RELATIVE DIFFERENT ENERGY NEUTRON RADIOMETRY IN REACTORS FOR PREVENTING OF ACCIDENTS CAUSED BY UNCONTROLLED REACTIVITY VARIATIONS

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The technology method based on measuring the different energy neutron flux from the coolant has been applied at nuclear reactors on NPP [1]. Further investigations have shown that the relative different energy neutron radiometry made it possible to consider and to solve new reactor safety problems during start-up, transient and extreme regimes.

Almost fifteen years investigations were concentrated on methods & instrumentation for preventing of accidents, arising from reactivity variations influenced by show neutron absorbers concentration changes.

Physical essence of proposed approach consists in measuring the neutron spectral relative shift effects (fig.1) arising during reactivity changes influenced by slow neutron absorbers [2].

Being processed in pulse or current form, ratio signals for two neutron detectors, which have different spectral sensitivities (for example - cadmium ratio), are conversed to basic reactors characteristic functions.

Each of these functions is controlled by two relatively switched pulse or current de tection units and detection assemblies (DU & DA), particularly - without any circuits for logarithm calculations.

The DA measuring part structure is universe for any discussed method in-pile boris acid concentration measurements in the WWPR-440 & WWPR-1000 primary coolant have been carried out by the DA, the DU of which [3] were installed in vertical positions into the ionization chambers channels in the biological shielding of the reactor during the first start-up and intermediate power operating regimes (fig3) and in similar positions in the tubes welded to the inner surface of the reactor core basket [4] during fuel reloading.

The detection assemblies developed on the base of helium-3 proportional counters [1,6] were used for the first start-up experiments. The detection assemblies on the base of uranium fission chambers [6] were used for fuel reloading experiments.

Summary data obtained in four runs, two for start-up and two for reloading, are plotted at fig.4. The relative neutron radiometry results highly correspond to chemical ones.

Neutron WWPR power evaluation by relative radiometry method has been carried out during the first start-up (fig.5). Reactor power (in percentage of nominal value) has been scaled by readings of regular equipment for monitoring the neutron flux [5]. It appeared that the subcritical pile neutron power would be a linear function of cadmium ratio for chosen experimental conditions.

Neutron power & its logarithm measurements, carried out at the V New-Voronezh NPP block up to 33 percents of nominal value has shown that being influenced only by boris acid concentration changes, the neutron power depends as logarithm on cadmium ratio (fig.6). Control rods moving disturbs this linear dependence.

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Reactivity evaluation has been completed at the first South-Ukrainian NPP block during its first start-up. Reactivity-to-cadmium ratio dependence has appeared to be non-linear, almost hyperbolic (fig.7).

Period measurements during the first start-up have been carried out at the same power block. It has been found that period T was a linear function of cadmium ratio R_{cd} in the experimental error limits (fig.8). Reactor period is a decreasing function of R_{cd} for three different positions of control rods. Using the obtained results, one would become capable to differ the reactivity effects caused by boris acid concentration changes and by rods moving.

Boris acid concentration control results during fuel reloading allowed to discover the inversion of the cadmium ratio dependence on Boris acid concentration in comparison with the first start-up experiments. The result of the reactor critical condition determination must not depend on neutron spectra, since this is only reactor state when its material (bulk) parameter is equal to geometricalone. That is why two plotted dependencies intersection gives the critical value of neutron absorber concentration (fig.9).

Other results of relative neutron radiometry application have been obtained at research reactors.

Reactor critical point determination during its first fueling has been carried out by inverse counts control and by plotting the corresponding curves (fig.10). The inverse counts curves were plotted for thermal neutrons while loading nuclear fuel cassettes and for fast neutrons while loading the reflector ones. The latter curve shows "safe" and practically linear character, that therefore increases reliability of critical amount of cassettes determination.

Additional investigations allowed to propose a method for determination of thermal neutron radiometers sensitivity. It has appeared that existed the extremal dependence of cadmium ratio on pulse discrimination level for almost any radiometer with pulse detector based on boron-10, helium-3, uranium-235. The maximum of R_{cd} corresponds strictly to theradiometer maximum sensitivity and selectivity to thermal neutrons (fig.11). The thinner is the neutron-sensitive detector radiator, the more evidently is shaped the maximum. This effect has made it possible to simplify the neutron radiometers calibration in neutron fields

For the practical purposes of the relative neutron radiometry the start-up DU [3] with sensitivity of 10 pulses per second by unit thermal flux density has developed. The DU contents 5 corona counters [1,6], switched in parallel. The DU sensitivity is approximately equal to the initial value when fail occurs to one or two counters. This DU has 1200 times as much radiation resource in comparison to the DU, based on helium counters [1,3].

In addition to the start-up DA [3] with this DU, the wide-band pulse current DA has been developed for power and research reactors, capable to withstand post-accident conditions. The DA has been constructed using the industrial ionization chamber KNU-3[5]. This chamber contents two pulse fission chambers with the ratio of their sensitivities to the thermal neutrons equal 1:1000, current boron chamber and compensating current chamber, containing no neutron-sensitive radiator, in one case. The block-diagram of this DA is shown in fig.12. The DA has been tested for a long time in the thermal column and in the vertical experimental channel (VEC) of the research reactor with the peak power equal to Mw. Figures 13-15 show basic characteristics of the DA. Two DA modifications have been investigated in which KNU-3 chambers had approximately 3,5 times different second pulse chamber sensitivity due to initial fission material dilution by uranium-238.

It can be seen that more rigid neutron spectrum in VEC when compared to that in the thermal column, caused that the second fission chamber sensitivity (with uranium-238) became 2,6 times less than equivalent pulse sensitivity of the third, i.e. current volume of the KNU-3 (dependencies 2,2 and 3 in fig.13).

Partial simulation of accident conditions for WWPR-1000 power operation has been conducted by three hours irradiation of the KNU-3 DU at 1Mw power (1, 88x10^{11} cm^{-2} s^{-1}, 15,4x10^{-2} A/kg (2,16x10^{6} R/h)). After shut down the background counts in the first pulse channel of the wideband DA has been found to be 110 s^{-1} ; 14 s^{-1} three hours later and 3s^{-1} 72 hours later. Using the lead screen 31 mm (approximately 12 inches) thick and compensating by the current of the fourth KNU-3 volume, practically full compensation of the reactor residual energy releasing current in the first two decades of the third control range (fig.14), has become possible.

Therefore it has become possible during the shut down to switch the channels over to the middle of the second pulse volume, inspire of increased background, thus proving the capability to withstand accident conditions. Figure 15 shows that such twin compensation is most effective in the intermediate range (0,1 - 10^{3} W).

As a result of investigations it is firmly established that startup and wide-band detection assemblies allowed to put into practice the methods of relative different energy neutron radiometry in reactors of different types in the range of neutron flux density changing no less than 14 decades (10^{-3} cm^{-2} s^{-1} - 10^{11} cm^{-2} s^{-1}).

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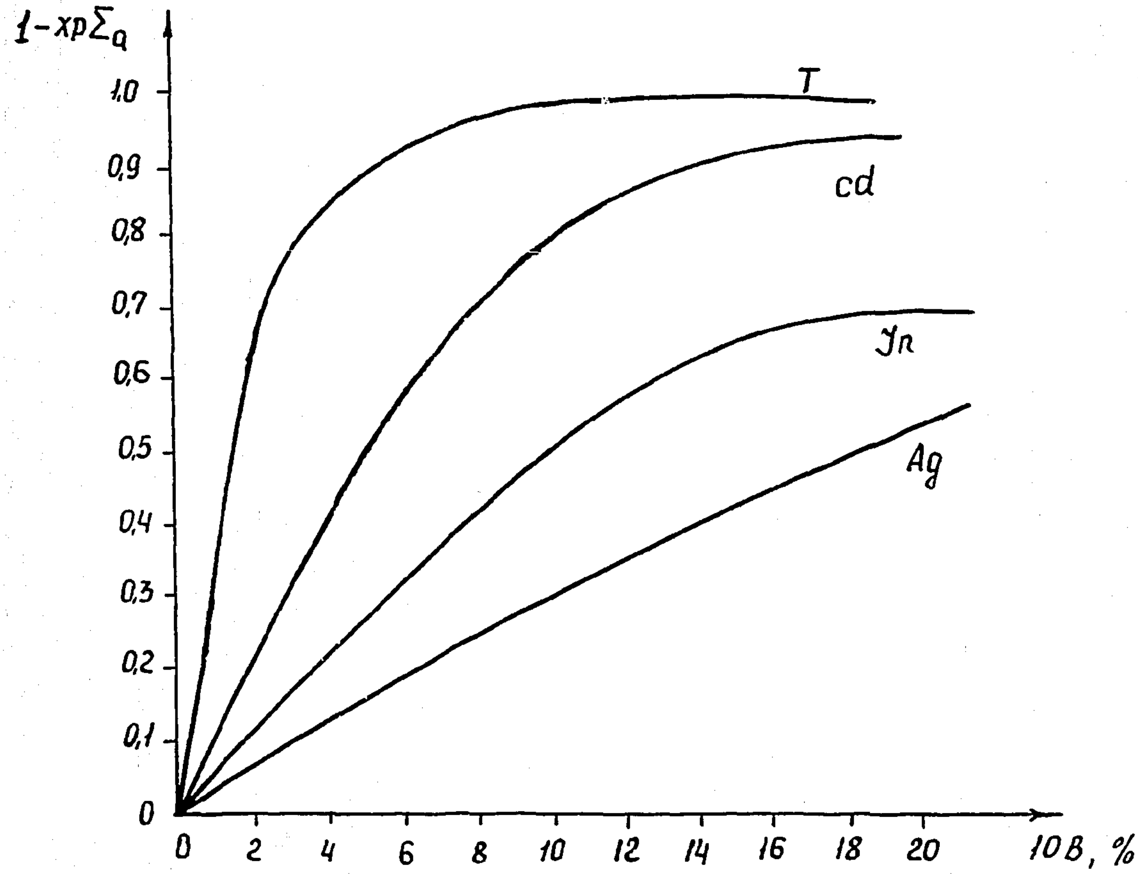


Рис. I. Зависимость изменения потока нейтронов в относительных единицах от содержания в пробах бора при регистрации тепловых (T) надкадмиевых (Cd) нейтронов, а также нейтронов в области резонанса индия (Jn) и серебра (Ag).

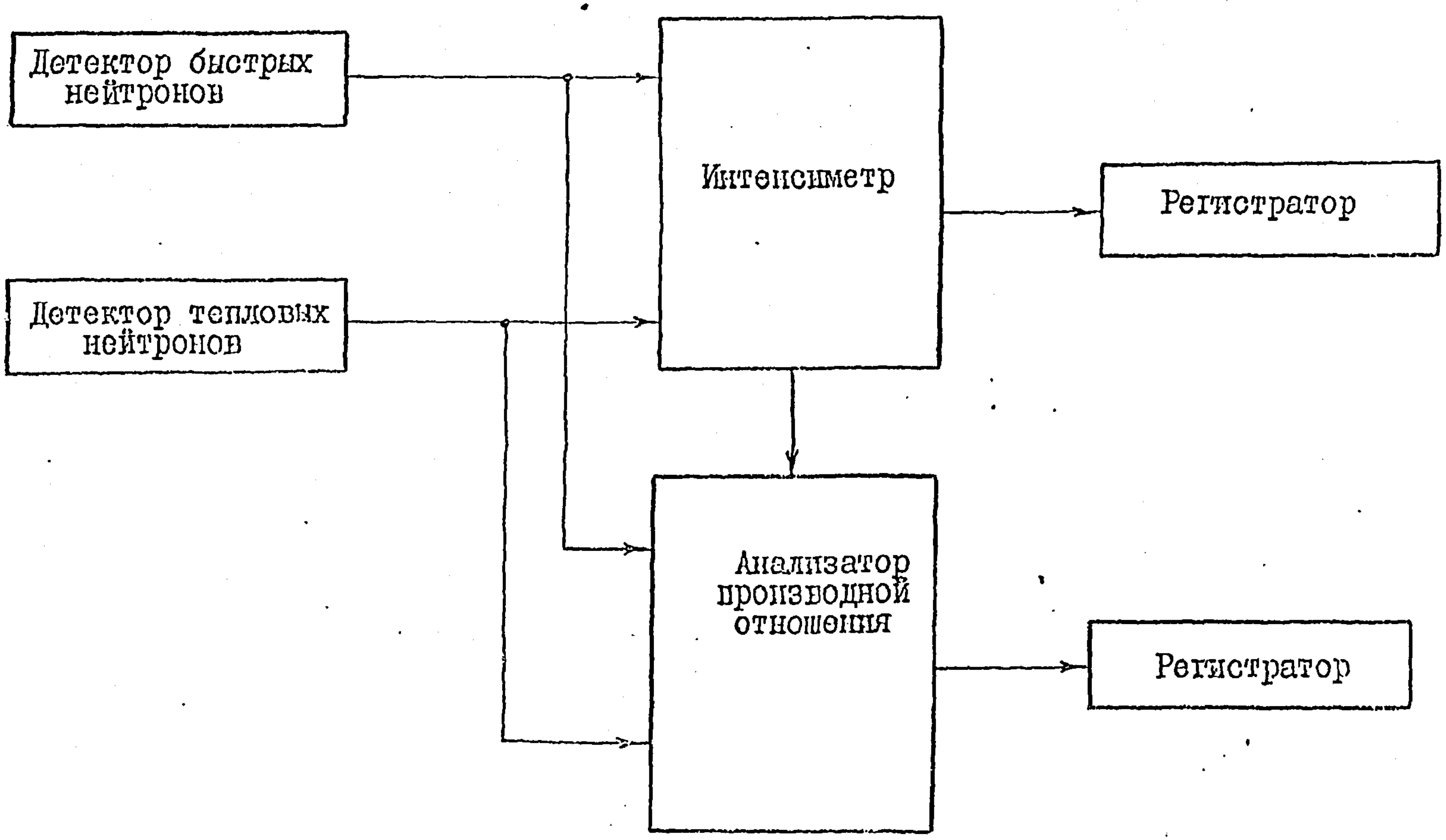


Рис.2. Структурная схема радиометрического канала АКНП и АКРБ повышенной эффективности для реактора ВВЭР.

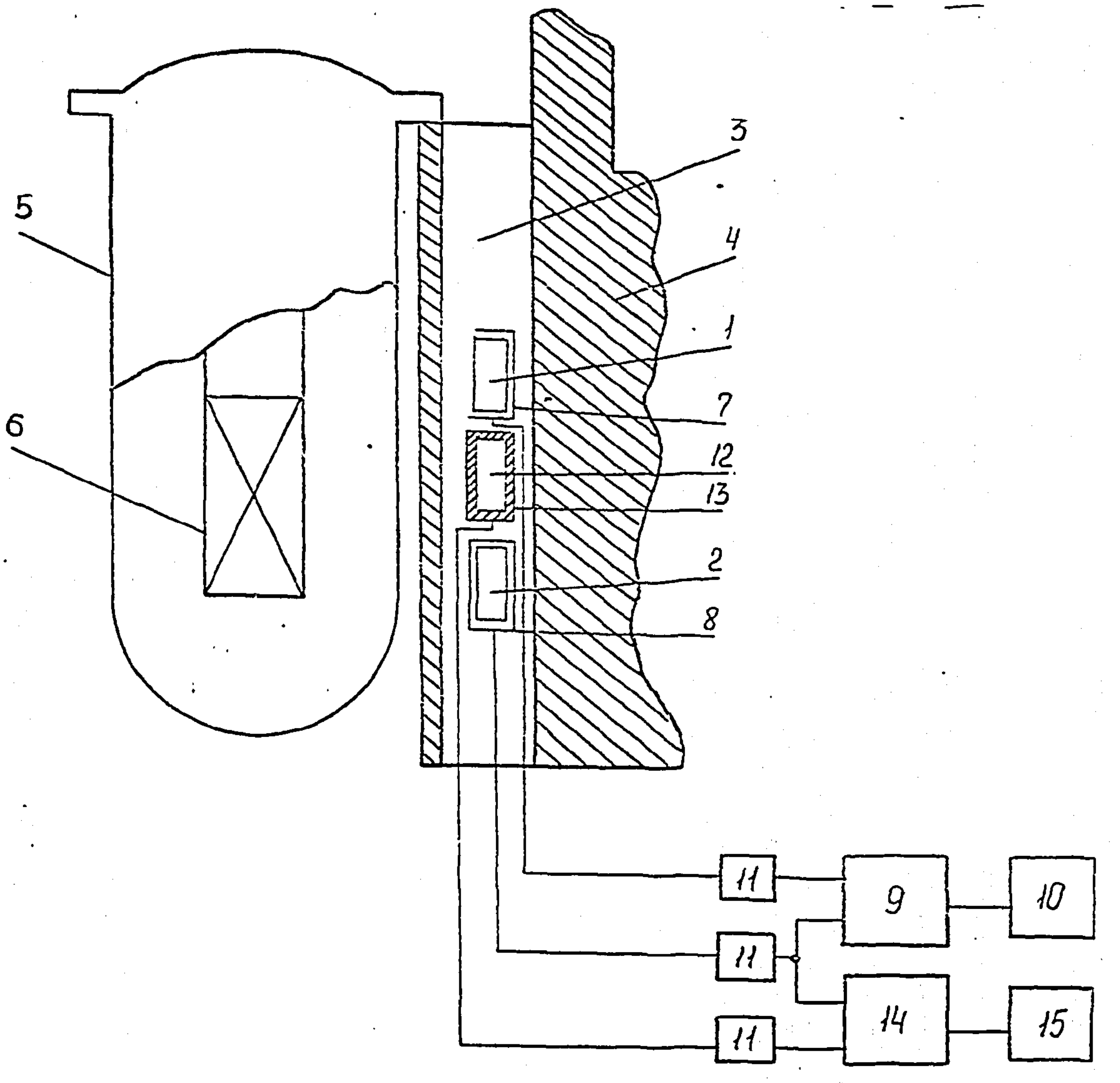
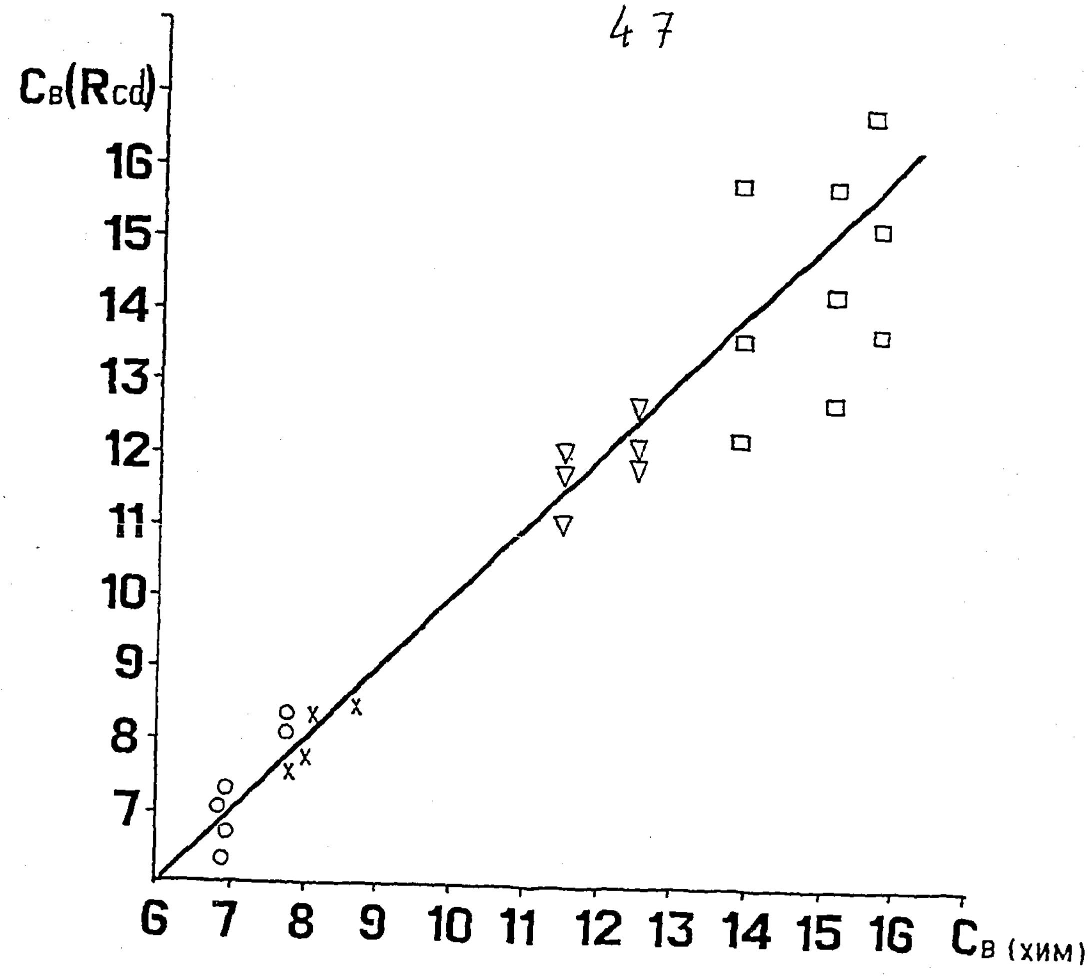


Рис.3. Устройство для непрерывного измерения концентрации поглощающего нейтроны вещества в теплоносителе ядерного реактора.



4 КОРРЕЛЯЦИЯ ХИМИЧЕСКОГО МЕТОДА ИЗМЕРЕНИЯ КОНЦЕНТРАЦИИ БОРНОЙ КИСЛОТЫ В РЕАКТОРНОЙ ВОДЕ И МЕТОДА ОТНОСИТЕЛЬНОЙ РАДИОМЕТРИИ

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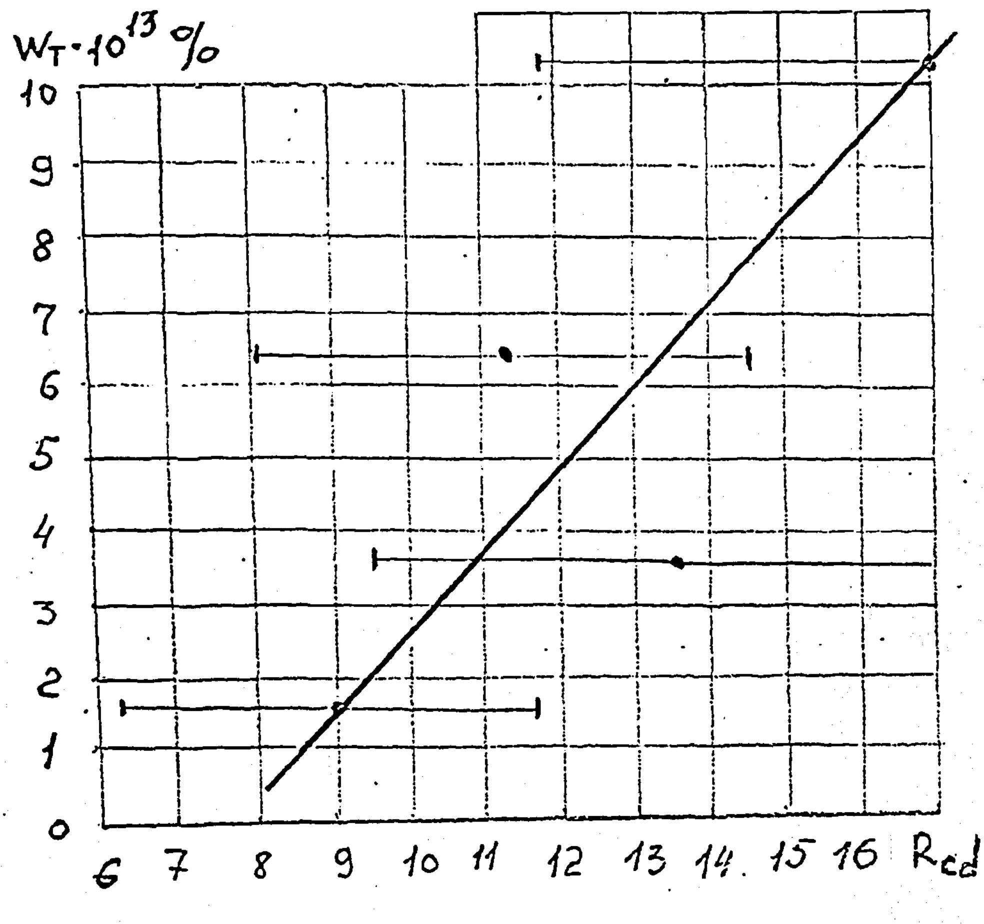


Рис. 5 Зависимость мощности (относительно показаний АКНП)подкритического реактора ВВЭР-1000 ЮУАЭС от кадмиевого отношения блоков детектирования АПП со счетчиками СНМ-I8.

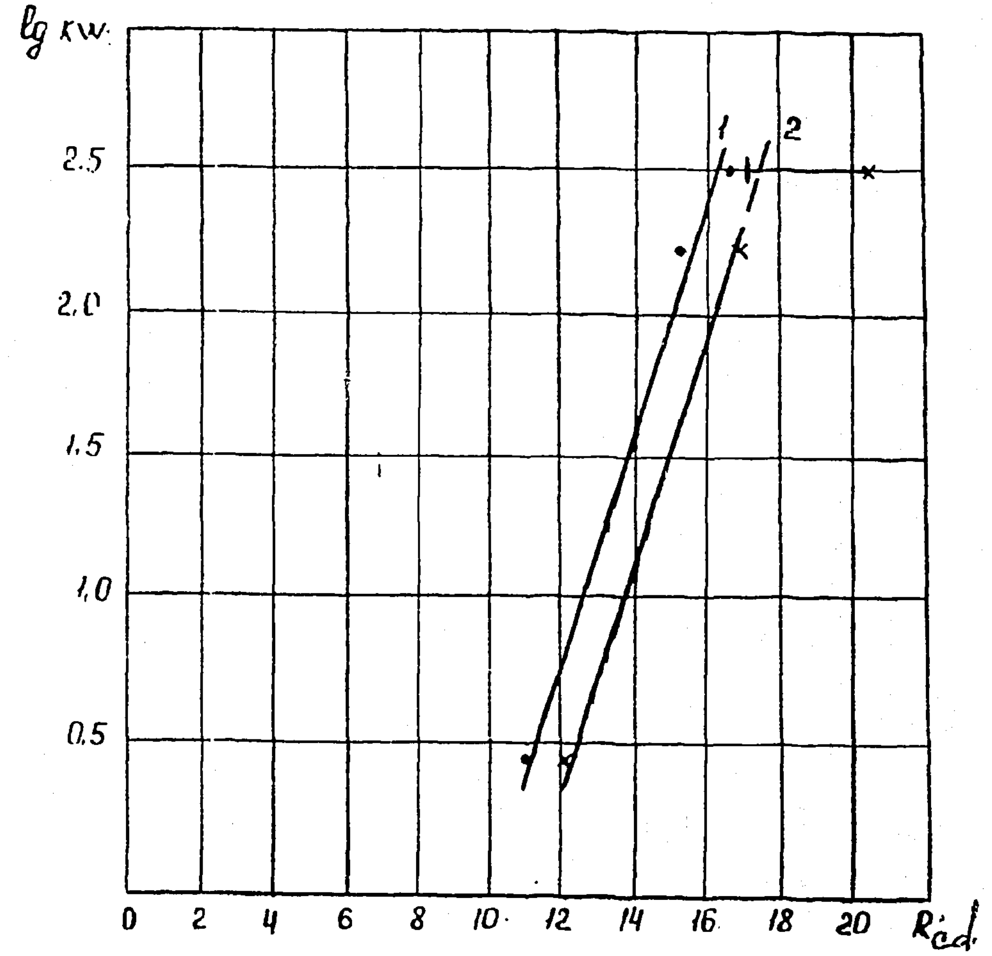


Рис 6. Зависимость логарифма мощности ВВЭР-1000 V блока НВАЭС от кадмиевого отношения по урану-235 ионизационных камер КНК-15 (измерения 1980 г.),

Способ определения реактивности подкритического реактора

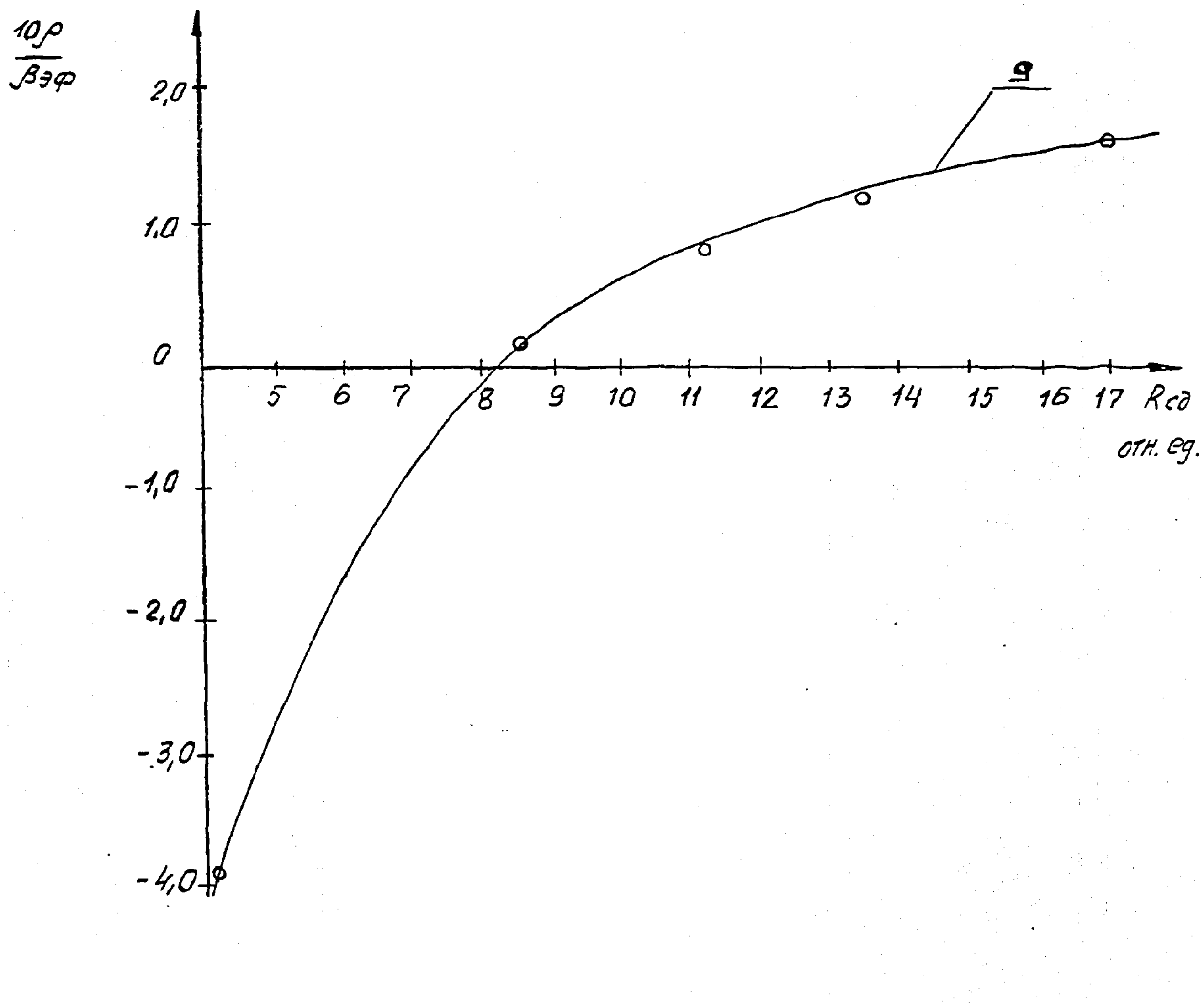


Рис. 7 Зависимость реактивности от кадмиевого отношения

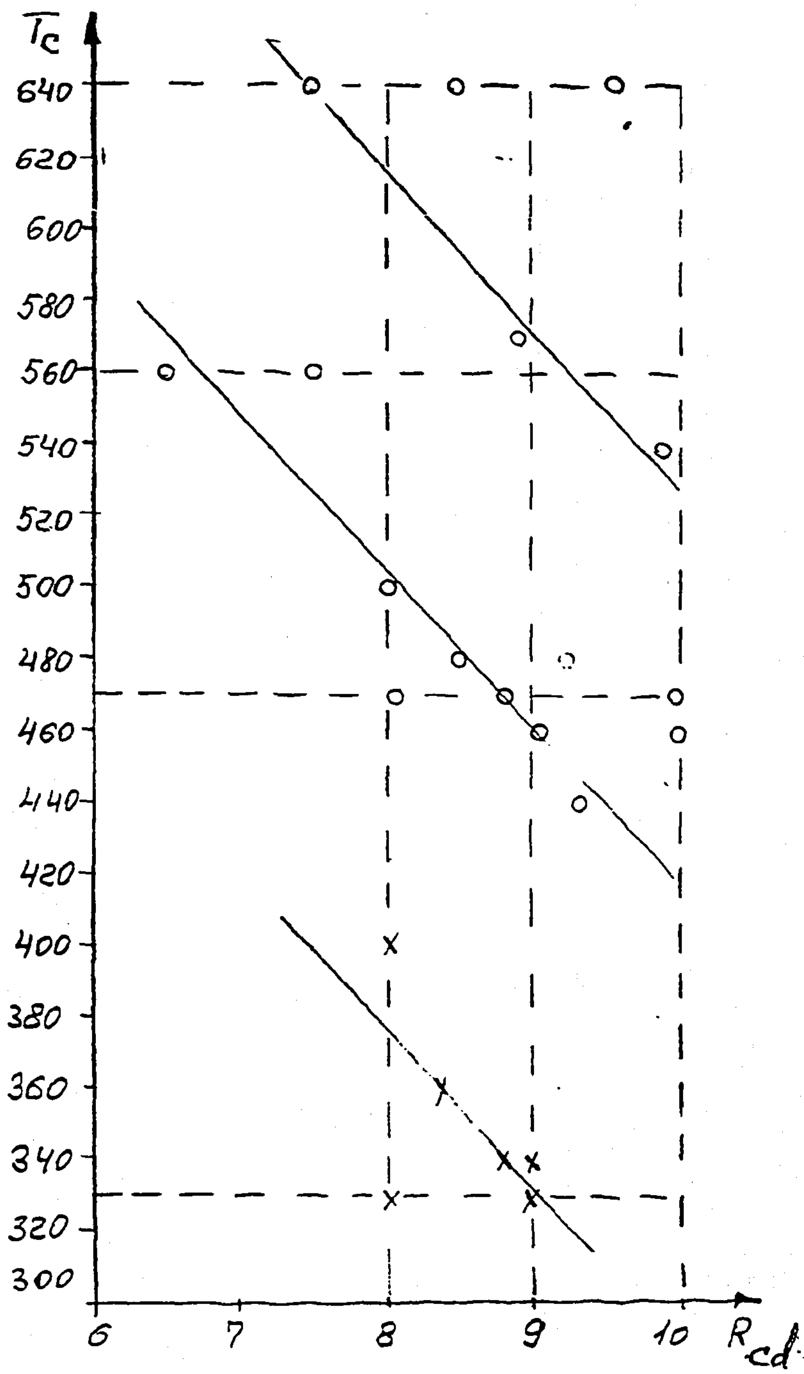


Рис. 8 Зависимость периода ВВЭР-1000 блока I Южно-Украинской АЭС от кадмиевого отношения блоков БДЛН-17Р (декабрь 1982)

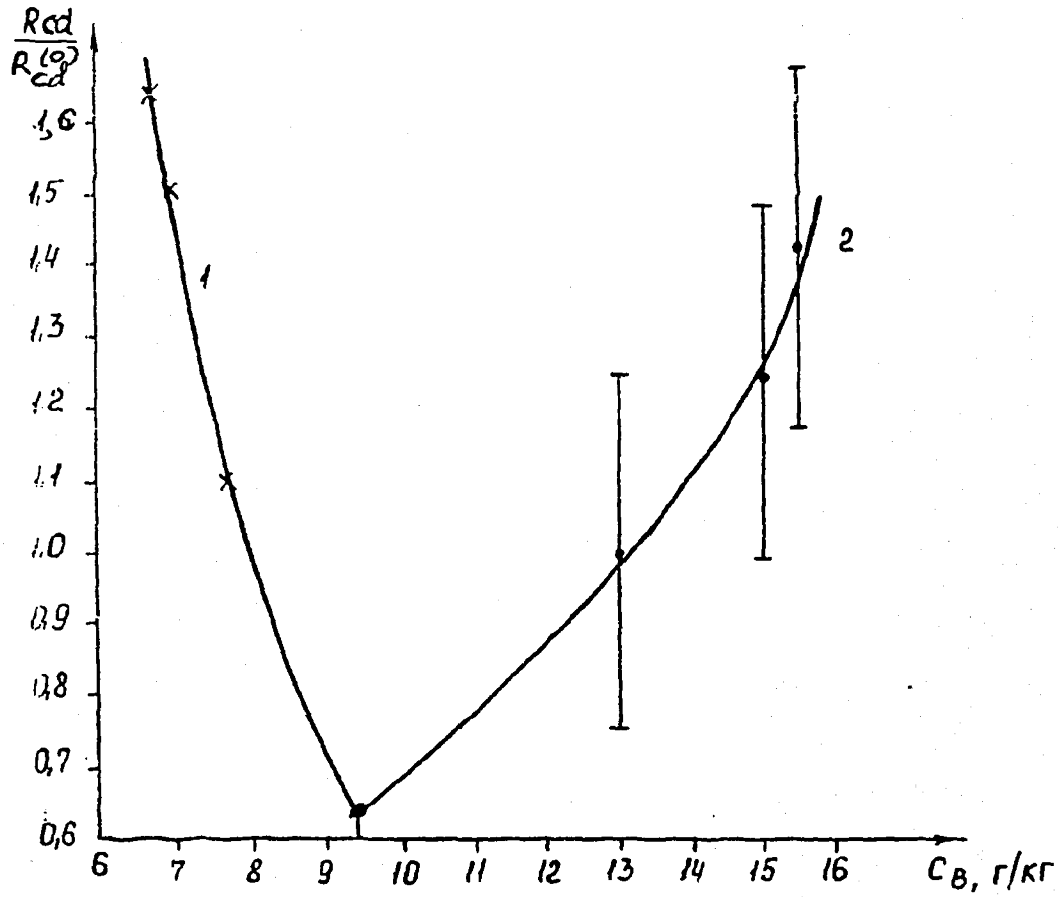


Рис.9. Инверсия зависимости R_{cd} от Σ_a для новой активной зоны (I) и облученной (при перегрузке) (2).

Способ определения критичности реакторной установки при ее загрузке

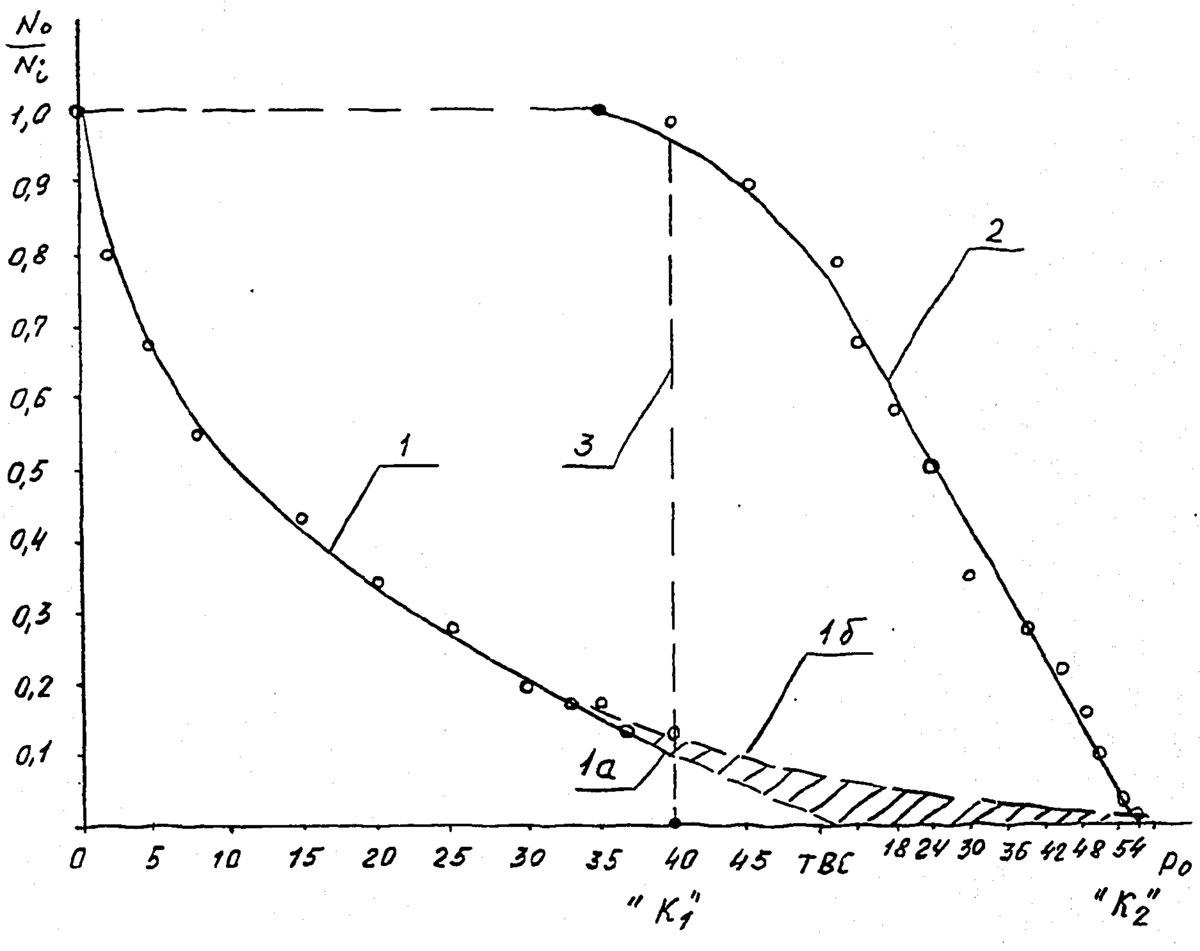
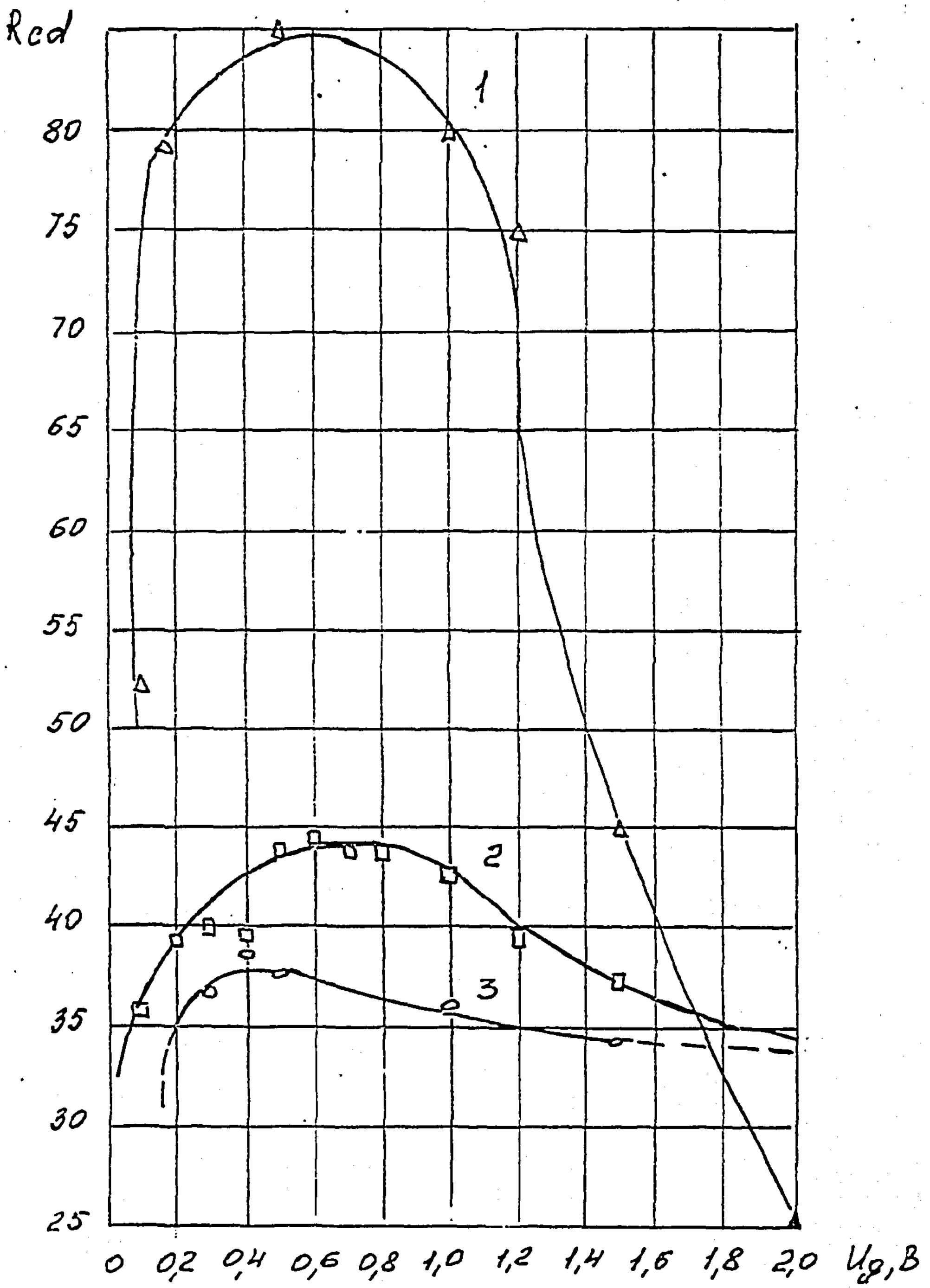


Рис. 10. Кривые обратного счета

Зависимость кадмиевого отношения по урану-235 ионизационных камер КНУ-3



I - объем 10^{-3};
2 - КНК-15;
3 - объем 1;

Рис. 11

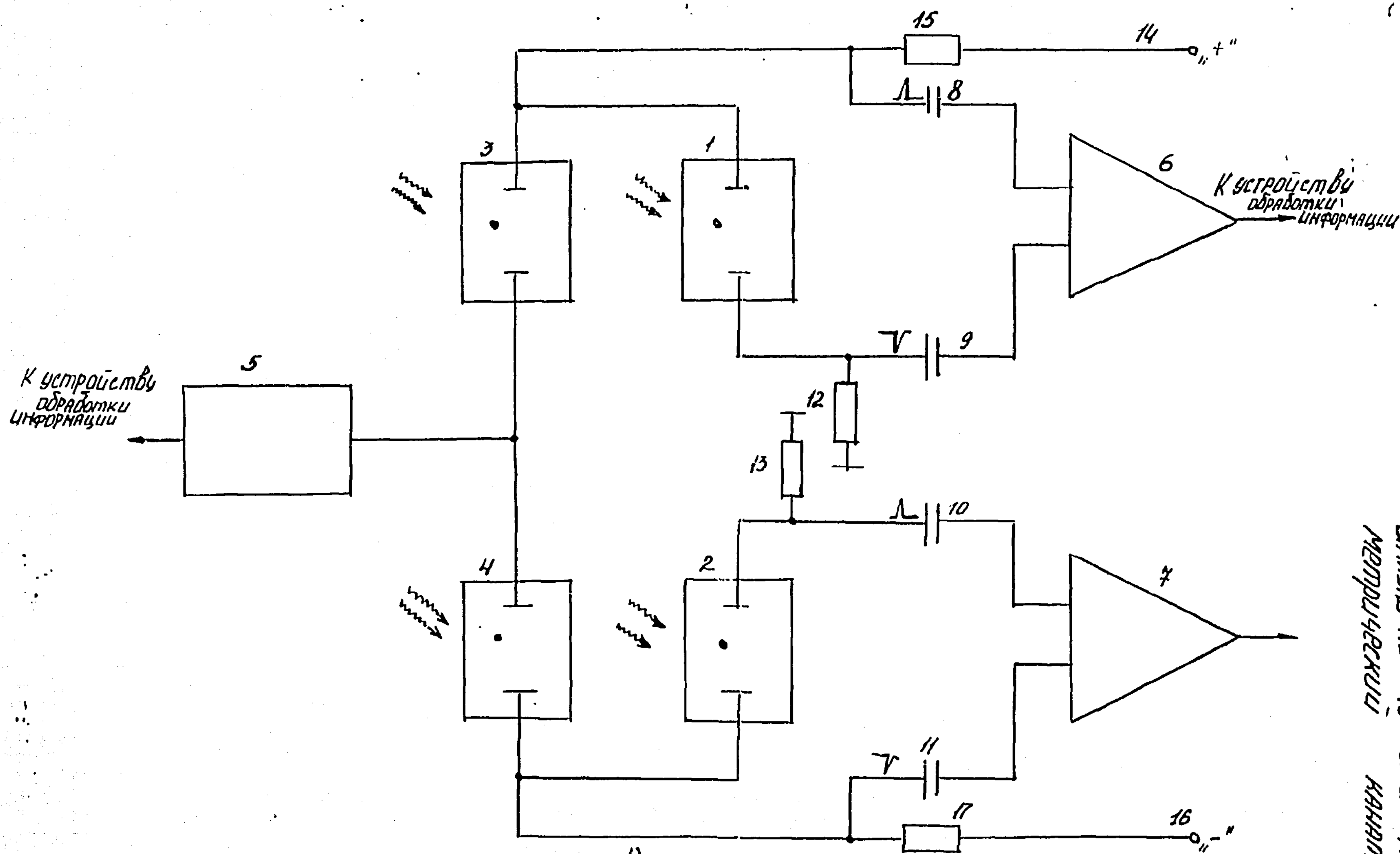
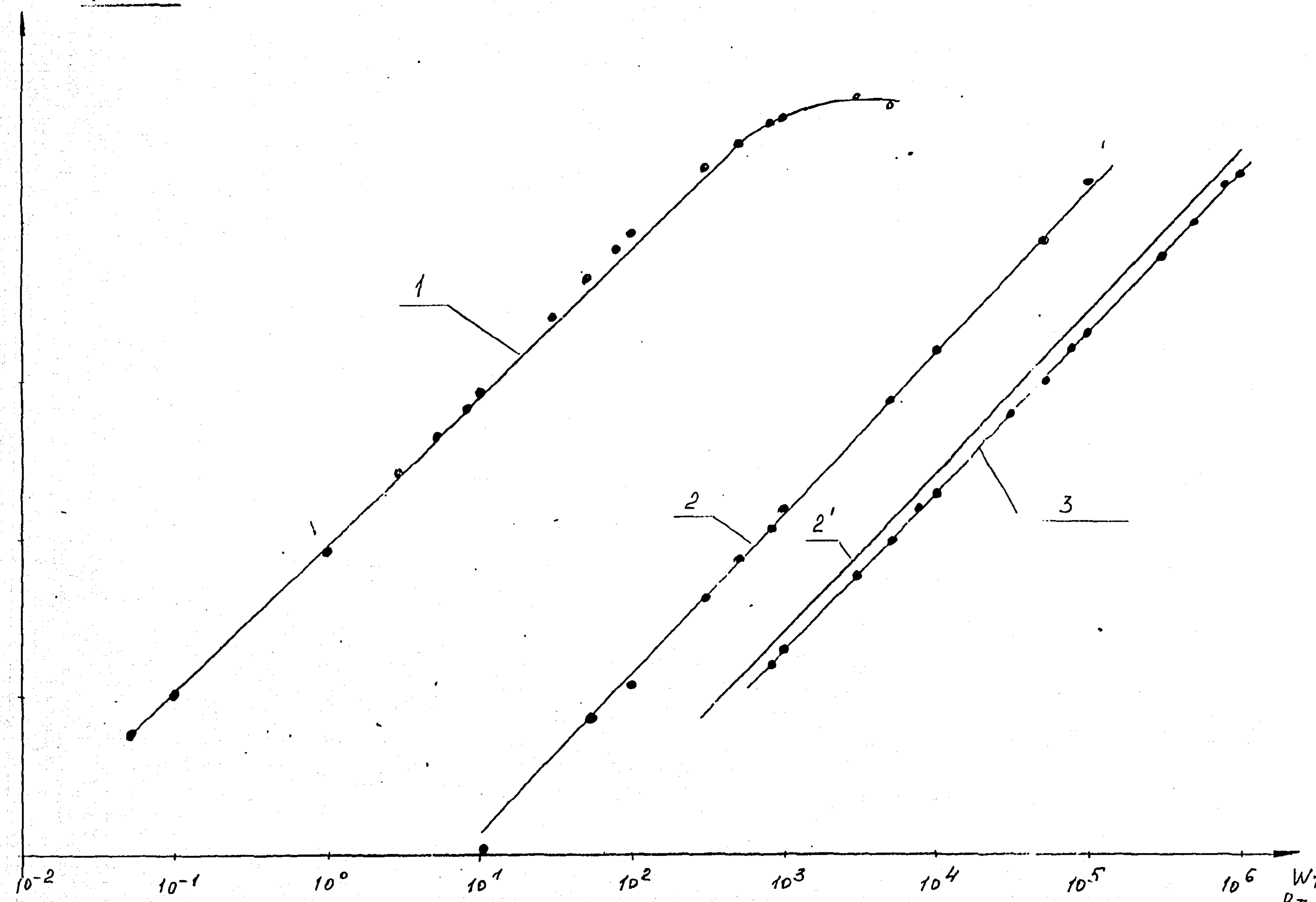


Рис. ~~фиг.~~ 12

Импульсно-токовый радиометрический канал.

Рабочие характеристики УДПН-13 с макетом КНУ-3 и 102 м кабелями в тепловой колонне

Рис. 13.



Инв. № подл.	Подп. и дата	Взам. инв. №	Инв. № дубл.	Подп. и дата

Характеристики УДПН-13с в ВЭК-10 с 31-мм Al стаканом макет КНУ-3 {не 01}

РИСУНОК 14.

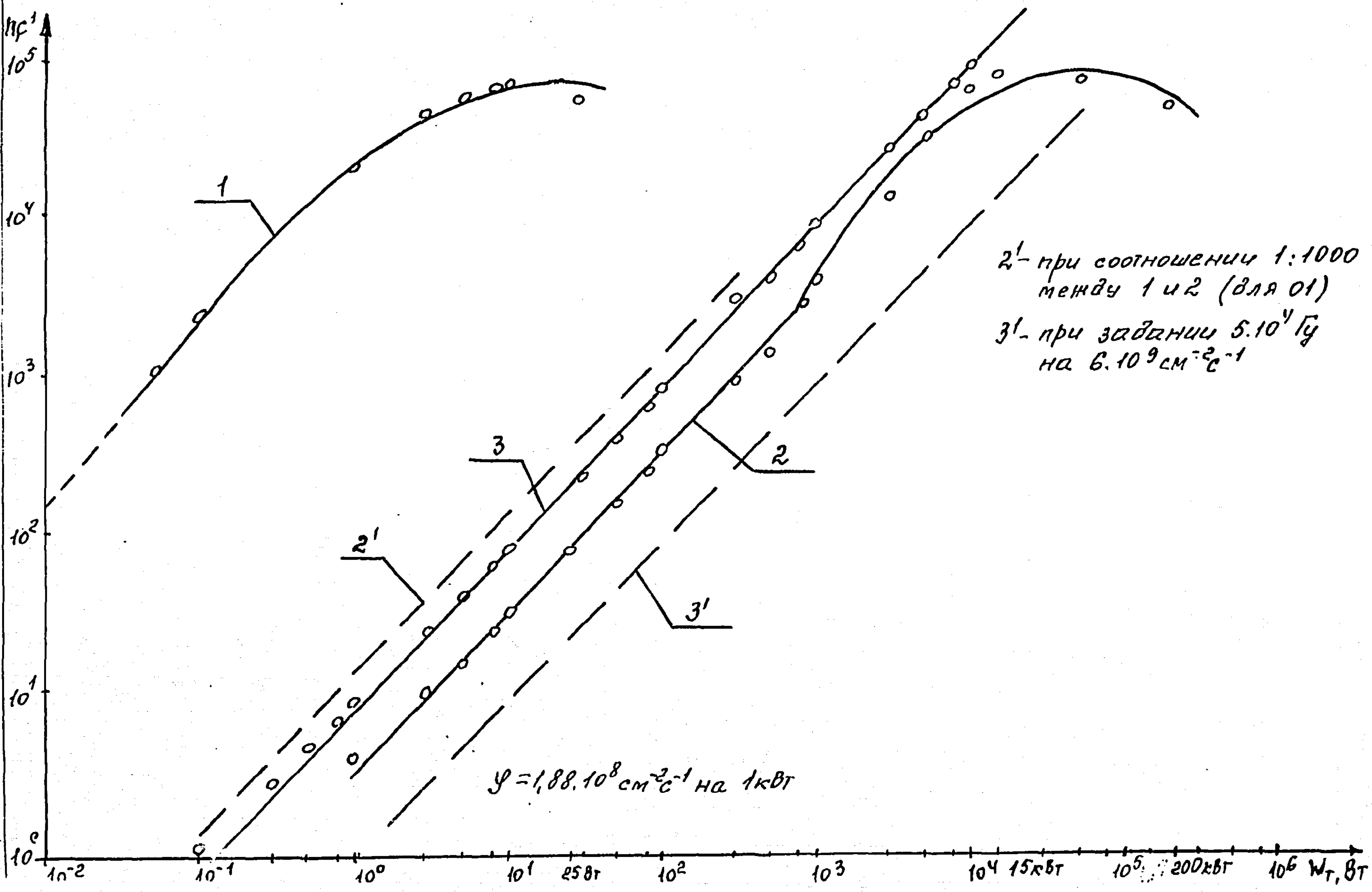


Рис.15 Погрешность электрической компенсации УДПН-13, борный объем {КНУ-3 не 01} без Pb в ВЭК-10