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Institut für Angewandte Reaktorphysik
Institut für Neutronenphysik und Reaktortechnik

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COMPARISON OF MEASUREMENTS IN SNEAK-1 AND ZPR III-41*

L. Barleon, R. Böhme, K. Böhnel, M. Edelmann, P. Engelmann, G. Fieg, F.W.A. Habermann+, D. Kuhn, W. Mayer++, W. Seifritz, D. Stegemann, P.L. van Velze+, H. Walze, H. Werle

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1. INTRODUCTION

The fast critical facility SNEAK was built to support basic research in fast reactor physics and to investigate mock ups of designed fast breeder reactors. Its first assembly, called SNEAK-1, became critical on December 15, 1966. SNEAK-1 was chosen to be similar to a well-known critical. The Argonne built ZPR III Assembly No. 41 was selected, since it was convenient in size and composition.

1.1 Description of SNEAK

A general description of SNEAK was given in Ref. /1/. A few items should be repeated here. The machine is composed of square stainless steel elements, each 275 cm long, hanging in an upper grid plate with a lattice spacing of 5.44 cm. In the outer region aluminium tubes, each with the cross section of 9 of the central elements, are used. Platelets of the size 5.07 x 5.07 x 0.31 cm^3 are used to built the core, rods of 1.7 x 1.7 x 30.5 cm^3 compose the blanket. The fuel sections of the control and shim rods contain the same materials as the surrounding core. In the shut-down condition the fuel section is replaced by a poison part containing boroncarbide powder and/or B_4C dispersed in a resin.

1.2 Core configuration

To make SNEAK-1 as similar as possible to Assembly 41 of ZPR III one could not construct a simple unit cell within the fuel tubes. The regular element was filled with a stack of the following composition:

36 platelets of natural uranium
52 platelets of 20% enriched uranium
24 platelets of 35% enriched uranium
140 platelets of aluminium with 40% natural density
24 platelets of stainless steel (SS).

The total height of this stack of platelets was 86.9 cm. On top of and below this core region a reflector of 30.5 cm thickness was constructed of depleted uranium rods (0.4% ^{235}U). With this arrangement of the core region uniformity in composition could be achieved with cells having a volume of approximately 600 cm^3. A typical sequence of platelets in the stack is shown in fig. 1. A horizontal cross section through the core and the radial reflector (depeleted uranium, reflector thickness about 30 cm) is sketched in fig. 2.

The average atom densities of all elements in the core and reflector regions are given in Table I. Also included are the data of ZPR III Ass. No 41. The average uranium enrichment within the core was 17.2%. The volume fractions in the core were (in YOM-densities)

5.8% ^{235}U
28.3% ^{238}U
14.2% stainless steel
17.0% Al
and 34.6% void.

In the blanket were 84.6% depleted uranium (0.4% ^{235}U), 6.8% steel and 8.6% void.

1.3 General remarks

In the following sections most experimental data are compared with calculations. All experimental data were converted to $\Delta k/k$ assuming an effective delayed neutron fraction of $\beta_{eff} = 7.1 \times 10^{-3}$ (cf. section 3.2.3.3).

The multigroup cross sections used are abbreviated in the following way:

YOM : a 16-group cross section set published by Yiftah et al. /2/

ABN : a 26-group set with self-shielding corrections published by Abagjan et al. /3/.
Within each energy group the flux per unit lethargy used for weighting was assumed constant.

KFK : a 26-group set similar to ABN, but using a typical spectrum of a fast sodium cooled breeder reactor for weighting. The cross sections of structural materials differ considerably from ABN /4/.

In a few cases ANL-results obtained with ELMOE /5/ and ANL 635 /6/ are listed.

Results of the Argonne Group are taken from references /6/ - /10/.

The Karlsruhe results were calculated with the multiphase computer code NUSYS.

A reproducibility index ϱ is defined:

$$\varrho = \frac{A^{Ass.41}_{exp.}}{A^{Ass.41}_{calc.}} \cdot \frac{A^{SNEAK-1}_{calc.}}{A^{SNEAK-1}_{exp.}}$$

where A may be any quantity obtained by experiments and calculations using identical methods and cross section sets. In most cases, this index depends only negligibly on the cross section set used for the calculation. It eliminates the influence of the differences in composition of the assemblies compared. ϱ is a measure of the reliability of the quoted results and errors. If ϱ is not unity within the error limits, one has to assume an inconsistency in the experimental results.

2. CRITICAL MASS

SNEAK-1 was constructed as shown in figs. 1 and 2. The assembly reached criticality with 181 fuel elements in the core region. The critical core volume was then 465.5 l with one control rod partially inserted. The height of the cylindrical core was 86.9 cm, the diameter approximately 82.6 cm.

Without any correction the critical mass was determined to be 510.1 $\pm$0.5 kg ^{235}U, the error arising mainly from the uncertainty in the determination of the isotopic composition of uranium. The critical mass quoted for Assembly 41 of ZPR III was 490.4 kg ^{235}U.

In order to allow a comparison of the critical masses, a reduction to the critical mass of a homogeneous clean critical sphere is carried out. The corrections applied are given in Table II.

2.1 Correction for the irregular core outline

Due to the plate and matrix structure of SNEAK the circumference of the core is not exactly cylindrical. A correction was determined by substituting edge elements of the core by blanket elements. The reactivity value of an edge element at a radius of 41.3 cm was measured to be $(9.9 \pm 0.1)\ 10^{-4}\ \Delta k/k$, the calculated value was $(9.1 \pm 0.2)\ 10^{-4}\ \Delta k/k$, independent of the cross section set used. This value decreased by $(9.0 \pm 1.5)\%$ per cm increase in the average radial position of a core element. From these values could be deducted that an ideal cylindrical core would contain (3.2 ± 0.8) kg ^{235}U less than the real one. This correction is eight times larger than the one quoted by the Argonne authors. A similar discrepancy was already found by G. Ingram et al. /11/.

2.2 Correction for the partially inserted control rod

For the fully inserted control rod a supercriticality of 13 ¢ was determined by period measurement. Using the ratio $\Delta M/M : \Delta k/k = 5.6 \pm 0.1$ for the fuel worth at the core boundary a correction of (2.3 ± 0.1) kg ^{235}U was found, by which the ideal core is smaller than the real one. In addition to this a correction of 0.3 kg ^{235}U had to be applied because a few elements contained fission chambers and a neutron source canal; these elements were later replaced by regular ones.

So far a corrected critical mass of (504.9 ± 1.0) kg was obtained, were the uncertainties in the measured value and in the individual corrections were added statistically. In this figure heterogeneity corrections are not included.

2.3 Heterogeneity corrections

Heterogeneity experiments were not carried out at SNEAK-1. An estimate was made based on data published for ZPR III Ass. No 41 /10/. For Assembly No 41 an increase in reactivity of 330 Ih $\approx 0.75\%$ k/k going from the homogeneous assembly to 93% enriched uranium metal platelets of 0.32 cm thickness was found by extrapolating measurements with different plate thicknesses. The platelets used in SNEAK have the same thickness but different enrichment: 58.8% of the fissile material is contained in platelets of 20% enrichment and 41.2% in platelets of 35% enrichment. For this reason only a fraction of the heterogeneity effect as determined for ZPR III Ass. 41 was assumed for SNEAK-1.

$$\left(\frac{\Delta k}{k}\right)_{het} \approx \left(\frac{0.20}{0.93} \cdot 0.588 + \frac{0.35}{0.93}\, 0.412\right) \cdot 0.75\% \, \frac{\Delta k}{k} = 0.21\% \, \frac{\Delta k}{k},$$

which corresponds to 5.9 kg ^{235}U added at the circumference of the core. Because this estimate assumes heterogeneity effects to be proportional to the ^{235}U concentration only and neglects the influence of the ^{238}U diluent this figure may be in error by as much as 30%. When it is used, the critical data of the homogeneous cylinder are found to be

$$\begin{aligned} m_{hom,cyl.} &= (510.8 \pm 2.5) \text{ kg } ^{235}U \\ V_{hom,cyl.} &= 466.1 \text{ l} \\ H &= 86.9 \text{ cm} \\ D &= 82.6 \text{ cm}. \end{aligned}$$

2.4 Shape factor correction

The shape factor method was used to obtain from the measured results the critical mass of a homogeneous sphere of SNEAK-composition. With data taken from Ref. /12/, the shape factor SF = 0.91 $\pm$0.005 was found. A 6 group, two-dimensional calculation yielded a shape factor 0.917 $\pm$0.006, but to be consistent with ANL the first value was taken. The final corrected critical mass of a homogeneous spherical

core with SNEAK-1 composition was found to be

$$m_{hom.sphere} = 465 \pm 4 \text{ kg}^{235}\text{U}.$$

2.5 Comparison with the ZPR III Ass. 41 critical mass

With each of the cross section sets used, calculations of the critical mass in spherical geometry gave for Ass. 41 a 1.65% lower value than for SNEAK-1. According to the experimental results at SNEAK the critical mass of Ass. 41 therefore should have been 457 ± 4 kg ^{235}U. The comparable figure quoted by ANL is 462 kg ^{235}U, in good agreement with the Karlsruhe experiment, if one assumes an equivalent uncertainty for the Argonne result. The agreement becomes even better, if the correction for irregular core outline of Ass. 41 is increased to the SNEAK-1 value. In Table III experimental and calculated critical masses are compared.

3. EXPERIMENTAL RESULTS

3.1 Spectral measurements

3.1.1 Proton recoil counter

The neutron spectrum in a central cavity of the SNEAK-1 core was measured with spherical proton recoil counters. To keep the dead time corrections below 20% the reactor was made subcritical by $\Delta k/k \approx -3.5 \times 10^{-4}$. The deadtime corrections were determined with the life timer of the analyser. For the energy region 10 - 60 keV Bennett's /13/ γ-n discrimination method was used. Measurements in the energy range above 60 keV were made without γ-discrimination using four counters containing different gas fillings (1 atm. H_2, 2 atm. H_2, 4 atm. H_2, 2.5 atm. CH_4). The spherical counters were made of 0.5 mm stainless steel with a diameter of 3.94 cm*.

*Manufactured by 20th Century Electronics, Great Britain

Measuring time per counter was in the order of 3 hours, the counting rate was about 2000 s^{-1}. The statistical error of the measured spectrum was a few percent. The data were corrected for wall effects as described by Benjamin /14/. The energy calibration was made at the Karlsruhe van de Graaf accelerator using the ^{7}Li (p,n) ^{7}Be reaction.

No fitting of adjacent energy regions was required, since the number of scattering atoms per counter was well known. The measured spectrum $\phi(u)$ (neutron flux per lethargy unit) together with a 26-group KFK-set calculation is shown in fig. 3. $\phi(u)$ was in each case normalized to equal integrals $\int \phi(u)du$ within the energy limits 15 keV and 1400 keV. In fig. 4 calculated spectra $\phi_i/\Delta u_i$ are compared with the experimental group spectrum $1/\Delta u_i \int_{\Delta u_i} \phi(u)du$, where Δu_i is the lethargy width of group i and ϕ_i the neutron flux in group i. The pronounced dips in the measured spectrum can be attributed to resonances of aluminium, iron, and chromium.

3.1.2 Foil irradiations

To obtain information on the neutron spectrum below 10 keV sandwiches of NaJ-crystals and Cd-metal-foils were irradiated in the center of SNEAK-1. The three-layer sandwiches had a diameter of 18 mm and a thickness of 3 x 0.5 mm. The sandwiches were placed inside Cd-covers to prevent any thermal irradiation. The evaluation procedure is described in Ref. /15/. The Cd-activity was corrected for higher energy resonance activation assuming a neutron spectrum as obtained from the ABN calculation. The index finally found was

$$\frac{\phi(2.85\text{keV})\Delta E}{\phi(0.12\text{keV})\Delta E} = 450 \pm 160 \text{ or } \frac{\phi(u_1)}{\phi(u_2)} = (1.1 \pm 0.4) \times 10^4$$

The calculations gave the following results:

$$\frac{\bar{\phi}(u_1)}{\bar{\phi}(u_2)} = (1.4 \pm 0.4)\ 10^4 \text{ with the ABN cross section set,}$$

$$\frac{\bar{\phi}(u_1)}{\bar{\phi}(u_2)} = (2.2 \pm 0.6)\ 10^4 \text{ with the KFK cross section set.}$$

$\bar{\phi}$ was obtained from a smoothed out plot of the step function $\phi(u) = \phi_i/\Delta u_i$.

3.2 Spectral indices

3.2.1 Central fission ratios

Central fission ratios were measured with pairs of parallel plate fission counters of 4 cm diameter placed back to back in a central cavity of SNEAK-1. The counters were constructed as thinwalled flow counters using a 90% Ar, 10% CH_4 mixture. The cathode foils were made of platinum coated with approximately 6 x 10^{17} or 2 x 10^{18} atoms/cm^2 ^{233}U, ^{235}U, ^{238}U, or ^{232}Th*. The gravimetrically known mass agreed within $\pm$1% for ^{233}U and within $\pm$3% for ^{238}U with the mass determined by low-geometry α-counting. A correction was applied for fission fragments producing very little ionization energy. This correction was in the case of thin foils of the order of 2%, in the case of thick foils of the order of 10%. The fission rates for ^{235}U, ^{233}U, ^{238}U were obtained with thin foils, for ^{232}Th with thick foils. With the assumed mass accuracy of $\pm$1.5% and the background uncertainty the error is $\pm$3% for the $^{233}U/^{235}U$ and $^{238}U/^{235}U$ fission ratio, and $\pm$6% for the $^{232}Th/^{235}U$ ratio. The measured fission ratios are listed in Table IV. They are compared with calculated ratios determined from fission rates n^x of the isotopes x

$$n^x = \sum_{i=1}^{26} f_i^x\ \sigma_i^x\ \phi_i$$

where f_i is the self-shielding factor and ϕ_i is the neutron flux in energy group i as calculated in the center of a critical sphere by diffusion calculation. $f^{233}U$ and $f^{232}Th$ are taken equal to 1, since

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* The foils were fabricated and weighed by the Euratom Central Bureau for Nuclear Measurements, Geel, Belgium

these materials are not contained in the normal core mixture. Also listed are fission ratios measured by Argonne. Calculations indicate that they should not deviate by more than 3% from the Karlsruhe results. The fission ratio $^{233}U/^{235}U$ is in agreement with the calculation and the ANL experiment, the measured threshold indices are higher than the calculated ratios. This contradicts the previous experience, as exemplified by the ANL results, that usually these threshold indices indicate a softer spectrum than is calculated. An intercalibration of fission counters seems appropriate to solve this discrepancy.

3.2.2 Material worth measurements

Several samples of different composition and size were inserted into a central void of the core. This was done using an automatic sample changer and/or a pile oscillator (Ref /16/). The drawer of the sample changer was 5.8 x 3.1 cm^2 in cross section and ran horizontally through the core and radial blanket in the height of the core center. The pile oscillator had a cross section of 4.7 x 4.7 cm^2, it was located in the element tube at position 17/20 and ran axially through the core and axial reflectors. A central pocket of the sample changing equipment was usually filled with the sample of interest, the remaining volume was filled by structural material only. In the course of the measurement the sample was withdrawn several times to a far outside position and inserted again into the core center. The automatic sample changer was also used for the measurement of radial material worth traverses, the pile oscillator for axial traverses.

The results of Fourier analyses, as listed in Table V, are not corrected for any possible spectral distortion due to the missing fuel in the sample drawer. Sample sizes varied approximately from 4.7 x 4.7 x 0.05 cm^3(^{235}U) to 4.7 x 4.7 x 2.5 cm^3(Al). Sample size effects were not investigated in detail.

Reactivity effects were of the order of 2 x 10^{-5} $\Delta k/k$. The errors shown are derived from the statistical error of 1 x 10^{-7} $\Delta k/k$.

Additional errors may be incurred by sample size effects and possibly by contributions of the transition part of a cycle to the basic harmonic. To facilitate comparisons of measured and calculated values, the absolute value is given only for a 1 g ^{235}U sample and for a Pu sample (Table V-A), in the second part of the table the material worth per sample atom is listed relatively to one atom of ^{235}U, the value of which is set equal to 1000.

As can be seen from the reproducibility index ϱ agreement with Argonne results is obtained within the limits of error for most samples. For Mo and Ni, however, the discrepancy (between ANL and Karlsruhe experiments) is too large. This may be due to a pronounced reduction of reactivity worth for the rather big samples used at Argonne (samples used at Karlsruhe had a thickness of 0.6 cm for Ni and 0.3 cm for Mo, the Argonne samples were about 10 times thicker).

Also listed are reactivity effects as calculated by perturbation theory. The fluxes for these calculations were found using a one-dimensional diffusion code in infinite cylinder geometry. The diffusion code applies a DB^2-correction to the removal cross section to take into account the separated coordinate. Since the cross section sets used give too low a critical mass, usually two calculations were carried out:

a) one with an energy-independent B^2 which renders the reactor critical,

b) one with a B^2 estimated from bare calculations and/or fission rate traverses (cf. chapter 3.3) which makes the reactor supercritical by 1 to 2%.

The worth of light scatterers such as carbon is considerably decreased in case b) (from 3.3 to 2.4 for the KFK set in Table V-B). Since neither case a) nor b) describe the reality correctly, the average of the two cases is quoted in Table V-B. the calculated worths of Al and C may therefore be wrong by $\pm$4% and $\pm$15%, respectively, the others by $\pm$1%.

The absolute values given for 1 g ^{235}U and for a Pu platelet of SNEAK are calculated for the exact core radius and an extrapolated core height of 126 cm, which is a reasonable assumption obtained from

fission counter traverses. For the caluclation of the normalization integral a cosine flux distribution in the axial direction was assumed.

The composition of the perturbed region was taken as the original core mixture plus ΔN^x atoms of the sample atom x per cubic centimeter.

Self-shielding in ABN and KFK is treated by f-factors

$$\sigma^x_{ieff} = f^x_i \cdot \sigma^x_i$$

with $f^x_i = f^x_i (\sigma^x_o)$,

where σ^x_o is the total macroscopic cross section of all non-x isotopes per x atom: $\sigma^x_o = \Sigma_t^{non-x}/N^x$.

N^x is the density of x atoms present in the original core composition plus the ΔN^x atoms added in the perturbation sample: $N^x = N^x_o + \Delta N^x$. Two calculations were carried out: for $\Delta N^x \ll N^x_o$ (usually 10^{20}), where σ^x_o does not change very much; and for $\Delta N^x \gg N^x_o$ where σ^x_o approaches zero.

Table V-B shows the perturbations calculated with the first method and in parenthesis the results obtained with the second method. The differences are not grave, since the SNEAK-1 spectrum is so hard that there are only a very few neutrons in the resonance region. The true perturbation should lie somewhere between the two values given in Table V-B, tending more towards the value in parenthesis for U, Mo, Ni and Fe.

3.2.3 Measurement of kinetics parameters

Several methods were employed to measure the decay constant of the prompt neutron flux, α. α depends on the multiplication constant k, the effective fraction of delayed neutron ß, and the prompt neutron lifetime l:

$$\alpha = \frac{1-k(1-ß)}{l} .$$

3.2.3.1 Rossi-α-measurements

A new time-analyser was developed /17/ which permits Rossi-α-measurements down to a signal-to-background ratio of 5% and up to trigger rates of 10 α. It mainly consists of a 104-stage fast shift register controlling 32 fast coincidence channels. An incoming pulse starts the analyser, the next pulse is registered in its appropriate time channel and, simulataneously, starts the next cycle. Up to 32 analyser cycles can overlap, the dead time for successive cycles being reduced to one channel width. With this apparatus Rossi-α has been measured in SNEAK-1 up to a reactor power of 10 mW at a subcriticality near 2×10^{-4} $\Delta k/k$. α was determined from the counting rate c(t) of delayed coincidences according to the equation /18/, /19/:

$$c(t)\Delta t = (a\, e^{-\alpha t} + b)\, b\Delta t$$

with $$a = \frac{W \chi_2 k^2}{2(1-k(1-\beta))^2} \cdot \alpha \quad , \quad b = WF$$

where t = delay time

Δt = channel width

W = detector sensitivity $\approx 4 \times 10^{-5}$ counts/fission

F = fission rate

$\chi_2 = \overline{\nu_p(\nu_p-1)} / \bar{\nu}^2 \approx 0.8$

ν, ν_p = number of (prompt) neutrons per fission.

Pulses of four ^{3}He-counters, connected in parallel and placed in position 18/20 of the SNEAK-1 core, were used for this autocorrelation experiment. Measuring time was about 1 hour at counting rates between 250 s^{-1} (at 1.5 \$ subcriticality) and 12000 s^{-1} (at 0.03 \$ subcriticality) resulting in signal-to-background ratios a/b between 17.5 and 1.6.

Least square fitting of the measured coincidences to an exponential and a constant term yielded the data plotted in fig. 5 as function of the average time intervall between two detected pulses, 1/b, which is a measure of reactivity. In any case only the fundamental exponential mode was observed. Extrapolation of the measured α to delayed critical (i.e., 1/b = 0) yields

$$\alpha_c = \frac{\beta}{l} = (5.2 \pm 0.1) \cdot 10^4\ s^{-1}.$$

3.2.3.2 Pulsed neutron source measurements

The decay constant of the prompt neutron flux was measured at several subcritical states using a pulsed neutron source. The essential features of the Karlsruhe built* neutron generator are a duoplasmatron deuterium ion source /20/ on high potential and a tritium target on ground potential at the end of a 2 m long tube in the center of the core. The maximum repetition frequency was 2000 s^{-1}, the pulse width was 1 μs, and the maximum source strength used was 5 x 10^4 neutrons per pulse. A ^{235}U-fission counter in position 17/16 was used as detector. Time analysing was performed with the shift-register mentioned in chapter 3.2.3.1. The dead time between the 32 channels of the analyser is about 30 ns.

The measured flux decay could be described well by a single exponential. The decay constants are plotted in fig. 6 versus the reactivity as derived from control rod positions. Extrapolation of the curve to delayed critical yields

$$\alpha_c = (5.3 \pm 0.1) \cdot 10^4 \ s^{-1}.$$

3.2.3.3 Comparison of measured with calculated α_c

The kinetics parameters of SNEAK-1 were calculated for the delayed critical condition using the data of Keepin /21/. The generation time Λ, was obtained by dividing the space- and energy integrated, adjoint weighted neutron density by the adjoint weighted neutron source term. The effective fraction of delayed neutrons was obtained from a division of the delayed neutron source term by the total adjoint weighted neutron source term. It is believed, that spherical calculations give the most appropriate results, since one-dimensional calculations do not account for the blanket in the separated direction. The results of the calculations are given in Table VI. Calculations for Assembly No 41 of ZPR III yielded the same β_{eff}, but a 3% shorter lifetime, resulting in a 3% higher value of α_c.

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*built by W. Eyrich, Karlsruhe

The reproducibility index ϱ for Rossi-α-measurements is $\varrho = 1.02 \pm 0.05$; this shows good agreement of the ANL and SNEAK-1 results. The pulsed neutron source technique yielded an α_c only, 2% higher than Rossi-α at delayed critical.

All calculated α_c are larger than the measured decay constant. But the discrepancy is only 10% for the KFK set, whereas the YOM set and the otherwise excellent ELMOE calculation of Argonne yield α_c about 30% larger than measured.

3.3 Reaction rate traverses

Reaction rates along the central axis of SNEAK-1 were measured with fission chambers placed in a 1.7 x 1.7 cm^2 guide tube in element position 19/18. Radial traverses were obtained from fission counters located in a pocket of a horizontal drawer. The axial fission rate traverse of ^{235}U is shown together with a calculated one in fig. 8, the ^{233}U-fission traverse is plotted in fig. 9. Within the core the experimental ^{235}U-fission rates are very well fitted by a cosine function with a half-period of 126 cm. Deviations from the calculated traverses occur near the outer boundary of the blanket, possibly due to streaming in the guide channel. The radial dependence of the $^{238}U/^{235}U$ fission ratio is shown in fig. 9. The deviation from the calculated traverse is mainly due to the ^{238}U fission rate in the blanket, where calculations give only half the experimental value.

3.4 Power calibration

Fission rate measurements with calibrated ^{235}U and ^{238}U counters together with calculated reaction rate traverses where used to estimate the operating power of SNEAK. It was also obtained from a two-detector cross correlation noise measurement /22/ at filter frequencies $\omega \ll \alpha_c$ in the range between 3 and 90 W and in

the course of the Rossi-α-measurement from the ratio of signal-to-background /19/. The power obtained for a certain detector current was (1.0 $\pm$0.2) W, (1.5 $\pm$0.2) W, and (1.2 $\pm$0.2) W for fission rate, cross-power spectral density, and Rossi-α-measurement, respectively. The error of the first method arises from inaccurate counter calibration and the uncertainty of the calculated traverses, the noise measurements are afflicted by counting statistics (statistical error less than 10%) and the uncertainty in a correction factor /23/ accounting for the spatial distribution of the fission processes. The discrepancy between the two noise measurements could not be solved.

4. CONCLUSIONS

The critical mass of a homogeneous sphere as determined by Argonne and Karlsruhe is in satisfactory agreement.* The critical mass calculated by the cross section sets used at Karlsruhe is up to 15% lower than the experimental one. Best results are still obtained by the application of YOM data or the ELMOE corrected cross sections. The weighting spectrum used for ABN is much softer than the SNEAK-1 spectrum and the YOM-weighting spectrum, this may partially account for the discrepancies.

Also the introduction of improved cross sections for structural materials and ^{235}U seems to give better agreement, as can be seen from the accurate result obtained with the ANL 635 set. For this reason new multigroup cross section sets which will better represent the conditions in SNEAK are now being developed at Karlsruhe.

The group width of the ABN and KFK sets in the 10 - 1000 keV region ($\Delta u \approx 0.7$) should be reduced to allow better comparison of measured and calculated spectra. So far, ABN and KFK seem to give quite reasonable average values in this energy region. The calculated YOM-spectrum is too hard as can be seen from the slope of the YOM-curve in fig. 4. In the lower energy region between 0.1 and 3 keV where YOM fails completely, the spectra calculated with ABN and KFK give acceptable results.

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* $\varrho = 1.01 \pm 0.01$

The fission ratio measurements are not very illuminating, as long as the discrepancy between Karlsruhe and Argonne results is not resolved.

With the exception of Ni and Mo, material worth measurements agree within the limits of error. For Ni and Mo sample size effects seem to produce a large discrepancy. For the thin samples used at Karlsruhe the difference between measured and calculated worth is considerably reduced. Al and C are not usefull for a comparison, since their reactivity worth is strongly influenced by slight distortions of the adjoint spectrum which may arise from the sample drawer filling. This leaves fissionable materials and ^{10}B. Good agreement between calculated and experimental results is obtained for the KFK and ABN cross section set. The measured ratio ^{235}U-worth:Pu-worth is almost 2% lower than the calculated one. Considering the small critical masses calculated with KFK and ABN, it appears possible that the average $(\nu-1)\sigma_f^{235U}$ is too high in both sets. A reduction, perhaps in the order of 2%, would yield a much better estimate of the critical mass and the relative worths of Pu, ^{235}U, ^{238}U, and ^{10}B. The calculated ^{238}U-worth would then be too low by only 2 to 4%, the ^{10}B-worth by 0 to 5%, but the discrepancy in the reactivity worths of the steel components would be slightly enhanced. The changes included in the new SNEAK-set /24/ act in this direction.

The decay constant of prompt neutrons at delayed critical, α_c, was obtained by two different methods. The α_c were in good agreement, also with the Argonne measurement. All calculations yield too heigh an α_c, indicating that the calculated spectrum is too hard. But the KFK-set is only 10% off, which is a considerable improvement as compared to the 25% deviation found with the YOM-set.

5. SUMMARY

It was shown that most experimental results obtained with the SNEAK facility agree with those of Argonne's ZPR III. The application of the KFK cross section set for calculations reduces the differences between experiments and calculations considerably with the exception of the critical mass, where a discrepancy of 8% was encountered.

6. ACKNOWLEDGEMENT

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Table I: Atom densities in SNEAK-1 and Ass. 41 of ZPR III

Material	N_o (10^{20} atoms/cm^3)			
	SNEAK-1 Core	SNEAK-1 Reflector	Ass.41 Core	Ass. 41 Reflector
^{235}U	28.09	1.54	28.61	0.91
^{238}U	135.5	399.3	139.7	399.8
Al	99.97	-	107.9	-
SS Fe	84.69	40.12	86.7	45.0
SS Cr	23.36	11.07	22.8	11.8
SS Ni	14.38	10.24	10.9	5.6
Mn	2.08	0.81		
Si	1.64	0.46		
Mg	1.13	-		
Ti	0.42	0.20		
C	0.29	0.14		
Mo	0.10	-		

Table II: The critical data of SNEAK-1 and Ass. 41

	SNEAK-1	ZPR III Ass. 41
cylinder height	86.9 cm	81.4 cm
cylinder diameter	82.3 cm	82.9 cm
core volume	465.5 l	440. l
exp. critical mass (m_{exp})	510.1 ±0.5kg ^{235}U	490.4 kg ^{235}U
exp.ΔM/M : Δk/k	5.6 ±0.1	5.0
correction for irregular shape	-3.2 ±0.8 kg	-0.4 kg
correction for central gap of ZPR III	-	-0.6 kg
correction for partially inserted control rod	-2.3 ±0.1 kg	-
correction for built-in detectors	+0.3 kg	-
m of heterogeneous critical cylinder	504.9 ±1.0 kg	483.6 kg
heterogeneity correction	+5.9 ±2.0 kg	+18.6 kg
m of homogeneous critical cylinder	510.8 ±2.5 kg	502.6 kg
shape factor	0.91 ±0.005	0.92
m of homogeneous critical sphere	465. ±4 kg	462 kg
correction for difference in composition	-1.65%	
m of equivalent spheres	457 ±4 kg ^{235}U	462 kg ^{235}U

Table III: Experimental and calculated critical mass of a homogeneous sphere of SNEAK-1 composition

	Laboratory	Cross Section Set	Approximation	m/kg ^{235}U*)
Experiment	Karlsruhe	-	-	465
	ANL	-	-	470
Calculation	ANL	ANL 635	S_4	464
	ANL	ELMOE	S_4	463
	K	YOM	Diff.	449
	K	ABN	Diff.	418
	K	KFK	Diff.	427
	K	ABN	S_4	399

*) ANL data increased by 1.65% to allow direct comparison

Table IV: Fission ratios in the center of SNEAK-1

	SNEAK-1 Experiment	Calculated for SNEAK-1	ZPR III Ass.41 Experiment	Calculated for Ass.41	δ
$\frac{\sigma_f^{233}U}{\sigma_f^{235}U}$	1.52 ±0.05	YOM 1.58 ABN 1.47 KFK 1.51 *)	1.52 **) 1.43 ***)	ANL635 1.576 ABN 1.512 ELMOE 1.567	0.97 ±0.03
$\frac{10^2\sigma_f^{238}U}{\sigma_f^{235}U}$	4.38 ±0.13	YOM 4.37 ABN 4.18 KFK 4.05	3.99	ANL635 4.37 ABN 4.19 ELMOE 4.02	0.91 ±0.03
$\frac{10^2\sigma_f^{232}Th}{\sigma_f^{235}U}$	1.00 ±0.09	YOM 0.89 ABN 0.81 KFK 0.80 *)		ABN 0.84	

*) fission cross sections of ^{233}U and ^{232}Th taken from ABN, spectrum calculated with KFK

**) quoted in Ref. /9/

***) Kirn type counter, quoted in Ref. /10/

Table V-A: Absolute reactivity change due to the insertion of fissile samples in the center of SNEAK-1 (in 10^{-6} $\Delta k/k$)

	SNEAK-1 Experiment	Calculated YOM	ABN	KFK	Sample description
1g ^{235}U-sample	2.28 $\pm$0.02	2.30	2.32	2.32	93.4% enriched U-metal, 0.05 cm thick, corrected for ^{238}U content
plutonium sample	104. $\pm$1.	108.	105.	104.	Steel-canned oxide sample of 0.6cm thickness; contents: 28.9g ^{239}Pu, 2.6g ^{240}Pu, 0.6g ^{235}U, 86,9g ^{238}U, 17.1g O, 14.7g stainless steel

Table V-B: Relative reactivity worth per atom in the center of SNEAK-1

	SNEAK-*) Experiment	Ass. 41-**) Experiment	YOM	ABN***)	KFK***)	ρ +)
^{235}U	1000. ±10.	1000. ±17.	1000.	1000. (999.6)	1000. (999.6)	1.00 ±0.02
^{238}U	-45.3 ±0.5	-44.3 ±1.7	-43.2	-43.9 (-43.6)	-42.9 (-42.5)	0.97 ±0.04
Al	-4.8 ±0.1	-4.1 ±1.3	-2.9	-3.5 (-3.7)	-4.4 (-4.4)	0.80 ±0.34
C	+1.7 ±0.1	+0.5 ±1.1	+2.0	+4.5 (+4.6)	+2.8 (+2.9)	0.4 ±2.2
Ni	-16.2 ±0.2	-13.0 ±0.9	-18.8	-18.3 (-16.9)	-21.5 (-19.7)	0.78 ±0.08
Mo	-39.6 ±0.4	-33.3 ±1.3	-42.0	-39.9 (-39.7)	-41.2 (-41.0)	0.84 ±0.05
^{10}B	-557. ±30.	-590. ±17.	-444.	-497. (-496.8)	-524. (-523.8)	1.07 ±0.08
Fe	-8.1 ±0.5	-8.5 ±1.0	-9.7	-9.0 (-8.7)	-9.0 (-8.6)	1.02 ±0.17
Ta	-159. ±1.	-147.5 ±3.0				
W	-73.4 ±0.7	-63.5 ±1.7				
Ag	-171. ±8.	-148. ±3.5				

*) For ^{10}B, Fe, Ag no Fourier analysis was carried out, the values were obtained by the inverse kinetics method

**) quoted in Ref. /10/

***) The first figure is calculated for a very few sample atoms added to the original core composition, the value in brackets is calculated for a number of atoms per cubiccentimeter added, which corresponds to the actual sample density

+) Set equal 1 for ^{235}U

Table VI: Prompt neutron-decay constant α_c

	Experiment $10^{-4}\alpha_c/s^{-1}$	Cross Section Set	Calculated β_{eff}	Caluclated $10^{+7}\Lambda/s$	Calculated $10^{-4}\alpha_c/s^{-1}$
SNEAK-1					
Rossi-α	5.2 ±0.1				
Pulsed Measurements	5.3 ±0.1				
Average	5.25 ±0.10	YOM	0.00708	1.08	6.6
		ABN	0.00712	1.16	6.2
		KFK	0.00709	1.22	5.8
ZPR III Ass.41					
Rossi-α	5.55±0.16	KFK	0.00709	1.17	6.1
		ANL635	0.0073*)	0.95	7.6
		ELMOE	0.0073*)	1.03	7.1

*) estimated

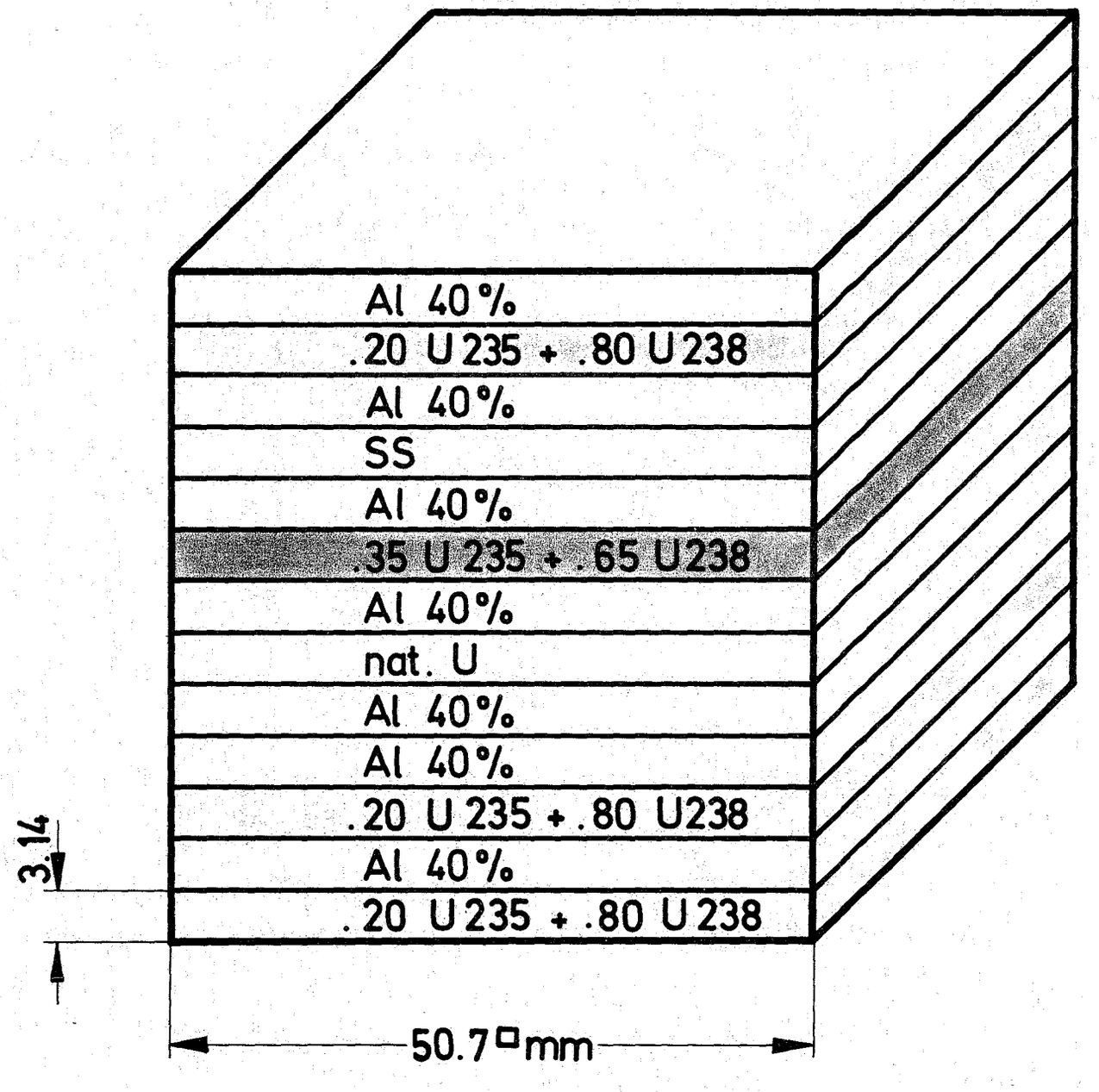


Fig. 1 Typical stack of plates used for loading SNEAK 1 core elements

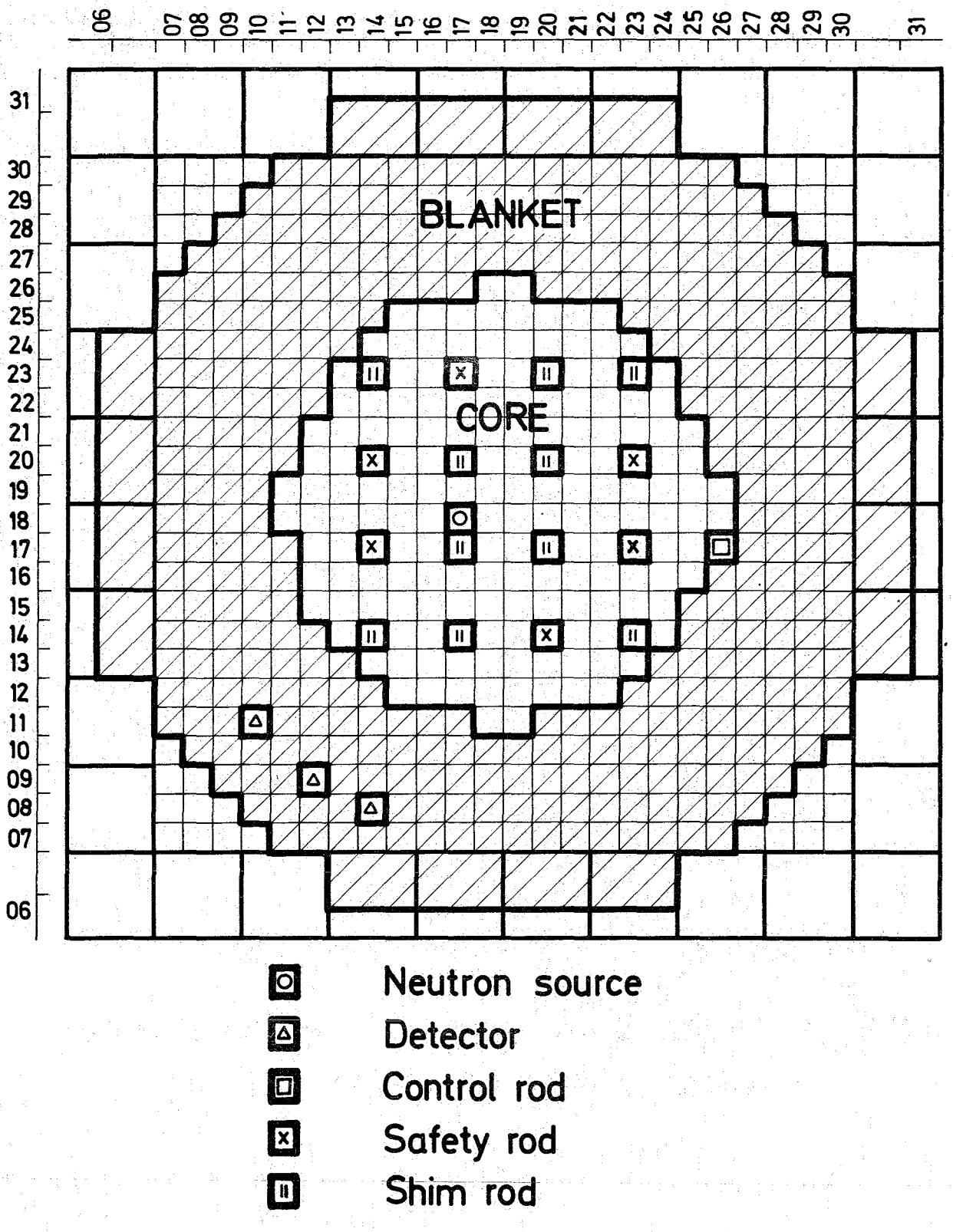
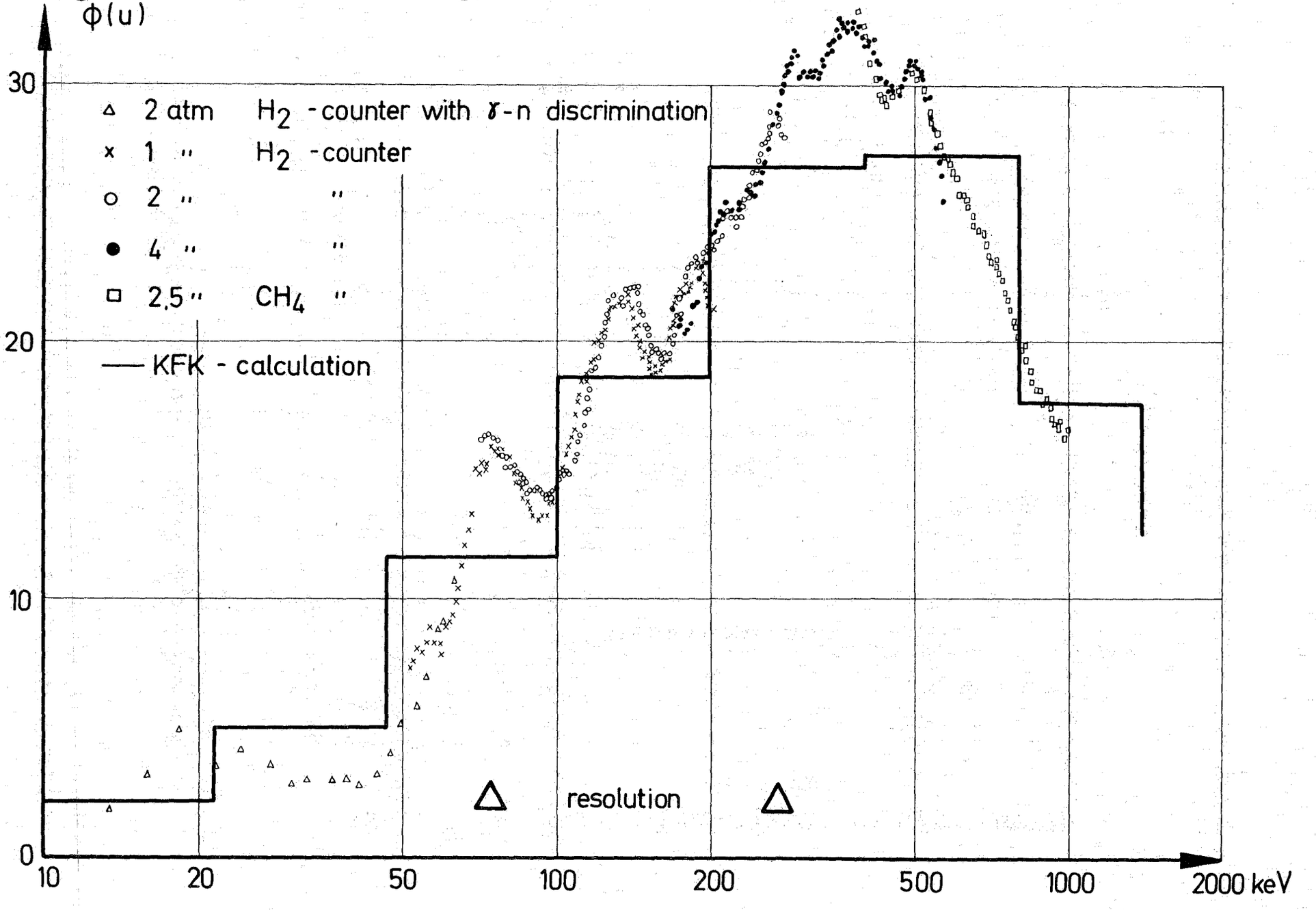


Fig. 2 SNEAK1. Horizontal core cross section

Fig.3 Flux per unit lethargy measured with proton recoil counters



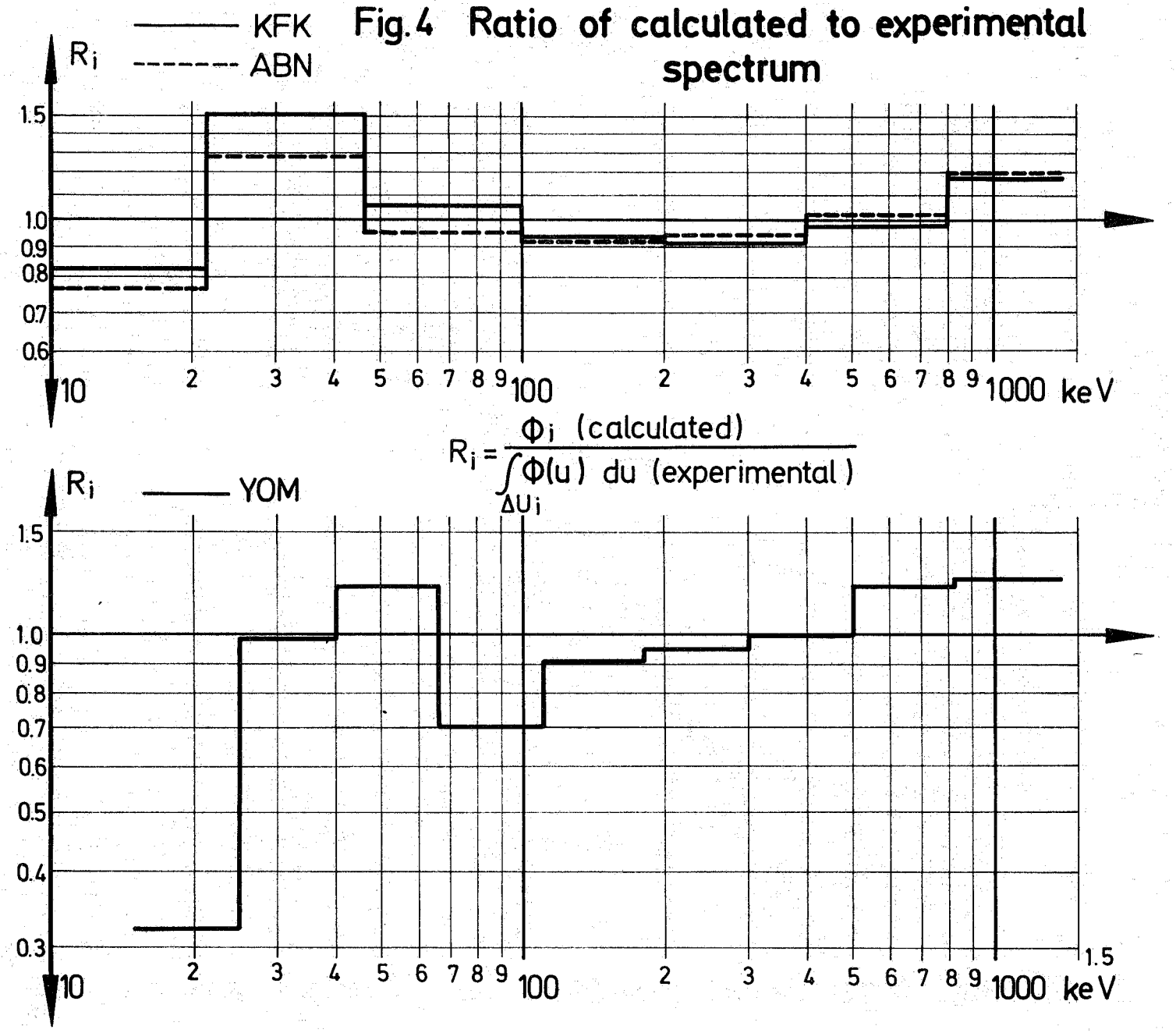


Fig. 4 Ratio of calculated to experimental spectrum

$$R_i = \frac{\Phi_i \text{ (calculated)}}{\int_{\Delta U_i} \Phi(u)\, du \text{ (experimental)}}$$

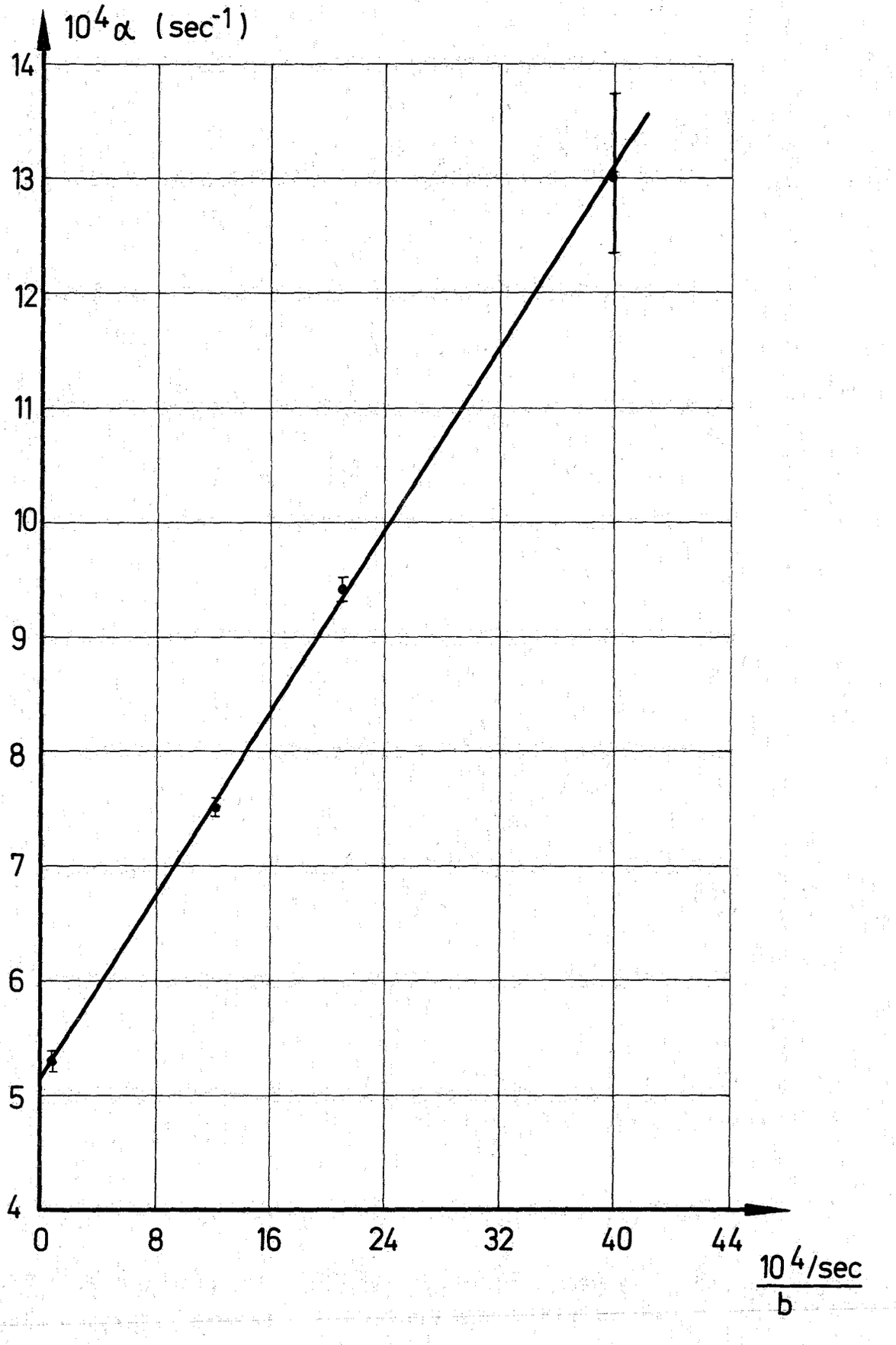


Fig. 5 Rossi-α versus average time interval between pulses

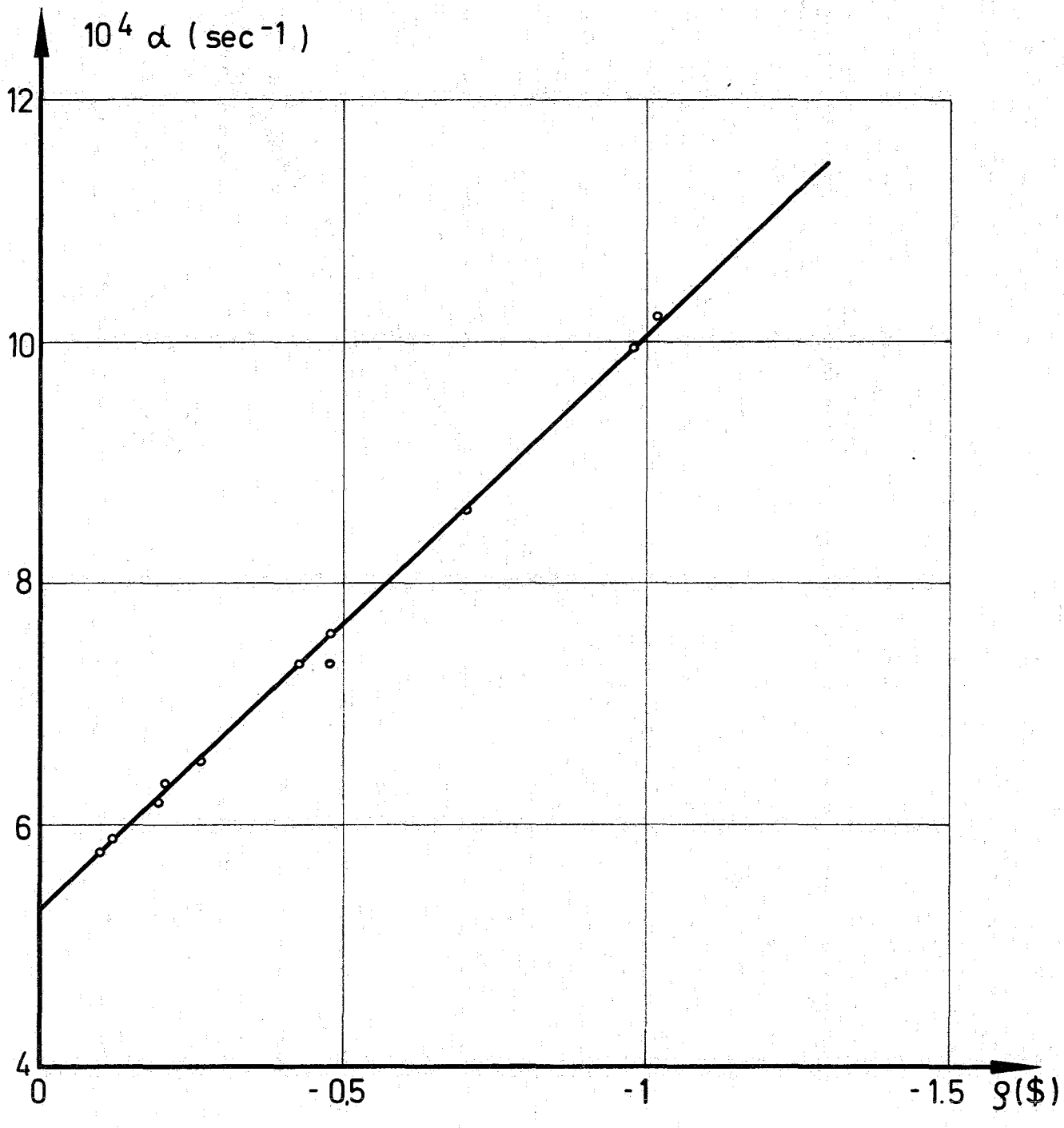


Fig. 6 Pulsed measurement : α versus subcriticality

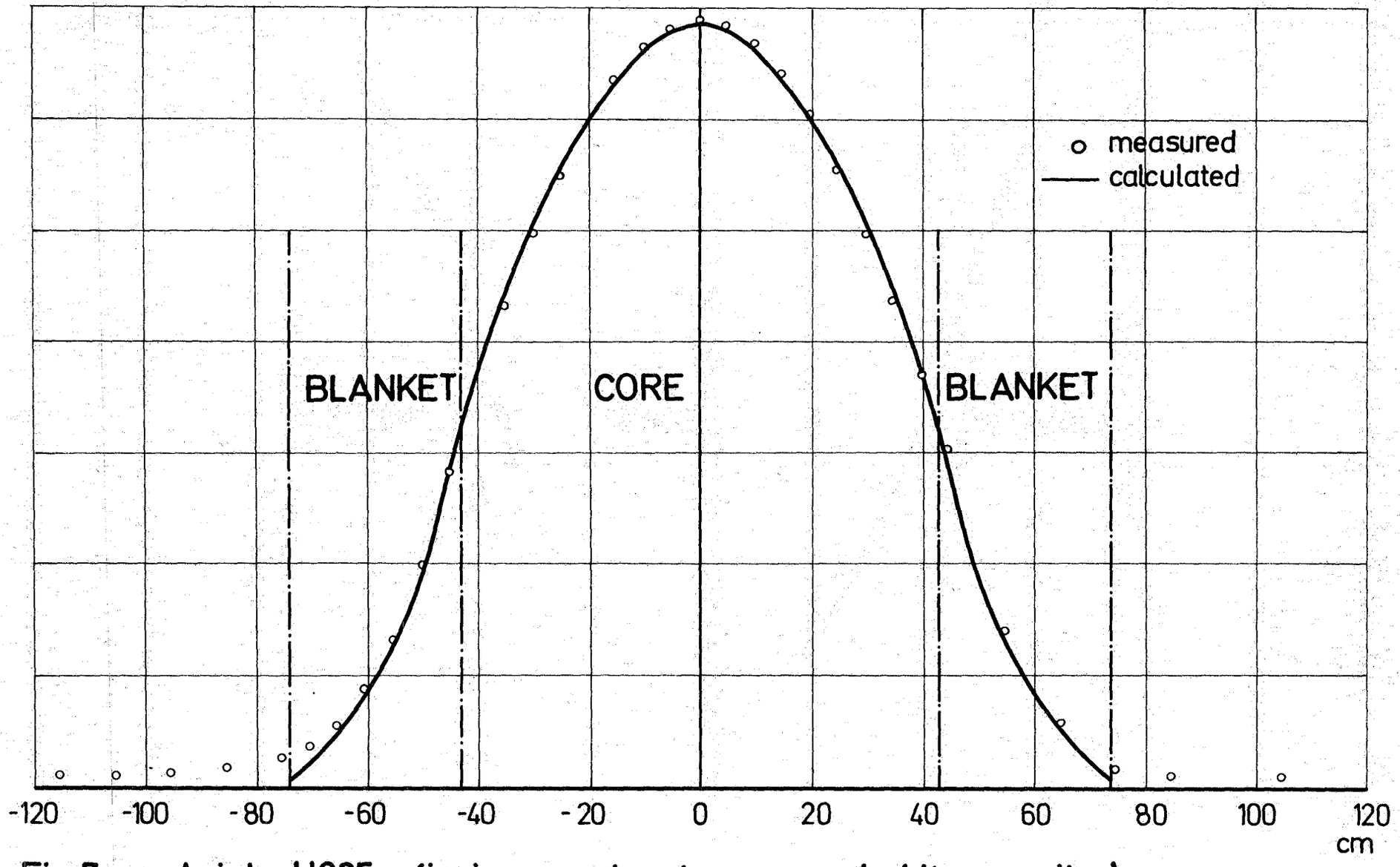


Fig. 7 Axial U235 - fission counter traverse (arbitrary units)

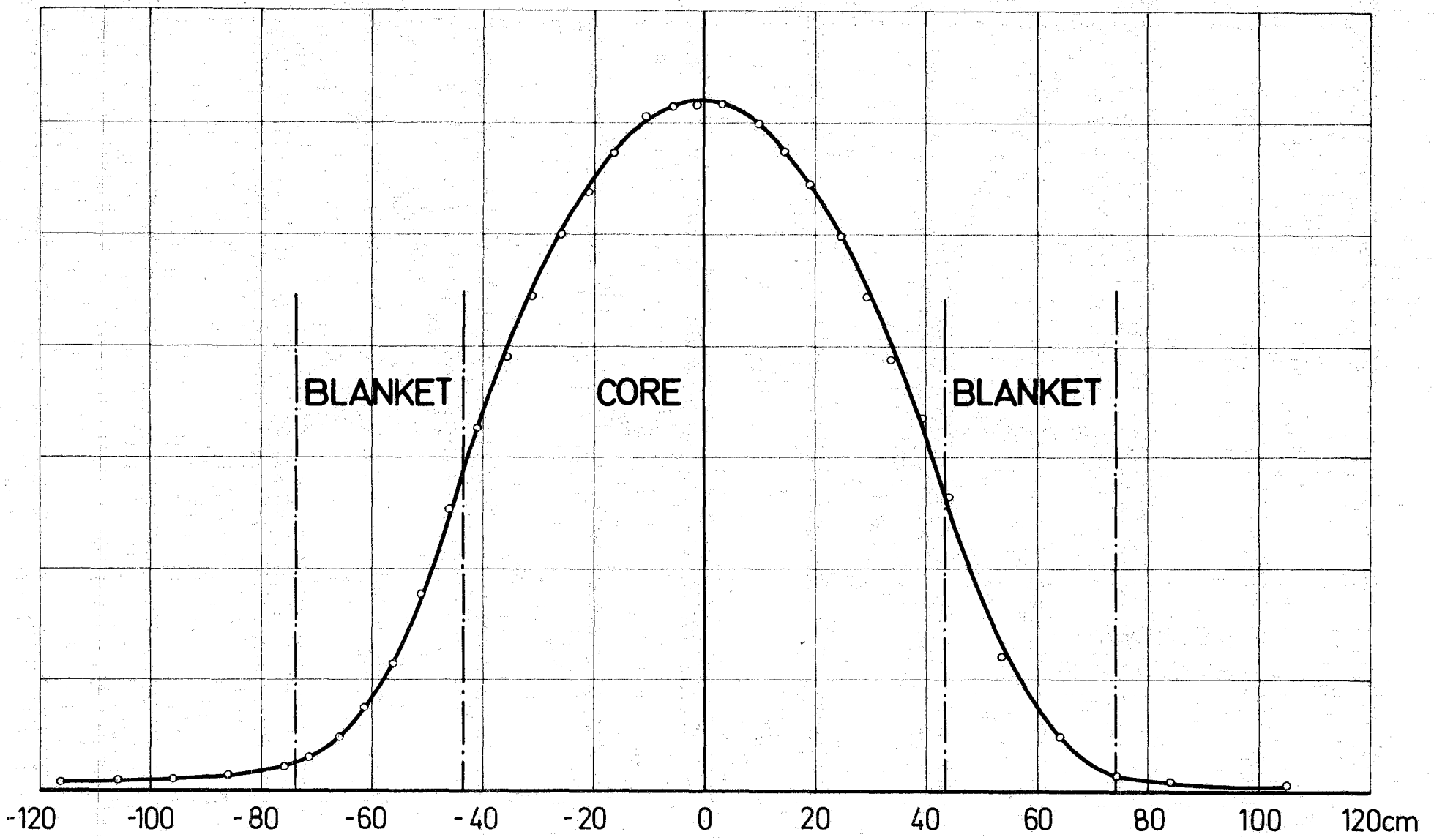


Fig. 8 Axial U233- fission counter traverse (arbitrary units)

Fig. 9 Radial traverse of $\frac{\sigma_f(U235)}{\sigma_f(U238)}$ (arbitrary units)