EUR 304.e

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

STUDY OF A NUCLEAR POWERED TANKER

RADIATION DOSES FROM A WATER REACTOR LOOP

by

A. GALLO CURCIO
(Comitato Nazionale per l'Energia Nucleare - Roma)
A.M. MONCASSOLI
(FIAT - Sezione Energia Nucleare - Torino)
S. TODISCO
(Società Ricerche Impianti Nucleari - SORIN - Milano)

1963

Work performed under the contract No 008-61-12 PNI I
between EURATOM, FIAT S.p.A. and ANSALDO S.p.A.
with the participation of
the Comitato Nazionale per l'Energia Nucleare

LEGAL NOTICE

The authors' names are listed in alphabetical order.

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

Please remit payments:

— to BANQUE DE LA SOCIETE GENERALE (Agence Ma Campagne) - Brussels - account No 964.558,
— to BELGIAN AMERICAN BANK AND TRUST COMPANY - New York - account No 121.86,
— to LLOYDS BANK (Foreign) Ltd. - 10 Moorgate - London E.C.2,

giving the reference: "EUR 304.e - Study of a nuclear powered tanker - Radiation doses from a water reactor loop".

Printed by Snoeck-Ducaju & Zoon, Brussels-Ghent, July 1963.

EUR 304.e

STUDY OF A NUCLEAR POWERED TANKER - RADIATION DOSES FROM A WATER REACTOR LOOP
by A. GALLO CURCIO, A. MONCASSOLI and S. TODISCO

European Atomic Energy Community - EURATOM
Work performed under the contract No 008-61-12 PNI I
between EURATOM, FIAT S.p.A. and ANSALDO S.p.A. with the participation of the Comitato Nazionale per l'Energia Nucleare.
Brussels, July 1963 - pages 18 - figures 11

In this study, the experimental measurements and theoretical analysis of the gamma dose rate from the primary loop of the Avogadro RS-I Reactor are described.

The comparison of experimental with calculated dose rates, particularly on the pump hall walls, gives an agreement within 10%. A disagreement by a factor of 2 is found between calculated and measured absolute source values.

This investigation enables to conclude that in performing isodose calculations it is only necessary to evaluate the contribution from the main sources, disregarding back scattering and shadow effects.

EUR 304.e

STUDY OF A NUCLEAR POWERED TANKER - RADIATION DOSES FROM A WATER REACTOR LOOP
by A. GALLO CURCIO, A. MONCASSOLI and S. TODISCO

European Atomic Energy Community - EURATOM
Work performed under the contract No 008-61-12 PNI I
between EURATOM, FIAT S.p.A. and ANSALDO S.p.A. with the participation of the Comitato Nazionale per l'Energia Nucleare.
Brussels, July 1963 - pages 18 - figures 11

In this study, the experimental measurements and theoretical analysis of the gamma dose rate from the primary loop of the Avogadro RS-I Reactor are described.

The comparison of experimental with calculated dose rates, particularly on the pump hall walls, gives an agreement within 10%. A disagreement by a factor of 2 is found between calculated and measured absolute source values.

This investigation enables to conclude that in performing isodose calculations it is only necessary to evaluate the contribution from the main sources, disregarding back scattering and shadow effects.

EUR 304.e

STUDY OF A NUCLEAR POWERED TANKER - RADIATION DOSES FROM A WATER REACTOR LOOP
by A. GALLO CURCIO, A. MONCASSOLI and S. TODISCO

European Atomic Energy Community - EURATOM
Work performed under the contract No 008-61-12 PNI I
between EURATOM, FIAT S.p.A. and ANSALDO S.p.A. with the participation of the Comitato Nazionale per l'Energia Nucleare.
Brussels, July 1963 - pages 18 - figures 11

In this study, the experimental measurements and theoretical analysis of the gamma dose rate from the primary loop of the Avogadro RS-I Reactor are described.

The comparison of experimental with calculated dose rates, particularly on the pump hall walls, gives an agreement within 10%. A disagreement by a factor of 2 is found between calculated and measured absolute source values.

This investigation enables to conclude that in performing isodose calculations it is only necessary to evaluate the contribution from the main sources, disregarding back scattering and shadow effects.

EUR 304.e

EUROPEAN ATOMIC ENERGY COMMUNITY — EURATOM

STUDY OF A NUCLEAR POWERED TANKER

RADIATION DOSES FROM A WATER REACTOR LOOP

by

A. GALLO CURCIO
(Comitato Nazionale per l'Energia Nucleare - Roma)

A. M. MONCASSOLI
(FIAT - Sezione Energia Nucleare - Torino)

S. TODISCO
(Società Ricerche Impianti Nucleari - SORIN - Milano)

1963

Work performed under the contract No 008-61-12 PNI I
between EURATOM, FIAT S.p.A. and ANSALDO S.p.A.
with the participation of
the Comitato Nazionale per l'Energia Nucleare

CONTENTS

KEY TO THE FIGURES

STUDY OF A NUCLEAR POWERED TANKER
RADIATION DOSES FROM A WATER REACTOR LOOP

SUMMARY

In this study, the experimental measurements and theoretical analysis of the gamma dose rate from the primary loop of the Avogadro RS-I Reactor are described.

The comparison of experimental with calculated dose rates, particularly on the pump hall walls, gives an agreement within 10%. A disagreement by a factor of 2 is found between calculated and measured absolute source values.

This investigation enables to conclude that in performing isodose calculations it is only necessary to evaluate the contribution from the main sources, disregarding back scattering and shadow effects.

1. — INTRODUCTION

The purpose of this work is to test theoretical methods for predicting the main gamma doses on the inside walls of the plant container of a water cooled and moderated reactor.

This problem is particularly important for the design of a direct cycle boiling water reactor for ship propulsion, in which there are large, widely spaced gamma sources (turbine, condenser, etc.). In this case the secondary shielding necessary for providing the required attenuation results very heavy.

For instance, the secondary shielding weight in a shipborne BWR plant (direct cycle) has been estimated to be 2400 t, while the comparable shielding for a PWR plant was 1760 t. The following figures were derived disregarding back scattering from the shield, components shadow effects and assuming large safety factors. It was desired to check the validity of such assumptions.

Measurements and analyses of dose rates coming from the primary loop of the Avogadro reactor have been used for this purpose.

In fact, the Avogadro Reactor primary loop presents a rather complicate layout of gamma sources due to specific activity of the primary water. The radiation sources are of different intensity and shapes. The difficulties that arise in calculating this source distribution are the same as for a power reactor primary loop radiation sources.

The work reported here consists of two parts, one experimental, the other theoretical. The experimental part deals with the mapping of the primary loop hall of the Avogadro Reactor, together with a source strength measurement. The theoretical one calculates the source strength and the dose distribution on the internal walls of primary loop hall, taking into account the main sources.

Shadow effects and back scattering from the walls resulted negligible. The agreement was within 10%.

2. — EXPERIMENTAL CONDITIONS

The dose rate mapping was done in the primary pump hall of the Avogadro Reactor where piping, heat exchanger and pumps are highly radioactive for the specific activity of the primary coolant water, when an hold up tank in the line from the core is bypassed.

The dose rates were measured in more than 1200 points within the pump room and in three points near the pipe at the reactor core outlet, using small Geiger counters.

During the whole experiment the reactor was running at 20 kW thermal power, the primary loop flow rate was 200 m^3/h and the water was by-passing the hold-up tank.

The experimental equipments included 3 small dimension Geiger counter — 18509 Philips with a total volume of 5 × 5 × 20 mm, fixed on a portable rack at a distance of 46 cm from each other and connected with 3 rate-meters. The rack was positioned vertically against the ceiling or the floor alternatively.

3. — SOURCE STRENGTH

The primary coolant water has a specific activity due to the reaction

$$O^{16}(n,p)\,N^{16} \underset{7.4\,s}{\rightarrow} O^{16}$$

The threshold for the (n,p) reaction is 10 MeV with a gamma emission for the 80% of the reaction. The gamma emission from N^{16} has the following spectrum:

6.12 MeV (87% of total emission)
7.1 MeV (12% of total emission)
2.7 MeV (1% of total emission)

To know indirectly, but experimentally, the source strength, dose rates were measured near the core outlet pipe.

Three values were measured corresponding to the position indicated in fig. 1 — Source Strength Measurement Location, in a plane passing through the pipe center line.

Results as a function of the distance from the pipe were as follows:

distance (cm)	dose rate (mR/h)
0	175
50	48
100	25

4. — PRIMARY PUMP HALL MAPPING

The primary loop arrangement is detailed in figure 4 — Pump Hall Layout.

The loop hall is 234 cm high, 522 cm wide, 840 cm long.

A cubic grid was built into the hall, subdividing it with 6 horizontal planes at a distance from the floor of 2, 48, 94, 140, 186, 232 cm.

The plan view of the grid is shown in figure 2 — Plan of Measuring Grid. The mesh width is of 50 cm for the x axis (capital letters), and 46,5 cm for the y axis (small letters).

Dose rates were measured at all the intersections of the grid, except for points falling within pieces of equipment.

A map of the experimental results is shown in figures 5 to 11 — Gamma Dose Maps. Maps were drawn for the 6 horizontal planes and for one vertical plane passing through a zone of peculiar interest.

The relative error in the dose rates measured is within 10%. The absolute error is difficult to calculate but it could be greater.

The results obtained show that for an arrangement like the one considered it is possible to design a shield having a thickness variable from one zone to another.

In fact dose rate at a wall may vary of a factor of five according to position.

5. — THEORETICAL APPROACH

The evaluation of the source strength for the water coming out from the reactor core was done using data on the reactor core configuration.

The fast flux above the (n, p) reaction energy threshold was calculated using a single collision calculation.

The resulting core average effective flux for the reaction is

$$\langle \phi_{eff} > 10 \text{ MeV} \rangle = 2.01 \cdot 10^8 \text{ n/cm}^2\text{.s})$$

The water entering the external loop has the following specific activity

$$S = 2.301 \ 10^4 \ \frac{\gamma(6.13 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

$$S = 3.174 \ 10^3 \ \frac{\gamma(7.1 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

$$S = 2.645 \ 10^2 \ \frac{\gamma(2.7 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

Taking into account the decay to the point of measurement on the core outlet pipe, the calculated sources in that point are:

$$9{,}45 \ 10^3 \ \frac{\gamma \ (6{,}13 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

$$1.303 \ 10^3 \ \frac{\gamma \ (7.1 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

$$1.086 \ 10^2 \ \frac{\gamma \ (2.7 \text{ MeV})}{\text{cm}^3 \text{ s}}$$

A comparison of these with the measured values is possible only after conversion to dose rates. From the measured dose rates, knowing the piping dimension, thickness, and material composition it is possible to go back to the volume source using

$$D = \frac{S_v R_0^2}{2} \left[\frac{.87 \, f \, (6.13) \, F \, (\theta, b_1) \, B \, (b_{1Al})}{a + z_1} + \frac{.12 \, f \, (7{,}1) \, F \, (\theta, b_2) \, B \, (b_{2Al})}{a + z_2} + \frac{.01 \, f \, (2.7) \, F \, (\theta, b_3) \, B \, (b_{3Al})}{a + z_3} \right]$$

where

$$F \, (\theta, b_i) = \int_0^\theta e^{-b_i \sec \theta} \, d\theta'$$

bi $= \mu_{si} Z_i + \mu_{Ali} t =$ total relaxation length of the source of energy i

Z_i $=$ self absorption distance for the cylindrical source (cm)

$B(b_{Ali}) =$ build-up factor

$f(E)$ $=$ conversion factor from flux to dose (mR/h/n/cm^2 s)

a $=$ distance between the dose point and the pipe inner diameter (cm).

The result obtained from the three measured values are shown in Table I.

TABLE I

a (cm)	0.93		50.93		100.93	
$\frac{\gamma\ (6.13\ \text{MeV})}{\text{cm}^3\ \text{s}}$	5.09	10^3	4.87	10^3	4.57	10^3
$\frac{\gamma\ (7.1\ \text{MeV})}{\text{cm}^3\ \text{s}}$	7.02	10^2	5.71	10^2	6.3	10^2
$\frac{\gamma\ (2.7\ \text{MeV})}{\text{cm}^3\ \text{s}}$	5.8	10^1	5.6	10^1	5.2	10^1

The discrepancy between the values in table I could be due to the neglected influence of a flow pattern straightener just in the zone near the dose points.

A comparison of the measured and calculated values shows discrepancy of a factor of $\sim$ 2. For our purpose the better value to start from seems to be the measured value particularly because of the unknown absolute error in the measured dose rates.

Part of the discrepancy could be explained by leakage past empty core position plugs, mixing unirradiated pool water with core water.

The next step is to evaluate the values of the radiation sources in the loop hall. Starting from the semiempirical values of table I (3rd column), the water activity is calculated as a function of time, $f(t)$ plot, and as a function of the distance from the measurement point at the core outlet, $f(s)$ plot.

The results are plotted in figure 3. The two full lines represent the water activity inside the loops, the dashed line corresponds to the heat exchanger source strength accounting for the self shielding.

A calculation of the dose rates on the equipment and on the walls was made using the line source approximation for the cylindrical sources (tubes, pump, heat exchanger), taking into account the contributions from all the sources seen from the dose point and neglecting shadow effects and back scattering. The formula used is

$$D = f(E)\, \frac{R_0^2 B(b) S_V}{4(a+z)} \left[F(\theta_1, b) + F\ (\theta_2, b)\right] \quad \left(\frac{\text{mR}}{h}\right)$$

where

$$\theta_1 = \text{arctg}\, \frac{h-y}{a}$$

$$\theta_2 = \text{arctg} \frac{y}{a}$$

h is the cylindrical source height
y is the vertical coordinate of the dose point
$B(b)$ is the build-up factor
b is the source relaxation length; $f(E)$ is the conversion factor from flux to dose.

Results are shown in table II.

TABLE II

Dose point coordinates	Exp. Value	Calcul. value I col. Tb. I	Deviation	Calcul. value III col. Tb. I	Deviation
F, a, IV	11	10.90	−0.00909	9.78	−0.11
A, l, IV	7.5	8.35	+0.11333	7.49	−0.00133
M, r, IV	10.5	11.7	0.114285	10.5	=
M, l, IV	6	5.75	−0.04166	5.16	−0.14
M, d, IV	4	4.5	0.125	4.0	=
A, c, VI	22	23.5	0.06818	21.1	−0.0409
A, q, VI	6	6.7	0.1166	6.0	=
F, u, III	2.5	2.2	−0.12	1.97	−0.121
M, q, III	10.5	11.2	+0.06666	10.1	−0.038
G, l, II	6.5	7.8	+0.2	7.0	+0.0769
L, r, II	26	30	+0.1538	26.9	0.03461

The values in table II are in mR/h dose unit.

The 3rd dose point coordinate corresponds to the horizontal plane of the cubic grid, starting with *I* on the ceiling. The 5th column values give a better agreement with the calculated values, conferming the considerations just outlined.

6. — CONCLUSIONS

A good agreement between calculated and measured values was found, but for the calculated absolute source value which disagreed of a factor of 2 with the experimental one.

This study permits to conclude that in performing isodose calculations very close to the sources, it is not necessary to evaluate the contribution from other sources of less importance.

Only very far from main sources all the dose contributions have to be examined.

Back scattering and shadow effects may be disregarded.

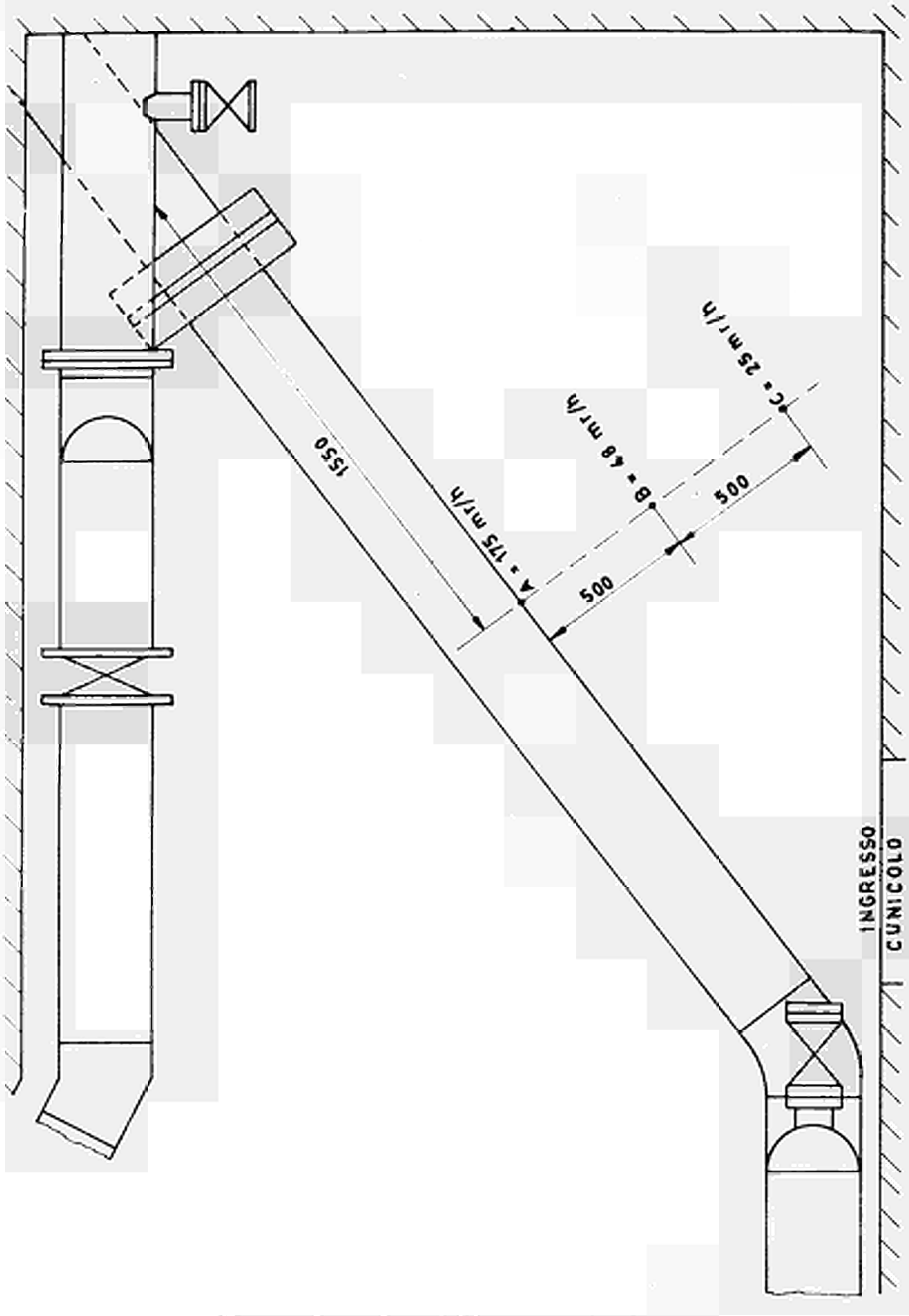

Fig. 1 — Source Strength Measurement Location.

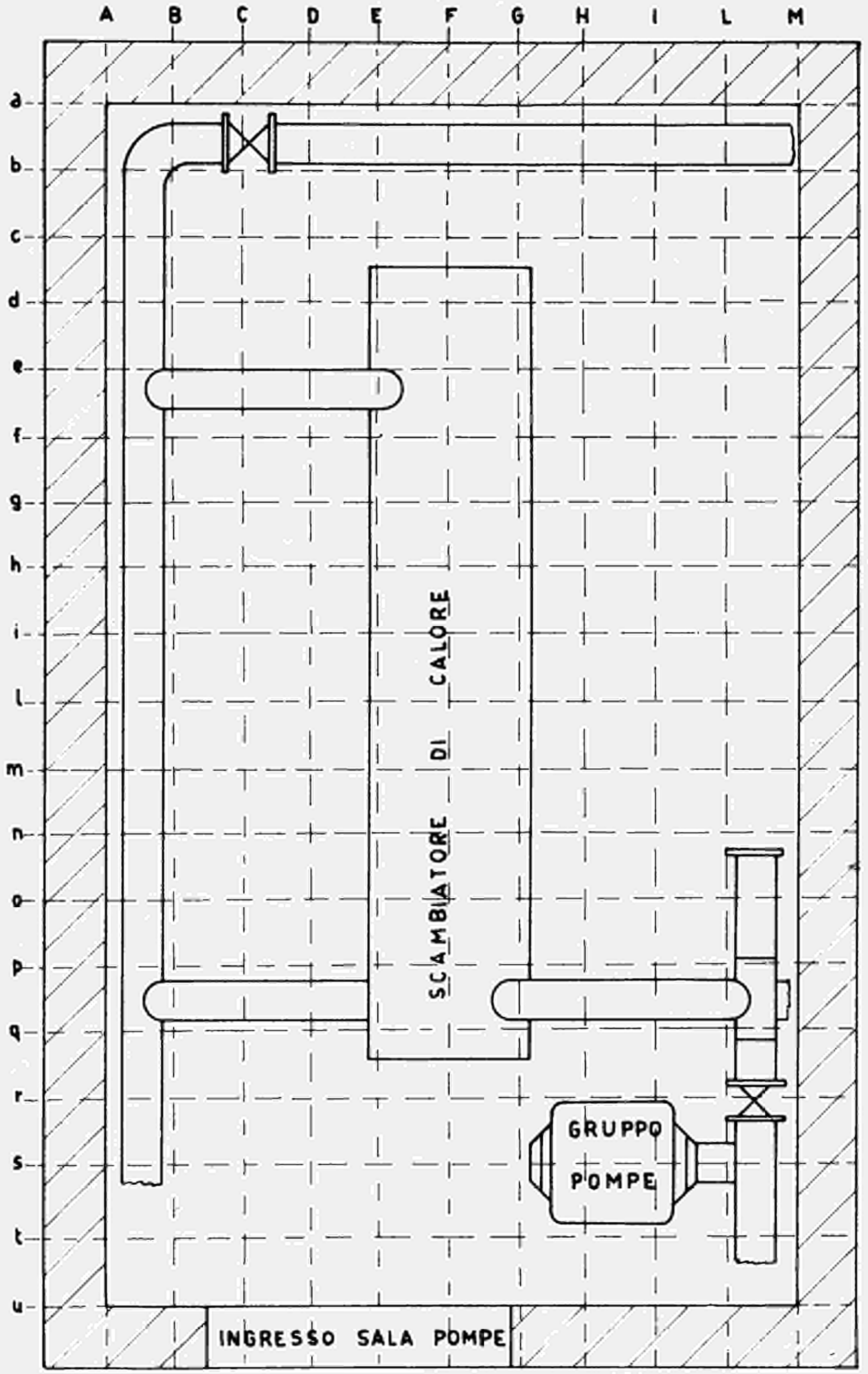

Fig. 2 — Plan of Measuring Grid.

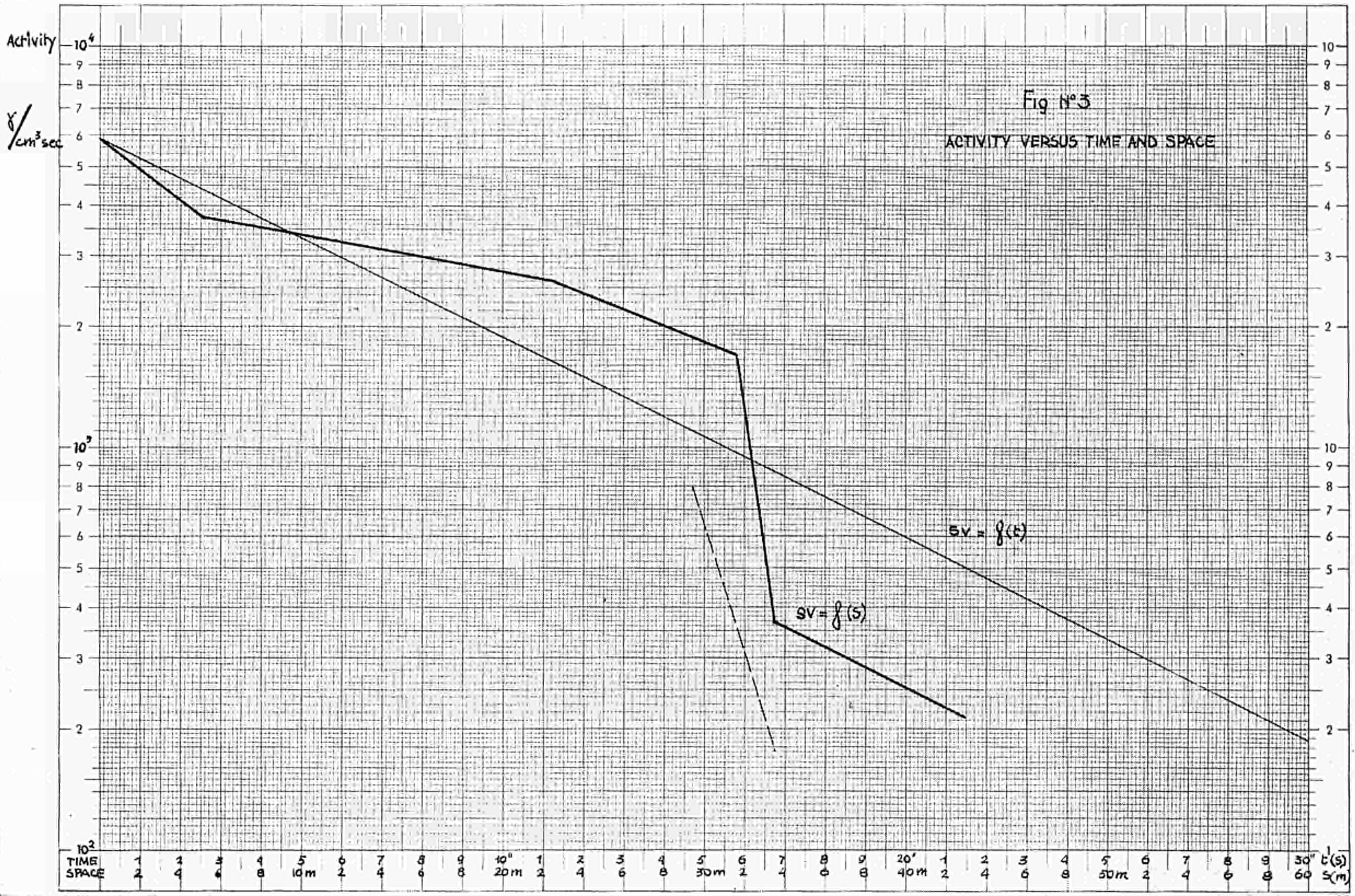

Fig. 3 — Activity Versus Time and Space.

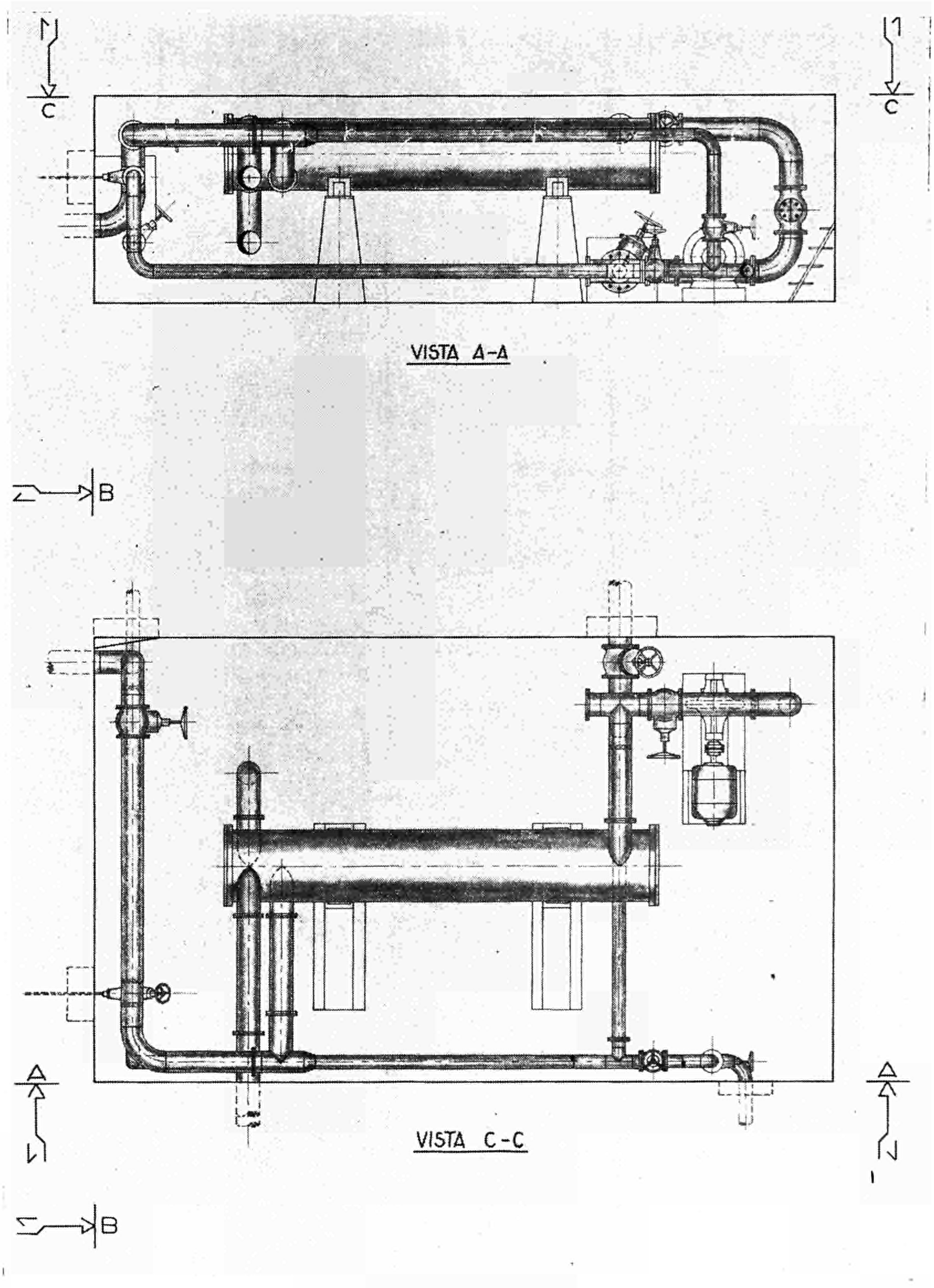

Fig. 4.1 — Plant Layout.

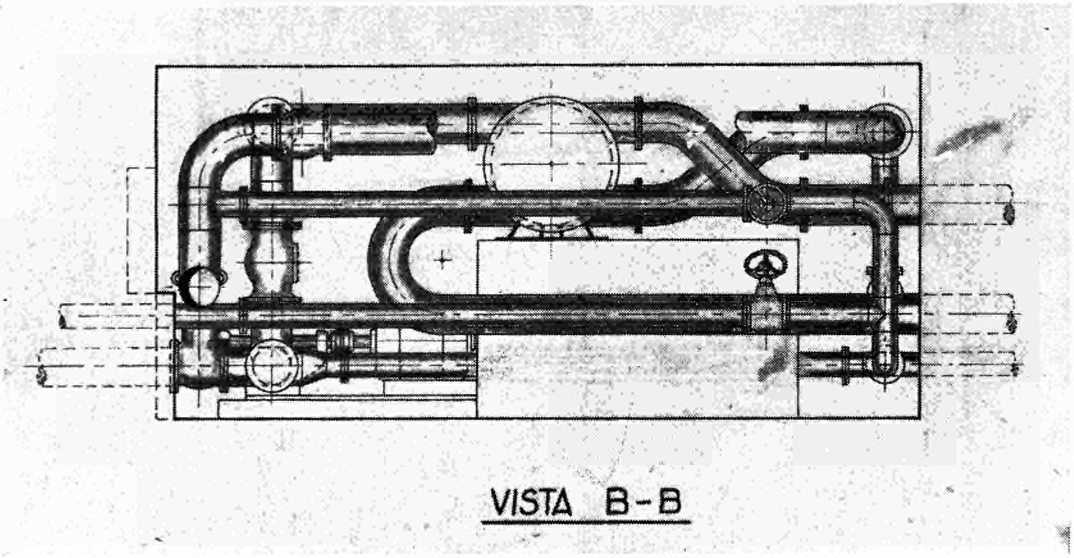

Fig. 4.2 — Plant Layout.

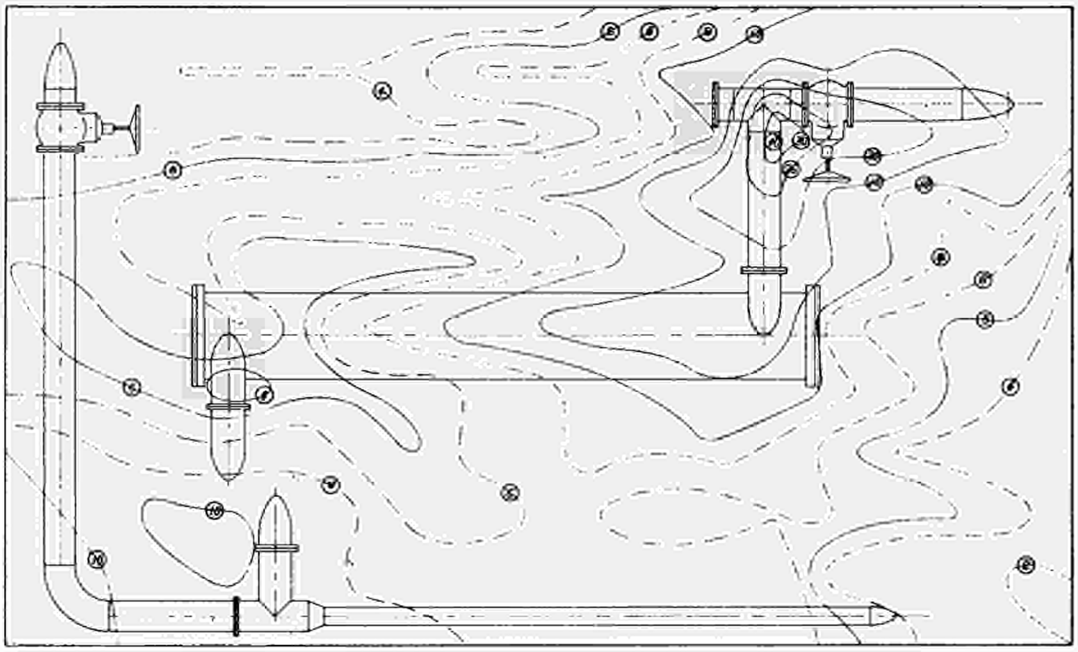

Fig. 5 — Dose Rate Mapping - Height: 232 cm - I Section.

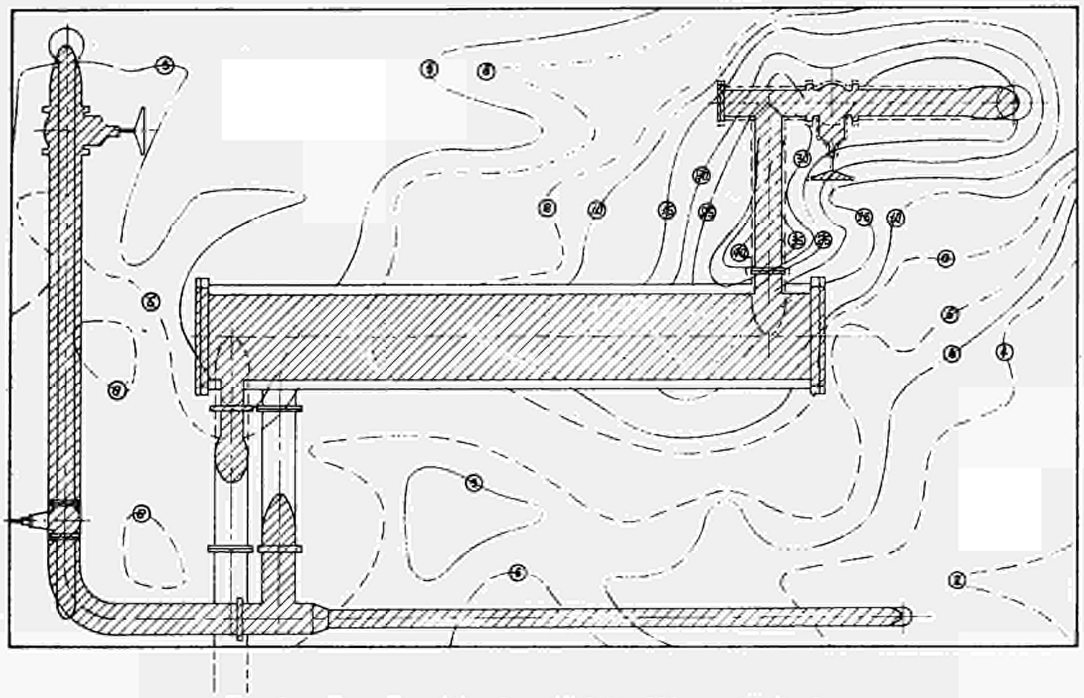

Fig. 6 — Dose Rate Mapping - Height: 186 cm - II Section.

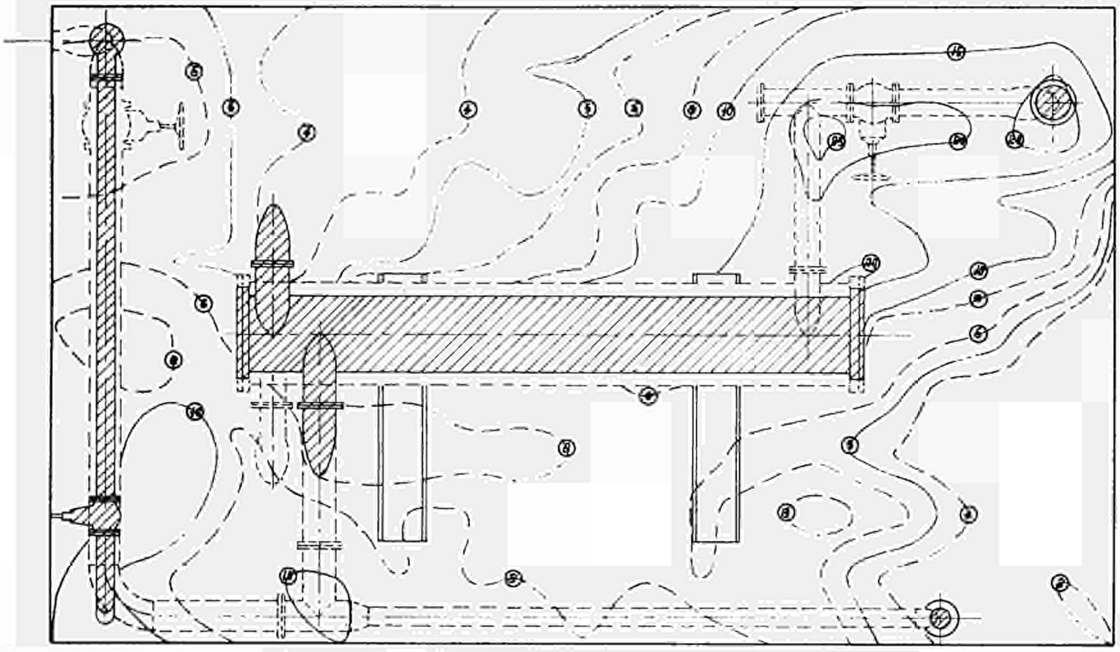

Fig. 7 — Dose Rate Mapping - Height: 140 cm - III Section.

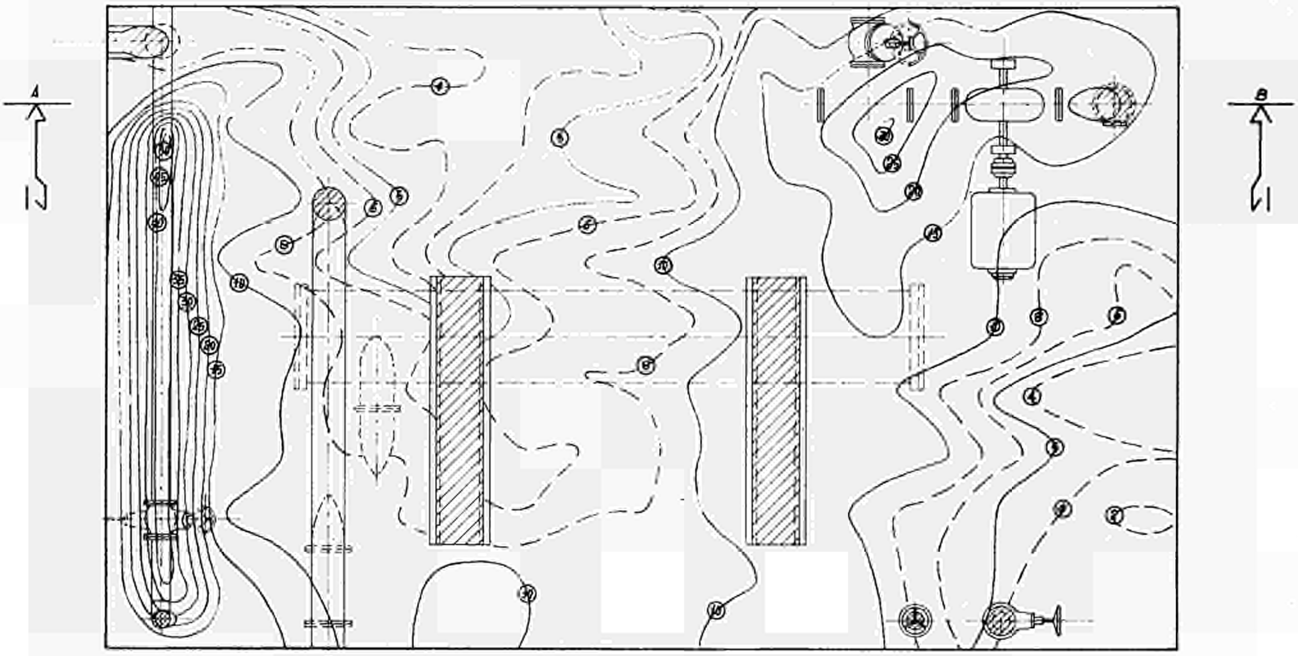

Fig. 8 — Dose Rate Mapping - Height: 94 cm - IV Section.

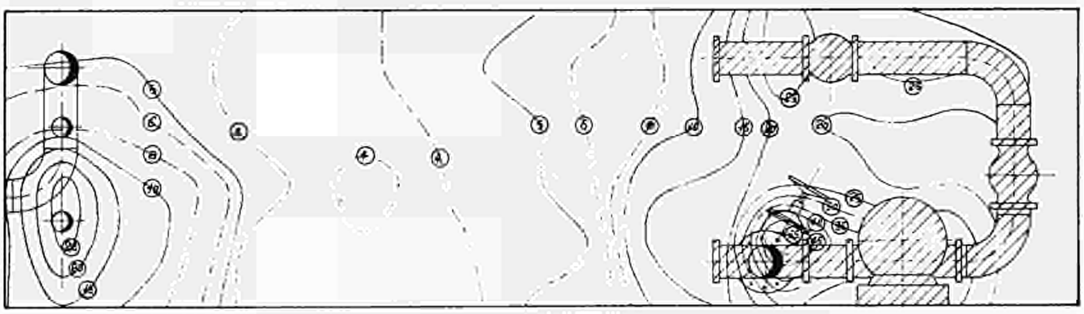

Fig. 9 — Dose Rate Mapping - Section A-B.

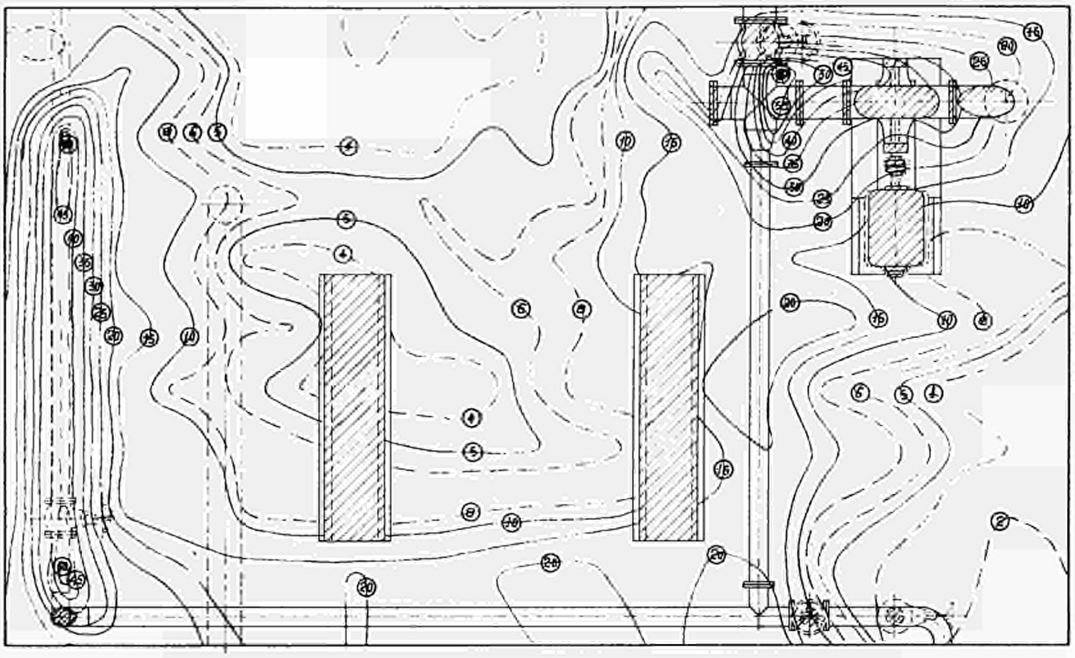

Fig. 10 — Dose Rate Mapping - Height: 48 cm - V Section.

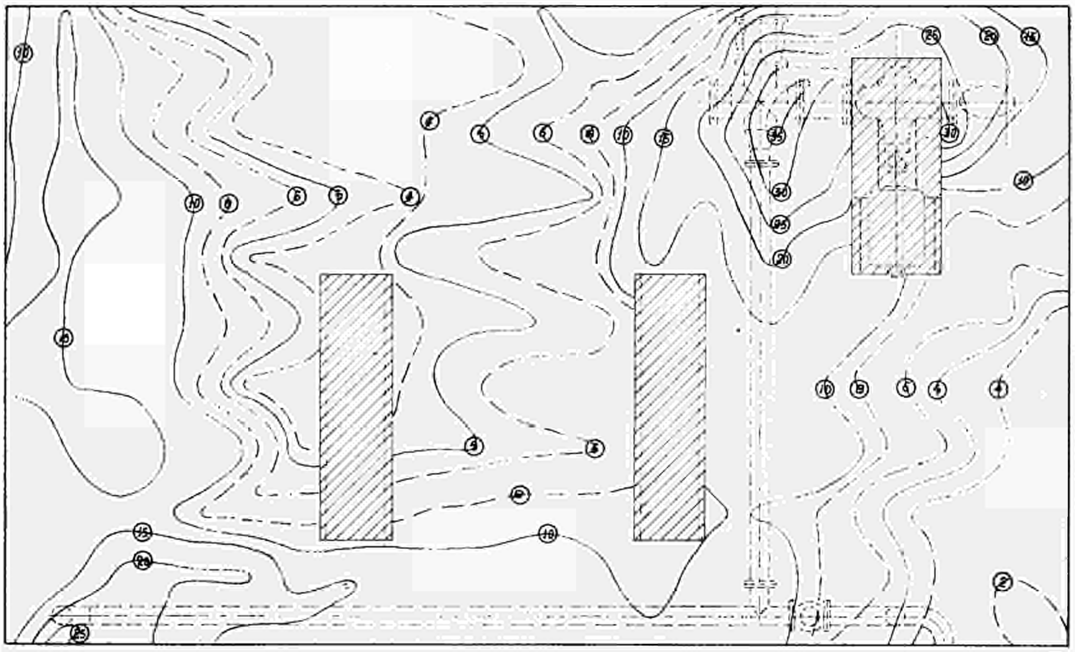

Fig. 11 — Dose Rate Mapping - Height: 2 cm - VI Section.