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SPLIT CORE EXPERIMENTS
Part I. Axial neutron flux distribution measurements in the reactor core with a central horizontal reflector

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Part I. Axial neutron flux distribution measurements in the reactor core with a central horizontal reflector

by

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I. Introduction

A series of critical experiments were performed on the RB heavy water reactor of the Boris Kidrič Institute of Nuclear Sciences, in order to determine the thermal neutron flux increase in a central horizontal reflector formed by a split reactor core. The objectives of these experiments were to study the possibilities of improving the thermal neutron flux characteristics of the neutron beam on the horizontal beam tube of the research RA reactor situated at the same institute.

The 6,5 MW research RA reactor has six horizontal beam tubes mainly used for solid state and gamma spectroscopy work. For this reason an increase in thermal neutron flux and the reduction in epithermal component as well as the reduction of gamma rays background are highly desirable. The construction of the RA reactor core gives the possibilities to split the core in two and to form a central horizontal reflector just in front of the beam tube entrance. This can be performed by rearranging the uranium slugs inside the fuel element. The fuel for the RA reactor is 2% enriched uranium in the form of hollow cylinder slugs. Eleven such slugs are arranged inside the aluminum. tube forming the fuel element. The central reflector can be easily formed replacing one or two slugs in the central possition of the element by a dummy slug made of aluminum, or other neutron low absorbing material. If the same number of slugs are used the thickness of bottom and top reflectors will decrease.

The purpose of the first series of experiments was to study-using a critical zero power reactor - the gain in thermal neutron component inside the horizontal reflector and the loss of reactivity as a function of the lattice pitch and central reflector thickness. To get the reference to the normal operation characteristics of the reactor, all measurements are normalized to the same reactor power and assumed to be proportional to the integral of the thermal neutron flux distribution over the reactor core region.

2. Experimental set up

The RB zero power reactor which was used for the experiment has been described elsewhere (1). The experiments were performed in the following way. For a selected lattice pitch the reactor core was adjusted by forming a central horizontal reflector of a variable thickness. Owing to the fact that the fuel element was formed of twelve slugs inserted in the aluminum tube, it was possible to rise the upper six slugs for a specified height by using a special arrangement and to form the central horizontal reflector of variable thickness (Fig.1). In all cases four to five different reflector thicknesses were examined. For each thickness critical conditions were established and the critical height of the heavy water was precisely measured. The axial neutron density distribution was measured using a semiconductor counter. For tightly packed lattice cores, the epithermal component was separately measured by using the gold foils technique. The measurements were made for the square lattices of the pitch 14, 9.9 and 7 cm. The reflector thickness was varied from zero until the maximum gain in the thermal neutron flux component was obtained, or as in the case of 7 cm lattice pitch until the maximum allowed critical level of heavy water in the reactor was reached. The neutron density distribution was measured by moving a semiconductor counter (lithium target with a silicon diode) along the vertical axis of the reactor core. Owing to the fact that this detector is of 1/v type, a correction is made for the epithermal component. According to the Westcott convention (2) the epithermal component in neutron density can be expressed as:

$$f = \left(\frac{\sqrt{\pi}}{2}\right) \left(\frac{T_o}{T}\right)^{1/2} \left(\frac{F_f}{F_s}\right) \left[\int \frac{dE}{E}\right]^{-1}$$

where integration is made over the whole epithermal region i.e. from 3.6 kT up to 2 MeV. The flux ratio can be determined by calculation. Owing to the fact that epithermal correction is small for broader lattice pitches and especially inside the reflector, for most of the measurements it was determined theoreticaly. For the 7 cm lattice pitch the thermal and epithermal flux components are determined separately by gold foils activation techniques.

3. Interpretation of the experimental results and comparaison with the theory

To be able to compare the flux gain for different central reflector thickness and lattice pitches, all results of the flux distribution measurements are normalized in the same way. The integral of the thermal neutron flux over the core region is taken as a reference. The maximal thermal flux value for the core without the central reflector was taken for unity. These two conditions enable us to compare two measured distributions and to conclude what is the real gain in the thermal neutron flux in the central reflector under the same conditions for reactor operation.

To be able to make the extrapolation and intrapolation of the experimental results for the core configuration a comparaison is made of the experimental results with the results of theoretical calculation using the two group diffusion theory. The neutron flux in various core regions is presented by the following equations.

Bottom core region:

$$F_{1s} = A \sin \beta z + E \, sh \, \beta' z$$

$$F_{1f} = A \, S_1 \sin \beta z + E \, S_1' \, sh \, \beta' z$$

Central reflector region:

$$F_{2s} = I \, sh \, \mu_s z + J \, ch \, \mu_s z + K \, sh \, \mu_f z + M \, ch \, \mu_f z$$

$$F_{2f} = KS_2' \, sh \, \mu z + MS_2' \, ch \, \mu z$$

Top core region:

$$F_{3s} = V \sin \beta (H-Z) + W \, sh \, \beta' (H-Z)$$

$$F_{3f} = V S_1 \sin \beta (H-Z) + W S_1' \, sh \, \beta' (H-Z)$$

The given equations are satisfying the boundary conditions that ϕ_1 and ϕ_2 are zero at r = 0 and r = H. Equating the fluxes and neutron current at the region interfaces the eight homogeneous algebraic equations are obtained. This gives the possibility to determine the axial buckling β^2 for the critical height H and the flux distribution paràmeters. The normalization conditions make if possible to determine one arbitrary constant.

The calculation programs are written for the ZUSE Z-23 digital computer. For the experimentally determined heavy water critical height, the computation program calculates the axial buckling β^2 and the axial thermal neutron flux distribution. From the difference in axial buckling values, between the clean core and the central reflected core the total change in reactivity was determined by using the relation

$$\rho = \left[\frac{\tau}{1 + B_c^2 \tau} + \frac{L^2}{1 + B_c^2 L^2} \right] \left(1 + \frac{\partial \alpha^2}{\partial \beta^2}\right) \Delta \beta^2$$

where $\left(1 + \frac{\partial \alpha^2}{\partial \beta^2}\right)$ is the radial reflector coefficient which was determined by calculation. B^2 is the total buckling for the clean core τ and L^2 slowing down and diffusion area, respectively. The parameters for the calculations are taken from reference (1). They are corrected for the D_2O 99.63% concentration.

Table I. D_2O constants (99.63% D_2O)

$\Sigma_{as} = 1.075\cdot10^{-4}cm^{-1}$	$\Sigma_{af} = 1.093\cdot10^{-2}cm^{-1}$
$D_s = 0.950$ cm	$D_f = 1.29$ cm
$L^2 = 8840$ cm^2	$\tau = 118.0$ cm^2

Table II. Core parameters

Lattice pitch	14 cm	9.9 cm	7 cm
p	0.9629	0.9196	0.8630
Σ_{as} (cm^{-1})	$5.014\cdot10^{-3}$	$1.149\cdot10^{-2}$	$3.439\cdot$[illegible]
Σ_{af} (cm^{-1})	$1.044\cdot10^{-2}$	$0.985\cdot10^{-2}$	$0.872\cdot10^{-2}$
D_s (cm)	0.956	0.967	0.994
D_f (cm)	1.29	1.29	1.29
L^2 (cm^2)	188.4	84.1	28.9
τ (cm)	123.5	131.0	148.5
B^2 (cm^{-2})	$14.04\cdot10^{-4}$	$18.08\cdot10^{-4}$	$18.55\cdot10^{-4}$
k_∞	1.484	1.425	1.329

Results

The results are given in Figs.2-21. Figures 2-17 show the thermal and epithermal flux distributions. The dotted line shows the experimental values the solid line shows the theoretical calculation. It is evident that the results agree within the experimental error. Each figure gives the main experimental data indicating the lattice pitch, the central reflector thickness, the temperature of D_2O and the measured critical height of D_2O. Since it was not possible to obtain the criticality for the maximal thermal flux peaking for the lattice pitch of 7 cm on the RB reactor the calculated flux distributions for reflector thickness of 25 cm and 35 cm are given in Figs.18-19. The maximal flux peaking factor, which was defined as a ratio between the thermal flux at the maximum in the reflector and the same flux at the center of the unreflected core for different lattice pitches, is given in Fig.20. The anti-reactivity of the central reflector as a function of the reflector for different lattice pitches is presented in Fig.21.

The analyses of the experimental results have shown that in the frames of investigated lattices a significant increase in thermal neutron flux can be obtained in flux peaking with a relatively small reflector thickness. Since the construction of fuel elements does not allow tighter lattices than 6 - 7 cm the maximal increase in thermal neutron flux is approx. four times bigger than without the reflector. Decrease in epithermal component for the identic core configuration is of the same order of magnitude. At the same time a loss in reactivity of 2000 pcm can be expected.

The presented results allow an optimization of the core configuration of the research reactor in order to obtain an optimum increase in thermal neutron flux with an acceptable loss of reactivity. Such an analysis for the research reactor of the Boris Kidrič Institute at Vinča is in progress.

References

1. N.Raišić et al.: Determination of D_2O - 2% enriched uranium lattice parameters by means of a critical system. SM/42/4 Symposium on exponential and critical experiments, Amsterdam (1963).

2. C.H.Westcott et al., II Geneve Conf. 1958, 16, P/202.

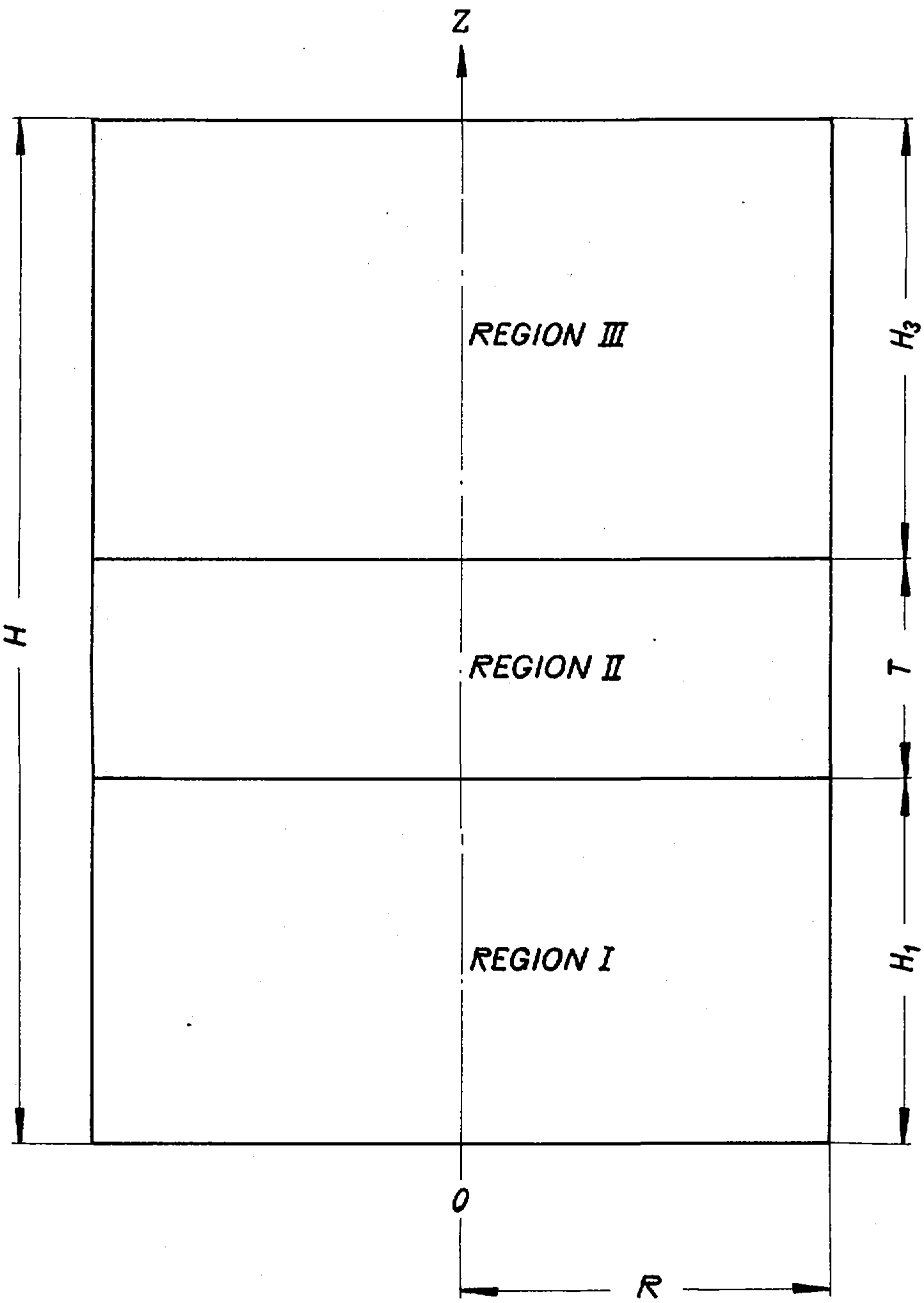

FIG. 1 - SHEME OF REACTOR SISTEM

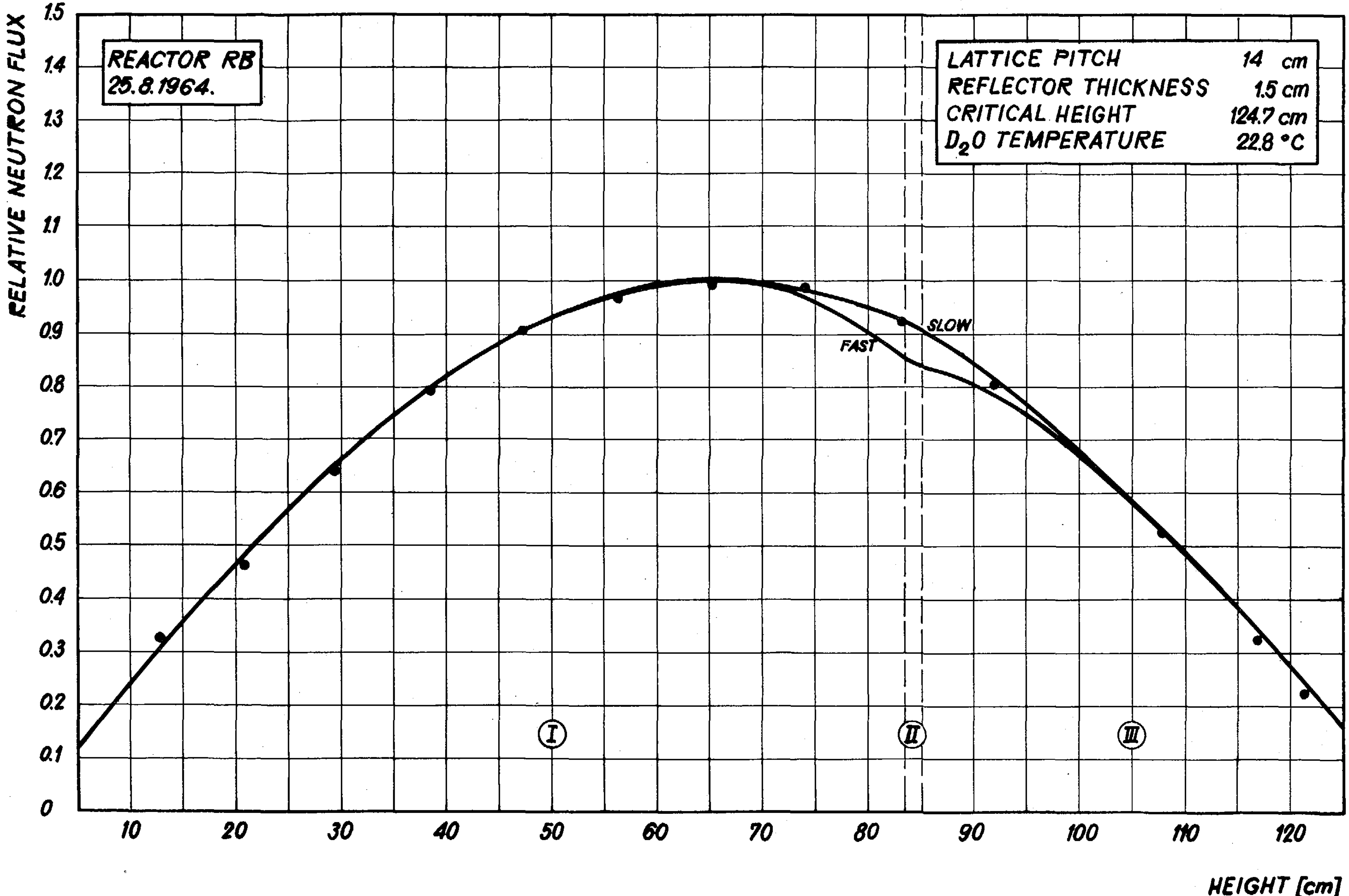

FIG. 2 – AXIAL FLUX DISTRIBUTION No 1

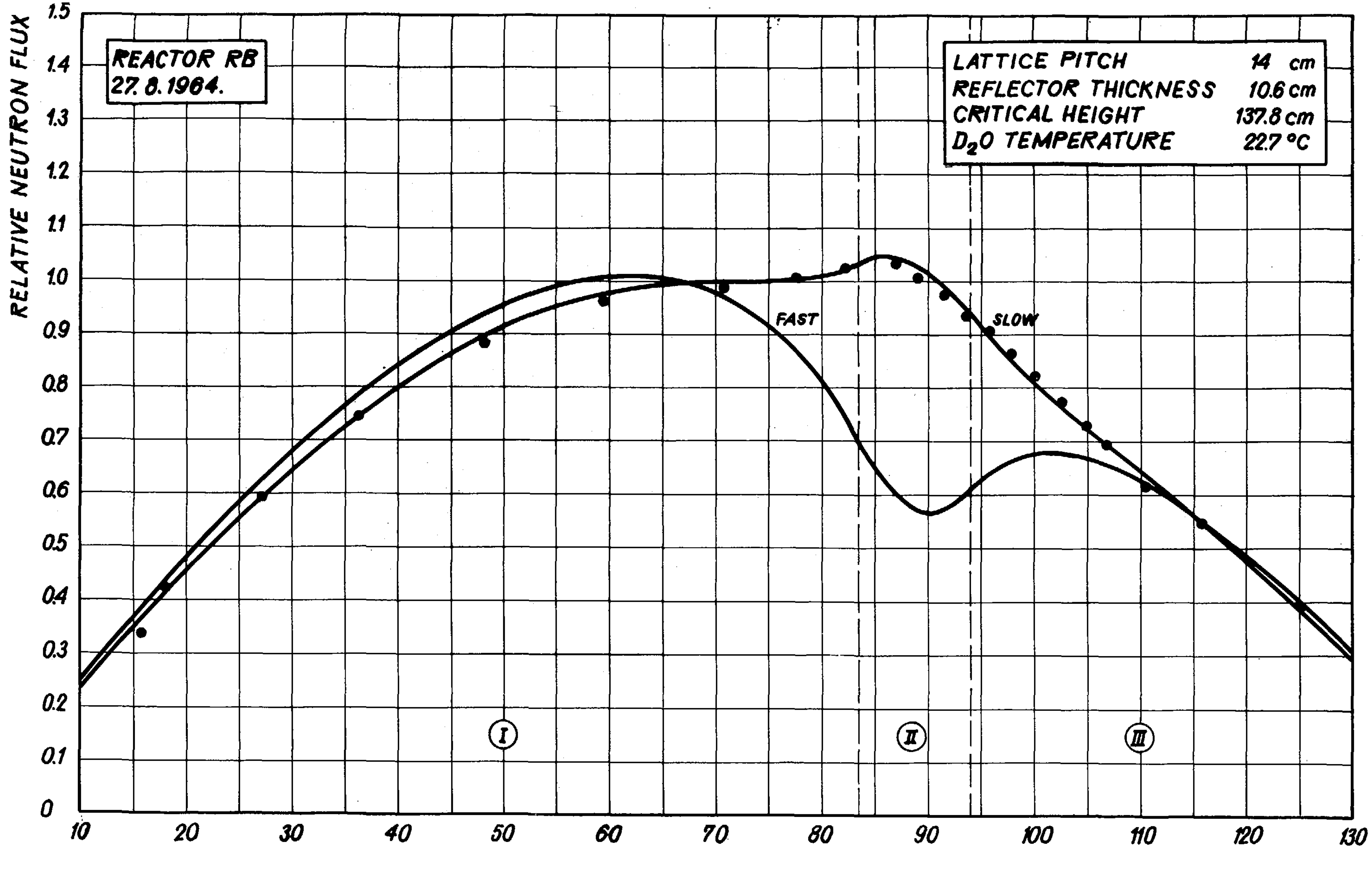

FIG. 3 – AXIAL FLUX DISTRIBUTION No 2

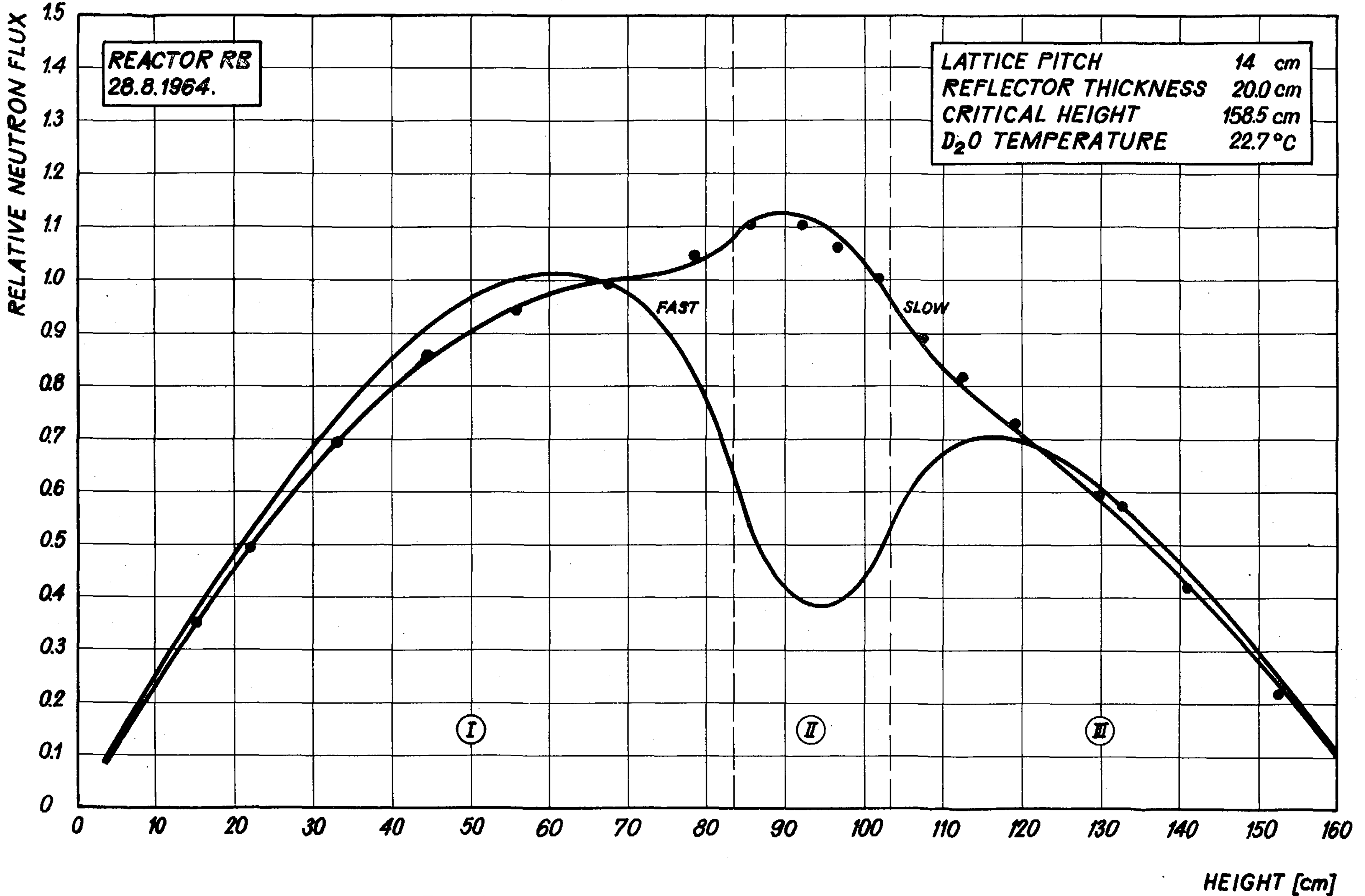

FIG. 4 – AXIAL FLUX DISTRIBUTION No 3

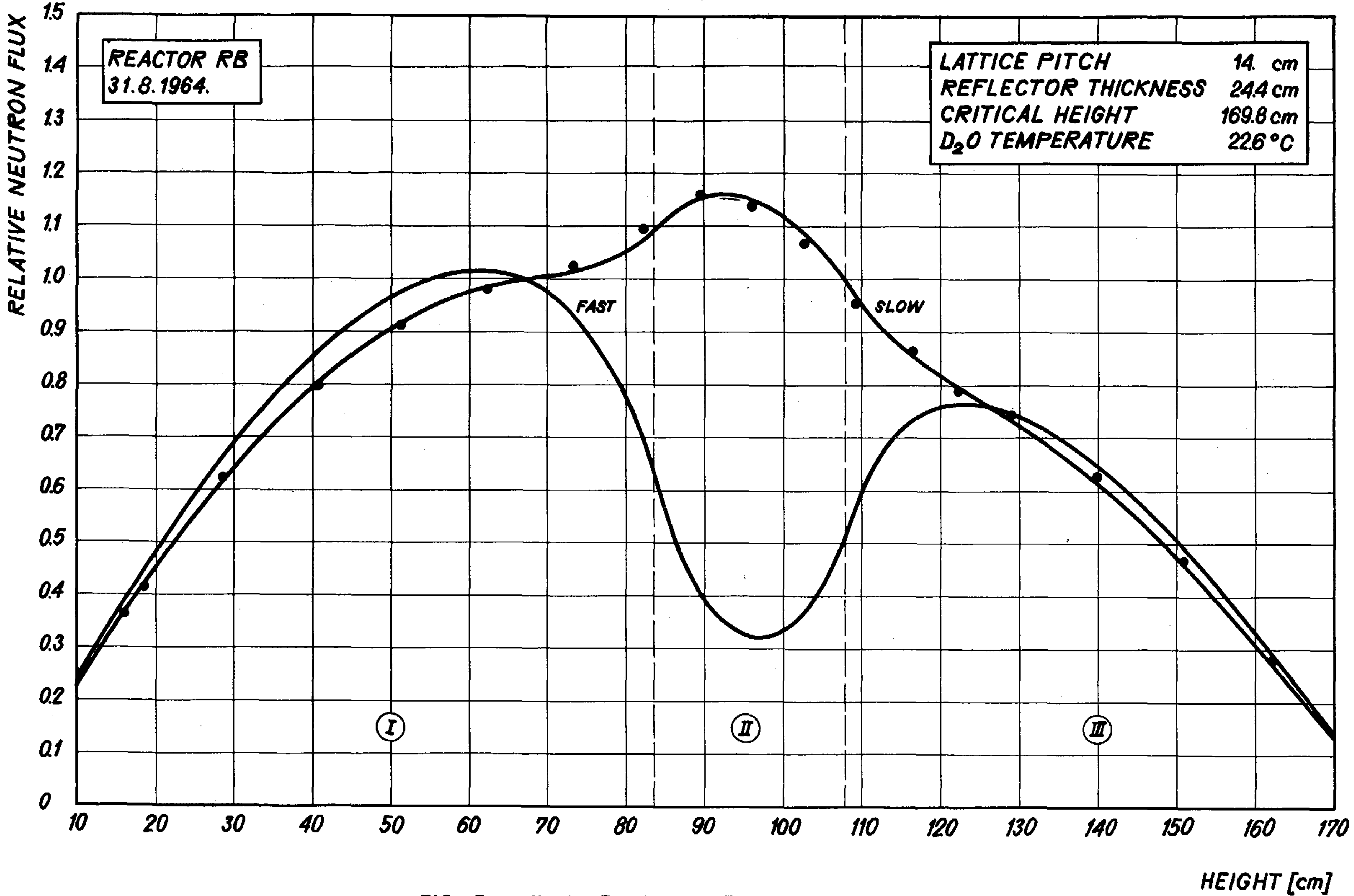

FIG. 5 – AXIAL FLUX DISTRIBUTION No 4

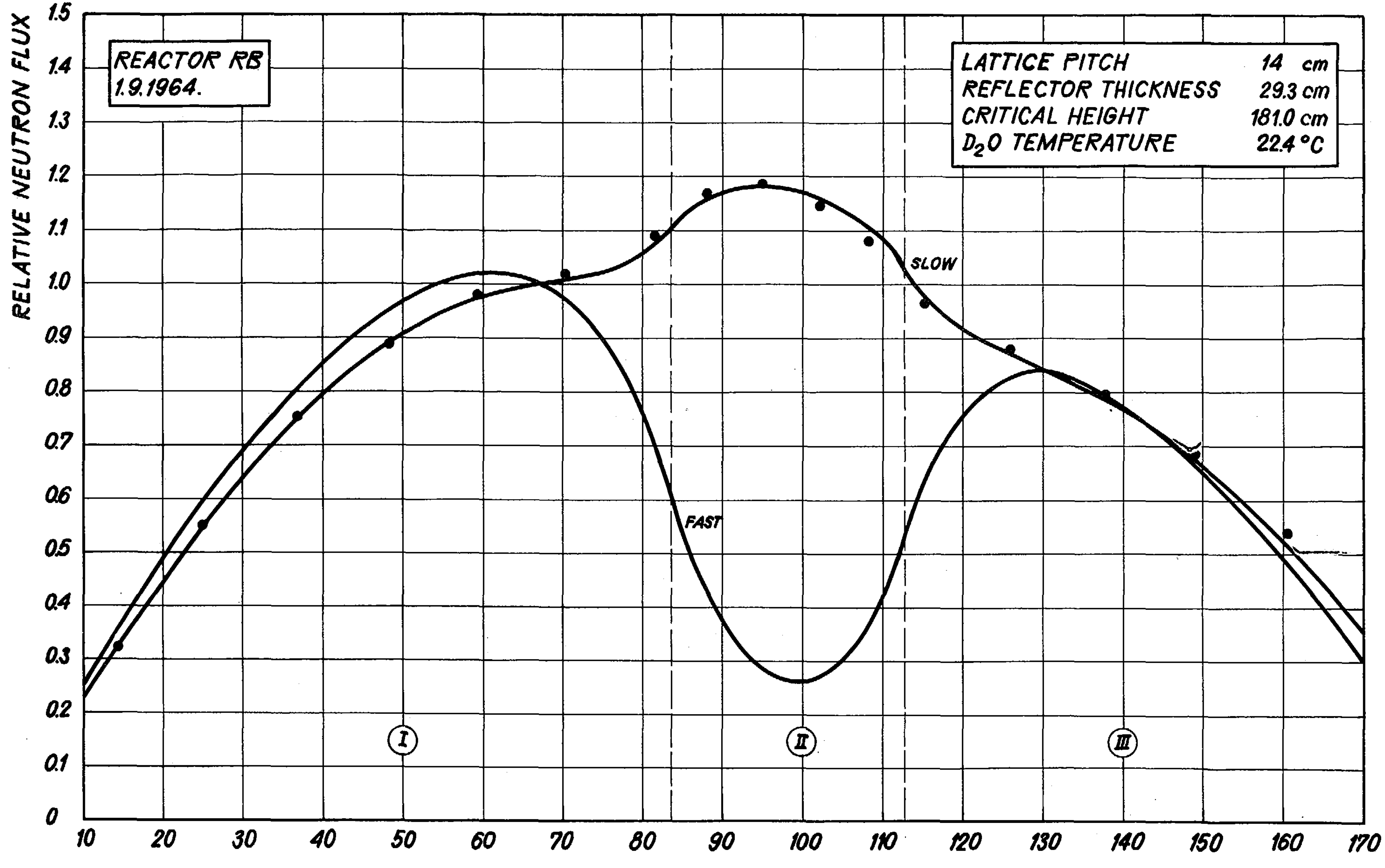

FIG. 6 – AXIAL FLUX DISTRIBUTION No 5

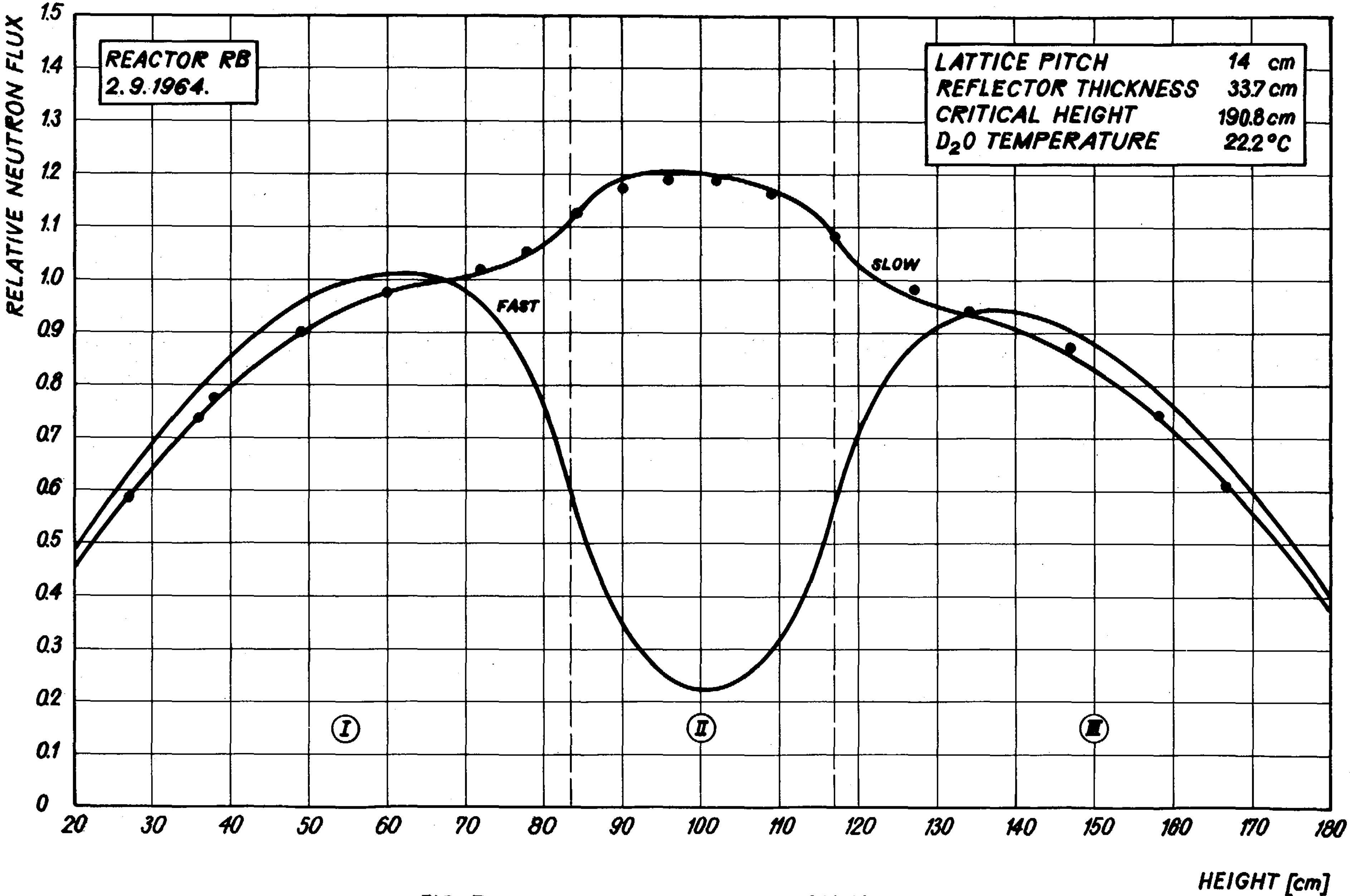

FIG. 7 - AXIAL FLUX DISTRIBUTION No 6

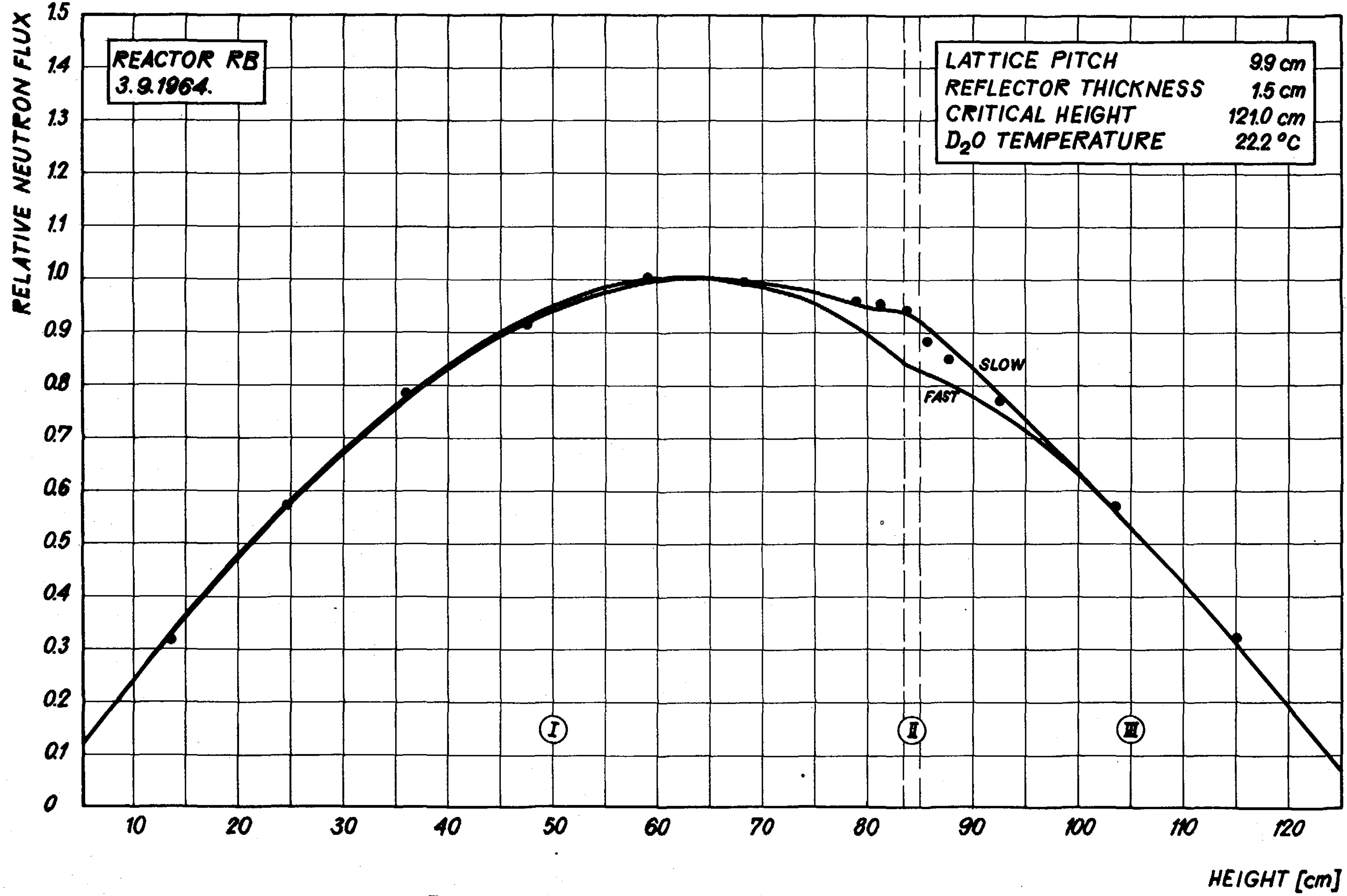

FIG. 8 – AXIAL FLUX DISTRIBUTION No 7

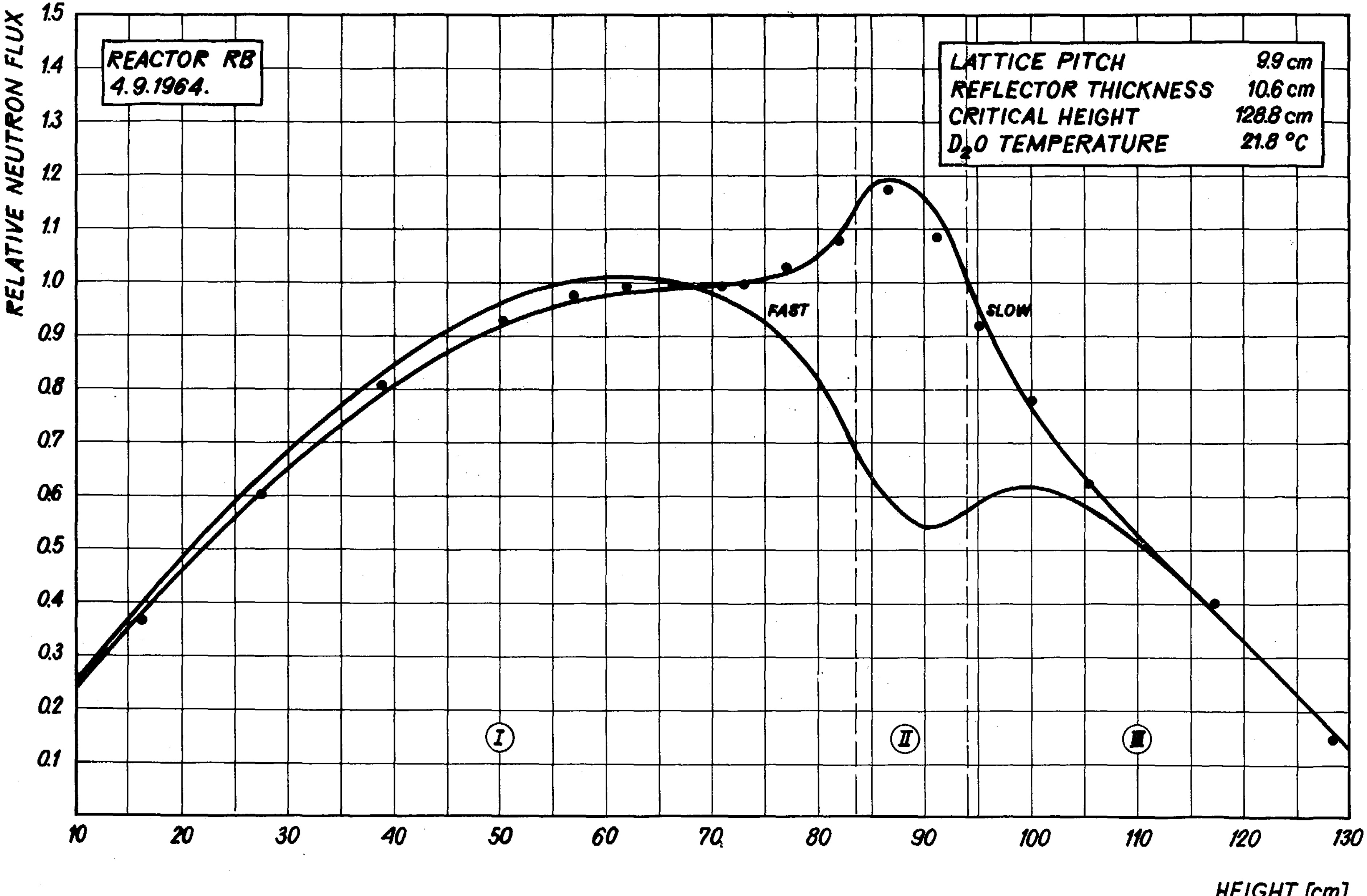

FIG. 9 – AXIAL FLUX DISTRIBUTION No 8

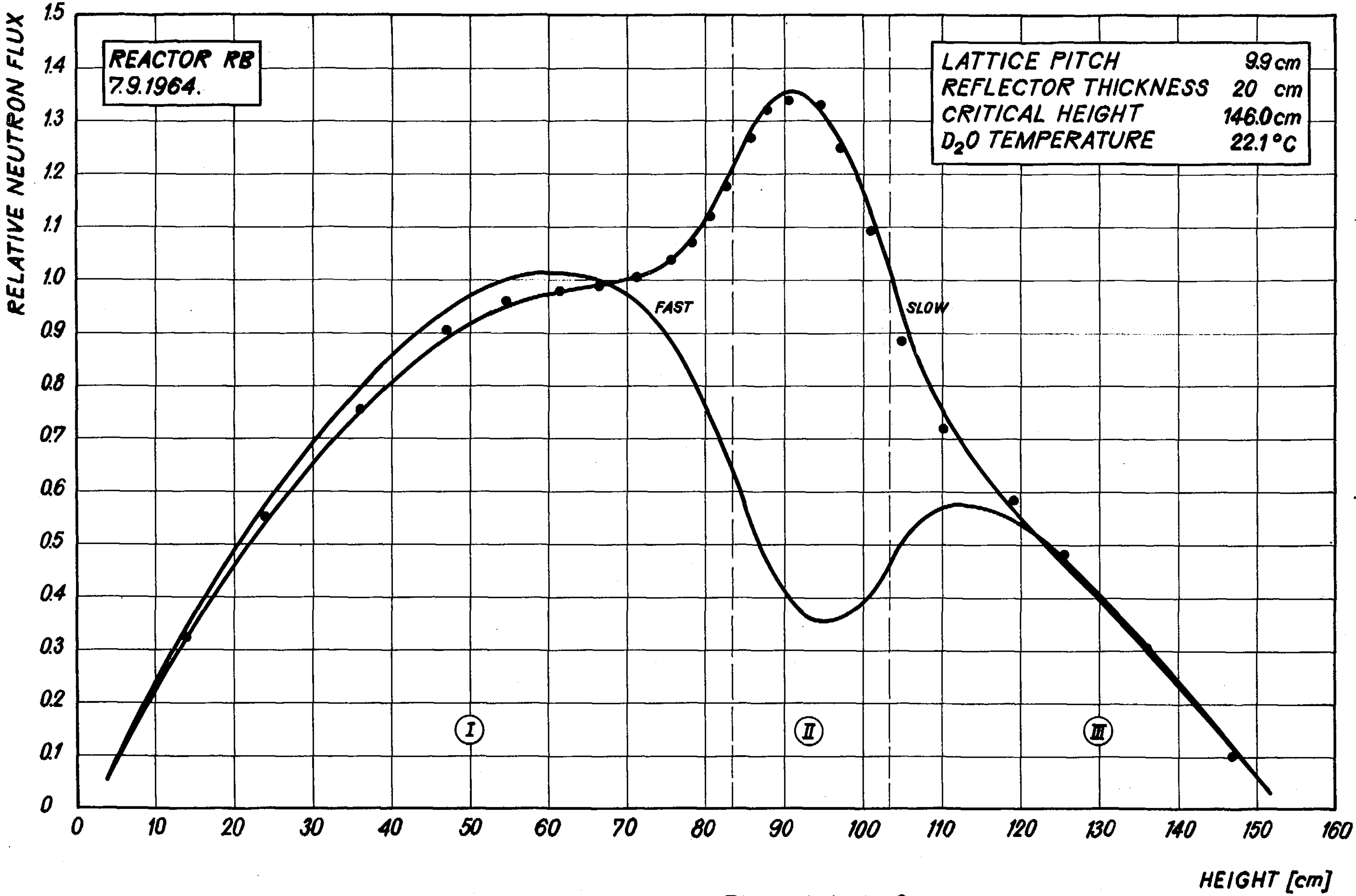

FIG. 10 – AXIAL FLUX DISTRIBUTION No 9

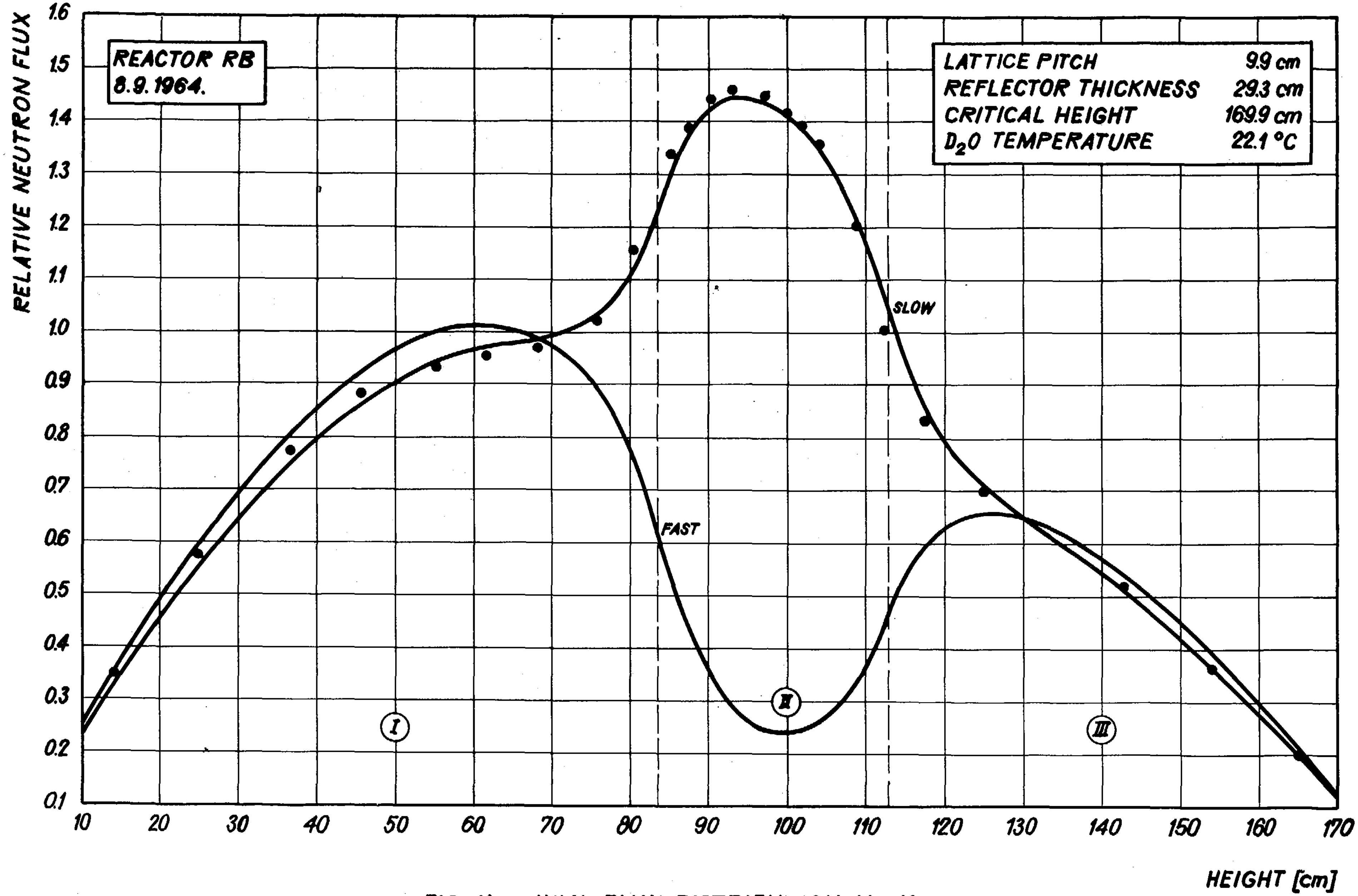

FIG. 11 – AXIAL FLUX DISTRIBUTION No 10

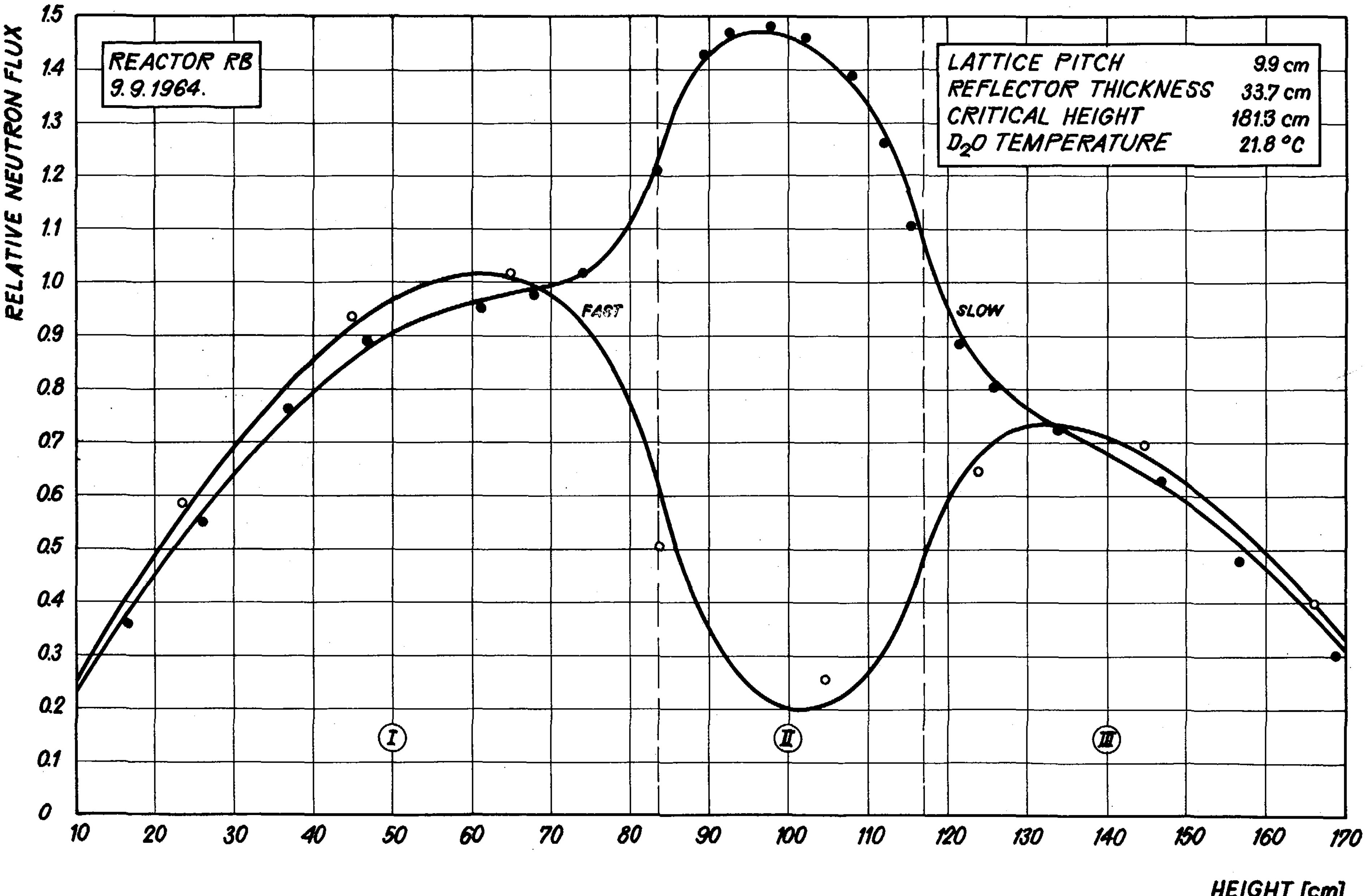

FIG. 12 – AXIAL FLUX DISTRIBUTION No 11

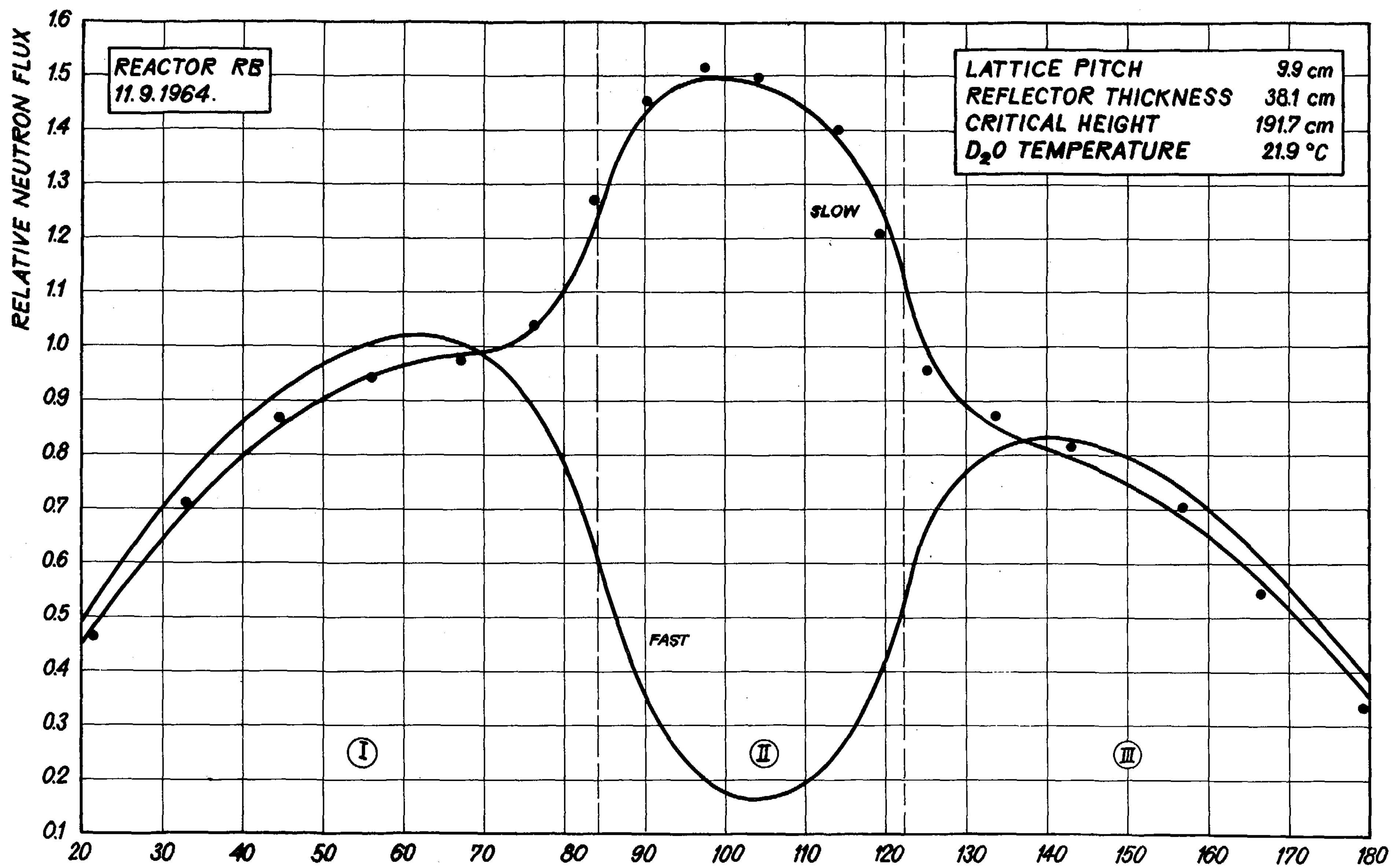

FIG. 13 – AXIAL FLUX DISTRIBUTION No 12

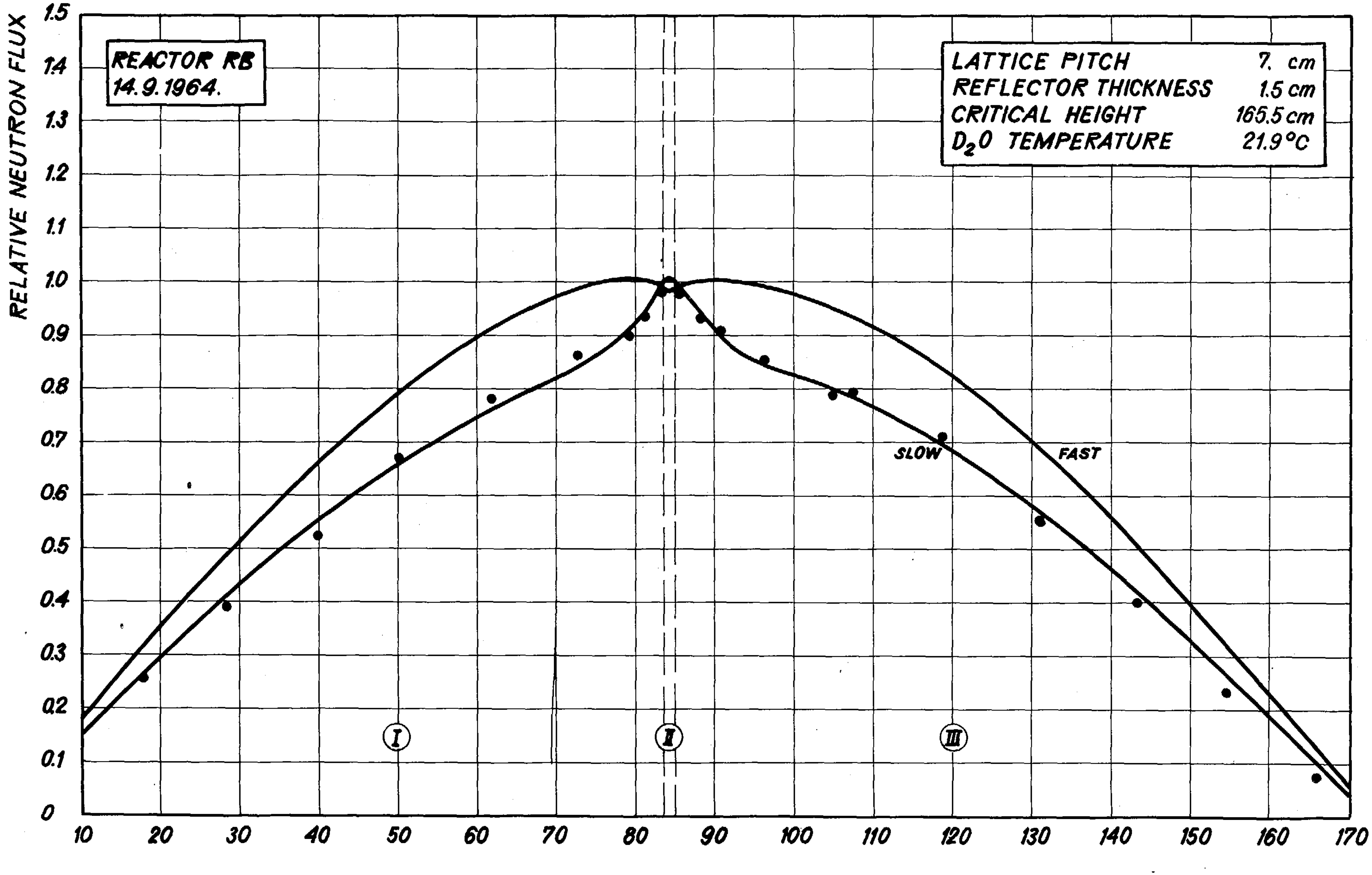

FIG. 14 - AXIAL FLUX DISTRIBUTION No 13

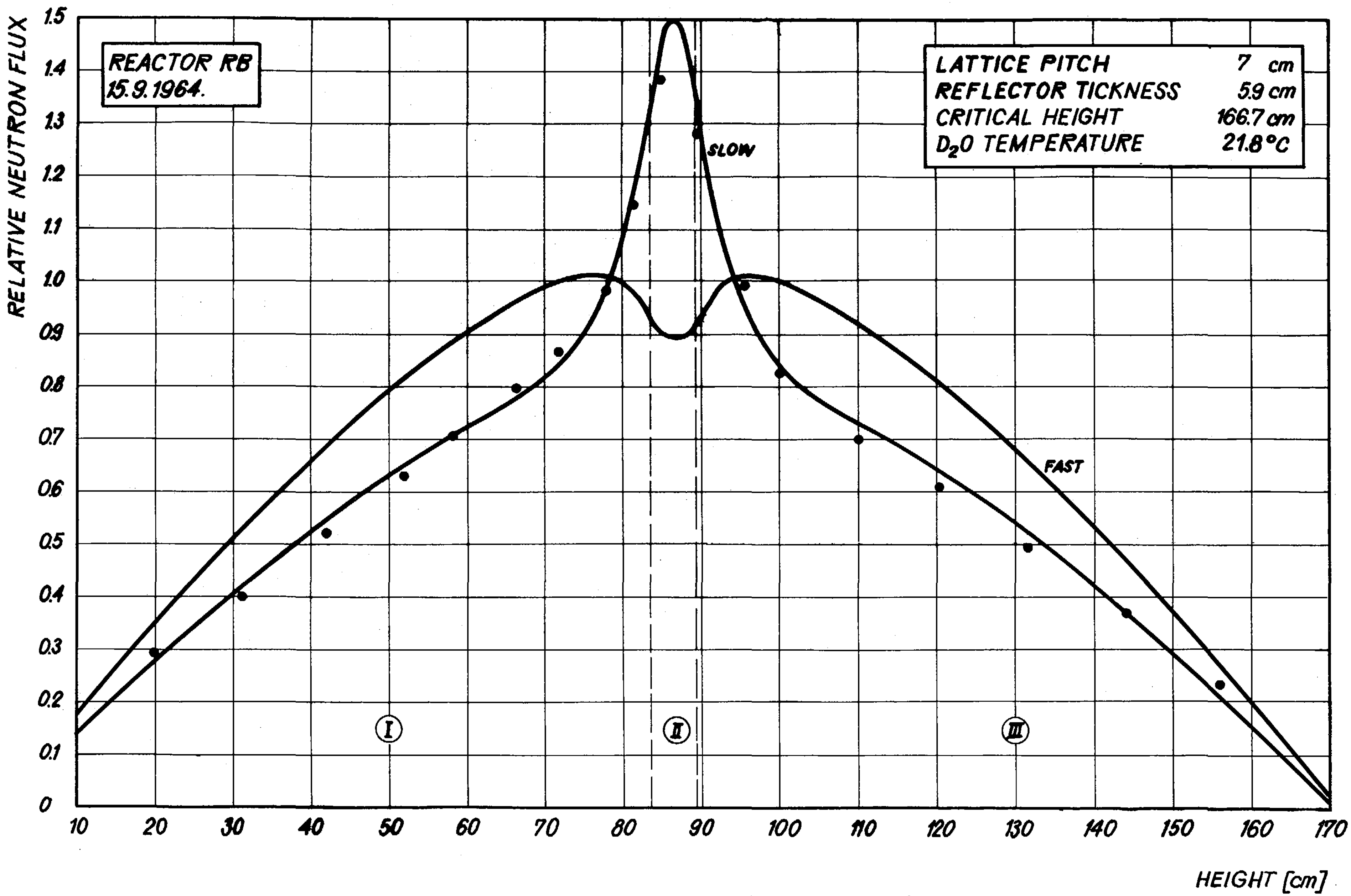

FIG. 15 – AXIAL FLUX DISTRIBUTION No 14

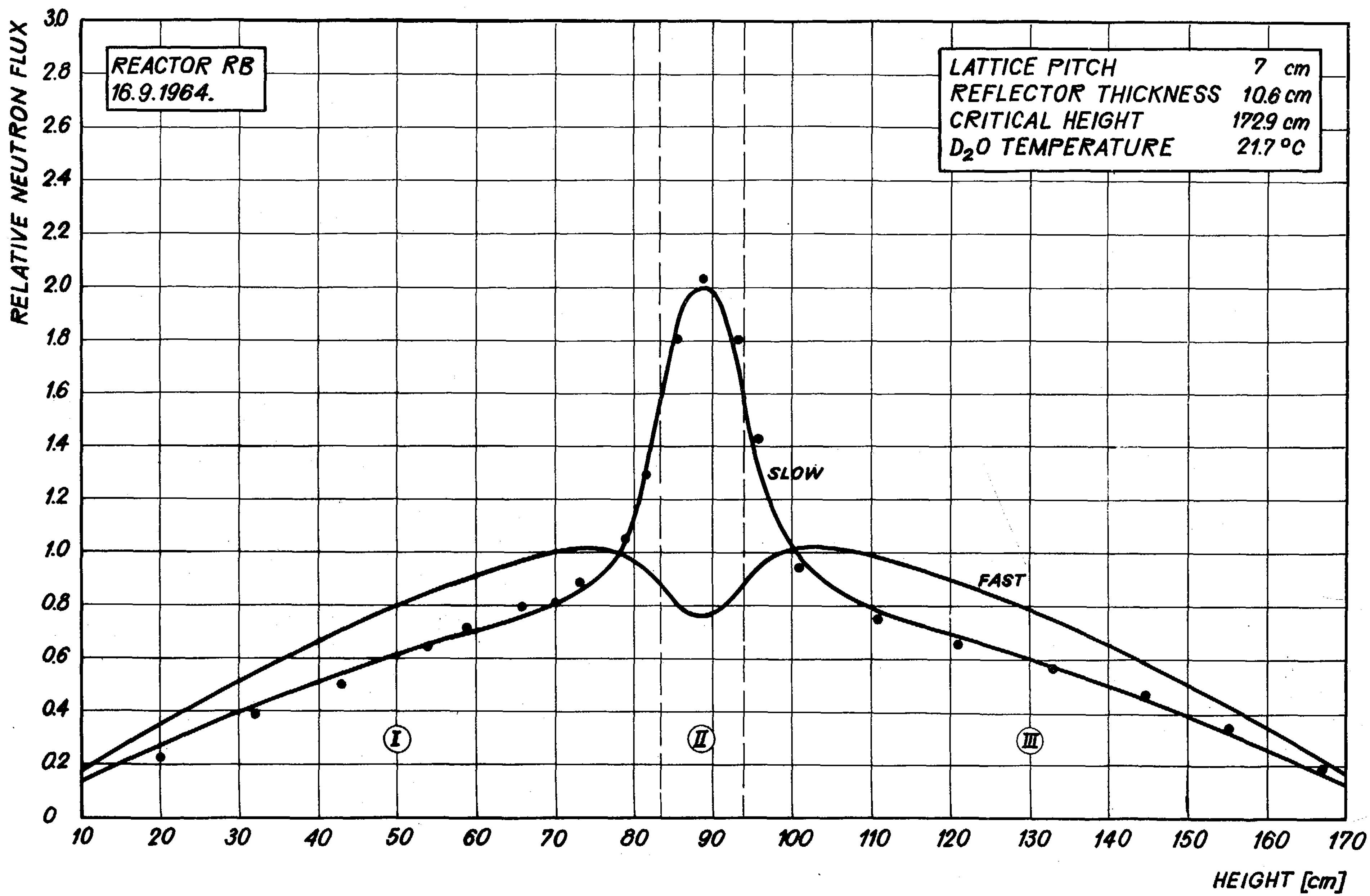

FIG. 16 - AXIAL FLUX DISTRIBUTION No 15

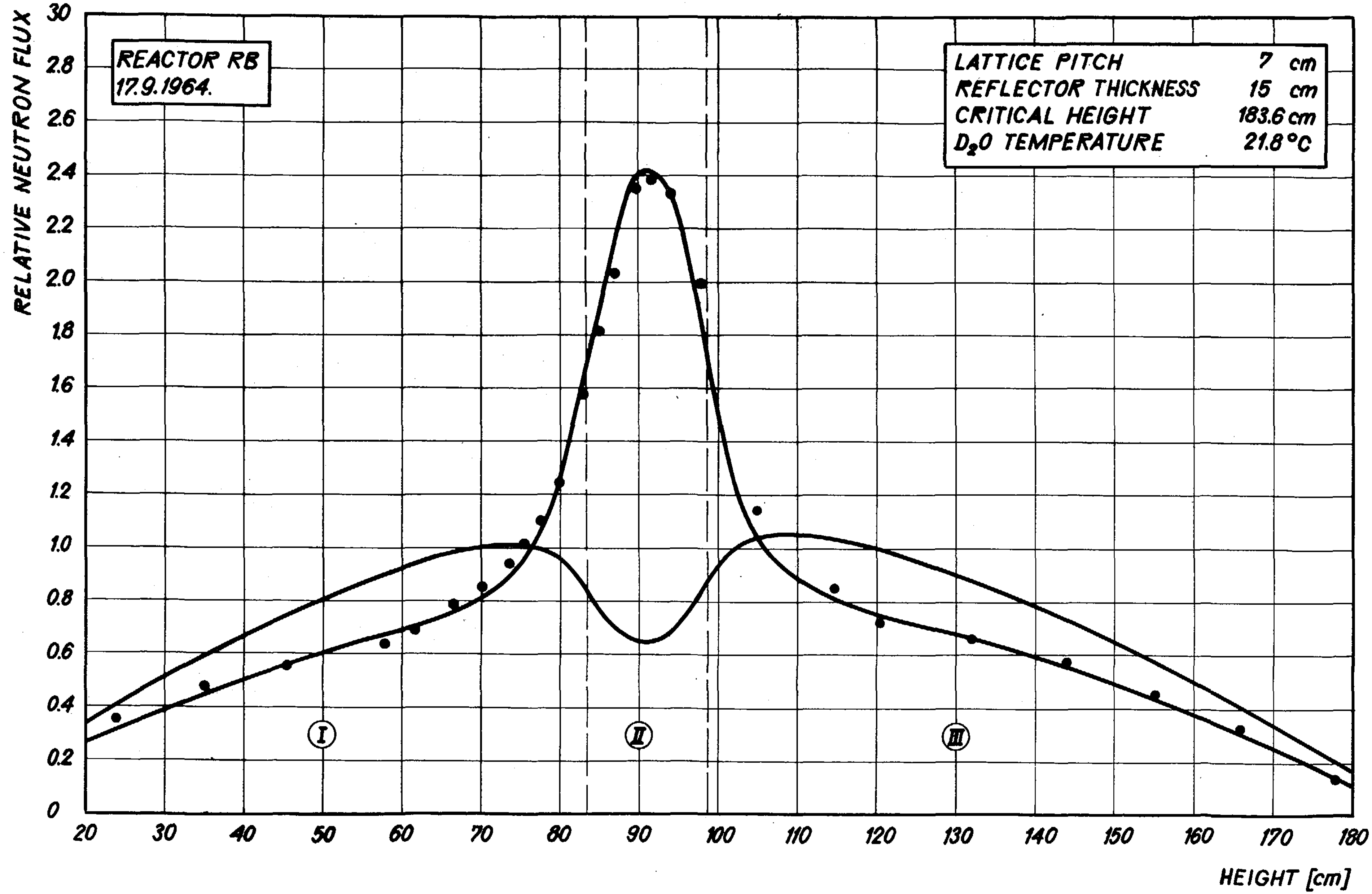

FIG. 17 – AXIAL FLUX DISTRIBUTION No 16

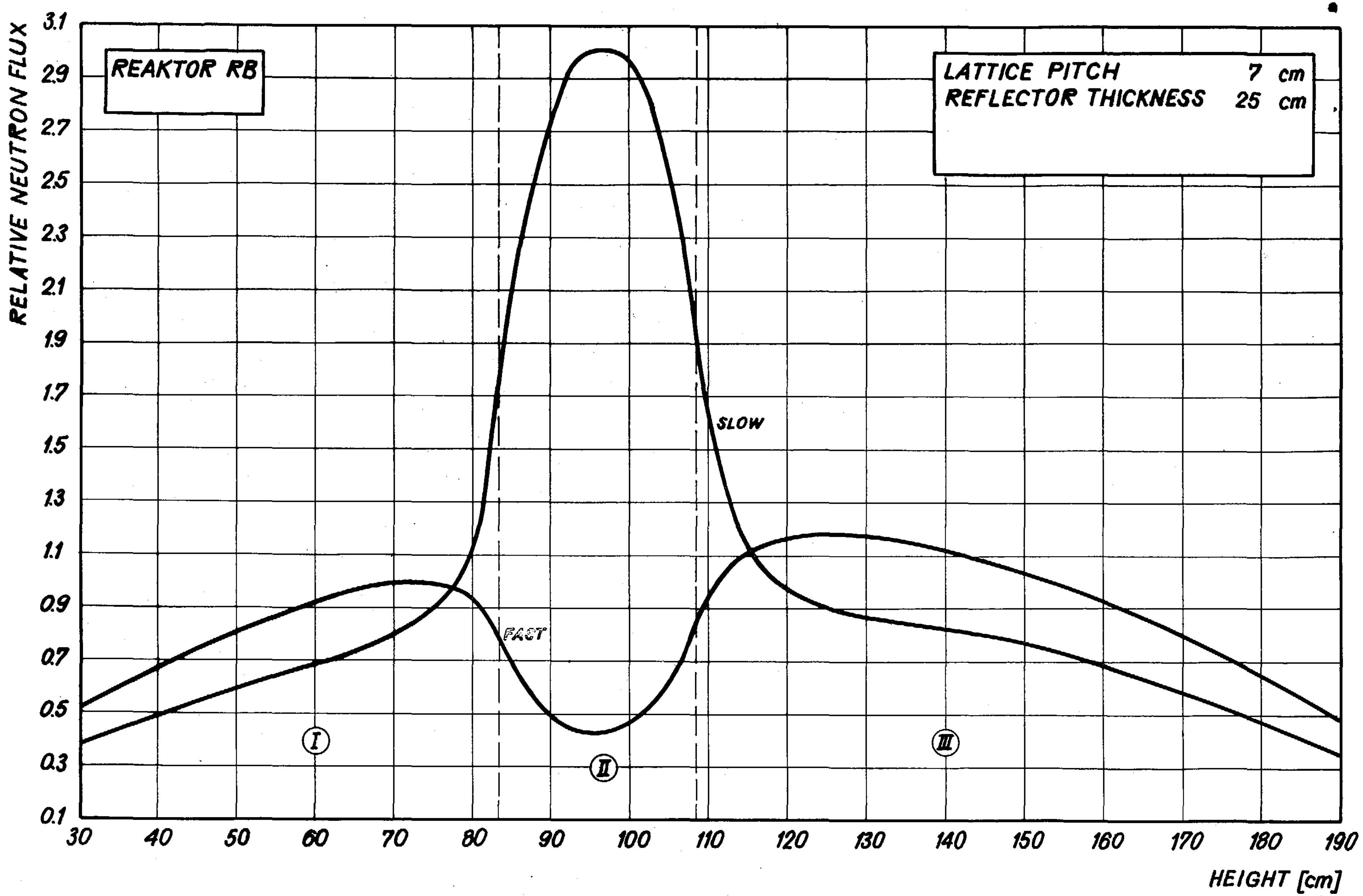

FIG. 18 – AXIAL FLUX DISTRIBUTION No 17

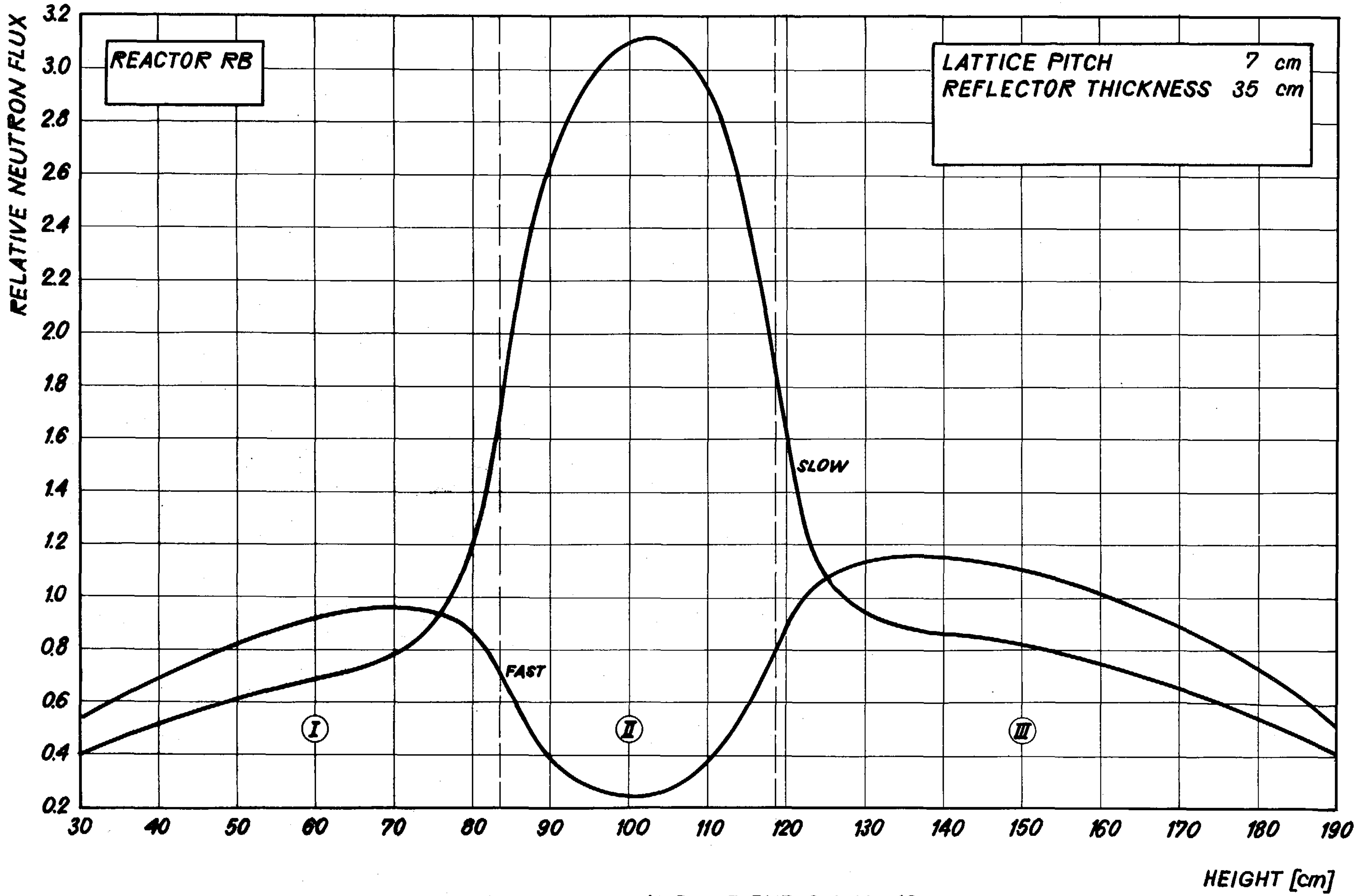

FIG. 19 – AXIAL FLUX DISTRIBUTION No 18

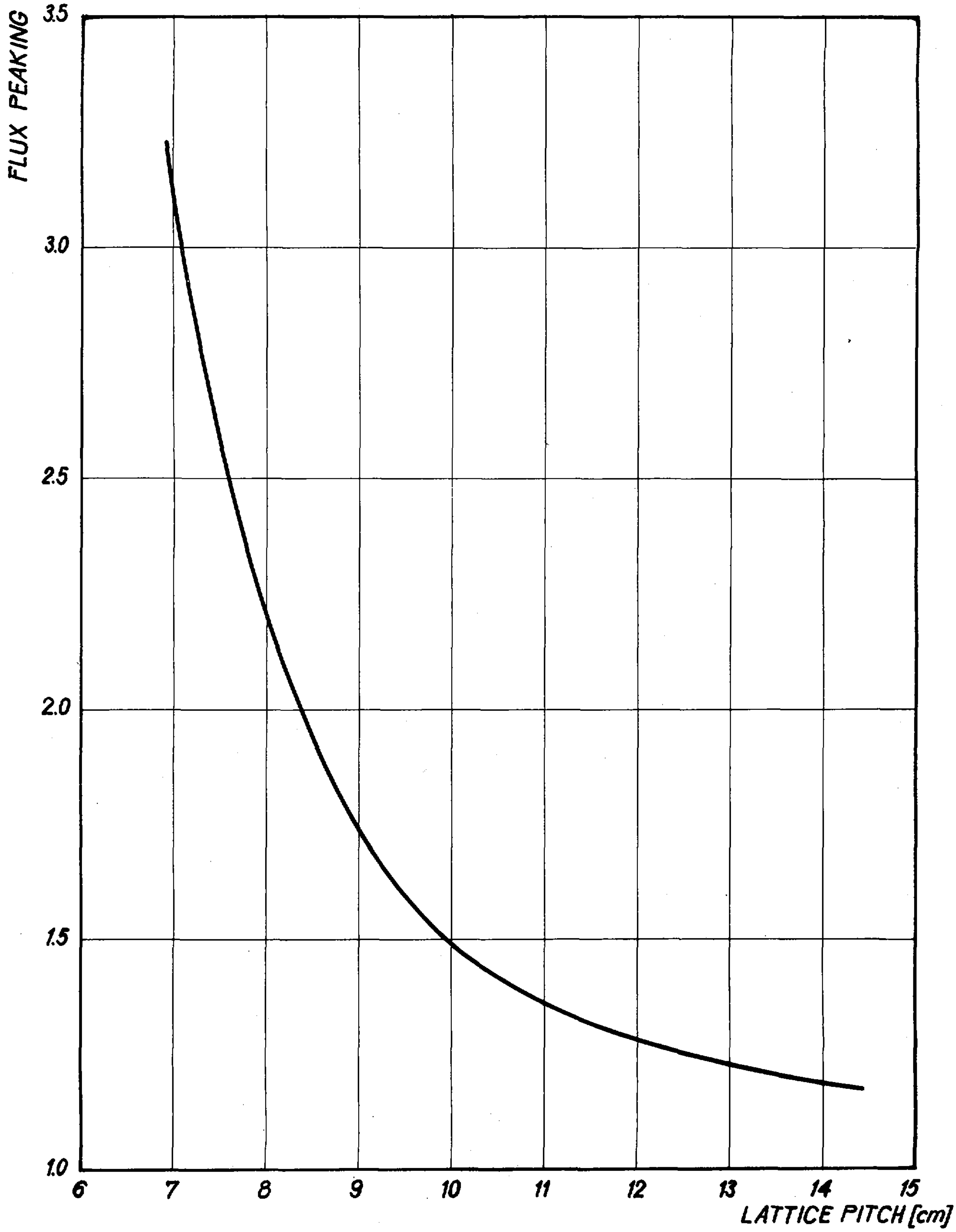

FIG. 20 - MAXIMAL FLUX PEAKING V.S. LATTICE PITCH

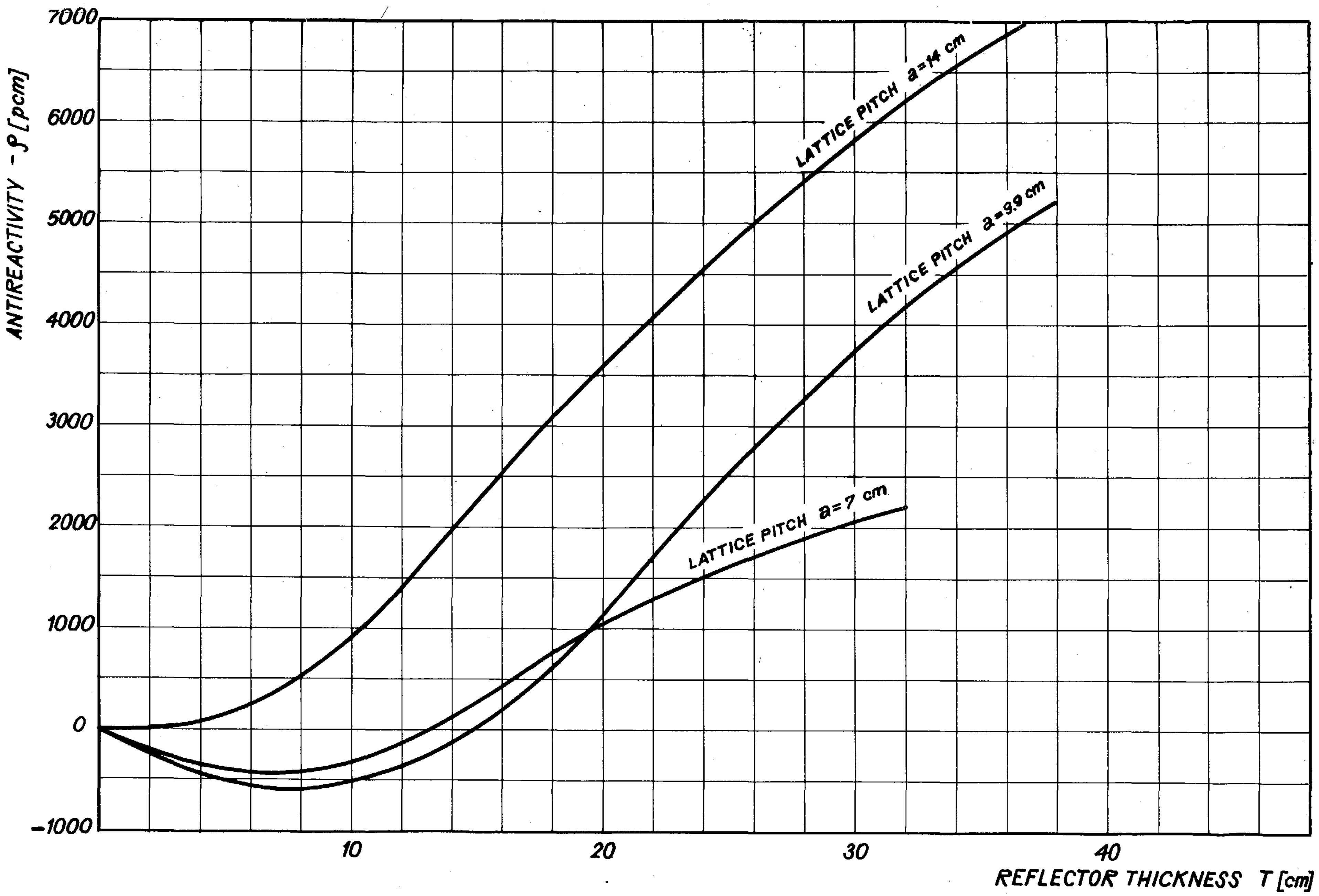

FIG. 21 – CENTRAL REFLECTOR ANTIREACTIVITY

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