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Nimrod Division
Radiation Protection

RADIATION PROTECTION GROUP (OPERATIONS)
PROGRESS REPORT FOR 1972

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1. INTRODUCTION

This note describes the work of the Operations Section of the Radiation Protection Group during 1972. The Section is responsible for those aspects of health physics detailed in the terms of reference of the Radiation Protection Officer given in RLSN 4/68.

2. ENVIRONMENTAL MONITORING

2.1 Nimrod Area

2.1.1 Residual Activity

2.1.1.1 There has been no significant change in the pattern of induced activity either in or near the machine or the extracted proton beams. This may change slightly after the Feb/Mar/April '73 shutdown since there will then be no operational internal target experimental beam lines.

The radiation doses to machine maintenance personnel fell slightly compared with the previous year (see fig 1), the average dose per man engaged in this work being about 0.9 rem (to be compared with about 1.3 rem for 1971). This drop is mainly attributed to the fact that 1972 only encompassed 1 month of major shutdown activity rather than the usual 2 months. It is to be expected that this "lost" dose load will appear during 1973, where longer than normal shutdown periods are scheduled.

Break-downs, by areas of work, of radiation doses received by Nimrod Engineering Dept personnel are shown in Table 1.

Table 1

Distribution of Nimrod's Personnel Dose Load

Area	Detail	% of Total Dose	
		1971	1972
Magnet Hall	Octants	11.7	8.8
	St. Sections	28.1	23.1
	Sec. Beam Targets	9.3	23.4
	Beam Lines	3.2	3.2
	Miscellaneous	0.6	0.0
		52.9	58.5
Experimental Halls	X1 Blockhouse	0.9	1.1
	X2 Blockhouse	13.2	2.2
	X3 Blockhouse	10.1	12.0
	X3X Blockhouse	3.4	5.3
	Miscellaneous	3.8	3.7
		31.4	24.3
R52 Workshop	Magnets	14.5	13.2
	Targets	0.1	0.9
	Miscellaneous	1.1	3.1
		15.7	17.2

The above information was abstracted from "Permits to Work" issued during the relevant years and from QFEs worn by the personnel involved.

2.1.1.2 A comprehensive survey has been made of the nuclides induced in various materials irradiated in and around Nimrod and of the detection efficiencies of a range of monitoring equipment to these nuclides [(1)]. The dominant nuclides with half lives greater than about 15 hours induced in the three main materials used in accelerator construction (iron, copper and aluminium) together with their production reactions, half lives and decay modes are given in Table II.

Table II

Main Nuclides Found in Nimrod Activated Materials

Irradiated Material	Nuclide	Production Reaction	Half Life	Decay Mode
Aluminium	Be^{7}	Fra	54d	EC, γ
	Na^{22}	(p,3p,3n)	2.6y	β^{+}, γ
	Na^{24}	(n,α), (p, 3pn)	15h	β^{-}, γ
Iron	Be^{7}	Fra	54d	EC, γ
	V^{48}	Spal	16d	EC, β^{+}, γ
	Cr^{51}	Spal	28d	EC, γ
	Mn^{52}	Spal	5.6d	EC, β^{+}, γ
	Mn^{54}	(p,2pn)	303d	EC, γ
Copper	Be^{7}	Fra	54d	EC, γ
	P^{32}	Spal	14d	β^{-}
	Sc^{46}	Spal	83d	β^{-}, γ
	Sc^{47}	Spal	3.4d	β^{-}, γ
	V^{48}	Spal	16d	EC, β^{+}, γ
	Cr^{51}	Spal	28d	EC, γ
	Mn^{52}	Spal	5.6d	EC, β^{+}, γ
	Mn^{54}	Spal	303d	EC, γ
	Co^{56}	Spal	77d	EC, β^{+}, γ
	Co^{57}	Spal	270d	EC, γ
	Ni^{57}	Spal	36h	EC, β^{+}, γ
	Co^{58}	Spal	71d	EC, β^{+}, γ
	Fe^{59}	Spal	45d	β^{-}, γ
	Co^{60}	Spal	5.3y	β^{-}, γ

It is clear from Table II that many high energy accelerator induced nuclides decay primarily by electron capture emitting little beta radiation. Because many health physics (geiger) instruments in common use have a low counting efficiency ($\sim$0.2%) for these nuclides great care is needed to detect surface contamination and airborne dust activities at about maximum permitted levels. It was found that the most useful detector for this purpose is a shielded $1\frac{1}{2}$" x 1" sodium iodide crystal operating with a discriminator bias level of about 25 keV, this giving a "safe" detection efficiency of about 13% for metallic samples and about 3% for "organic" samples.

2.1.1.3 A careful comparison has been made between measured and predicted levels of induced activity for a number of irradiation conditions around Nimrod [2]. It was demonstrated that a simple method due to Sullivan [3] predicts hadron induced activity levels in medium Z materials to a degree of accuracy that should be sufficient for all practical health physics and planning purposes. Briefly, Sullivan says that the dose-rate near irradiated objects is given by,

$$DR = K \phi \log_{10} \left(\frac{T + t}{t}\right)$$

where, DR = the dose-rate in rads/hr

ϕ = the irradiating (hadron) flux or flux density

T = the irradiation time

t = the decay time in same units as T

K = a constant depending on units and geomety

Values of K are given for the following conditions:-

Condition	K
At 1 metre from a thin target of m g/cm^2 irradiated with a beam of $\emptyset$ particles/sec	1.2×10^{-14} m
At 1 metre from a thin target of total mass m grams irradiated with a beam of $\emptyset$ particles/cm^2/sec	1.2×10^{-14} m
At 1 metre from a thick target irradiated with a beam of $\emptyset$ particles per sec	3.6×10^{-13}
Near the surface of a large object irradiated uniformly with $\emptyset$ particles/ cm^2/sec	2.2×10^{-8}

The general shapes of the predicted decay areas are shown in fig 2 for a range of irradiation times, and demonstrate the relative insensitivity of initial activity with irradiation time.

2.1.2 Machine Prompt Leakage Radiation

2.1.2.1 Radiation levels throughout the year during machine operational periods have, in general, been acceptably low but towards the end of the year high intensity running ($\sim 10^{12}$ ppp) at greater than normal prf ($\sim$30 ppm) of the X3/X3X complex in Experimental Hall No 3 was beginning to reveal the limitations of the shielding of that complex. This topic is further discussed in Section 9.

2.1.2.2 As part of an exercise to investigate the feasibility of removing a portion of the Nimrod mound with the machine operational (to expedite the construction of the 70 MeV injector), a series of vertical holes were sunk in the mound to beam height level along a radius roughly half-way between the 15 MeV injector and the "North" access tunnel. This enabled the radial fall-off of

DE-rate in the mound at beam height to be measured for a "quiet" area of the machine. The results of many measurements (with film packs and activation detectors) are summarised in fig 3 which shows an effective overall exponential fall-off with a TVL of 1.4 metres.

2.2 Other Areas

2.2.1

There have been no requirements during the year to handle work involving significant amounts of loose contamination in the Radioactive Workshop (R52). The unsealed source usage of the Radiochemistry Wing of R34 has been spasmodic but generally low.

2.2.2

A comprehensive survey of all offices, laboratories, workshops and stores (other than those in controlled areas) throughout the site during Dec '72/Jan '73 revealed a dozen radioactive items ranging from Nimrod activated components that had not been labelled to small sources that had not been registered. Although none of the items discovered presented any great hazard their presence was indicative of either ignorance of, or slackness in applying, the Laboratory's Regulations.

3. PERSONAL MONITORING

3.1 Technical Aspects

There have been no developments of note in this field during the year.

3.2 Personnel Results

3.2.1

At Dec 1972 regular dosimeter issues were as follows:-

Beta-gamma films (monthly issue) 350

Beta-gamma TLD (6-monthly issue) 210

Fast neutron films plus slow neutron TLD (monthly issue)..250

Beta-gamma TLD plus slow neutron TLD (6-monthly issue)....170

The total number of persons at the Laboratory issued regularly with some kind of personal dosimeter is falling slowly: 800 in 1970, 780 in 1971, 730 in 1972.

3.2.2

A histogram of the 1972 reported whole body doses to those personnel working at the Laboratory who are issued with dosimeters every 4 weeks is given in fig 4; for those issued with dosimeters every 6 months in fig 5.

The vast majority of monitored personnel continue to receive trivial doses; for those monitored monthly 75% received less than 500 mrem and 97% less than 1500 mrem; of those monitored 6-monthly 92% received less than 500 mrem and 100% less than 1500 mrem.

3.2.3

A breakdown of those personnel who received 1000 mrem or more gives the following in terms of areas of employment:

Machine Maintenance Staff	17
Experimental Halls Staff	14
Vacuum Staff	9
Members of Experimental Teams	1
Total	41

The total of 41 is less than the 1971 figure (54) - practically the whole of the difference being accounted for in the number for the machine maintenance staff for the reasons stated in para 2.1.1.1 but who nevertheless continue to be the most heavily exposed group at the Laboratory. The possible consequences on personnel doses of the proposed increase in machine intensity are dealt with in section 9.

4. INSTRUMENTATION AND EXPERIMENTAL TECHNIQUES

There have been no developments of note in these fields during the year.

5. RADIOACTIVE SOURCES, WASTE DISPOSAL & HAZARDS FROM HV EQUIPMENT

5.1 Radioactive Sources

At the end of the year 157 sources were registered with the Group comprising a total activity of 33.4 Ci (to be compared with the 40 Ci permitted by the Laboratory's Certificate of Registration under the Radioactive Substances Act).

Apart from a 30 Ci Co^{60} source used by Chemical Technology Group to calibrate high level dosimeters and to perform radiation damage studies, the use of radioactive sources at the Laboratory has not produced any significant health physics problems.

All sealed sources were checked for leakage during the year - all were found to be intact.

5.2 Radioactive Waste

Solid and liquid waste continues to be disposed of via AERE. The total quantity of long-lived particulate beta/gamma particulate activity discharged from the R34 Radiochemistry Wing stack was less than 12 µCi; the quantity of long-lived alpha particulate activity discharged was not measurable - say an upper limit of a few nCi.

5.3 High Voltage Equipment

Two new pieces of equipment working with a peak voltage greater than 5kV were notified to the Group during the year (a Klystron in R1 and a laser in R25). Neither was found to emit significant levels of X-rays.

6. INCIDENTS OF NOTE

There have been no known incidents of note during the year.

7. ADMINISTRATION

7.1 Local Organisation

As from 1st May 1972 the Radiation Protection Group was transferred from Applied Physics Division to Nimrod Division.

7.2 Regulations

There have been no significant changes in either International, National or Local Regulations.

In Nov 1972 the ICRP issued a statement regarding the outcome of a re-examination of the adequacy of its system of dose limits. It concluded:

> ".........The Commission does not see grounds for making any reduction in its dose limits for exposures of the whole body or of individual organs, either for workers or for members of the general public."

This, in effect, was the "official" reply to those environmentalists and others who have been lobbying for several years for a reduction in permitted doses.

7.3 Publicity and Training

Short lectures and demonstrations have been given to staff as and when requested. In particular a series of "question and answer" sessions were held with members of the SME and EF Groups of Nimrod Engineering Dept. The Group has continued to assist in the Laboratory's general course in safety training.

7.4 Staff

At the end of the year the staff of the section consisted of:

1 SSO (Radiation Protection Officer)

1 SO) Personal Dosimetry
1 MO (P/T))

1 ASO General Assistance

1 NT I) Health Physics Assistants
1 NT III)

1 PTO IV) Instrumentation
1 Contract Mechanic)

8. CONCLUSIONS

There have been no particularly noteworthly incidents or technical developments during the year although the prediction of induced activity levels and the measurement of low levels of induced activity have both been rationalised in an empirical manner.

From personal dosimetry results no one working at the Laboratory exceeded the permitted levels for either external radiation or internal contamination. In fact the total dose load to the Laboratory was slightly less compared with the previous year due to the shorter-than-usual shut down period of Nimrod.

9. A LOOK TO THE FUTURE

It was announced during the year that the Laboratory intended to up-rate Nimrod's injection system from 15 MeV to 70 MeV. This combined with a second RF accelerating cavity is hoped to result in an increase, by an order of magnitude, of the machine's trapped circulating beam. The health physics consequences of this can be conveniently divided into those arising from induced activity, prompt leakage and the storage and disposal of active material.

9.1 Induced Activity

9.1.1

Since a large fraction of the Laboratory's total dose-load is accrued as external doses from activated machine and extracted beam components and the immediate surroundings, "active" maintenance and modification is certain to be the critical aspect of any overall increase in beam intensity.

9.1.2

As a starting point, we can assume that the total dose load is directly proportional to beam intensity, ie we assume that beam losses remain constant in distribution and as a fraction of the total, that the tasks to be performed are the same in kind, frequency and duration, and that working methods and practices remain the same. For present intensities the total dose load per year from induced activity is about 75 rem ie about 750 rem for an order of magnitude increase in intensity. The number of people required to cope with this, assuming all are exposed to 5 rem/yr. is therefore 750/5 = 150. However, since all men are not equal in all skills and 5 rem/yr is a normal upper limit and not an average (ie it is not the general policy of the Laboratory to invoke the "5 (N-18) rule"), a total of twice this number ie 300 is probably a more realistic figure. This may be compared with a total "working" population of the Laboratory (defined as PTO III and below for this purpose) of something under 400. The above argument, admittedly somewhat naive in that it assumes nothing is done to improve the situation illustrates the generalisation that the external dose from induced activity is most likely to set upper limits to accelerator intensities unless it is possible to use remote handling methods for all maintenance tasks in high activity regions; this is usually only possible if it is incorporated in the design from the beginning. The possibility of spreading the dose load by employing higher grade staff on some tasks is feasible but is not likely to be successful on anything but a small scale for fairly obvious reasons.

9.1.3

Those measures which can (indeed must, in some cases) be taken to reduce personnel exposure include:

(i) The operation of the machine itself. This should be orientated to the production of the minimum possible unwanted beam loss by (say) careful tuning and the limitation of intensities to those really required by the Experimenter. Practices like running the machine at a higher intensity than required followed by collimation (to reduce intensity) and leaving the machine operating when no one is using it, should be abhorred.

(ii) The designers of equipment which is liable either to interact with the beam (deliberately or otherwise) or is situated near (within a few metres) to other parts of significant beam loss should ensure, as part of the primary specification, that maintenance, repair and forseeable modification is made as easy and as quick as possible. This should include if necessary the provision of special long-handled tools. Any remote handling devices provided should be as simple as possible - complicated mechanisms (prone to failure), particularly those in situ, should be avoided.

(iii) As many staff as possible should be trained to perform those tasks known to be in the highest dose-rate areas. Whenever possible "dry-runs" on inactive components should be performed and the procedures critically examined with a view to reducing the time needed for a particular job. The possibility of using simple shielding configurations should also be investigated. The practice of specialisation by a few individuals is to be deplored.

(iv) As much use as possible should be made of the natural decay of components. Unfortunately the cooling times required to produce a significant reduction in dose-rate are rather long for anything other than very short irradiation times (see fig 2). The least that can be done is to plan to perform the "hottest" tasks last. As a last resort it might be necessary to impose a lengthy cooling period (of the order of a week) before work commneces.

If the above measures are all conscientiously applied and combined with a general tightening up of working discipline a worthwhile reduction in the total dose load should result - possibly by a factor of 2 or 3.

9.1.4

On the debit side there are several factors which could tend to make the total dose load supra-linear with beam intensity:-

(i) The resultant increase in radiation damage to components might mean an increase in failure rates and hence an increase in the frequency of replacement or repair. This puts an additional responsibility onto the designer to specify those materials with the best possible radiation resistance properties.

(ii) The employment of more people to perform a given task, as will almost certainly be necessary for the "hottest" jobs, usually results in a decrease in working efficiency ie an increase in the number of man-hours required.

(iv) The new injector itself will add a significant potential dose-load, since induced activity production which is relatively slight at 15 MeV becomes significant at 70 MeV.

9.1.5

With so many factors involved or potentially involved it is clearly impossible to predict with any degree of certainty the resultant dose load from induced activity. Nevertheless there is an overall impression that increasing Nimrod's intensity by an order of magnitude will result in a total dose-load that is near the practical limit for a machine not initially designed for active maintenance and for the Laboratory's present labour force.

9.2 Machine Prompt Leakage

9.2.1

The consequences of the proposed increase in beam intensity on the shielding requirements for the machine and extracted proton beams have been discussed elsewhere [4], the overall conclusion being that an order of magnitude increase in intensity does not imply an overall requirement to increase <u>all</u> the machine's shielding by one TVL. In some cases the present shielding will be more than adequate, in others it is barely coping with present intensities. The overall answer therefore will be a combination of some addition of shielding, some re-distribution where this is possible, and a tighter control on beam losses in areas of "thin" shielding.

9.2.2.

In principle shielding can be extended to cope with any increase in beam intensity but in practice the limit is often set by the economics of cost and space as well as the problems posed by the necessity to provide exit holes for beam lines and entrance labyrinths and escape tunnels for personnel use. Nevertheless it is important to keep the prompt leakage dose-rates as low as possible for the following reasons:

(i) Personnel doses accrued from this cause is lost from the total available to be expended on shut-down tasks.

(ii) Personal dosimetry for the prompt leakage radiation is not, at the present time, very reliable or accurate. The system in use at the Rutherford Laboratory is considered to be better than that used elsewhere but is nevertheless based on an empirical calibration with no firm understanding of its physical basis.

(iii) Accurate control of personnel in high prompt leakage dose rates is not practicable on anything but a very small scale because a neutron sensitive equivalent of the "QFE" is not available.

(iv) Because most practical extracted beam systems (eg the present X3 complex) produce a fairly slow fall off of dose-rate with distance outside the shielding, the boundaries of the consequent controlled area could become rather widespread, possibly extending beyond the shell of the original building in some cases.

(v) High background levels are, at best a nuisance and at worst unacceptable, to many local experimenters. In extreme cases the interference could extend to neighbouring establishments.

9.2.3

The problems posed by machine leakage are probably best tackled by initially designing to a specification - say, an upper limit of 1 mrem/hr at the sides and 10 mrem/hr on the roof for extracted beam complexes. The experimental data for effective source strengths and the attenuation of iron and light concrete given by Shaw and Stevenson (5) can be used with some confidence for designing bulk shielding. Local "hot spots" should then be tackled as and when they arise this implying a positive feed-back of information from radiation surveyors to constructors via designers. Requirements for the provision of "thin" shielding on the grounds that beam losses will be controlled to a low level should be treated with scepticism - experience has shown that this hardly ever happens satisfactorily in practice.

9.3 Storage and Disposal of Active Material

The increase in both the quantity of, and activity levels on, components and scrap will necessitate a rather more formal system of screening and storage than at present. Ideally all potentially active material (and this will mean practically everything from the Magnet Hall and extracted beam complexes) not immediately being used should be taken to a central storage area where it can be either stored or sorted for active waste disposal. The present practice of keeping active material and components in any convenient empty space in and around the experimental areas is to be deplored.

REFERENCES

(1) R C HACK "The Estimation of Low Levels of Accelerator Induced Nuclides". RHEL/M/NIM/16, Dec 1972.

(2) R C HACK "The Prediction of Induced Activity Levels in and around Nimrod". RHEL/R268, Jan 1973.

(3) A H SULLIVAN "An Approximate Relation for the Prediction of Dose Rate from Radioactivity Induced in High Energy Particle Accelerators". Health Physics Vol 23 pp 253-255, Aug 1972.

(4) D R PERRY "Nimrod Shielding: A Brief Guide". Nimrod (RP) 73-9, March 1973.

(5) K B SHAW and G R STEVENSON "Radiation Studies Around Extracted Proton Beams at Nimrod". RHEL RPP/R6, Feb 1969.

ACKNOWLEDGEMENTS

The contributions of all members of the Section and the Group as a whole are gratefully acknowledged.

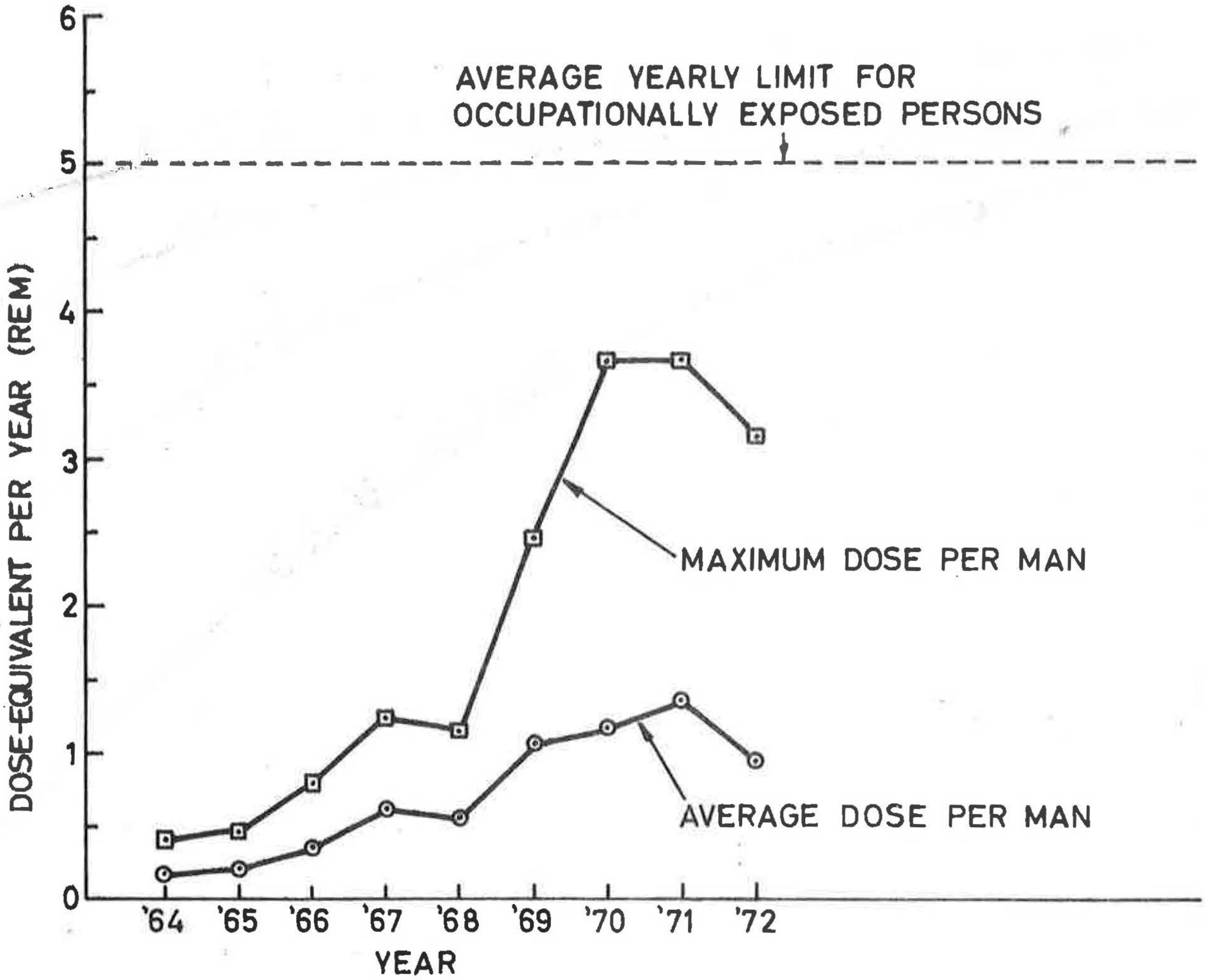

FIG. 1. RADIATION DOSES TO THE NIMROD MECHANICAL MAINTENANCE STAFF (1964-1972)

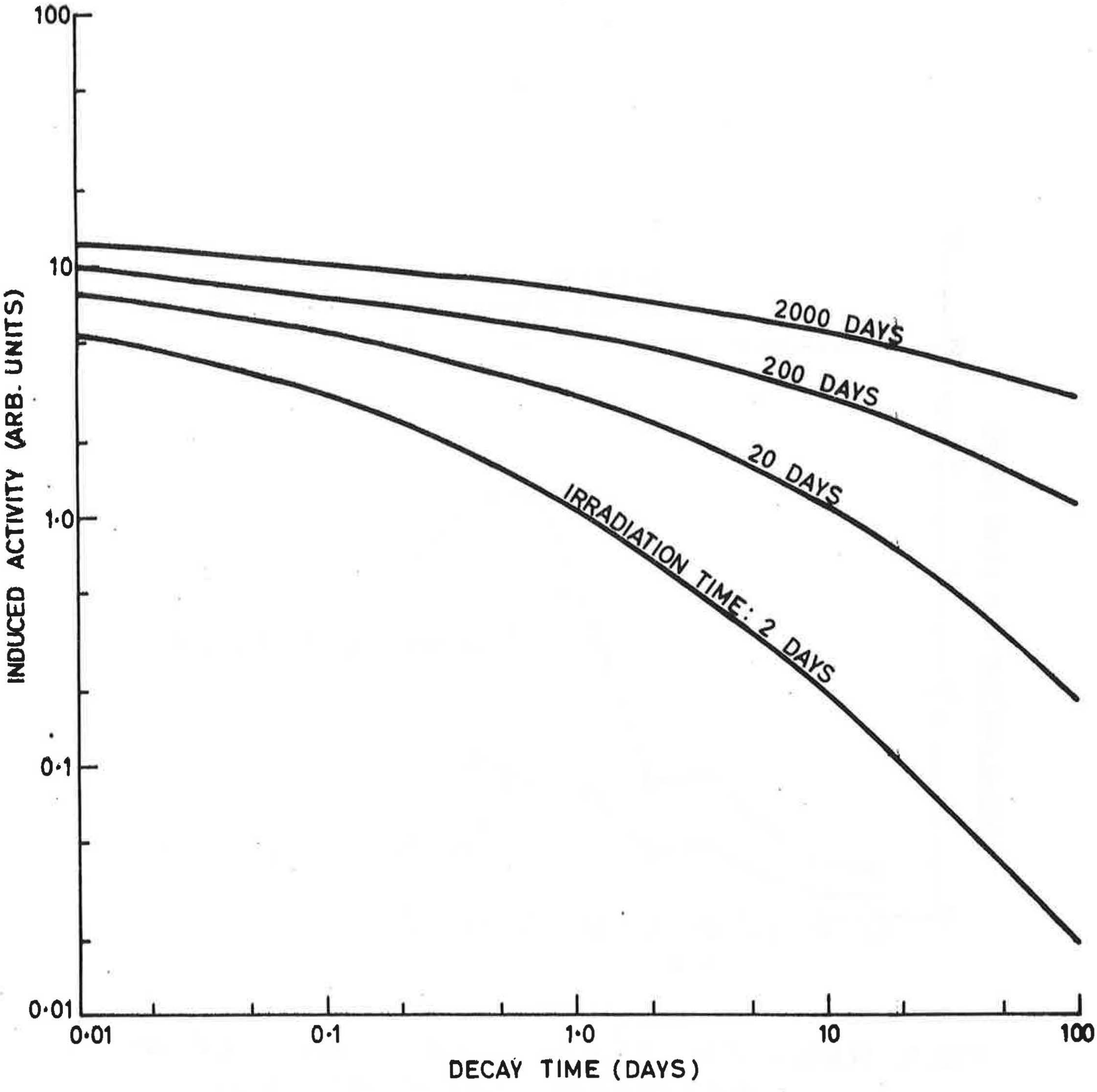

FIG. 2. VARIATION OF INDUCED ACTIVITY WITH IRRADIATION AND DECAY TIMES (AFTER SULLIVAN)

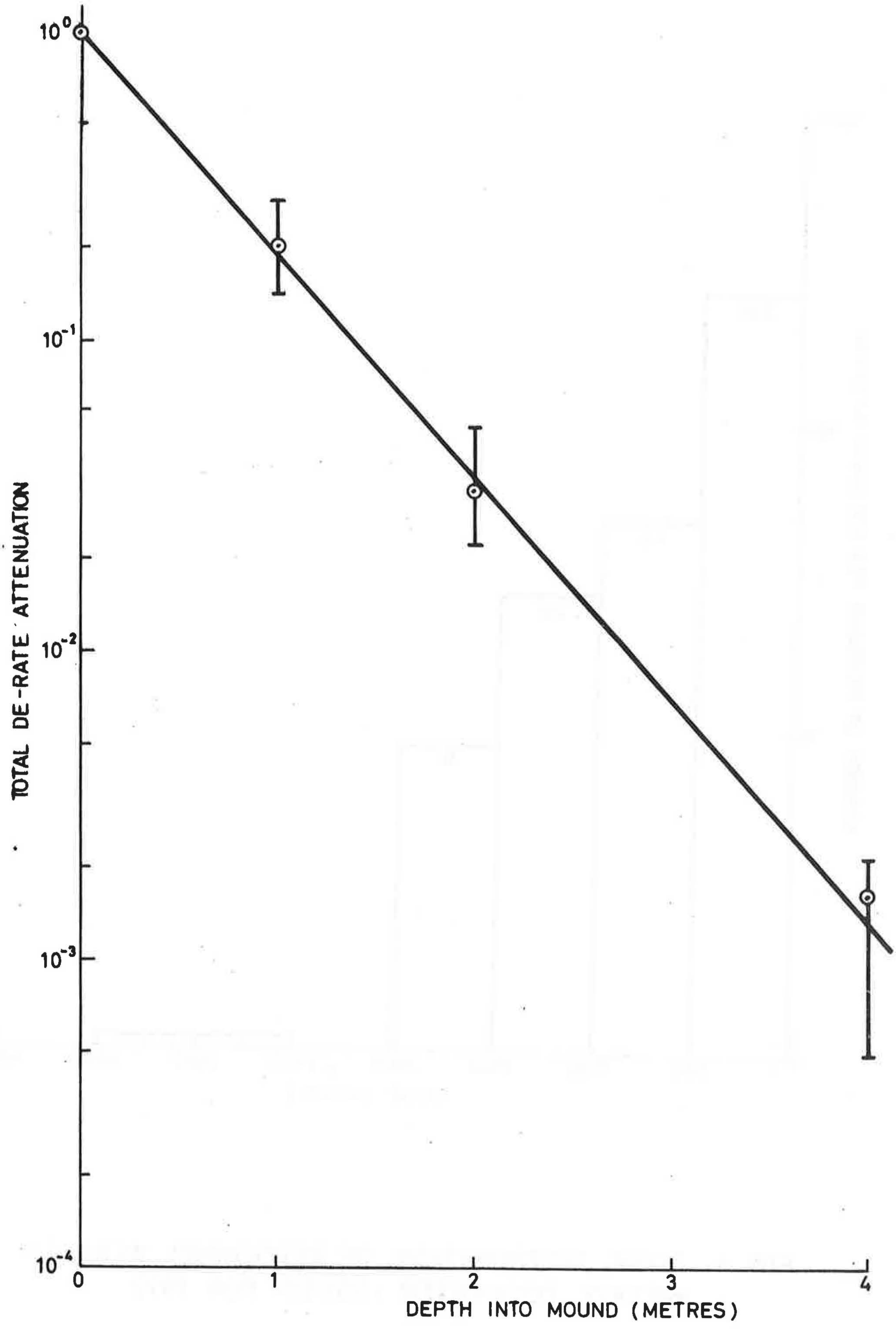

FIG. 3. ATTENUATION OF TOTAL DE-RATE IN THE NIMROD MOUND (ERROR BRACKETS REFER TO TOTAL SPREAD OF EXPERIMENTAL RESULTS)

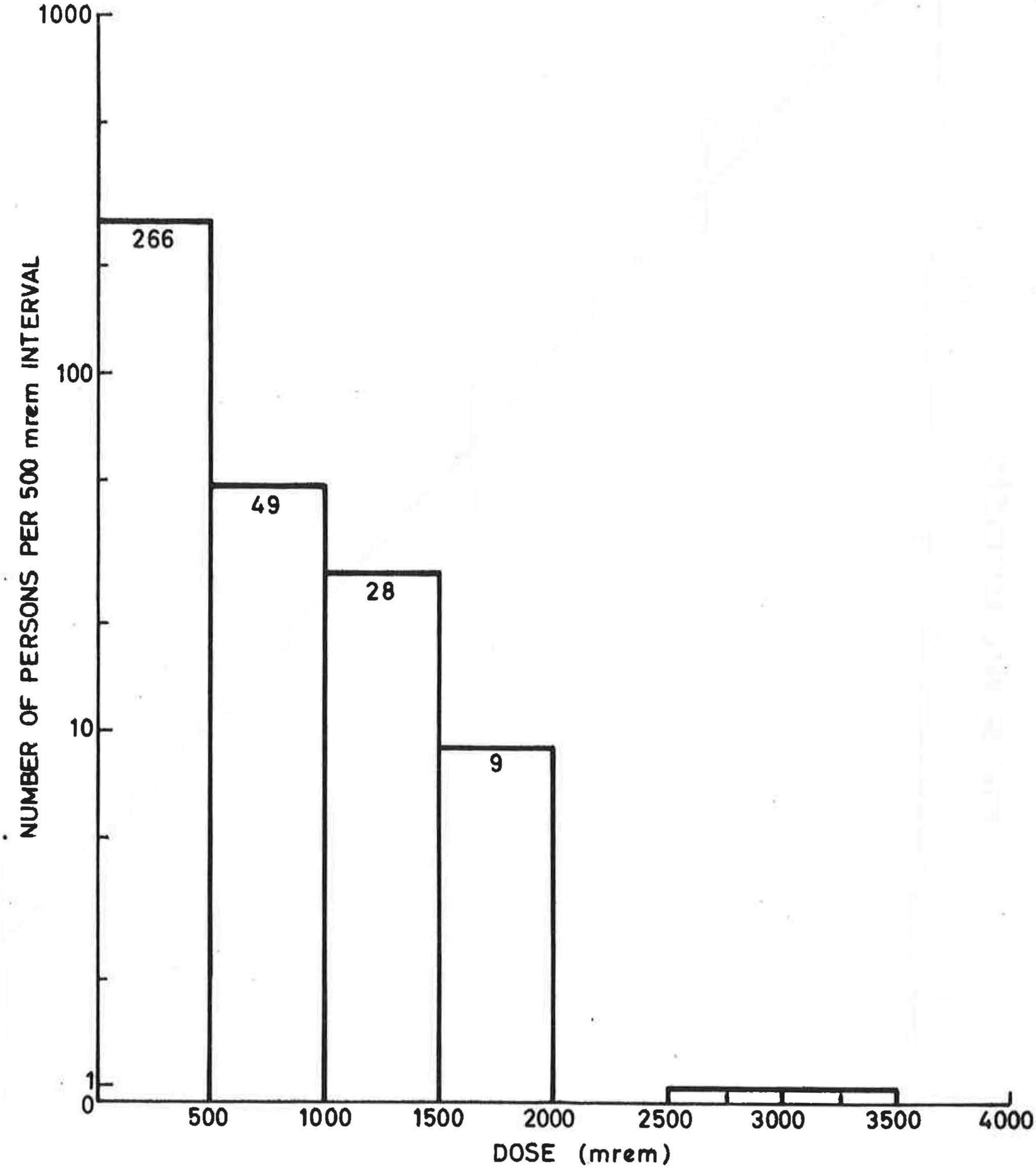

FIG. 4. DOSE DISTRIBUTION OF PERSONNEL WITH 4-WEEKLY DOSIMETER ISSUES FOR 1972

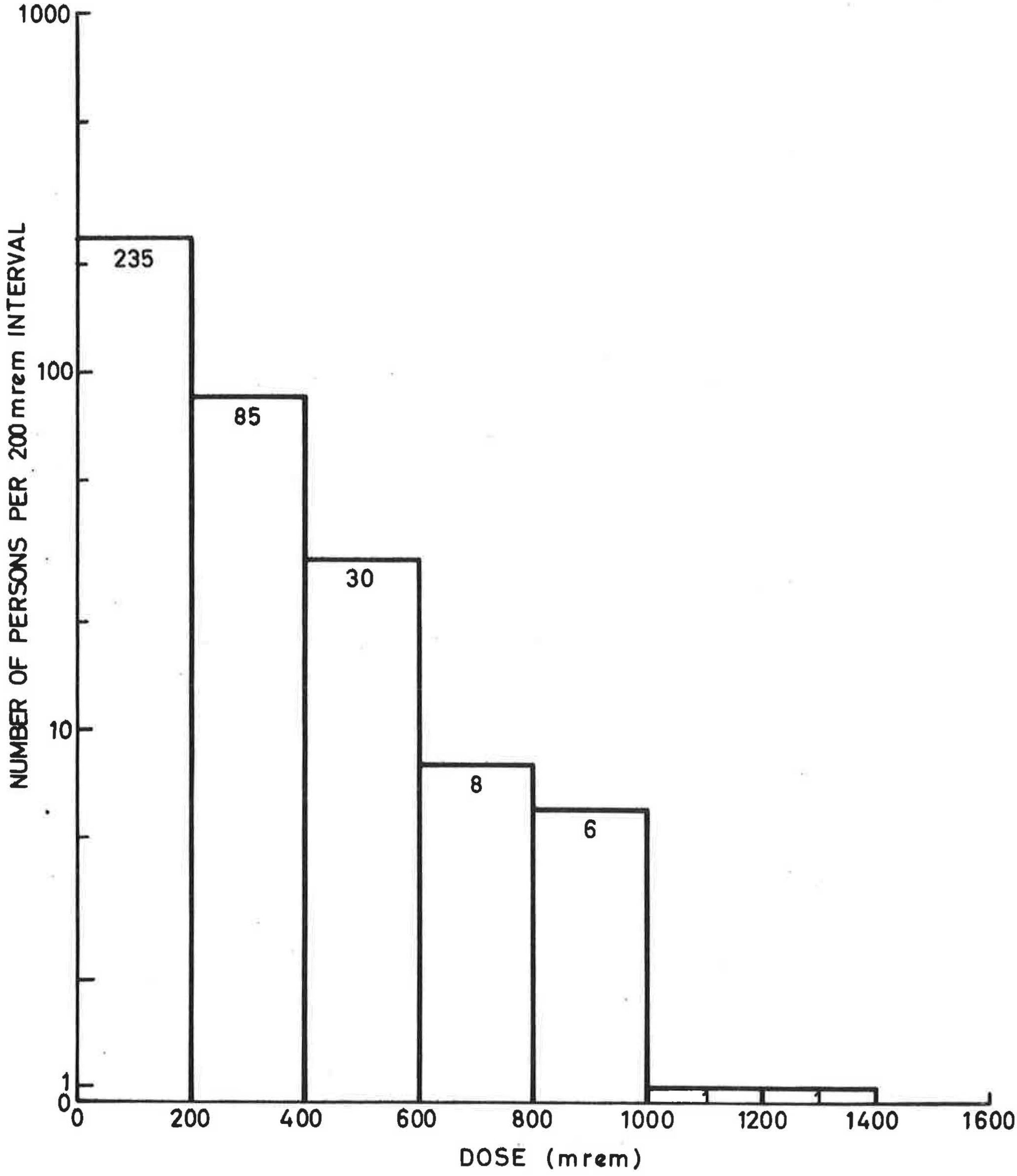

FIG. 5. DOSE DISTRIBUTION OF PERSONNEL WITH 6-MONTHLY DOSIMETER ISSUES FOR 1972