

**EUR 134.e**

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

# CAROLINE I

## A CALCULATION METHOD FOR NON IRRADIATED ORGANIC LIQUID HEAVY WATER LATTICES

by

G. CASINI, W. de HAAN, E. DIANA  
C. FOGGI, A. KIND, G. ROSSI

1962



**ORGEL Program**

**Joint Nuclear Research Center  
Ispra Establishment - Italy**

**Reactor Physics Department  
Applied Physics and Mathematics**



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European Atomic Energy Community - Euratom — ORGEL Program  
Joint Nuclear Research Center — Ispra Establishment — Italy  
Reactor Physics Department (Applied Physics and Mathematics)  
Brussels, November 1962 — pages 21 + figures 5

The main lines of the non irradiated lattice calculations in ORGEL type reactors are set out below. This method (called CAROLINE I) is based on the French correlation for heavy water moderated and cooled lattices and takes due account of the differences arising out of the presence of organic in the fuel element.

The method has been compared with the results of critical experiments carried out on natural uranium oxide, heavy water, organic lattices and a fairly satisfactory agreement has been found.

Annex I illustrates the criteria used to determine the effective resonance integral constants of the uranium carbide lattices for which no experimental values are available.

CAROLINE I has been programmed on IBM 7090. Annex II shows the arrangement of the code input and output data.

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CAROLINE I  
A CALCULATION METHOD FOR NON IRRADIATED  
ORGANIC LIQUID HEAVY WATER LATTICES

SUMMARY

The main lines of the non-irradiated lattice calculations in ORGEL type reactors are set out below. This method (called CAROLINE I) is based on the French correlation for heavy water moderated and cooled lattices and takes due account of the differences arising out of the presence of organic in the fuel element.

The method has been compared with the results of critical experiments carried out on natural uranium oxide, heavy water, organic lattices and a fairly satisfactory agreement has been found.

Annex I illustrates the criteria used to determine the effective resonance integral constants of the uranium carbide lattices for which no experimental values are available.

CAROLINE I has been programmed on IBM 7090. Annex II shows the arrangement of the code input and output data.

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## 1. Introduction

The aim of this report is to illustrate the calculation method of organic-liquid cooled, heavy water moderated lattices within the framework of the ORGEL reactor studies.

This method of calculation, which relates to non-irradiated hot lattices, is based on the results of the French correlation for heavy water moderated and cooled lattices (Ref. 1).

This correlation, for which we are indebted to Mr. Naudet and his associates, was obtained as the result of a long series of cold lattice buckling measurements made at Saclay on AQUILON, a heavy water, natural uranium critical assembly.

The parameters adjusted in this correlation are :

- $\eta$  (thermal fission factor),
- the constants A and B of the effective resonance integral.

We have assumed the fundamental hypothesis that these three constants remained identical for the ORGEL lattices.

The fact of having accepted these values requires conformity with Naudet's calculation method as regards the magnitudes which, in the correlation, are assigned to calculation, as well as with the values put forward by him for the nuclear constants which enter into the calculations.

In order to make allowance for the characteristics for which the studied lattices differ from those on which the French correlation was based, particularly the presence of organic liquid instead of heavy water in the fuel element, appropriate modifications to Mr. Naudet's calculation method have been introduced.

This procedure may be considered all the more correct as the evaluation of the effects peculiar to organic liquid cooled lattices is more thorough.

## 2. Lattice calculations

### a. Thermal utilization

For the calculation of the lattice thermal utilization, we have adopted the hypothesis (which, according to Mr. Rossi's studies (Ref. 2), seems a reasonable one) that the spectrum hardening



due to absorption in the fuel element and the heating effect due to the interaction of the neutrons with the hot coolant are, at least in a first approximation, independent of each other.

In view of the fact that in the French correlation of the heavy water lattices we use, the spectrum hardening due to absorption is not calculated theoretically but directly incorporated in the adjusted constants (Ref. 3), we have, in the thermal utilization calculation, only taken account of the spectrum effects connected with the heating of the organic liquid.

In this regard, use is made of the results of the "Termidor" program (Ref. 4) in which, by means of a thermal neutron two-group model, the thermal cross sections of the various lattice materials are calculated.

On the basis of these data, the thermal utilization factor is calculated with reference to the following cell geometry :

- a) homogenized cylindrical region obtained by linking each fuel rod with its own cladding and the same quantity of coolant and, if needed, of filler ("elementary cell" method);
- b) cylindrical ring between the homogenized rod surface a) and the pressure tube internal radius (organic liquid homogenization, with filler if appropriate);
- c) cylindrical rings including pressure tube, thermal insulation layer and calandria tube;
- d) heavy water cylindrical ring.

As regards the materials contained in the region a), the absorption of the casing and organic liquid around the fuel rods in the cluster is calculated by adopting the same disadvantage factor, which is given by the expression of the Amouyal and Benoist theory relating to the rod (Ref. 5). The ratios between the average fluxes in the various rings b), c), d) and the average flux in the homogenized central region are calculated by the Amouyal and Benoist method extended to cover the case of a cell containing any number of concentric media (Ref. 6).

#### b. Fast fission factor

The fast fission factor is calculated with the formulae and constants used by Naudet (Ref. 7), as adjusted to the well-known article by Spinrad (Ref. 8). Owing to the presence of hydrogen

in the organic liquid, one introduces into the "inelastic" section a contribution due to the elastic collisions with the H nuclei, as a consequence of which the neutron is below the fission threshold in  $U_{238}$ .

c. Diffusion area

The diffusion area is calculated by averaging (on the volumes and the fluxes) the transport cross sections inside the fuel element and the mean free paths by passing from the element to the cell. In the absence of substantial anisotropy effects, it has been possible to verify that this procedure gives very close results to those obtained by the Benoist method (Ref. 9).

d. Slowing-down area

The slowing-down area is calculated by the conventional formula, which brings into prominence the age of the neutrons in the pure moderator. In evaluating this latter factor, account is taken of the neutrons which begin to slow down beyond an energy lower than the average fission energy as a result of the inelastic collisions with the U nuclei and elastic collisions with the H nuclei of the organic liquid inside the original fuel element.

e. Resonance escape probability

The resonance escape probability is calculated by the conventional formula :

$$p = e^{-\frac{I_{\text{off}}}{(\xi \Sigma_s)_m \frac{V_m}{V_c}}}$$

by introducing a corrective factor so as to take into account the non-uniform distribution of the slowing-down density at the energy  $E_R$  of the  $U_{238}$  resonances (Ref. 10) : the determination of this factor depends on the choice of  $E_R$ , which is relatively arbitrary in view of the extent of the resonance region. In keeping with the results of the Canadian correlation (Ref. 11),  $E_R$  has been chosen equal to 30 eV.

As regards the effective resonance integral

$$I_{\text{off}} = A + B \sqrt{\frac{S}{M}}$$



Naudot's recommendations have been complied with (Ref. 3). They can be summarized as follows :

- a) the constants A and B are provided by correlation, with two different values for the metal and the oxide;
- b) the effective surface S is expressed in the form :

$$S = S_o + \alpha S_i$$

$S_o$  is defined in fig. 1

$S_i$  is the difference between  $S_{tot}$  and  $S_o$

- c) the factor  $\alpha$  is calculated by the formula :

$$\alpha = 1 - 2 E_3 \left( \sum_s^{ris} r \right)$$

in which  $\sum_s^{ris}$  is the resonance scattering cross section for the organic inside the cluster; r is the hydraulic radius of the organic liquid of each fuel rod, being defined in a somewhat different manner from the usual one, i.e. :

$$r = \frac{2 \times \text{volume of organic connected with each rod}}{\text{fuel surface of one rod}}$$

It should be noted that the French correlation does not give the values of the constants A and B for the case of uranium carbide, as no buckling measurements were carried out on AQUILON for this type of fuel.

It was therefore necessary to determine the values of the constants which fall within the effective resonance integral, on the one hand by using Vernon's theoretical studies (Ref. 25) and on the other hand by taking as a basis the correlated values for the oxide and the metal. The general criteria adopted and the further calculations made in order to arrive at an effective resonance integral value of the carbide in line with the selected correlation, are described in Annex I.

### 3. Choice of nuclear constants

As regards the data on the effective fuel sections, the values adopted were, as stated above, those proposed by Mr. Naudet and co-workers. The evaluation of the uranium thermal absorption cross section was carried out with the Westcott factors  $g_{a5}$  and  $g_{f5}$  (Ref. 26). By using the data proposed in this report, a satisfactory agreement is obtained in the cold state with the effective uranium section value used in the French correlation.

The SAP (Sintered Aluminium Powder) nuclear constants were calculated on the basis of a 230 mb 2200 m/s microscopic aluminium cross section value (Ref. 14). This value is about 10 % lower than the one used by the French in evaluating the AQUILON heavy water lattice experiments, a value deduced after oscillation measurements (Ref. 1).

This difference may be due either to the presence of impurities in the aluminium used in the AQUILON experiments, or to the measuring method. In this connection, it should be noted that in Supplement No. 1 of BNL 325 a British value (Harwell) is recorded for the 241 mb 2200 m/s aluminium cross-section, which is thus somewhere between what we use and the French value.

We have given preference to the 230 mb value because it makes it possible to obtain a better agreement with the first experimental results (see § 4).

The nuclear constants of the organic liquid have been evaluated for diphenyl and triphenyl.

a) thermal sections : use has been made of the Ref. 12 values, and in particular of the diffusion and transport microscopic section curves of hydrogen bound in an organic molecule. These curves are deduced from the results of measurements made by Molkonian for various hydrocarbons (Ref. 13). The butadiene curve was adopted because it represents an average value. It must, however, be pointed out that the differences may reach 14 %, which gives an idea of the uncertainty of these values.

On the basis of the diffusion and transport section curves of the bound hydrogen, the effective diffusion sections and the transport mean free path of the organic liquid have been averaged over a Maxwellian distribution at neutron temperature.



- b) epithermal sections : the chemical binding effects were disregarded.
- c) sections averaged over the fission spectrum : the averages were evaluated numerically by referring to the BNL 325 curves (Ref. 14) and to the ANL 5800 report data (Ref. 15) with respect to the fission spectrum.

#### 4. Comparison with experiments

A first comparison between the buckling values calculated by the CAROLINE I method and the experimental values was made, using the results of critical experiments conducted at Saclay by Euratom and at Chalk River by the Canadians of the AECL.

The first series of measurements was carried out on the AQUILON II pile at Saclay (France); the progressive replacement method (Ref. 16) was used to determine the bucklings of 9 natural uranium heavy water organic liquid lattices (Ref. 17). During the experiments, three types of fuel element were used, namely :

- a) cluster of 19 magnesium-clad uranium oxide rods 12 mm in diameter, immersed in an organic liquid contained in a hexagonal aluminium tube; the distance between the boundaries of two adjacent rods was 1 mm (AO-12-1);
- b) the same fuel element, but with adjacent rods in contact (AO-12-0);
- c) cluster of 19 uranium oxide rods 16.2 mm in diameter, with a distance of 1 mm between rods, arranged as in the previous cases (AO-16-1).

The results are shown in figures 1, 2 and 3. As will be seen, the trend of the curves calculated is in fairly satisfactory agreement with the experimental results. As regards the absolute values, these are seen to have been kept for the most part within the experimental error margin, except in case AO-12-1 where a slight degree of optimism is observed.

The second series of measurements used was carried out on ZED-2 at Chalk River (Canada). In these experiments, the fuel elements were clusters of 7 aluminium-clad uranium oxide rods 24.4 mm in diameter, immersed in an organic liquid (HB-40) contained in a circular aluminium tube.

Measurements were made at 5 different hexagonal pitches and the results are shown in fig. 4 (Ref. 18).

Here the trend of the theoretical curve is slightly different from the one of the experimental curve. However, taking account of the fact that the range of the considered pitches is very wide (19 to 28 cm) and that the points calculated generally stand within the experimental margins, it may be said that in this case too there is quite a satisfactory measure of agreement. In particular, it can be noted that the theoretical calculations are slightly pessimistic in the pitch region with which we are directly concerned for the purpose of the project (between 22 and 26 cm).

Since in the case of 19 rods the opposite phenomenon was observed, there is reason to believe that in our formula due account is not taken of some effects connected with the element geometry, i.e. of the fact that the cluster consists of 7 or 19 rods.

##### 5. Remarks on the calculation method development

The formulae, as outlined above, were devised at the start of the ORGEL studies, when no experimental results were available on organic liquid heavy water lattices.

Referring to a correlation for heavy water moderated and cooled lattices offered the advantage of making it necessary to work out the differential effects due to the presence of the organic liquid rather than to make absolute evaluations for the neutron balance of our type of lattice.

Furthermore, as the French calculation method is expressed very synthetically, we have been able to develop an instrument that was fairly easy to handle, being thoroughly suitable for orientation calculations and not requiring the use of big computers.



As the experimental results on organic liquid, heavy water lattices are becoming usable, and as remarkable data processing facilities are now available at Ispra, the opportunity arises of devising a new set of formulae for this type of lattices.

However, the fact that on the one hand the set of formulae has to be used continually for the ORGEL project calculations, and that on the other hand there is a fairly satisfactory agreement with the first experimental results, has justified programming the formulae on the IBM 7090 computer.

The CAROLINE I code as drawn up in this form is described in broad outline in Annex II.

The following items show the main respects in which we believe the present method of calculation can be improved in order to establish a new set of formulae more in keeping with the physical reality.

a.) Effects related to thermal neutron spectrum

As we said at the start, the present set of formulae does not calculate the hardening effect due to thermal absorption in the fuel, which practically remains within the constants  $\lambda$ , A and B deduced from the experiments.

Considering that this effect is proportionate to the lattice pitch and to the geometry of the fuel element, it would be more convenient to entrust it to theoretical calculation than to leave it to correlation.

A study on this subject is now in progress at Euratom; the reference adopted is E.U. Vaughan's method (Ref. 19), which is applied to a cylindrical rod, and due account is taken of the presence of a moderator such as organic liquid in the central homogenized rod of the ORGEL lattices. The initial comparisons of this method with the results of the Canadian experiments seem to be satisfactory (Ref. 20).

It can also be seen that the present calculation method is not suitable for the epithermal effects. This point, like the previous one, is more generally related to the problem of representing the spectrum in a well-moderated reactor as in the case of ORGEL; it will furthermore be possible to resolve it accurately, either by selecting a satisfactory spectrum model in the reactor (e.g., the Westcott or the Horowitz and Tretiakoff model) (Ref. 21), or by

calculating the thermal and epithermal utilization factor by a several energy group method. In this connection, a study is shortly going to be started for utilizing the  $S_n$  method.

b) Thermal utilization factor calculation

The homogenization criteria of the central rod in the calculation of the disadvantage flux factors on the lattice are rather arbitrary. It will be possible to improve this calculation by dividing the fuel cluster (and the materials that can be connected to it) into several cylindrical layers corresponding to the various crowns which make up the cluster.

This substitution of several cylindrical regions for the homogenized central rod will also improve the accuracy of the results obtained by the Amouyal and Benoist method. This method is based on the hypothesis that in each concentric region the collision probability is the one which corresponds to a distribution of the uniform sources after the first (or second) collision. It will be possible to fulfil this condition more easily by increasing the number of these regions. (\*)

c) Calculation of the resonance escape probability p

The use of a very simple relation for the evaluation of p involves the risk of creating difficulties, even if the  $I_{off}$  constants are adjusted to the experiment, especially on account of the presence of an important moderator inside the rod, such as organic liquid.

It is therefore planned to improve the present formulation by making the several neutron group calculation in the resonance region by means of the calculating method developed by Brooks and others (Ref. 22).

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(\*) In view of the importance which these effects will assume in the case of ORGEL type fuel elements, a series of fine structure experiments of the neutron density to be conducted at Saclay on AQUILON has been programmed in the current year.

d. Calculation of  $\epsilon$

A revision of the initial data for the calculation of  $\epsilon$  is in progress. In particular, the fast  $v_8$  used (2.51) seems to be much too low in relation to the values obtained from the latest experiments (2.83).

e. Organic liquid nuclear constants

The diffusion section of the bound proton in the organic molecule has been measured by Molkonian in 1949. We have temporarily used his curve, disregarding the fact that Molkonian's measurements refer to hydrocarbons with a low hydrogen concentration. We contemplate using more recent measurements (Ref. 23), while at the same time an experimental program has also been launched at Ispra in this connection.

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## ANNEX I

### Effective resonance integral for uranium carbide

As stated at the beginning, in the French correlation for heavy water lattices the resonance absorption is determined by adjusting the numerical coefficients of the effective integral to a series of material buckling measurements. The effective integral  $I_{\text{eff}}$  thus determined is fictitious : it is only valid as part of the expression of the lattice  $k_{\infty}$  and often differs appreciably from the true effective integral.

The lack of buckling measurements for heavy water uranium carbide lattices, and of information on the resonance absorption measurements of these lattices, has induced us to make a brief estimate of the effective integral in accordance with the following considerations :

1. The resonance absorption theory (Ref. 24) shows that the effective integral for uranium rods mixed with diffusing materials mainly depends on the parameter :

$$\zeta = \frac{S}{4VN_U U} + \frac{N_m \sigma_m}{N_U \sigma_U}$$

in which :

$S$  and  $V$  are the surface and the volume of the rod

$N_U$  is the atom number per  $\text{cm}^3$  of uranium 238

$\sigma_U$  is the uranium potential cross-section

$\sigma_m$  is the diffusion cross-section of the diffusing materials

$N_m$  is the atom number in the diffusing materials per  $\text{cm}^3$

The equality between the resonance integrals of two rods containing different diffusing materials, leads to the equality between the respective values of  $\zeta$ .

This equality makes it possible to link up the  $\frac{S}{V}$  (or  $\frac{S}{M}$ ) values of the two rods.

2. Vernon (Ref. 25) has adjusted the numerical coefficients of this relation in the case of uranium carbide (UC) with regard to metal and to oxide, by using Hellstrand's experimental results.

The following expressions were found :

$$\left(\frac{S}{M}\right)_{UC} = 0.952 \left(\frac{S}{M}\right)_U - 0.046 \quad (1)$$

$$\left(\frac{S}{M}\right)_{UC} = 1.08 \left(\frac{S}{M}\right)_{UO_2} + 0.027 \quad (2)$$

3. It was confirmed that these two relations, with the same coefficients, are also valid (at least in a certain field) for the integrals derived from the French correlation and, on the basis of these relations, the carbide integral was finally calculated.

The details of the calculations are as follows :

The expressions of the  $I_{\text{eff}}$  as correlated in line with our set of formulae are, for the oxide and the metal respectively (  $\rho$  being the fuel density ) :

$$I_{\text{eff}} = \frac{P}{10} \left[ 0.133 + 0.088 \sqrt{\frac{S}{V} \frac{10}{\rho}} \right] \quad (3)$$

$$I_{\text{eff}} = \frac{P}{18.9} \left[ 0.101 + 0.195 \sqrt{\frac{S}{V} \frac{18.9}{\rho}} \right] \quad (4)$$

The same, when expressed as a function of  $\frac{S}{M}$ , take the following form :

$$I_{\text{eff}} = \frac{P}{10} \left[ 0.133 + 0.278 \sqrt{\frac{S}{M}} \right] \quad (5)$$

$$I_{\text{eff}} = \frac{P}{18.9} \left[ 0.101 + 0.847 \sqrt{\frac{S}{M}} \right] \quad (6)$$

The microscopic effective integrals are in both cases :

$$i_{\text{eff}} = 2.12 + 17.81 \sqrt{\frac{S}{M}} \quad (7)$$

$$i_{\text{eff}} = 5.96 + 12.47 \sqrt{\frac{S}{M}} \quad (8)$$

If the relations (1) and (2) are introduced in (7) and (8), the following two expressions are obtained for uranium carbide :

$$i_{\text{off}} = 2.12 + 18.17\sqrt{\frac{S}{M} + 0.046} \quad (9)$$

$$i_{\text{off}} = 5.96 + 12.0\sqrt{\frac{S}{M} - 0.027} \quad (10)$$

By plotting a graph of the two functions, it can easily be verified that they coincide almost perfectly in the case of  $\frac{S}{M}$  ranging between 0.05 and 0.2.

This means that the correlated integrals of metal and oxide are in fact interlinked by the relations given by Vernon.

In conclusion, an expression adapted to (9) and (10) is assumed as the  $i_{\text{off}}$  of the carbide and has the following value :

$$i_{\text{eff}} = 19.664\sqrt{\frac{S}{M} + 0.1155} \quad (11)$$

By making on (11) the opposite transformations to those performed in the cases of the oxide and the metal, we obtain :

$$I_{\text{eff}} = \left[ 0.171\sqrt{\frac{S}{V} \frac{13}{\rho} + 1.5} \right] \frac{P_{UC}}{13}$$

which is the value used in our calculation method.





## ANNEX II

The calculation method which we have just outlined has been programmed on IBM 7090. The program was written in FORTRAN language by Mr. Dorpema of the CETIS at Ispra.

The code consists of a main program, which calculates the lattice parameters, and a number of sub-programs for calculating the effective cross-sections and the geometrical data of the various media.

The program is written for the following fuel element geometries (with and without outer fillers) :

- 7-rod hexagonal
- 19-rod hexagonal
- 19-rod circular
- 22-rod, with three types of rods of different radius
- 4-element (with central filling tube)
- single rod.

The lattice cell is divided into the regions shown in the following table (which contains the option number, the possible materials for each region and the number of options for these materials) :

<u>Name of region</u>	<u>Materials</u>
Fuel	URO(2), URC(3), URM(1)
Canning	SAP(8), STEEL(9)
Coolant	SAN(1), DIPH(2)
Outer coolant	as 3 with filling(1) or without (0)
Pressure tube	SAP(8), STEEL(9)
Insulation	SAN(1), DIPH(2), $Al_2O_3$ (3), $SiO_2$ (4)
Calandria	SAP(8), STEEL(9)

The key to the various symbols is as follows :

- URO = uranium oxide
- URC = uranium carbide
- URM = uranium metal
- SAP = sintered aluminium powder
- SAN = Santowax
- DIPH = diphenyl

DATA ARRANGEMENT

The input data for the program are set out on 5 punch-cards, as shown in the attached sheet.

1. Card of Materials

The options relating to the selected materials are to be introduced in columns 1, 6, 11, 16, 21, 26 and 31 of the first card. The remaining columns (up to 55) are filled in with the values of the spectral constants of the various media (numbers must be filled in on the extreme right). These latter constants  $T_{ni}$  are defined by the following expressions :

-  $\frac{1}{v}$  materials : 
$$T_{ni} = \frac{\pi T_o}{4} / \Lambda_i^2$$

in which  $\Lambda_i$  is defined in Ref. 3 and represents a Termidor program result.

- non  $\frac{1}{v}$  materials :  $T_{ni}$  is obtained by solving the equation :

$$g_i (T_{ni}) \sqrt{\frac{\pi T_o}{4 T_{ni}}} = g_i MV$$

in which  $g_i MV$  represents a Termidor result.

2. General data

The second card contains the following data :

- x  $U_{235}$  enrichment relating to value of  $U_{235}$  in natural uranium
- $S_f$  fuel density relative to reference density (UC = 13, UM = 18.9,  $UO_2 = 10 \text{ gr/cm}^3$ )
- $S_g$  filling density (graphite) relative to reference density ( $1.65 \text{ gr/cm}^3$ )  
weight percentage of  $Al_2O_3$  in SAP
- $\rho_{SAP}$  SAP density (in  $\text{gr/cm}^3$ )
- HBR(%) percentage of high boiling residues in SANTOWAX in %
- $\Sigma_{al}$  effective absorption section (averaged over a Maxwellian flux at fuel temperature  $T_n$ ) due to alloys contained in the fuel
- t grade (0 to 1) of heavy water
- $\Sigma_{HW}$  additional heavy water absorption section due to impurities other than light water (value at 2200 m/s)
- $\Sigma_{ex(SAP)}$  extra absorption in SAP due to impurities  $\times 10^5$  (value at 2200 m/sec)
- Name place (12 columns) for characterizing the calculation (which may be expressed by numbers or letters)

### 3. Geometrical data cards

These cards contain the geometrical data relating to the various types of fuel considered.

For the geometrical lay-outs, we have for Hex 7, Hex 19, Cir 19 :

#### CARD 3

s fuel rod radius  
s<sub>1</sub> clad rod radius  
a internal radius of pressure tube  
a<sub>1</sub> external radius of pressure tube  
a<sub>2</sub> internal radius of calandria tube  
a<sub>3</sub> external radius of calandria tube.

For the other cases, the following symbols must be used :

#### 4 rod case :

r external radius of central filling tube  
r-dr internal radius of filling tube

#### 22 rod case :

s<sub>1</sub> radius of central rod  
s<sub>2</sub> radius of second-ring rods  
s<sub>3</sub> radius of third-ring rods.

#### Single rod case :

S rod radius  
S<sub>1</sub> cladding inner radius  
S<sub>2</sub> cladding outer radius

Column 51 : type of geometry :

geometry	symbol	option number
7-rod hexagonal	Hex 7	1
19-rod hexagonal	Hex 19	2
19-rod circular	Cir 19	3
22-rod	Bun 22	4
4-rod	Bun 4	5
single rod	single	6

CARD 4

d axial distance from rods in hexagonal geometry

4-rod case :

d distance of other rods from centre of element

22-rod case :

d distance of centre of external ring of rods from centre of element

d<sub>1</sub> cladding thickness of central rods

d<sub>2</sub> cladding thickness of rods in first ring

d<sub>3</sub> cladding thickness of rods in second ring

For all geometries :

V<sub>r</sub> total volume of filling

V<sub>rif</sub> volume of filling inside homogenized central rod for f calculation

V<sub>ri</sub> do. for  $\epsilon$  calculation

V<sub>rip</sub> do. for p calculation

$\frac{V_m}{V_f}$  moderator (heavy water fuel volume ratio)

Code 1 without intermediate results

0 with intermediate results

CARD 5

Number of regions : number of regions for f calculation  
(00000006 must be introduced)

Iteration factor : relative difference between last two values of f  
iteration calculation (preferred value 0.00001)

Intermediate results : intermediate results for f calculation (print-  
out if  $\neq 0$ )

Second flight corr. : correction factor to make allowance for non-  
uniformity of neutron density after first col-  
lision.



RESULTS OF PROGRAM

The machine gives the following results :

a) Thermal utilization

For each region i (designated with a serial number beginning with the innermost), the thermal flux relating to the value of the first region is obtained.

Next come the thermal utilization factor and the averaged absorption cross-section, followed by the main lattice data :

b) FAST FISSION FACTOR

SLOWING DOWN AREA

SLOWING DOWN CROSS SECTION

FAST DIFFUSION COEFFICIENT

INFINITE MULT. FACTOR

PS. MATERIAL BUCKLING

TAU MODERATOR

RESONANCE INTEGRAL

RESONANCE ESCAPE PROB.

DIFFUSION AREA

THERMAL DIFFUSION COEFFICIENT

THERMAL FISSION FACTOR

NEGATIVE MATERIAL BUCKLING

CELL S.D. AREA RES. EN.

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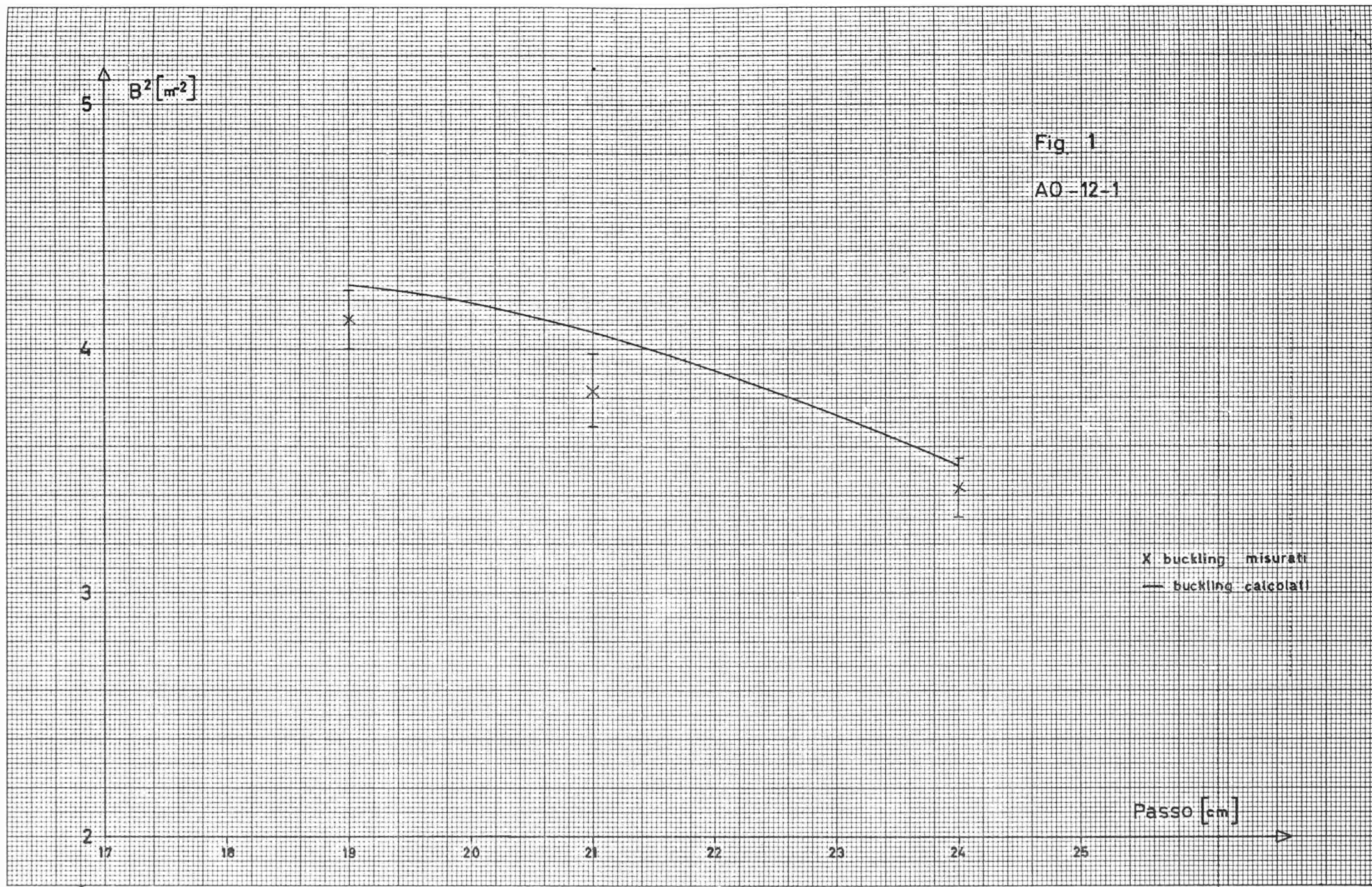


Fig. 1

AO-12-1

x: buckling misurati

— buckling calcolati

the 1990s, the number of people with a diagnosis of schizophrenia has increased in many countries, including the United Kingdom (Murray & Lewis, 1998). The prevalence of schizophrenia is estimated to be 1% of the population (Murray & Lewis, 1998).

There is a growing awareness of the need to improve the lives of people with schizophrenia. The World Health Organization (WHO) has developed a set of principles for the care of people with schizophrenia (WHO, 1993). These principles are based on the idea of recovery, which is defined as the process of living a meaningful life despite the presence of a mental illness.

Recovery is a process, not a destination. It is a journey that involves the development of a sense of purpose and meaning, the building of a supportive network of relationships, and the acquisition of the skills and resources needed to live a fulfilling life. Recovery is a personal and unique process, and it is important to recognize that there is no one-size-fits-all approach to recovery.

There are many factors that can influence the process of recovery, including the severity of the illness, the availability of social support, and the presence of co-occurring conditions. However, there are several key factors that are essential for recovery: a strong sense of purpose and meaning, a supportive network of relationships, and the acquisition of the skills and resources needed to live a fulfilling life.

One of the most important factors in recovery is the development of a sense of purpose and meaning. This can be achieved through a variety of activities, including work, education, and community involvement. It is important to find activities that are meaningful and that provide a sense of accomplishment and purpose.

Another key factor in recovery is the building of a supportive network of relationships. This can be achieved through a variety of ways, including joining a support group, participating in community activities, and seeking out friends and family members who are understanding and supportive. A strong network of relationships can provide the emotional support and encouragement needed to overcome the challenges of living with schizophrenia.

Finally, the acquisition of the skills and resources needed to live a fulfilling life is essential for recovery. This can be achieved through a variety of ways, including seeking out training and education, developing new skills, and accessing community resources. It is important to take advantage of all the opportunities available to improve one's skills and resources.

Recovery is a process, and it is important to be patient and persistent. It may take time to develop a sense of purpose and meaning, to build a supportive network of relationships, and to acquire the skills and resources needed to live a fulfilling life. However, with the right support and resources, recovery is possible.

There are many resources available to help people with schizophrenia on their journey to recovery. These include support groups, community centers, and mental health services. It is important to seek out these resources and to use them to the best of one's ability.

Recovery is a journey, and it is important to take it one step at a time. It is important to focus on the present and to celebrate the small victories along the way. Recovery is a process, and it is a journey that is worth the effort.

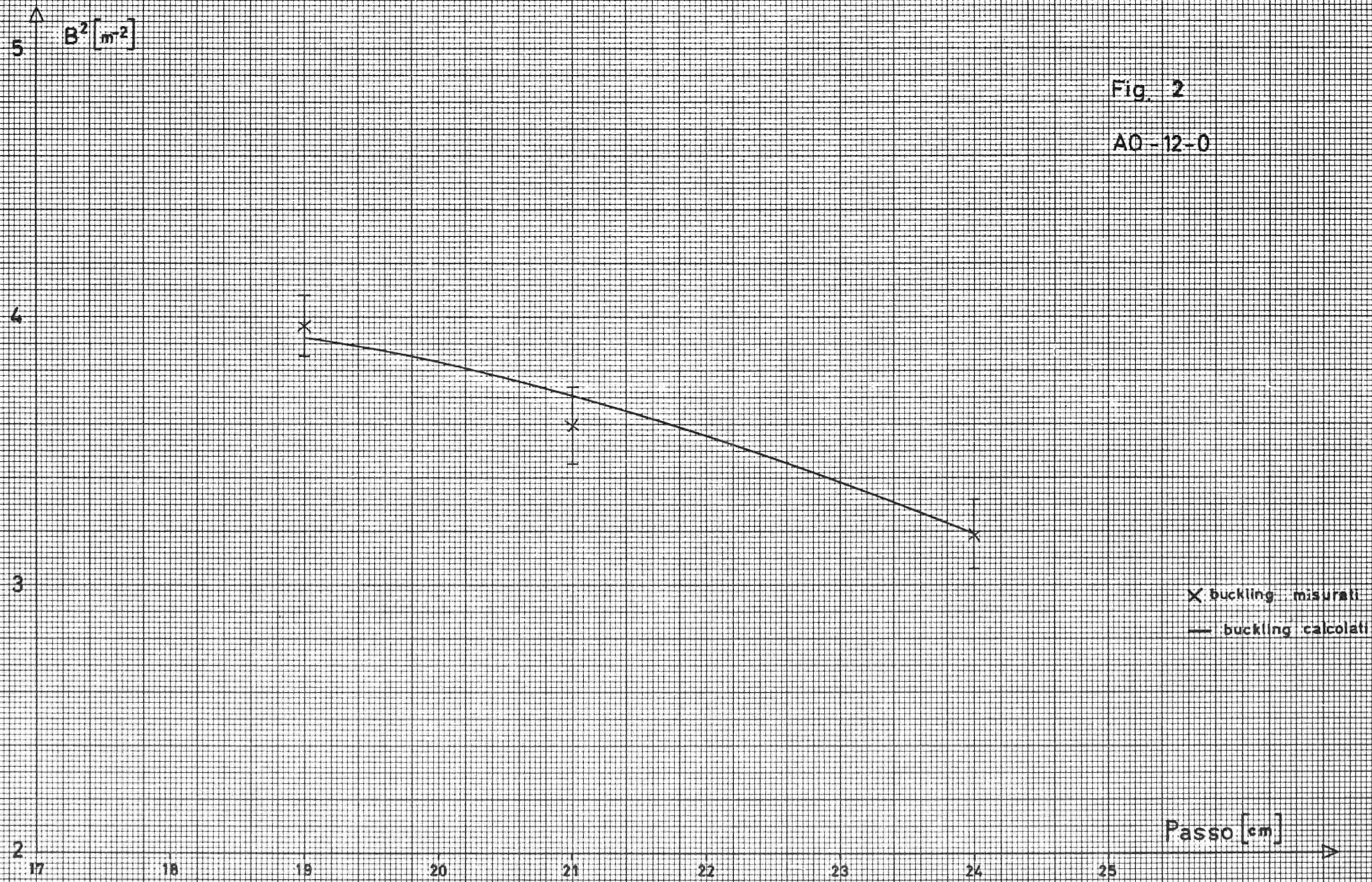
Recovery is a process, and it is a journey that is worth the effort. It is a journey that involves the development of a sense of purpose and meaning, the building of a supportive network of relationships, and the acquisition of the skills and resources needed to live a fulfilling life.

Recovery is a process, and it is a journey that is worth the effort. It is a journey that involves the development of a sense of purpose and meaning, the building of a supportive network of relationships, and the acquisition of the skills and resources needed to live a fulfilling life.



Fig. 2

A0-12-0



the 1990s, the number of people with a diagnosis of schizophrenia has increased in the United Kingdom (Meltzer and Pebody 1999).

There is a growing awareness of the need to improve the lives of people with mental health problems. The United Kingdom has a long history of psychiatric care, but in the 1950s and 1960s, the emphasis was on institutional care. In the 1970s, there was a move towards community care, and in the 1980s and 1990s, there has been a focus on recovery and self-help. The current emphasis is on recovery and self-help, and the need to improve the lives of people with mental health problems. The current emphasis is on recovery and self-help, and the need to improve the lives of people with mental health problems.

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Fig. 3

A0-16-1

$B^2 [m^2]$

5

4

3

2

18

19

20

21

22

23

24

25

Passo [cm]

x buckling misurat  
— buckling calcolati

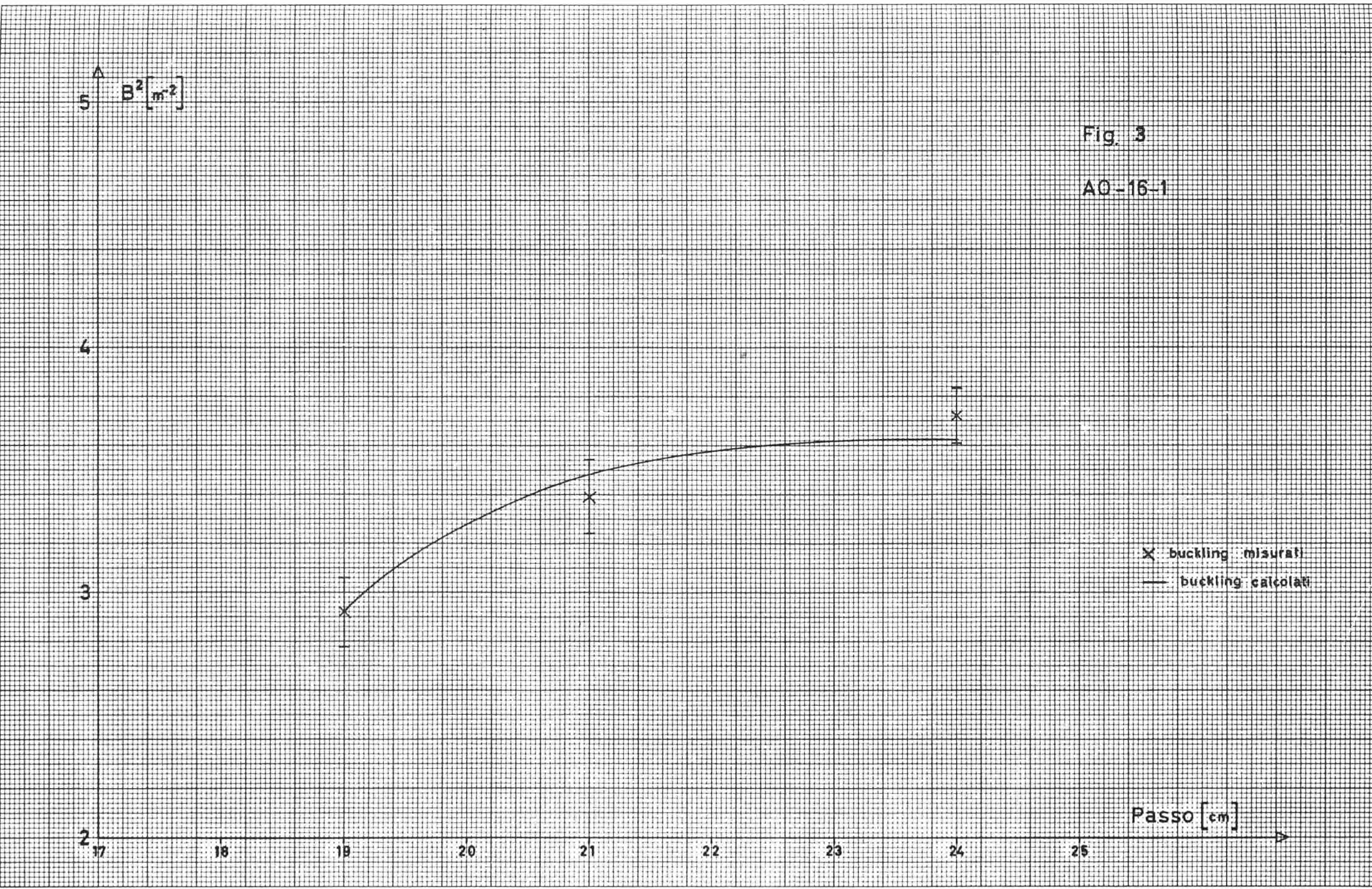
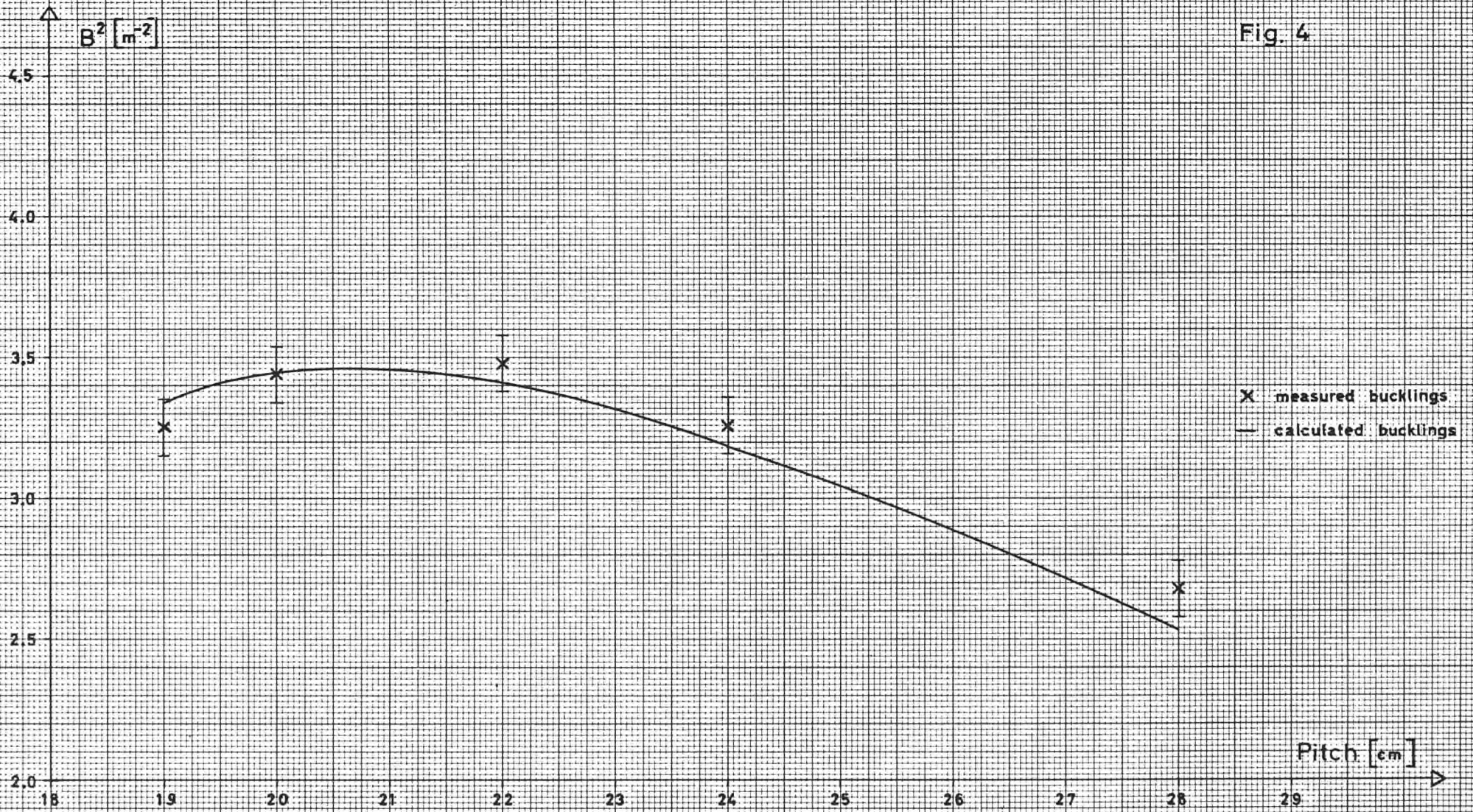






Fig. 4





# CAROLINE I

## Materials

Fuel		Canning		Coolant		Outer coolant		Pressure tube		Insulation		Calandria		Moderator	Fuel	Coolant	Insulation	Moderator	
C	Spectral const.	C	T <sub>n</sub>	C	T <sub>n</sub>	C	T <sub>n</sub>	C	T <sub>n</sub>	C	T <sub>n</sub>	C	T <sub>n</sub>	T <sub>n</sub>	T	T	T	T	
1		6		11		16		21		26		31		36	40	44	48	52	55

1 = URM  
2 = URO  
3 = URC

8 = SAP  
9 = STEEL

1 = SAN  
2 = DIPH  
(Graphite)

8 = SAP  
9 = STEEL

1 = SAN  
2 = DIPH  
3 = Al<sub>2</sub>O<sub>3</sub>  
4 = Si O<sub>2</sub>  
0 = VOID

## Common data

X	S <sub>f</sub>	S <sub>g</sub>	α	ρ <sub>SAP</sub>	HBR (%)	Σ <sub>a1</sub> · 10 <sup>4</sup>	t	Σ <sub>HW</sub>	Σ <sub>SAP</sub> (EXTRA)	Name	
1	6	11	16	21	26	31	36	41	46	51	56

## Geometry

s	s <sub>1</sub>	s <sub>2</sub>	s <sub>3</sub>	a	a <sub>1</sub>	a <sub>2</sub>	a <sub>3</sub>	r	d <sub>r</sub>	Option
1	6	11	16	21	26	31	36	41	46	51

1 = HEX 7  
2 = HEX 19  
3 = CIR 19  
4 = BUN 22  
5 = BUN 4  
6 = SINGLE

d	d <sub>1</sub>	d <sub>2</sub>	d <sub>3</sub>	VR	V <sub>rif</sub>	V <sub>rIE</sub>	V <sub>rIP</sub>	V <sub>m</sub> /V <sub>f</sub>	Code
1	6	11	16	21	27	33	39	45	51

1 = Normal  
0 = Intermediate results

Number of regions	Iteration factor ε	Intermediate results ≠ 0	Second flight correction
1	9	13	19
			27
			31
			36









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