This report was written on request of the Advisory Committee on Programme Management (CCMGP) for the Information Analysis Services and is a transcription of the talk given at the CCMGP meeting held at CCR Ispra on March 17-19, 1975.

Only work done after the CCMGP meeting in October 1974 is presented with the exception of some points, essential to the understanding of the given results, which are recalled in the text. Thus it is assumed that the information previously released in written form (annual progress reports, etc.) is known.

Results shown are in a preliminary form, not yet revised, and possibly subject to change; they are updated to the status of the work at middle April 1975.

The issue of the report was somewhat delayed to include results not yet available at the time of the talk, i.e. of "B^{10} capture/\text{U}^{235} fission" measurements (section 5).

It is reminded that this work is done within a collaboration agreement among CCR Ispra, AGIP Nucleare and CNEN.

1. INTRODUCTION

1A. Principle of the experiment

Goal of the experiment is the determination of the neutron capture cross section of elements used as structural materials in fast reactors (as Fe, Cr, Ni), averaged over neutron energy spectra which maximize this capture in the energy range (1-100 KeV) where the present uncertainties in the measured differential cross sections are higher.
The measurements are made by the "void-null reactivity" method (PCTR method), in media consisting of microspheres of fissile material (UO₂ with 93% U235 enrichment) and graphite containing the amount of boron required to reduce k-inf of the medium to unity.

The "void-null reactivity" method is based on the elementary principle that replacement by void, of a portion of an infinite homogeneous medium with multiplication factor equal to unity, does not modify its reactivity. For practical reasons the composition of the sample, which when replaced by void gives a null-reactivity variation, is determined by linear interpolation of reactivity signals obtained by samples with varying poison content.

In reality multiplying media are finite, and even at their center some residual mismatch of the local spectrum with respect to the infinite medium spectrum may occur; also, neutron leakage may introduce a curvature in the flux distribution extending to the medium center. Thus, the medium with "null-reactivity composition" has a k-inf = 1/(1-E), E being the correction factor for non-asymptotic spectrum conditions and leakage, usually calculated by a first order perturbation formalism.

The experiment is based on a set of two independent "void-null reactivity" measurements: the first with a test-medium containing only fissile and moderator particles (reference medium), the second with a test-medium which also includes homogeneously dispersed microspheres of the material under investigation.

The resolving equations are shown with condensed notation in Table 1; equation 1 refers to the reference test-medium equation 2 refers to the a test-medium with added Fe particles.

Having determined the null-reactivity composition and calculates the correction factor E, one infers k-inf = 1/(1-E) pertaining to the infinite medium with that composition.

The neutron balance shown at the right side of eqs.1, 2 is thus for the asymptotic (infinite medium) spectrum conditions.

The solution of eqs.1 and 2 for R^Fe = C^Fe / P^5 is shown in eq.3. R^Fe / P^5 is then the result of the experiment and is the value pertaining to the infinite medium spectrum.

Part of the quantities at the right side of eq.3 are directly measured, namely

null reactivity compositions, R^Fe = C^Fe / P^5, R^8 = C^8 / P^5, P^8 / P^5.

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The uranium of the actual test medium being highly enriched (93% U235), the last two quantities can also be calculated, without affecting the uncertainty of the experimental value of $R_{Fe}$.

Since the measured quantities are determined in the local spectrum (i.e. the spectrum at the center of the test medium), they must be converted into the corresponding asymptotic spectrum values, by calculated conversion factors of the kind $R_{Inf}/R_{Local}$, etc.

The other quantities, namely $\nu^5$, $\rho^3$, $\chi^5$, $R_C$ are theoretically calculated for the infinite medium spectrum.

It follows that an accurate theoretical calculation is essential, both for the design and the interpretation of this kind of experiment.

1B. Remarks on the design and interpretation of the experiment
The design was carried out mainly on the basis of calculations done at CCR Ispra, using ENDF/B1,2 data files and the 27-group, 1-dimension, transport code ANISN (for instance, this calculation lead to the choice of the atomic ratio $C/U235 = 150$ for the reference test medium, as that giving the best spectral conditions).

The interpretation of the experiment is at present carried out by CNEN, Centro di Calcolo di Bologna; the data and codes so far used are:

<table>
<thead>
<tr>
<th>data file</th>
<th>cross section averaging code</th>
<th>calculation code</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDF/B3</td>
<td>GAM2 (100 groups)</td>
<td>ANISN (transport, 1-d, 27 groups)</td>
</tr>
<tr>
<td>UX-B</td>
<td>MC2 (2000 groups)</td>
<td>ALCI (diffusion, 2-d, 10 groups)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PRAVDA (27 groups)</td>
</tr>
</tbody>
</table>

Several combinations were tested (e.g. ENDF/3-GAM 2 - ANISN vs. ENDF/B3 - MC2 - ANISN) reaching the conclusion to select the MC2 group-cross sections generation code for the definitive interpretation of the experiment; however most calculations were originally made using the GAM 2 code, and their results are often shown for comparison with measured data presented in this report.

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As quantitatively shown in a detailed error analysis presented previously, the two basic conditions to reduce the experimental error (ref. eq. 3) are:

a) closeeness of local spectrum to the corresponding asymptotic spectrum;

b) closeeness of the asymptotic spectra of the reference test medium and the test medium containing the structural material (Fe, in eq. 3).

To which extent the first condition is met for the "reference" medium is evidenced in Table 2, showing results of an BNDP/E3-\(\beta^2\)-ANISN calculation made for the infinite medium and the central zone of the same medium in the RB2/TV reactor. As spectral indexes are taken the same fissions (Pu240, Pu239, U238, U235) measured by miniaturized chambers (see section 4), as well as quantities relevant to the neutron balance (\(\phi^5/\phi^5, \alpha^5\)).

In order to meet the second condition, the asymptotic spectrum of the test medium containing the structural material (Fe in the actual case) was matched to that of the "reference" medium characterized by the atomic ratio C/U235 = 150, by varying its C/U235 value keeping constant the Fe/C value (=0.4, so as to have a significant fraction of total capture by Fe, which was required by the above mentioned error analysis). As matching parameters were taken the same quantities specified above.

In Table 3 are presented the results of a CARNAVAL 3 (CMA, France) calculation (Fe/C=0.5) which show that the best match is obtained when C/U235=120. A similar calculation carried out by CNEN for Fe/C=0.4, gave a slightly lower C/U235 value (110), which was chosen for the test samples actually used.

2. EXPERIMENTAL FACILITY

A horizontal cross-section of the experimental facility in the RB2/TV reactor is shown in Fig.1. The diameters of the so called fast zone (loaded with the reference medium) and buffer zone (loaded with arrays of WTR fuel plates with 90\% enriched U and wedged graphite slabs, with C/U235=150) are 300 and 500 mm, respectively.

A vertical cross-section is shown in Fig.2: the heights of the fast and buffer zone are 700 mm and 950 mm, respectively. Also shown is the central (50-mm-dia) oscillated element used to replace the test sample (100-mm-high) by void.

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The "reference" medium consists of a mixture of 1-mm-dia. pyrocarbon coated, fissile particles (UO₂, enriched to 93% U₂₃⁵) and graphite particles with B content required to poison the k-inf of the medium to unity; the test medium contains also 0.75-mm-dia Fe particles.

Boron is contained only in part of the graphite particles, to allow a fine adjustment of the B content of the medium. In order to be able to recover the boron loaded from the pure graphite particles for further use, the two kinds of particles were manufactured with different mean densities (1.32 vs. 1.57) and narrow density distribution curves (see Fig.3) so that an effective separation (~99%) was attainable by heavy liquids mixtures (dibromoethane and alcohol).

The main characteristics of the particles (fissile, graphite, boron loaded graphite) are listed in the Appendix.

The KB2/TV reactor with the above experimental facility reached its first criticality on Sept.3rd, 1974. A summary of the set of tests performed to meet the usual safety requirements, and of the results obtained (as presented in the 1974 Progress Report) is given in the Appendix.

3. DETERMINATION OF THE NULL REACTIVITY COMPOSITIONS
3A. Mechanical oscillator : neutron detection equipment and data analysis method

The pile oscillator (Fig.4) is a wheel-cam type engine, transmitting, via a cross head running on a rail, a vertical motion to the oscillated element. Owing to the long rest time relative to the transit time, the oscillation approximates a square-wave function. Main features: run 0≥200 cm, transit time 141 sec/run, max. induced acceleration ≤0.3 g.

The oscillated element (60-mm-dia, 4000-mm-long) consists of a train of tube segments, containing a particle mixture with the same composition of the "reference" medium, and two 100-mm-high samples, spaced by 1500 mm (high and low sample).

The instrumentation for the pile density modulation detection consists of a gamma-compensated ionization chamber (placed inside the graphite reflector), with calibrated zero suppression, conversion to frequency, double scaler unit (alternate counting), tape puncher.

The data analysis yields the ratio of the first harmonic amplitude of the Fourier series expansion of the signal divided by the mean power level (A/P, in short notation).
3B. Preliminary tests

Preliminary tests were performed to check the instrumentation and select the best oscillation conditions. The varied parameters were: oscillation period (60, 120 and 240 sec), reactor power (1, 10 and 30 W) single reading time (0.2, 0.4, 1 sec), etc. The conditions chosen were: period 60 sec, power 1 W, reading time 1 sec.

Careful tests were also carried out to verify some essential conditions as:

a) stability of the particles mixture homogeneity to vibrations induced during oscillation;

b) reproducibility of homogeneity and composition of mixture in test sample;

c) sensitivity to B and U235.

Conditions a) and b) were verified within the experimental error (as 1σ) A/P = 6×10⁻⁵; the measured sensitivities (c) were 0.01 gr B and 0.1 gr U235, respectively.

3C. Null reactivity measurements (reference medium)

Four test samples, with varying B content around the theoretical value for k-inf = 1, were confectioned with compositions as shown in Table 4. The particle mixtures were characterized by their value of B/U235 (in atoms). One notes a small (less than 1%) variation of the total weight of particles contained in the samples, due to a variation of the particles void coefficient (theoretically 0.37 for equal diameter spheres, measured mean value: 0.37).

The determination of the reactivity (better said A/P value) of a test-sample resulted from the performance of two measurements, with the following oscillated element composition:

1) oscillated element with test-sample high, voided-sample low
2) ” " " " " " " " " " " voided " " " " " " " " " "

Subtraction of the results (=A/P) of the two measurements gave A/P (test-sample) − A/P (voided sample), i.e. the reactivity due to the replacement "test-medium vs. void", having eliminated spurious signals (as A/P) from non homogeneities of the oscillated column, sample containers, delayed neutrons (most part of), etc.

The results of the measurements are shown in Fig.5. The values presented are from measurements at 1 W power and oscillation periods of 60, 120 and 240".
One may note that:

a) the experimental error (as evidenced by the flag) is higher for the oscillation period 2:0". this is mainly due to the fact that fewer oscillation periods were recorded and analysed;

b) the alignment of the measured values on the straight lines, drawn by least square best fits, is very good (except for the data at 240" period, coherently with a)), suggesting that the assigned experimental error is perhaps in excess;

c) this alignment gives an almost conclusive evidence that homogeneity, reproducibility and stability of composition of the particle mixtures are satisfactory, i.e. no significant error seems to result from sample composition defects;

d) the linear relationship A/P vs. B/U235 is valid over an extended B/U235 range (at least from 1.7 to 2.4), implying the indication that spectrum perturbations by the samples are not significant, at least in terms of $\sigma_c^u/B/\sigma_f^u$;

e) the spread of the intercepts (B/U235) for varying oscillation periods id very small, with no systematic trend on the oscillation period (this gives some indication that the residual delayed neutron effect should not be important, anyhow a direct experimental determination of this effect will be made); the corresponding uncertainty in the k-inf of the medium with the null-reactivity composition is ±170 pcm, just midway the two a-priori error assumptions (120 pcm min. error, 240 pcm max. error), thus confirming the reliability of the error analysis performed;

f) the sample 01, with 7% lower U235 content (Table 4) fits also well the straight line: this confirms that the parameter B/U235 is correctly chosen to characterize the null reactivity measurements.

3D. Null Reactivity measurements (test medium with Fe)

For these preliminary measurements Fe particles were only added to the test sample in the oscillated element, the composition of the fast zone being unmodified. This was made, either to rapidly obtain preliminary information on the Fe capture, and to have a test for the calculation of the spectrum mismatch correction factor E (see Table 1, eq.3). It is understood that the definitive measurements will be done with the whole fast zone containing Fe.

Following the evidence of the calculation for a good match to the spectrum typical of the "reference" medium with C/U235 = 150 (see section 1), the test sample composition was characterized by C/U235=110 and Fe/C=0.4 (always as atom ratios).
The composition of the four samples oscillated is shown in Table 5. One may note that, due to improved practice, the spread in the void coefficient (or total weight of the sample) is reduced to 0.2% max.

The results of the measurements, carried out at 1 W power and 60" oscillation period, are presented in Fig.6. Again the alignment of the measured values $A/P$ on the straight line resulting from the fit is good. The observation that the slope of the line is close to that of the corresponding line (50" period) through the data for the "reference" medium, could suggest that $(C_{e} / C_{F})^{50\circ}$ has closely the same value in the two cases.

3E. Determination of the oscillated samples composition

The fundamental importance of the accurate knowledge of the medium composition, for the correct interpretation of this kind of measurements, is an established fact.

The oscillated samples are confectioned starting from homogeneous lots of the particles mixture components (fissile, pure graphite, boron loaded graphite, iron).

The analyses, carried out on statistical samples taken from the individual lots, are:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ANALYSIS</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>fissile</td>
<td>$U_{235}/U$ (at %)</td>
<td>+0.02%</td>
</tr>
<tr>
<td></td>
<td>$U$ (wt %)</td>
<td>+3.2%</td>
</tr>
<tr>
<td>boron loaded</td>
<td>$B_{10}/B$ (at %)</td>
<td>+0.2%</td>
</tr>
<tr>
<td>graphite</td>
<td>B (wt %)</td>
<td>+0.2%</td>
</tr>
</tbody>
</table>

Each sample is obtained by:

- weighing the required amounts of the mixture components (e.g. fissile, graphite, boron loaded graphite), with precision +0.01 gr;
- mixing by an air-jet device to achieve an homogeneous mixture, according to a routine established through a previous study (see 1973 Progress Report);
- filling sample container, drying, sealing cover.

By combining the lots analysis data and the mixture components weights, the samples composition is inferred essentially with the precision specified for the above analyses.
To improve the confidence level of the samples composition, after oscillation for the null-reactivity determination, the fissionable particles contained in each sample are separated by the heavy liquids technique (100% efficiency) and the B content of the graphite is measured using a statistical sample taken from the "pure graphite plus boron loaded graphite" phase.

It is noted that the precision by which the samples composition is thus measured is well within the limits assumed for the a-priori error analysis of the experiment (see Progress Report 1972): e.g. the B content is measured to within ±0.2%, vs. the ±0.5% value assumed for the error analysis.

4. SPECTRUM INDEX MEASUREMENTS

4A. Principle of the measurement

A complete mapping (radial and axial) of the fast zone containing the microspores is performed, for each test-medium composition, using miniaturized fission chambers with various spectrum sensitive deposits.

The spectrum indexes thus measured do not enter directly into the resolving equation for the experiment (Table 1, Eq.3), but provide useful information to test the spectrum matching to the asymptotic value, as well as the reliability of the theoretical calculation codes used for the interpretation of the experiment.

The spectrum sensitive deposits are U235, U238, Pu239 and Pu240; the deposits thickness and isotopic composition are listed in Table 6.

The fissionable (Pu240, U239) deposits are spiked with small amounts of fissionable isotopes (Pu239, U235), to normalize the chambers efficiencies (e.g. U238 to U235) by intercalibration in a thermal spectrum. The ratios of the effective (fast zone) cross sections are then inferred from equations of the type

\[
\frac{\bar{\sigma}_f^g}{\bar{\sigma}_f^h} = \left[ \frac{C_f^g}{C_f^h}, \frac{C_{th}^g}{C_{th}^h} - 1 \right] \frac{N^5}{N^8}
\]

where C is the chamber count rate and N^5/N^8 is the atomic ratio for the deposit of the U238 chamber.

Normalization of the Pu239 and U235 chamber efficiencies requires intercalibration in a well known thermal spectrum (e.g. Maxwellian distribution with Westcott parameters T \sim T_{medium} and r \sim 0). Then the ratio of the effective (fast zone) cross sections is

\[
\frac{\bar{\sigma}_f^g}{\bar{\sigma}_f^h} \text{ fast zone} = \frac{C_f^g}{C_f^h} \frac{C_{th}^g}{C_{th}^h} - \frac{C_{th}^g}{C_{th}^h}
\]

being

\[
\bar{\sigma}_{th} = \left[ \frac{g(T)}{g(T) + \alpha L} \frac{1}{T} \right] T_{200} \text{ m/Å}
\]
4B. Thermal column characterization

The thermal spectrum in the thermal column coupled to the RB2 reactor was measured by a standard foil activation method. Am measurement of Pu239, In and Cu activations on the thermal column axis, showed exponential variations, with practically identical exponents for the three different spectrum sensitive detectors (Fig.7), evidencing that the westcott parameters are constant over an extended space interval.

A measurement of the T, r parameters at an intermediate position in the column (by activation of Pu239, In and U235 detectors, normalized by simultaneous irradiation of the same detectors in the thermal well of the E.FERMI reactor at CESNEF, Milan) gave the following values:

<table>
<thead>
<tr>
<th></th>
<th>T (°C)</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB2/TV</td>
<td>24°C</td>
<td>6.9x10^-3</td>
</tr>
<tr>
<td>thermal column</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CESNEF</td>
<td>20°C</td>
<td>5x10^-4</td>
</tr>
<tr>
<td>thermal well</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the WESTCOTT parameters tables for Pu239 and U235 one obtains:

\[
\frac{\sigma_{cii}}{\sigma_{ci}} = 1.283
\]

4C. Instrumentation

The fission chambers used have 1.5 mm outer diameter, 10 mm sensitive height, and are integrated with extension lines, clad by stainless steel, to a total length of about 2000 mm. Electrical insulation is provided by a 0.2-mm-thick teflon tube.

The chambers are introduced in the fast zone through eight 2.2-mm-dia,0.1-mm-thick, axial stainless steel tubes, fixed at various radial positions as shown in Fig.8. Each chamber is connected to its preamplifier, for proper signal transmission to the instrumentation rack. All preamplifiers are intercalibrated to an accuracy of ±0.2%.

The fission chambers scanning and counting system is shown as a block diagram in Fig.9.

Simultaneous scanning of the fast zone by eight chambers is performed through a mechanical device, via a perpetual screw driven by a SLOSNYN stepping motor (vibration free), fed by a 170 Hz pulse generator. Axial positioning of the chambers is accurate to within ±0.1 mm.
The scanning sequence is predetermined by a coded program on punched tape, read via a TELETYPE unit and fed to a digital programming unit, which supplies the required number of pulses to the SLOSYN motor (a 0.4 mm axial displacement corresponds to 100 pulses supplied to the motor).

Punched on the same tape are also the instructions to the digital programming unit, to choose, via a coded selector, the chamber to be counted for a predetermined time. The chamber pulses are fed to a standard amplifier-discriminator-scaler line.

For each chamber counting, the data printed and punched on tape for digital computer analysis are: chamber radial and axial position, counting time, pulses registered by the scaler. The fission chambers pulses (after the amplifier) are also fed to a multichannel analyser - fast printer unit, for more detailed analysis.

The emission spectra of the U235 and Pu239 chambers are shown in Fig.10; the resolution of the gross fission product peak is good. The emission spectrum is the same for chamber exposure to the thermal and fast zone neutron spectra.

4D. Results of measurements

Typical results of measurements of the axial and radial distributions of fissions in the fast zone (preliminary analysis of data) are shown in Fig.11 to 13.

The measurements were performed at 15 axial levels, i.e. over +140 mm from the core midplane (note that the sample height is +50 mm from the midplane), at 30 W reactor power, counting time from 100 s to 500 s. The experimental error for each data point, in terms of 1σ, is typically 1+1.5%.

Fig.11 shows the measured axial distributions of fissions (U235, U238, Pu239, Pu240), normalized to unity at the core midplane. Second degree curves (continuous line) are fitted to the data by the least squares method.

Comparison with the typical error flag r ported in the figure, shows that the data fit the curves within the measurement error.

Also shown are the normalized curves (dotted line) calculated by the chain GAM 2 – ALCI. The agreement between experimental and calculated curves can be considered good for all isotopes. Note that the distributions are flat over the test sample height (+50 mm from the midplane).
Shown in Fig. 12 are the measured and calculated spectrum index distributions inferred from the data of Fig. 11. Again the curves are flat and the agreement between experiment and theory is good.

The measured and calculated (GAM 2 - Alci) radial distributions of fissions, normalized to unity on the core axis, are shown in Fig. 13. One notes that the curvature of the distributions is higher and that some discrepancy between measurement and theory appears toward the outer boundary of the fast zone.

Absolute values for the experimental indexes \( \left( \frac{<2_{2}}{<2_{1}} \right) \) as inferred from the fission chambers count rates at the fast zone center and in the thermal column (preliminary results), are given in Table 7 and compared with values calculated by the GAM 2 - Alci and MC2 - ANISN chains.

The measured values lie within the range of calculated values produced by the two calculation schemes, but at this stage the comparison must be considered only as indicative. A study of the sensitivity of the considered spectrum indexes to neutron energy spectrum variations, in the present fast zone configuration, is underway.

5. MEASUREMENT OF \(^{13}C\) CAPTURE/U235 FISSION IN THE TEST SAMPLE

5A. Instrumentation and experimental technique

The measured quantity \(^{13}C\) capture/U235 fission in the test sample is directly entered into the resolving equation of the experiment (Table 1, Eq. 3) and its uncertainty is the main source of error in the experiment (ref.1972 Progress Report).

The measurement is made by B coated, resp. U235 coated, chambers with following characteristics:

- deposit thickness: 50 \( \mu g/cm^2 \)
- isotopic composition: \(^{13}C\) 90\%, resp. U235 93.2\%
- chambers structural material: zirconium
- chambers outer dia.: 4 mm
- sensitive part height: 10 mm

The chambers are connected through integrated extension lines (1.5-mm-dia., 1900-mm-long, clad by stainless steel) to SChLUMBERGER fast response preamplifiers, for correct pulse shaping and transmission (a requirement for the B coated chambers). The following components of the counting line are common to those used in connection with the 1.5-mm-dia fission chambers (ref. section 4).
The chambers are placed at the center of a test sample, identical to the sample used for the null reactivity determination, but provided with a 5-mm-inner diameter, 0.1-mm-thick stainless tube on its axis. The chamber integrated extension line goes inside a 2.2-mm-dia, 0.1-mm-thick tube, through the axis of the upper section of the central fuel element.

Electrical insulation is provided by two thin teflon rings at the ends of the chamber (away from the sensitive zone) and a 0.2-mm-thick teflon tube covering the extension line. Each chamber is counted alternatively at the test sample center and at an accurately reproducible position in the thermal column coupled to the RR2/TV reactor.

The chamber counting is normalized to the simultaneous measurement of the count rate of a 1.5-mm-dia, U235 fission chamber placed at a fixed position in the thermal column. Due to the high counting statistics (up to 2,500,000 pulses collected) and the use of very stable components for the counting line, the error introduced by this normalization is insignificant.

Neutron capture by B10 yields a Li7 nucleus and an alpha particle. Owing to the relatively low energy of the emitted particles, high amplification and accurate pulse shaping is required for an effective discrimination from background noise. In addition parasite reactions (n,p type, by high-energy neutrons) with the chamber wall and gamma pile-up occur and must be accounted for.

To this effect the count rate of dummy chambers (i.e., without the B deposit) is measured and properly subtracted from the B chambers count rates. A typical emission spectrum of the B chamber, as measured in the thermal column, is shown in Fig.14. The resolution of the Li7 (left) and alpha peaks is satisfactory.

The measurement yields the ratio of the effective cross sections, averaged in the fast zone spectrum, as:

$$\frac{C_{B10}^{B}}{C_{Th}^{B}} \cdot \frac{C_{Th}^{U}}{C_{Th}^{U}} \cdot \frac{C_{Th}^{B}}{C_{Th}^{B}} \cdot \frac{C_{Th}^{O}}{C_{Th}^{O}}$$

where C is the chamber count rate normalized to the monitor count rate and corrected for dead time, flux depression, self-shielding, etc. For the actual thermal column conditions

$$\left(\frac{C_{Th}^{B10}}{C_{Th}^{U}}\right) = 6.65$$

(ref. section 4B).

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The quantity to be introduced in the resolving equation of the experiment (Table 1, eq.3), namely "$^{310}$ capture/$^{235}$ fission" in the test sample, is obtained as

$$\left(\frac{C_{310}}{C_{235}}\right) = \left(\frac{N_{310}}{N_{235}}\right) \left(\frac{N_{235}}{N_{238}}\right)$$

where $\left(\frac{N_{310}}{N_{235}}\right)$ is the measured value (as atoms ratio) for the "null reactivity" test sample composition (ref. section 3B).

5B. Measurements and results

Measurements were done in the following test samples at the fast zone center:

1. Test sample containing the reference medium with "null reactivity" composition;
2. Test sample containing the test medium with Fe ($C/U_{235} = 110$, Fe/C = 0.4) with "null reactivity" composition;
3. Test sample voided.

Auxiliary measurements were carried out to determine:

A. dead time of the chambers (relative to the monitor);
B. flux perturbation caused by the 0.1-mm-thick steel tube containing the chambers placed in the test sample;
C. effect of uncertainty in the position of the chamber, when placed in the thermal column, on chamber count rate.

A. The dead time of the chambers was inferred from measurements of normalised count rates of the chambers placed in the thermal column, at four different reactor powers, namely 30, 20, 10 and 5 W.

The values obtained: for the B chambers $\tau = 3 + 0.3 \mu s$; for the U235 chambers, $\tau = 2 + 0.2 \mu s$.

B. The effect of the flux perturbation by the 0.1-mm-thick steel tube around the chamber in the test sample on the chamber count rate was inferred by extrapolation of the count rates measured with the chamber surrounded by an additional 0.2-mm-thick stainless steel layer.

The correction factors obtained were equal to unity, within the experimental error limits.

C. The effect on the chamber count rate of the uncertainty of its axial position in the thermal column was determined by a series of measurements made at 5 different positions (nominal position, $+2 \text{ mm}$, $+4 \text{ mm}$, $-2 \text{ mm}$, $-4 \text{ mm}$).
The measured effect was 0.4% per mm displacement. Since the actual uncertainty in the chamber position was ±0.2 mm, the corresponding count rate uncertainty was limited to ±0.1%.

The results of measurements 1, 2 and 3 (preliminary analysis of data) are presented in Table 3. The values given include corrections for chamber dead time, flux perturbation by containment tube in test-sample, self-shielding of chamber deposit (significant for chamber placed in thermal column), flux depression around chamber (significant in thermal column), Westcott T, r parameters measured in the thermal column, background of (n,p) and (n,γ) reactions with the B10 chamber walls (as measured by the dummy chamber).

The evaluation of the chamber self-shielding and flux depression correction factor, applied to the values of Table 3, is a very preliminary one. An accurate transport calculation, as well as a direct experimental determination of these corrections, are underway.

At the present stage of the data analysis, the uncertainty of the results presented in Table 3 is roughly estimated as ±2%.

One can note that the results of measurements 1 and 2 ("reference" medium and test-medium with Fe) are quite close; this fact tends to confirm the validity of the choice C/U235 = 110 for the test-medium with Fe (see section 1B).

6. ADDITIONAL REMARKS ON THE THEORETICAL CALCULATION FOR THE INTERPRETATION OF THE EXPERIMENT

Mainly to test either the nuclear data files and the ground-cross sections generation codes, a series of k-inf calculations was performed, using the ENDF/B3 (ENDF/B1 for Fe, since recent comparisons suggest that the version 1 data for Fe are better) and UNDL files, with the GAM2, MC2 and PRAVDA cross section averaging codes. k-inf was calculated for both the reference medium and the test medium with Fe.

The results presented in Table 9, are in very good agreement (within some hundred pcm) for the reference medium, with the exception of the values obtained by GAM 2 (confirming that this code is not adequate).
Significant discrepancies are instead observed among the k-inf values calculated for the test-medium with Fe, likely owing to the large uncertainty in the Fe cross-section data. Reported below is a comparison between k-inf calculations by the ENDF/B3 - MC2 - ANISN chain and CARNAVAL 3 (CEA, France).

<table>
<thead>
<tr>
<th></th>
<th>C/U235=150</th>
<th>C/U235=110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe/C=0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENDF/B3</td>
<td>1.011</td>
<td>1.049</td>
</tr>
<tr>
<td>MC2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANISN</td>
<td>1.012</td>
<td>1.021</td>
</tr>
<tr>
<td>CARNAVAL 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Again, one notes excellent agreement for the reference medium and a large discrepancy for the medium with Fe. On the basis of the above evidence, the ENDF/B3 (B1 for Fe)-MC2 chain was chosen to obtain the group-cross sections used in the calculations for the interpretation of the experiment.

The calculated quantities and correction factors entered into the resolving equation of the experiment (Table 1, eq.3) are inferred mainly by 27-group ANISN calculations (with group-bucklings obtained through a fit to the 10-group axial flux distributions calculated by ALCI).

The correction E (flux mismatch and leakage effects) is calculated following the OLDEKOP perturbation formalism, in diffusion, 2 dimensions, using $\Phi$ and $\Phi^2$ values (10 groups) generated by ALCI calculations. A one-dimension transport calculation (27-groups, perturbative) by the DTFTV-DACI codes is now operative and is being compared with the above scheme for the determination of the correction factor E.
7. CONCLUSION

The report on the status of the experiment, updated to April 15th, 1975, is concluded at this point. Aim of the report was to put in evidence how the experimental techniques, equipments and procedures, required to supply the data used to infer the final experimental result (see Table 1, eq.3) were developed, tested and put into operation.

Typical results of a complete series of measurements have also been presented, but it is stressed that the data reduction and analysis yielding the above results are in general preliminary and not complete.

On the whole, the results obtained were considered satisfactory, both from the point of view of the internal consistency of the data and of the correspondence between the experimental error values found and the a-priori values assumed in the error analysis established for the assessment of the main experimental parameters. The interpretation of the results (e.g. solution of eq.3, Table 1) requires a careful revision of either the experimental and calculated quantities introduced in the equation, which is underway (dated April 15th, 1975).

The program of the RB2/TV work in 1975 foresees the performance of complete sets of measurements, as described in this report, for

- fast zone and test-sample containing Fe particles (likely with test-samples with varying Fe content and C/U235 values)

- fast zone containing Fe particles and test-sample containing Ni particles (likely with varying Ni content and C/U235 values)

- similar configurations with test-samples containing stainless steel and Cr particles.
### APPENDIX

#### 1. COATED PARTICLE CHARACTERISTICS

##### A. FISSILE PARTICLES

<table>
<thead>
<tr>
<th>Materials</th>
<th>$\text{UO}_2$ kernels coated by pyrocarbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kernel dia.</td>
<td>$606 \pm 5 \mu$</td>
</tr>
<tr>
<td>&quot; density</td>
<td>$10.52%$</td>
</tr>
<tr>
<td>&quot; $\text{U}$ content</td>
<td>$83.15%$</td>
</tr>
<tr>
<td>Isotopic composition</td>
<td>$\text{U}^{234}$ 0.740</td>
</tr>
<tr>
<td>(wt %)</td>
<td>$\text{U}^{235}$ 93.16$\pm$0.02</td>
</tr>
<tr>
<td></td>
<td>$\text{U}^{238}$ 5.82</td>
</tr>
<tr>
<td>Impurities (kernel)</td>
<td>B 0.2 ppm</td>
</tr>
<tr>
<td></td>
<td>Cl 60</td>
</tr>
<tr>
<td></td>
<td>F 10</td>
</tr>
<tr>
<td></td>
<td>Al 18</td>
</tr>
<tr>
<td></td>
<td>Fe 170</td>
</tr>
<tr>
<td>Coating thickness</td>
<td>$200 \pm 4 \mu$</td>
</tr>
<tr>
<td>&quot; density</td>
<td>$1.7 \pm 0.02$</td>
</tr>
<tr>
<td>Particle diameter</td>
<td>$1003 \pm 9 \mu$</td>
</tr>
<tr>
<td>&quot; density</td>
<td>$3.67 \pm 0.06$</td>
</tr>
<tr>
<td>&quot; $\text{U}$ content</td>
<td>$55.59%$</td>
</tr>
<tr>
<td>&quot; $\text{H}_2$ content</td>
<td>$8\text{ ppm}$</td>
</tr>
<tr>
<td>Total weight $\text{U}$</td>
<td>$10,138$ kg</td>
</tr>
</tbody>
</table>

##### B. GRAPHITE PARTICLES

<table>
<thead>
<tr>
<th>Materials</th>
<th>Graphite kernel coated by pyrocarbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia.</td>
<td>$1020 \pm 70 \mu$</td>
</tr>
<tr>
<td>Density</td>
<td>1.322</td>
</tr>
<tr>
<td>Purity</td>
<td>Nuclear grade</td>
</tr>
<tr>
<td>$\text{H}_2$ content</td>
<td>100 ppm</td>
</tr>
<tr>
<td>Total weight</td>
<td>33 kg</td>
</tr>
</tbody>
</table>

##### C. BORON LOADED GRAPHITE PARTICLES

<table>
<thead>
<tr>
<th>Materials</th>
<th>Graphite kernel containing $\text{B}_4\text{C}$ coated by pyrocarbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia.</td>
<td>$1020 \pm 70 \mu$</td>
</tr>
<tr>
<td>Density</td>
<td>1.553</td>
</tr>
<tr>
<td>$\text{B}$ content</td>
<td>$4.53 \pm 0.01%$</td>
</tr>
<tr>
<td>Purity</td>
<td>Nuclear grade</td>
</tr>
<tr>
<td>$\text{H}_2$ content</td>
<td>100 ppm</td>
</tr>
<tr>
<td>Total weight</td>
<td>30 kg</td>
</tr>
</tbody>
</table>
2. CORE LOADING AND SAFETY TESTS

A. TEST ZONE LOADING

- Fissile particles: 9.55 kg (U235 5 kg)
- Graphite particles: 23.9 kg
- Boron loaded
  - Graphite particles: 11.4 kg

B. BUFFER ZONE FUEL LOADING

- Fuel plates: 120
  - U235: 28.52 kg

C. DRIVER ZONE LOADING

- Fuel plates: 224
  - U235: 3.8 kg

D. SUMMARY OF SAFETY TESTS

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Effect measured (pcm)</th>
<th>Safety limit (pcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control rods insertion</td>
<td>2150</td>
<td>≥ 1600</td>
</tr>
<tr>
<td>Cold clean core excess reactivity</td>
<td>180 (at 20°C)</td>
<td>≤ 500</td>
</tr>
<tr>
<td>Void coefficient of driver zone</td>
<td>-0.17/cm³</td>
<td>≥ -0.15/cm³</td>
</tr>
<tr>
<td>Fast water dump from driver zone</td>
<td>8500</td>
<td>≥ 6000</td>
</tr>
</tbody>
</table>

EUR/C/IS/319/75 e
Table 1 - Resolving equations for the experiment

\[
K_{-\inf_1} = \frac{1}{1 - E_1} = \left\{ \frac{\left( V_i F_i + V_i F_i^B \right)}{\left( F_i + F_i^B + C_i + C_i^B + C_i + C_i^B \right)} \right\}_{\text{infinite medium spectrum}}
\]  

(1)

\[
K_{-\inf_2} = \frac{1}{1 - E_2} = \left\{ \frac{\left( V_2 F_2 + V_2 F_2^B \right)}{\left( F_2 + F_2^B + C_2 + C_2^B + C_2 + C_2^B \right)} \right\}_{\text{inf.}}
\]  

(2)

\[
R^B_{R_2} = \frac{C_2}{F_2} = \left\{ \frac{V_2 F_2 + F_2^B + V_2 F_2^B}{V_2 + F_2 + V_2 F_2^B} \right\} \left( 1 + \frac{F_2}{F_2^B} + \alpha_1^B + R_1 + R_1^B \right) - \left( 1 + \frac{F_2}{F_2^B} + \alpha_2^B + R_2 + R_2^B \right) \right\}_{\text{inf.}}
\]  

(3)

with: \( R = C/F^5 \)

**Measured quantities:** null reactivity compositions, \( R_1, R_2, (F_1/F_1^B), (F_2/F_2^B), R_1, R_2 \)

**Calculated quantities:** \( E_{1/2}, V_{1/2}, \alpha_{1/2}, \gamma_{1/2} \)

**Calculated conversion factors:** \( (R_{1\infty}/R_{1\text{loc.}}), (R_{2\infty}/R_{2\text{loc.}}), \text{etc.} \)
TABLE 2: COMPARISON OF SPECTRUM INDEXES

calculation by (ENDF/B-3 - PRAVDA - ANISN (27g))
test medium \( C/U235 = 150 \) \( Fe/C=0 \)

<table>
<thead>
<tr>
<th>neutron spectrum</th>
<th>( C^B_{/Pu235} )</th>
<th>( P^U238_{/Pu235} )</th>
<th>( P^Pu239_{/Pu235} )</th>
<th>( P^Pu240_{/Pu235} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>asymptotic</td>
<td>2.059</td>
<td>0.0128</td>
<td>1.020</td>
<td>0.0922</td>
</tr>
<tr>
<td>local (center)</td>
<td>2.058</td>
<td>0.0124</td>
<td>1.011</td>
<td>0.0940</td>
</tr>
</tbody>
</table>

NB. The values are in terms of microscopic cross-sections.
TABLE D : RESULTS OF CALCULATIONS TO MATCH THE TEST-MEDIUM TO THE REFERENCE MEDIUM ASYMPOTIC SPECTRUM

<table>
<thead>
<tr>
<th></th>
<th>C/U = 150</th>
<th>C/U = 110</th>
<th>( \frac{X}{X_0} )</th>
<th>C/U = 120 Fe/C = 0.5</th>
<th>( \frac{X}{X_0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_Y^s )</td>
<td>5.103</td>
<td>4.934</td>
<td>0.967</td>
<td>5.155</td>
<td>1.010</td>
</tr>
<tr>
<td>( \alpha_C^s )</td>
<td>2.252</td>
<td>2.168</td>
<td>0.953</td>
<td>2.296</td>
<td>1.019</td>
</tr>
<tr>
<td>( \alpha_F^s )</td>
<td>0.441</td>
<td>0.439</td>
<td>0.995</td>
<td>0.445</td>
<td>1.009</td>
</tr>
<tr>
<td>( \frac{\sigma_{Y_{\infty}}}{\tau} )</td>
<td>10.839</td>
<td>10.257</td>
<td>0.947</td>
<td>10.884</td>
<td>1.004</td>
</tr>
<tr>
<td>( \alpha_{Y_{\infty}}^s )</td>
<td>0.0158</td>
<td>0.0144</td>
<td>0.911</td>
<td>0.0149</td>
<td>0.943</td>
</tr>
<tr>
<td>( \alpha_C^s )</td>
<td>0.0575</td>
<td>0.0408</td>
<td>0.709</td>
<td>0.0398</td>
<td>0.592</td>
</tr>
<tr>
<td>( \frac{\alpha_{Y_{\infty}}^s}{\alpha_C^s} )</td>
<td>0.0113</td>
<td>0.0083</td>
<td>0.733</td>
<td>0.0078</td>
<td>0.533</td>
</tr>
<tr>
<td>( \sigma_C^s )</td>
<td>2.540</td>
<td>2.547</td>
<td>0.985</td>
<td>2.783</td>
<td>1.054</td>
</tr>
<tr>
<td>( \frac{\sigma_{Y_{\infty}}^s}{\sigma_C^s} )</td>
<td>0.517</td>
<td>0.516</td>
<td>0.998</td>
<td>0.540</td>
<td>1.044</td>
</tr>
<tr>
<td>( \sigma_{\infty} )</td>
<td>1.01084</td>
<td>1.04886</td>
<td>1.0376</td>
<td>1.01098</td>
<td>1.0001</td>
</tr>
</tbody>
</table>
### TABLE 4: COMPOSITION OF OSCILLATED SAMPLES

**Test medium:** \( C/U_{235} = 150 \quad Fe/C = 0 \)

<table>
<thead>
<tr>
<th>Sample (n)</th>
<th>Microspheres weights (gr)</th>
<th>Graphite with B</th>
<th>Fissile</th>
<th>( U_{235} )</th>
<th>B</th>
<th>Atom ratios B/( U_{235} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>264.18 143.37</td>
<td>67.74</td>
<td>53.07</td>
<td>27.52</td>
<td>3.069</td>
<td>2.544</td>
</tr>
<tr>
<td>02</td>
<td>263.13 139.91</td>
<td>66.76</td>
<td>56.47</td>
<td>29.28</td>
<td>3.024</td>
<td>2.356</td>
</tr>
<tr>
<td>03</td>
<td>267.28 149.65</td>
<td>60.00</td>
<td>57.33</td>
<td>29.88</td>
<td>2.718</td>
<td>2.075</td>
</tr>
<tr>
<td>04</td>
<td>264.62 155.62</td>
<td>51.68</td>
<td>57.32</td>
<td>29.72</td>
<td>2.341</td>
<td>1.797</td>
</tr>
</tbody>
</table>

### TABLE 5: COMPOSITION OF OSCILLATED SAMPLES

**Test medium:** \( C/U_{235} = 110 \quad Fe/C = 0.4 \)

<table>
<thead>
<tr>
<th>Sample (n)</th>
<th>Microspheres weights (gr)</th>
<th>Graphite with B</th>
<th>Fissile</th>
<th>( U_{235} )</th>
<th>B</th>
<th>Atom ratios B/( U_{235} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Fe ) 1</td>
<td>535.65 103.52</td>
<td>49.41</td>
<td>59.54</td>
<td>323.38</td>
<td>30.87</td>
<td>2.238 1.954</td>
</tr>
<tr>
<td>( Fe ) 2</td>
<td>533.55 95.13</td>
<td>57.27</td>
<td>59.12</td>
<td>321.03</td>
<td>30.55</td>
<td>2.594 1.931</td>
</tr>
<tr>
<td>( Fe ) 3</td>
<td>534.40 92.81</td>
<td>51.33</td>
<td>59.12</td>
<td>321.09</td>
<td>30.55</td>
<td>2.780 2.070</td>
</tr>
<tr>
<td>( Fe ) 4</td>
<td>534.62 99.40</td>
<td>65.42</td>
<td>59.05</td>
<td>320.75</td>
<td>30.61</td>
<td>2.963 2.209</td>
</tr>
</tbody>
</table>
TABLE 5: MISSISSIPPI CHAMBERS DEPOSITS

<table>
<thead>
<tr>
<th>chambers type</th>
<th>deposit thickness (ug/cm²)</th>
<th>isotopic composition (at %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U234</td>
<td>U235</td>
</tr>
<tr>
<td>U235</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U238</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pu239</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Pu240</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 7: COMPARISON OF MEASURED AND CALCULATED SPECTRUM INDEXES

<table>
<thead>
<tr>
<th>values of average fission cross-sections at center of fast zone of PWR</th>
<th>Pu239</th>
<th>Pu238</th>
<th>Pu240</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDF/B3 - PRAVDA - ANISN</td>
<td>0.927</td>
<td>0.0131</td>
<td>-</td>
</tr>
<tr>
<td>ENDF/B3 - GAM 2 - ALCI</td>
<td>1.010</td>
<td>0.0124</td>
<td>0.0940</td>
</tr>
</tbody>
</table>

EUR/C/18/319/75 e
### TABLE 8: RESULTS OF MEASUREMENTS OF $\frac{\lambda_{\mathrm{C}}}{\lambda_{\mathrm{Fe}}}$ IN THE TEST SAMPLE

<table>
<thead>
<tr>
<th>test sample composition</th>
<th>measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathrm{C}, \mathrm{U}_{235}=150$</td>
<td>2.27</td>
</tr>
<tr>
<td>$\mathrm{Fe}/\mathrm{C} = 0$</td>
<td></td>
</tr>
<tr>
<td>$\mathrm{C}, \mathrm{U}_{235}=110$</td>
<td>2.26</td>
</tr>
<tr>
<td>$\mathrm{Fe}/\mathrm{C} = 0.4$</td>
<td></td>
</tr>
<tr>
<td>void</td>
<td>2.27</td>
</tr>
</tbody>
</table>

### TABLE 9: COMPARISON OF K-INF CALCULATED VALUES

<table>
<thead>
<tr>
<th>data file</th>
<th>averaging method</th>
<th>k-inf code</th>
<th>$\mathrm{C}/\mathrm{U}_{235}=150$ $\mathrm{Fe}/\mathrm{C}=0.0$</th>
<th>$\mathrm{C}/\mathrm{U}_{235}=110$ $\mathrm{Fe}/\mathrm{C}=0.5$</th>
<th>$\mathrm{C}/\mathrm{U}_{235}=150$ $\mathrm{Fe}/\mathrm{C}=0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDF/B-2</td>
<td>GAM-2</td>
<td>ANISN</td>
<td>1.0147</td>
<td>0.9969</td>
<td>1.0015</td>
</tr>
<tr>
<td>ENDF/B-3</td>
<td>GAM-3</td>
<td>id</td>
<td>1.0197</td>
<td>0.9937</td>
<td>0.9963</td>
</tr>
<tr>
<td>id</td>
<td>PRATVA</td>
<td>id</td>
<td>0.9873</td>
<td>1.0150</td>
<td>1.0281</td>
</tr>
<tr>
<td>id</td>
<td>MC-2</td>
<td>id</td>
<td>1.0013</td>
<td>0.9970</td>
<td>1.0009</td>
</tr>
<tr>
<td>id</td>
<td>MC-2 II</td>
<td>MC-2 II</td>
<td>0.9947</td>
<td>-</td>
<td>1.0219</td>
</tr>
<tr>
<td>UK-3</td>
<td>PRATVA</td>
<td>ANISN</td>
<td>0.9749</td>
<td>1.0022</td>
<td>1.0095</td>
</tr>
</tbody>
</table>

(1) $\mathrm{Fe}$ cross-sections from ENDF/B-1

(2) $\mathrm{Fe}$ is as 0.4-mm-dia. wire

EUR/C/IS/319/75 e
Fig. 3
Density Distribution Curves of Graphite Microspheres

pure graphite
boron loaded graphite

[\%]

[9/cm^3]
Fig. 5

$A/P$ vs. $B/U_{235}$

Test medium: $c/U_{235} = 150$
$Fe/C = 0$

$A/P \times 10^{-3}$

Sample

$B/U_{235}$

$T = 60^\circ$
$T = 120^\circ$
$T = 240^\circ$
Fig. 6

A/p vs. B/U235

Test medium C/U235 = 110, Fe/C = 0.4

Oscillation period: 60 s

Reactor Power: 1 W
Axial distribution of activations measured in the RB2/TV Thermal Column.

\[ A(z) = A_0 e^{-\frac{z}{\gamma}} \]

\[
\gamma_{In} = -3.617 \times 10^{-2} \pm 1.3\% \text{ cm}^{-1}
\]

\[
\gamma_{U235} = -3.638 \times 10^{-2} \pm 1.5\% \text{ cm}^{-1}
\]

\[
\gamma_{Pu239} = -3.580 \times 10^{-2} \pm 0.15\% \text{ cm}^{-1}
\]
Radial arrangement of Fission chambers in fast zone
Fig. 9  Fission chambers counting system
FIG. 10 TYPICAL EMISSION SPECTRA OF THE U235 AND PU239 MINIATURIZED FISSION CHAMBERS.
Fig. 11 Axial distributions of fissions

ENDF/B-3-ASM-ALC1
Measured
--- Calculated

Fig. 12 - Axial distributions of spectrum indexes
Fig. 13
Radial distribution of fissions

- Measured
- Calculated

(ENEFB - GAMMA - ALG)

Pu 240
U 238
Pu 239
U 235

Axis: Reactor

140 Radius (mm)

Channel

5 6 7 8 9 10 11 12
FIG. 14 TYPICAL EMISSION SPECTRUM OF THE B10 CHAMBER