EUR 470.e

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

THEORETICAL ANALYSIS OF SOME PROBLEMS WHICH ARE DUE TO THE PRESENCE OF PLUTONIUM IN HETEROGENEOUS THERMAL REACTORS

by

E. DIANA

1963

ORGEL Program

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Applied Mathematical Physics Service

LEGAL NOTICE

This document was prepared under the sponsorship of the Commission of the European Atomic Energy Community (EURATOM).

Neither the EURATOM Commission, its contractors nor any person acting on their behalf :

1° — Make any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights ; or

2° — Assume any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

This report can be obtained, at the price of Belgian Francs 40, from : PRESSES ACADEMIQUES EUROPEENNES — 98, Chaussée de Charleroi, Brussels 6.

Please remit payments :

— to BANQUE DE LA SOCIETE GENERALE (Agence Ma Campagne) — Brussels — account No 964.558,

— to BELGIAN AMERICAN BANK AND TRUST COMPANY — New York — account No 121.86,

— to LLOYDS BANK (Foreign) Ltd. — 10 Moorgate — London E.C.2,

giving the reference : « EUR 470 . e — Theoretical analysis of some problems which are due to the presence of plutonium in heterogeneous thermal reactors ».

This document was duplicated on the basis of the best available copy.

Printed by IMPRIMERIE L. VANMELLE S.A., GHENT
Brussels, October 1963

EUR 470.e

THEORETICAL ANALYSIS OF SOME PROBLEMS WHICH ARE DUE TO THE PRESENCE OF PLUTONIUM IN HETEROGENEOUS THERMAL REACTORS by E. DIANA

European Atomic Energy Community — EURATOM
ORGEL Program
Joint Nuclear Research Center
Ispra Establishment (Italy)
Reactor Physics Department - Applied Mathematical Physics Service
Brussels, October 1963 — pages 18 — figures 5

Oscillation experiments with Pu-containing fuel elements are planned to be done in the reactor ECO at the ISPRA JRC in a near future. To study the inference that one can draw from such integral measurements to the calculation of the reactivity of irradiated lattices we have investigated in a number of cases the influence of the plutonium on the spectrum as well in the fuel as in the moderator ; also we studied the effects of a non-uniform spatial distribution of the plutonium in the fuel.

EUR 470.e

THEORETICAL ANALYSIS OF SOME PROBLEMS WHICH ARE DUE TO THE PRESENCE OF PLUTONIUM IN HETEROGENEOUS THERMAL REACTORS by E. DIANA

European Atomic Energy Community — EURATOM
ORGEL Program
Joint Nuclear Research Center
Ispra Establishment (Italy)
Reactor Physics Department - Applied Mathematical Physics Service
Brussels, October 1963 — pages 18 — figures 5

Oscillation experiments with Pu-containing fuel elements are planned to be done in the reactor ECO at the ISPRA JRC in a near future. To study the inference that one can draw from such integral measurements to the calculation of the reactivity of irradiated lattices we have investigated in a number of cases the influence of the plutonium on the spectrum as well in the fuel as in the moderator ; also we studied the effects of a non-uniform spatial distribution of the plutonium in the fuel.

Finally we estimated the values of the heterogeneous parameters for such a fuel.

Finally we estimated the values of the heterogeneous parameters for such a fuel.

EUR 470.e

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

THEORETICAL ANALYSIS OF SOME PROBLEMS WHICH ARE DUE TO THE PRESENCE OF PLUTONIUM IN HETEROGENEOUS THERMAL REACTORS

by

E. DIANA

1963

ORGEL Program

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Applied Mathematical Physics Service

TABLE DES MATIERES

THEORETICAL ANALYSIS OF SOME PROBLEMS WHICH ARE DUE TO THE PRESENCE OF PLUTONIUM IN HETEROGENEOUS THERMAL REACTORS

SUMMARY

Oscillation experiments with Pu-containing fuel elements are planned to be done in the reactor ECO at the CCR ISPRA in a near future. To study the inference that one can draw from such integral measurements to the calculation of the reactivity of irradiated lattices we have investigated in a number of cases the influence of the plutonium on the spectrum as well in the fuel as in the moderator; also we studied the effects of a non-uniform spatial distribution of the plutonium in the fuel. Finally we estimated the values of the heterogeneous parameters for such a fuel.

I. Introduction

In order to understand completely the variation of the lattice parameters as a function of irradiation in a reactor fuelled with uranium, it is very important to understand exactly the reactivity effects due to the formation of plutonium in the fuel elements.

These effects may be studied more easily in synthetic fuel elements containing plutonium. For this reason we are planning (in the framework of the ORGEL Project) a series of experiments with synthetic fuel elements of the ORGEL type, containing different percentages of plutonium with two different isotopic compositions. More precisely the percentages and the isotopic compositions are in table I.

The basic fuel element is a cluster of 19 rods of natural uranium; radius of the rods 0.6 cm.

Table I

fuel element	% of Pu	isotopic composition % of Pu^{239}	% of Pu^{240}
1	0.05	94	6
2	0.15	94	6
3	0.2	94	6
4	0.3	94	6
5	0.4	94	6
6	0.05	85	15
7	0.15	85	15
8	0.2	85	15
9	0.3	85	15

The experiments on these fuel elements will be done in ECO (Expérience Critique ORGEL) at the CCR ISPRA. In ECO we have the choice between two fundamental types of experiments : substitution experiments or oscillation experiments. In this case, due to the high costs of the plutonium and of the fabrication of the synthetic elements, we decided to perform oscillation experiments.

In such a way we need only a piece 50 cm long for each type of fuel element to be tested.

II. Description of the oscillation experiments and their interpretation

In the oscillation experiments another rod is attached to the central rod of the reference lattice (see fig.1), such that the square-wave oscillation exchanges alternatively the two elements.

In the case of the synthetic fuel elements the second rod is an element of the same type as those of the reference lattice with only the central part, for a length of 50 cm, replaced by the synthetic fuel. It may be interesting to give some fundamental data for the oscillating apparatus :

weight of the oscillating rods	350 kg
amplitude of the oscillation	4 m
time of transit	4 s
period	from 20s to 200s

For the interpretation of the oscillation experiments we rely on the general theory developed at ISPRA by G.BLAESSER [1]. Briefly, by employing two detectors at different locations to measure the oscillating part of the neutron flux, we can determine separately the differences between the total absorption of the fuel element tested and of the reference fuel element and the difference between total productions, i.e. the two integrals

$$A = \iiint [\Sigma_a(E) - \Sigma_a^{ref}(E)]\, \varphi(\vec{r}, E)\, dV\, dE$$

$$P = \iiint [\nu\Sigma_f(E) - \nu\Sigma_f^{ref}(E)]\, \varphi(\vec{r}, E)\, dV\, dE$$

where the spatial integration is extended over the volume of the sample tested.

In fact the theory gives for the oscillating part of the neutron flux, as measured by a detector placed at the point $\vec{r}$, the following expression

$$J_\rho = G_f(\vec{r}, \vec{r}_0, \rho)\, P - G_a(\vec{r}, \vec{r}_0, \rho)\, A$$

where ρ is the frequenoy, $\vec{r}_0$ is a point representative of the location of the sample, A and P are defined above. The functions $G_f(\vec{r}, \vec{r}_0, \rho)$ and $G_a(\vec{r}, \vec{r}_0, \rho)$ which we shall call "production response function" and "absorption response function" respectively, do not depend on the sample characteristics but only on the properties of the reactor and the detector in question.

The determination of $G_f(\vec{r}, \vec{r}_0, \rho)$ and $G_a(\vec{r}, \vec{r}_0, \rho)$ may be accomplished theoretically by the employ of standard approximation methods as multigroup diffusion theory, Monte-Carlo or S_N calculations. On the other side we can determine these functions experimentally by calibration with some standard samples (for instance boron and U^{235}).

A remarkable property of these two functions is that their dependence on $\vec{r}$ is not the same.

III. Calculations made to olarify some points for the use of the results of the oscillation experiments

At this point we must remember that in synthetic fuel elements the spatial distribution of plutonium is uniform and therefore different from the real case. Thus the question arises on how to use this information obtained from the experiment for the interpretation and prediotion of the behaviour of real fuel where the plutonium is formed under irradiation. To shed some light on this, we investigated especially the changes in the thermal spectrum due to the presence of the plutonium in the case of a lattice of simple fuel elements embedded in heavy water moderator.

We used the code THERMOS for the calculator 7090, i.e. a spectrum and cell-code using integral transport theory. The geometrical dimensions of our lattice were the following :

solid cylindrical fuel element of 2.54 cm diameter

canning = 1 mm Al

lattice pitch = 9.22 cm (corresponding to a radius of the Wigner-Seitz-cell of 5.20 cm).

These data correspond to a moderator-fuel volume ratio of 15.7.

The fuel was metallic natural uranium in the first case, 0.36% U^{235}, 0.192% Pu^{239} and the rest U^{238} in the second case, 0.192% Pu^{239} and the rest natural uranium in the third case.

The calculation for the second choice of fuel composition have been carried out also for another lattice pitch 11.43 cm, corresponding to a cell radius of 6.45 cm, and a moderator-fuel volume ratio of 24.8.

IV. Results of the calculations

The results of these calculations are shown in table II and in the curves II-V. In curve II the spectrum in the moderator (neutron density) near the fuel surface (at 3.4 mm from the surface of the rod) is shown for the three cases considered at the lattice pitch 9.22 cm. One can see very easily that the spectrum in the second case is almost the same as in the first case, except for the distorsion in the neighborhood of the 0.3 eV resonance of Pu. This is due to the fact that the total thermal absorption is not much changed, the reduction in U^{235}-concentration cancelling the additional absorption due to Pu^{239}.

In the third case instead the Pu^{239} brings an additional absorption to that already present by the natural uranium, and this results in a much stronger distorsion of the thermal spectrum, especially on the low energy side. Obviously the second case corresponds more to the real situation in an irradiated fuel element than the third case, and we continue therefore with the comparison of the first and second cases only.

In curve III the spectrum for these two cases is shown for a distance of 1.78 cm from the fuel element surface. One sees that the deformation of the spectrum due to the presence of Pu is a relatively local effect, sensible only in the immediate neighbourhood of the fuel, provided that the total absorption remains the same.
In other words, far away from the fuel element the thermal spectrum is determined only by the total absorption taking place in the fuel, but not by the detailed energy dependence of this absorption.

In curve IV instead the spectrum inside the fuel (at 0.53 cm from the center) is shown. One sees the still more pronounced flux depression in the resonance. In curve V finally we have compared the results of the second case for the two different lattice pitches (at a distance of 3.4 mm from the surface of the rod). It is obvious that in the case of higher pitch the ratio of thermal to epithermal neutrons is higher, but the detailed form of the thermal spectrum remains unaltered (both curves had the same normalization of the thermal part).

From these results we can draw the following conclusions :

1. The moderator spectrum far from the fuel element is not sensitive to the details of thermal absorption. Therefore, the absorption integral as measured by the oscillation technique is already a sufficient characteristics for the thermal spectrum in the moderator far from the elements. Especially, there is no reciprocal influence of the details of thermal absorption for two neighbouring fuel elements. This makes more easy the interpretation of the behaviour of Pu-containing samples in a reactor containing only natural U-fuel.

2. It seems that the total absorption in the fuel can be divided into two parts : i.e. the absorption in the 0.3 eV resonance of Pu^{239} and the thermal absorption in the strict sense, and in the latter the Pu^{239} does not play a role different from U^{235}. Under these assumptions a relatively straightforward application of the results of these integral measurements to cases of practical interest could be made.

Additional calculations have been made to study the effect of non-uniform distribution of Pu in the fuel. We recalculated the case 2 (with 9.22 cm pitch) with a spatial Pu-distribution of approximately parabolic shape, having a surface-to-center ratio of 1.4. The differences in the values of the effective cross sections are rather small, as can be seen from table II.

We also calculated the values of the heterogeneous parameters that enter a kernel-type theory. They are given in table II too. Concerning these parameters one has to keep in mind that the criticality of a reactor is a rather insensitive function of γ so that the indicated changes in η which directly correspond to changes in k of the lattice are probably more important. One sees that η is relatively insensitive to the lattice pitch (which is a fundamental assumption of a kernel-type heterogeneous theory) and that it changes rather little with the spatial distribution of the Pu.

References :

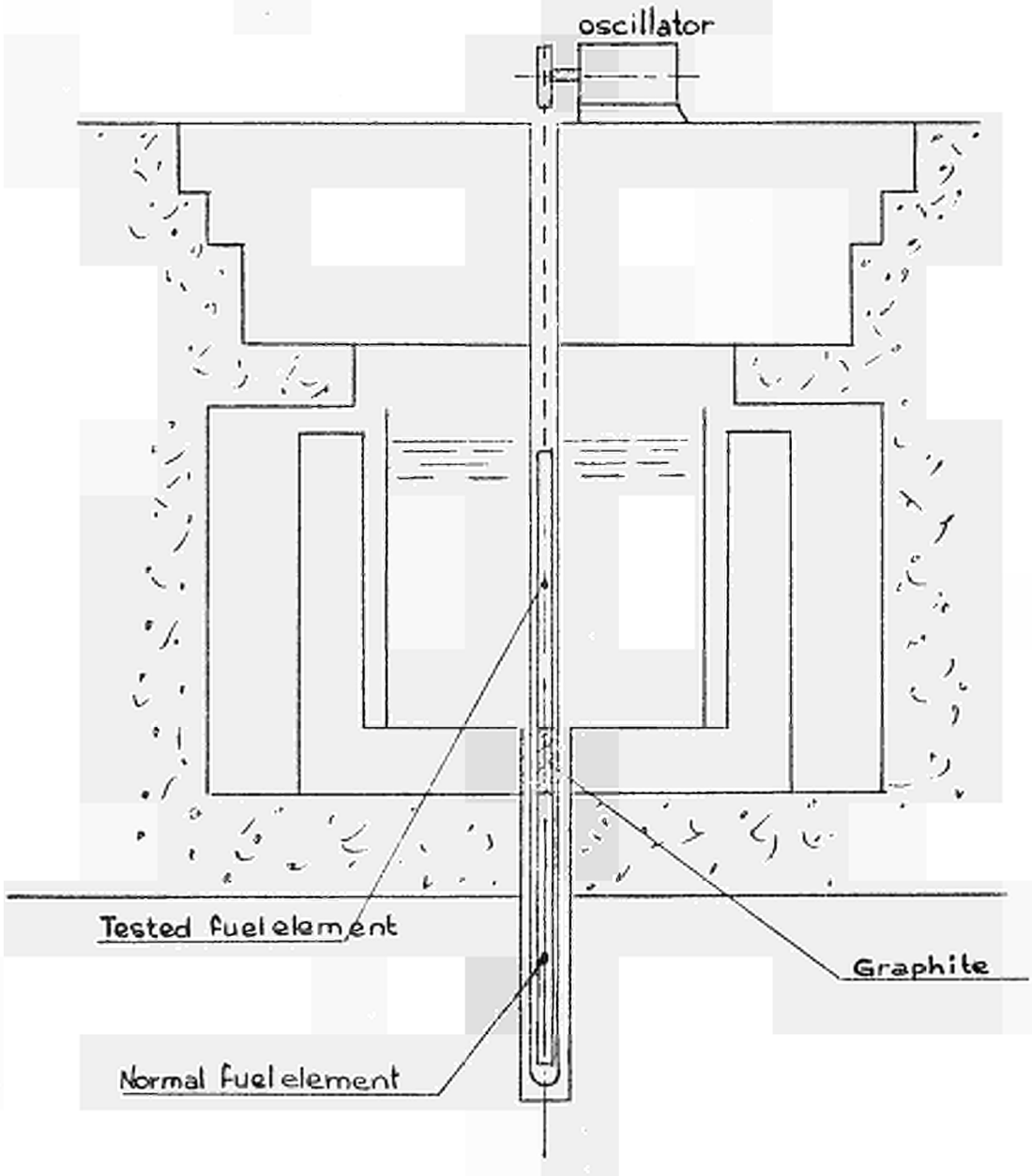
[1] G.BLAESSER : Theoretical foundations of parameter oscillation measurements, EUR 221.e (1963)

Table II

	U 0.714% N_{25} V_m/V_f=15.7	Pu 0.367% N_{25} 0.192% N_{39} V_m/V_f=15.7	Pu 0.367% N_{25} 0.192% N_{39} V_m/V_f=24.8	U.Pu 0.714% N_{25} 0.192% N_{39} V_m/V_f=15.7
ρ (thermal utilization)	0.98600	0.98684	0.98304	0.98898
$\bar{N}_m/\bar{N}_f$	1.493	1.539	1.580	1.680
$\bar{\varphi}_m/\bar{\varphi}_f$	1.664	1.6708	1.716	1.865
$\sigma_{f\,25}$(fuel)	369	378.8	402.7	360.4
$\sigma_{f\,39}$(fuel)	670.8	635.4	628.5	635.2
$\bar{\Sigma}_a$ (fuel)	0.2349	0.25718 0.25793+	0.26485	0.32073
$\bar{\Sigma}_a$ (cell)	0.009725	0.010335	0.006717	0.011828
$\overline{\nu\Sigma_f}$ (fuel)	0.30620	0.33022 0.33172+	0.33856	0.46788
$\overline{\nu\Sigma_f}$ (235)	0.30620	0.16136 0.16124+	0.17153	0.29907
$\overline{\nu\Sigma_f}$ (239)		0.16886 0.17048+	0.16703	0.16881
η	1.3035	1.2840 1.2861+	1.2783	1.4588
γ	1.0065	1.0851 1.0901+	1.1176	1.2902

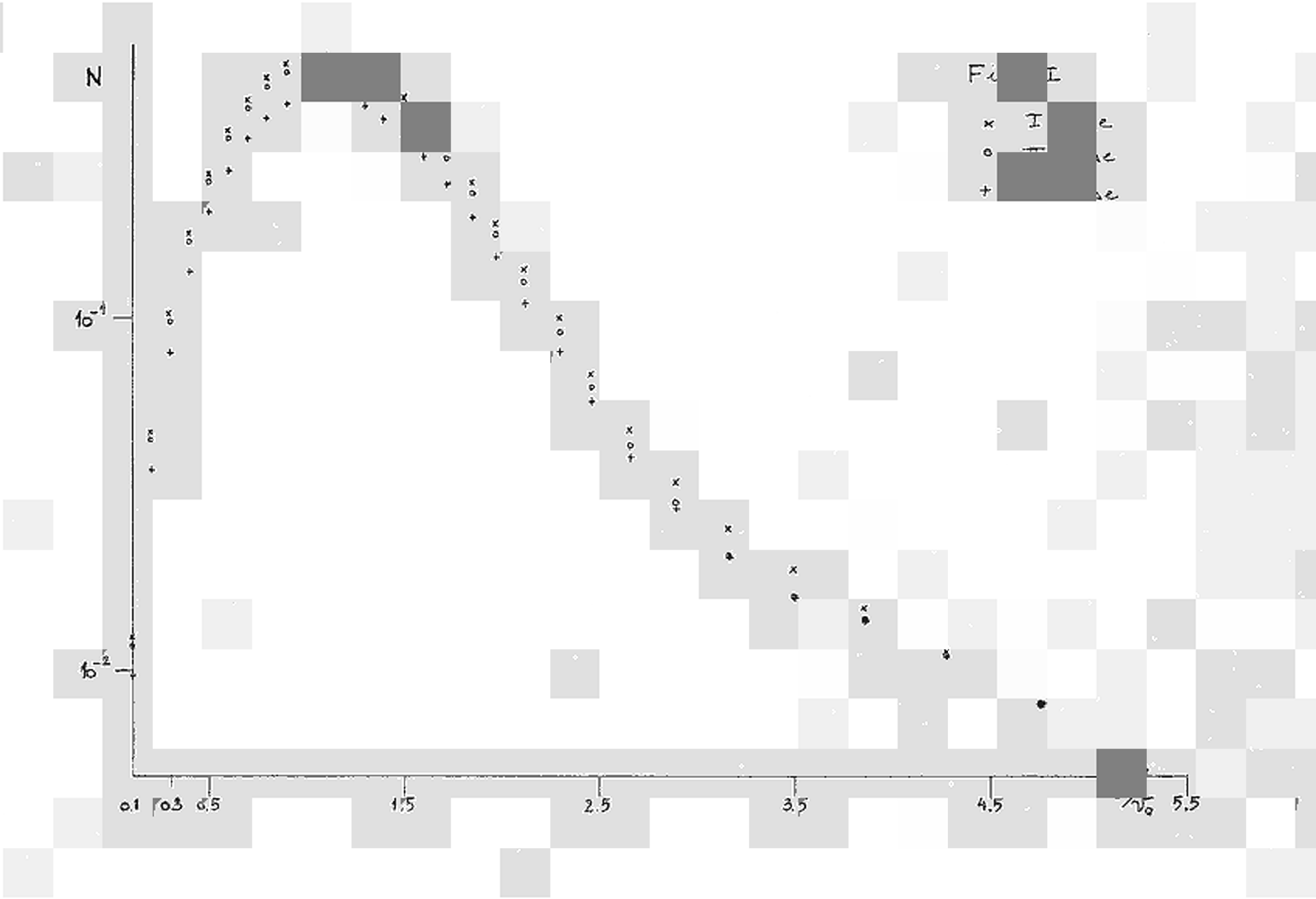
+. values for non uniform distribution of Pu

Oscillator of the central element ECO

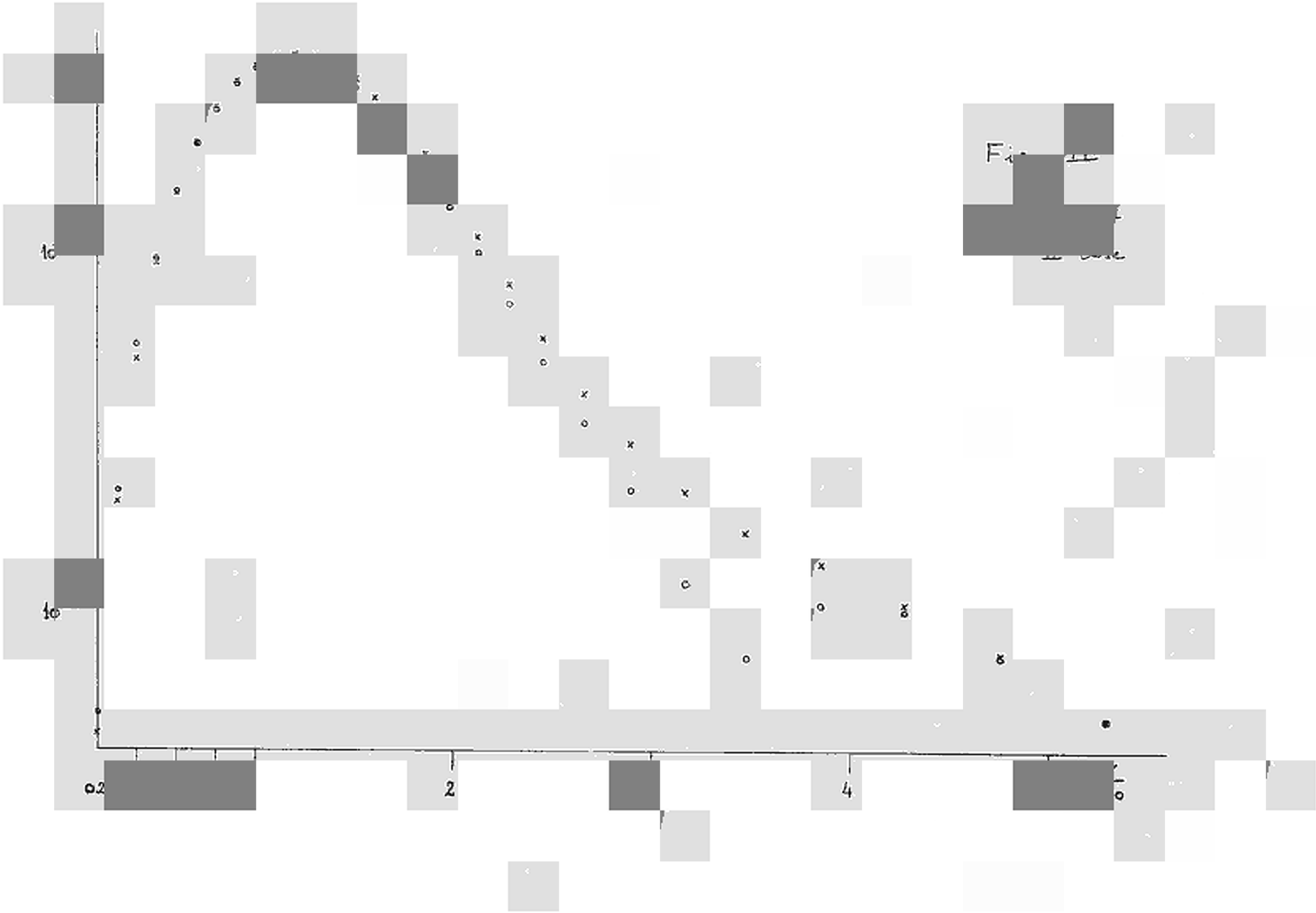


(Fig. I)

scheme of the arrangement


N
10^{-1}
10^{-2}
0.1
0.3
0.5
1.5
2.5
3.5
4.5
$\sqrt{s_0}$
5.5

N
10^{-1}
10^{-2}
1
5
5
5
5
F
I case
II case


10
10
0.2
2
4

0.1
0.3
0.5
1.5
2.5
3.5
4.5
5.5