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THE EFFECT OF NUCLEAR RADIATION ON THE MECHANICAL PROPERTIES OF EPOXY RESINS

by

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1. INTRODUCTION

This report contains the results of the effects of nuclear radiation on the mechanical properties of epoxy resins obtained since the publication of the first part (1). In principle, it contains the radiation resistance of new resin compositions which may be used for electrical insulation in a strong radiation environment. Due to the difficulties involved in their processing, most of these compositions are not yet generally used for these applications, but in view of the work being done in the electrical industry on this subject their exploitation will definitely become more wide-spread. For comparison, the radiation resistance of some resin compositions made at CERN is given.

Two different types of epoxy resins were studied: cyclo-aliphatics and aromatics of the diglicidyl type. The influence of hardener type and concentration was also studied for some epoxies.

Some filled epoxies were examined at levels at which they lost their mechanical properties completely. The effect of filler concentration was taken into account. The influence of the presence of boron in glass reinforced epoxies was also studied; some samples were reinforced with glass containing 8 o/o B_2O_3 and some with pure silica.

The influence of radiation field was studied. Some resins were irradiated in a nuclear reactor and some in spent fuel elements.

The adhesion to copper under irradiation was also studied.

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All the measurements are done according to ASTM norms.

The rad is always used as unit of absorbed dose.

IRRADIATION CONDITIONS

- Table I -

IRRADIATION SOURCE	SPENT FUEL ELEMENTS Reactor SILOE (2) Grenoble	NUCLEAR REACTOR ASTRA-AUSTRIA (3)
Type of irradiation	γ-rays	γ-rays + neutrons
Intensity and energy spectrun	2.10^{6} rad/hr Practically mono energetic ~0,8 Mev	$\emptyset_{th} = 5.10^{12}$ η/cm2. sec $\emptyset_{f} = 2.4.10^{12}$ η/cm2. sec ($E > 1$ Mev) $\gamma = 1.0\ 10^{8}$rad/hr
Temperature during irradiation	~ $25\,^{o}C$	Max. $44\,^{o}C$
Dosimetry and Reproducibility	Ionization chambre type Victoreen ± 10 o/o	Calorimeter ± 10 o/o
Cooling system	Air	Water

3. MATERIALS STUDIED

DESIGNATION	COMPOSITION	CURING CYCLE
Araldite D + HY 951	100-9	24 hrs at 25°C 2 hrs at 60°C
Araldite CY 175 + HY 905	100-65	24 hrs at 140°C
Araldite CY 179 + HY 905	100-72	24 hrs at 140°C
Araldite F + HT 971	100-14,5	(1 hr at 65°C (3 hrs at 155°C
Araldite F + HT 972	100-27	5 hrs at 80°C
Araldite EPN 1138 + HT 976	100-35	(12 hrs at 80°C (24 hrs at 140°C
Araldite F + X 8157/131	100-40	12 hrs at 120°C
Araldite F + HY 906 - 960	100-80-1	(2 hrs at 80°C (2 hrs at 100°C (2 hrs at 120°C (10 hrs at 180°C
Araldite F + HY 964 + DY 064	100-120-0.5	30 hrs at 80°C
Epikote 828 + BF 3-1040	100-10	4 hrs at 130°C
Epikote 828 + DDM + Al_2O_3	100-27-100	(3 hrs at 75°C (3 hrs at 100°C
Araldite F + HT 972 + Alumina (Al_2O_3)	100-27-220	(3 hrs at 75°C (3 hrs at 100°C
Araldite F + HT 972 + Aerosil + $BaSO_4$	100-27-2-150	(3 hrs at 75°C (3 hrs at 100°C
Araldite F + HT 972 + Graphite	100-27-60	(3 hrs at 75°C (3 hrs at 100°C
Araldite F + HY 905 + DY 061 + DY 040	100-100-0.1-10	(12 hrs at 80°C (3 hrs at 100°C

DESIGNATION	COMPOSITION	CURING CYCLE
Araldite EPN 1138 + HY 905 + DY 062	100-105-0.5	(4 hrs at 80°C (16 hrs at 140°C
Araldite X 33-1020 + HY 905 + DY 062	100-136-0.5	(4 hrs at 80°C (4 hrs at 100°C (12 hrs at 140°C
Epikote 828 + BF 3-400	100-2	(4 hrs at 105°C (4 hrs at 175°C
Araldite B + HT 901	100-30	(6 hrs at 120°C (10 hrs at 140°C
Araldite X 33/1189 - HY 905 + DY 062	100-100-0.2	(4 hrs at 100°C (4 hrs at 120°C (12 hrs at 140°C
Araldite EPP + HY 905	100-135	(4 hrs at 120°C (24 hrs at 140°C
Araldite DY 032 + HY 905 + DY 062	100-160-0.5	(10 hrs at 60°C (12 hrs at 120°C
Araldite F + HT 912	100-150	24 hrs at 120°C

4. RESULTS AND CONCLUSIONS

The results are shown on the accompanying graphs which are self-explanatory. A list of graphs is also added.

4.1 The epoxy resins generally made up to now at CERN are completely damaged at 2.10^9 rad. Some compositions have no mechanical resistance at 5.10^8 rad (Fig. 16).

4.2 Some newly developped epoxies resist doses of 5.10^9 rad (Fig. 17). Some mineral filled epoxies still retain 20 per cent of their material values at 1.10^{10} rad (Fig. 38).

4.3 The influence of different hardeners on the radiation resistance of classical epoxy resins is given in Fig.18. It is again confirmed that aromatic amines and anhydrides are more radiation resistant than aliphatics (Fig. 18).

4.4 Fig. 20 shows the results obtained by curing eight different resins with an anhydride (HY 905). By comparing the levels at which 50 o/o and 75 o/o damage occurs, it can be concluded that these resins rank in the following order of decreasing radiation resistance:

L 1.)	EPN 1138	)	aromatics
2.)	X33/1020	)	dto.
3.)	X33/1189	)	dto.
4.)	EPP resin	)	dto.
5.)	Araldite F	)	dto.
6.)	Araldite CY 175	)	cyclo aliphatics
7.)	Araldite DY 032	)	cyclo aliphatics
8.)	Araldite CY 179	)	dto.

4.5 Cyclo aliphatic resins are not very radiation resistant. They cannot be used for levels higher than 10^9 rad. Among them Araldite CY 175 is the most radiation resistant and CY 179 the least radiation resistant (Fig.21).

4.6 Only a small difference was noted by curing Araldite F with HY 905 and HY 906. HY 906 seems somewhat better at high levels (Fig. 22).

4.7 The samples irradiated in a nuclear reactor or in spent fuel elements gave practically the same results (Figs. 23-25).

4.8 Resins cured with a stoichiometric ratio of hardener are more radiation resistant than those cured with incorrect ratios. Too much hardener is usually not too critical but too little can lead to problems (Figs. 30 - 37). This effect becomes more pronounced by increasing the absorbed dose.

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4.9 The influence of fillers on a classical epoxy cured with an aromatic hardener is shown in Fig. 38. All mineral filled epoxies have a good radiation resistance. Above 10^{10} rad graphite seems the most resistant, followed by alumina and silica. All compositions have lost practically all their mechanical properties at 2.10^{10} rad.

4.10 The influence of filler concentration can be seen in Fig. 39. The larger concentrations give best results at levels above 5.10^{9} rad.

4.11 Normal glass fibres used for the reinforcement of epoxy resins contain 8 o/o B_2O_3. Boron has a large cross section for thermal neutrons. It was of interest to check if boron increases the sensitivity to radiation damage. In Figs. 40-41 some glass and silica reinforced resins were studied. It can be concluded that epoxies containing boron are not as radiation resistant as without, but the differences are not large.

4.12 A decrease of the adhesion to copper due to irradiation was measured. A very high bond strength under irradiation was found for some aromatic systems (table 2).

In general rupture occured in the epoxy resin for the unirradiated samples and at the resin-copper surface after irradiation.

Acknowledgement

We wish to thank Dr. L. Resegotti who was kind enough to review the draft for this paper.

- Table 2 -

Bond Strength (kg/cm2)

Dose Absorbed (rad)	Ar. F + HT 976	Ar. F + HT 972	Ar. F + HY 906 + 960	Ar. F + HT 976
-	122	216	175	> 250
5,56. 10^8	183	147	137	-
1. 10^9	--	143	138	-
2,65. 10^9	128	101	99	157

Dose Absorbed	LY 558 + HT 971	LY 558 + HT 972	Araldite D + HY 951
-	85.5	150	190
1,05. 10^8	-	-	123
1.10.^{9}	130	-	-
2,6.10^9	101	121	-

REFERENCES :

(1) G. Pluym, M. van de Voorde - ISR/MAG/67-3 (1967)

(2) Y. Droulers and C. Meunier, C.E.A. - R. 2.5.36 (1964)

(3) A. Burtscher and G. Petschnik, Atompraxis 7 (9), 1963.

LIST OF FIGURES:

Fig. 1	Araldite D + HY 951
Fig. 2	" CY 175 + HY 905
Fig. 3	" CY 179 + HY 905
Fig. 4	" F + HT 912
Fig. 5	" F + HT 971
Fig. 6	" F + HT 972
Fig. 7	EPN 1.138 + HT 976
Fig. 8	Araldite F + X 8157/131
Fig. 9	" F + HY 906 + 960
Fig. 10	" F + HY 964
Fig. 11	Epikote 828 + BF 3 - 1040
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Fig. 13	Araldite F + HT 972 + Alumina
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Fig. 18	Influence of different hardeners on the radiation resistance of classical epoxy resins.
Fig. 19	Influence of different hardeners on the radiation resistance of classical epoxy resins.
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Fig. 22	Araldite F cured with HY 905 and HY 906.
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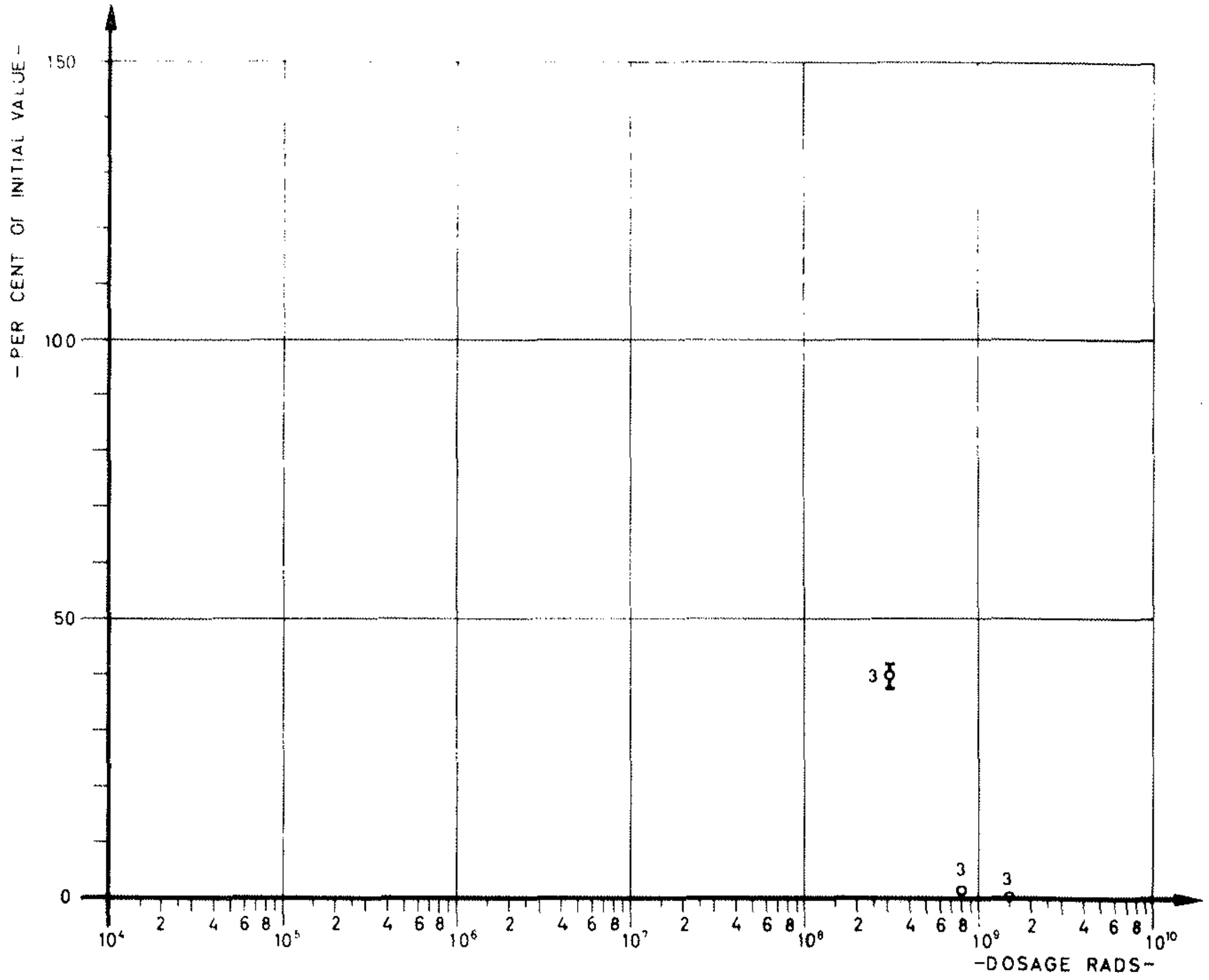
Fig. 24	EPN 1138 + HY 905 + DY 062 irradiated in reactor and spent fuel elements.
Fig. 25	Araldite F + HY 905 + DY 061 + DY 040 irradiated in reactor and spent fuel elements.
Figs.26-30-34	Influence of hardener concentration Araldite D + HY 951
Figs.27-31-35	Influence of hardener concentration Araldite F + HT 972
Figs.28-32-36	Influence of hardener concentration Araldite F + HT 976

Figs. 29-33-37	Influence of hardener concentration - LY 558 + HT 972.
Fig. 38	Araldite F + HT 972 + different fillers.
Fig. 39	Influence of filler concentration on the radiation resistance of classical epoxy resins.
Fig. 40	Influence of the presence of boron in glass reinforced epoxies. Araldite F + DDM + glass or silica.
Fig. 41	Araldite X 33-1020 + HT 972 + glass or silica.

ARALDITE D + HY 951 (100-9)

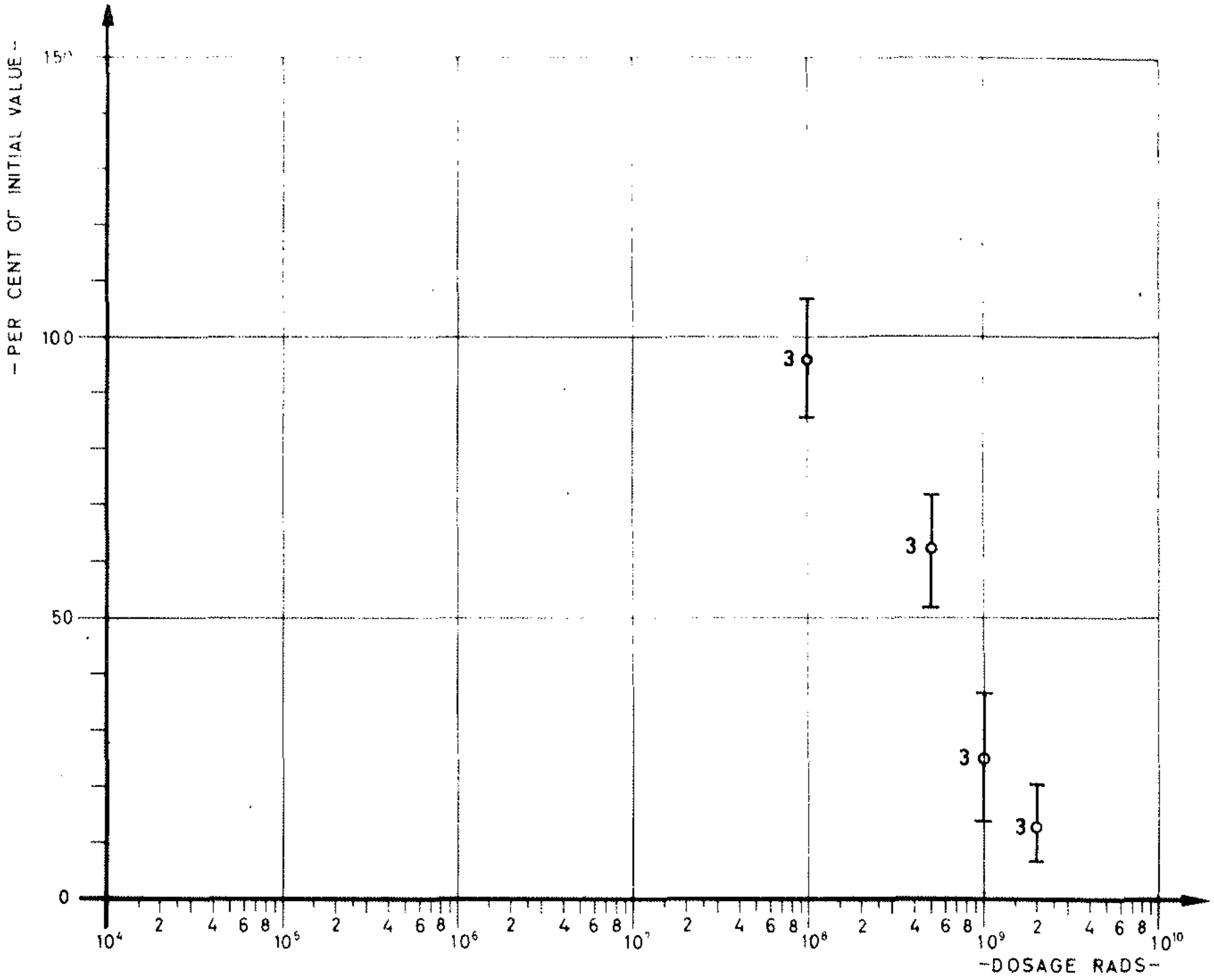


CURVE N°	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	8,5 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION REACTOR (~ 20% n + ~ 80% γ)

Fig. 1

ARALDITE CY 175 + HY 905 (100 - 65)

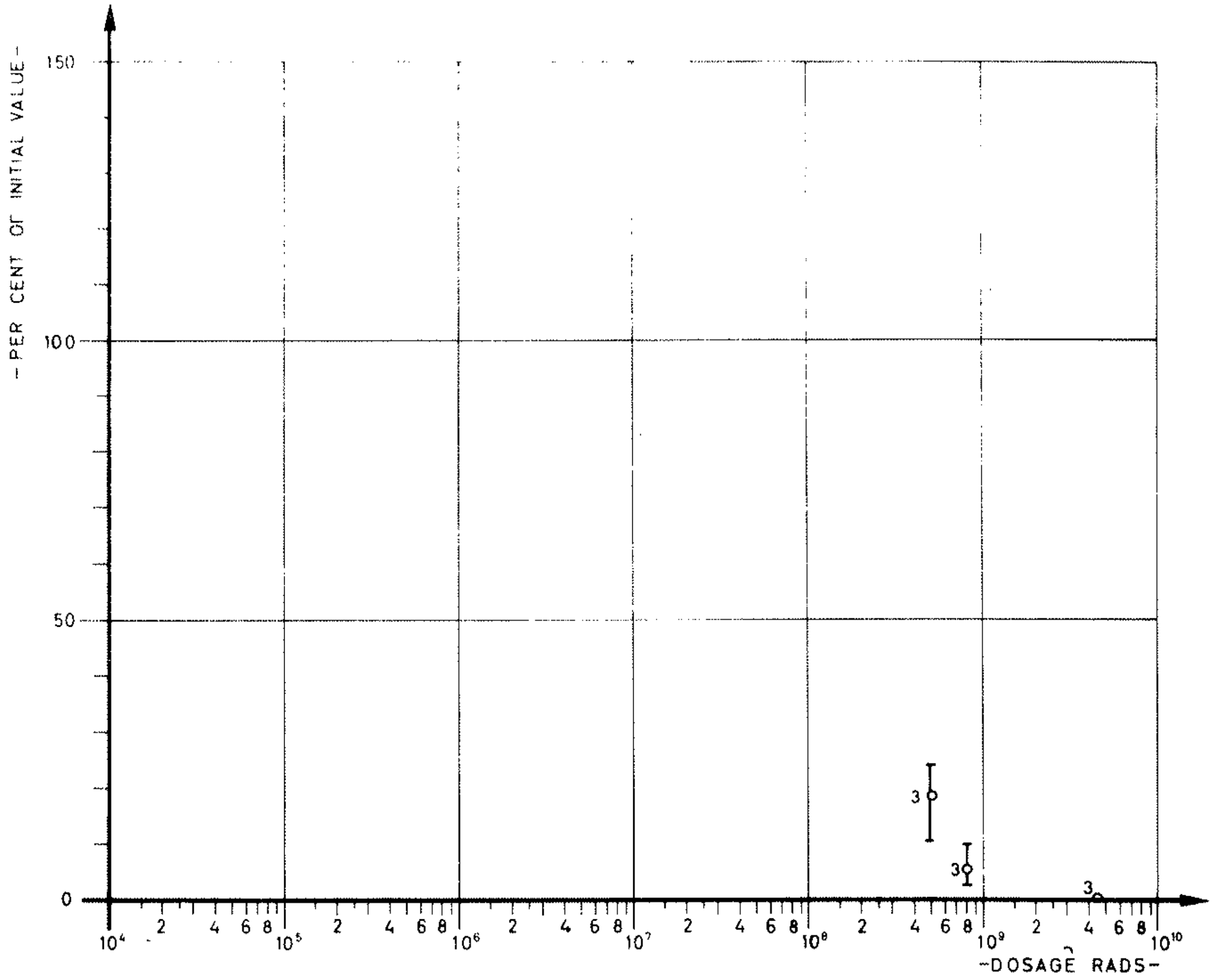


CURVE N°	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	4,8 (kg / mm^2)
4	ELASTIC MODULUS	(kg / mm^2)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION REACTOR (- 20% n + - 80% γ)

Fig. 2

ARALDITE CY 179 + HY 905 (100-72)

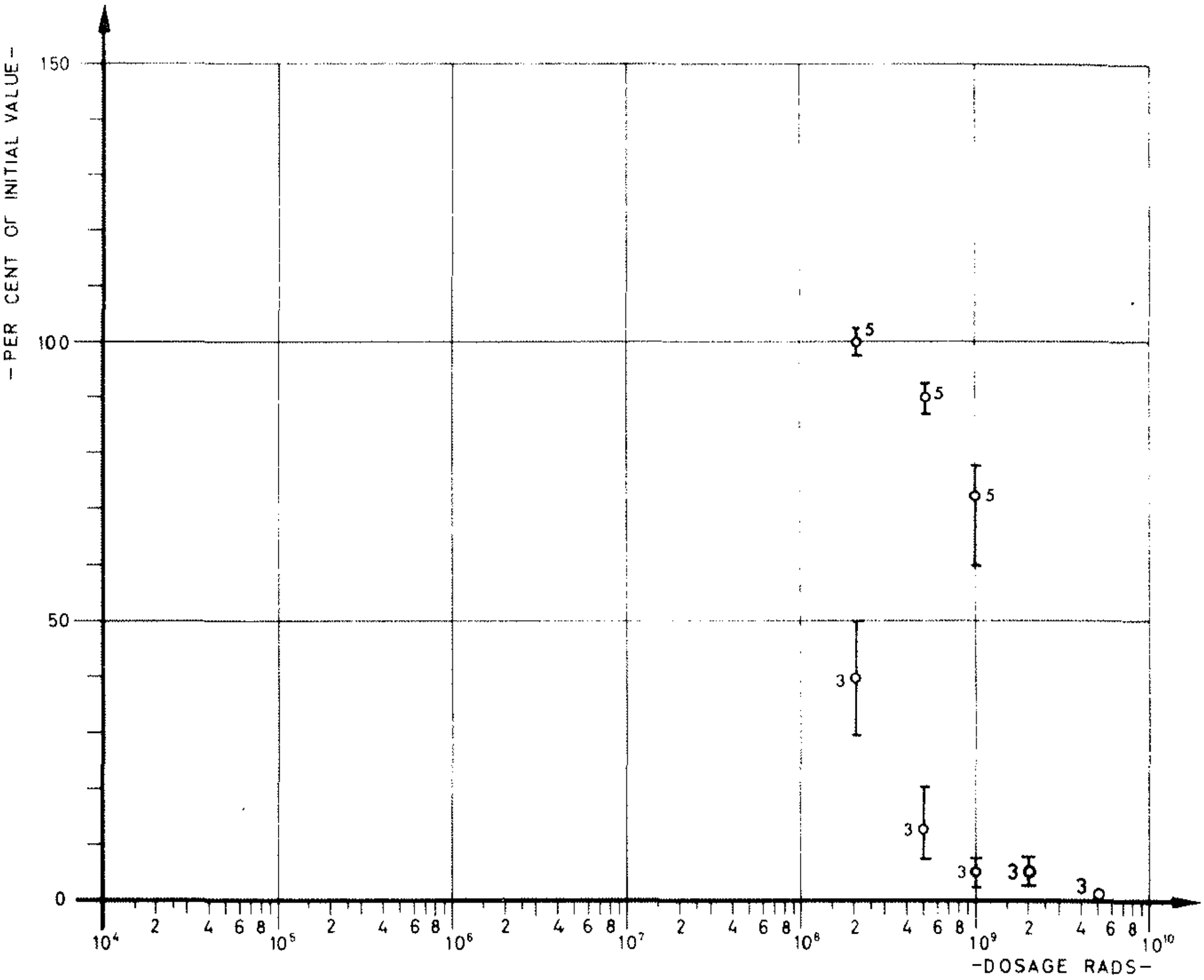


CURVE N°:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	6,1 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~ 20% n + ~ 80% γ)

Fig. 3

ARALDITE F + HT 912 (100 – 150)

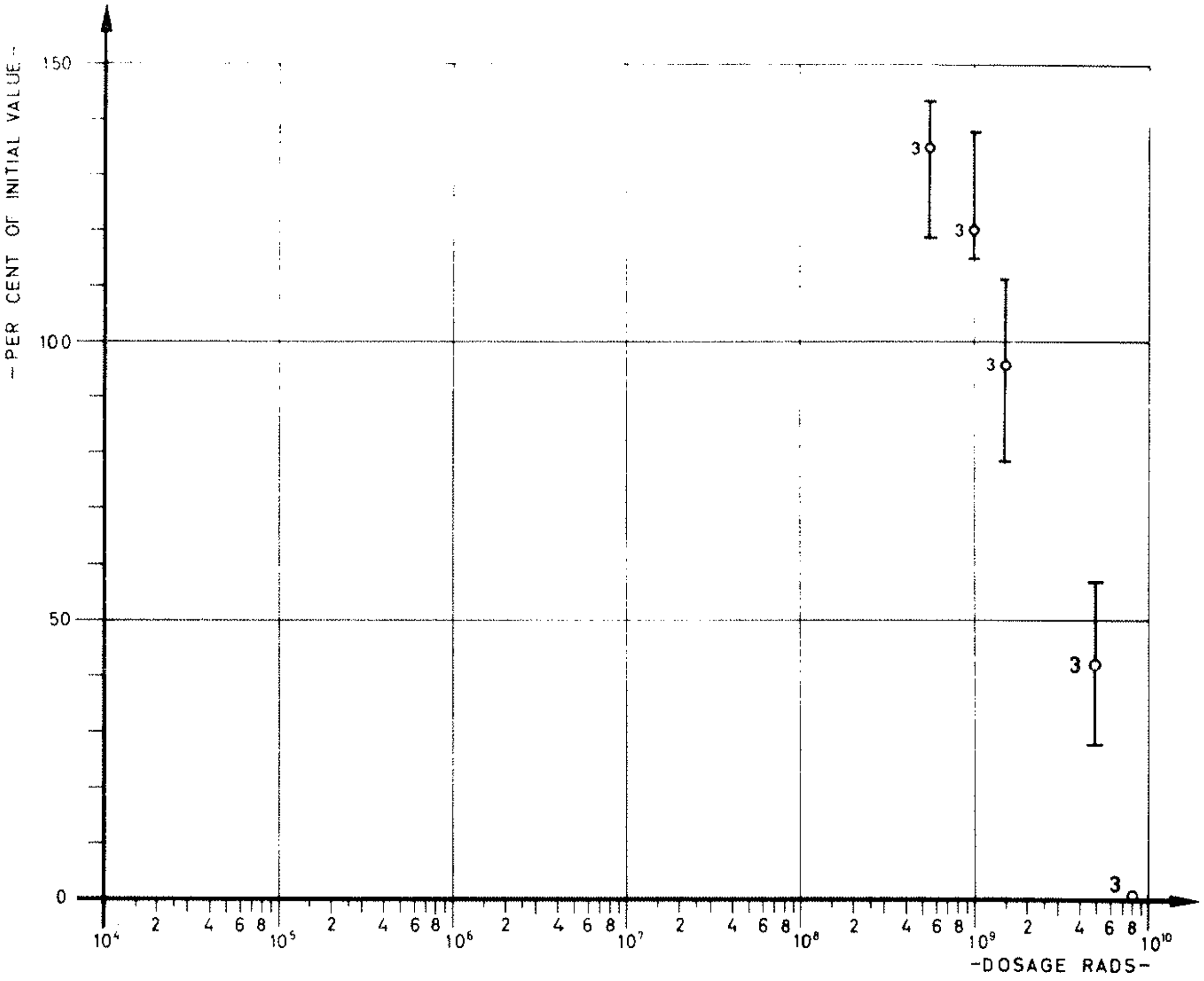


CURVE Nº:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	9,9 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	89 (Shore D)

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 4

ARALDITE F + HT 971 (100-14,5)

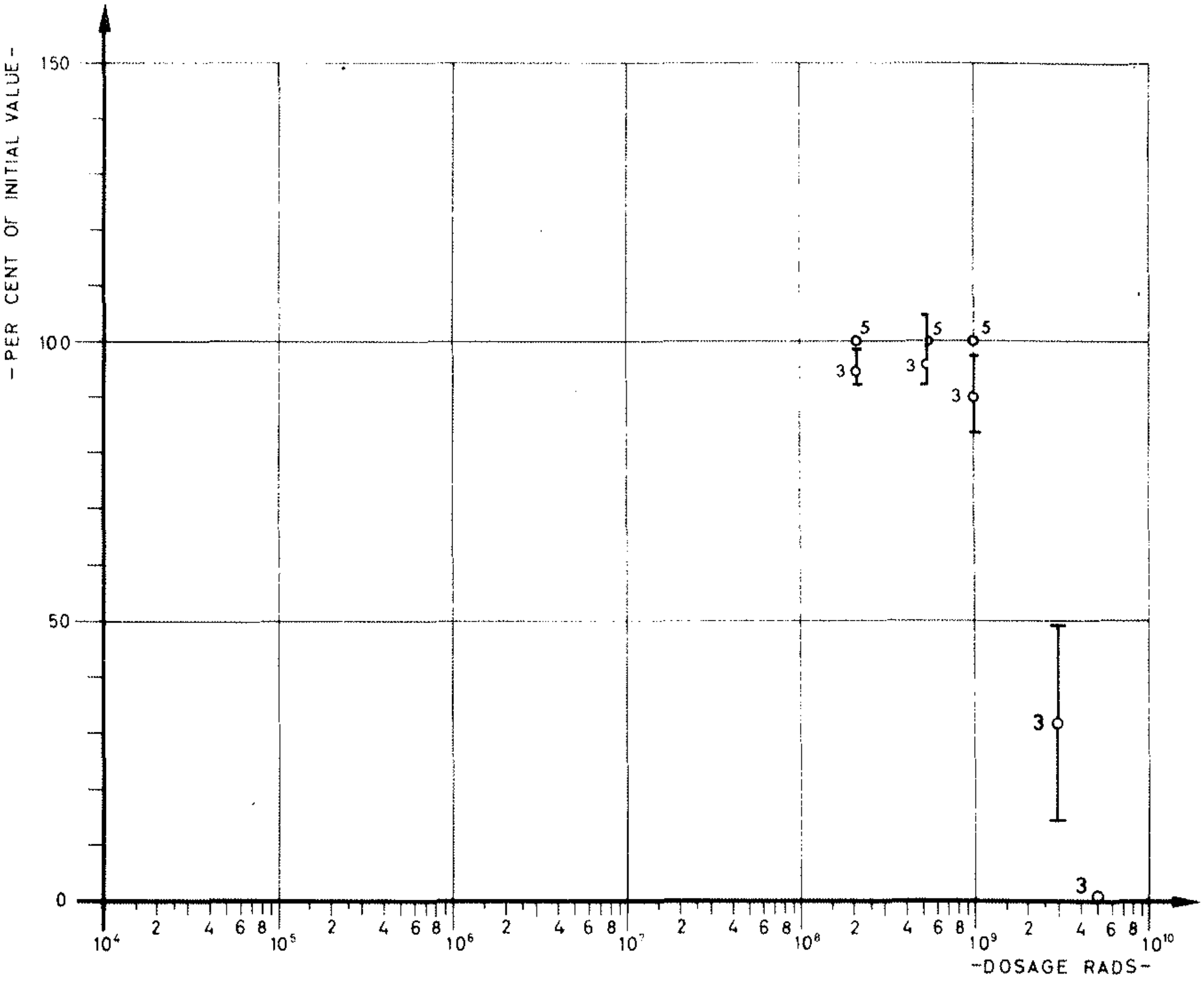


CURVE N°	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	12 (kg / mm^2)
4	ELASTIC MODULUS	(kg / mm^2)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~ 20% n + ~ 80% γ)

Fig. 5

ARALDITE F + HT 972 (100 - 27)

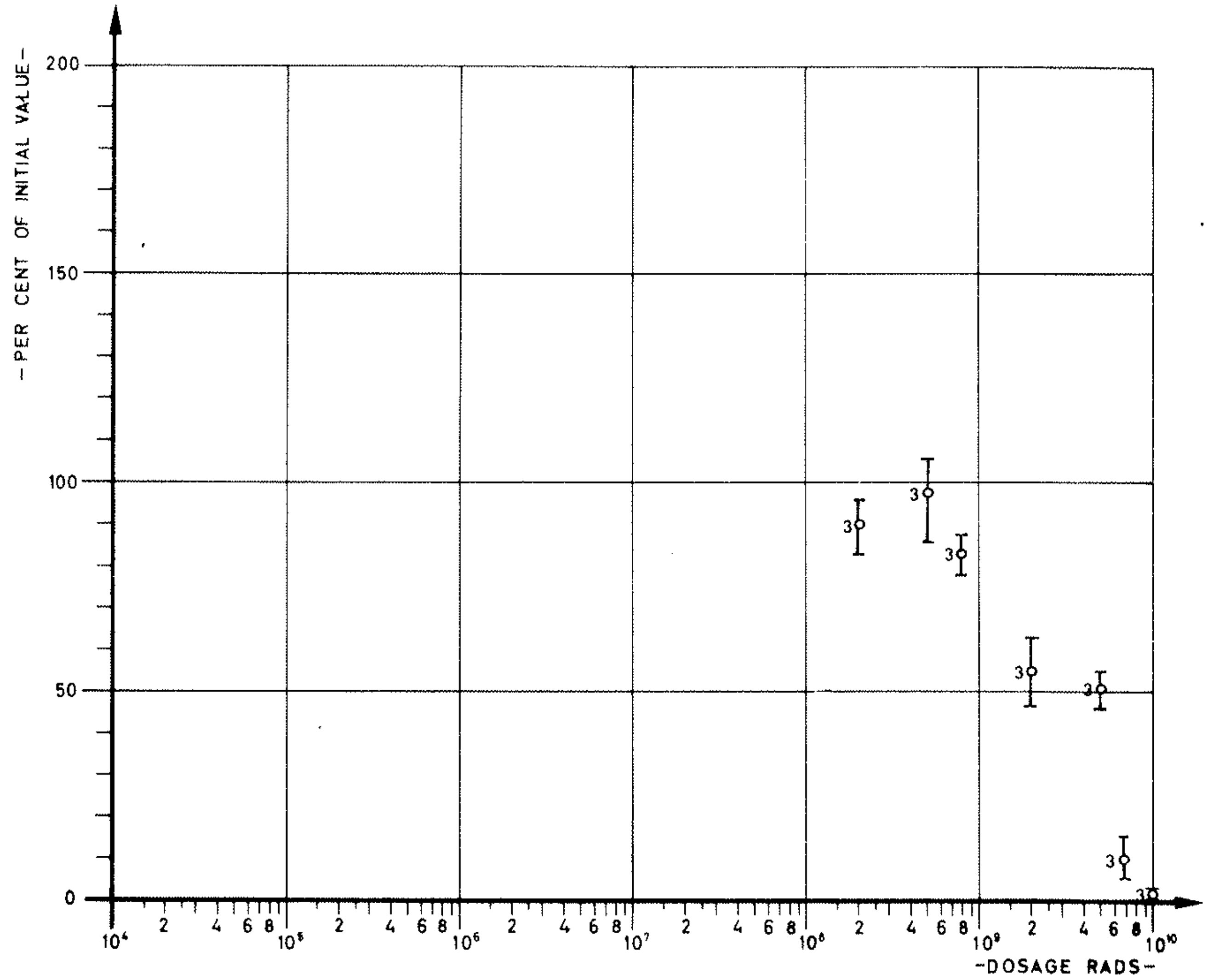


CURVE Nº	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg/mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	16,3 (kg/mm^2)
4	ELASTIC MODULUS	(kg/mm^2)
5	HARDNESS	86 (Shore D)

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 6

EPN 1138 + HT 976 (100-35)

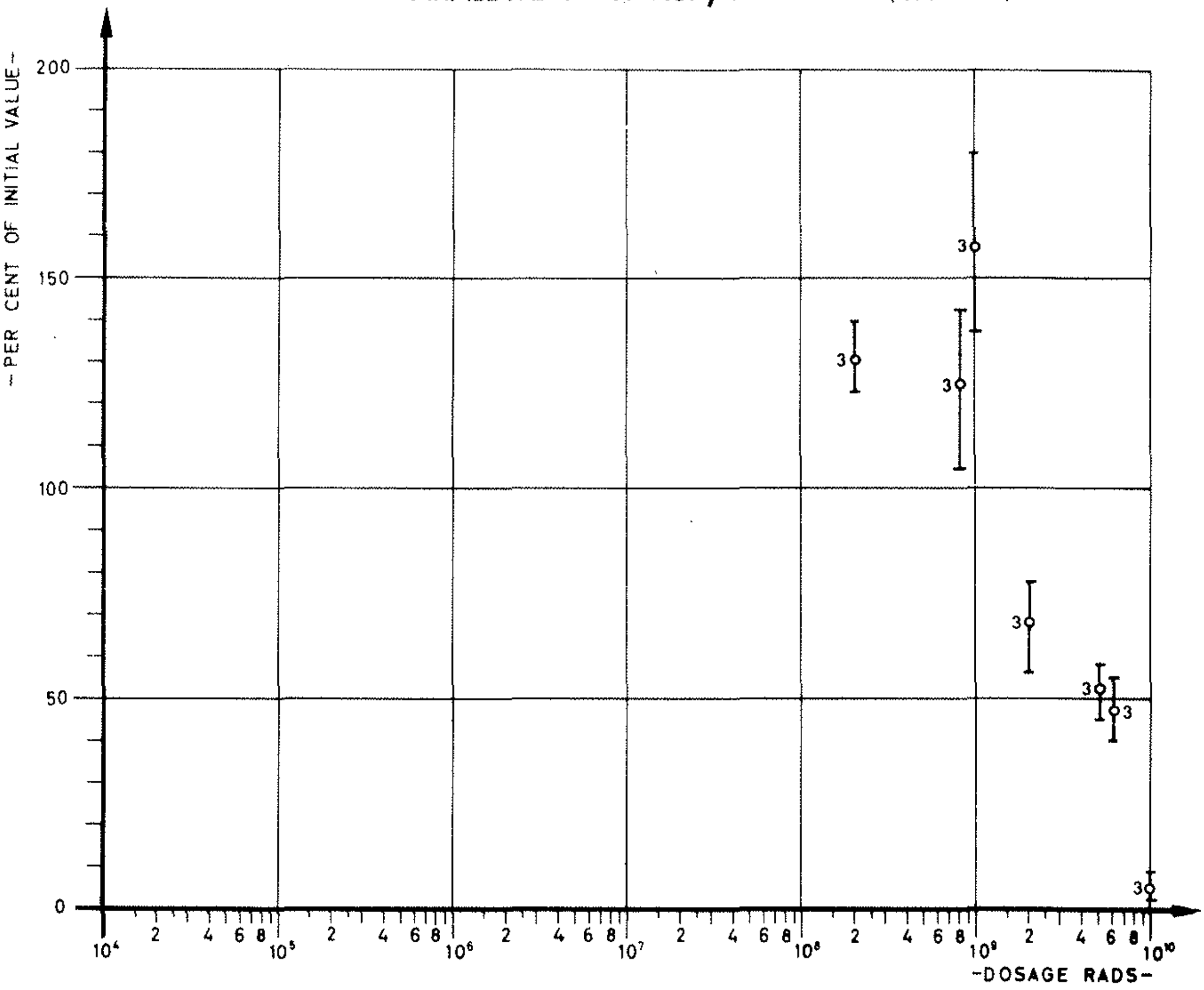


CURVE Nº:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg/mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	14,5 (kg/mm²)
4	ELASTIC MODULUS	(kg/mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION: REACTOR (~20% n + ~80% γ)

Fig. 7

ARALDITE F + X 8157/131 (100 – 40)

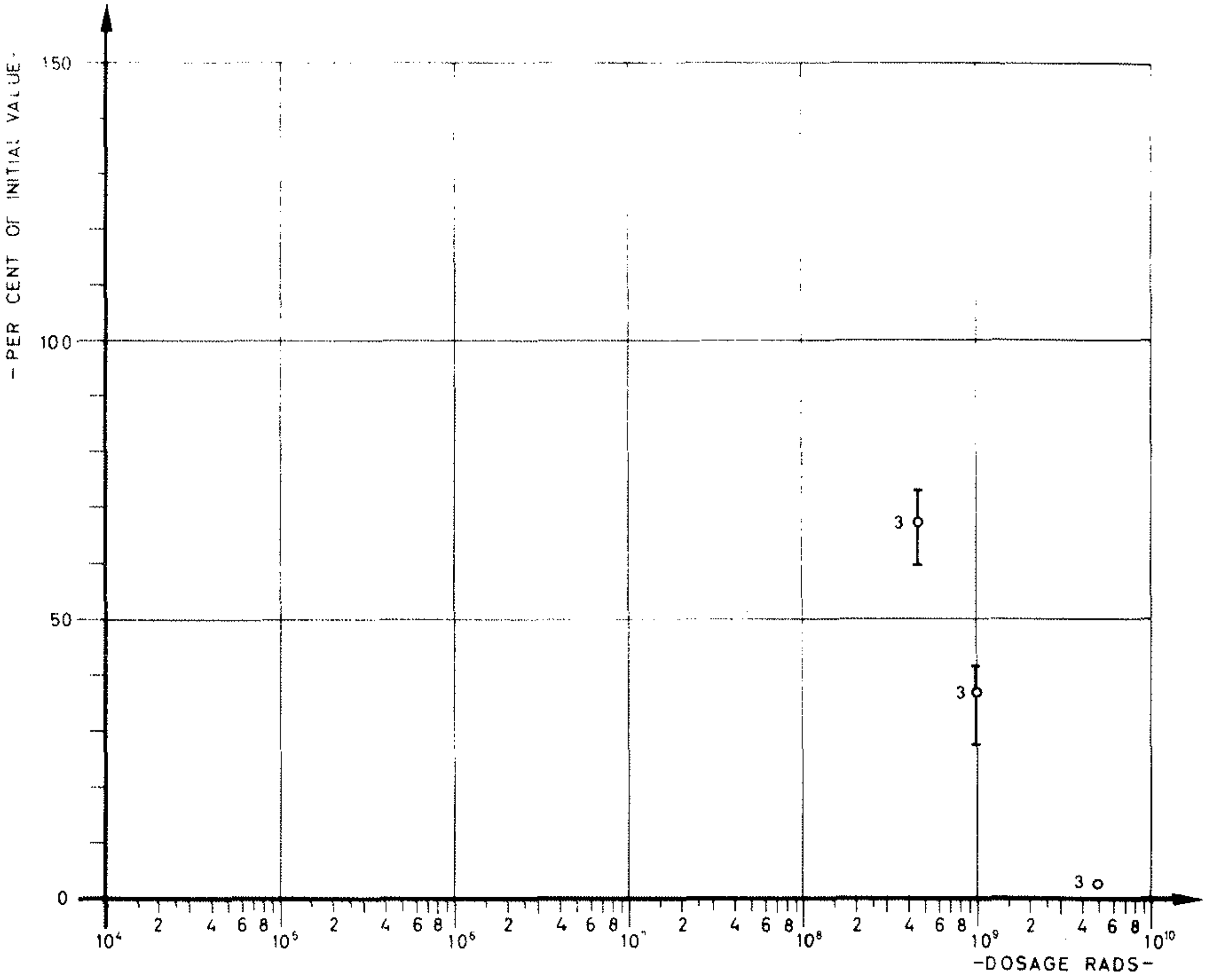


CURVE Nº:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	10 (kg / mm^2)
4	ELASTIC MODULUS	(kg / mm^2)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~20% n + ~80% γ)

Fig. 8

ARALDITE F + HY 906 + 960 (100 - 80 - 1)

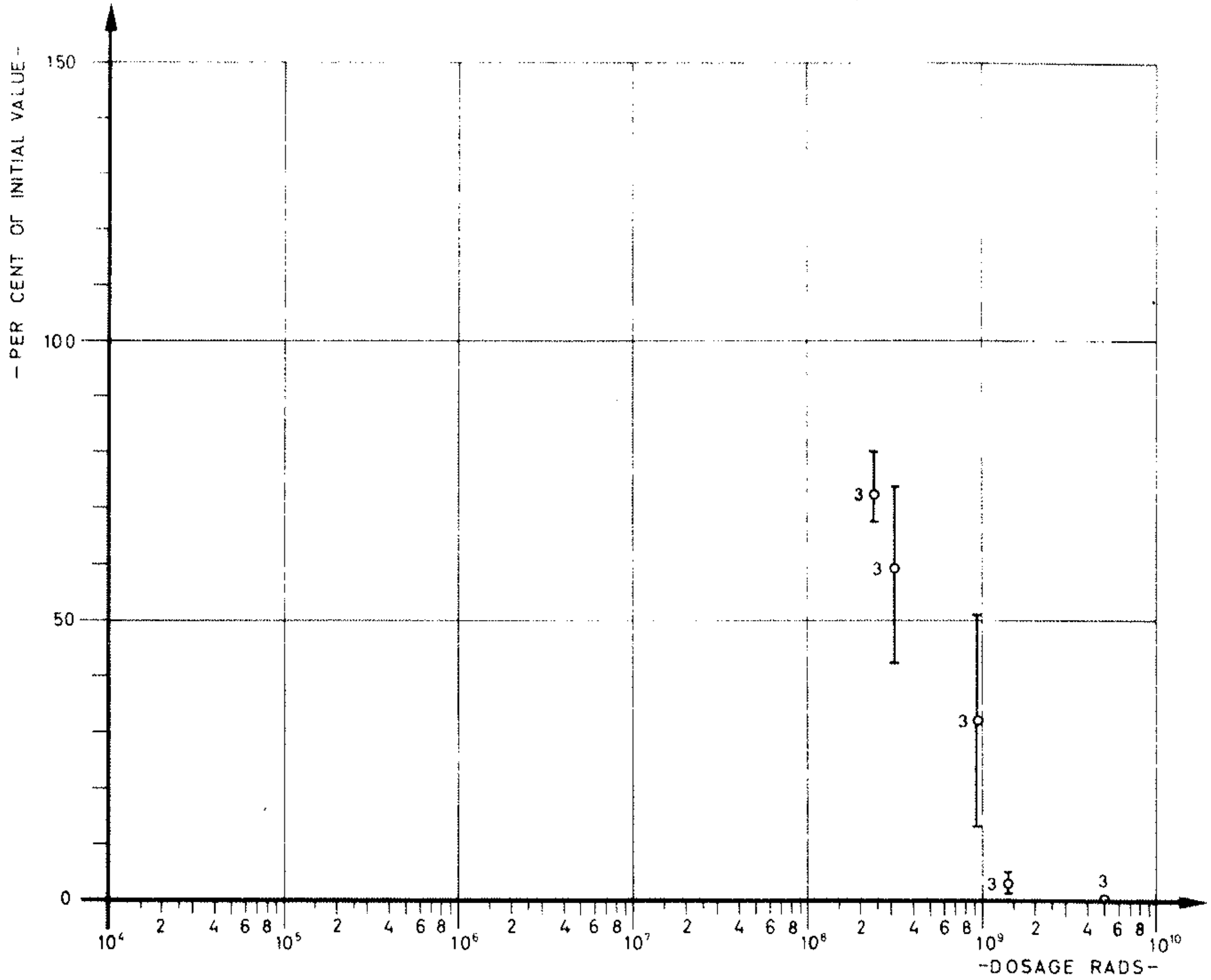


CURVE N°	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	11,8 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~ 20% n + ~80% γ)

Fig. 9

ARALDITE F + HY 964 (100 - 120)

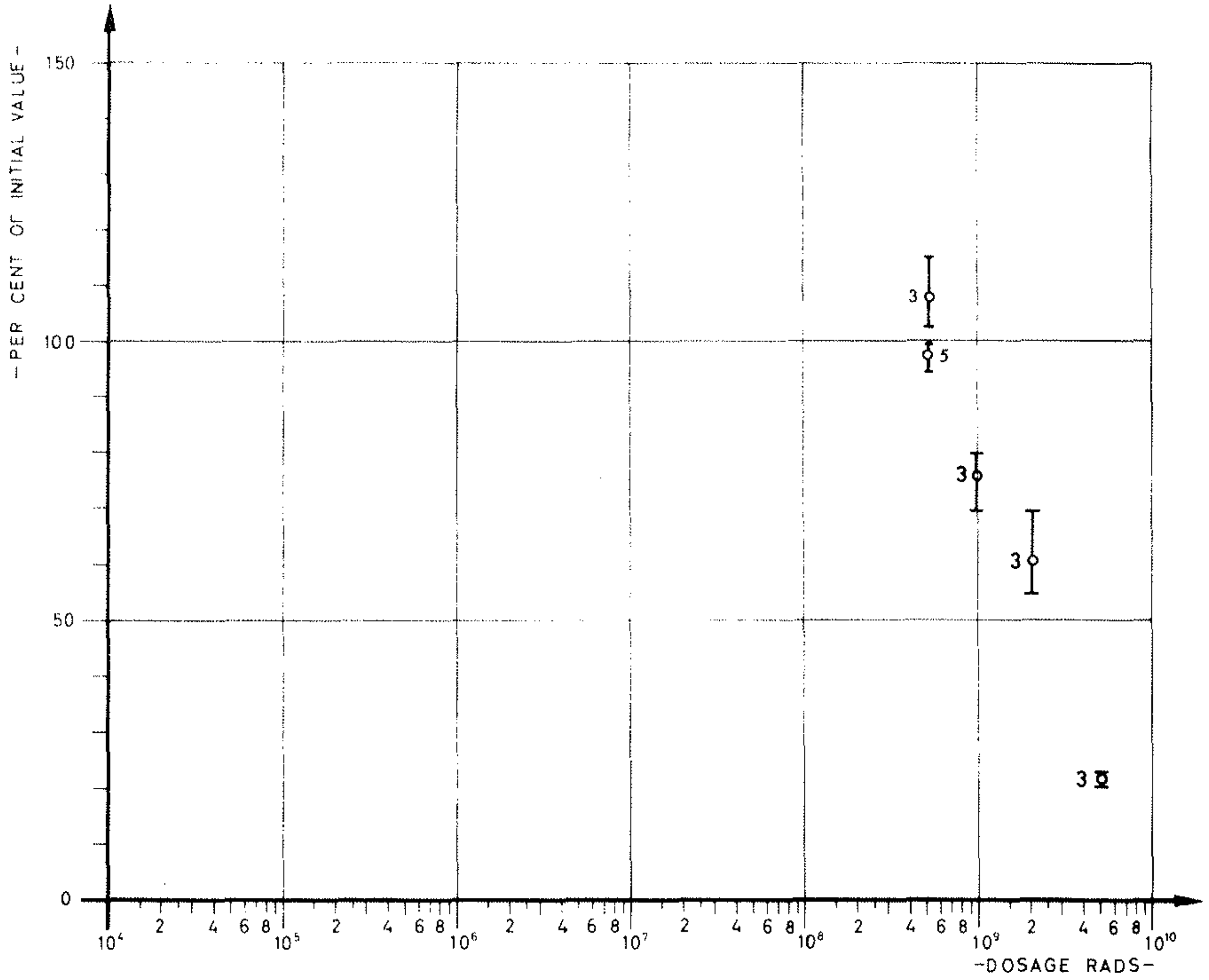


CURVE N°	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	9 (kg / mm^2)
4	ELASTIC MODULUS	(kg / mm^2)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION REACTOR (~ 20% n + ~ 80% γ)

Fig. 10

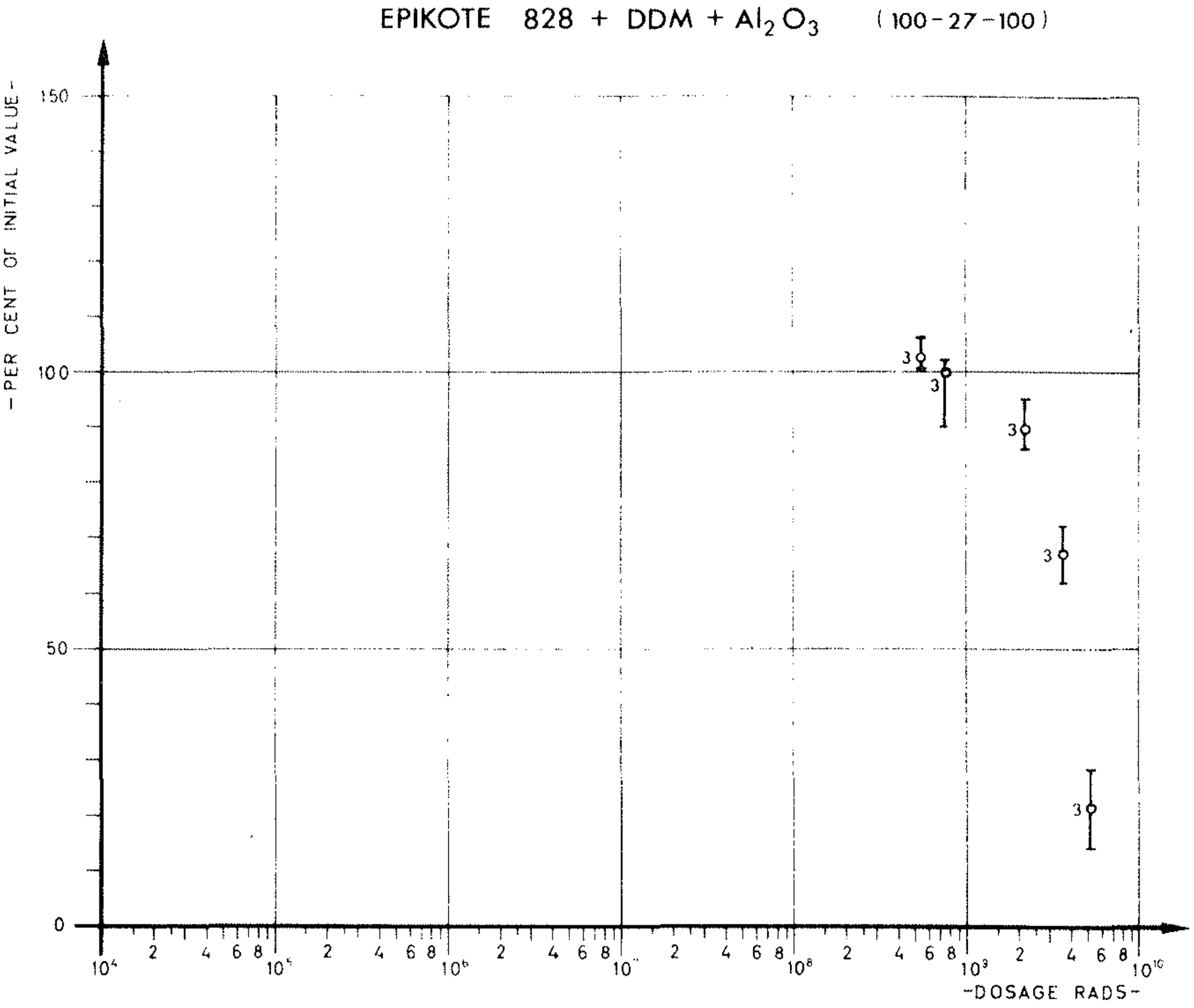
EPIKOTE 828 + BF 3 - 1040 (100-10)



CURVE Nº.	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg/mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	11,4 (kg/mm^2)
4	ELASTIC MODULUS	(kg/mm^2)
5	HARDNESS	87 (Shore D)

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 11

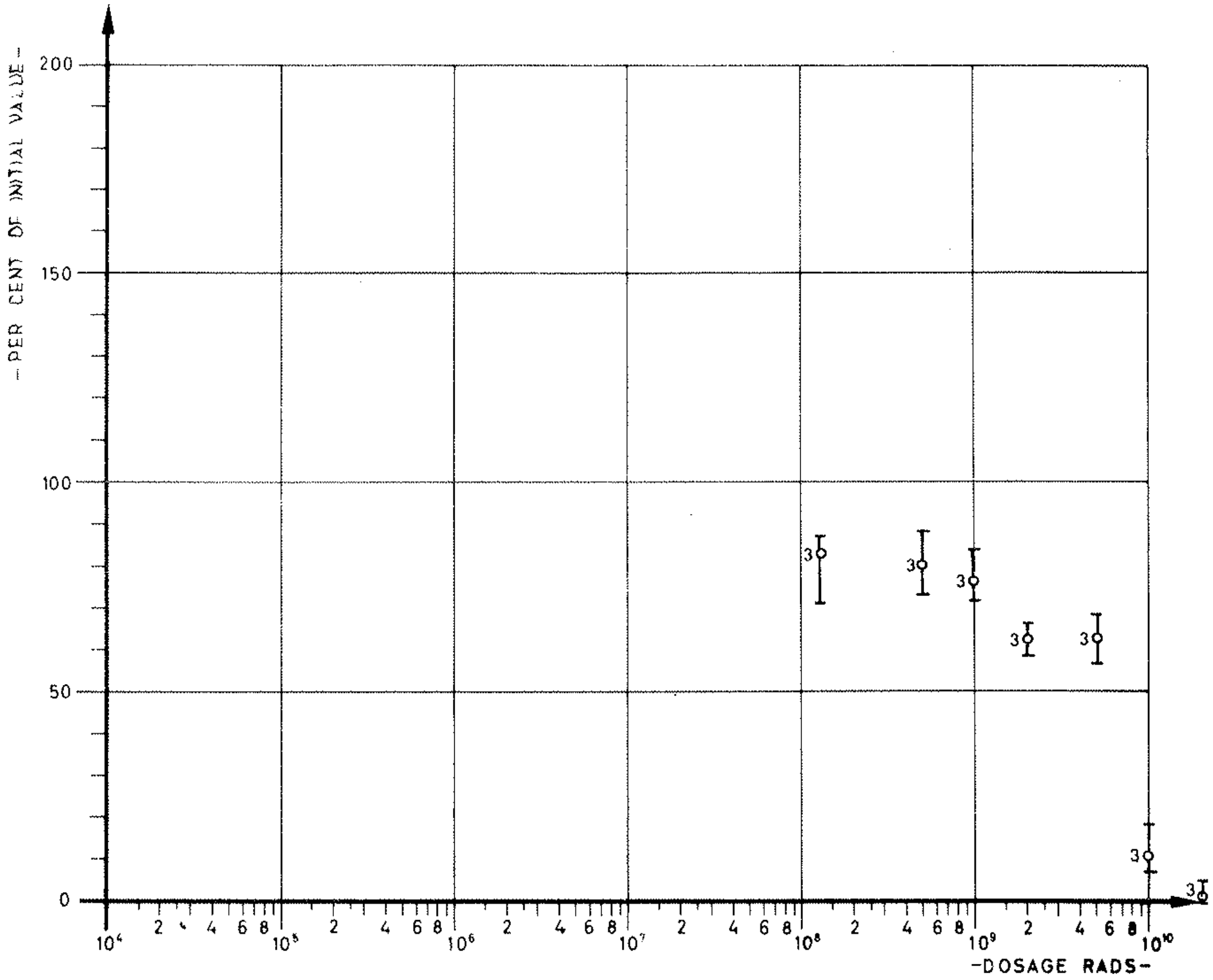


CURVE N°.	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	12 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION REACTOR (~20% n + ~80% γ)

Fig. 12

ARALDITE F + HT 972 + ALUMINA (100 – 27 – 220)

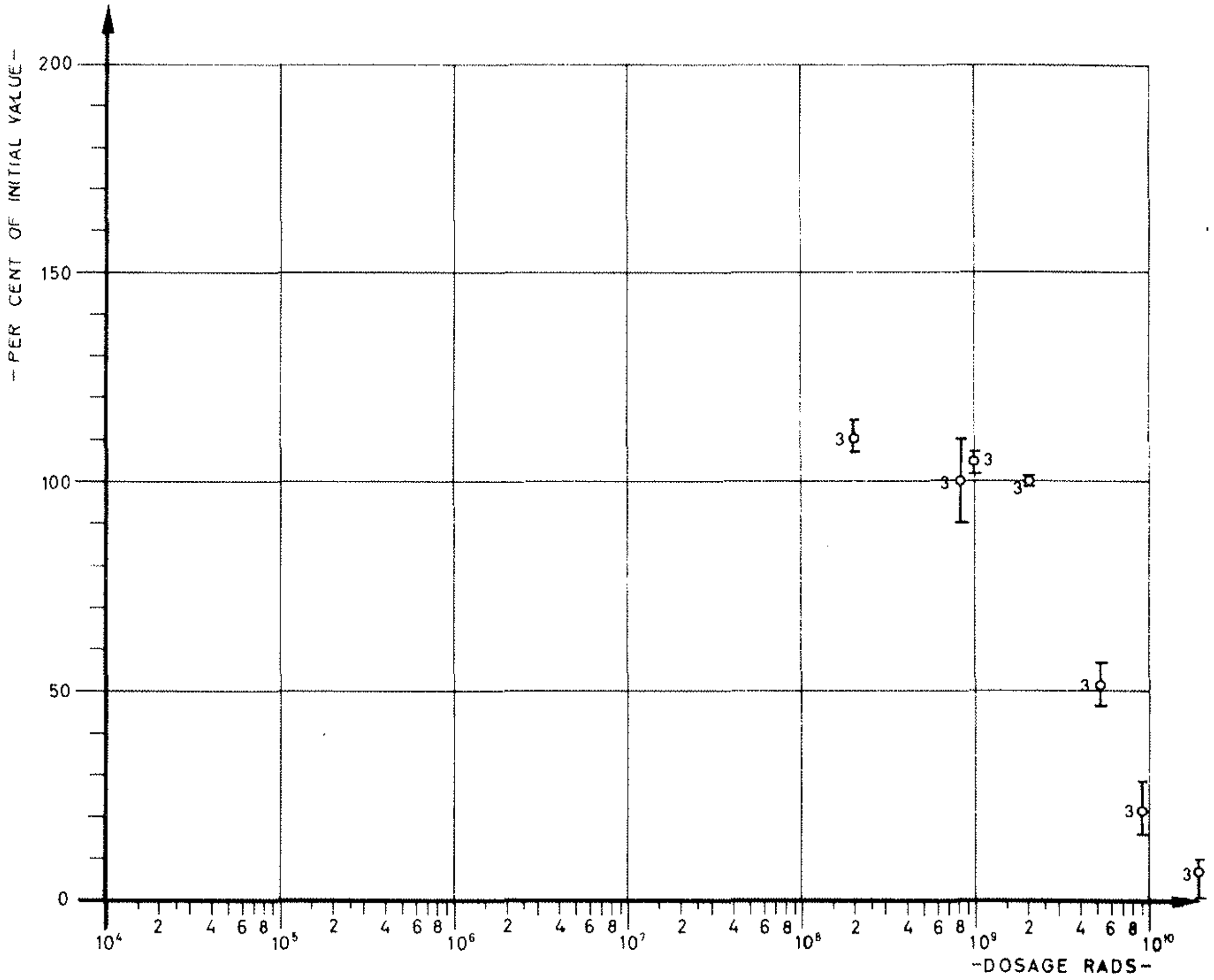


CURVE N°:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	11,4 (kg / mm²)
4	ELASTIC MODULUS	(kg / mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~20% n + ~80% γ)

Fig. 13

ARALDITE F +HT 972 +GRAPHITE (100-27-60)

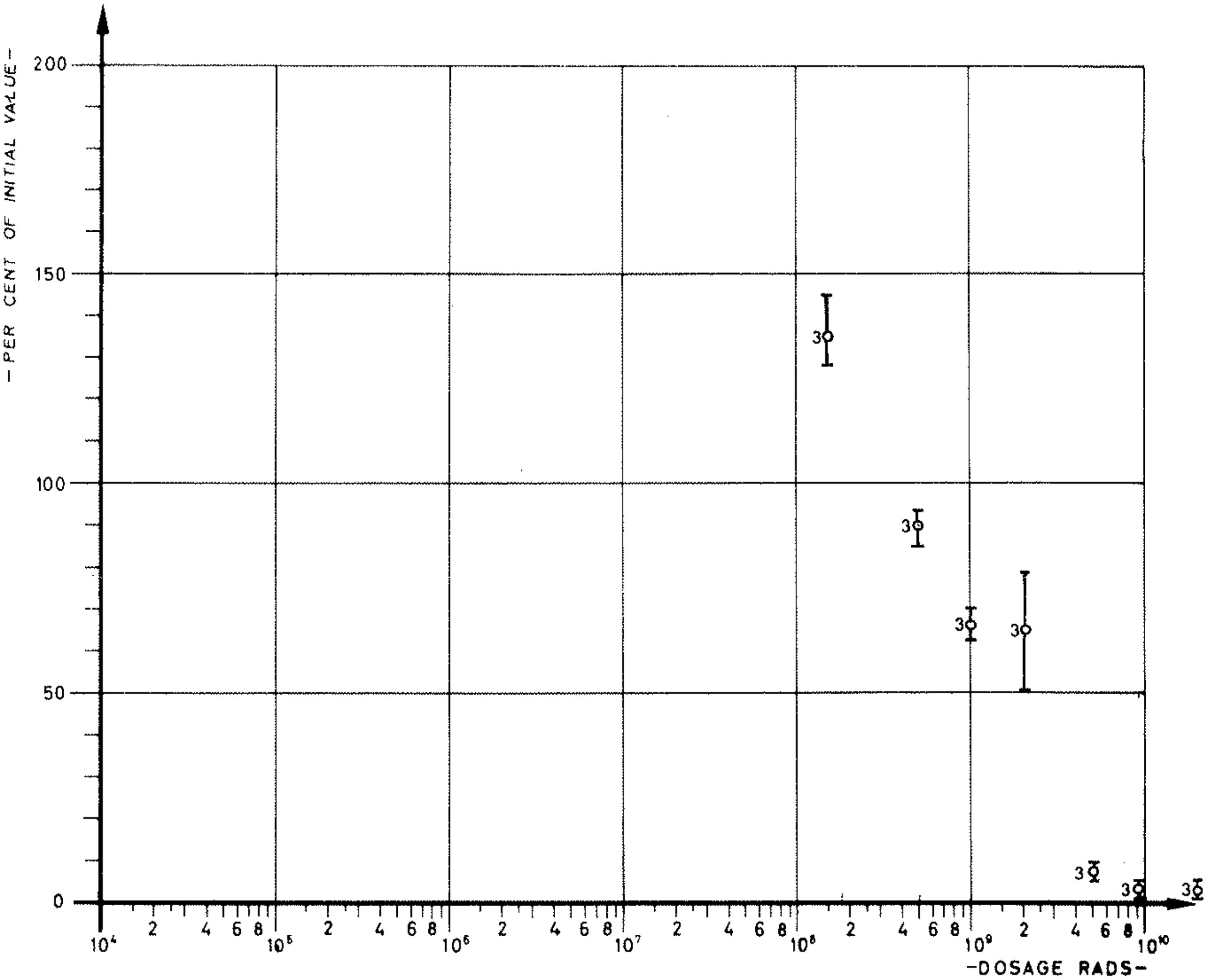


CURVE N°:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg/mm²)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	6,3 (kg/mm²)
4	ELASTIC MODULUS	(kg/mm²)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~20% n + ~80% γ)

Fig. 14

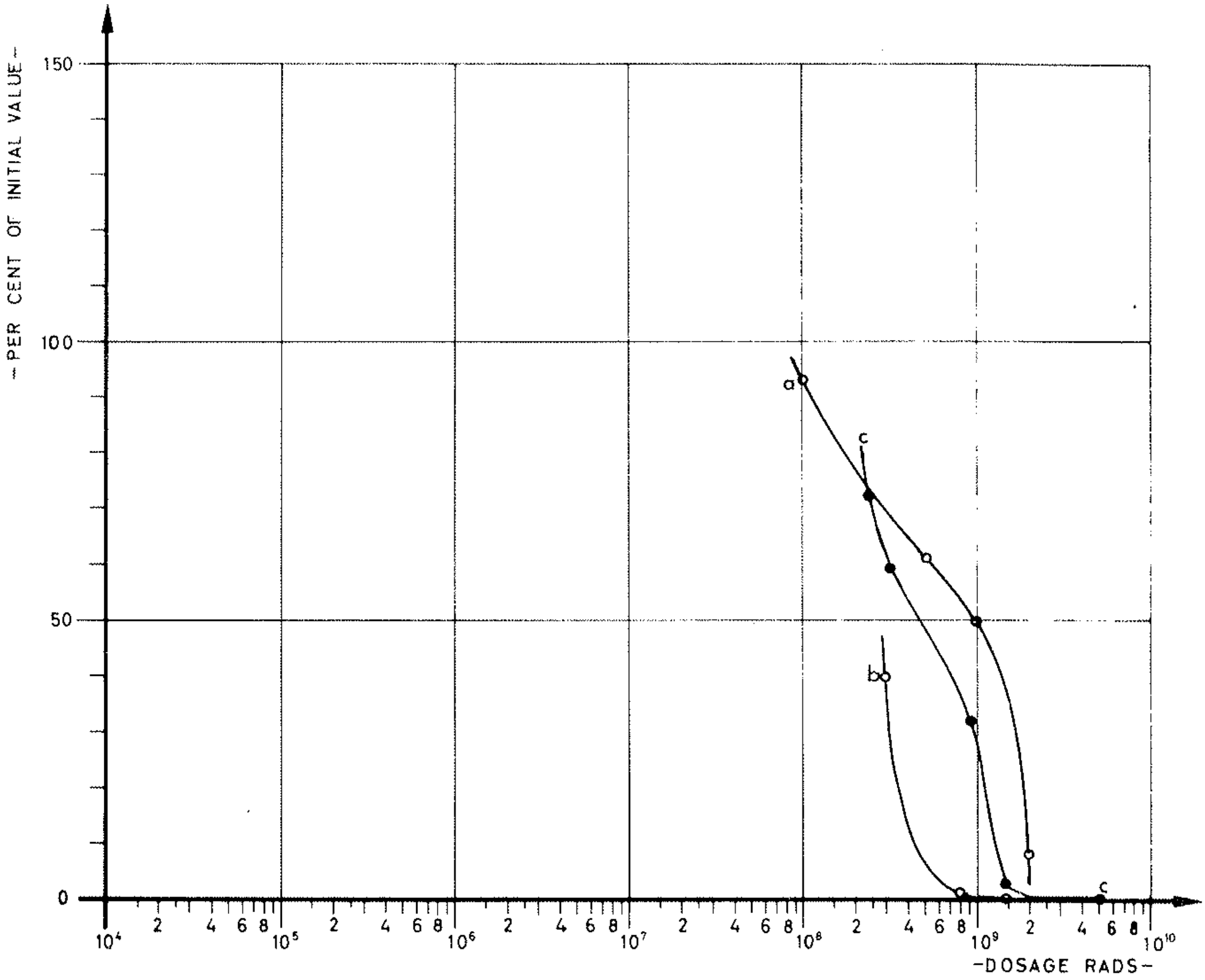
ARALDITE F + HT 972 + AEROSIL + BARIUM SULFATE (100–27–2–150)



CURVE N°:	PROPERTY	INITIAL VALUE
1	TENSILE STRENGTH	(kg / mm^2)
2	ELONGATION	(%)
3	FLEXURAL STRENGTH	5,8 (kg / mm^2)
4	ELASTIC MODULUS	(kg / mm^2)
5	HARDNESS	(Shore D)

NUCLEAR SOURCE OF RADIATION : REACTOR (~20% n + ~80% γ)

Fig. 15



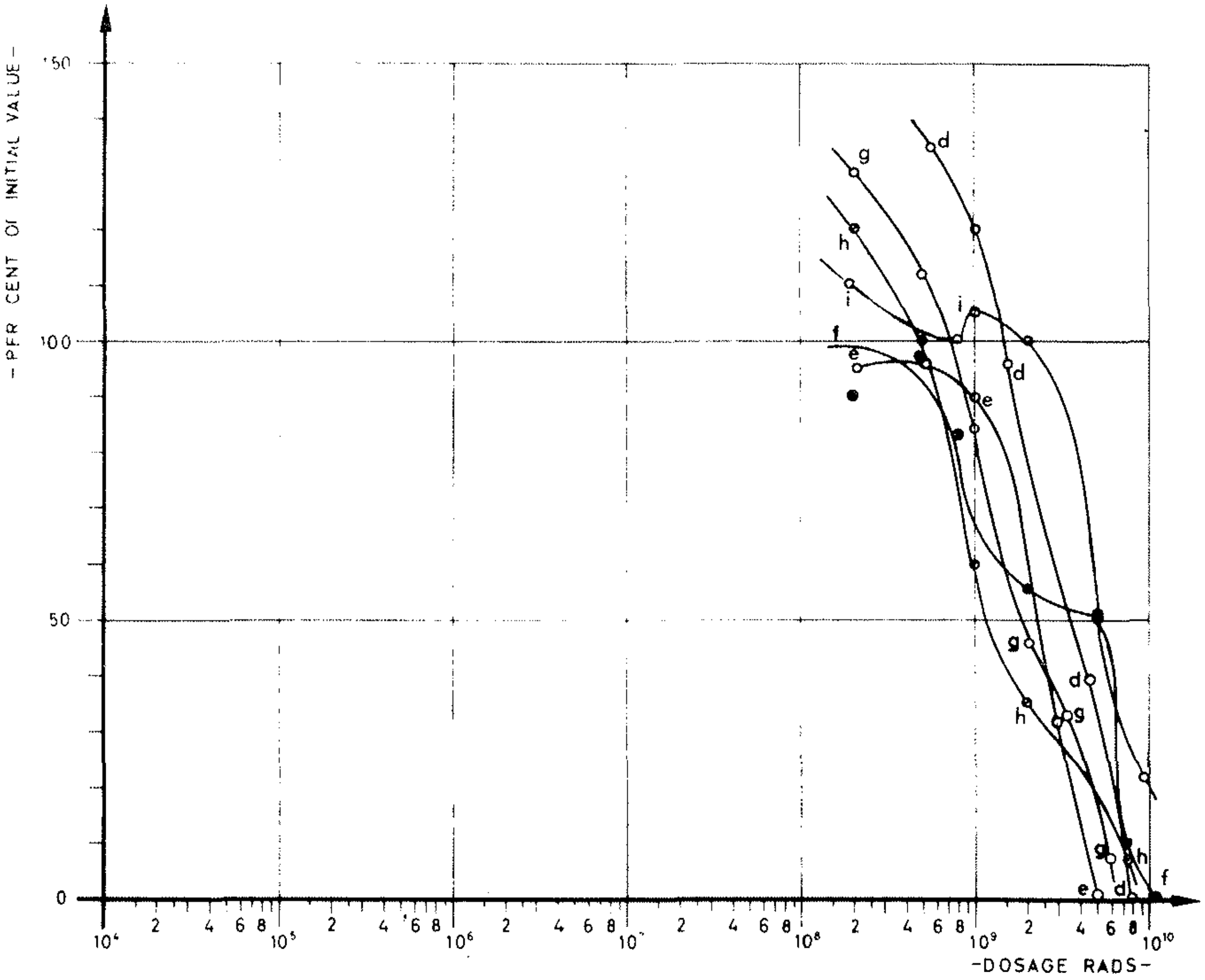
RADIATION RESISTANCE OF SOME CLASSICAL RESIN COMPOSITIONS

FLEXURAL STRENGTH INITIAL VALUE

— CERN COMPOSITIONS :

a	ARALDITE	F + HY 905 + DY 061 + DY 040	100 - 100 - 0,1 - 10	12,3	kg / mm^2
b	"	D + HY 951	100 - 9	8,5	kg / mm^2
c	"	F + HY 964	100 - 120	9	kg / mm^2

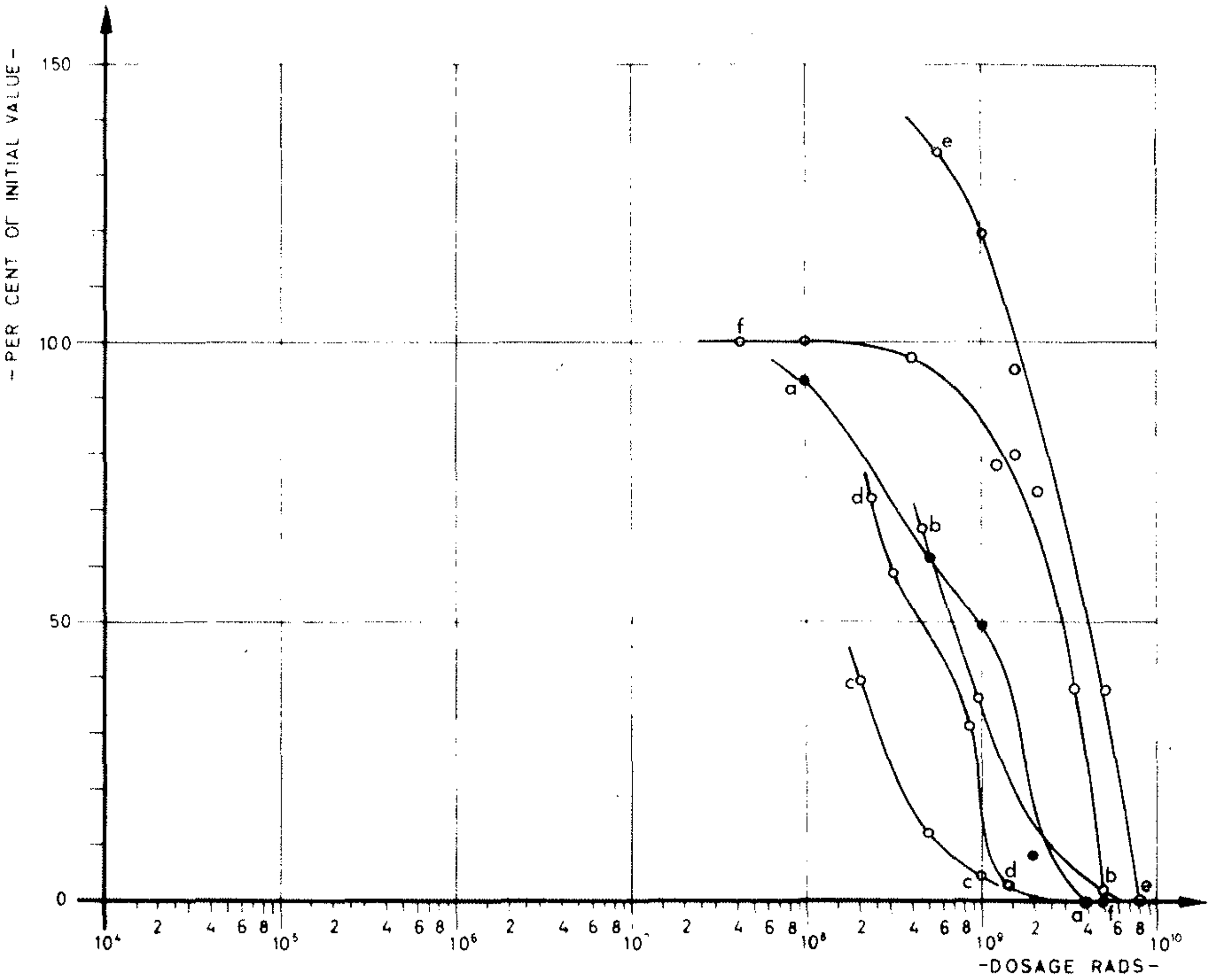
Fig. 16



RADIATION RESISTANCE OF SOME NEW RESIN COMPOSITIONS

FLEXURAL STRENGTH		INITIAL VALUE	
— RADIATION RESISTANT COMPOSITIONS:			
d / ARALDITE F+HT 971	100 – 14,5	12	kg / mm²
e / ARALDITE F+HT 972	100 – 27	16,3	kg / mm²
f / EPN 1138 +HT 976	100 – 35	14,5	kg / mm²
g / EPN 1138 +HY 905 + DY 062	100 – 105 – 0,5	10,3	kg / mm²
h / X 33 / 1020 +HY 905 + DY 062	100 – 136 – 0,5	6,9	kg / mm²
i / ARALDITE F +HT 972 + GRAPHITE	100 – 27 – 60	6,3	kg / mm²

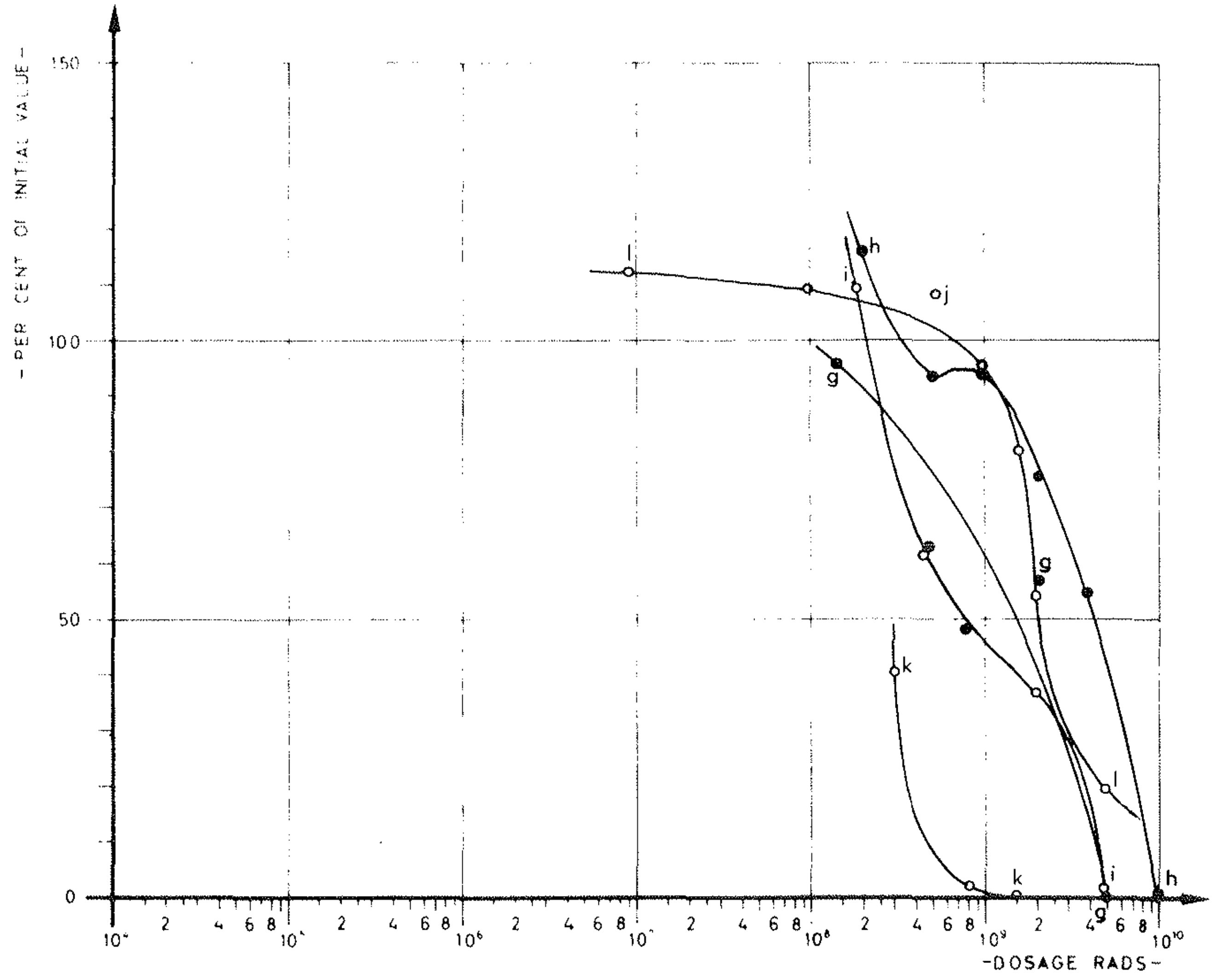
Fig. 17



INFLUENCE OF DIFFERENT HARDENERS ON THE RADIATION RESISTANCE OF CLASSICAL EPOXY RESINS

	FLEXURAL STRENGTH		INITIAL VALUE	
a)	ARALDITE F + HY 905 + DY 061 + DY 040	(100-100-01-10)	12,3	kg/mm²
b)	ARALDITE F + HY 906 - 960	100-80-1	11,8	kg/mm²
c)	ARALDITE F + HT 912	100-150	9,9	kg/mm²
d)	ARALDITE F + HY 964	100-120	9	kg/mm²
e)	ARALDITE F + HT 971	100-145	12	kg/mm²
f)	ARALDITE F + HT 972	100-27	17	kg/mm²

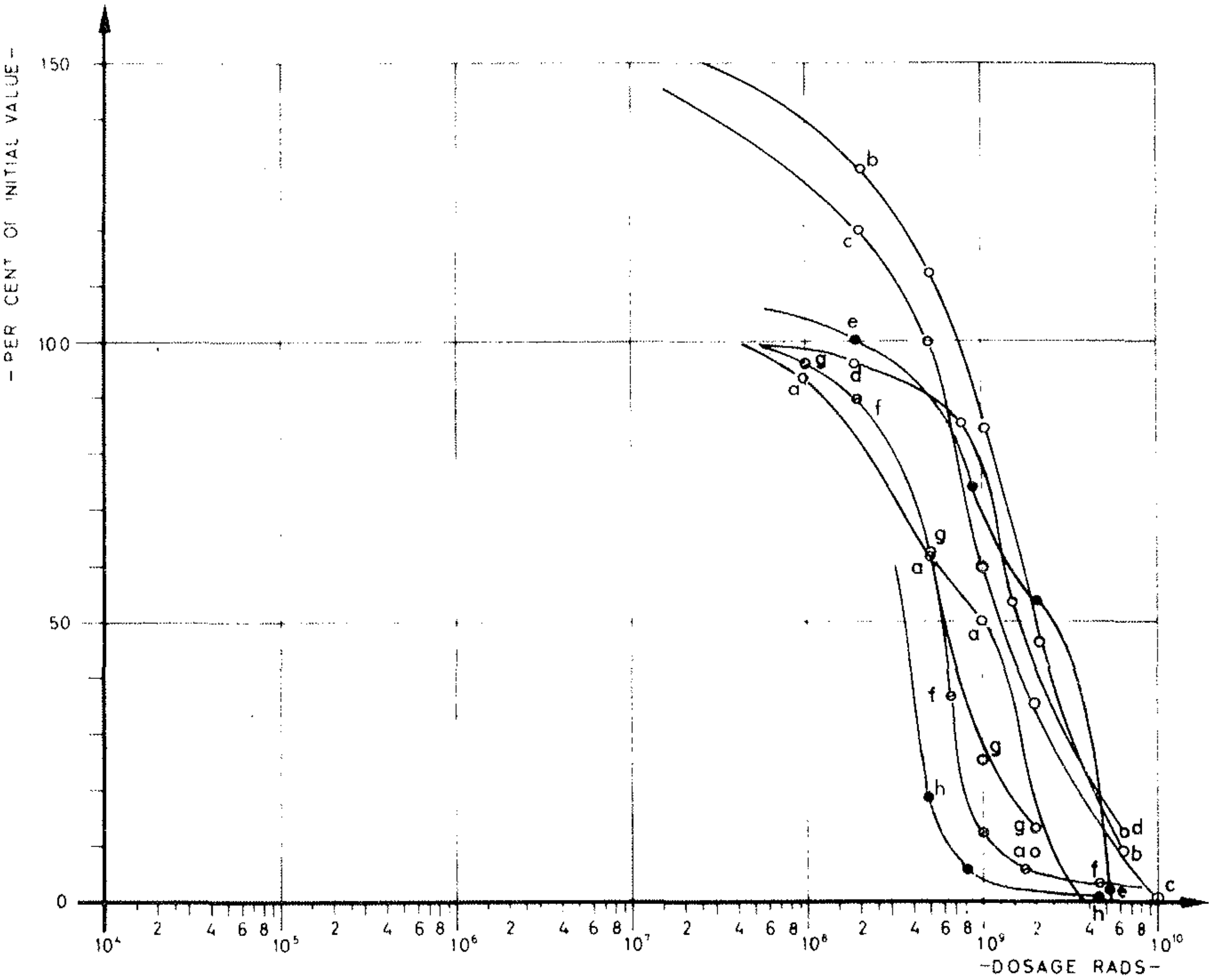
Fig. 18



INFLUENCE OF DIFFERENT HARDENERS ON THE RADIATION RESISTANCE OF CLASSICAL EPOXY RESINS

	FLEXURAL STRENGTH		INITIAL VALUE
g)	ARALDITE F + HT 976	100 – 35	15,6 kg / mm^2
h)	ARALDITE F + X 8157/131	100 – 40	10,1 kg / mm^2
i)	EPIKOTE 828 + BF_3 – 400	100 – 2	12,3 kg / mm^2
j)	EPIKOTE 828 + BF_3 – 1040	100 – 10	11,4 kg / mm^2
k)	ARALDITE D + HY 951	100 – 9	8,5 kg / mm^2
l)	ARALDITE B + HT 901	100 – 30	16,2 kg / mm^2

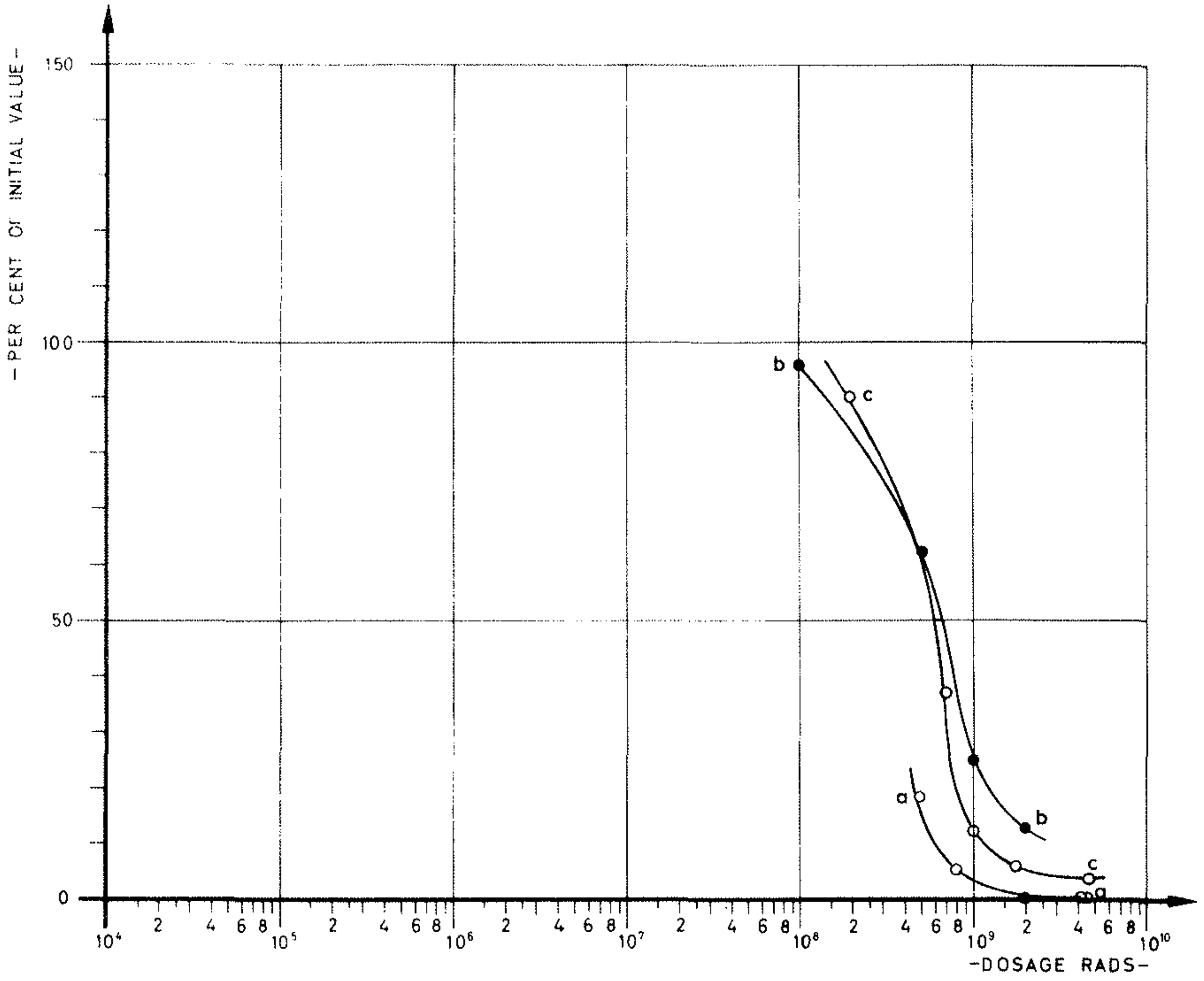
Fig. 19



RADIATION RESISTANCE OF DIFFERENT EPOXY RESINS CURED WITH AN ANHYDRIDE HARDENER (HY 905)

	FLEXURAL STRENGTH		INITIAL VALUE	
a)	ARALDITE F + HY 905 + DY 061 + DY 040	(100 – 100 – 0,1 – 10)	12,3	(kg/mm²)
b)	EPN 1138 + HY 905 + DY 062	(100 – 105 – 0,5)	10,3	(kg/mm²)
c)	X 33/1020 + HY 905 + DY 062	(100 – 136 – 0,5)	6,9	(kg/mm²)
d)	X 33/1189 + HY 905 + DY 062	(100 – 100 – 0,2)	10,5	(kg/mm²)
e)	EPP RESIN + HY 905	(100 – 135)	8,5	(kg/mm²)
f)	DY 032 – HY 905 + DY 062	(100 – 160 – 0,5)	7,5	(kg/mm²)
g)	ARALDITE CY 175 + HY 905	(100 – 65)	4,8	(kg/mm²)
h)	ARALDITE CY 179 + HY 905	(100 – 72)	6,1	(kg/mm²)

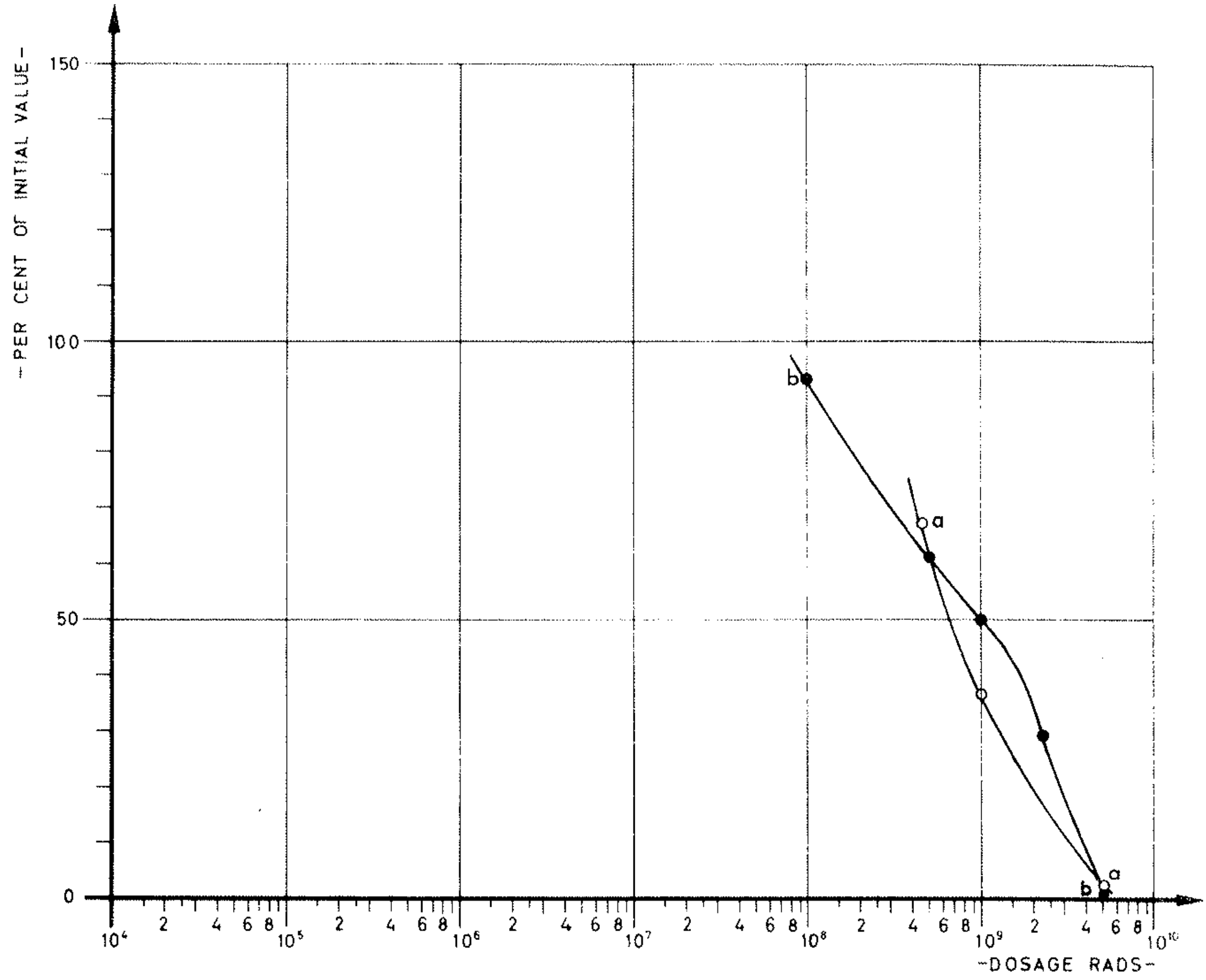
Fig. 20



RADIATION RESISTANCE OF CYCLOALIPHATIC EPOXY RESINS

FLEXURAL STRENGTH		INITIAL VALUE
a) ARALDITE CY 179 + HY 905	100–72	6,1 kg/mm^2
b) ″ CY 175 + ″	100–65	4,8 kg/mm^2
c) ″ DY 032 + ″ + DY 062	(100–160–0,5)	7,5 kg/mm^2

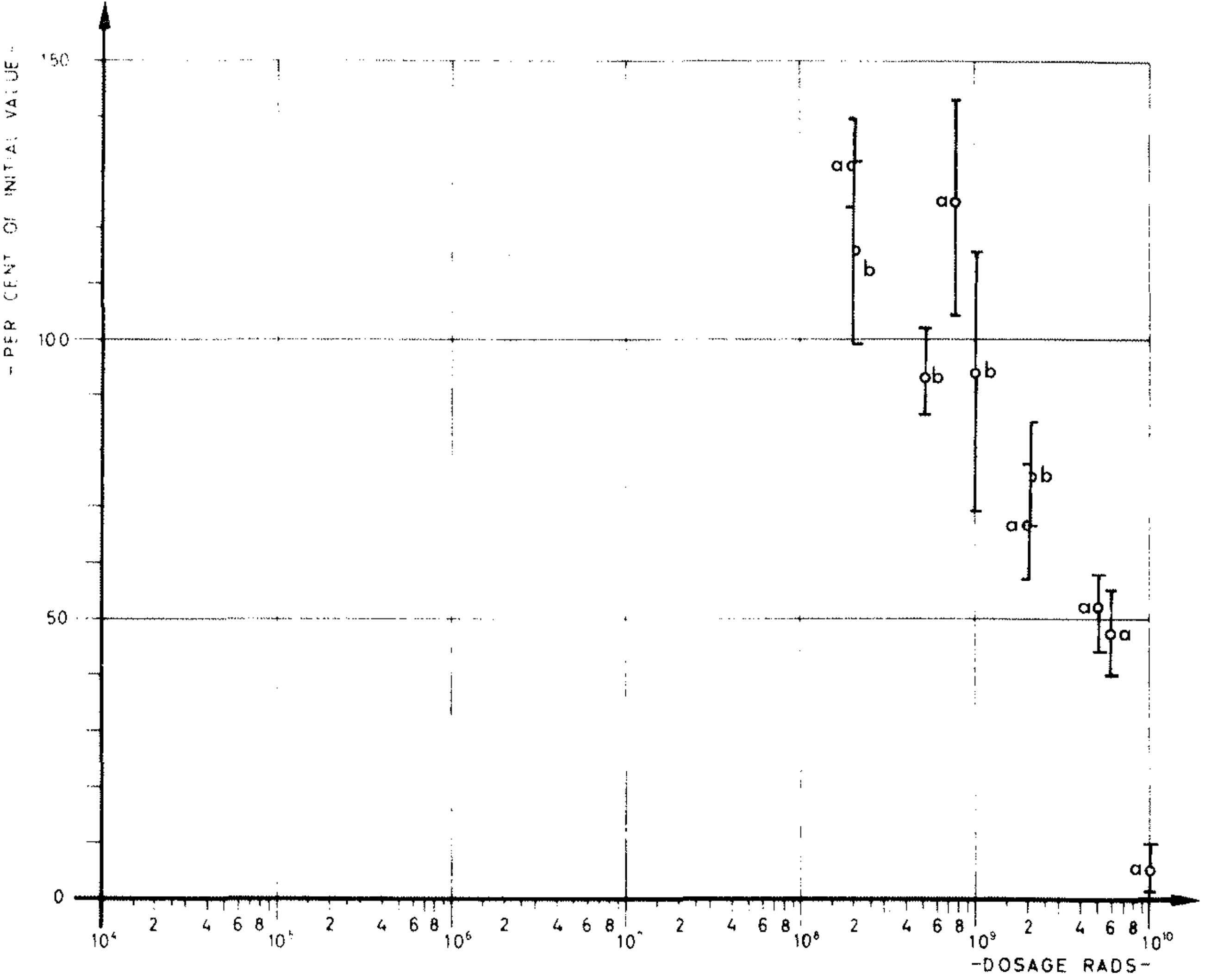
Fig. 21



FLEXURAL STRENGTH			INITIAL VALUE
a) ARALDITE	F + HY 906 + 960	100–80–1	11,8 kg/mm^2
b) 〃	〃 + HY 905 + DY061+DY040	(100–100–0,1–10)	12,3 kg/mm^2

Fig. 22

ARALDITE F + X 8157/131 (100 – 40)



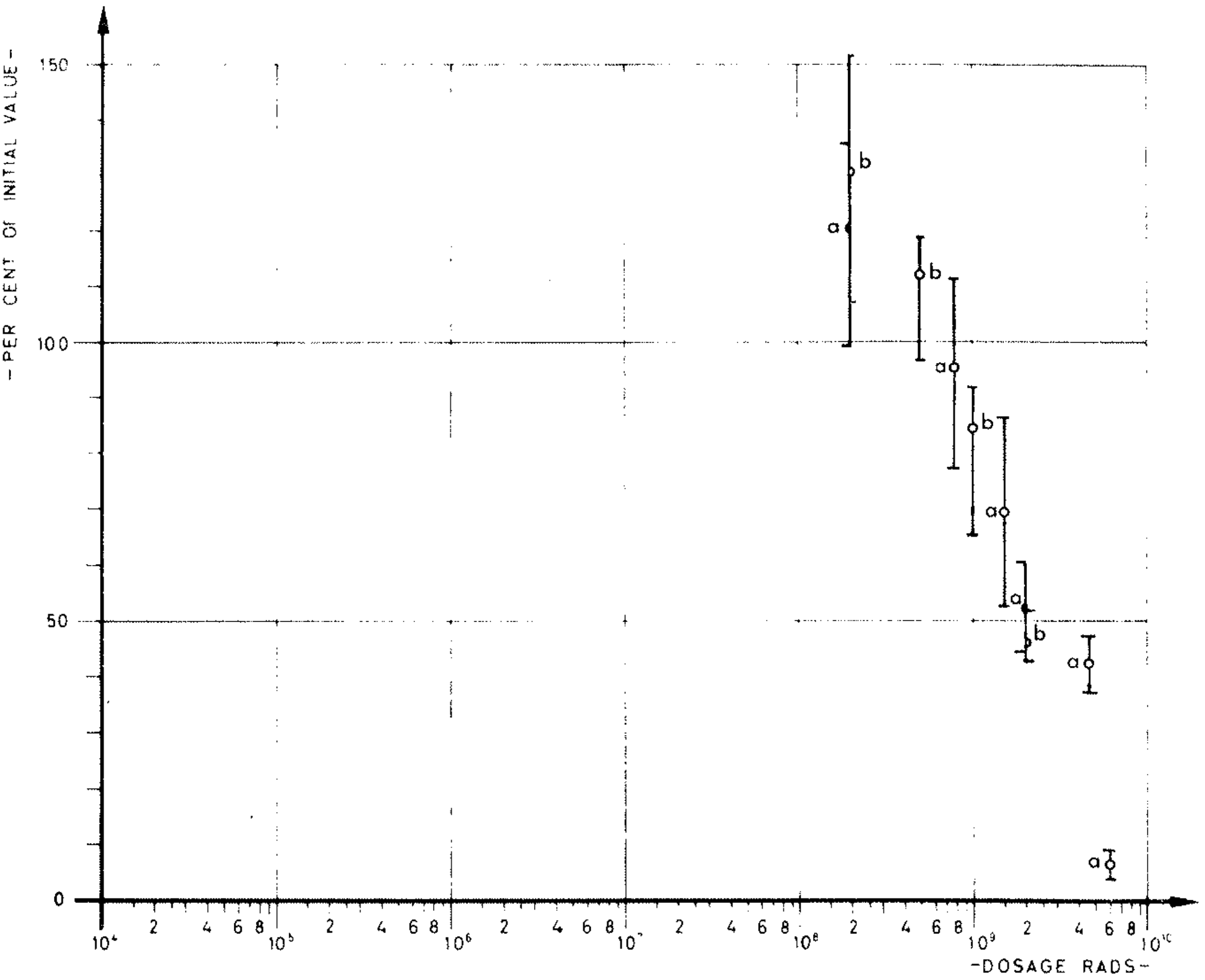
FLEXURAL STRENGTH 10,1 (kg/mm^2)

NUCLEAR SOURCE OF RADIATION :

a) REACTOR (~ 20% n + ~ 80% γ)
b) SPENT FUEL ELEMENTS (γ ~ 1Mev)

Fig. 23

EPN 1138 + HY 905 + DY 062 (100-105-0,5)



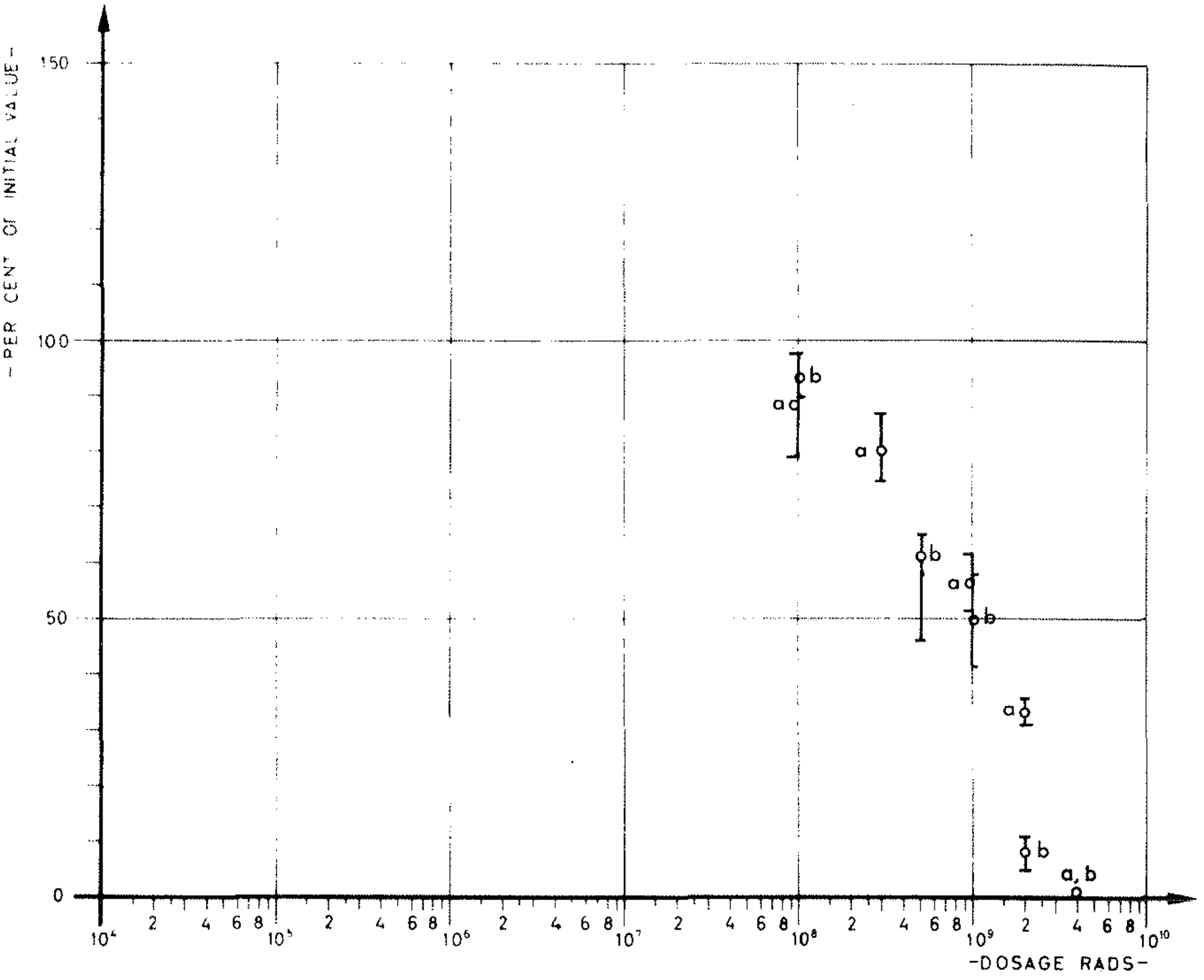
FLEXURAL STRENGTH 10,3 (kg/mm^2)

NUCLEAR SOURCE OF RADIATION :

a) REACTOR (~20% n + ~80% γ)
b) SPENT FUEL ELEMENTS (γ ~ 1Mev)

Fig. 24

ARALDITE F + HY 905 + DY 061 + DY 040 (100 – 100 – 0,1 – 10)



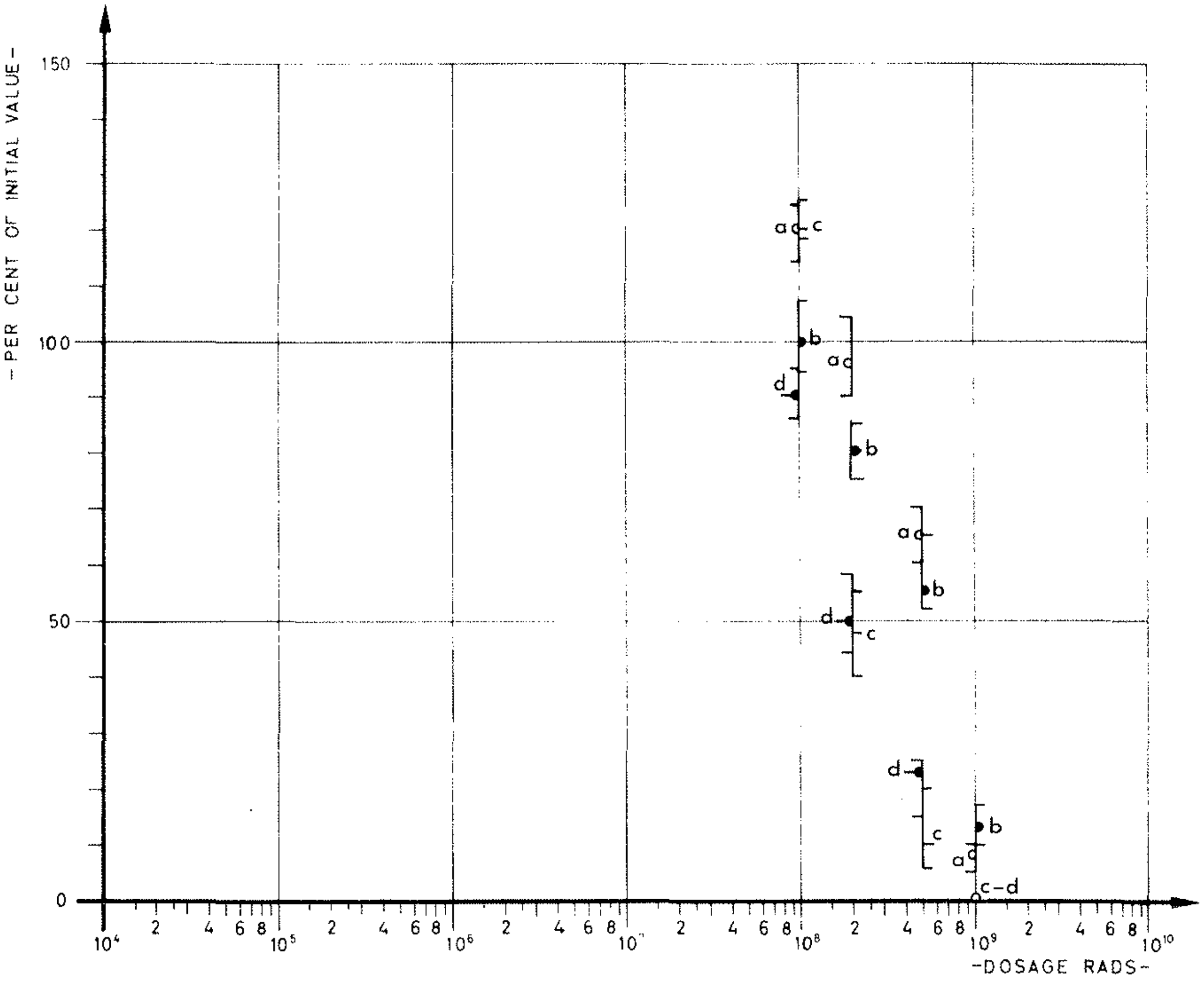
FLEXURAL STRENGTH 12,3 (kg/mm^2)

NUCLEAR SOURCE OF RADIATION :

a) REACTOR (~ 20% n + ~ 80% γ)
b) SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 25

ARALDITE D + 951

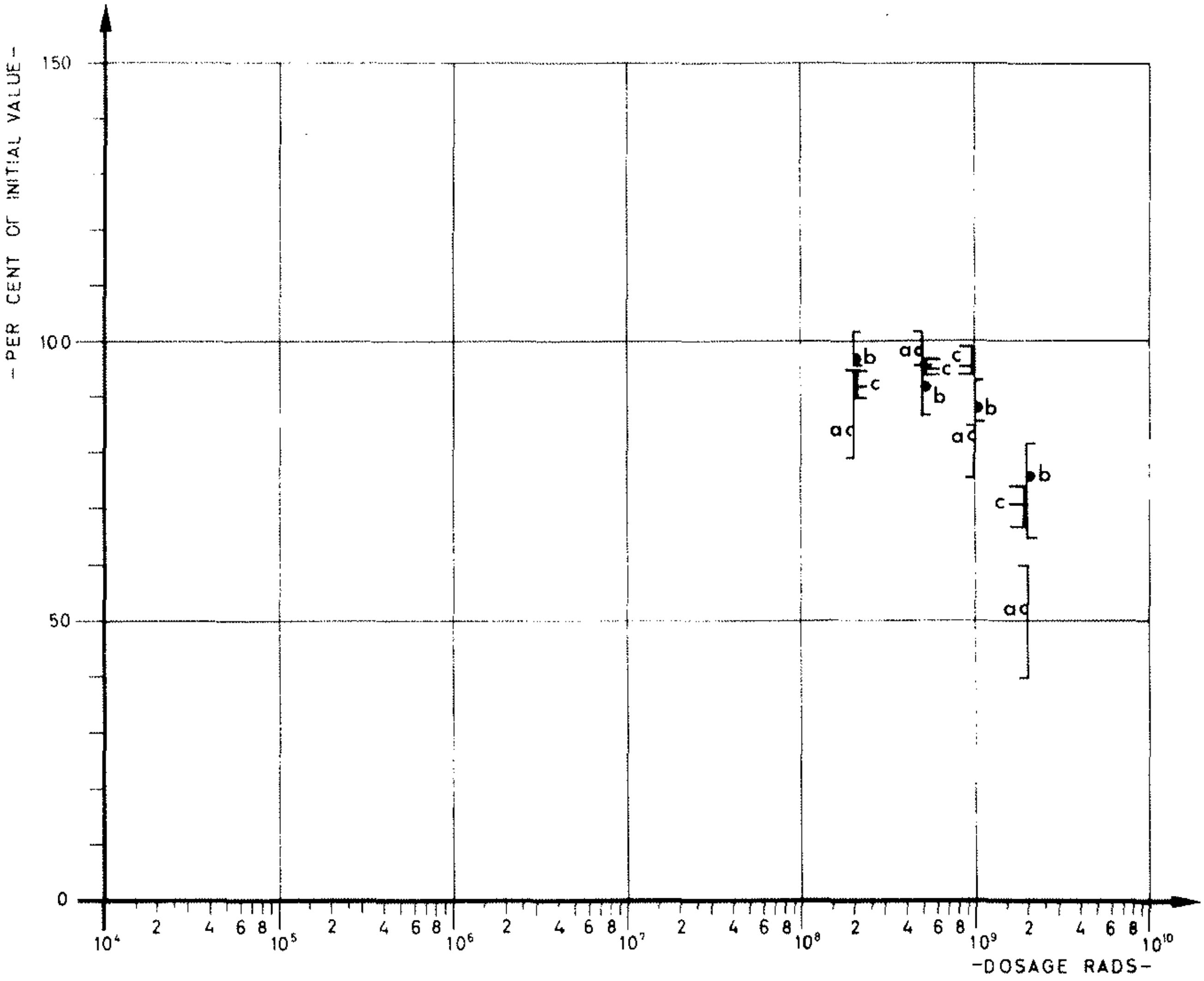


PROPERTY	FLEXURAL STRENGTH		INITIAL VALUE	
D + 951	100 - 14	a	11	kg/mm^2
"	100 - 11	b	10,5	kg/mm^2
"	100 - 17	c	11	kg/mm^2
"	100 - 9	d	9	kg/mm^2

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 26

ARALDITE F + HT 972

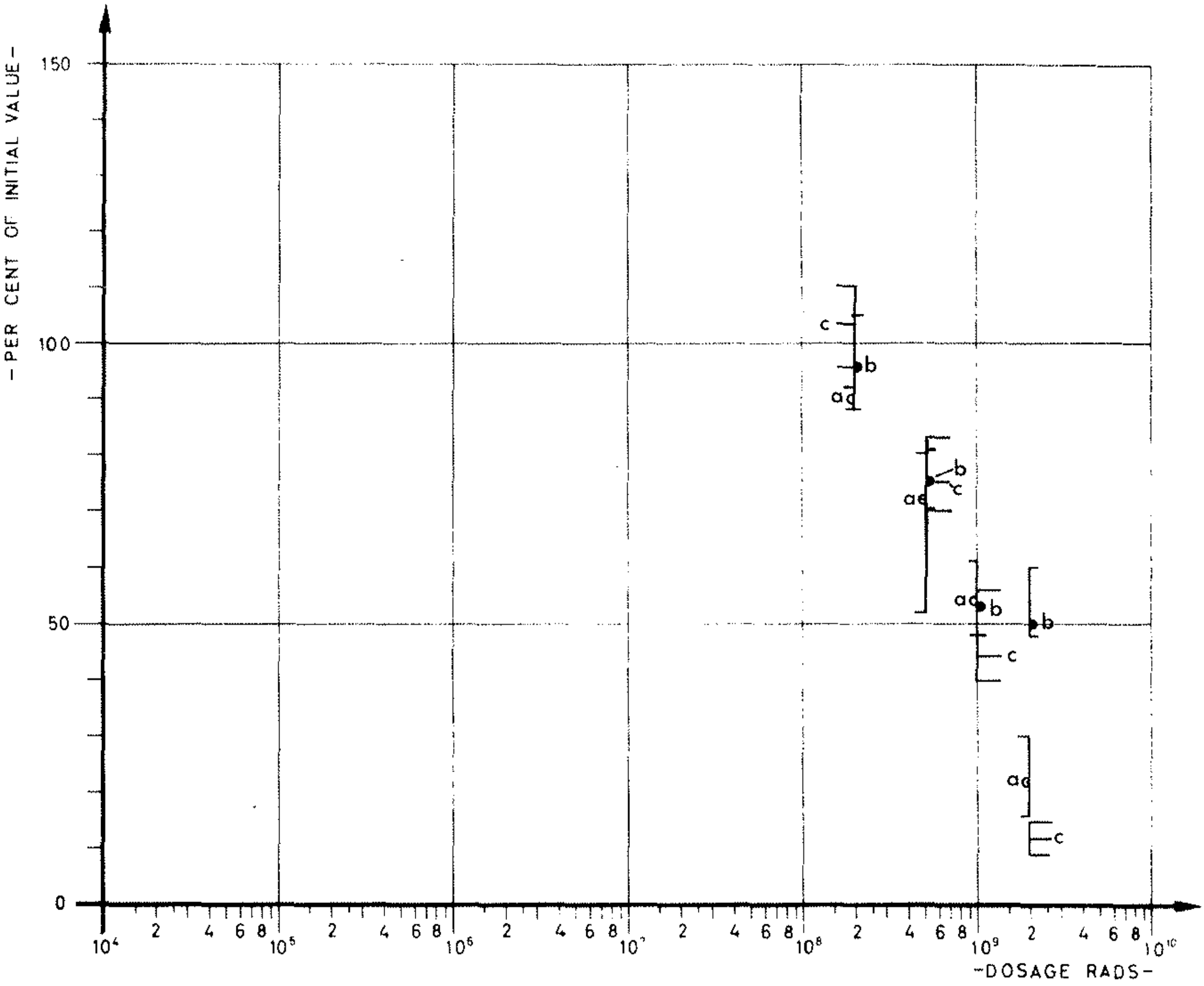


PROPERTY	FLEXURAL STRENGTH		INITIAL VALUE
Araldite F + HT 972	100 - 24	a	15,4 kg/mm²
"	100 - 27	b	15,8 kg/mm²
"	100 - 30	c	16 kg/mm²

NUCLEAR SOURCE OF RADIATION · SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 27

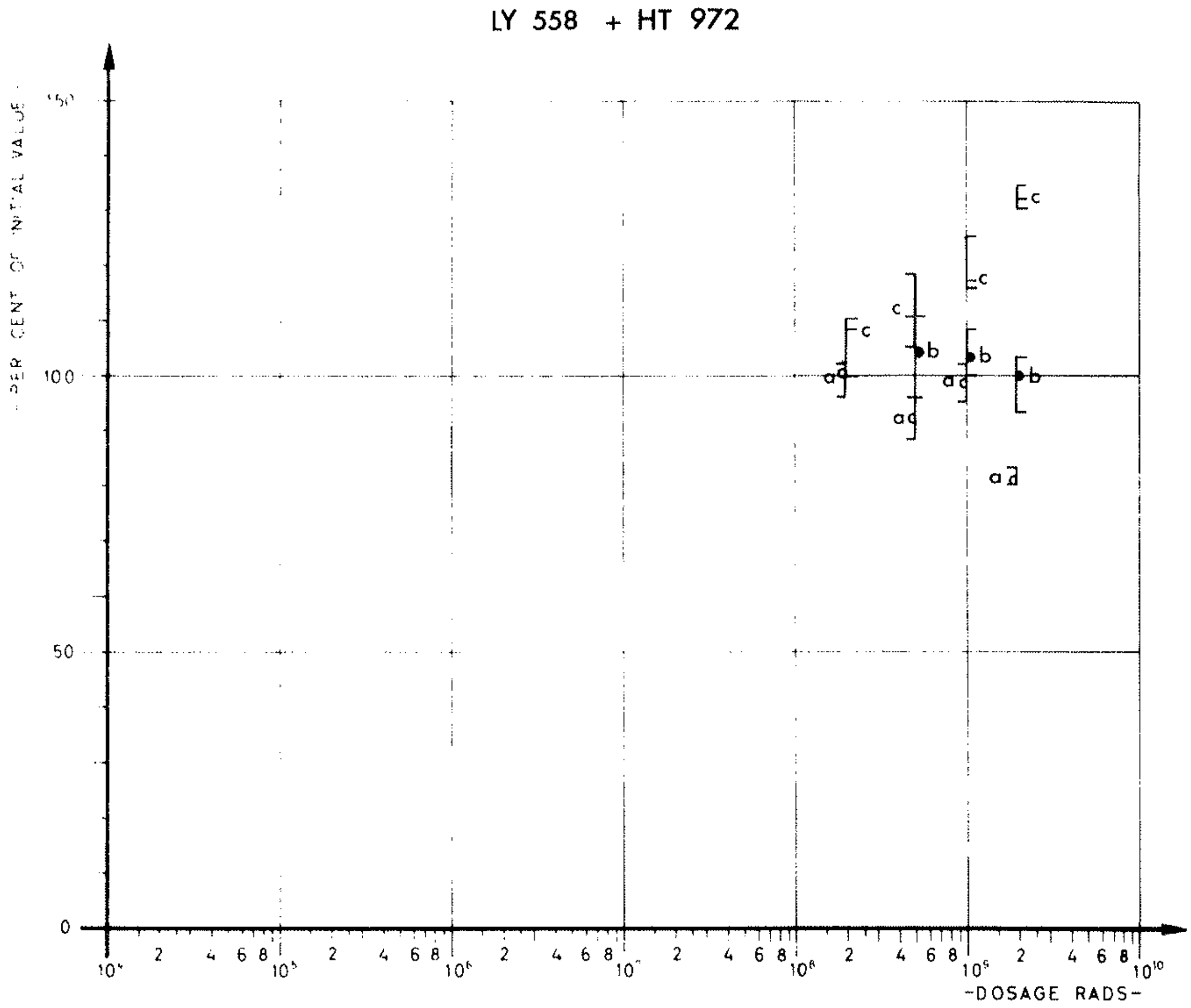
ARALDITE F + HT 976



PROPERTY	TENSILE STRENGTH		INITIAL VALUE	
Araldite F + HT 976	100 – 31	a	16,1	kg/mm^2
"	100 – 35	b	15,6	kg/mm^2
"	100 – 39	c	15	kg/mm^2

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 28

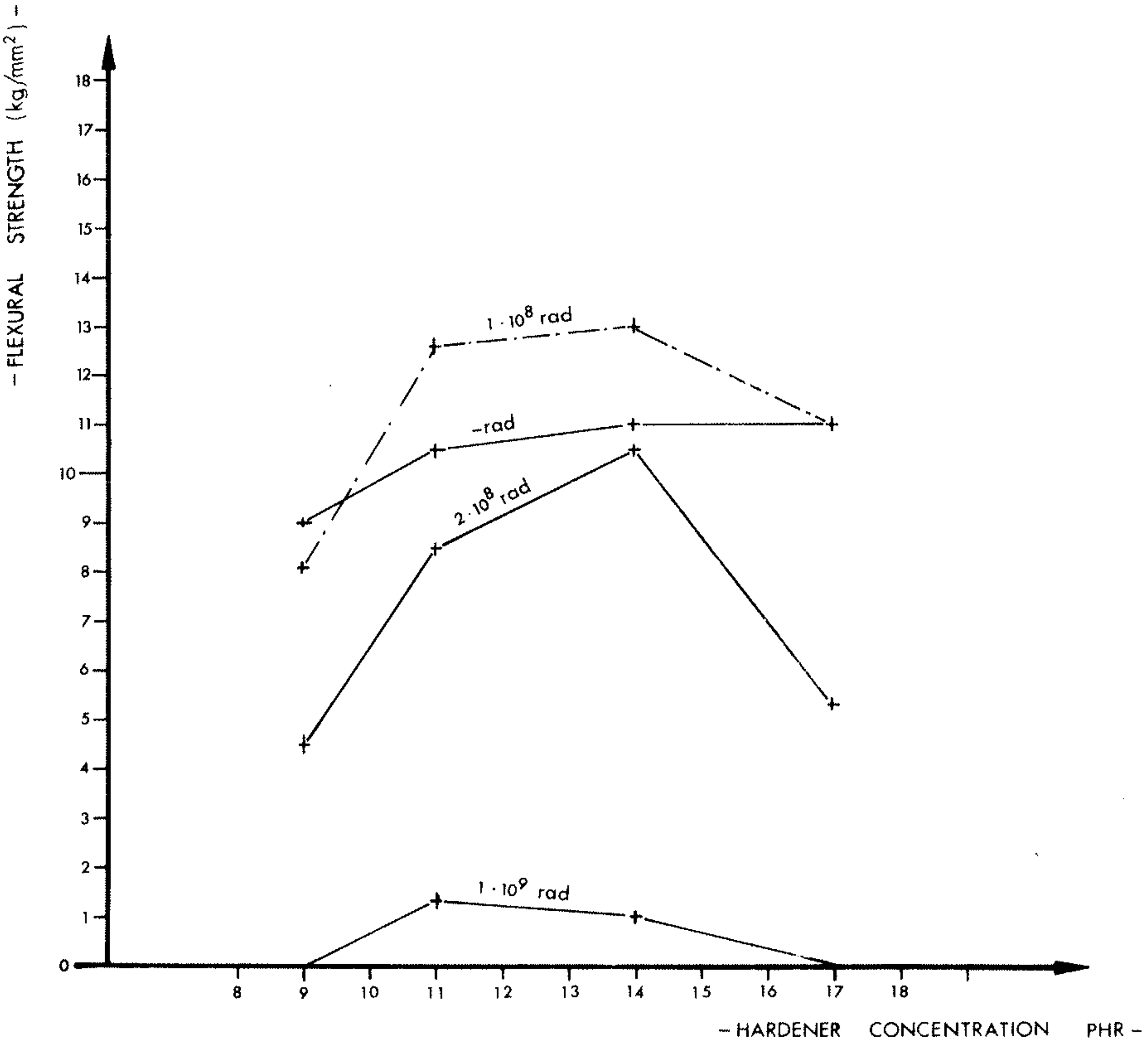


PROPERTY	TENSILE STRENGTH		INITIAL VALUE	
LY 558 + HT 972	100 – 24	a	13,8	kg/mm^2
"	100 – 27	b	13,5	kg/mm^2
"	100 – 30	c	11,7	kg/mm^2

NUCLEAR SOURCE OF RADIATION SPENT FUEL ELEMENTS (γ ~ 1 Mev)

Fig. 29

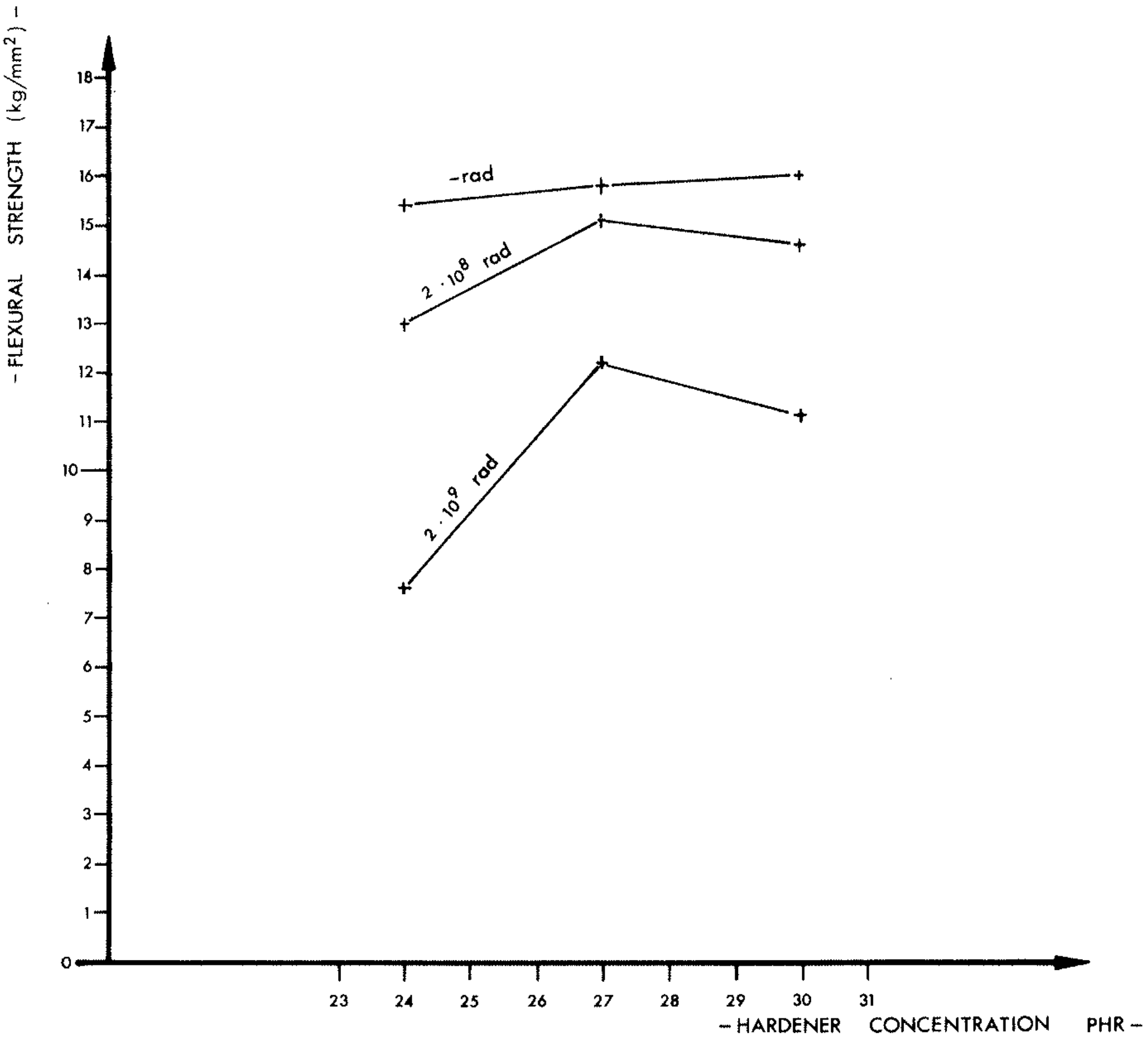
ARALDITE D + HY 951



Effect of HY 951 concentration on the Flexural strength of epoxy cured resins (D)

Fig. 30

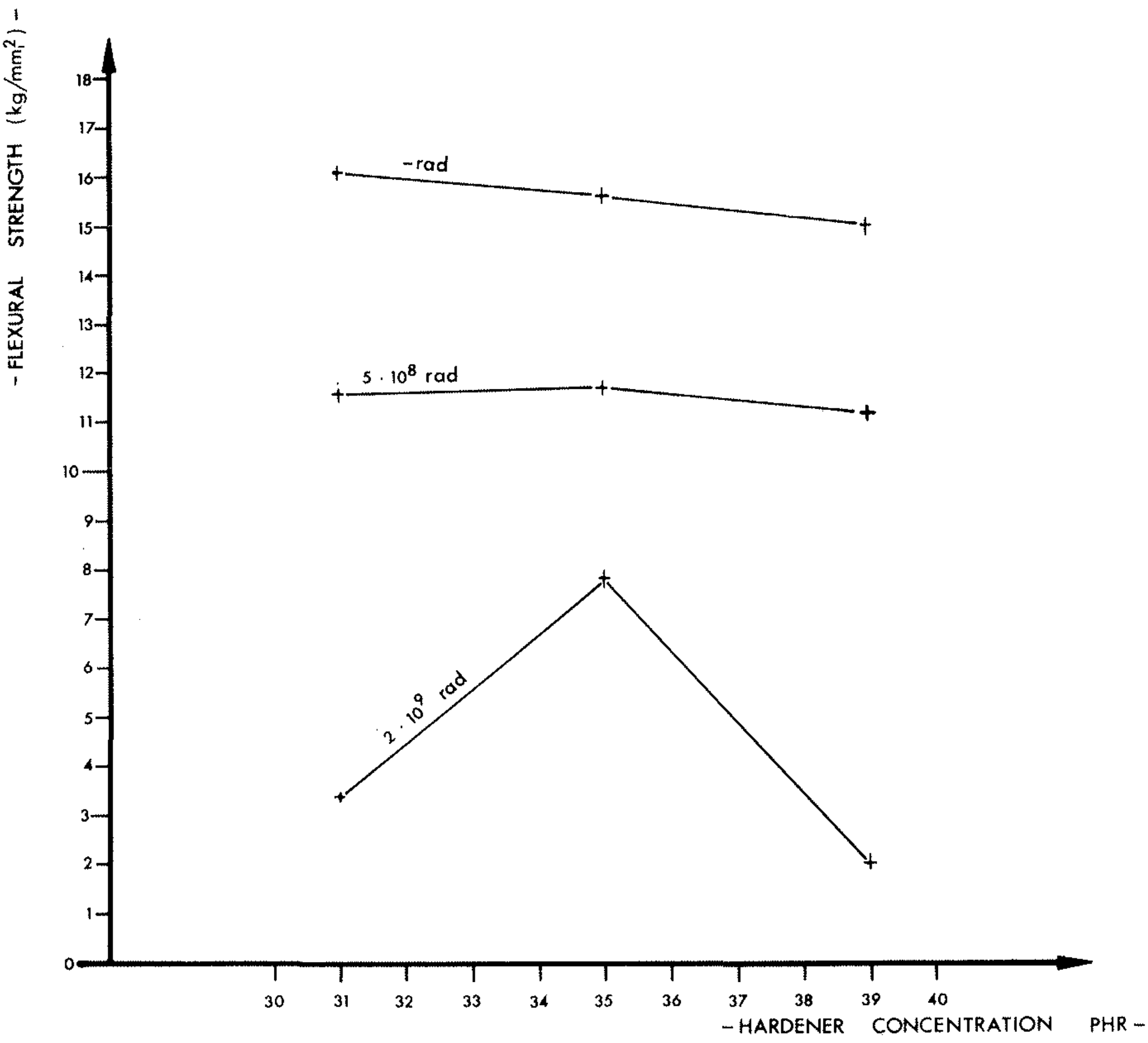
ARALDITE F + HT 972



Effect of HT 972 concentration on the Flexural strength of epoxy cured resins (Araldite F)

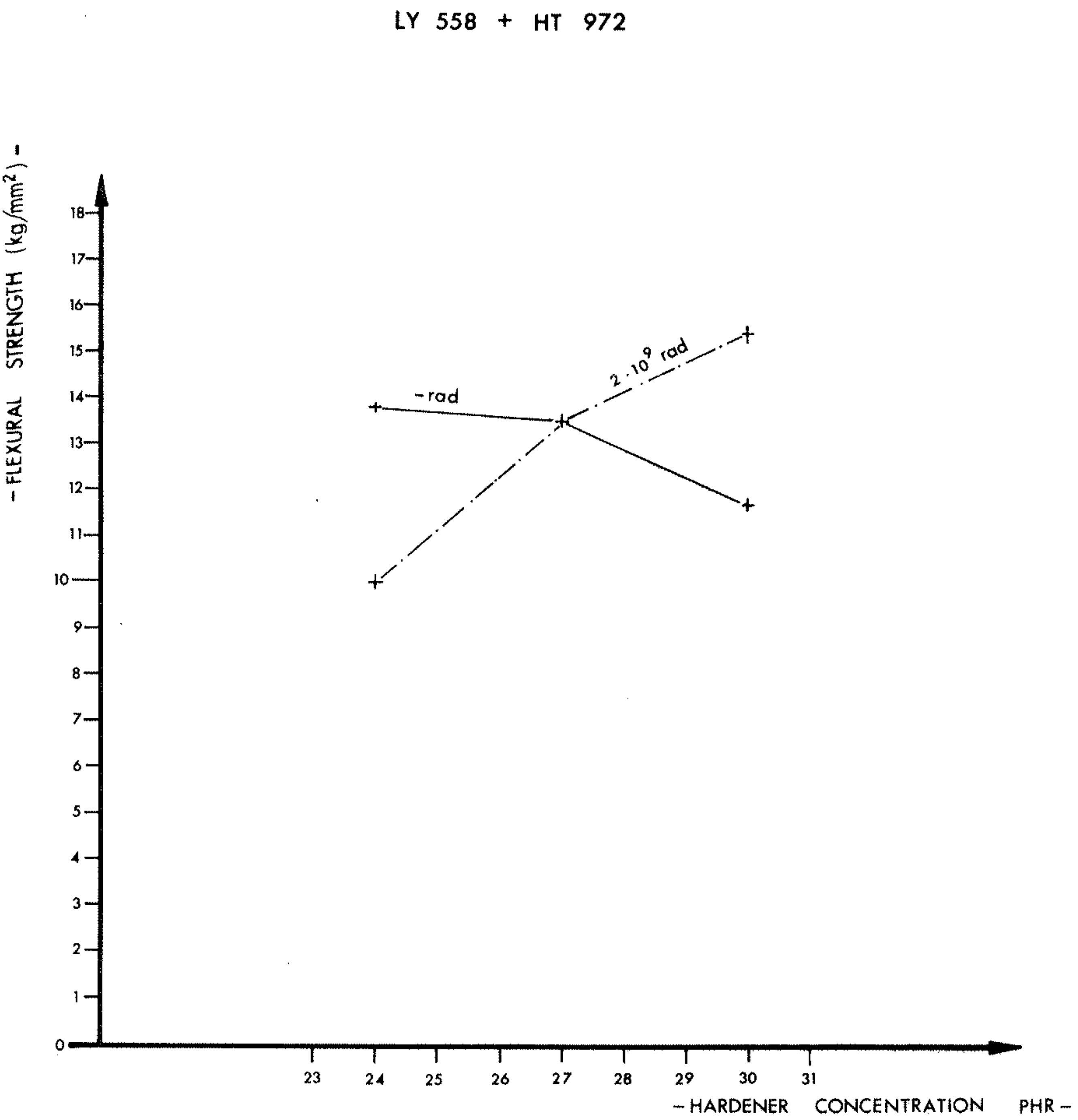
Fig. 31

ARALDITE F + HT 976



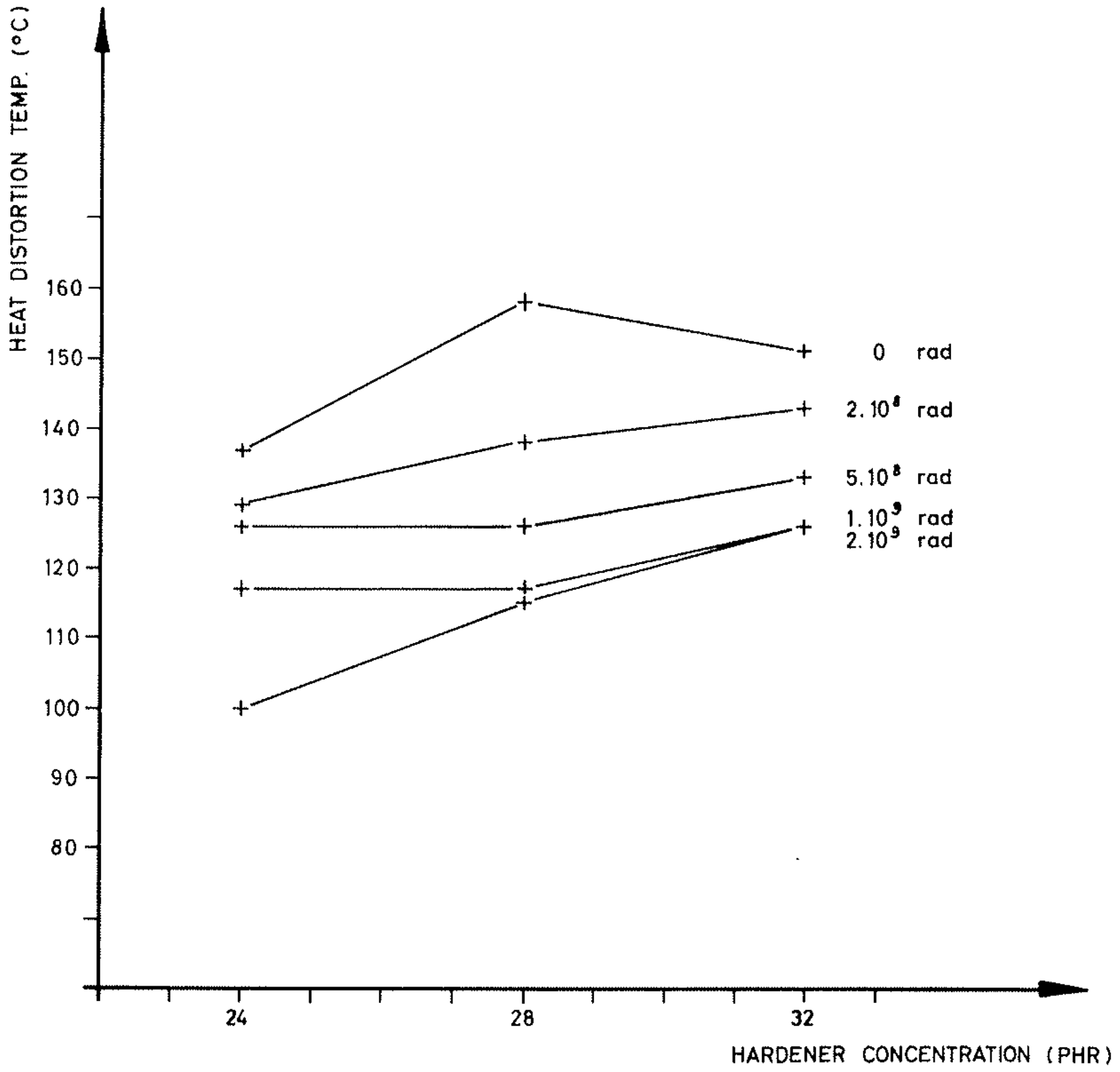
Effect of HT 976 concentration on the Flexural strength of epoxy cured resins (Araldite F)

Fig. 32



Effect of HT 972 concentration on the Flexural strength of epoxy cured resins (LY 558)

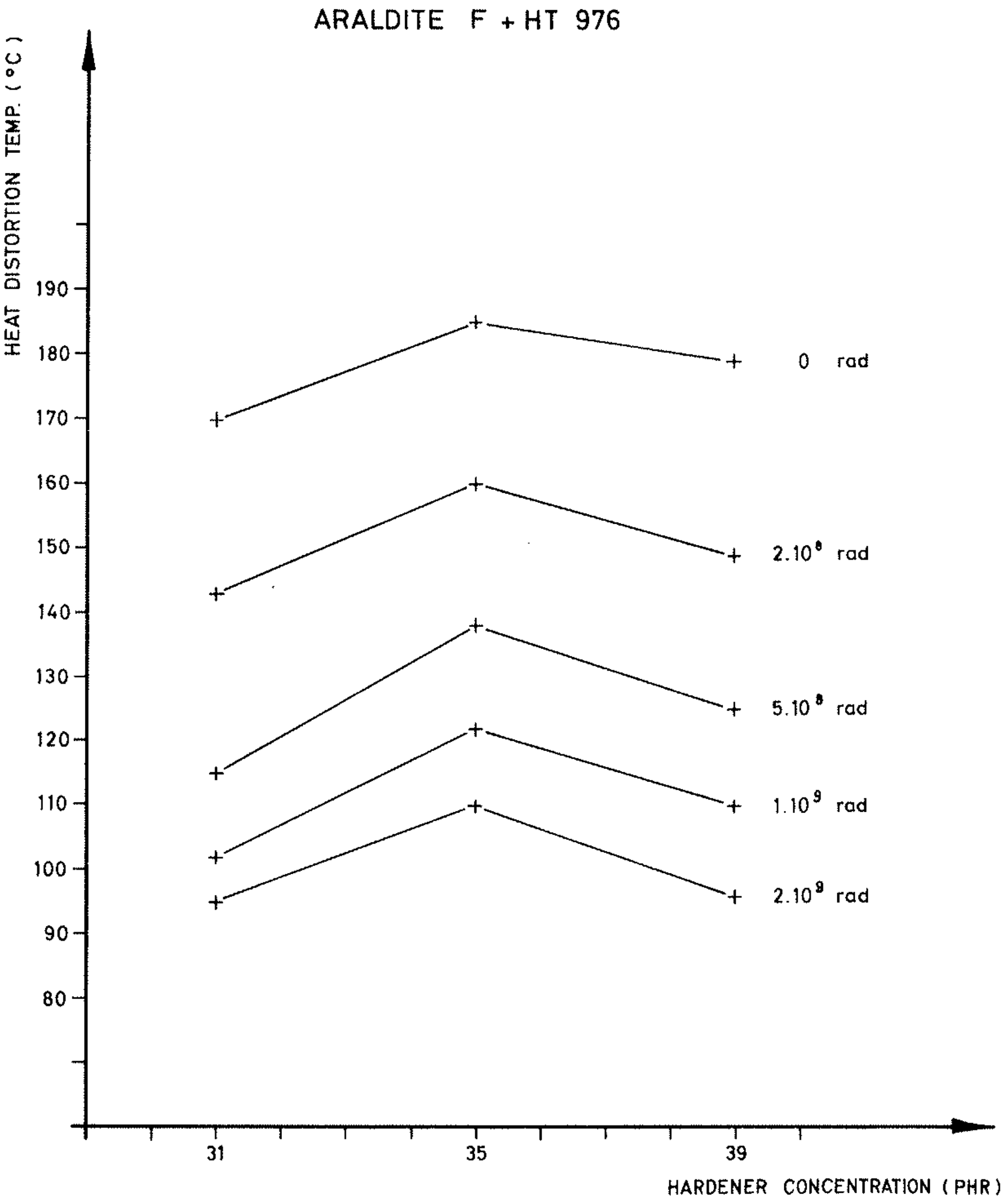
Fig. 33



ARALDITE F + HT 972

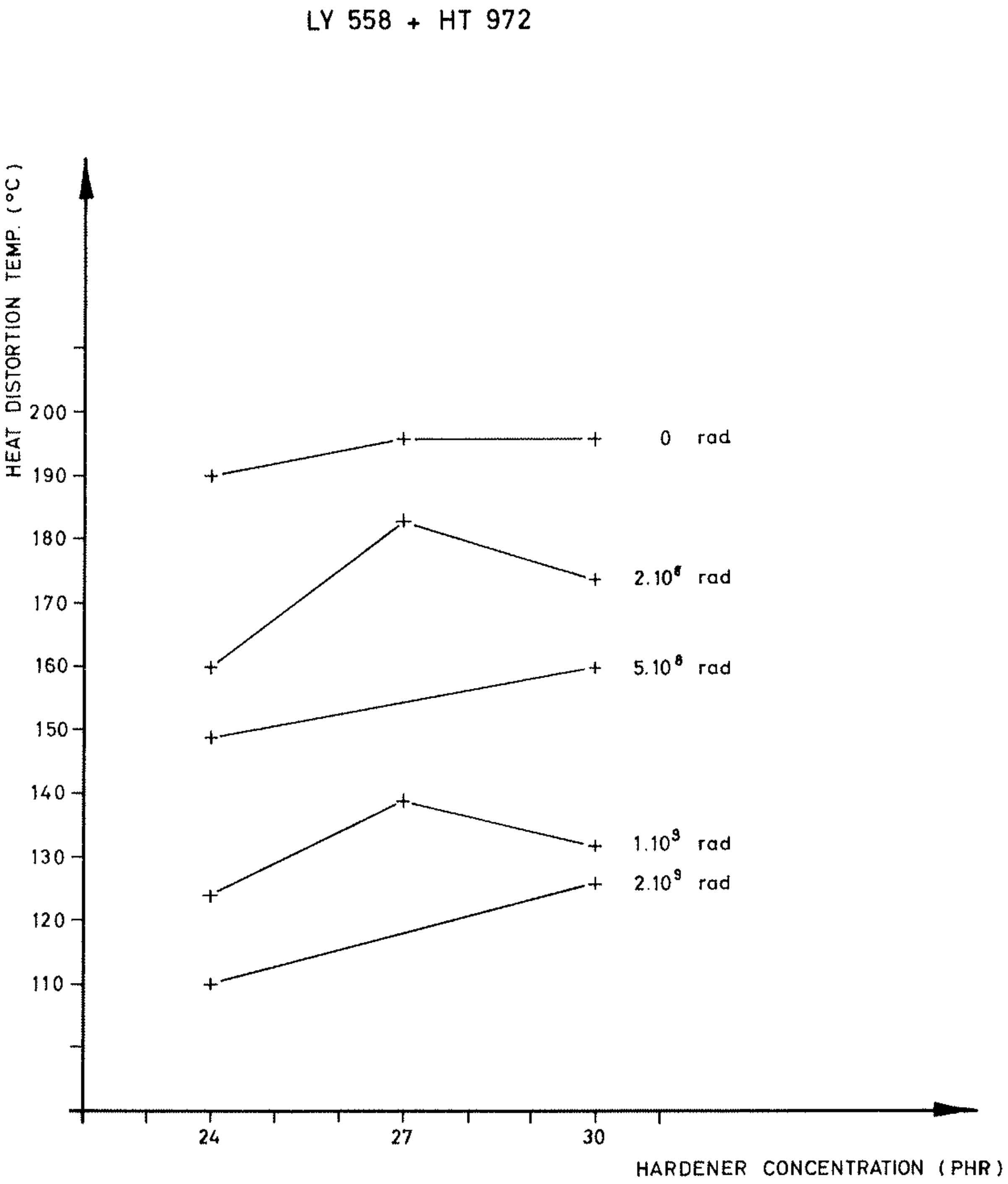
Effect of HT 972 concentration on the heat distortion temperature of epoxy cured resins (Araldite F)

Fig. 34



Effect of HT 976 concentration on the heat distortion temperature of epoxy cured resins (Araldite F)

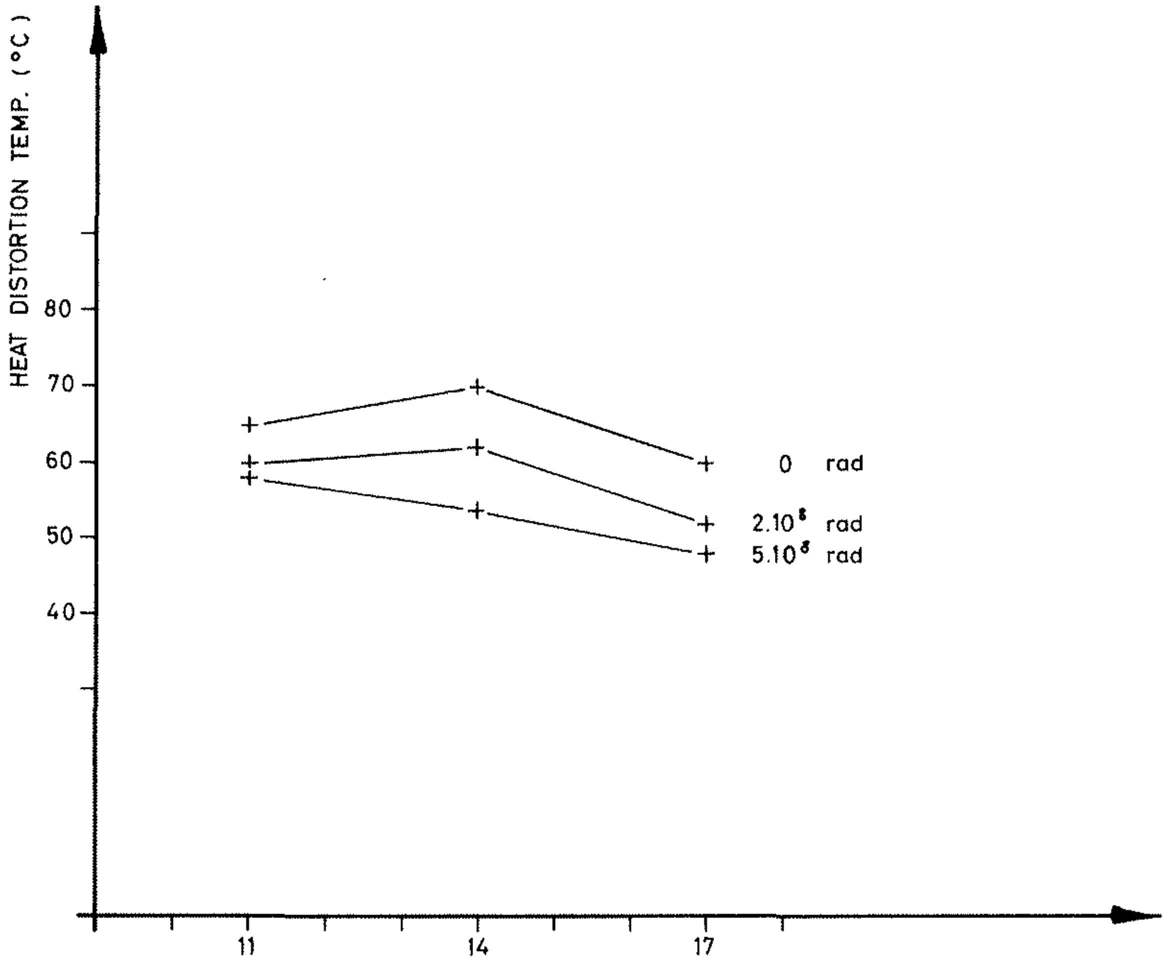
Fig. 35



Effect of HT 972 hardener on the heat distortion temperature of epoxy cured resins (LY 558)

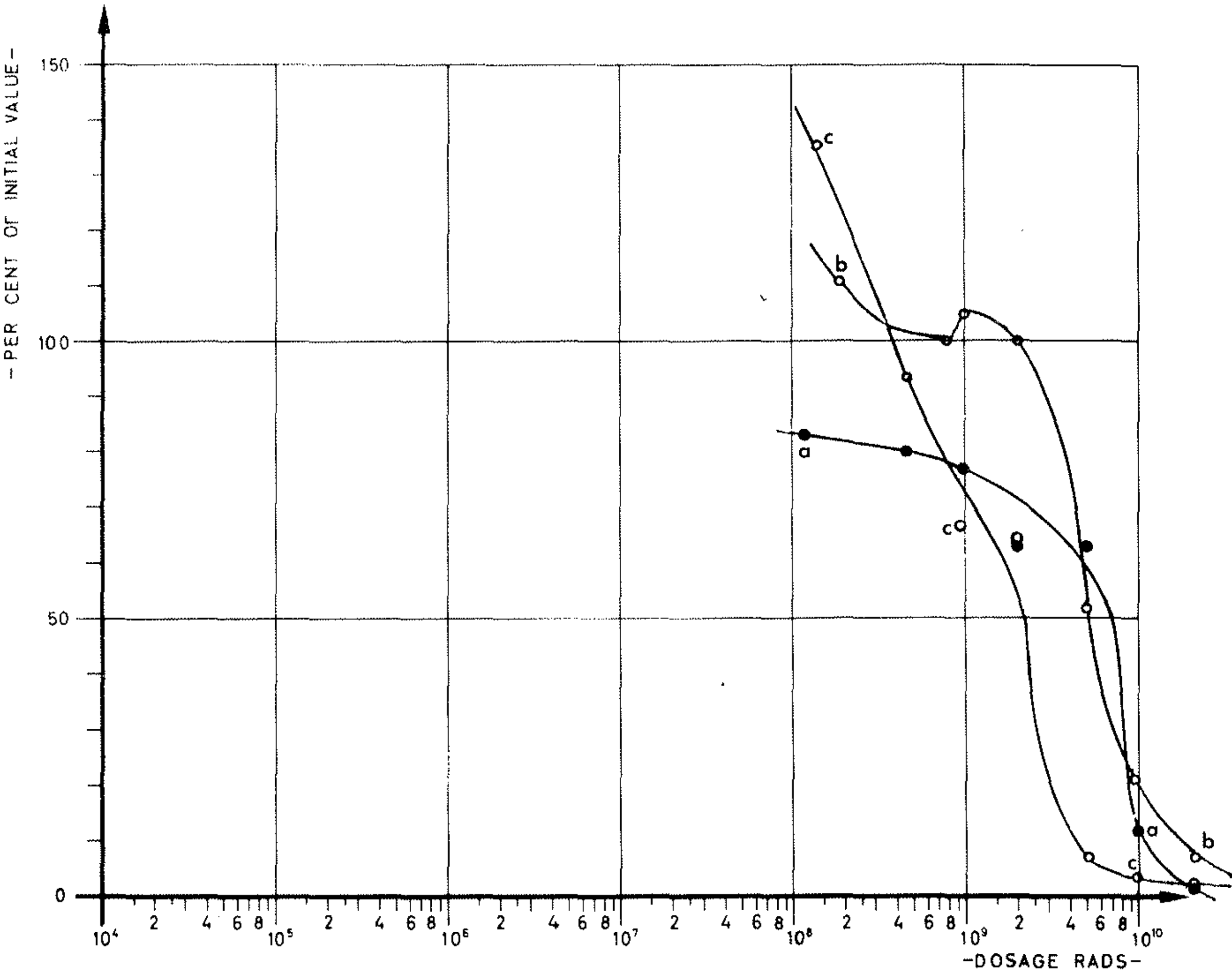
Fig. 36

ARALDITE D + HY 951



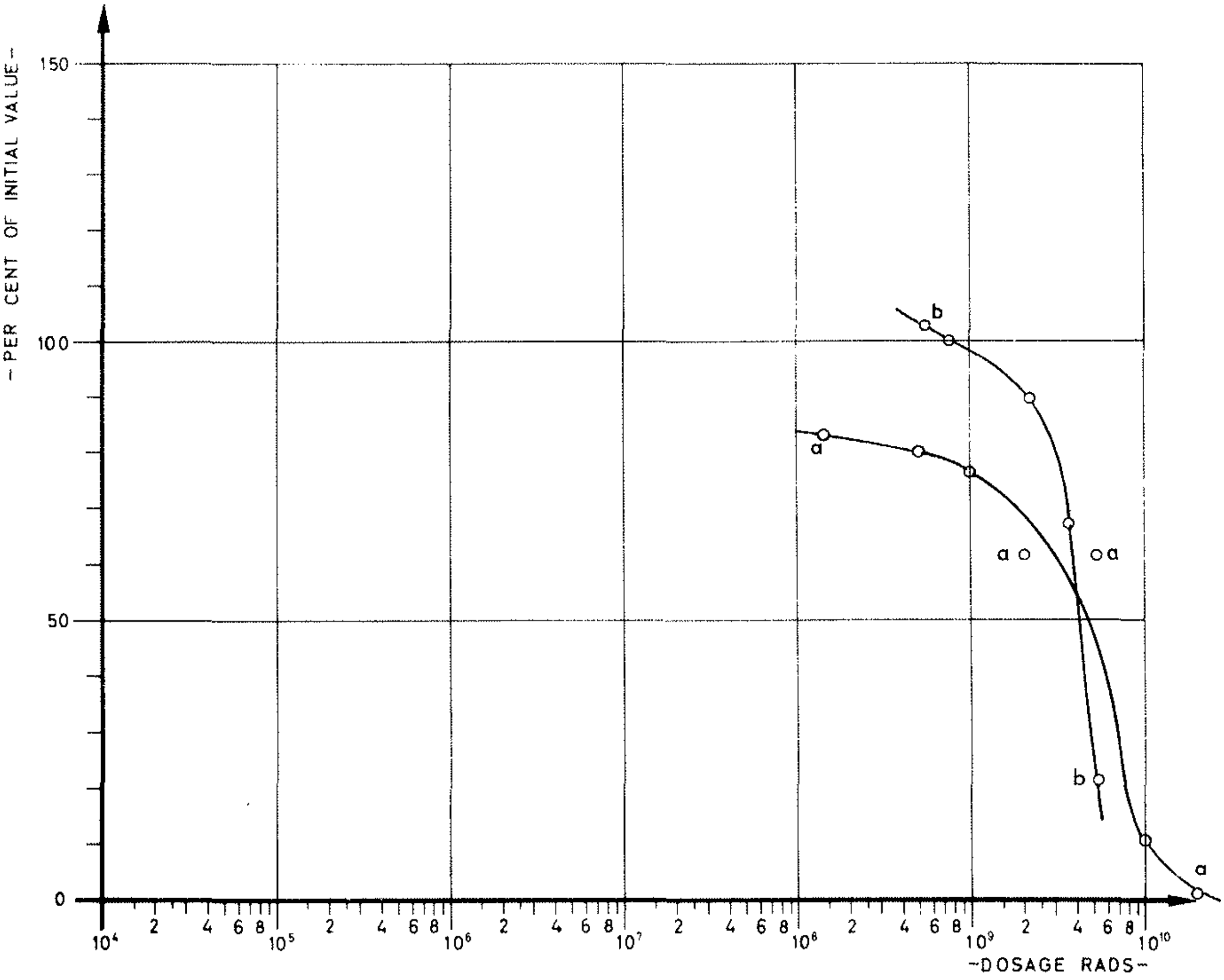
Effect of HY 951 concentration on the heat distortion temperature of epoxy cured resins (Araldite D)

Fig. 37



FLEXURAL STRENGTH			INITIAL VALUE
a)	ARALDITE F + HT 972 + ALUMINA	100–27–220	11,4 kg/mm^2
b)	〃 〃 + 〃 + GRAPHITE	100–27–60	6,3 kg/mm^2
c)	〃 〃 + 〃 + AEROSIL + BARIUM SULFATE	(100–27–2–150)	5,8 kg/mm^2

Fig. 38

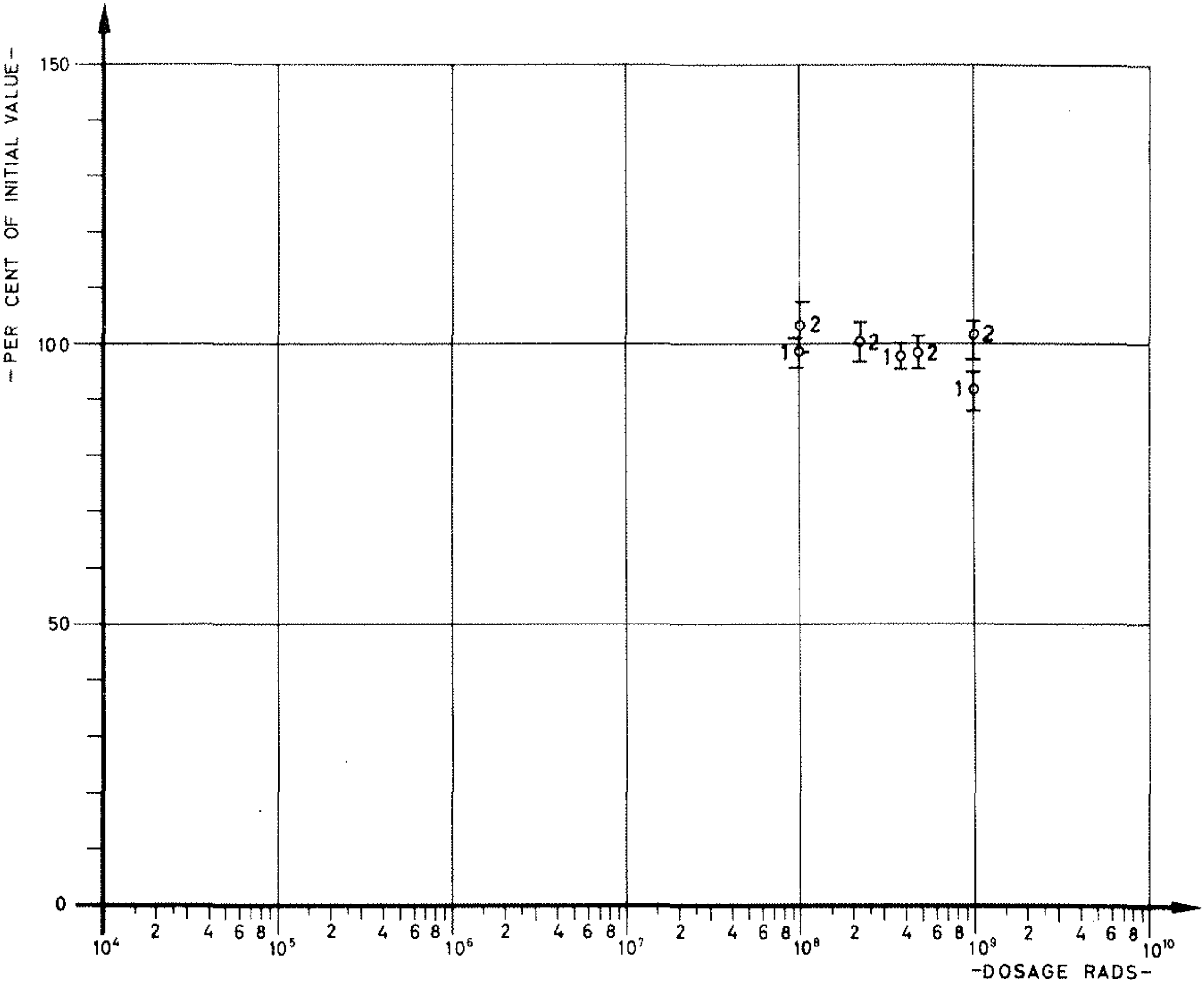


INFLUENCE OF FILLER CONCENTRATION ON THE RADIATION RESISTANCE OF CLASSICAL EPOXY RESINS

FLEXURAL STRENGTH		INITIAL VALUE
a) ARALDITE F + HT 972 + ALUMINA	100 – 27 – 220	11,4 kg/mm^2
b) EPIKOTE 828 + DDM + "	100 – 27 – 100	12 kg/mm^2

Fig. 39

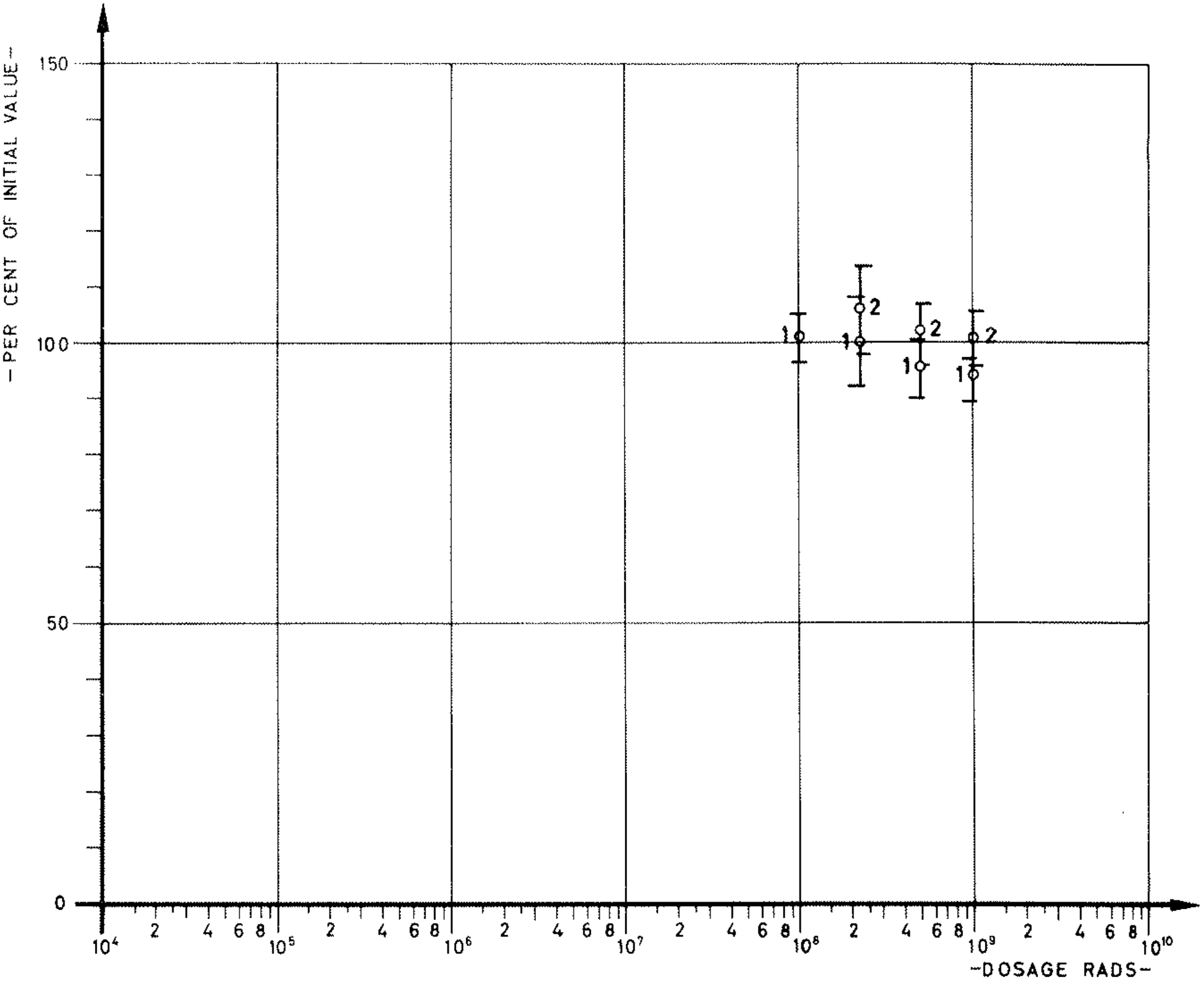
ARALDITE F + HT 972 + GLASS OR SILICA



CURVE N°:	FLEXURAL STRENGTH :	
1	Glass reinforced	39,1 kg / cm ^{2}
2	Silica "	59,6 "

Fig. 40

X 33 - 1020 + HT 972 + GLASS OR SILICA



CURVE N°:	FLEXURAL STRENGTH:	
1	Glass reinforced	39,4 kg/cm^2
2	Silica "	50,5 "

Fig. 41