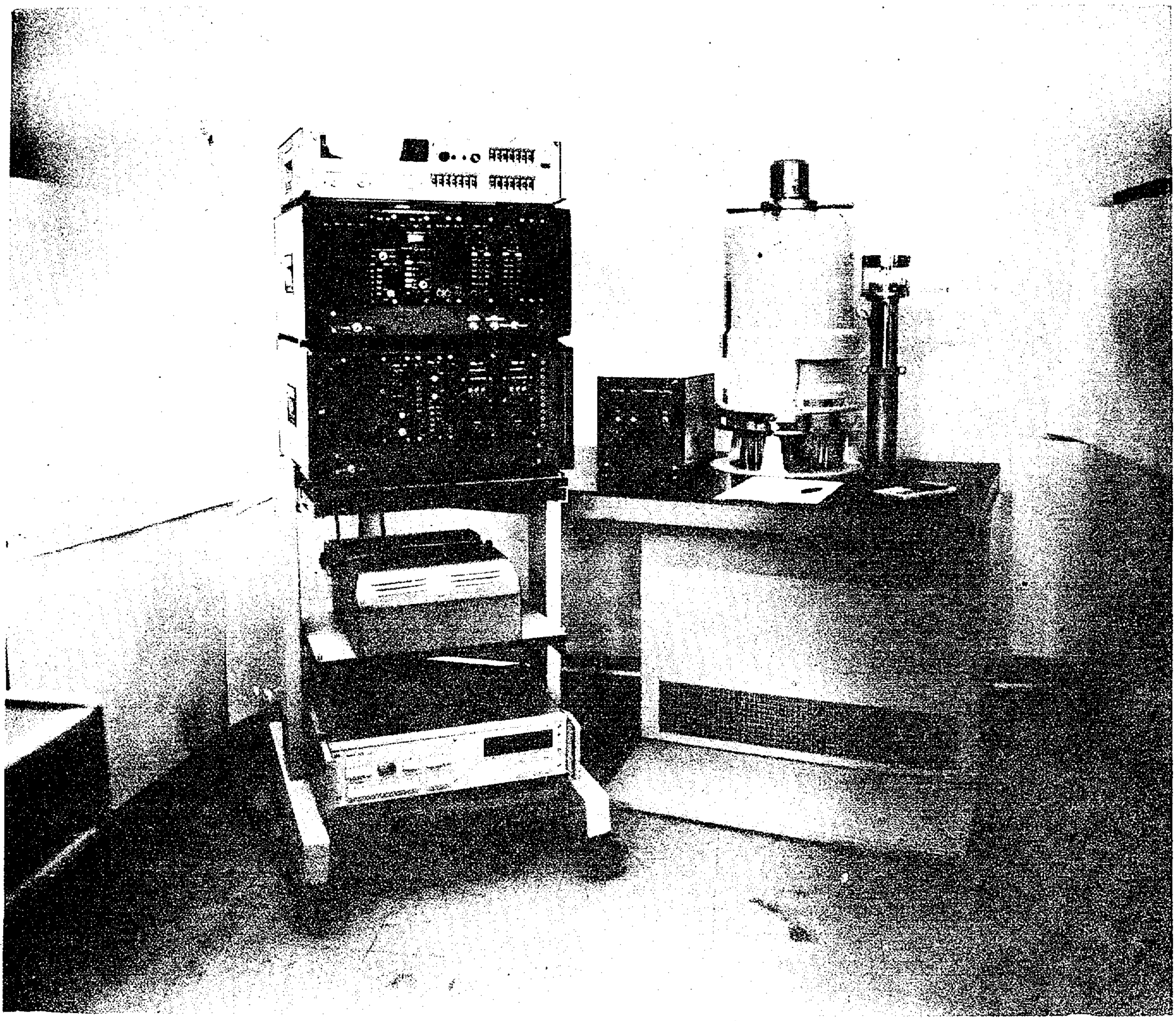

Fig.7. Device for determination of U-235 amount in kernels and CFP portions.

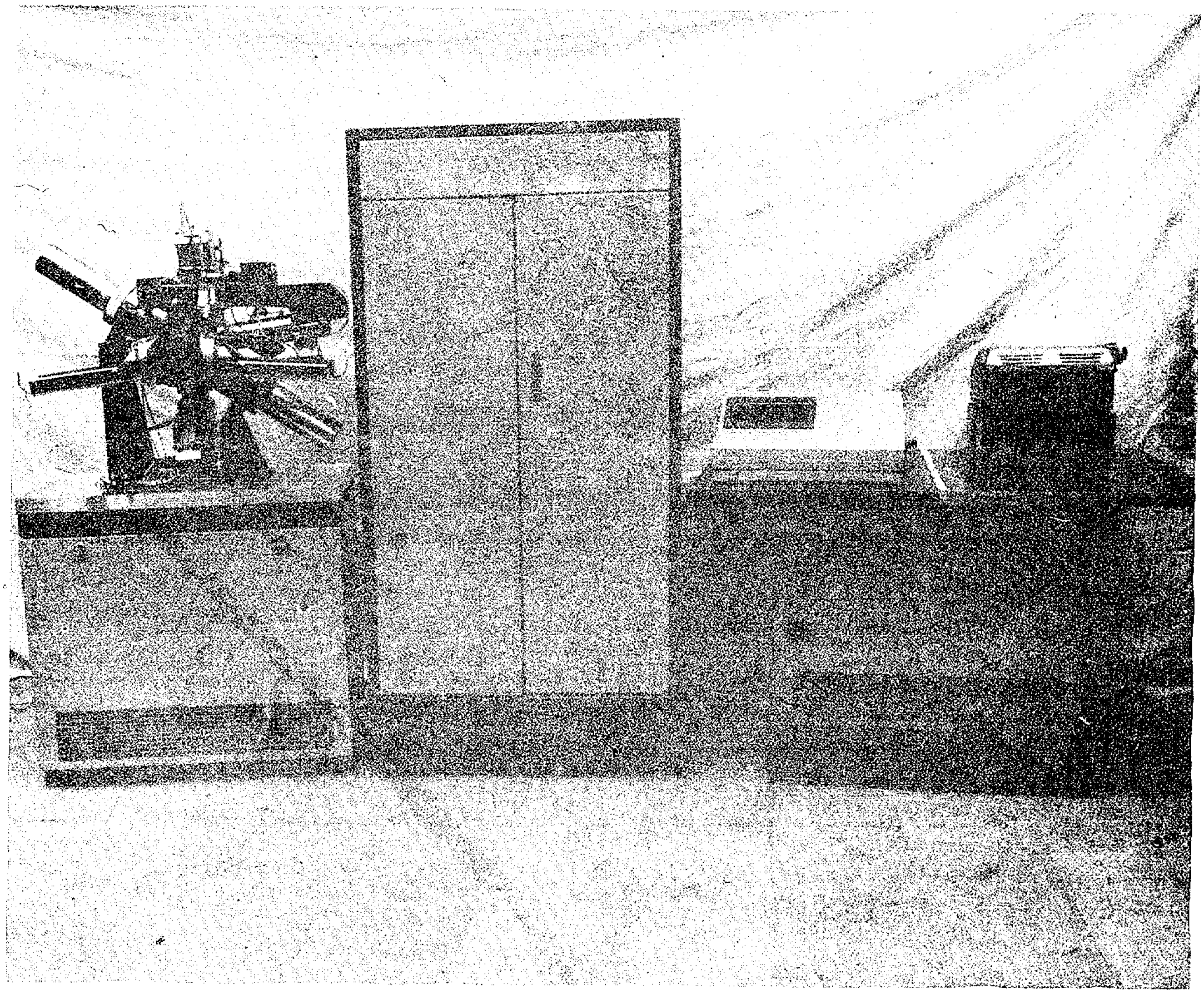

Fig.8. Radiometric device for U-235 content control in fuel elements.

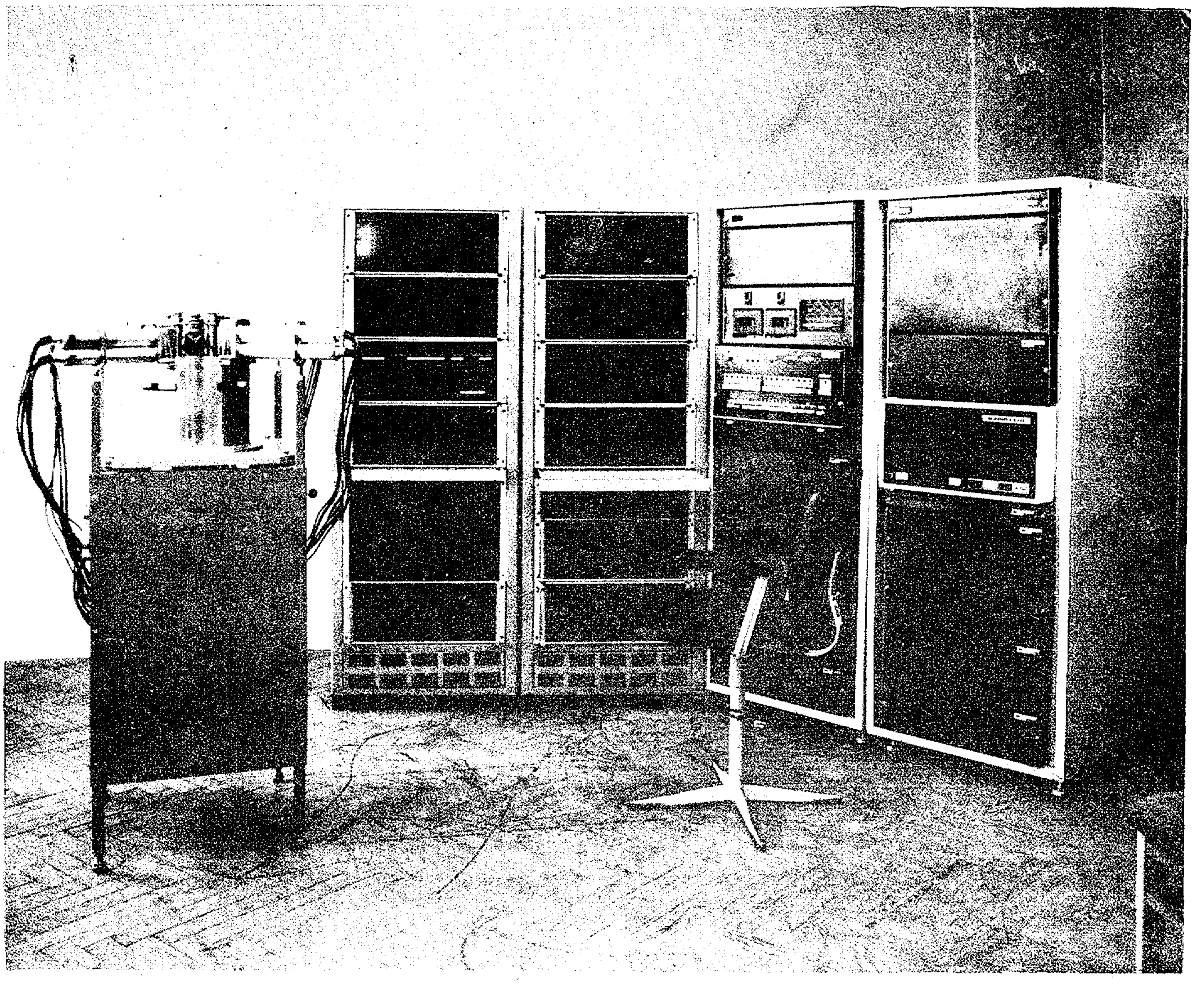

Fig.9. Appearance of computer tomograph.

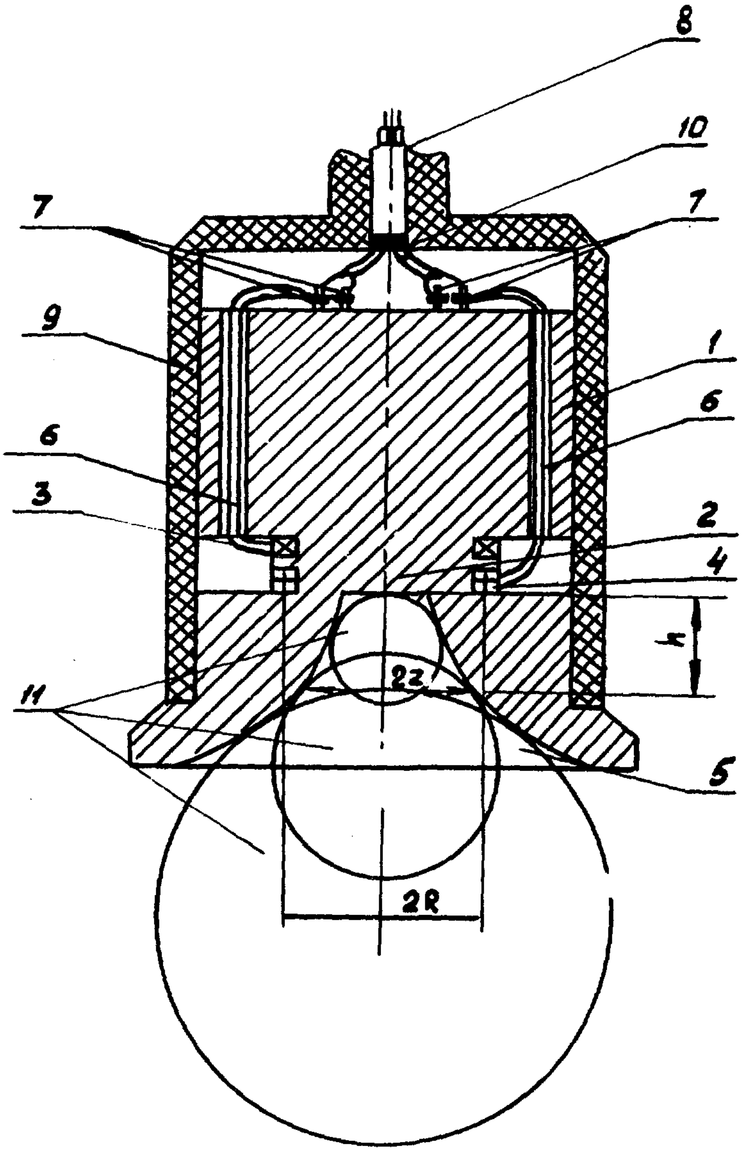


Fig.10.Eddy-current converter for control of spherical elements

1 - body; 2 - end face plane; 3,4 - exciting and receiving inductance coil; 5 - tapered hole; 6 - hole for conductors; 7 - contacts; 8 -cable; 9 -case; 10 - hole; 11 - controlled fuel element.