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hearing loss

due to exposure to steady-state broadband noise

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report 35 april 1968

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RESEARCH INSTITUTE FOR PUBLIC HEALTH ENGINEERING

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sound and light division

CONTENTS

SUMMARY

In this Report the influence is determined of steady-state broadband noise on the hearing levels of people exposed to noise for 8 hours a day, at least 5 days a week. For this purpose, literature data are analyzed that relate to 20 groups of employees; all in all about 4600 people. Noise-induced shifts of hearing levels are considered for exposure times between 10 and 40 years and for noise with Noise Ratings for 500 to 2000 Hz between 75 and 98, or sound levels between 79 and 102 dB (A).

First the median noise-induced hearing losses ($D_{50\%}$) at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz are examined as a function of exposure time. The increase of $D_{50\%}$ with exposure time varies with frequency. The results are:

- $D_{50\%}$ at 4000 Hz remains constant at exposure times of at least 10 years. The only exception is the female group, for which $D_{50\%}$ increases slightly after 10 years of exposition.
- $D_{50\%}$ at 2000 Hz is a linearly increasing function of exposure time from the very beginning of exposure.
- $D_{50\%}$ at 500, 1000 and 3000 Hz increases, for exposure times of at least 10 years, per year with respectively 2%, 2.5% and 1% of the median hearing loss caused by an exposure to noise for 10 years. If $D_{50\%}$ after 10 years is zero, then $D_{50\%}$ remains zero at longer exposure times.
- $D_{50\%}$ at 6000 and 8000 Hz does not increase after 10 years of exposure, if the NR for 500 to 2000 Hz is at most 92. At higher NR's for 500 to 2000 Hz, $D_{50\%}$ at 6000 and 8000 Hz increases per year with about 0.3(X-92)% of the median noise-induced hearing loss after 10 years of exposure, where X is equal to the NR for 500 to 2000 Hz.

Our analysis showed that the relation between noise and median noise-induced hearing losses is most accurate, if the NR for 500 to 2000 Hz is taken as a parameter of the noise. To estimate the median noise-induced hearing losses, the sound level in dB (A) can be used too, of the octave band spectrum contains sound pressure levels in the two highest octave bands (midfrequencies 4000 and 8000 Hz) that are relatively low compared with the sound pressure levels in the other octave bands; if the sound pressure levels in these two octave bands are about as high as the other sound pressure levels, the median noise-induced hearing losses will be estimated too high.

The only difference found between the median noise-induced hearing losses of men and those of women, is a slight increase of $D_{50\%}$ at 4000 Hz for the female group at longer exposure times. At the other frequencies there was not any difference between the $D_{50\%}$-values of men and women. However, the data on only one female group could be considered.

As the mean hearing levels of four groups were given in the literature, the mean noise-induced hearing losses of these four groups have been calculated. It appeared that there was no difference between these four mean values and the median values of the noise-induced hearing losses, if all these values are related to the NR for 500 to 2000 Hz. However, we do not exclude the possibility that curves based on mean values only have a shape, different from curves based on median values only.

Considering the median hearing losses caused by an exposure to noise for 10 years as a function of frequency, our analysis shows that these hearing losses are maximal at 4000 Hz and decrease with increasing and decreasing frequency. After 10 years of exposure, differences between the hearing losses

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at 3000 Hz and 4000 Hz are slight. With increasing exposure time the median noise-induced hearing loss moves from 4000 Hz towards lower frequencies at higher NR's for 500 to 2000 Hz. At NR 98 the median hearing loss caused by an exposure to noise for 40 years is even maximal at 2000 Hz. If the NR for 500 to 2000 Hz is at most 80, the median noise-induced hearing losses are generated during the first 10 years of exposure. At NR 85, $D_{50\%}$ increases at longer exposure times - mainly at 2000 Hz. At higher NR's for 500 to 2000 Hz the increase of $D_{50\%}$ at all frequencies, except 4000 Hz, is considerable after 10 years of exposure. At exposure times of at least 10 years, the spread of hearing levels of people exposed to noise is independent of exposure time, at least when are considered the values limited by the hearing levels not exceeded in 75% and 25% of the people exposed to noise. The spread of the hearing levels does depend upon the NR for 500 to 2000 Hz; it is an increasing function of the NR for 500 to 2000 Hz, at each frequency, except at 4000 Hz. At 4000 Hz the spread is a decreasing function of the NR for 500 to 2000 Hz. A consequence is that NR's of at most 80 at all frequencies, except 4000 Hz, the spread of the hearing levels of people exposed is just as large as that of people not exposed. The reverse occurs at high NR's (at least 96) where the spread of the hearing levels at 4000 Hz is the same for people exposed and people not exposed, but at the other fequencies the spread of the hearing levels of the people exposed is larger, If the spread of the hearing levels of people exposed to noise is larger than that of people not exposed to noise, this increase in spread is caused by noise. So, it is possible that in addition to an increase in median hearing level the spread of the hearing levels increases too as a result of exposure to noise.

Next the approximations of the noise-induced hearing losses not exceeded in 75% and 25% of the people, have been calculated. We subtracted from the hearing levels not exceeded in 75% and 25% of the people exposed, the median hearing level of those people not exposed to noise that had the same mean age as the people exposed. This implies an approximation,as the spread in the hearing levels of people not exposed to noise has not been taken into account. Calculation of the exact values of the noise-induced hearing losses not exceeded in 75% and 25% of the people is impossible, as it is not known exactly what could have been the hearing level of a person, when he had not been exposed to noise. However, it is possible to calculate the noise-induced increase in the hearing levels not exceeded in 75% and 25% of the people. When we indicate these shifts by $D_{75\%}$ and $D_{25\%}$, then $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are equal if the spread in the hearing levels do not increase as a result of exposure to noise, and they are different if the spread increases. The differences between $D_{75\%}$ and $D_{50\%}$ and between $D_{50\%}$ and $D_{25\%}$ are independent of exposure time, at exposure times of at least 10 years. These differences increase with the NR for 500 to 2000 Hz at all frequencies except at 4000 Hz, where they are decreasing functions of the NR for 500 to 2000 Hz.

To the Report an appendix is added; it gives all data necessary to estimate from noise measurements:
- the median noise-induced hearing loss;
- the approximations of the noise-induced hearing losses, not exceeded in 75% and 25% of the people;
- the noise-induced shifts of the hearing levels not exceeded in 75% and 25% of the people;
- the distribution of the hearing levels of a group exposed to noise, with an arbitrary mean age.

All these estimations can be made for exposure times between 10 and 40 years and NR for 500 to 2000 Hz between 75 and 98.

I. INTRODUCTION

Sound is essential to human society. It gives information on what is happening in our surroundings. Sounds are important because they serve as signals in our work, at home and in traffic. Moreover, the voices that daily surround us are important in our contacts with other people. We may, in fact, conclude that sounds to a large extent affect everything we do. Sounds have either positive or negative influences. At high sound levels, even "noise deafness" can be generated. Formerly "noise deafness" was mainly restricted to that of boilermakers, shipbuilders and weavers. However, industrialization has spread and intensified, and noise sources in various fields have become so much stronger that nowadays there is a distinct danger that noise gives rise to unacceptable hearing losses in the employees of many industries.

Of course, one can apply different criteria to judge whether or not a given hearing loss, so generated, is acceptable or unacceptible. Actually, speech intelligibility is frequently taken as a standard. The criterion then applied is often that the speech intelligibility to a large percentage of the people exposed shall not be influenced. Once a criterion is accepted for unacceptable hearing loss, the next problem is: which sound levels generate unacceptable hearing loss and which sound levels do not. For years already, several investigators have made attempts to establish a limit between noise that does not cause unacceptable hearing loss (safe noise) and noise that does (unsafe noise).

For some years now the International Organization for Standardization (I.S.O.) has dealt with draft proposals in which a like limit is mentioned, the so-called NR 85 limit. In these draft proposals it is said that if the sound pressure levels in the octave bands with midfrequencies 500, 1000 and 2000 Hz do not exceed 87.5 , 85 and 82.8 dB resp., after many years of exposure at most 10% of the people exposed will have a hearing loss that affects speech intelligibility. In another draft proposal a sound level of 90 dB (A) has been mentioned as a limit between safe and unsafe noise. This limit is based on the same speech intelligibility-criterion as the NR 85-limit; only the unity in which the noise is expressed has been changed.

The determination of these limits has been based on a relation between the temporary threshold shift (T.T.S.) of young people with normal hearing and the noise-induced permanent threshold shift (P.T.S.) of people that are exposed to noise for years. This has the advantage that the laborious collection of data about P.T.S. can be omitted and that, instead, young people are exposed to noise in an experimental situation. Only at 4000 Hz does an obvious relation exist between P.T.S. and T.T.S. At this frequency, the permanent threshold shift caused by exposure to noise for 10 years is, on an average, equal to the T.T.S. of young people measured two minutes after cessation of an exposure for one working day. At other frequencies, however, less is known about the P.T.S. - T.T.S. relation.

Therefore, the working group called: "Relation between Noise and Noise Deafness" of the Research Committee on Occupational Health TNO (CArGO) has aimed at testing the NR 85 and 90 dB (A) limits by determining the permanent threshold shifts caused by exposure to noise for a long time. In the present Report, these threshold shifts are determined for noise with Noise Ratings between 75 and 98 or sound levels between 79 and 102 dB (A). The determination is based mainly on findings distilled from articles in the pertinent literature.

- II. Data -

II. DATA

From a multitude of published data about noise and threshold shifts, those data have been selected that deal with rather large groups of employees, working in noise. With respect to noise we limited ourselves to

- noise whose energy is spread rather evenly over the acoustic spectrum and does not contain audible tones: broadband noise;
- noise with a rather constant noise level during the working day as well as in the course of the years: steady-state noise.

Furthermore, we have only considered groups of employees that worked continuously in noise for 8 hours per day, and that at least 5 days a week.
The people whose data we examined had neither been exposed to noise in previous jobs, nor did they have a congenital or sustained hearing damage; they had, however, some noise-induced hearing loss. Through this procedure of data selection we found eight authors, whose publications are within the scope of this Report. Their names are given in the first column of Table I. "Relations" does not indicate the name of an author: it is an abbreviation for the title of the Report on "The Relations of Hearing Loss to Noise Exposure". Altogether, these 8 authors published data about some 4600 audiograms , and some of them published data about more than one group of subjects. These groups are often distinguished by differences in sound level to which their work subjected them. The indications of the groups are presented in column 2 of Table I. All but one groups consist of men; group F consists of women. The total number of audiograms per group is mentioned in column 3 of Table I.

At which frequencies useful data about the audiograms are published is indicated in the last seven columns of Table I.
Since many symbols will be used in this Report, a list of these symbols is added on page 18.

Table I

author	group indication	total number of audiograms	useful data about audiograms at						
			500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
Burns [1]	A	44	–	–	+	–	+	–	–
Gallo [2]	B	400	+	+	+	+	+	+	–
Relations[3]	C_1	132	–	+	+	–	+	–	–
"	C_2	42	–	+	+	–	+	–	–
"	C_3	12	–	+	+	–	+	–	–
Rosenwinkel[4]	D	540	+	+	+	+	+	+	–
Nixon [5]	E_1	1948	–	–	+	–	+	–	–
"	E2	490	–	–	+	–	+	–	–
"	E_3	221	–	–	+	–	+	–	–
Taylor [6]	F	461	+	+	+	+	+	+	+
Kylin [7]	G_1	14	+	+	+	+	+	+	+
"	G_2	44	+	+	+	+	+	+	+
"	G_3	50	+	+	+	+	+	+	+
"	G_4	46	+	+	+	+	+	+	+
"	G_5	24	+	+	+	+	+	+	+
F.v.Laar[8]	H1	49	–	–	+	+	+	+	–
"	H_2	11	–	–	–	+	+	+	–
"	H_3	11	–	–	+	+	+	+	+
"	H_4	–	–	–	+	+	+	+	+
"	H_5	18	–	–	+	+	+	+	+

III. MEDIAN AND MEAN NOISE-INDUCED HEARING LOSSES

III. 1 Noise-induced hearing losses as a function of exposure time

Twelve of the groups mentioned in Table I, consist of employees who have worked about the same time in noise (at least 10 years). The remaining 8 groups consist of employees, who have worked in noise either some months up to 40 till 50 years. The indications of these eight groups are: A, B, C_1, D_1, E_1, E_2, E_3 and F. Their data were used to examine in which way the hearing losses increase in the course of years. For this purpose, these eight groups were split up into sub-groups according to exposure time.

The authors quoted gave the mean or median hearing level of each sub-group at the frequencies shown in Table I. The median hearing level, i.e. the hearing level which is just not surpassed by 50% of the hearing levels, at a certain frequency is indicated by $L_{e,50\%}$; the mean hearing level is indicated by $\overline{L}_e$. $L_{e,50\%}$ was given for the sub-groups of six groups and $\overline{L}_e$ for the sub-groups of the other two groups (C_1 and D).
In general, an increase of hearing levels of people exposed to noise is not caused only by such exposure during working hours. Also people not working in noise exhibit an increase of hearing level when they grow older. From a number of publications by several authors, Spoor [9] compiled, for frequencies between 250 Hz and 8000 Hz, curves which give the relation between the median hearing level and the mean age of groups, whose subjects had not been exposed to noise during working hours, nor did they display any congenital or sustained hearing damage. This median hearing level at a given frequency is indicated by $L_{n,50\%}$. In Figures 1 and 2, $L_{n,50\%}$ is plotted as a function of frequency, with the mean age as parameter, for men and women. Spoor's publication reveals hardly any difference between mean and median hearing levels.

The mean age of every sub-group is given by the authors quoted. From the mean age of a sub-group $L_{n,50\%}$ was calculated at the frequencies where $L_{e,50\%}$ or $\overline{L}$ is known. The difference between $L_{e,50\%}$ and $L_{n,50\%}$ is the median threshold shift caused by noise. This increase in median hearing level is called: "mean noise-induced hearing loss"; it will be indicated by $D_{50\%}$. The difference between $\overline{L}_e$ and $L_{n,50\%}$ is called: "mean noise-induced hearing loss" and this is indicated by $\overline{D}$.

$$L_{e,50\%} - L_{n,50\%} = D_{50\%} \qquad (1)$$

$$\overline{L}_e - L_{n,50\%} = \overline{D} \qquad (2)$$

In Figures 3 ... 9, for each group, $D_{50\%}$ or $\overline{D}$ of the sub-groups is shown as a function of the mean exposure time of the sub-groups for these frequencies: 4000 Hz, 2000 Hz, 3000 Hz, 500 Hz, 1000 Hz, 6000 Hz and 8000 Hz.

4000 Hz (Figure 3)
From Figure 3 it follows that $D_{50\%}$ and $\overline{D}$ increase as a function of exposure time (T) until about 10 years; after an exposure time of 10 years, $D_{50\%}$ and $\overline{D}$ remain more or less constant with exposure time. Group B is an exception due to the low $D_{50\%}$-value at T = 39 years. For each group, the best fitting line was calculated according to the method of least squares from the $D_{50\%}$- and $\overline{D}$-values of the sub-groups with exposure times of at least 10 years. These best fitting lines are the lines for which the vertical distances of the points to the line are minimal. The slopes of these lines can be taken from Table II. For group B, two best fitting

- lines -

lines are calculated, one (slope -0.15) with $D_{50\%}$ at T = 39 years excluded and the other with $D_{50\%}$ at T = 39 years not excluded (slope - 0.55). Under a hypothesis that the slopes of the best fitting lines do not differ from zero, it was found that this hypothesis is correct for 6 of the 8 groups at a significans level of 5%. The lines of groups B and F are the exceptions. However, when we ignore the value at T = 39 years, our hypothesis can also be accepted for group B. For the exceptionally low value of $D_{50\%}$ at T = 39 years we cannot give any explanation. For group F the hypothesis is rejected; the chance that this conclusion is incorrect is of the order of 1%. Group F is the only group that consisted of women. With respect to men we conclude that $D_{50\%}$ and $\bar{D}$ are independent of exposure time for exposure times of at least 10 years. $D_{50\%}$ and $\bar{D}$ for exposure times of at least 10 years are indicated by $D_{50\%}$ (T ≥ 10) and $\bar{D}$ (T ≥ 10).

$D_{50\%}$ (T ≥ 10) and $\bar{D}$ (T ≥ 10) are characteristic parameters of the noise-induced hearing losses at 4000 Hz.

2000 Hz (Figure 4)

From Figure 4 it follows that at 2000 Hz $D_{50\%}$ and $\bar{D}$ are increasing functions of exposure time; a constant course at longer exposure times cannot be perceived. Therefore, at this frequency we determine the best fitting lines per group from the $D_{50\%}$- and $\bar{D}$-values of all the sub-groups. The slopes of these lines can be taken from Table III.

Table II / Table III

Slope at 4000 Hz	Group	Slope at 2000 Hz
0.0 dB/year	A	1.33 dB/year
(-0.15)-0.55 "	B	0.62 "
0.01 "	C	0.76 "
0.05 "	D	0.32 "
0.05 "	E_1	0.10 "
0.02 "	E_2	0.31 "
-0.05 "	E_3	1.19 "
0.26 "	F	1.10 "

At 2000 Hz the slopes of the lines $D_{50\%}$ versus T and $\bar{D}$ versus T are the characteristic parameters of the noise-induced hearing losses. These slopes are indicated by $\Delta_{50\%}$ and $\bar{\Delta}$,respectively

3000, 500, 1000, 6000 and 8000 Hz (Figs 5 ... 9)

From Figures 5 ... 9 it follows that $D_{50\%}$ and $\bar{D}$ at the frequencies mentioned above are neither linearly increasing functions of exposure time (see 2000 Hz) nor do they remain constant for longer exposure times (see 4000 Hz). However, it is found that $D_{50\%}$ and $\bar{D}$ increase more rapidly during the first 10 years of exposure than during longer exposure times. Therefore, at these frequencies the best fitting lines were calculated for exposure times of at least 10 years. The equations of these lines are shown in Table IV and the lines are drawn in Figures 5 ... 9.

Table IV

group	best fitting line for $T \geq 10$ years				
	500 Hz	1000 Hz	3000 Hz	6000 Hz	8000 Hz
D	$\bar{D} = -0.08T + 1.1$	$\bar{D} = -0.03T + 1.1$	$\bar{D} = 0.09T + 12.0$	$\bar{D} = 0.05T + 10.1$	-
B	$D_{50\%} = -0.07T + 3.3$	$D_{50\%} = 0.12T + 1.7$	$D_{50\%} = 0.21T + 25.5$	$D_{50\%} = -0.02T + 21.5$	-
C_1		$\bar{D} = 0.17T + 3.4$	-	-	-
F	$D_{50\%} = 0.17T + 6.2$	$D_{50\%} = 0.23T + 4.4$	$D_{50\%} = 0.40T + 33.0$	$D_{50\%} = 0.47T + 21.3$	$D_{50\%} = 0.38T + 10.8$

Under the hypothesis that the slopes of the lines do not differ from zero, it was found that this hypothesis is correct at a significans level of 5% for the lines of group D at 500, 1000 and 6000 Hz and group B at 500 and 6000 Hz.

To characterize the noise-induced hearing losses at 500, 1000, 3000, 6000 and 8000 Hz, we have chosen the following two parameters: the mean or median hearing loss caused by exposure to noise for 10 years ($D_{50\%}(T=10)$ or $\bar{D}(T=10)$) and the increase per year of $D_{50\%}$ or $\bar{D}$ for exposure times longer than 10 years.

III.2 Relation between noise and the characteristic parameters of the noise-induced hearing losses

Twelve of the groups mentioned in Table I consist of employees who have worked about the same time in noise. In Table V the mean exposure times of these 12 groups are presented.

Table V

group	mean exposure time in years
C_2	17
C_3	18
G_1	12.5
G_2	12.5
G_3	12.5
G_4	12.5
G_5	12.5
H_1	15
H_2	15
H_3	15
H_4	15
H_5	15

For these 12 groups the mean or median noise-induced hearing losses have been calculated at the various frequencies. As the exposure time of every group is more than 10 years the value calculated at 4000 Hz for a given group is equal to $D_{50\%}$ $(T\geq 10)$ or $\bar{D}(T\geq 10)$. For all groups split up into

- sub-groups -

sub-groups, the mean value of $D_{50\%}$ or $\overline{D}$ has been calculated from the $D_{50\%}$ or $\overline{D}$ values at 4000 Hz of all the sub-groups with exposure times of at least 10 years.

It goes without saying that $\Delta_{50\%}$ or $\overline{\Delta}$ at 2000 Hz of a group has been calculated by dividing $D_{50\%}$ or $\overline{D}$ by the mean exposure time of the group.

As can be seen from Table I, $D_{50\%}$ or $\overline{D}$ at 500, 1000, 3000, 6000 and 8000 Hz could not be calculated for each of the twelve groups. The mean of the mean exposure times of the groups with data at 500 Hz is 13 years and, at the other frequencies, 14 years. Therefore, we consider the calculated values at 500 Hz representative for an exposure time of 13 years and, at the other frequencies, for an exposure time of 14 years. The $D_{50\%}$- and $\overline{D}$-values of the groups split up into sub-groups, have been calculated by substituting T = 13 or T = 14 in the best fitting lines, calculated in III.I.
Although $D_{50\%}$ (T = 13), $\overline{D}$ (T = 13), $D_{50\%}$ (T = 14) and $\overline{D}$ (T = 14) are not the characteristic parameters of the noise-induced hearing losses at the frequencies 500, 1000, 3000, 6000 and 8000 Hz, the difference between these values and the values of characteristic parameters $D_{50\%}$ (T = 10) or $\overline{D}$ (T = 10) is rather small; this can be seen from the best fitting lines $D_{50\%}$ (or $\overline{D}$) versus T, calculated in III.1.

Noise
In the preceding paragraphs the values of the characteristic parameters of the noise-induced hearing losses have been calculated. We want to relate these values to noise; therefore we have to characterize noise in some way. It is for instance possible to characterize noise with the sound level in dB (A) or with an octave band spectrum. The sound level in dB (A) gives the overall sound level, although the intensities of the high and low frequencies are attenuated in a standardized way. In this way, noise is characterized with one number. To characterize an octave band spectrum in one number we can for instance use the "noise rating" system. This number can be determined by comparing the octave band spectrum with a set of noise rating curves, some of which are shown in Figure 10. For some years the I.S.O. has dealt with a draft recommendation in which noise was characterized by the noise rating number for the three octave bands with midfrequencies 500, 1000 and 2000 Hz. The NR for 500 to 2000 Hz of a noise is equal to the number of the noise rating curve that is just not exceeded by the part of the octave band spectrum in these three octave bands. The NR for 500 to 2000 Hz of the spectrum, drawn in Figure 10, is equal to 96. Although the I.S.O. related only the hearing losses at 500, 1000 and 2000 Hz to the NR for 500 to 2000 Hz, we shall examine whether there is also a relation at other frequencies.

The octave band spectra of the noise in which the groups worked, are plotted in Figures 11 and 12. From these spectra have been calculated the sound level in dB (A) and the NR for 500 to 2000 Hz. The results are presented in Table VI.
For most of the groups, the numerical difference between sound level and NR for 500 to 2000 Hz is about 4; for group C_1 this difference is 7.

- Table VI -

Table VI

group	sound level in dB(A)	NR for 500 to 2000 Hz
A	102	98
B	97	92
C_1	102	95
C_2	95	92
C_3	97	94
D	86	82
E_1	86	82
E_2	94	90
E_3	100	96
F	102	98
G_1	79	75
G_2	84	80
G_3	89	86
G_4	97	93
G_5	100	96
H_1	86	82
H_2	86	82
H_3	95	92
H_4	100	97
H_5	100	97

Most of the spectra have about the same shape: relatively low octave band levels in the lower octave bands, a maximum at 500, 1000 or 2000 Hz and relatively low octave band levels in the two highest octave bands. As the relative low levels in the lower octave bands are attenuated in determining the sound level, these levels do not attribute to the value of the sound level. The levels of the two highest octave bands hardly attribute either, as these levels are relatively low compared with the levels of the octave bands with midfrequencies 500, 1000 and 2000 Hz. Since the levels of the two highest octave bands of group C_1 are relatively large, these octave bands attribute to a large degree to the dB (A)-value for this group.

In Figures 13 ... 19, $D_{50\%}$ $(T \geq 10)$ and $\overline{D}$ $(T \geq 10)$ at 4000, $\Delta_{50\%}$ and $\overline{\Delta}$ at 2000 Hz are drawn as a function of the NR for 500 to 2000 Hz, and so are $D_{50\%}$ $(T = 13)$ and $\overline{D}$ $(T = 13)$ at 500 Hz and $D_{50\%}$ $(T = 14)$ and $\overline{D}$ $(T = 14)$ at the remaining frequencies.

In Figures 20 ... 26, these values are plotted as a function of the sound level in dB (A).

With reference to Figures 13 ... 26 we will now answer the following questions:

1. Which noise quantity gives the most accurate relation between noise and noise-induced hearing loss?
2. Is there any difference between mean and median values of the noise-induced hearing losses in relation to noise?
3. Is there any difference between noise-induced hearing losses of men and women?

- As -

As to 1. Considering Figures 13 ... 19 it is found that the deviations of the points from the curves are small, although the NR for 500 to 2000 Hz only depends upon the sound pressure levels in the octave bands with midfrequencies 500, 1000 and 2000 Hz. Evidently the sound pressure levels in the other octave bands do not affect the hearing level. For the octave band with midfrequency 8000 Hz this can be demonstrated by means of the $\overline{D}$-values of group C_1, known at 1000, 2000 and 4000 Hz. Group C_1 is the only group that worked in noise with a high level in the 8000 Hz octave band. If this level had originated any hearing loss, then the points of group C_1 would have to be found above the curves.

Since the deviations of the points from the curves in Figures 13 ... 19 are rather small, the NR for 500 to 2000 Hz is a quantity from which the noise-induced hearing losses can be estimated accurately. When we ignore the points of group C_1, it is not surprising that the deviations of the points in Figures 20 ... 26 (sound level in dB (A)) and those in Figures 13 ... 19 are about the same, as the numerical differences between sound level and NR for 500 to 2000 Hz is about 4 for all groups. The deviation of the $\overline{D}$-values of group C_1 in Figures 20 ... 26 is, of course, caused by the high level in the 8000 Hz octave band; it affects the sound level, but not the hearing level. Therefore, for spectra with an arbitrary shape, the relation between noise-induced hearing loss and NR for 500 to 2000 Hz is more accurate than that between noise-induced hearing loss and sound level.

As to 2. The mean noise-induced hearing losses of 4 groups (C_1, C_2, C_3 and $\overline{D}$) are plotted in Figures 13 ... 19. The vertical distances of the mean values to the curves in the Figures are about as large as the distances of the median values to the curves, although the curves are mainly based on median values. Although there is no difference between mean and median values, we cannot exclude the possibility that curves based on mean values only, will have a different shape. Since the curves in Figures 13 ... 19 are mainly based on median values, we consider these curves representative for the median noise-induced hearing losses.

As to 3. The $D_{50\%}$ values of the female group (F) hardly deviate from the curves in Figures 13 ... 19, although these curves are mainly based on noise-induced hearing losses of men. This means that the noise-induced hearing losses of this group of women do not differ from those of men. However, we should remember that the noise-induced hearing losses at 4000 Hz of women increase for exposure times longer than 10 years. For the rest, this increase is rather small, viz. about 9 dB during the whole exposure time (36 years), which means a variation of 4.5 dB around the mean value drawn in Figure 13.

III. 3 Increase in the median and mean noise-induced hearing losses in relation to the median and mean hearing losses caused by an exposure to noise for 10 years.

In III.1 has been calculated the increase of $D_{50\%}$ and $\overline{D}$ 1000 and 3000 Hz for exposure times of at least 10 years. These increases per year are equal to the slopes of the best fitting lines, calculated in III.1. The increase per year of $D_{50\%}$ and $\overline{D}$ for exposure times of at least 10 years is denoted by $\Delta_{50\%}$ ($T \geq 10$) and $\overline{\Delta}$ ($T \geq 10$). In Figure 27, $\Delta_{50\%}$($T \geq 10$) and $\overline{\Delta}$ ($T \geq 10$) at 500, 1000 and 3000 Hz are plotted as a function of NR for 500 to 2000 Hz. We will relate $\Delta_{50\%}$ ($T \geq 10$) and $\overline{\Delta}$ ($T \geq 10$) with $D_{50\%}$ ($T = 10$); this relation will turn out to be very simple.

- Therefore -

Therefore, first D50% (T = 10) at 500, 1000 and 3000 Hz has been calculated by subtracting from D50% (T = 13) at 500 Hz (Figure 16) 3 times Δ50% (T≥ 10) and from D50% (T = 14) at 1000 Hz and 3000 Hz (Figures 17 and 15) 4 times Δ50% (T≥ 10); Δ50% (T≥ 10) is taken from Figure 27. For some NR's for 500 to 2000 Hz the results are presented in Table VII. Next has been calculated the relative increase of D50% for exposure times of at least ten years in relation to D50% (T = 10). This relative increase per year is: $100 \times \frac{\Delta 50\% \ (T \geq 10)}{D50\% \ (T = 10)}$ %

The results are shown in the last columns of Table VII

Table VII

500 Hz				
NR for 500 to 2000 Hz	D50% (T = 13)	Δ50% (T ≥ 10)	D50% (T = 10)	$100 \times \frac{\Delta 50\% \ (T \geq 10)}{D50\% \ (T = 10)}$
80	0.0 dB	0.0 dB/Year	0.0 dB	- % per year
85	0.0 "	0.0 "	0.0 "	- "
90	0.0 "	0.0 "	0.0 "	- "
92	1.5 "	0.0 "	1.5 "	0.0 "
94	3.4 "	0.06 "	3.2 "	1.9 "
96	5.5 "	0.11 "	5.2 "	2.1 "
98	8.5 "	0.17 "	8.0 "	2.1 "
1000 Hz				
NR for 500 to 2000 Hz	D50% (T = 14)	Δ50% (T ≥ 10)	D50% (T = 10)	$\frac{\Delta 50\% \ (T \geq 10)}{D50\% \ (T = 10)}$
80	0 dB	0.0 dB/year	0.0 dB	- % per year
85	0 "	0.0 "	0.0 "	- "
90	3.0 "	0.07 "	2.8 "	2.5 "
92	5.0 "	0.11 "	4.6 "	2.4 "
94	6.5 "	0.15 "	4.9 "	2.6 "
96	8.5 "	0.19 "	7.7 "	2.5 "
98	10.5 "	0.23 "	9.5 "	2.5 "
3000 Hz				
NR for 500 to 2000 Hz	D50% (T = 14)	Δ50% (T ≥ 10)	D50% (T = 10)	$\frac{\Delta 50\% \ (T \geq 10)}{D50\% \ (T = 10)}$
80	6.2 dB	0.09 dB/year	5.8 dB	1.5 % per year
85	13.0 "	0.13 "	12.6 "	1.0 "
90	21.0 "	0.17 "	20.3 "	0.9 "
92	25.2 "	0.21 "	24.8 "	0.9 "
94	30.0 "	0.26 "	29.0 "	0.9 "
96	35.2 "	0.32 "	34.0 "	1.0 "
98	41.5 "	0.40 "	39.9 "	1.0 "

Table VII shows that at 500 Hz Δ50% (T ≥10) is about 2% of D50% (T = 10) If D50% (T = 10) is zero, then Δ50% (T ≥10) is zero too. At 500 Hz we assume that the increase per year of D50% for exposure times of at least ten years is equal to 2% of D50% (T = 10). The maximal mistake (0.03dB/year is at NR 92, where we assume that the increase is 2% whereas zero % has

- been -

been calculated. At 1000 Hz and 3000 Hz we assume that the increase of $D_{50\%}$ per year for exposure times of at least 10 years is equal to 2.5% and 1% of $D_{50\%}$ (T = 10); the maximal mistake is at NR 94 (0.01 and 0.03 dB/year).

In paragraph III.1 it was found that at 6000 Hz $\Delta_{50\%}$ ($T \geq 10$) below NR 92 is equal to zero, and that at NR 98 the relative increase of $D_{50\%}$ is equal to 1.7% of $D_{50\%}$ (T = 10). The only thing which can be said about 8000 Hz is that at NR 98 the relative increase of $D_{50\%}$ is equal to 2.2% of $D_{50\%}$ (T = 10).

In Table VIII the results are presented about the relative increase of $D_{50\%}$ for exposure times of at least 10 years.

Table VIII

Frequency	Increase of $D_{50\%}$ at $T \geq 10$ years in relation to $D_{50\%}$ (T = 10)
500 Hz	2 % per year
1000 "	2.5 "
2000 "	10 "
3000 "	1 "
4000 "	0 "
6000 "	" " below NR 92
	1.7 at NR 98
8000 "	2.2 " at NR 98

With respect to Table VIII some restrictions have to be made. In Figure 27, $\Delta_{50\%}$ ($T \geq 10$) is plotted as a function of the NR for 500 to 2000 Hz both for men and for women (working at NR 98). However, we cannot accept without further evidence that $\Delta_{50\%}$ ($T \geq 10$) of men and women is equal, as this is incorrect at 4000 Hz. Actually, at 4000 Hz the relative increase of $D_{50\%}$ for men is 0.0% and for the female group 0.5%. At 2000 Hz $\Delta_{50\%}$ of men and women is equal. Table VII and Figure 27 show that at 1000 Hz for men working in noise with an NR of at most 95, the relative increase is equal to 2.5% and for women working at NR 98 it is also equal to 2.5%. It seems safe to state that for men working at NR 98 the relative increase of $D_{50\%}$ is also equal to 2.5%. The same reasoning can b be made for 3000 Hz. Accepting that the increase of $D_{50\%}$ for men and women is equal at 1000, 2000 and 3000 Hz, it seems reasonable to suppose that this is also correct at 500 Hz. We have to be more cautious with conclusions about the increase of $D_{50\%}$ at 6000 and 8000 Hz. At 6000 Hz it has been shown that for men $\Delta_{50\%}$ ($T \geq 10$) is equal to zero below NR 92. However, by assuming that $\Delta_{50\%}$ ($T \geq 10$) above NR 92 is equal for men and women, we can make a mistake that cannot be verified from our data. However, in view of the relative small difference at 4000 Hz between the data of men and women (difference 0.5 dB/year) we accept that at NR 98 the value of $\Delta_{50\%}$ ($T \geq 10$) for men is the same as that for women. This is also done at 8000 Hz. Further, we will show that it is most improbable that $D_{50\%}$ at 8000 Hz would still increase after 10 years of exposure at NR's of at most 92. To estimate the increase of $D_{50\%}$ at 6000 Hz and 8000 Hz, for NR's between 92 and 98, we assume that $D_{50\%}$ increases linearly with the NR. Then the increase of $D_{50\%}$ relative to $D_{50\%}$ (T=10) at NR's of at least NR 92 is:

at 6000 Hz : 0.28 (NR - 92) % per year
at 8000 Hz : 0.37 (NR - 92) % per year.

- From -

From the data of Table IX, and from Figures 13 ... 19, the median hearing losses caused by an exposure to noise for 10 years and 40 years have been calculated. In Figures 28 and 29 $D_{50\%}$ (T = 10) and $D_{50\%}$ (T = 40) are plotted as a function of the NR for 500 to 2000 Hz.

III.4 Noise-induced hearing losses as a function of frequency

Up till now we have considered the data of the median hearing losses at fixed frequencies. Finally we will relate the results at the various frequencies. Therefore, the median hearing losses caused by exposure to noise for 10 and 40 years are plotted as a function of the frequency at NR 75, 80, 85, 90, 95 and 98 in Figures 30, 31 and 32. At the same time, $D_{50\%}$ (T = 25) at NR 98 has been plotted. In these Figures it can be seen that $D_{50\%}$ (T = 10) at each NR for 500 to 2000 Hz increases with frequency up till 4000 Hz, but decreases for still higher frequencies. This means that $D_{50\%}$ (T = 10) is maximal at 4000 Hz for all NR's considered; this could already be concluded from Figure 28.

At NR 75 and NR 80, $D_{50\%}$ (T = 10) and $D_{50\%}$ (T = 40) are equal at each frequency, except at 3000 Hz; then $D_{50\%}$ (T = 40) is only one dB higher. So both at NR 75 and NR 80 the median hearing losses are caused by noise during the first 10 years of exposure and remain constant at longer exposure times.

At NR 85, $D_{50\%}$ does increase after 10 years of exposure at 2000 and 3000 Hz and at NR 90 at 1000, 2000 and 3000 Hz. At NR 90 the maximum of $D_{50\%}$ changes from 4000 Hz to 3000 Hz in the course of years. At NR 95 there is a distinct increase of $D_{50\%}$ at all frequencies except at 4000 Hz for longer exposure times. Finally at NR 98 the maximum of $D_{50\%}$ moves from 4000 Hz towards 2000 Hz in the course of years.

III. 5 Review of III.1 ... III.4

Below follows a short review of the subjects treated in this chapter.

In the first part of Chapter III, we considered the dependence of the mean and median noise-induced hearing losses on exposure time. We found that this dependence varied with frequency. Characteristic parameters at the various frequencies of noise-induced hearing losses have been determined from the relation between noise-induced hearing loss and exposure time.

The values of the parameters can be estimated most accurately if the noise is expressed in NR's for 500 to 2000 Hz, although the sound level in dB(A) can be used for spectra with a certain shape as well.

The calculated mean noise-induced hearing losses quite well fit the curves mainly based on median noise-induced hearing losses. Further, the median noise-induced hearing losses of the only female group are about equal to those of men, although a slight increase of $D_{50\%}$ at 4000 Hz for longer exposure times has been found for the female group. As there are only data on one female group, it is not justified to conclude that at each sound level the median noise-induced hearing losses of men and women are equal. Therefore, we consider our results valid for men only.

For simplification, the increase of the median noise-induced hearing losses for longer exposure times have been expressed in the median hearing loss caused by an exposure to noise for 10 years.

In III.4 we considered the median noise-induced hearing losses as a function of frequency for various NR's for 500 to 2000 Hz and exposure times.

- Median -

Median noise-induced hearing losses do give important information about the damage caused by noise, but we should not base on it a limit between safe and unsafe noise. To do this it is necessary to have information about the maximum hearing losses caused by noise, i.e. we have to be informed about the hearing losses which are less favourable than the median values. These problems are elaborated in the next chapter.

IV SPREAD OF NOISE-INDUCED HEARING LOSSES

This part of the Report deals with the spread of the hearing levels and hearing losses. Unfortunately, some of the authors whose data were elaborated in Chapter III, do not give information about the spread in the hearing levels and hearing losses. Table IX shows for which groups, at which frequencies, spread-quantities are known.

Table IX

Group	Frequency in Hertz						
	500	1000	2000	3000	4000	6000	8000
B	+	+	+	+	+	+	−
E_1	−	−	+	−	+	−	−
E_2	−	−	+	−	+	−	−
E_3	−	−	+	−	+	−	−
F	+	+	+	+	+	+	+
G_1	+	+	+	+	+	+	+
G_2	+	+	+	+	+	+	+
G_3	+	+	+	+	+	+	+
G_4	+	+	+	+	+	+	+
G_5	+	+	+	+	+	+	+
H_1	−	−	−	+	+	+	−
H_2	−	−	+	+	+	+	−
H_3	−	−	+	+	+	+	+
H_4	−	−	+	+	+	+	+

IV.1 Spread as a function of exposure time

For each of the groups from Table IX, $L_{e,75\%}$, $L_{e,50\%}$ and $L_{e,25\%}$ are known at the given frequencies. $L_{e,x\%}$ is the hearing level that is just not exceeded by x% of the employees. Both the difference between $L_{e,75\%}$ and $L_{e,50\%}$ and that between $L_{e,50\%}$ and $L_{e,25\%}$ are measures of the spread in the hearing levels. These differences will be denoted by:

$$\Delta^{+}L_{e,50\%} \equiv L_{e,75\%} - L_{e,50\%}$$

$$\Delta^{-}L_{e,50\%} \equiv L_{e,50\%} - L_{e,25\%}$$

First we examined in which way $\Delta^{+}L_{e,50\%}$ and $\Delta^{-}L_{e,50\%}$ vary with exposure time for exposure times of at least 10 years. Therefore, the $\Delta^{+}L_{e,50\%}$- and $\Delta^{-}L_{e,50\%}$-values of the sub-groups with exposure times of at least 10 years of the groups split up into sub-groups were considered as a function of exposure time. Figures 33 ... 41 give $\Delta^{+}L_{e,50\%}$ and $\Delta^{-}L_{e,50\%}$

of the sub-groups as a function of exposure time for the frequencies 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Table X presents the best fitting lines, calculated according to the method of least squares, and the mean values of $\Delta^{+}L_{e,50\%}$ and $\Delta^{-}L_{e,50\%}$ (it goes without saying that these values are the mean of the $\Delta^{+}L_{e,50\%}$- and of the $\Delta^{-}L_{e,50\%}$-values of the sub-groups with exposure times of at least 10 years).

Table X

Freq.	Group	Best fitting line of $\Delta^{+}L_{e,50\%}$ versus T, $T \geq 10$ years	Mean value of $\Delta^{+}L_{e,50\%}$, $T \geq 10$ years	Best fitting line of $\Delta^{-}L_{e,50\%}$ versus T, $T \geq 10$ years	Mean value of $\Delta^{-}L_{e,50\%}$, $T \geq 10$ years
500 Hz	B	$\Delta^{+}L_{e,50\%}$ = 0.06T + 4.2	5.3	$\Delta^{-}L_{e,50\%}$ = -0.12T + 9.6	7.4
"	F	" = 0.07T + 3.2	5.1	" = 0.07T + 2.6	4.5
1000 Hz	B	" = 0.13T + 5.9	8.4	" = 0.06T + 5.6	6.7
"	F	" = 0.14T + 4.9	8.8	" = -0.01T + 7.0	6.7
2000 Hz	E_1	" = 0.01T + 7.3	7.5	" = 0.09T + 3.6	5.7
"	E_2	" = -0.03T + 12.6	12.0	" = 0.10T + 6.9	8.8
"	E_3	" = -0.33T + 19.0	10.7	" = 0.00T + 13.1	13.1
"	B	" = 0.32T + 7.0	13.0	" = 0.20T + 3.7	7.4
"	F	" = -0.09T + 14.1	11.6	" = 0.12T + 6.8	10.3
3000 Hz	B	" = -0.12T + 18.0	15.8	" = 0.05T + 11.5	12.4
"	F	" = -0.10T + 9.8	7.0	" = -0.10T + 13.3	10.5
4000 Hz	E_1	" = -0.26T + 21.0	15.0	" = -0.20T + 17.7	13.1
"	E_2	" = 0.10T + 7.9	9.8	" = 0.01T + 11.4	11.6
"	E_3	" = -0.06T + 8.4	6.9	" = -0.10T + 10.3	7.8
"	B	" = -0.10T + 12.9	11.0	" = -0.08T + 13.2	11.6
"	F	" = -0.05T + 8.0	6.6	" = -0.17T + 12.8	8.1
6000 Hz	B	" = -0.35T + 20.3	13.6	" = 0.18T + 14.6	17.8
"	F	" = -0.04T + 11.0	9.9	" = 0.04T + 9.1	10.2
8000 Hz	F	" = 0.06T + 12.0	13.7	" = 0.04T + 10.3	11.4

At each frequency, the mean of the slopes of the best fitting lines were calculated (see Table XI).

Table XI

Frequency	Mean of the slopes of the best fitting lines $\Delta^{+}L_{e,50\%}$ versus T	Mean of the slopes of the best fitting lines $\Delta^{-}L_{e,50\%}$ versus T
500 Hz	0.07 dB/year	- 0.03 dB/year
1000 "	0.14 "	+ 0.03 "
2000 "	- 0.02 "	0.10 "
3000 "	- 0.11 "	- 0.03 "
4000 "	- 0.08 "	- 0.11 "
6000 "	- 0.20 "	+ 0.11 "
8000 "	0.06 "	0.04 "

Table XI shows that there is hardly an increase or decrease of $\Delta^{+}L_{e,50\%}$ and of $\Delta^{-}L_{e,50\%}$ with exposure time. Under a hypothesis that the slopes of the best fitting lines do not differ from zero, we can accept this hypothesis for all best fitting lines independently on a significans-level of 5%.

- Therefore, -

Therefore, our final conclusion is: the spread of the hearing levels is independent of exposure time, at least for the range that embraces 50% of the hearing levels.

IV. 2 Approximations of noise-induced hearing losses as a function of NR for 500 to 2000 Hz

In Chapter III, the median noise-induced hearing loss is defined by:

$$D_{50\%} = L_{e,50\%} - L_{n,50\%} \qquad (1)$$

In the present chapter we now define:

$$D'_{75\%} = L_{e,75\%} - L_{n,50\%} \qquad (5)$$

$$D'_{25\%} = L_{e,25\%} - L_{n,50\%} \qquad (6)$$

The accent at $D_{x\%}$ indicates that $D'_{75\%}$ and $D'_{25\%}$ are only approximations of the noise-induced hearing losses, not exceeded in 75% and 25% of the people exposed. We have accepted, as it were, that each employee working in noise, would have had a hearing level equal to the median hearing level at his age, if he had not worked in noise.

Consider the difference between $D'_{75\%}$ and $D_{50\%}$ and between $D_{50\%}$ and $D'_{25\%}$:

$$D'_{75\%} - D_{50\%} = (L_{e,75\%} - L_{n,50\%}) - (L_{e,50\%} - L_{n,50\%}) = L_{e,75\%} - L_{e,50\%} = \Delta^{+}L_{e,50\%} \qquad (7)$$

$$D_{50\%} - D'_{25\%} = (L_{e,50\%} - L_{n,50\%}) - (L_{e,25\%} - L_{n,50\%}) = L_{e,50\%} - L_{e,25\%} = \Delta^{-}L_{e,50\%} \qquad (8)$$

In IV.1 we have already seen that $\Delta^{+}L_{e,50\%}$ and $\Delta^{-}L_{e,50\%}$ are independent of exposure time. If we know the difference between $D'_{75\%}$ and $D_{50\%}$ and between $D_{50\%}$ and $D'_{25\%}$ at a certain exposure time, then we know these differences at any exposure time. In which way these differences depend upon noise is not yet known. In the following we will examine this point.

Calculation of $D'_{75\%}$ and $D'_{25\%}$

$D'_{75\%}$ and $D'_{25\%}$ of the groups, not divided into sub-groups, are calculated by subtracting $L_{n,50\%}$ from $L_{e,75\%}$ and $L_{e,25\%}$. $L_{n,50\%}$ belongs to the mean age of the group (see formulas 5 and 6). The mean exposure time of each group is between 10 and 20 years. $D'_{75\%}$ and $D'_{25\%}$ of the groups that are divided into sub-groups, are determined by calculating the mean of the $D'_{75\%}$- and of the $D'_{25\%}$values of the sub-groups with exposure times between 10 and 20 years. (At 500 Hz, 7 values of $D'_{75\%}$ and of $D'_{25\%}$ are known, at 1000 Hz 9 values, at 2000 Hz 13 values, at 3000 HZ 11 values, at 4000 Hz 14 values, at 6000 Hz 11 values and at 8000 Hz 7 values.)
As the mean of the mean exposure times of the groups considered at 500 and 1000 Hz is 13 years, and at the remaining frequencies 14 years, we consider the values at 500 and 1000 Hz representative for 13 years and at the remaining frequencies for 14 years. In Figures 42 ... 48 $D'_{75\%}$ and $D'_{25\%}$ are plotted as a function of the NR for 500 to 2000 Hz, and so are $D_{50\%}$ (T = 13) at 500 and 1000 Hz and $D_{50\%}$ (T = 14) at the remaining frequencies.

In Figure 49 the difference between $D'_{75\%}$ and $D_{50\%}$ ($\Delta^{+}L_{e,50\%}$) and the difference between $D_{50\%}$ and $D'_{75\%}$ ($\Delta^{-}L_{e,50\%}$), are plotted as a function of NR for 500 to 2000 Hz. These differences come from Figures 42 ... 48. Although these differences are calculated for a certain exposure time, they can be used for every exposure time of at least 10 years, as we have already indicated in the foregoing.

To calculate $D'_{75\%}$ and $D'_{25\%}$ for any exposure time, the following formulas are applied, which are derived from formulas 7 and 8:

$$D'_{75\%}(T) = D_{50\%}(T) + \Delta^{+}L_{e,50\%}$$

$$D'_{25\%}(T) = D_{50\%}(T) - \Delta^{-}L_{e,50\%}$$

To calculate the hearing levels of a group of men exposed to noise, with any mean age A and exposure time T_1, we use these formulas:

$$L_{e,75\%}(A,T_1) = D_{50\%}(T) + L_{n,50\%}(A) + \Delta^{+}L_{e,50\%}$$

$$L_{e,50\%}(A,T_1) = D_{50\%}(T) + L_{n,50\%}(A)$$

$$L_{e,25\%}(A,T_1) = D_{50\%}(T) + L_{n,50\%}(A) - \Delta^{-}L_{e,50\%}$$

IV.3 Noise-induced shifts of hearing levels exceeded in 75% and 25% of people exposed to noise

Analogously to the definition of $D_{50\%}$, we define:

$$D_{75\%} = L_{e,75\%} - L_{n,75\%} \qquad (9)$$

$$D_{25\%} = L_{e,25\%} - L_{n,25\%} \qquad (10)$$

where $L_{n,x\%}$ is the hearing level not exceeded by x% of a group of people not exposed to noise, with the same mean age as the group exposed.

$D_{75\%}$ and $D_{25\%}$ are the noise-induced shifts of the hearing levels not exceeded by 75% and 25% of the people exposed.
We now state that:

$$D'_{75\%} - D_{75\%} = L_{n,75\%} - L_{n,50\%} \equiv \Delta^{+}L_{n,50\%}$$

$$D_{25\%} - D'_{25\%} = L_{n,50\%} - L_{n,25\%} \equiv \Delta^{-}L_{n,50\%}$$

In continuation of the article by Spoor [9] , a publication will be edited by the Research Institute for Public Health Engineering TNO, in which estimations of $\Delta^{+}L_{n,50\%}$ and $\Delta^{-}L_{n,50\%}$ are given. $\Delta^{+}L_{n,50\%}$ and $\Delta^{-}L_{n,50\%}$ are somewhat increasing functions of age. These increases, however, are rather small. The values of $\Delta^{+}L_{n,50\%}$ and $\Delta^{-}L_{n,50\%}$ shown in Table XII are representative for an age of 45 years.

Table XII

Frequency	$\Delta^{+}L_{n,50\%}$	$\Delta^{-}L_{n,50\%}$
500 Hz	5	4
1000 "	5	4
2000 "	6	5
3000 "	9	8
4000 "	9	8
6000 "	9	8
8000 "	9	9

- Figures -

Figures 50 ... 56 plot $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ as a function of NR for 500 to 2000 Hz. $D_{75\%}$ is calculated from $D_{75\%}$ in Figures 42 ... 48, by subtracting $\Delta^{+}L_{n,50\%}$ and $D_{25\%}$ is calculated from $D'_{25\%}$ by adding $\Delta^{-}L_{n,50\%}$ (see formulas 9 and 10).

Figures 50 ... 56 show that the differences between $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are small. $D_{75\%} - D_{50\%}$ is independent of exposure time, for $D'_{75\%} - D_{50\%}$ and $D'_{75\%} - D_{75\%}$ are independent of exposure time. $D_{50\%} - D_{25\%}$ is independent of exposure time as well. At each frequency, $D_{75\%} - D_{50\%}$ and $D_{50\%} - D_{25\%}$ are increasing functions of the NR for 500 to 2000 Hz, only 4000 Hz is an exception. At this frequency, $D_{75\%} - D_{50\%}$ and $D_{50\%} - D_{25\%}$ are decreasing functions of the NR for 500 to 2000 Hz, while $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are even equal at very high NR's.

IV. 4 Noise-induced shifts of hearing levels and approximations of noise-induced hearing losses as a function of frequency

To illustrate the results of Chapter IV we shall consider the noise-induced shifts of hearing levels ($D_{75\%}$, $D_{50\%}$, $D_{25\%}$) and the approximations of the noise-induced hearing losses ($D'_{75\%}$, $D_{50\%}$, $D'_{25\%}$) as a function of frequency. The values of these quantities are dependent upon exposure time and noise (NR for 500 to 2000 Hz). Therefore, we consider $D_{75\%}$, $D_{50\%}$, $D_{25\%}$ and $D'_{75\%}$, $D_{50\%}$, $D'_{25\%}$ at different exposure times (10 and 40 years) and at different NR's (NR 75, 80, 85, 90, 95 and 98). The results are presented in Figures 57 ...80.

Figures 57 ... 60 show that at NR 75 the noise-induced shifts of the hearing levels are small. The maximal shift is at 4000 Hz for both exposure times. 4000 Hz is also the only frequency at which a spread in the hearing levels is caused by noise, since $D_{75\%}$ is larger than $D_{25\%}$. From these four Figures it is found that already at the rather low NR of 75 noise causes hearing losses.

At NR 80 (Figures 61 ... 64) there is hardly any shift at 500, 1000 and 2000 Hz, not even with a 40-years exposure to noise. At NR 85 noise-induced shifts of hearing levels occur, especially at an exposure for 40 years. Further we see that at T = 40 years the shifts at 3000 Hz and 4000 Hz are about equal.

From Figures 69 ... 72 it is seen that at NR 90 the threshold shifts spread over a larger frequency range with increasing exposure time, although $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ at 500 Hz are still zero for an exposure time of 40 years. The maximum of $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ moves with increasing exposure time from 4000 Hz towards 3000 Hz.

At NR 95 (Figures 73 ... 76), $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ at an exposure time of 10 years are maximal at 4000 Hz and, at an exposure time of 40 years, $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are about equal at 4000, 3000 and 2000 Hz. There is only a slight difference between $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ at 4000 Hz.

At NR 98 it is striking that $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ at 4000 Hz are equal. Apparently the whole distribution of the hearing levels increases with 50 dB, but the size of the distribution remains constant. There is a large difference in shape between the curves for 10 years and those for 40 years. At T = 10 years the large threshold shifts are localized at 4000 Hz and 3000 Hz, but at T = 40 years the threshold shifts at 2000 Hz are very large as well.
At the same time we draw attention to the fact that at T = 40 years the approximations of the noise-induced hearing losses are maximal at 2000 Hz.

- IV.5 -

IV. 5 Review of IV.1 ... IV.4

Chapter IV is now concluded with a short review of the subjects treated in this chapter.

First, it was found that the spread of the hearing levels is independent of exposure time, at least for the range in which 50% of the hearing levels are located. The spread depends upon the NR for 500 to 2000 Hz and increases with the NR for 500 to 2000 Hz at all frequencies, except at 4000 Hz where it is a decreasing function of the NR for 500 to 2000 Hz.

Next were calculated the approximations of the noise-induced hearing losses not exceeded in 75% and 25% of the people exposed to noise. From these values the hearing levels of a group men exposed to noise can be calculated by adding to these values the median hearing level of non-exposed people with the same nean age as the group exposed.

At the same time were calculated the noise-induced shifts of the hearing levels not exceeded in 75% and 25% of the people exposed. $D_{75\%} - D_{50\%}$ and $D_{50\%} - D_{25\%}$ are independent of exposure time, but increase with the NR for 500 to 2000 Hz at each frequency. Only at 4000 Hz the differences mentioned above decrease with increasing NR in such a way that at very large NR's $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are equal. At low NR's for 500 to 2000 Hz $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ at the various frequencies are equal, except at 4000 Hz.

Conclusions

Using the data of this Report one can estimate from a noise measurement:
- the median noise-induced hearing loss of men exposed to noise;
- the approximations of noise-induced hearing losses, not exceeded in 75% and 25% of men exposed;
- the noise-induced shifts of hearing levels not exceeded in 75% and 25% of men exposed;
- the distribution of hearing levels of men exposed.

Conditions are that the exposure time is between 10 and 40 years and the NR for 500 to 2000 Hz is between 75 and 98.

Note:
To avoid time-consuming search in the Report an appendix is added; it presents all the data that are necessary for the estimations specified above.

Acknowledgement

This Report was drawn up within the scope of activities under a programme of the Working-Group: "Relation between Noise and Noise Deafness" of the Research Committee on Occupational Health TNO.

List of symbols

$L_{e,x\%}$	Hearing level, not exceeded in x% of the people exposed to noise (x = 75, 50 and 25)
$\overline{L}_e$	Mean hearing level of people exposed to noise
$L_{n,x\%}$	Hearing level not exceeded in x% of the people not exposed to noise (x = 75, 50 and 25)
$\overline{D} \equiv \overline{L}_e - L_{n,50\%}$	Mean noise-induced hearing loss
$D_{50\%} \equiv L_{e,50\%} - L_{n,50\%}$	Median noise-induced hearing loss
$D_{x\%} \equiv L_{e,x\%} - L_{n,x\%}$	Noise-induced shift of the hearing level not exceeded in x% of the people exposed to noise (x = 75 and 25)
T	Exposure time
$D_{x\%}(T \geq 10)$	$D_{x\%}$ caused by an exposure to noise for at least 10 years
$D_{x\%}(T = T_1)$	$D_{x\%}$ caused by an exposure to noise for T_1 years
$\overline{D}(T \geq 10)$	$\overline{D}$ caused by an exposure to noise for at least 10 years
$\overline{D}(T = T_1)$	$\overline{D}$ caused by an exposure to noise for T_1 years
$\Delta_{50\%} \equiv \frac{D_{50\%}}{T}$	Increase per year of $D_{50\%}$
$\overline{\Delta} \equiv \frac{\overline{D}}{T}$	Increase per year of $\overline{D}$
$\Delta_{50\%}(T \geq 10)$	Increase per year of $D_{50\%}$ at exposure times of at least 10 years
$\overline{\Delta}(T \geq 10)$	Increase per year of $\overline{D}$ at exposure times of at least 10 years
$D'_{x\%} \equiv L_{e,x\%} - L_{n,50\%}$	Approximations of the noise-induced hearing losses not exceeded in x% of the people exposed to noise (x = 75 and 25)

$\Delta^+ L_{e,50\%} \equiv L_{e,75\%} - L_{e,50\%}$

$\Delta^- L_{e,50\%} \equiv L_{e,50\%} - L_{e,25\%}$

$\Delta^+ L_{n,50\%} \equiv L_{n,75\%} - L_{n,50\%}$

$\Delta^- L_{n,50\%} \equiv L_{n,50\%} - L_{n,25\%}$

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APPENDIX

1. Aim

The aim of this appendix is to give the data that are necessary to estimate from noise measurements:
- the median noise-induced hearing losses;
- the approximations of the noise-induced hearing losses;
- the noise-induced shifts of the hearing levels of men exposed to noise;
- the distribution of hearing levels of men exposed to noise.

The said data are to be used only for:
- steady state broadband noise;
- continuous exposure to noise for 8 hours a day, and at least 5 days a week, only interrupted by normal rest and meal periods.

2. Terms and definitions

2.1 Steady-state noise

Steady-state noise is noise with a rather constant intensity and spectral composition, both during the working day and in the course of years.

2.2 Broadband noise

Broadband noise is noise, the energy of which is spread rather evenly over at least several octave bands of the acoustic spectrum and does not contain audible tones.

2.3 Noise exposure

Noise exposure is specified by:
- the Noise Rating for 500 to 2000 Hz;
- the number of years worked in noise with the same Noise Rating for 500 to 2000 Hz.

2.4 Noise Rating for 500 to 2000 Hz

The Noise Rating (NR) for 500 to 2000 Hz of noise is equal to the number of the noise rating curve, just not exceeded by the octave band spectrum of the noise in the 3 octave bands with mid-frequencies 500, 1000 and 2000 Hz.

2.5 Median noise-induced hearing loss

The noise-induced hearing loss ($D_{50\%}$), not exceeded in 50% of the people exposed to noise, is the difference between the hearing level not exceeded in 50% of the people exposed, and the hearing level not exceeded in 50% of the people not exposed to noise with the same mean age as the group exposed.

2.6 Noise-induced shift of hearing level

The noise-induced shift ($D_{x\%}$) of the hearing level not exceeded in x% of the people exposed to noise, is the difference between the hearing level not exceeded in x% of the people exposed and the hearing level not exceeded in x% of the people not exposed to noise with the same mean age as the exposed group.

Note:
If x = 50, the noise-induced shift of the hearing level is equal to the median noise-induced hearing loss.

2.7 Approximation of noise-induced hearing loss

The approximation of the noise-induced hearing loss ($D'_{x\%}$) not exceeded in x% of the people exposed to noise, is the difference between the hearing level not exceeded in x% of the people exposed to noise and the hearing level not exceeded in 50% of the people not exposed to noise, with the same mean age as the group exposed.

Note:
If x = 50, then $D'_{50\%} = D_{50\%}$. If $x \neq 50$, $D'_{50\%}$ is only an approximation of the noise-induced hearing loss, as it is accepted, as it were, that each man working in noise, would have had a hearing level equal to the median hearing level belonging to his age, if he had not worked in noise.

3. Noise measurements

An octave band level is established by determining the mean of the frequently occurring maximal readings of the indicating instrument, the instrument set at "fast response".

4. Relation between NR for 500 to 2000 Hz and median noise-induced hearing loss

Figure A gives for 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz the relation between the median hearing loss ($D_{50\%}$ (T = 10)) caused by an exposure to noise for 10 years and the NR for 500 to 2000 Hz.

From Table A and Figure A, the median hearing loss caused by an exposure to noise for T_1 years can be determined, with T_1 between 10 and 40 years.

Example. From Figure A it is found that the median hearing loss at 3000 Hz caused by an exposure to noise with NR 96 for 10 years, is equal to 34 dB. From Table A it is seen that the increase per year of the median hearing loss is 1% of $D_{50\%}$(T = 10); so, in this case, 0.34 dB/year. Therefore, the median hearing loss at 3000 Hz caused by exposure to noise with NR 96 for 40 years is 34 + 30 x 0.34 = 44.2 dB.

5. Noise-induced shift of hearing levels not exceeded in 75% and 25% of people exposed to noise

From the data of Figure A and Table A, only $D_{50\%}(T = T_1)$ can be determined. The noise-induced shift $D_{75\%}$ $(T = T_1)$ of the hearing level not exceeded in 75% of the people exposed to noise for T_1 year is calculated by adding to $D_{50\%}$ $(T = T_1)$ the appropriate number of Table B, while $D_{25\%}$ $(T = T_1)$ is calculated by subtracting from $D_{50\%}$ $(T = T_1)$ the appropriate number of Table B.

Example In the example of point 4 has been calculated that the median hearing loss at 3000 Hz, caused by an exposure to noise for 40 years with NR 96, is equal to 44.2 dB. From Table B it is found that the shift of the hearing level not exceeded in 75% of the people, is equal to 44.2 + 4.5 = 48.7 dB and the shift of the hearing level not exceeded in 25% of the people, is equal to 44.2 - 3.5 = 40.7 dB.

6. Approximations of noise-induced losses not exceeded in 75% and 25% of people exposed to noise

To calculate the approximation ($D'_{75\%}$ $(T = T_1)$) of the noise-induced hearing loss not exceeded in 75% of the people exposed to noise for

T_1 years, the appropriate number of Table C has to be added to $D_{50\%}$ ($T = T_1$) one can calculate $D'_{25\%}$ ($T = T_1$) by subtracting from $D_{50\%}$ ($T = T_1$) the appropriate number of Table C.

Example. In point 4 we have calculated that $D_{50\%}$ ($T = 40$) at 3000 Hz, caused by exposure to noise with NR 96, is equal to 44.2 dB. Using Table C, it is seen that the approximation of the noise-induced hearing loss not exceeded in 75% of the people, is equal to 44.2 + 13.5 = 57.7 dB, and that the approximation of the noise-induced hearing loss not exceeded in 25% of the people, is equal to 44.2 - 11.5 = 32.7 dB.

7. Relation between NR for 500 to 2000 Hz and hearing levels of people exposed to noise

To calculate the hearing levels not exceeded in 75%, 50% and 25% of the people exposed to noise for T_1 years, with a given mean age, the median hearing level of people not exposed to noise, but with the same mean age, has to be added to $D'_{75\%}$ ($T = T_1$), $D_{50\%}$ ($T = T_1$) and $D'_{25\%}$ ($T = T_1$) resp. In Figure B, the median hearing levels of people not exposed to noise has been plotted as a function of frequency, with the mean age as parameter.

Example. In points 4 and 6 we calculated that at NR 96 $D'_{75\%}$ ($T = 40$), $D_{50\%}$ ($T = 40$) and $D'_{25\%}$ ($T = 40$) at 3000 Hz are equal to 57.7, 44.2 and 32.7 dB. Suppose that the mean age of the group is 60 years; from Figure B it then follows that the median hearing level of people not exposed to noise is 22.5 dB at 3000 Hz and 60 years. So, the hearing levels at 3000 Hz not exceeded in 75%, 50% and 25% of the people exposed for 40 years to noise with NR 96 and having a mean age of 60 years, are 80.2 dB, 66.7 dB and 55.2 dB.

Table A

Frequency	Increase of $D_{50\%}$ in relation to $D_{50\%}$ (T = 10) for exposure times of at least 10 years	
500 Hz	£ % per year	
1000 "	2,5 "	
2000 "	10 "	
3000 "	1 "	
4000	0 "	
6000 "	0 "	NR ≤ 92
	0.28 (NR-92) "	NR ≥ 92
8000 "	0 "	NR ≤ 92
	0.37 (NR-92) "	NR ≥ 92

Table B

NR for 500 to 2000 Hz	Number of decibels to be added to $D_{50\%}$, in order to calculate $D_{75\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	0	0	0	0	4	0	0
80	0	0	1	0	3.5	1	1
85	0	0	2	2.5	3	2.5	2
90	0	0	3	4.5	2	3.5	3
94	0	0	4.5	4.5	0.5	4	3
98	0	0.5	7	4.5	0	5	3

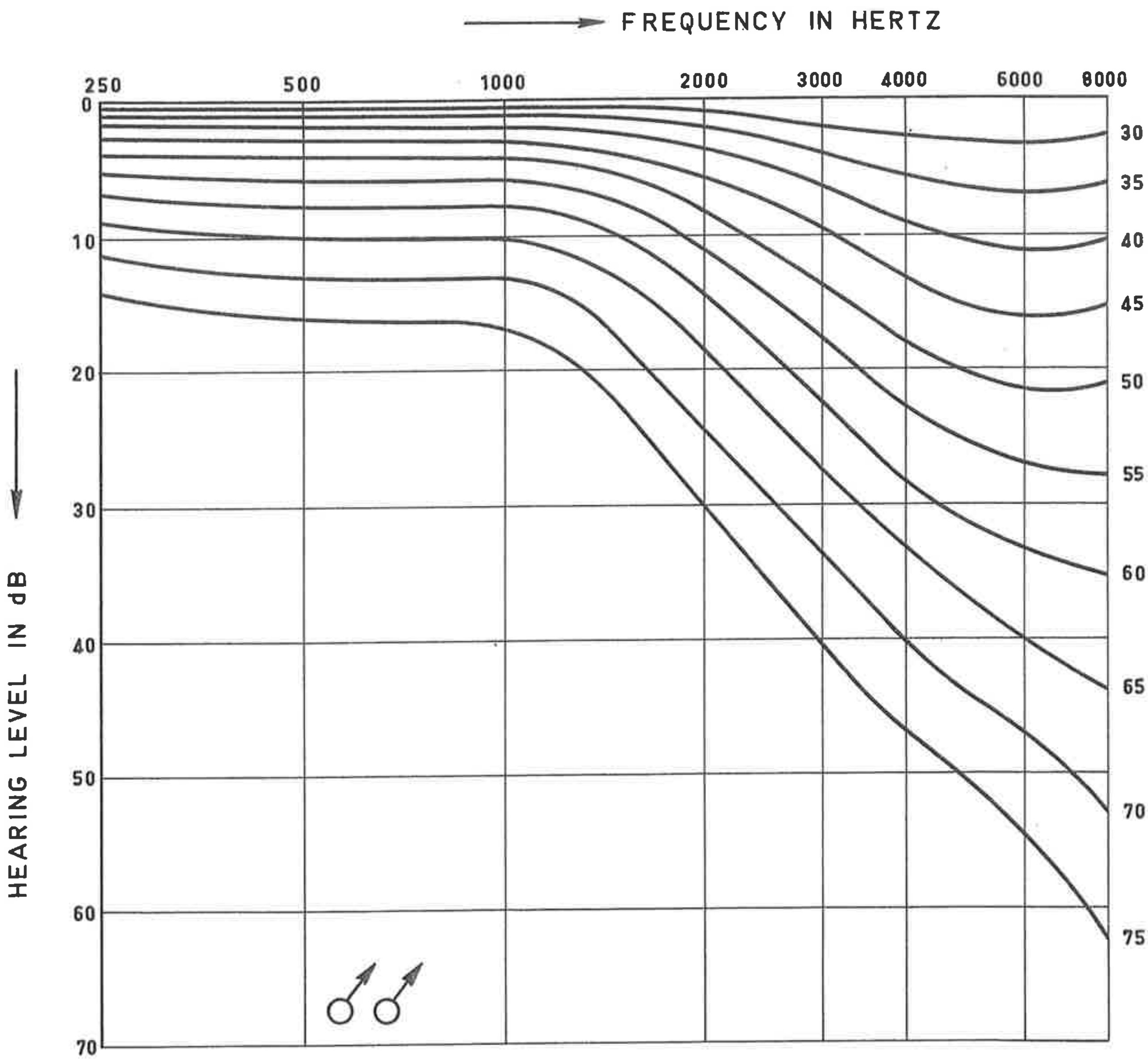
NR for 500 to 2000 Hz	Number of decibels to be substracted from $D_{50\%}$,in order to calculate $D_{25\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	0	0	0	1	5	1	0
80	0	0	0	1	5	3.5	0
85	0	0	0.5	2.5	5	6	0
90	0	0	3	3.5	4	7	0
94	0.5	0.5	4	3.5	2	7.5	0
98	1.5	1.5	5	3.5	1	8	0

Table C

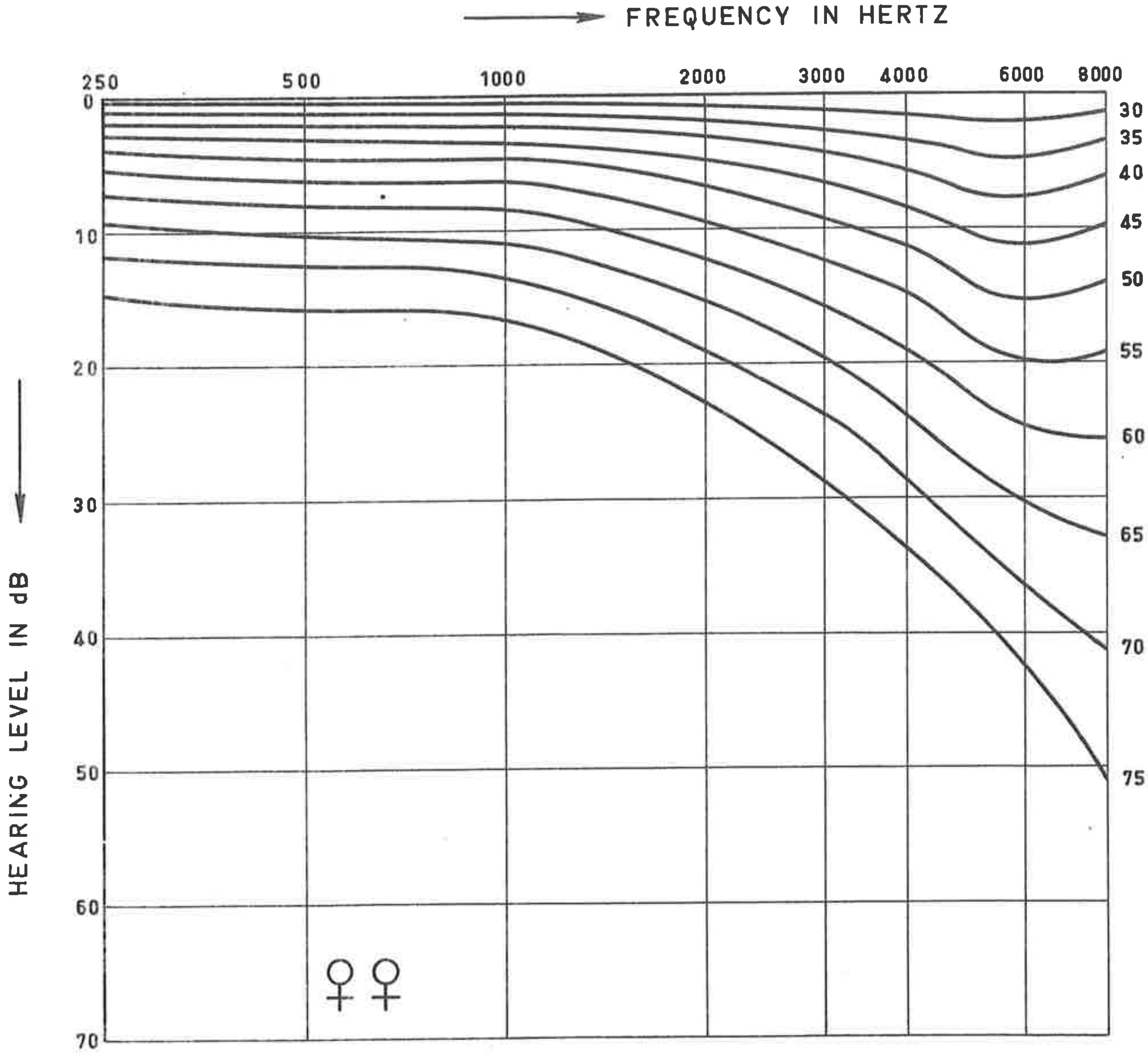
NR for 500 to 2000 Hz	Number of decibels to be added to $D_{50\%}$, in order to calculate $D'_{75\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	4	5	5.5	6	13	8	8
80	5	5	7	8	12.5	10	10
85	5	5	8	11.5	12	11.5	11
90	5	5	9	13.5	11	12.5	12
94	5	5	10.5	13.5	9.5	13	12
98	5	5.5	13	13.5	7.5	14	12

NR for 500 to 2000 Hz	Number of decibels to be subtracted from $D_{50\%}$, in order to calculate $D'_{25\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	4	4	3	9	13	9	6
80	4	4	3	9	13	11.5	7
85	4	4	5.5	10.5	13	14	7.5
90	4	4	8	11.5	12	15	7.5
94	4.5	4.5	9	11.5	10	15.5	8
98	5.5	5.5	10	11.5	9	16	8.5

MEDIAN HEARING LEVELS OF MEN NOT EXPOSED TO NOISE, AS A FUNCTION OF FREQUENCY; AGE IS PARAMETER.



MEDIAN HEARING LEVELS OF WOMEN NOT EXPOSED TO NOISE, AS A FUNCTION OF FREQUENCY; AGE IS PARAMETER.



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IG-TNO AFD. GELUID EN LICHT

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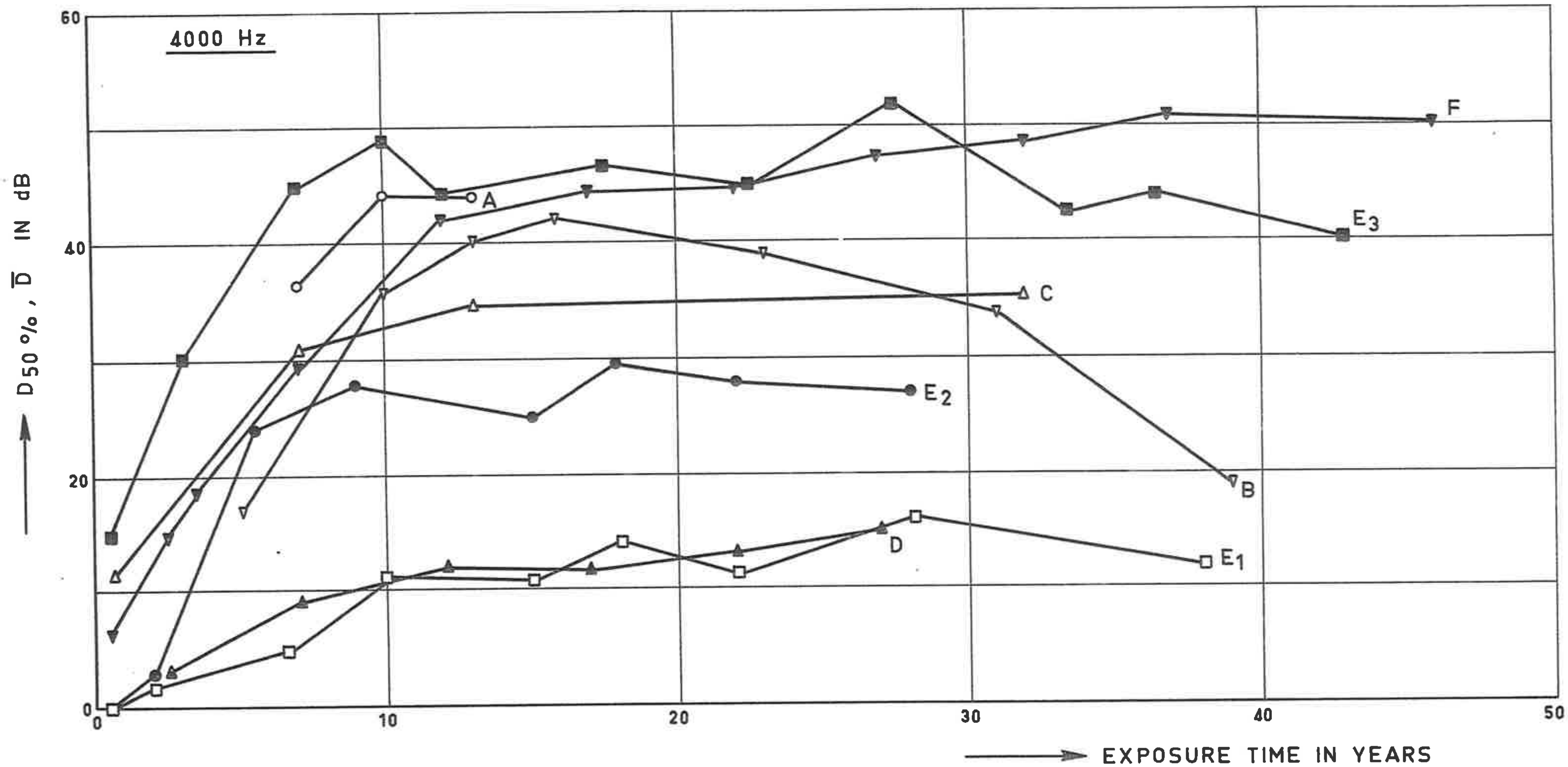
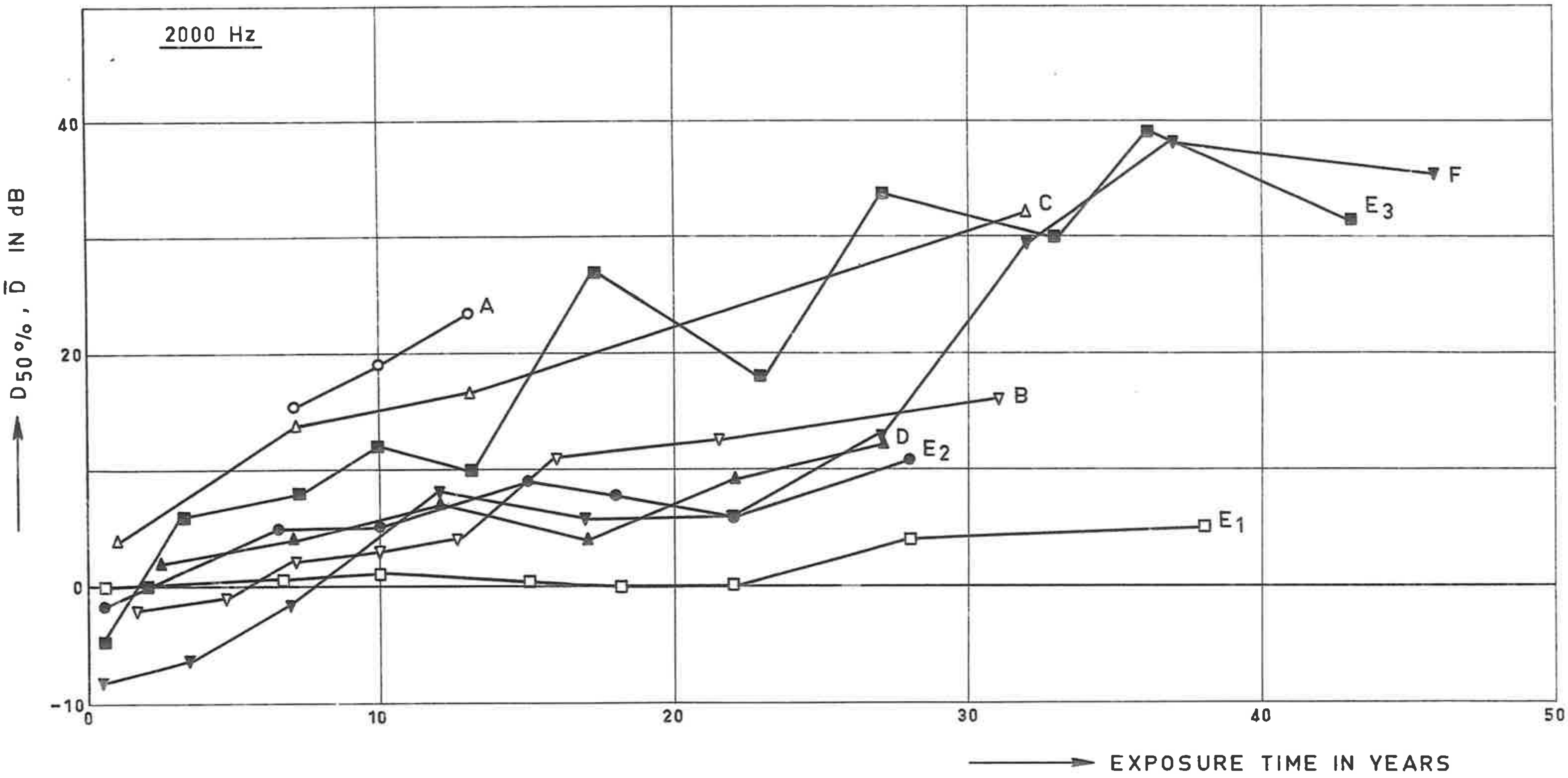
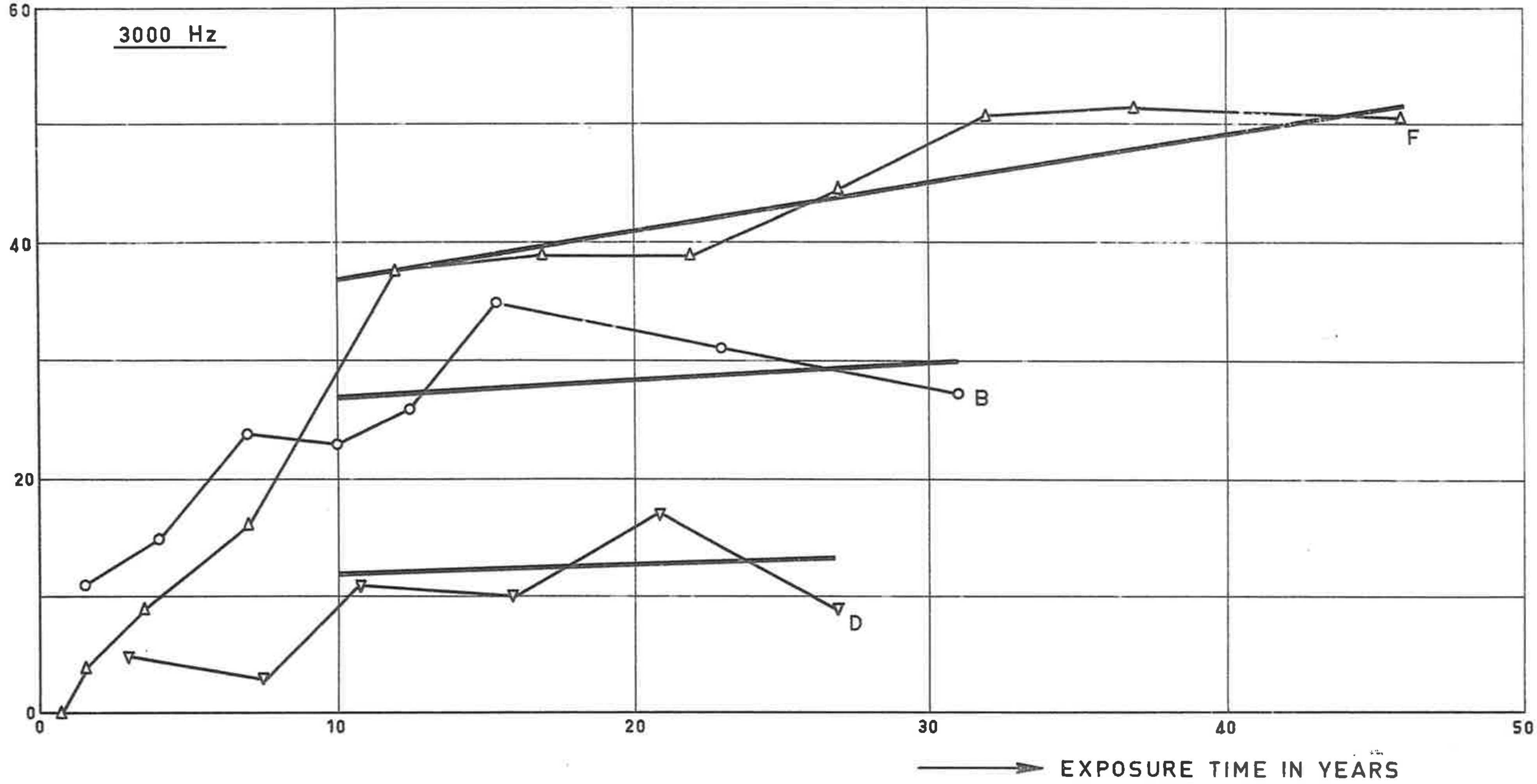
MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



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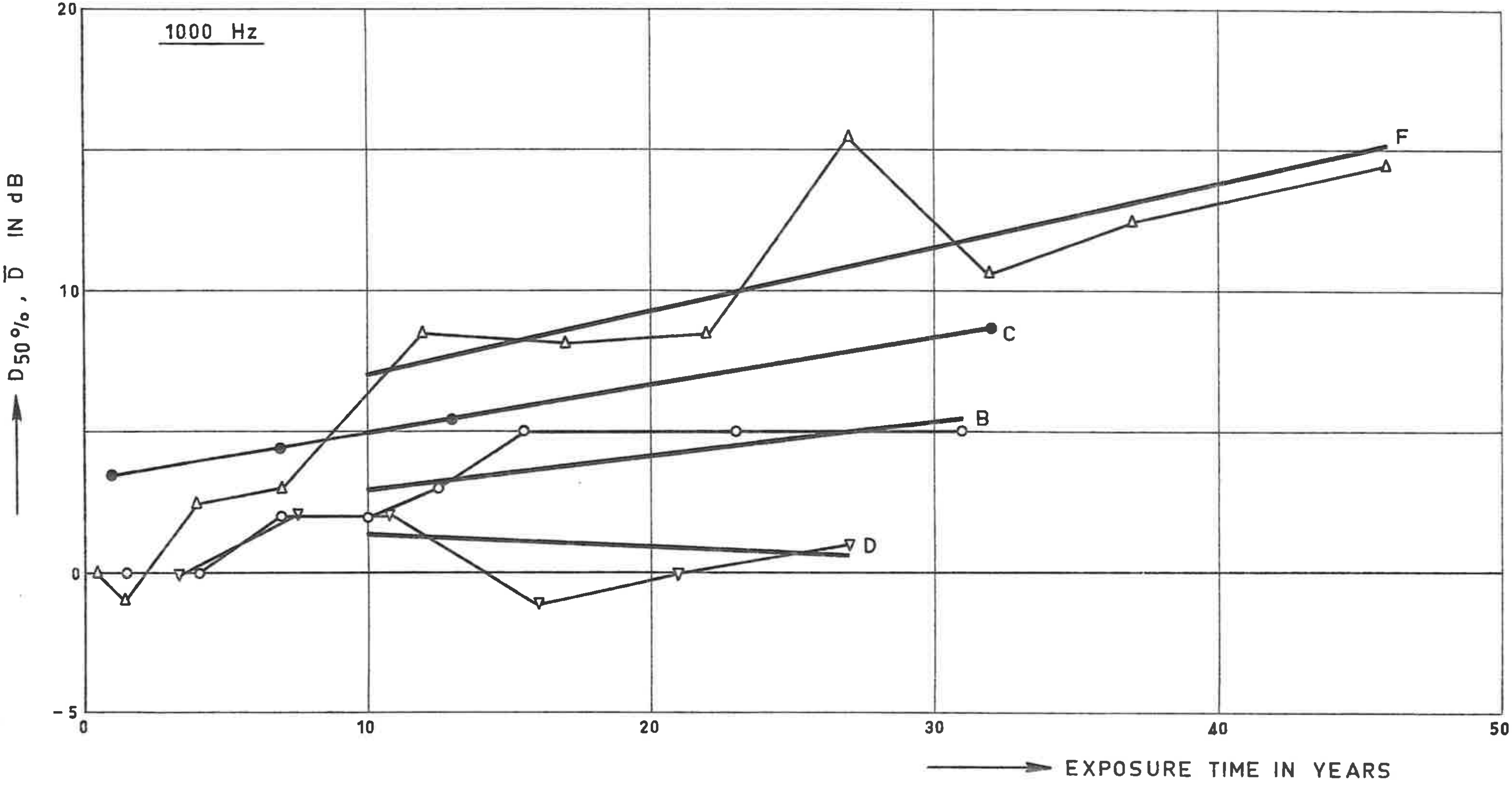
R 35 - 6

MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



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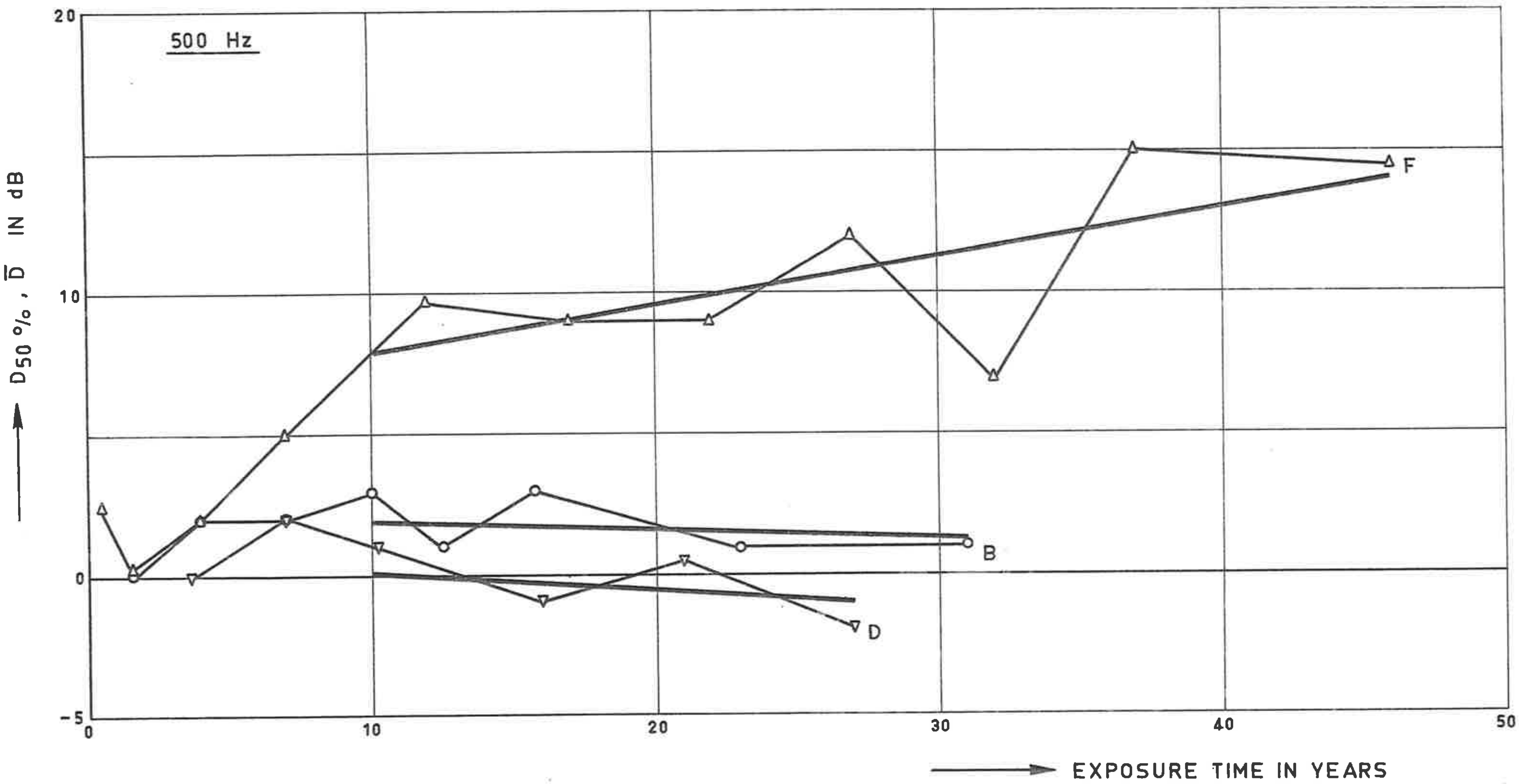
MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



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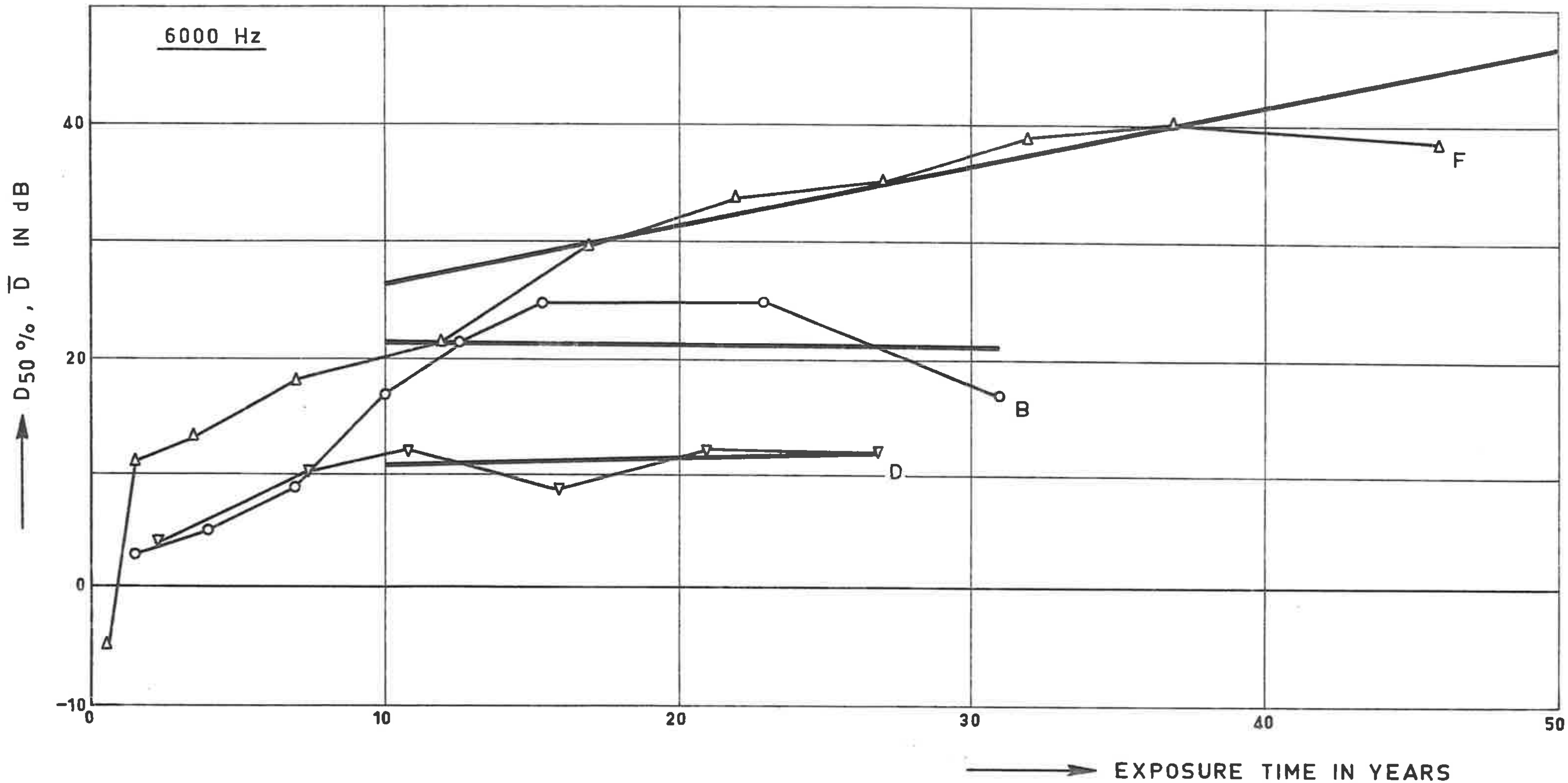
MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS ($D_{50\%}$ AND $\overline{D}$) AS A FUNCTION OF EXPOSURE TIME.



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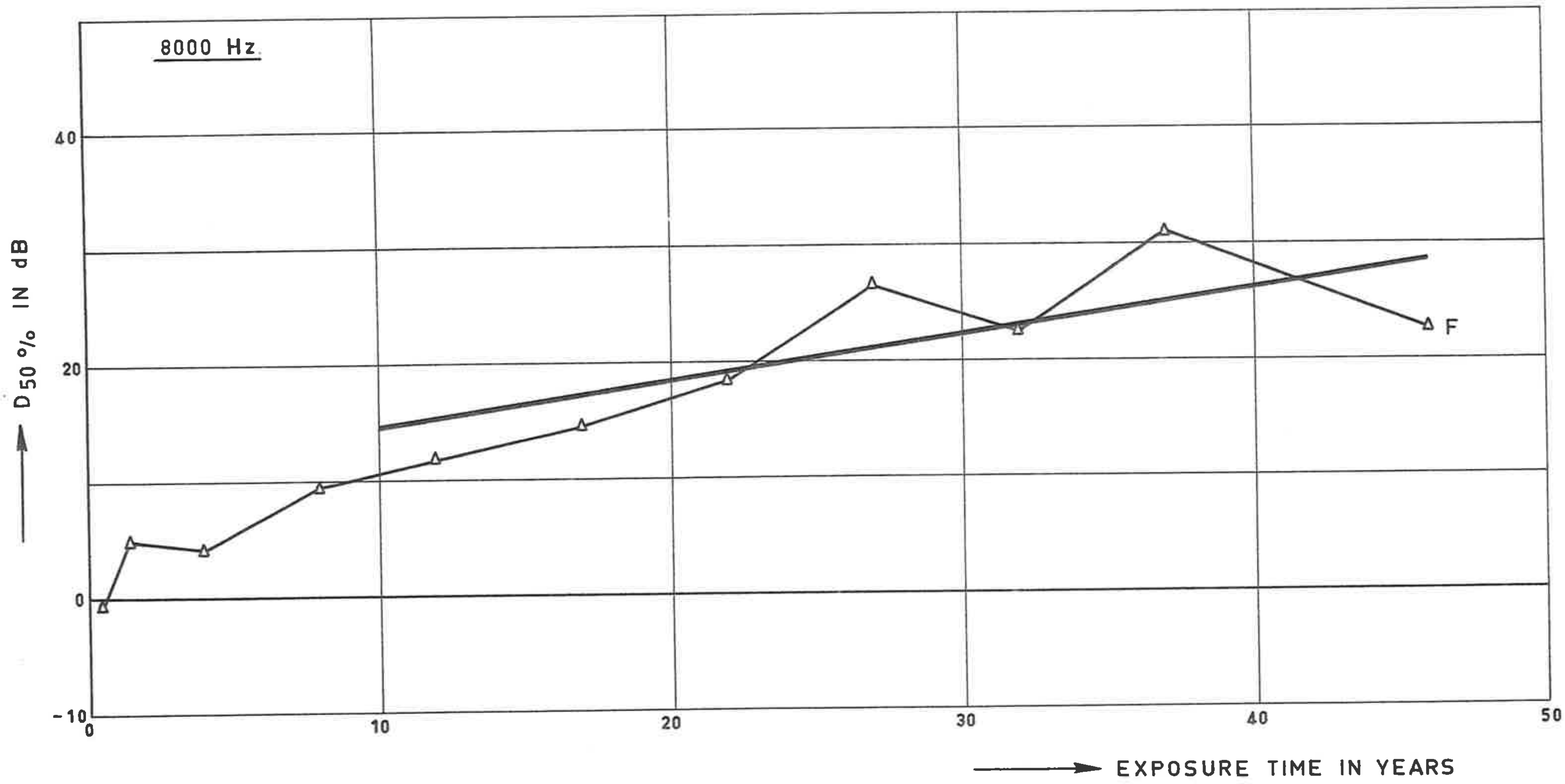
MEDIAN NOISE-INDUCED HEARING LOSS (D_{50} %) AS A FUNCTION OF EXPOSURE TIME.



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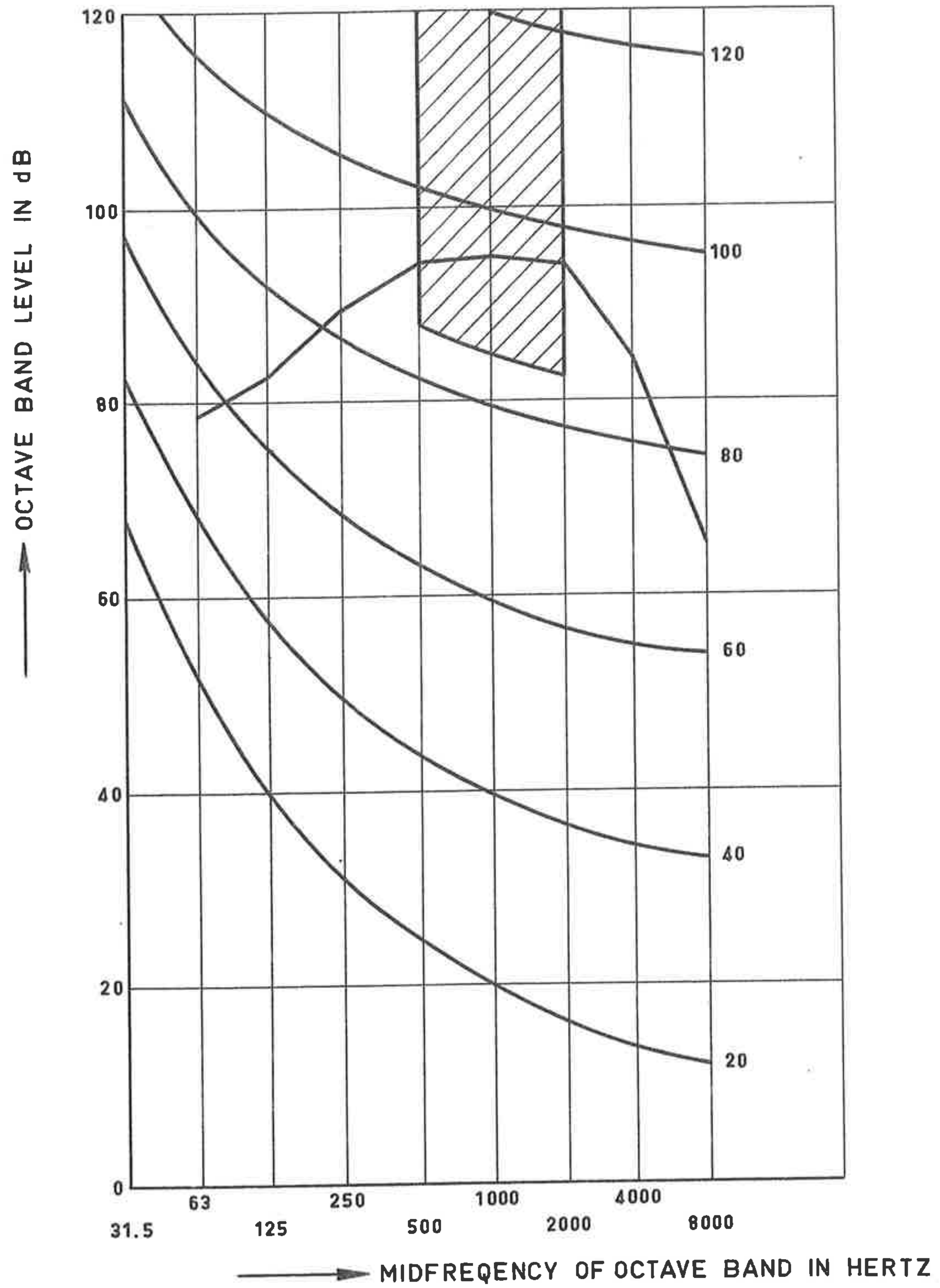
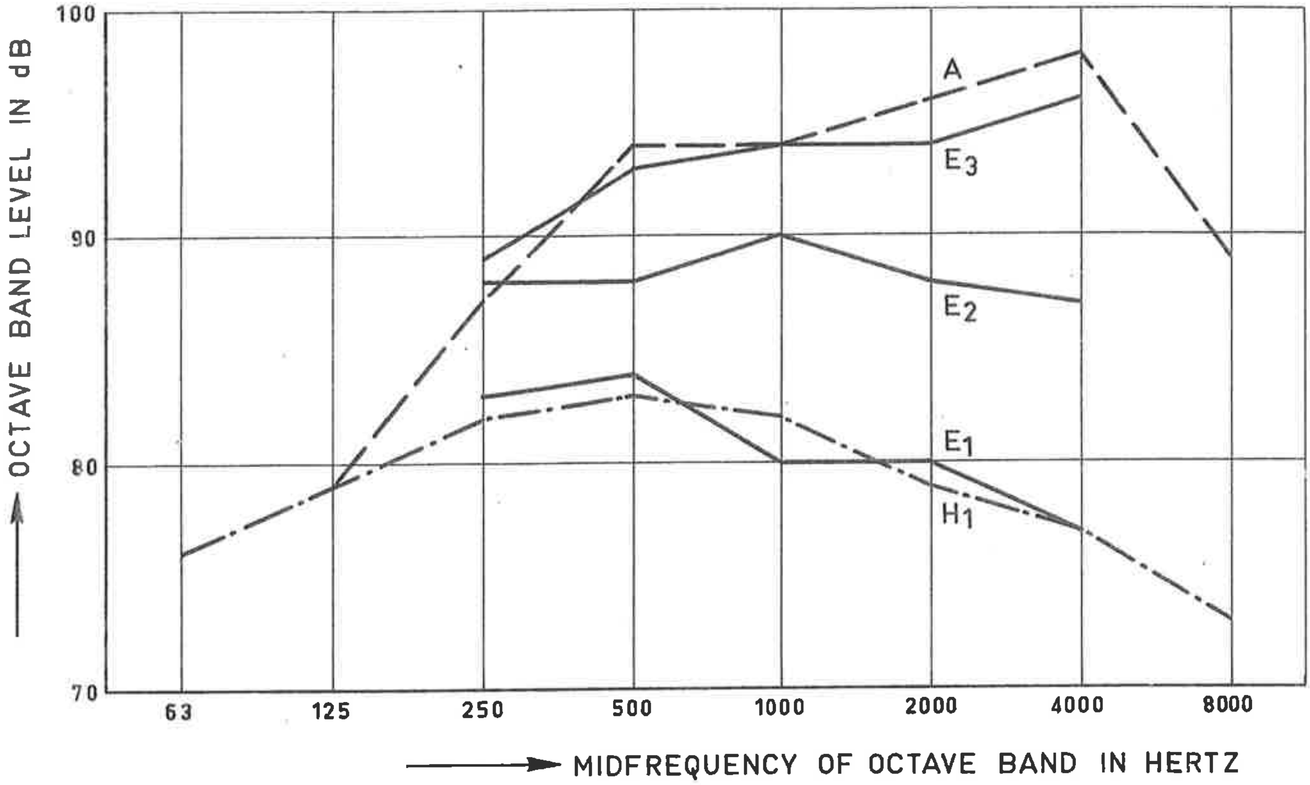
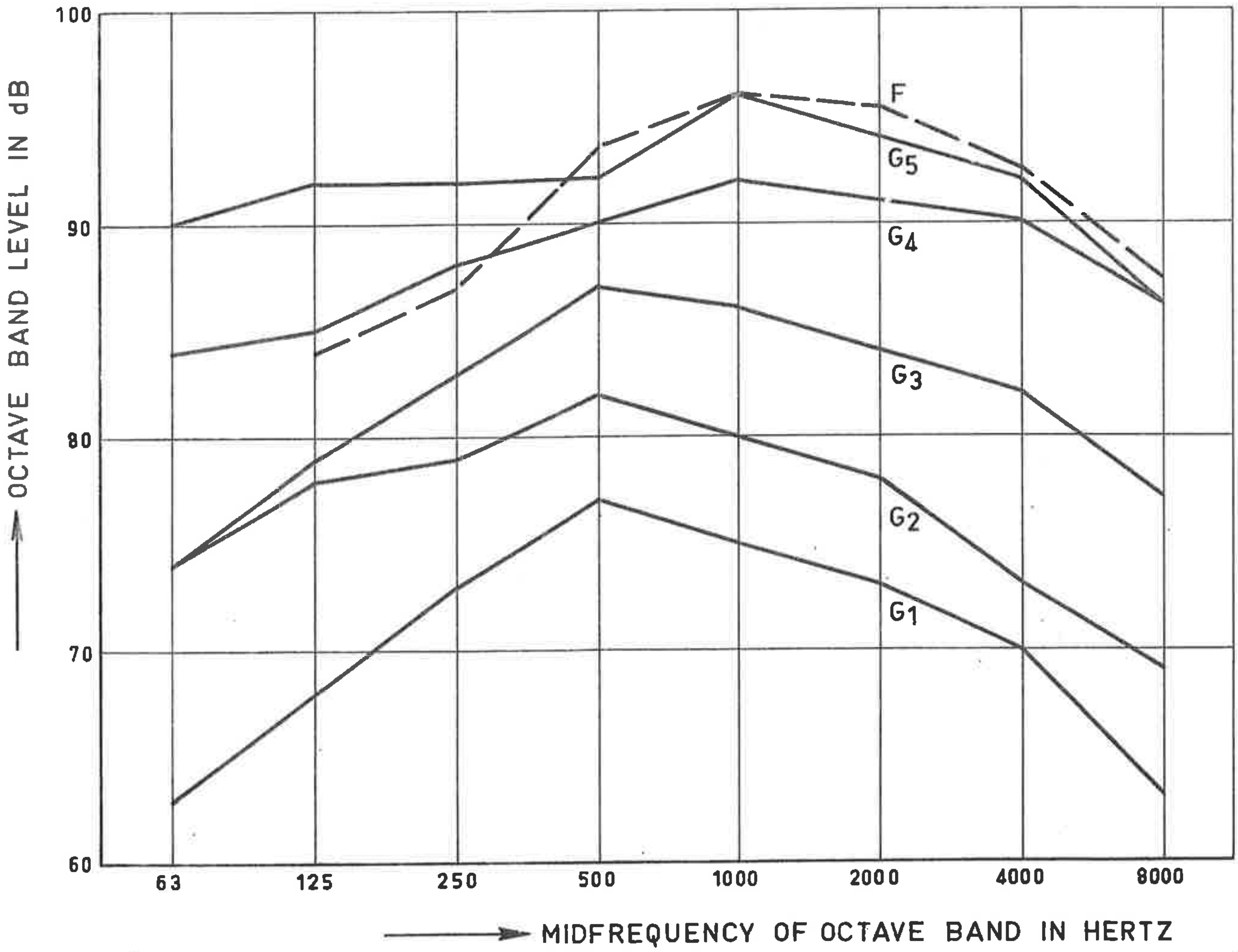
R 35-9

NOISE RATING CURVES, ACCORDING TO C.W. KOSTEN AND G.J. VAN OS
SHADED PART : UNSAFE NOISE ACCORDING TO A DRAFT I.S.O. RECOMMENDATION.



OCTAVE BAND SPECTRA





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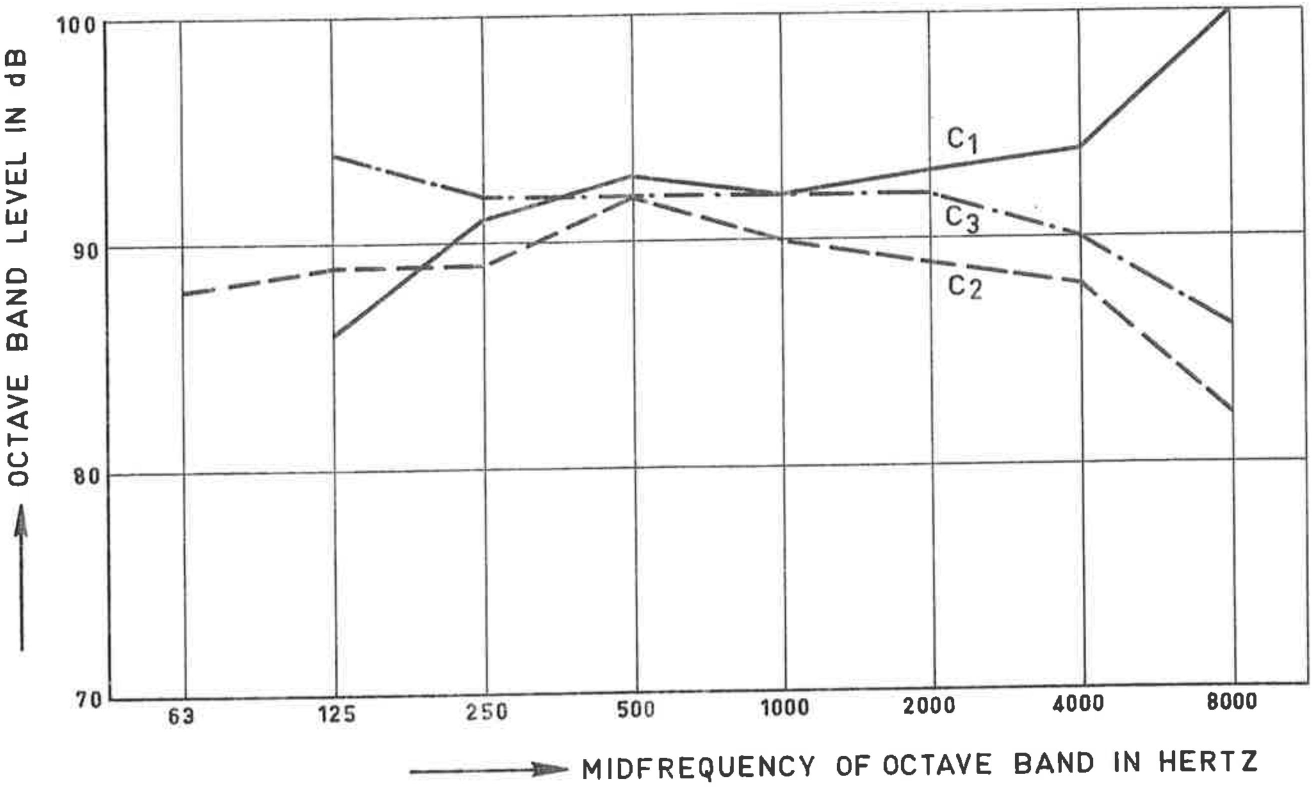
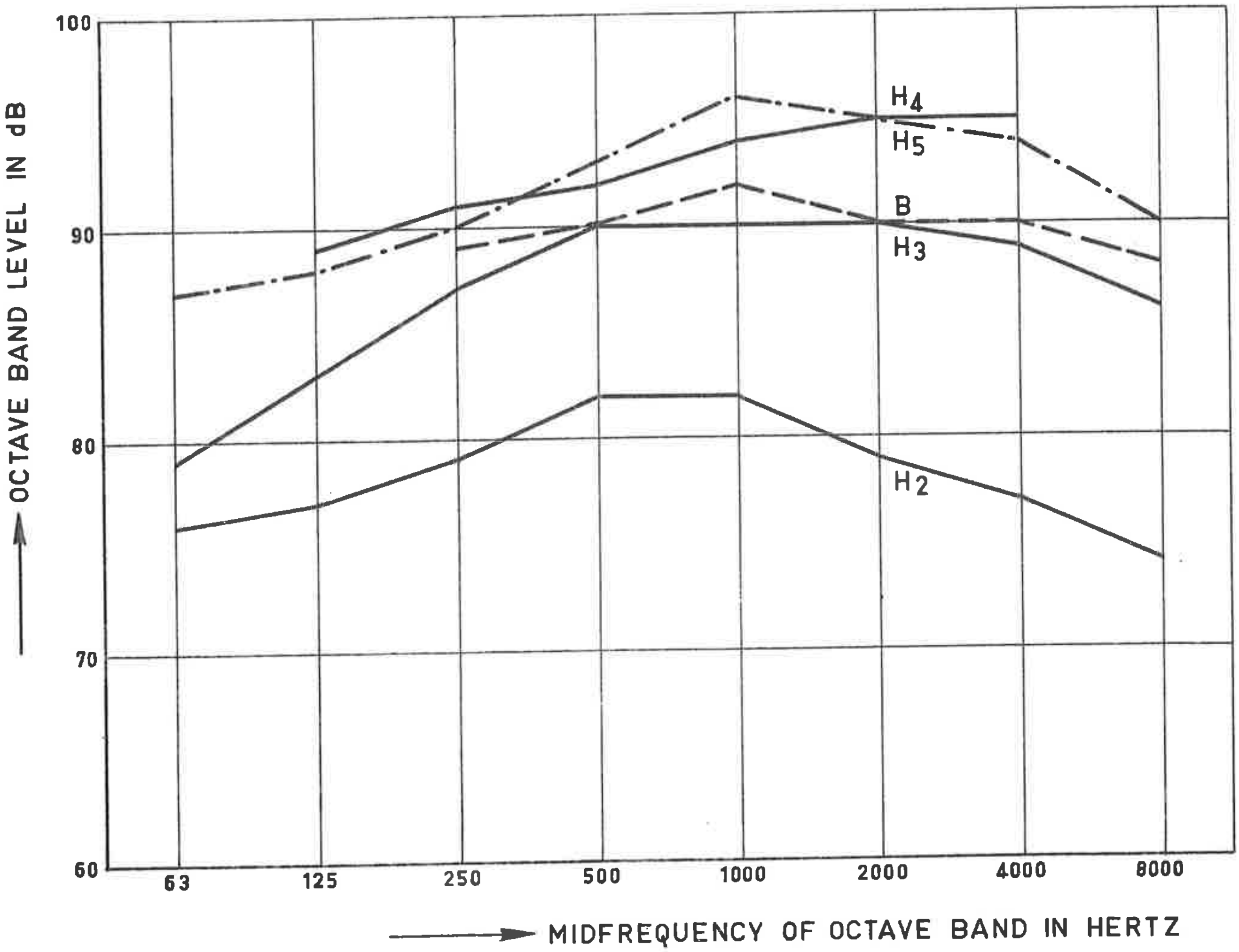
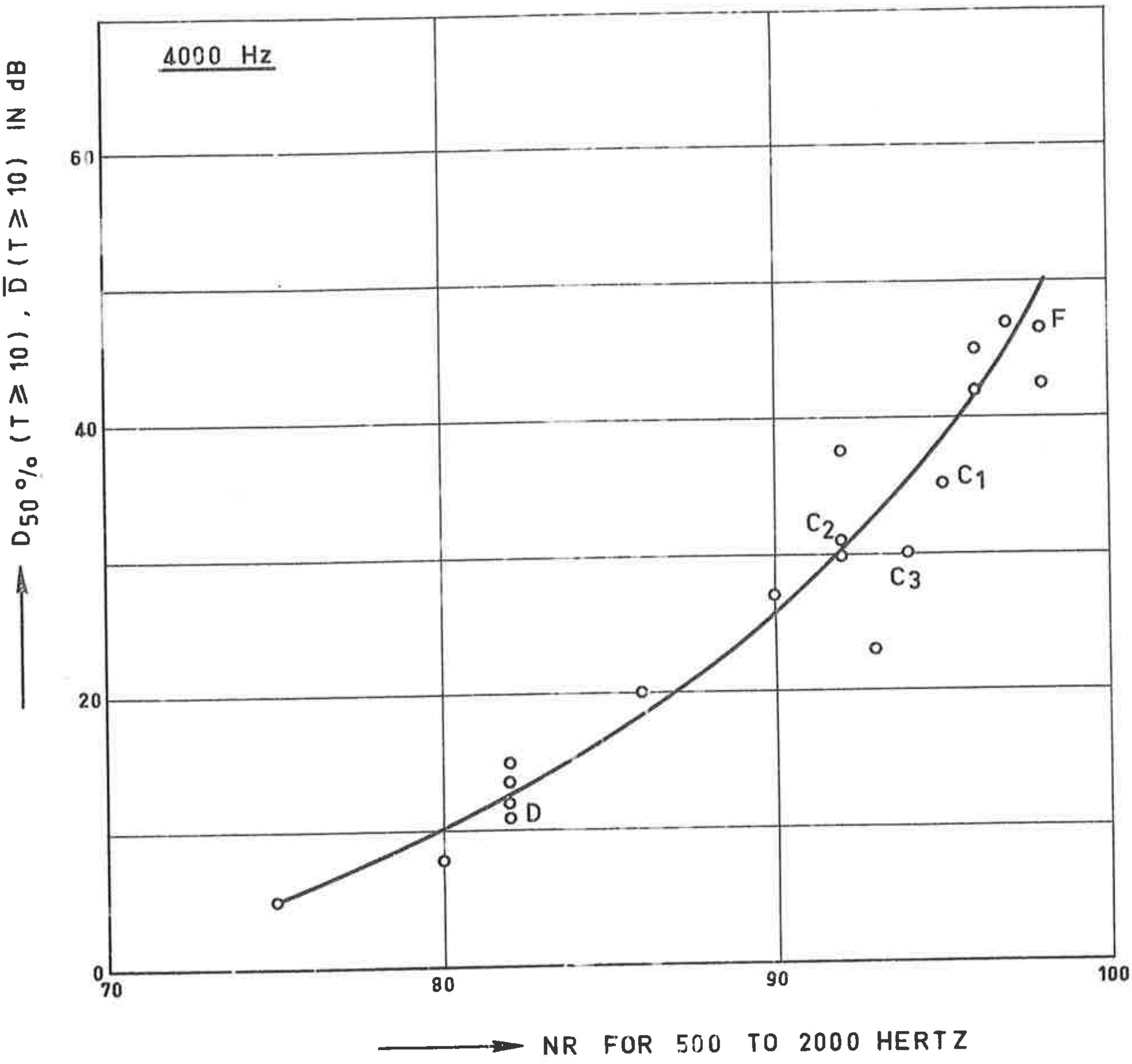
OCTAVE BAND SPECTRA



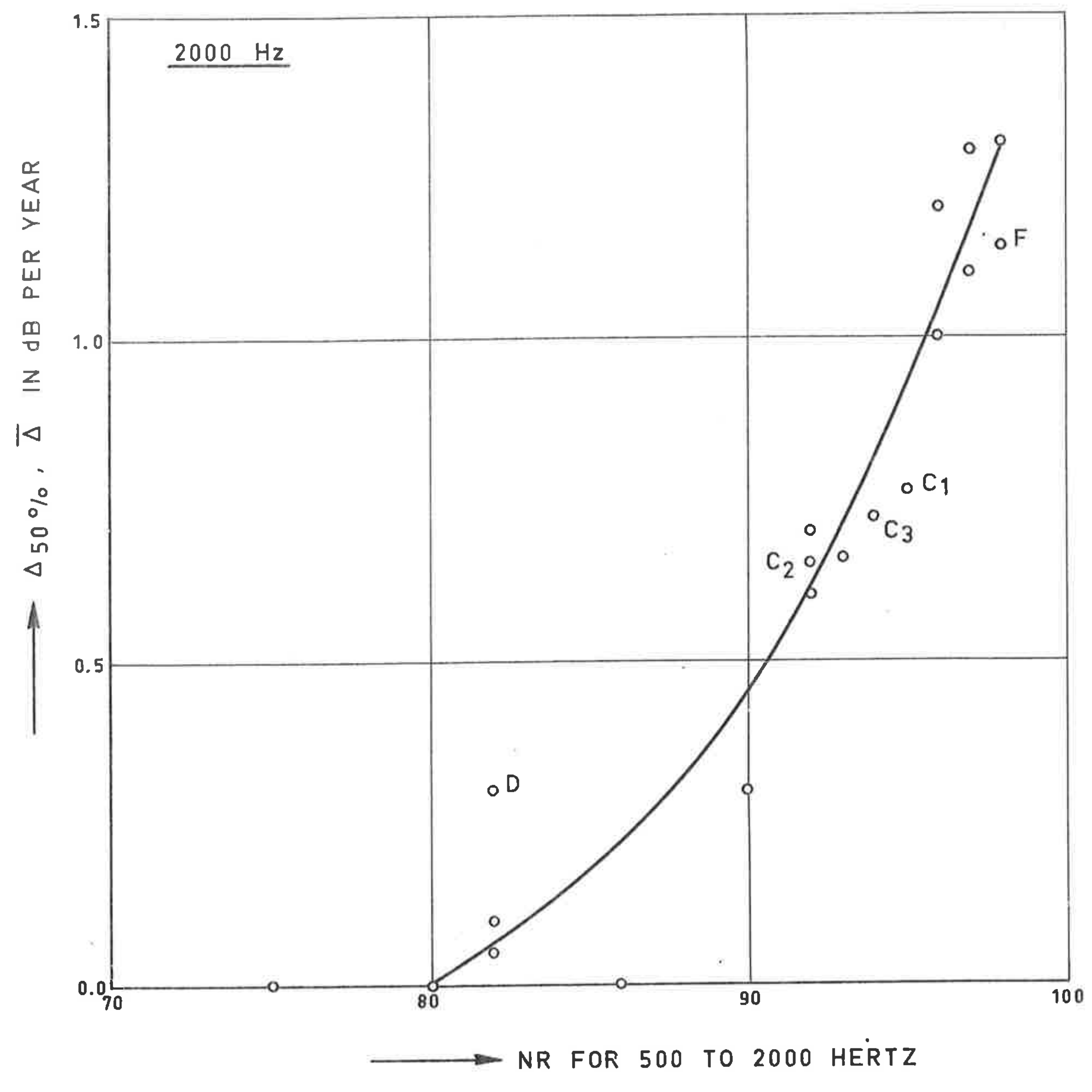


68 B 71	I G - T N O AFD. GELUID EN LICHT	R35 - 12

MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR AT LEAST 10 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.

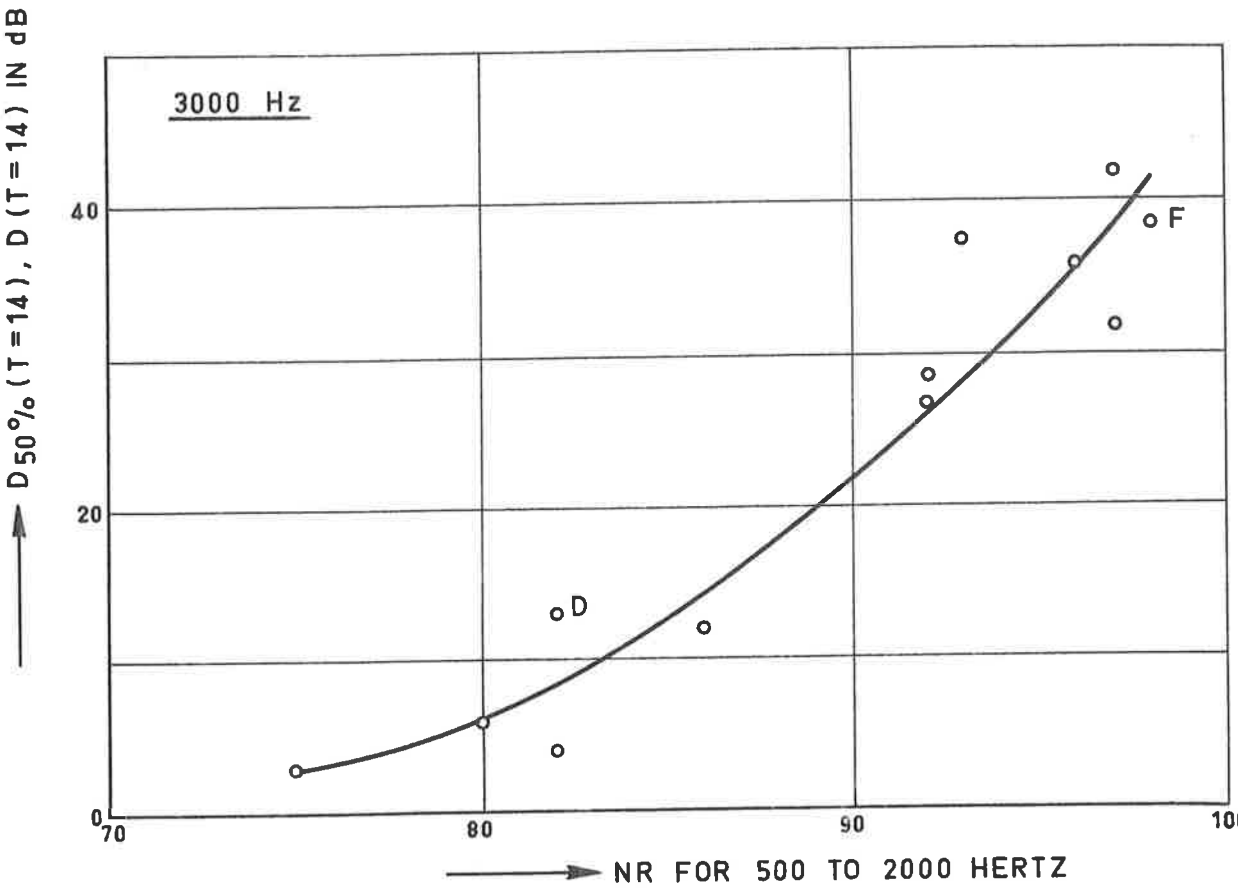


INCREASE IN MEDIAN AND MEAN HEARING LEVEL, CAUSED BY EXPOSURE TO NOISE, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.

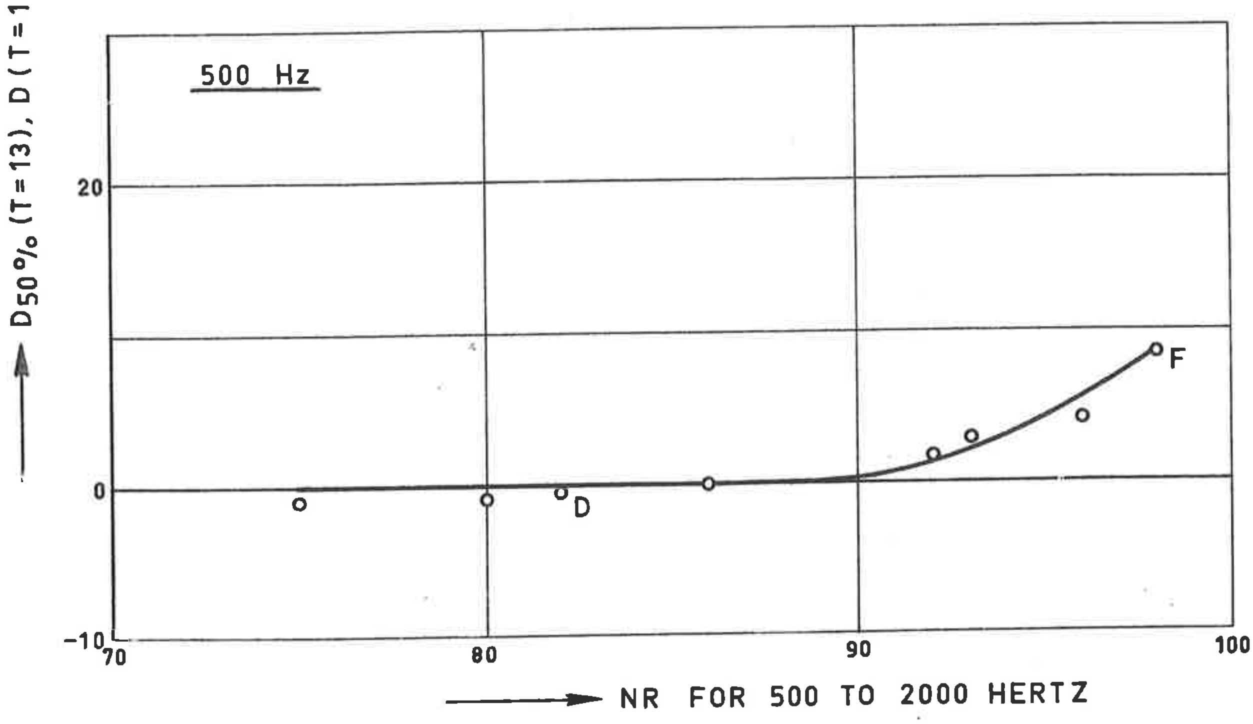


68B73	IG-TNO AFD. GELUID EN LICHT	R35-14

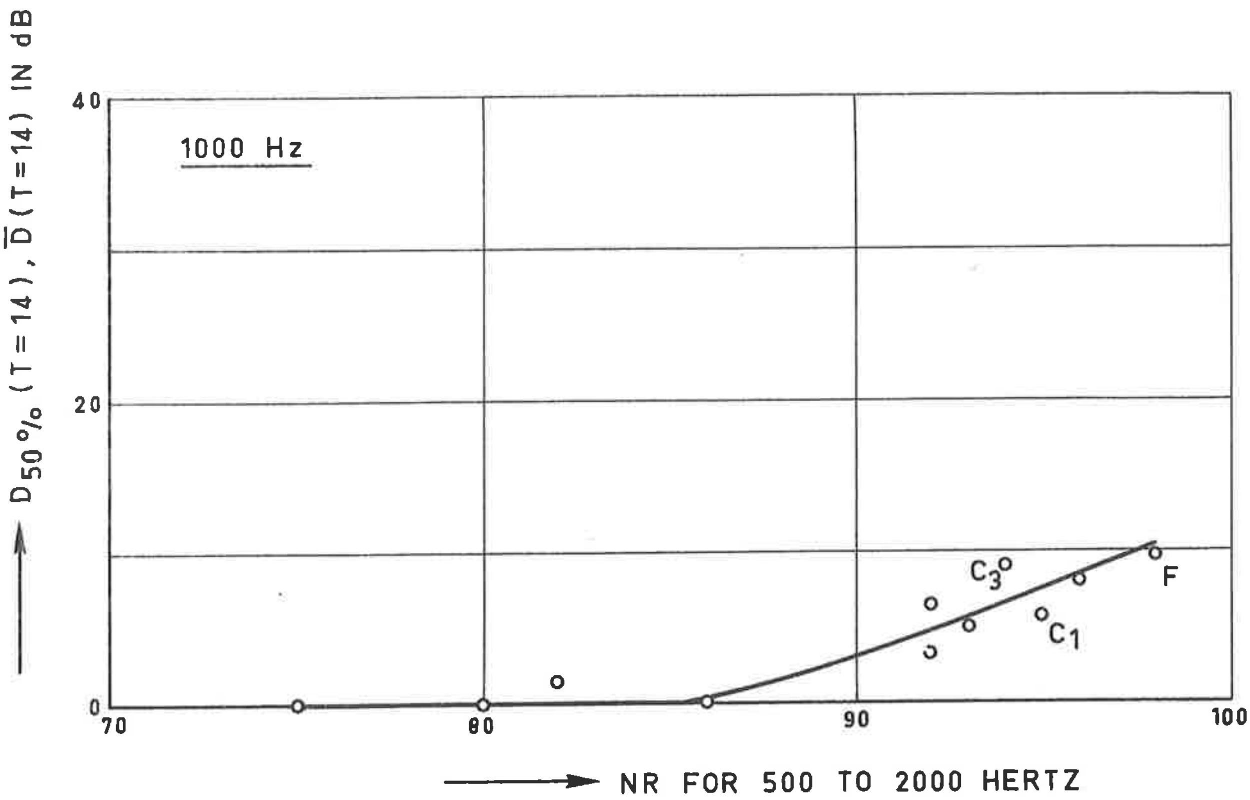
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



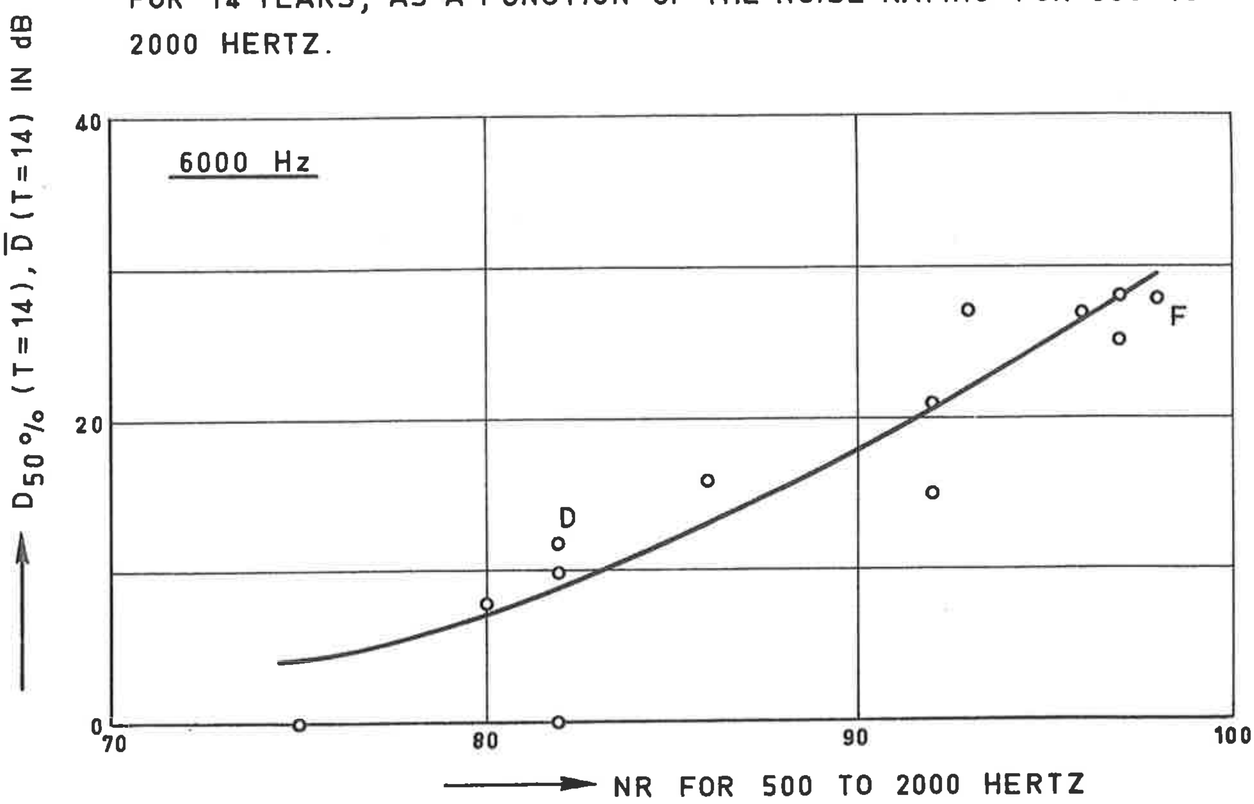
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 13 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



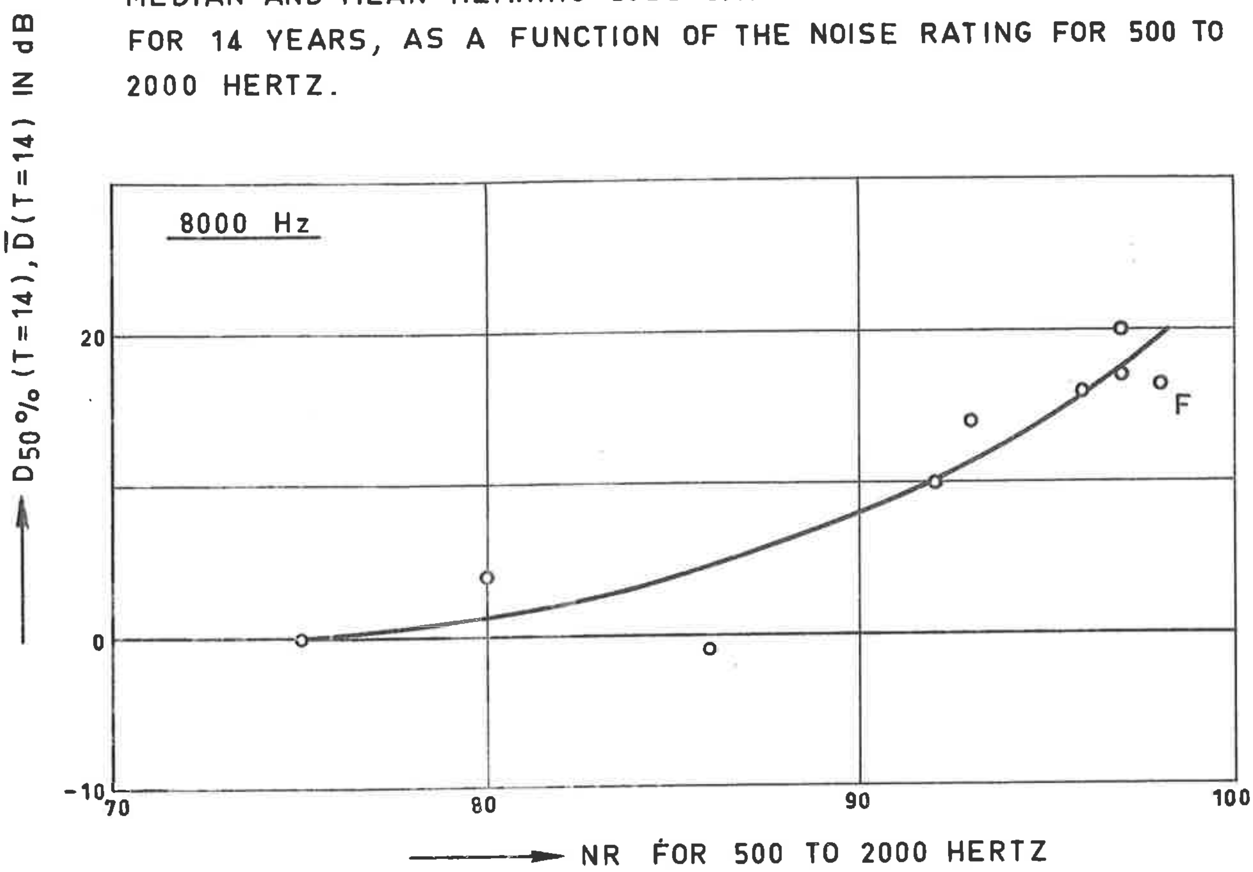
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



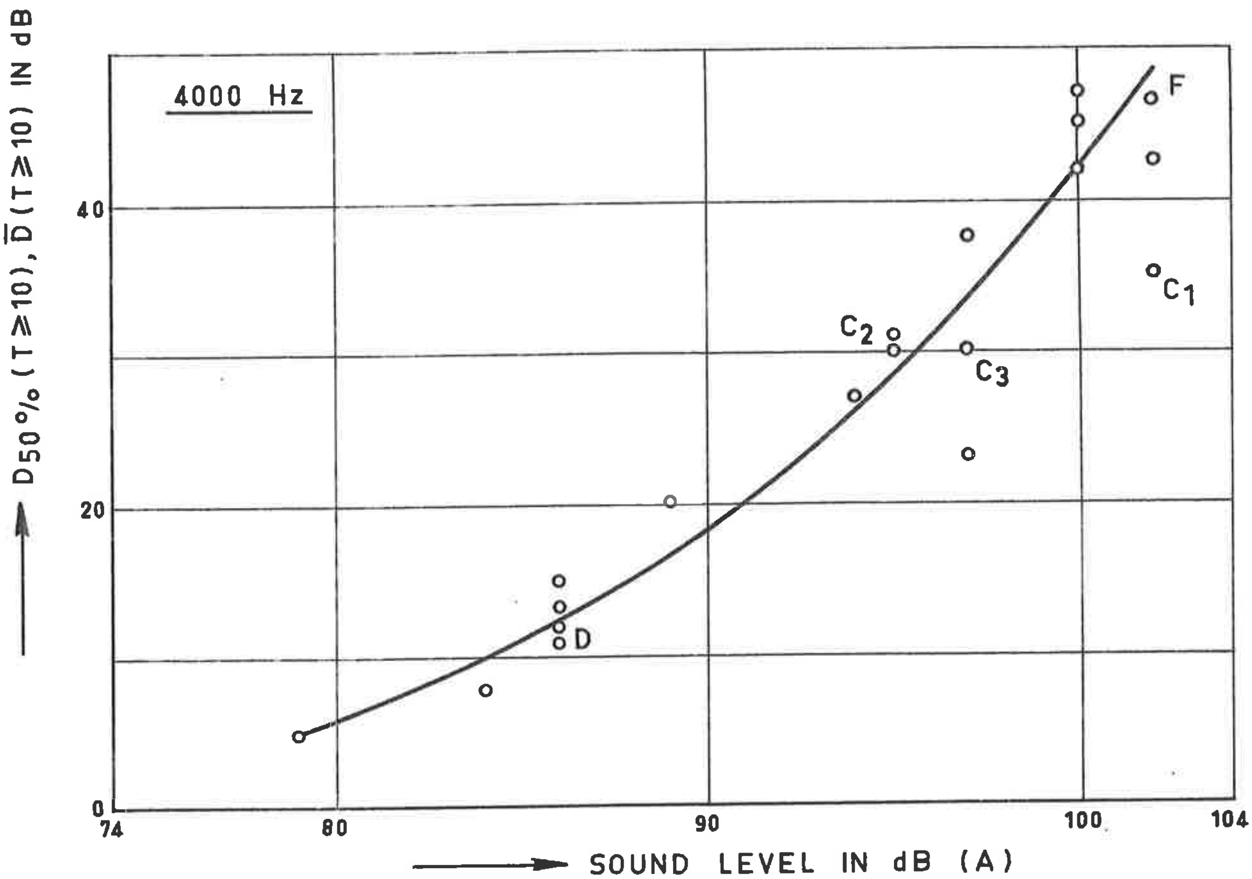
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



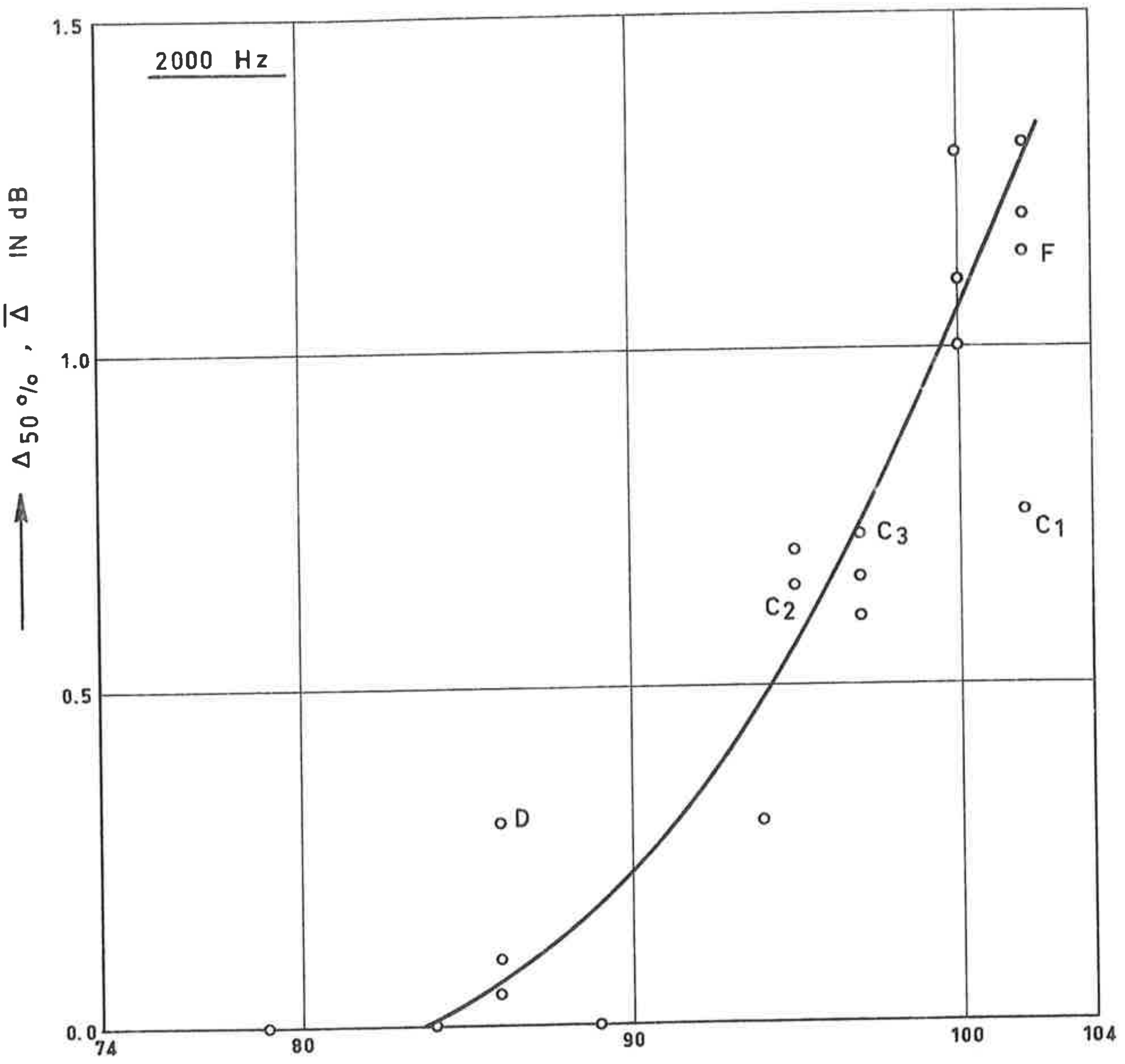
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



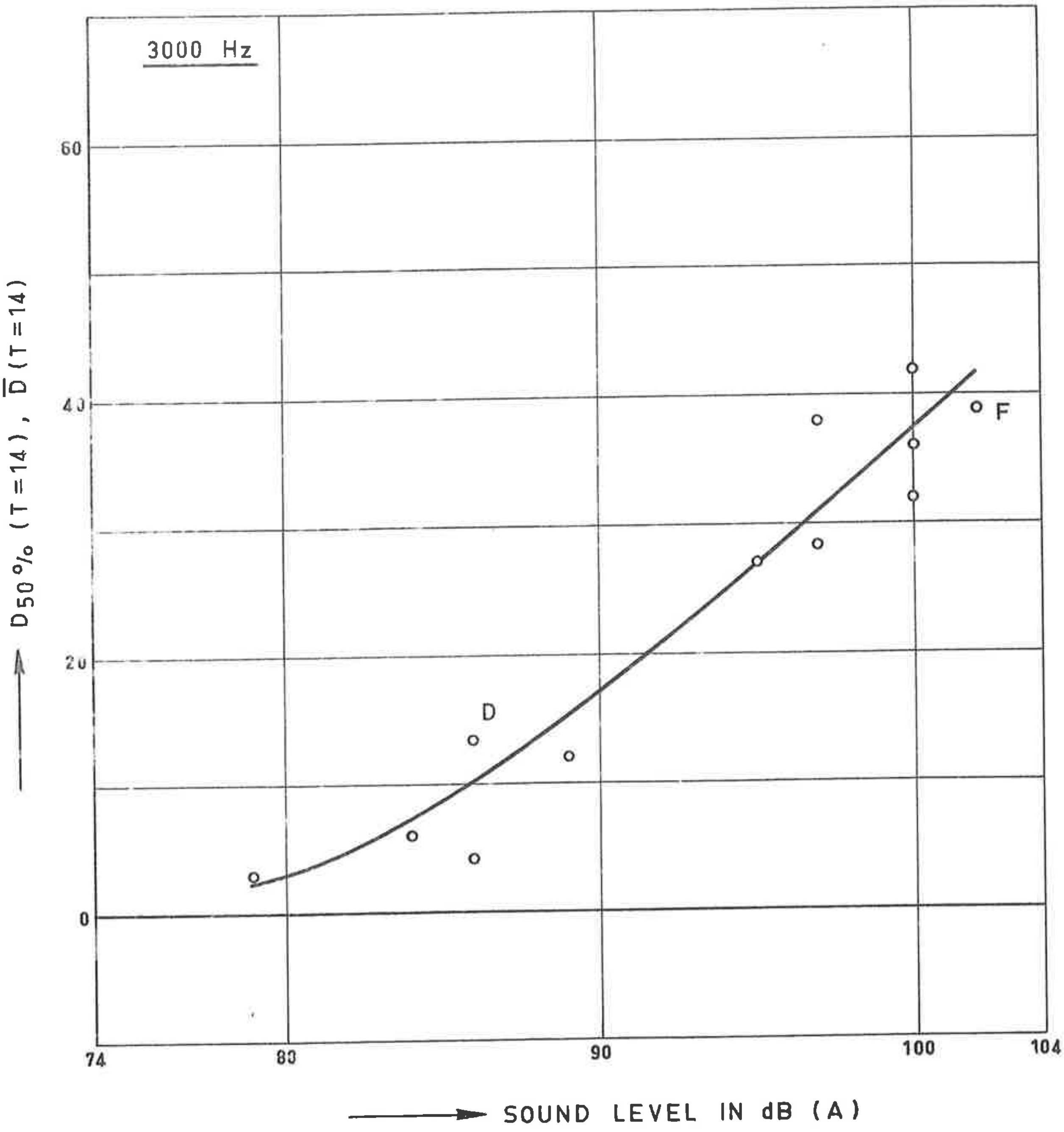
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR AT LEAST 10 YEARS, AS A FUNCTION OF SOUND LEVEL.



INCREASE IN MEDIAN AND MEAN HEARING LEVEL, CAUSED BY EXPOSURE TO NOISE, AS A FUNCTION OF SOUND LEVEL.

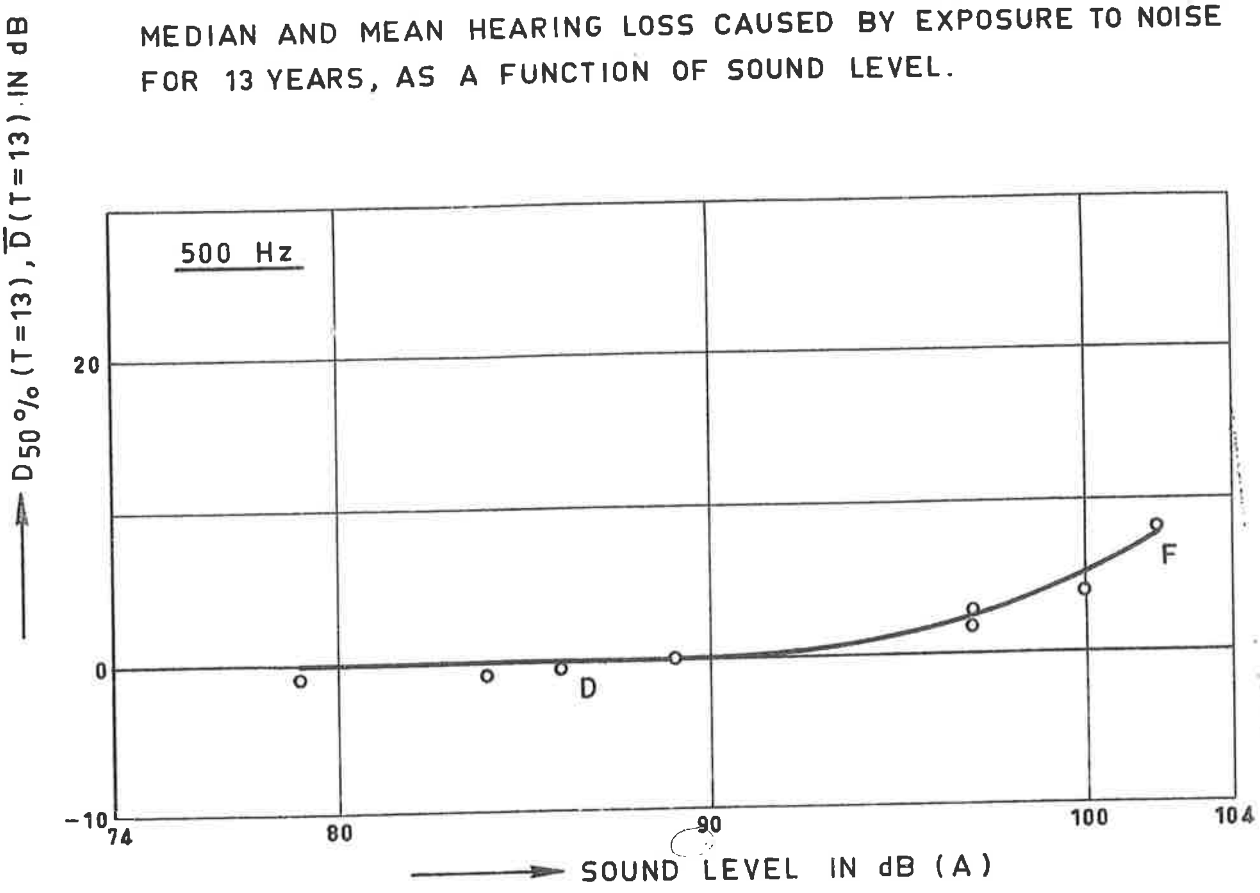


MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF SOUND LEVEL.

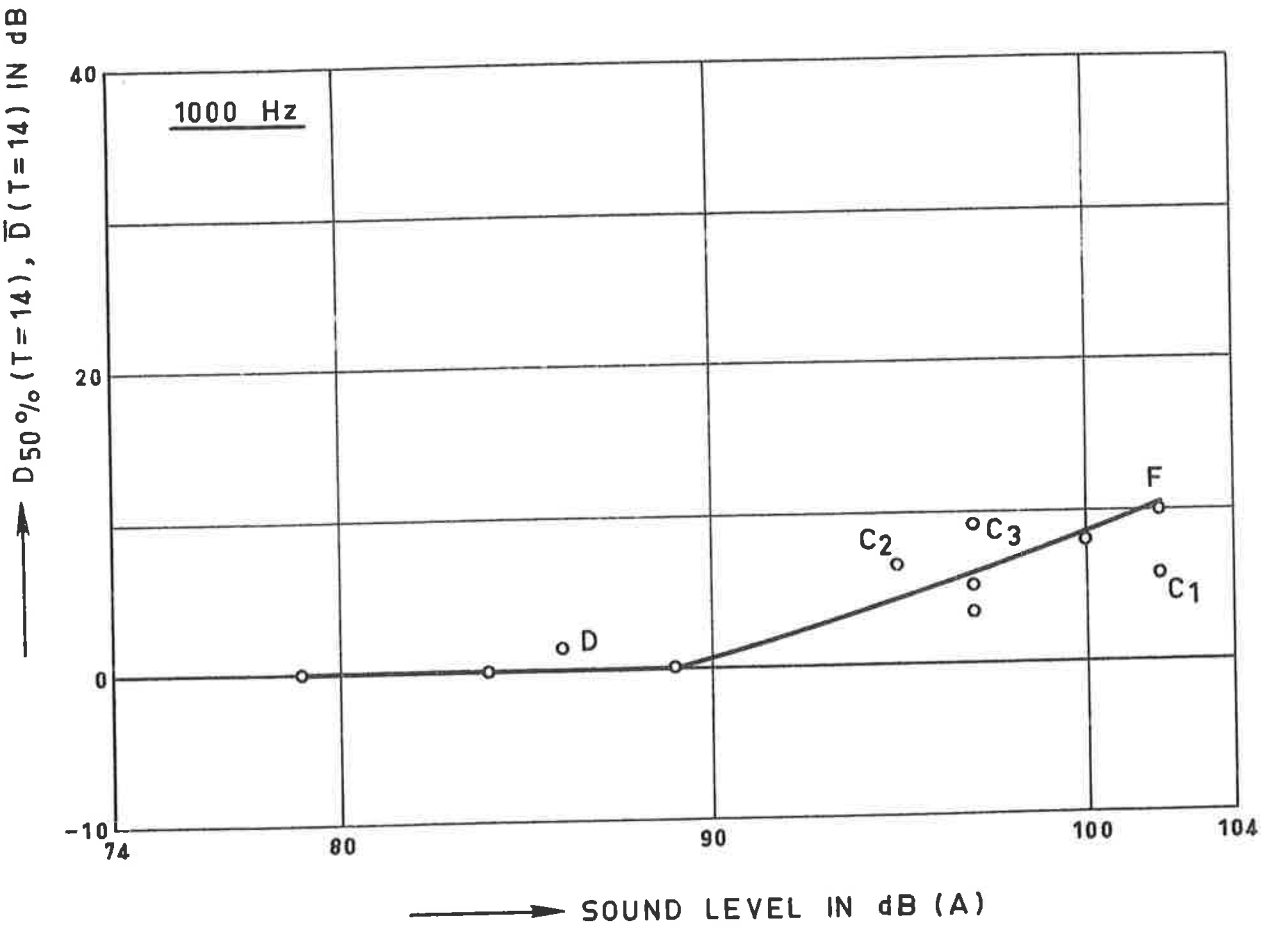


68 B 78	IG - TNO AFD. GELUID EN LICHT	R35 - 22

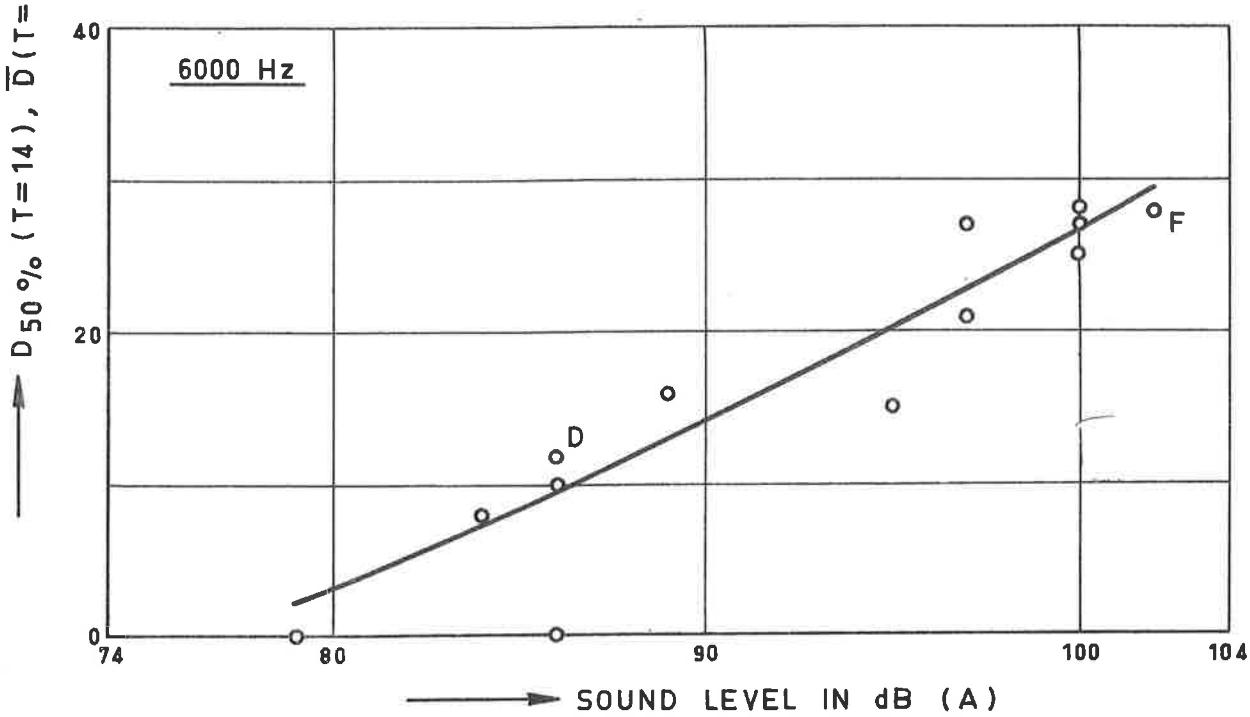
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 13 YEARS, AS A FUNCTION OF SOUND LEVEL.



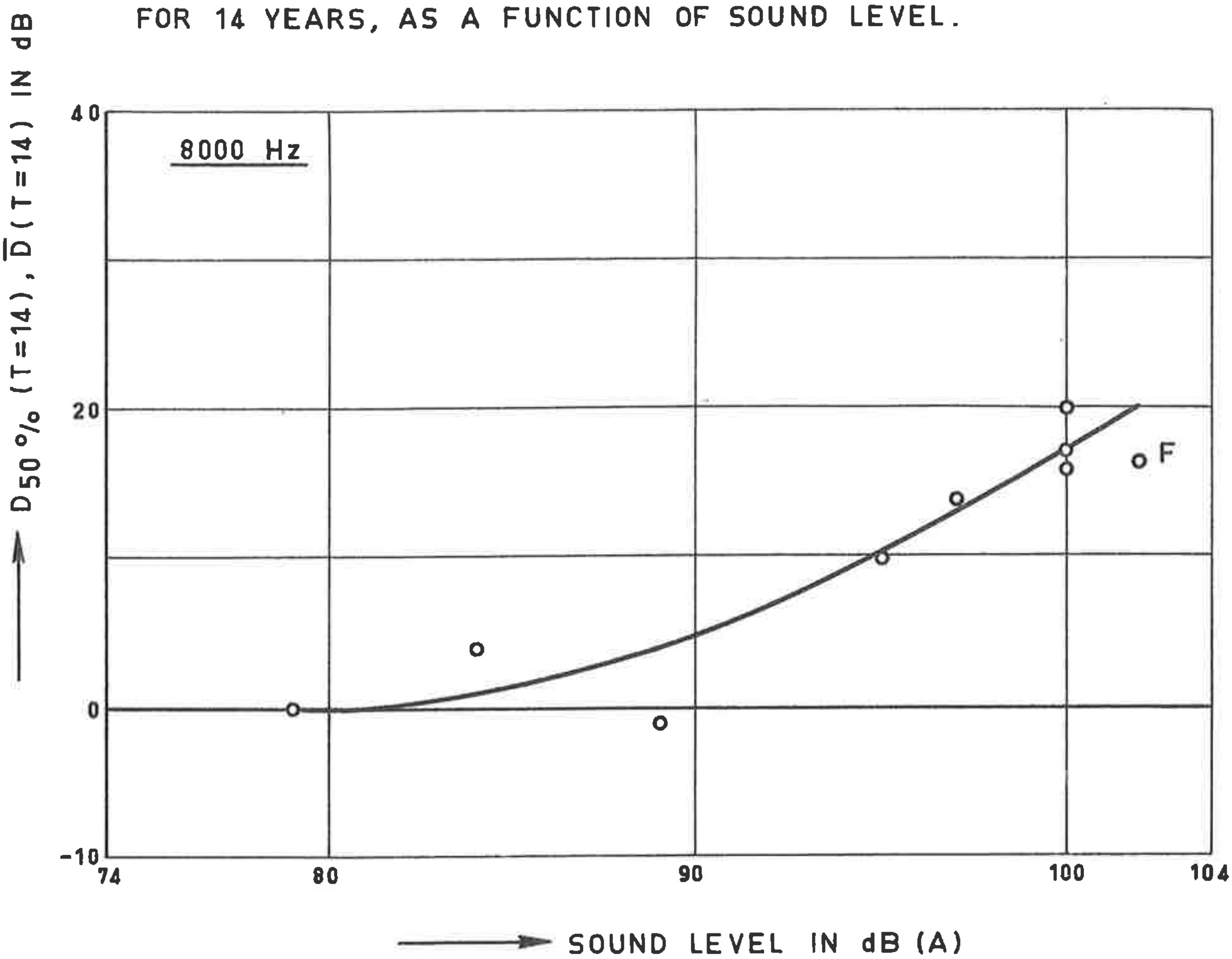
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF SOUND LEVEL.



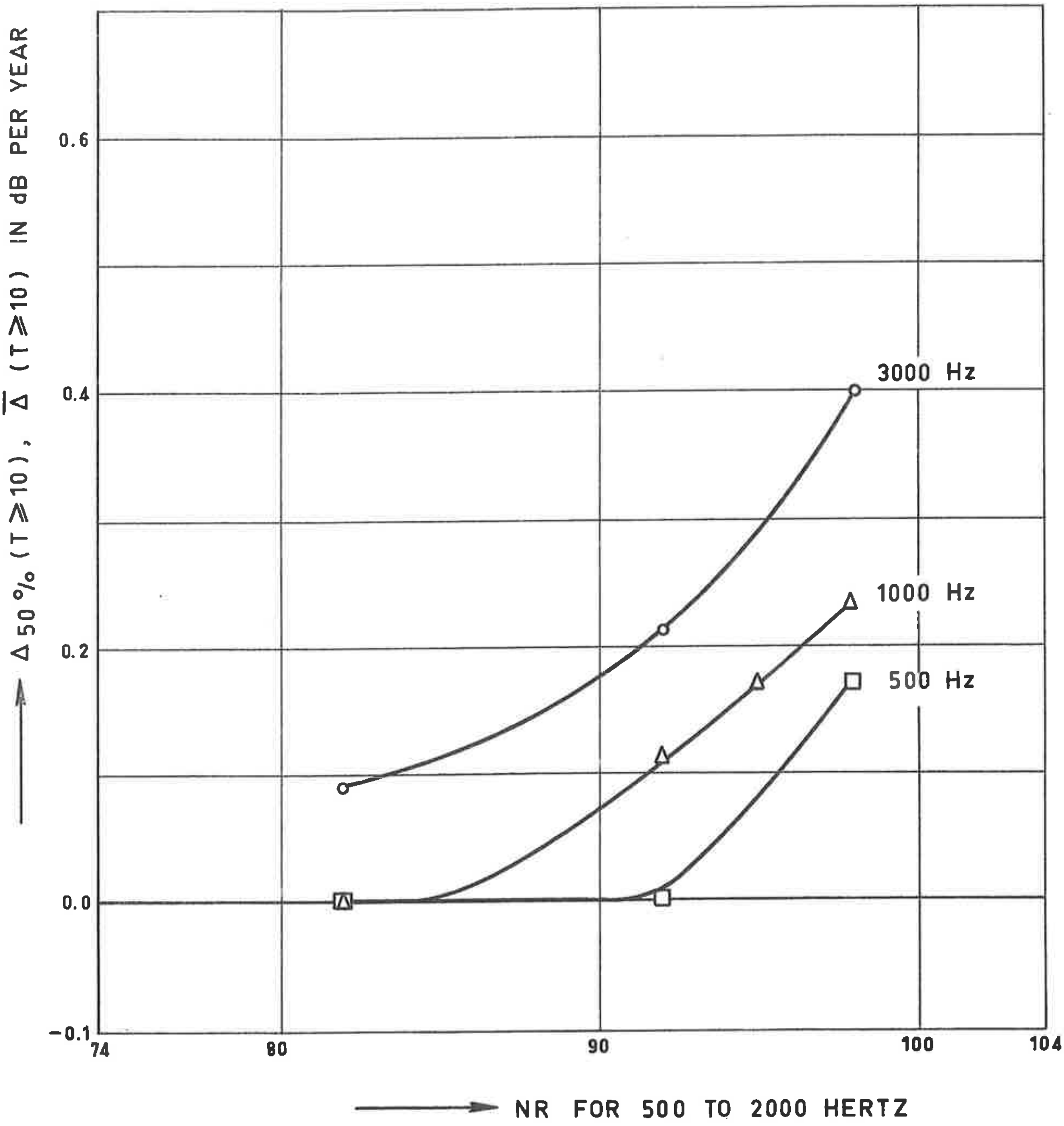
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF SOUND LEVEL.



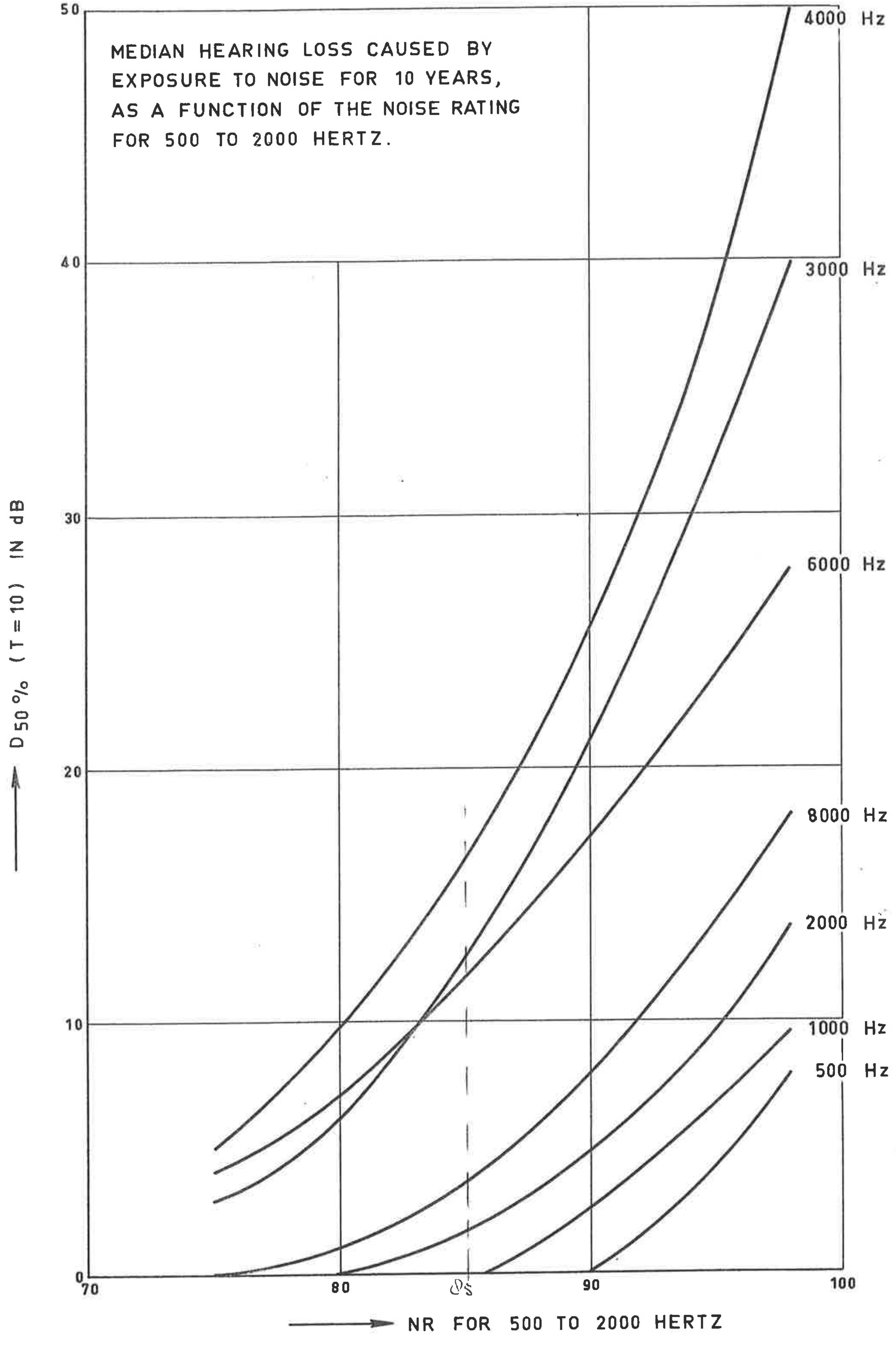
MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 14 YEARS, AS A FUNCTION OF SOUND LEVEL.



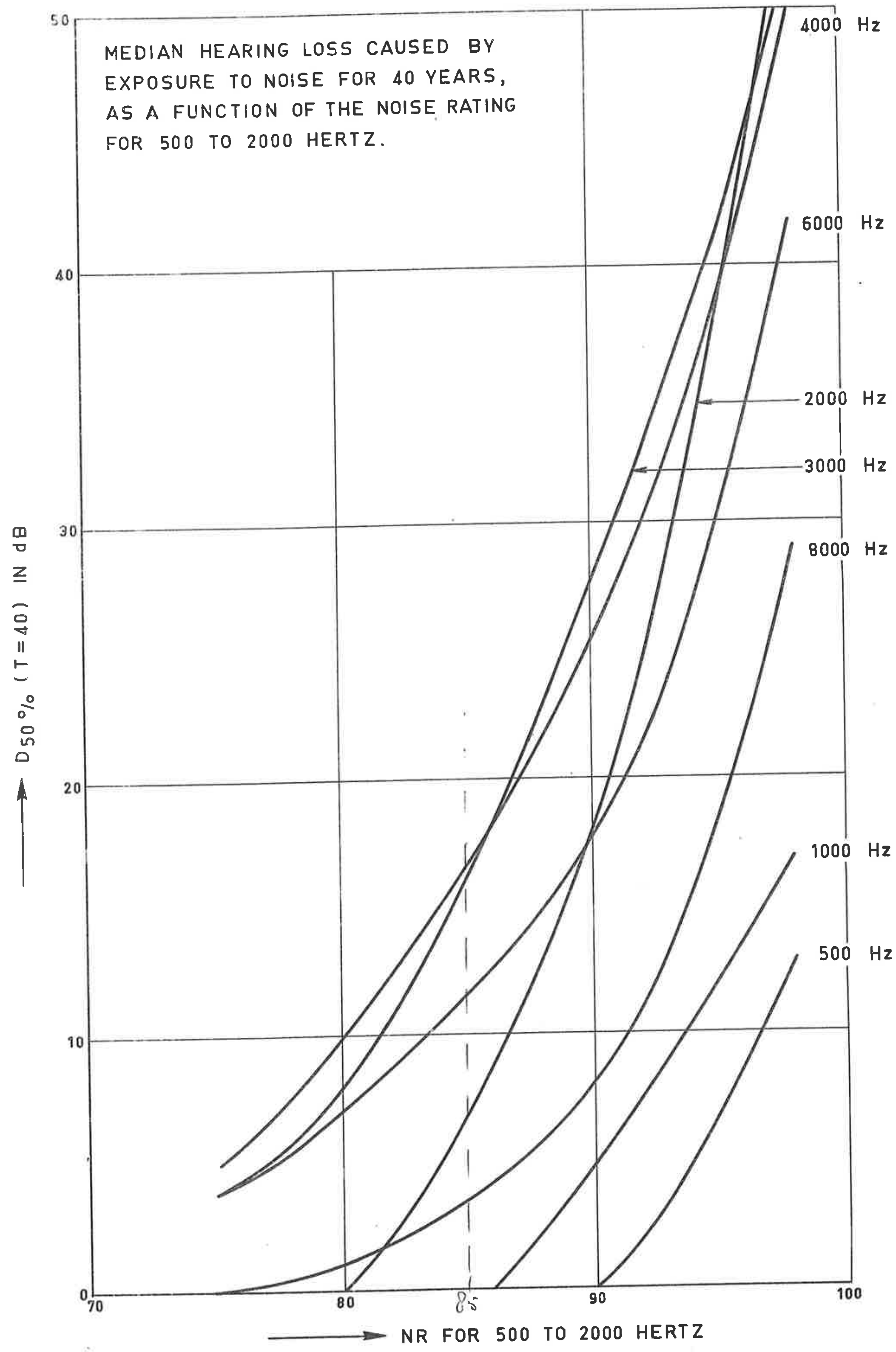
INCREASE IN MEDIAN AND MEAN NOISE-INDUCED HEARING LOSS AT EXPOSURE TIMES OF AT LEAST 10 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.



68 B 81	I G - T N O AFD. GELUID EN LICHT	R35 - 27



68 B 82	IG - TNO AFD. GELUID EN LICHT	R35 - 28

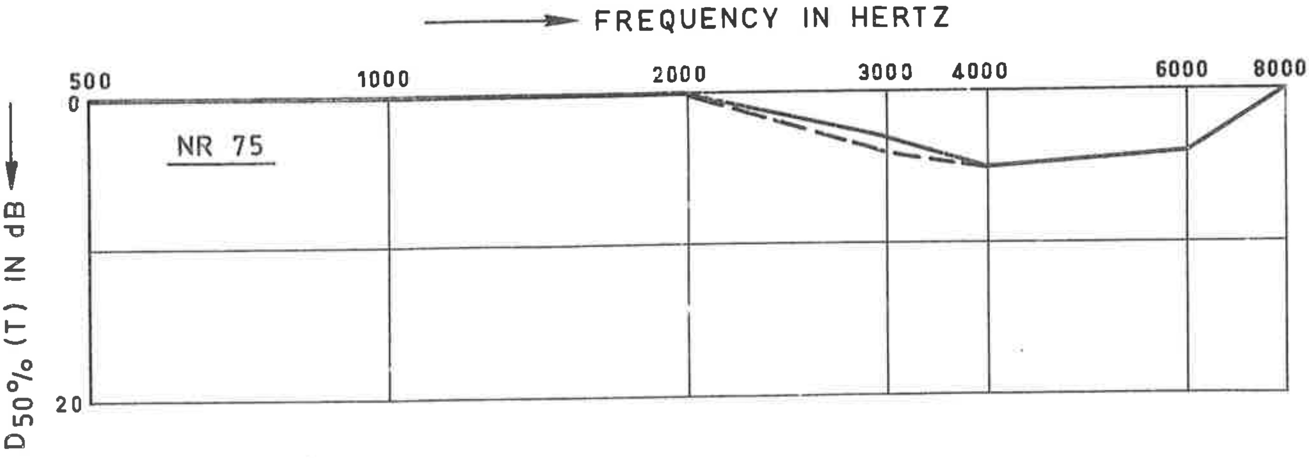


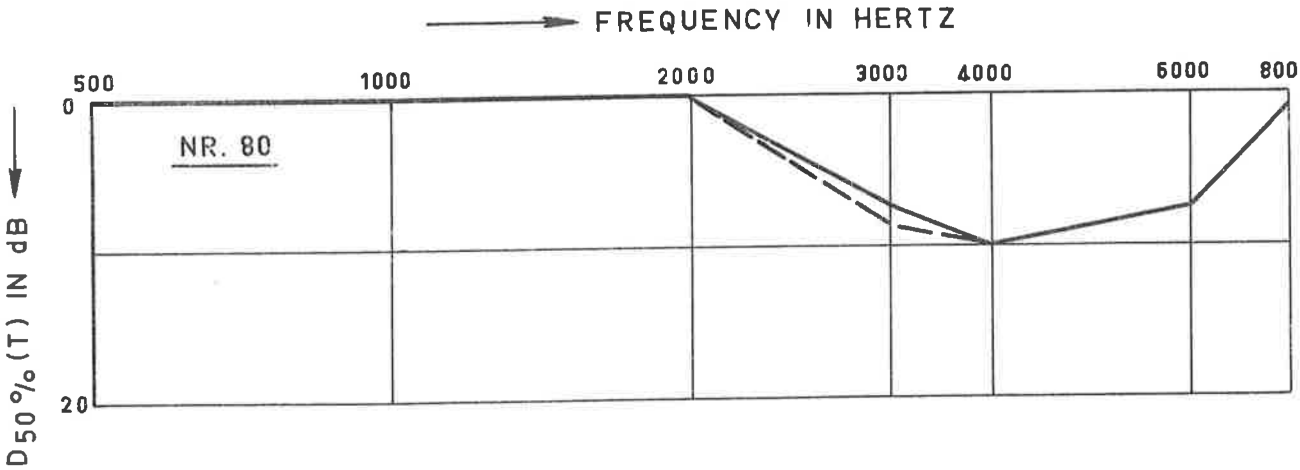
68 B 83	IG-TNO AFD. GELUID EN LICHT	R35-29

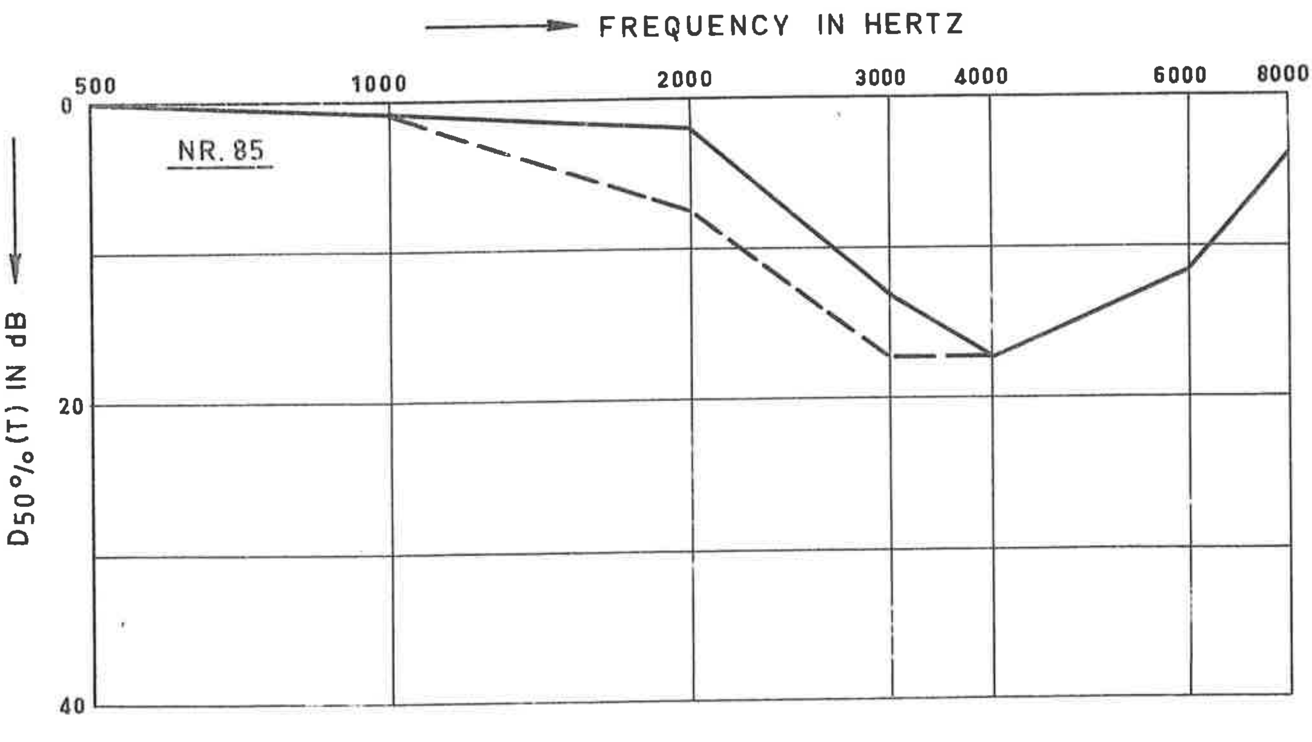
MEDIAN NOISE - INDUCED HEARING LOSS, AS A FUNCTION OF FREQUENCY.

——————— EXPOSURE TIME : 10 YEARS

— — — — — EXPOSURE TIME : 40 YEARS

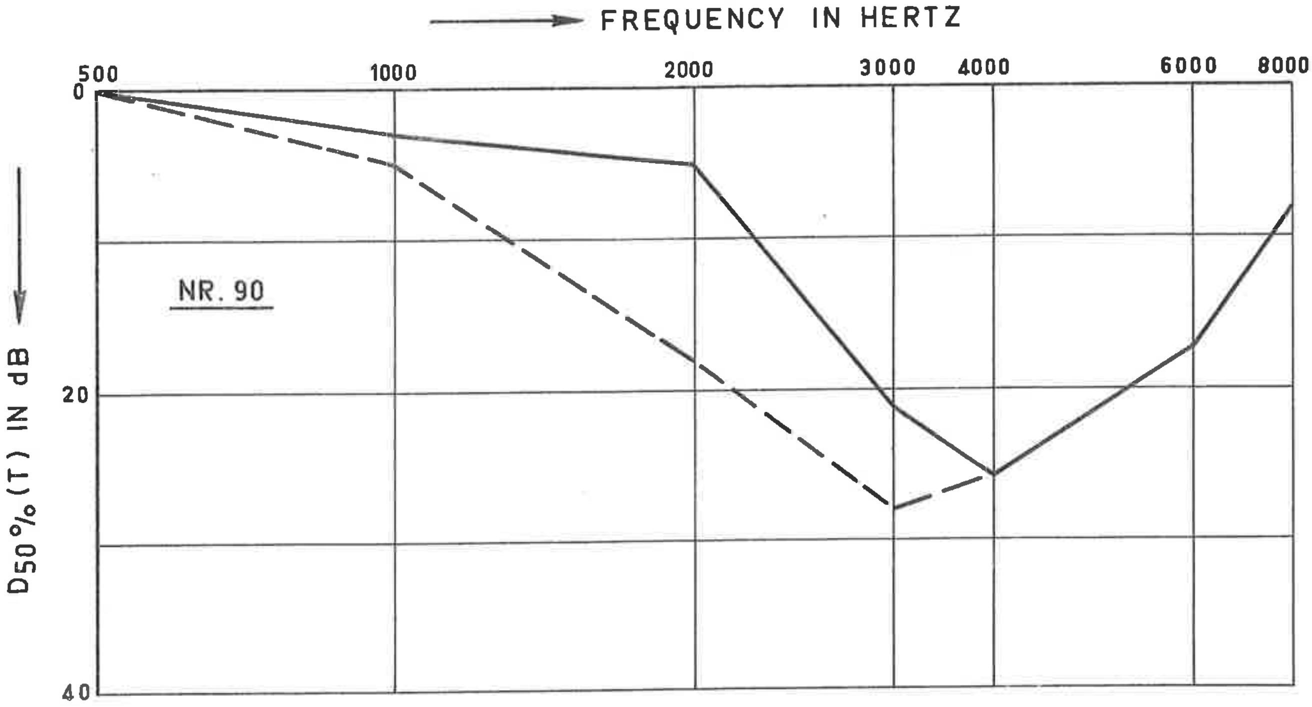


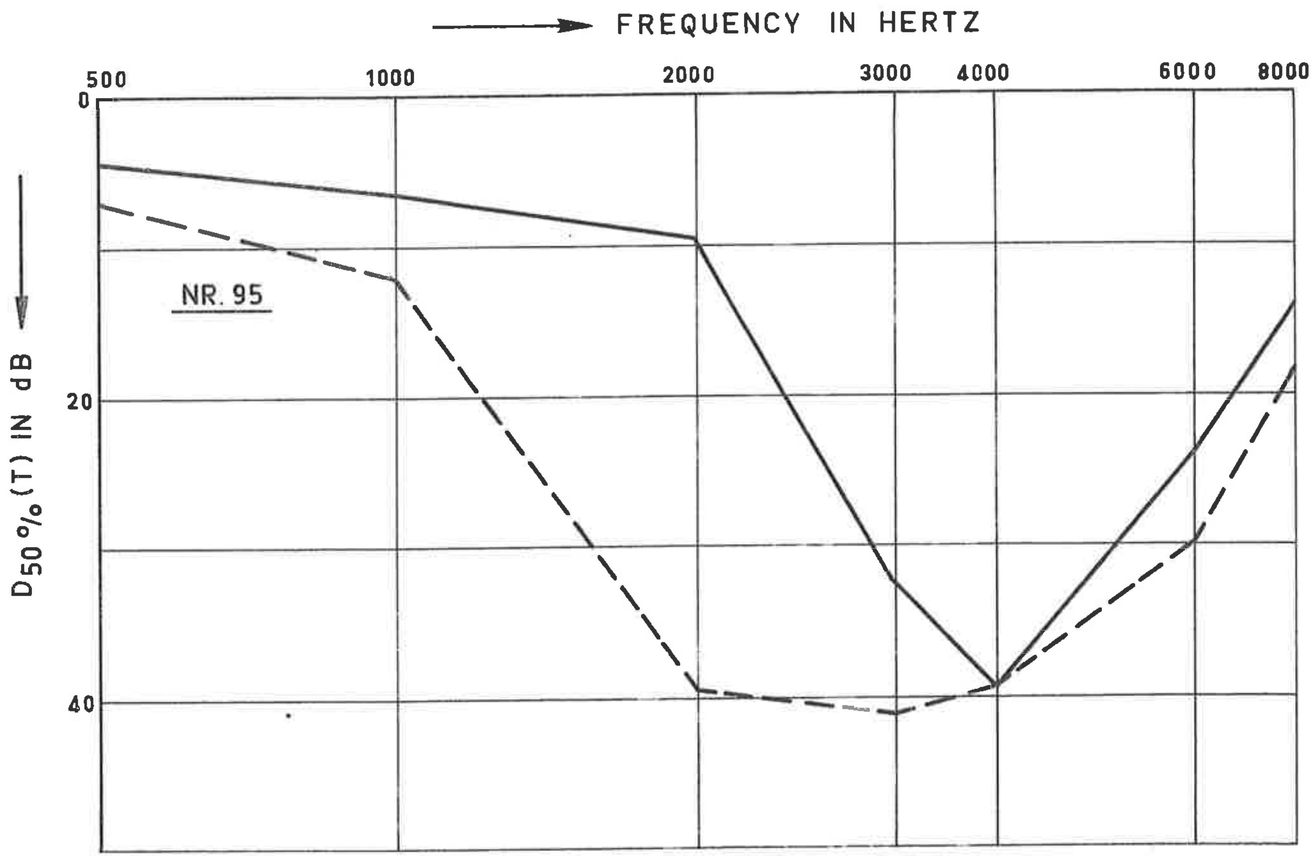




MEDIAN NOISE-INDUCED HEARING LOSS, AS A FUNCTION OF FREQUENCY.

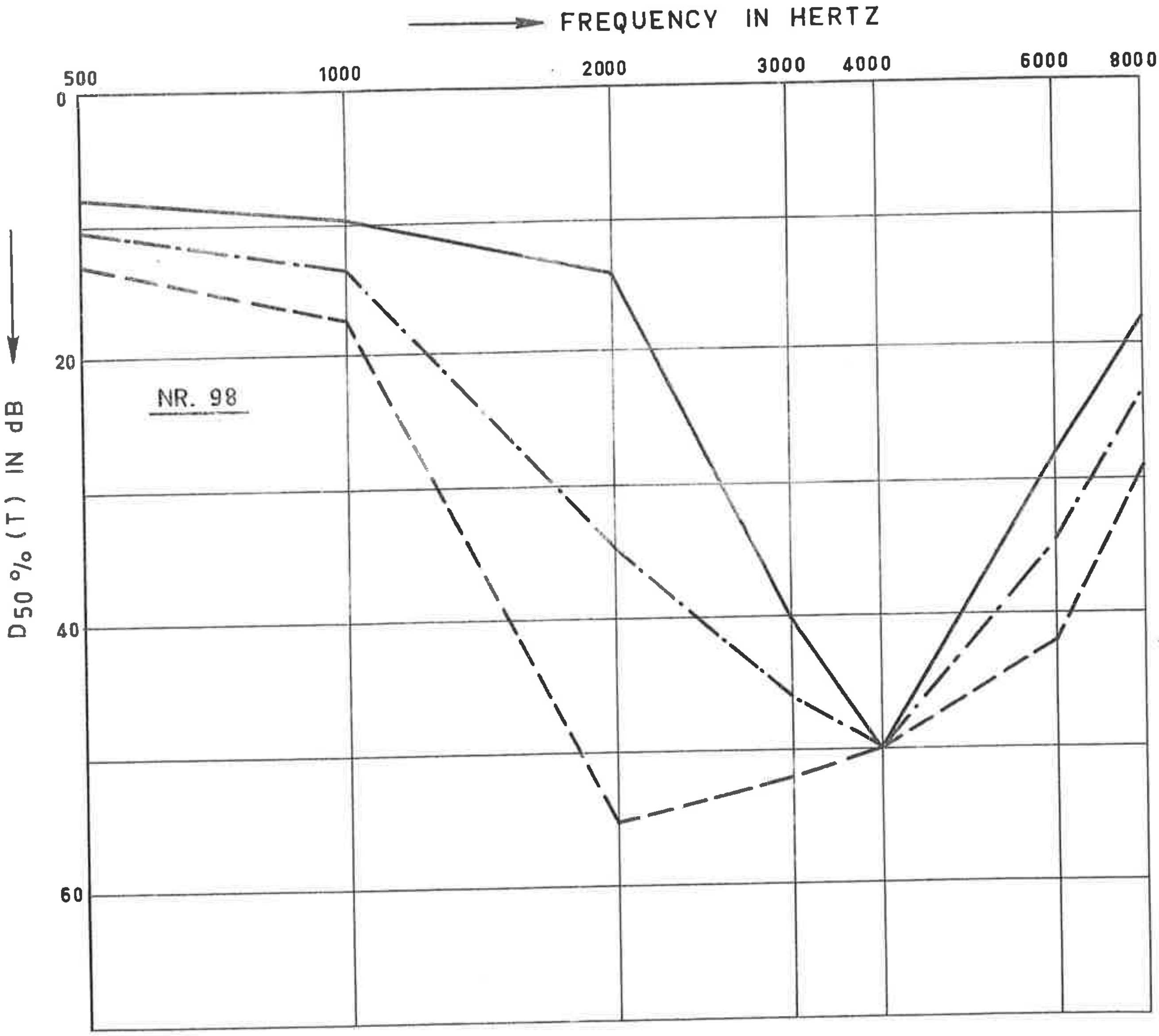
——— EXPOSURE TIME : 10 YEARS
– – – EXPOSURE TIME : 40 YEARS



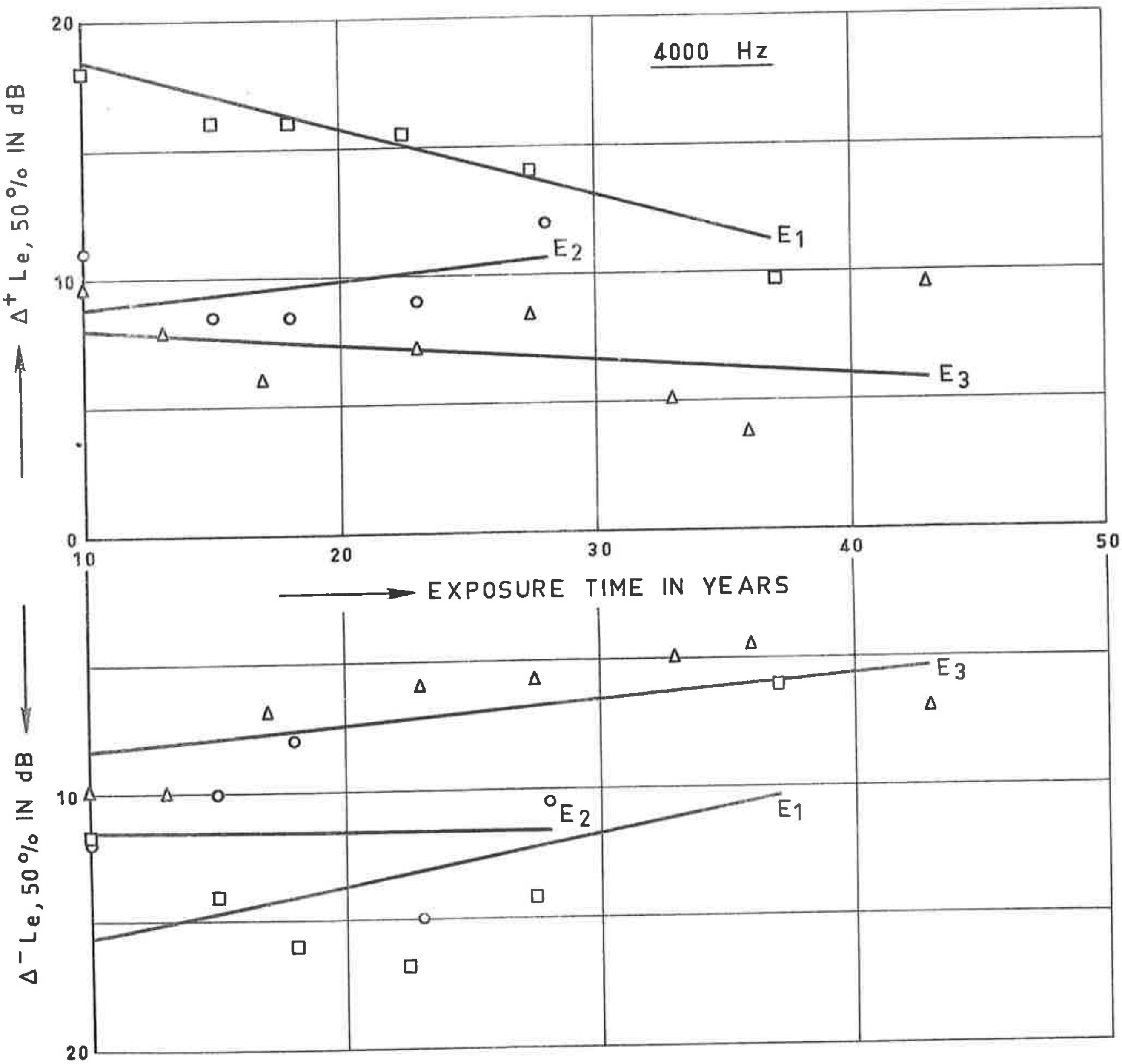


MEDIAN NOISE-INDUCED HEARING LOSS, AS A FUNCTION OF FREQUENCY.

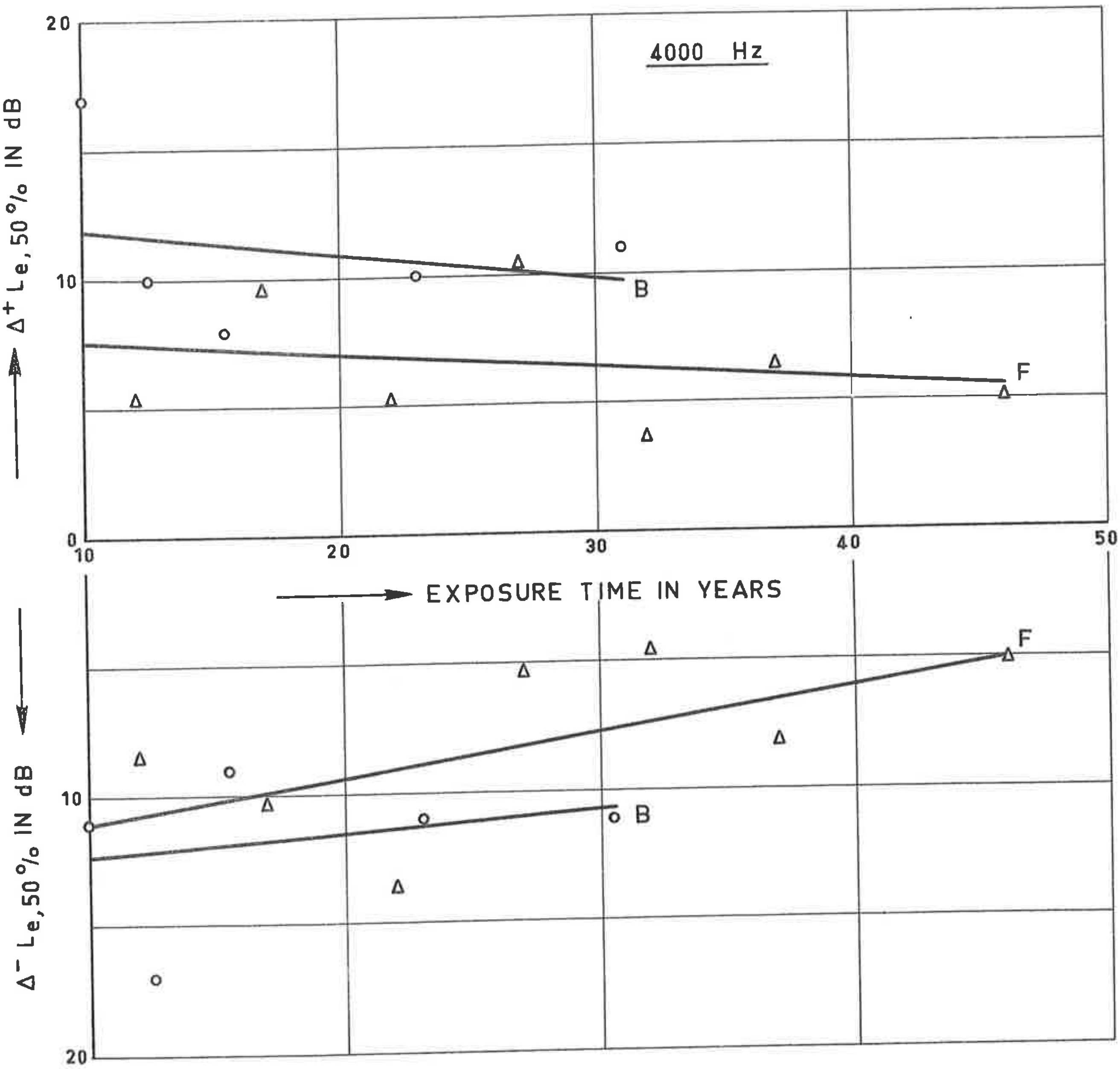
——— EXPOSURE TIME : 10 YEARS
—·—·— EXPOSURE TIME : 25 YEARS
— — — EXPOSURE TIME : 40 YEARS



THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME

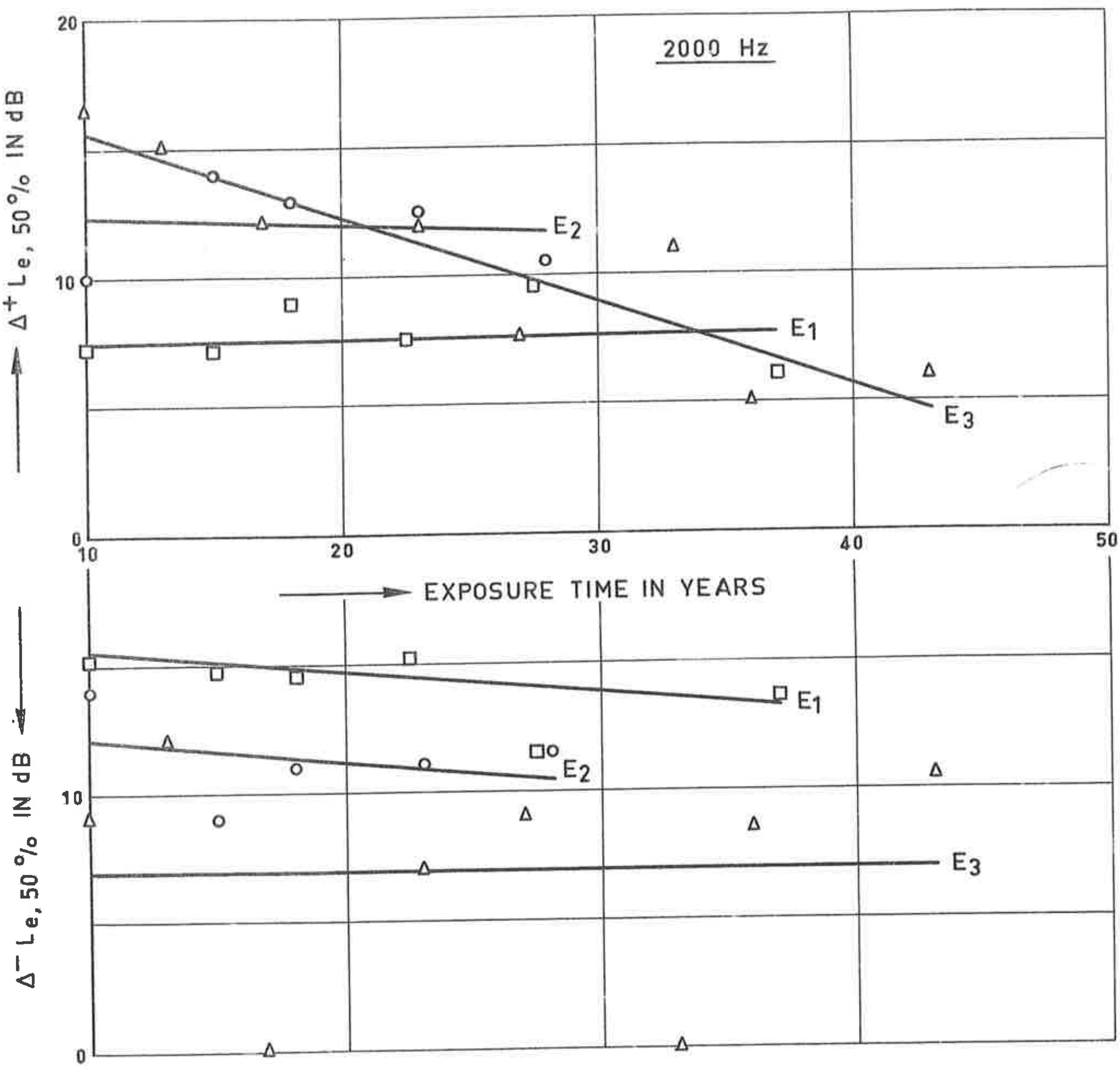


THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.

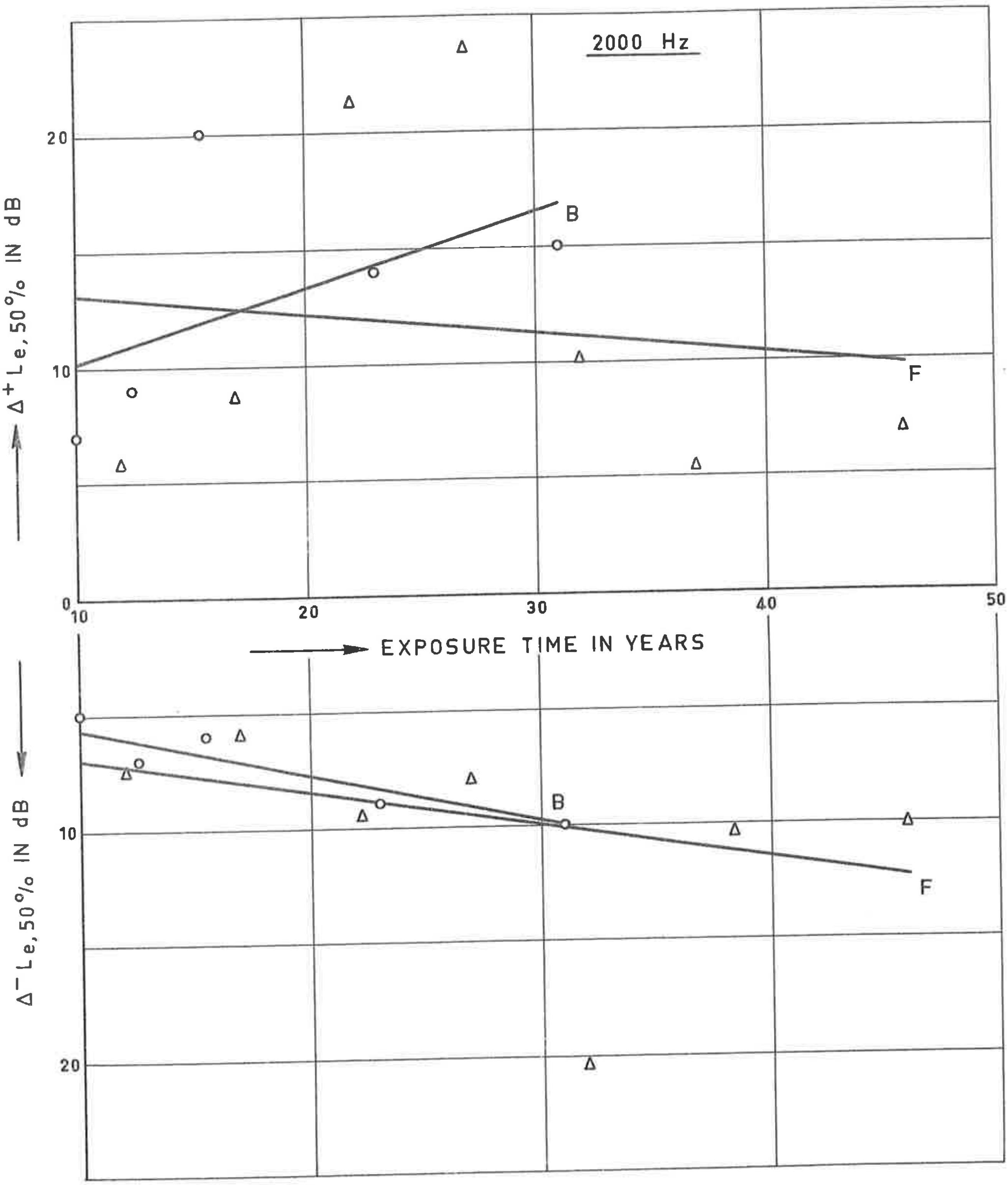


68 B 88	I G - T N O AFD. GELUID EN LICHT	R 35 - 34

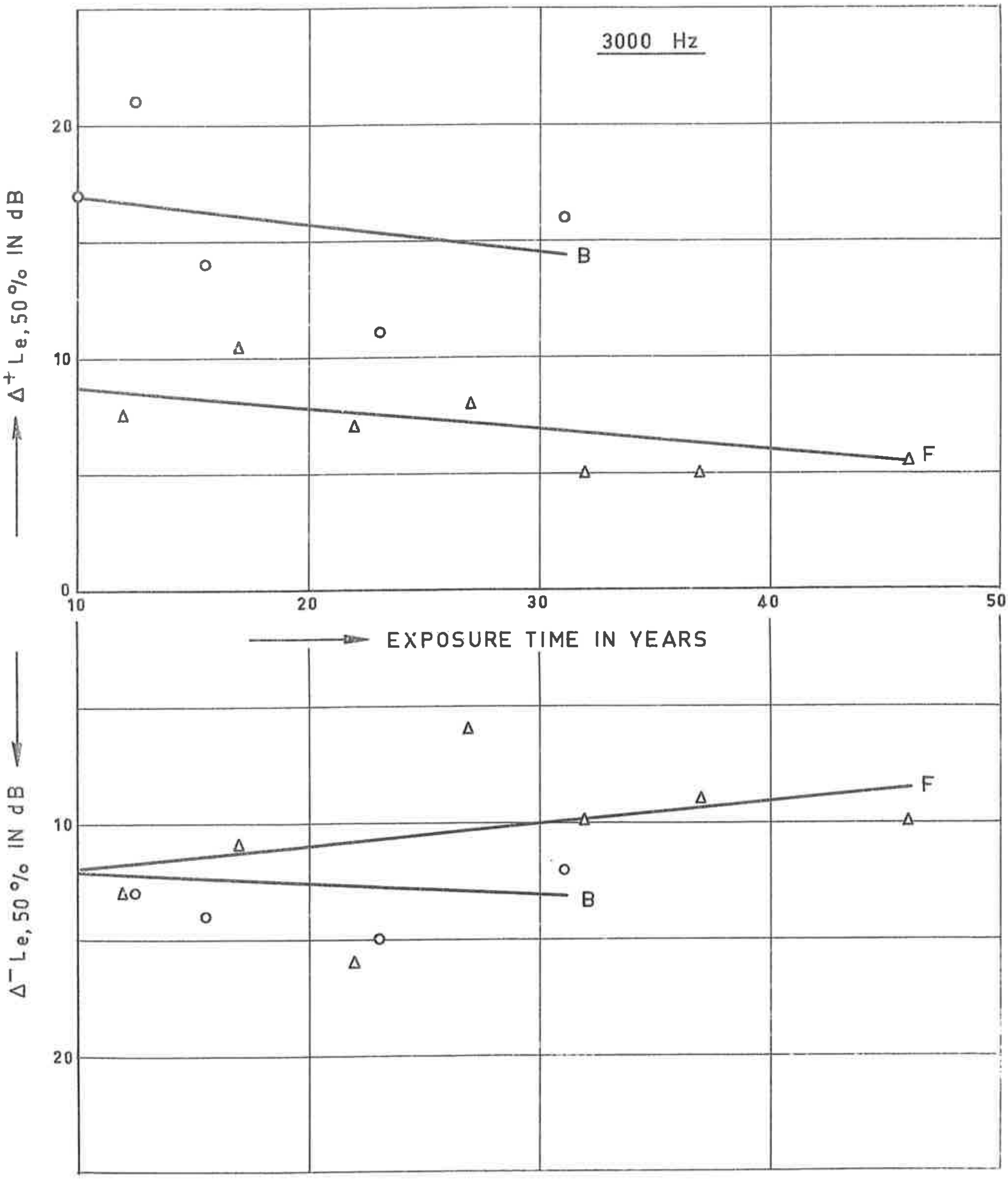
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



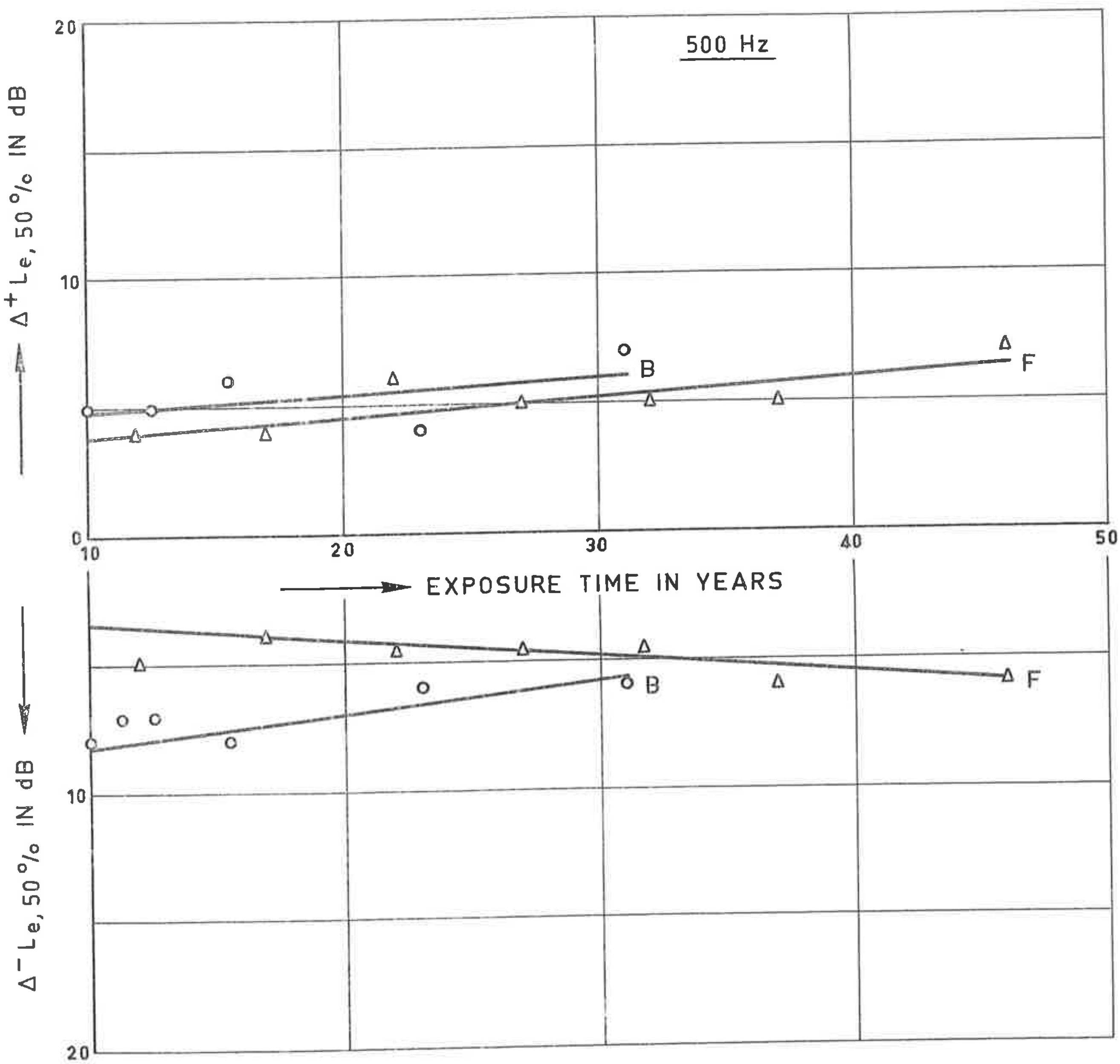
THE DIFFERENCE ($\Delta^{+} L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^{-} L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



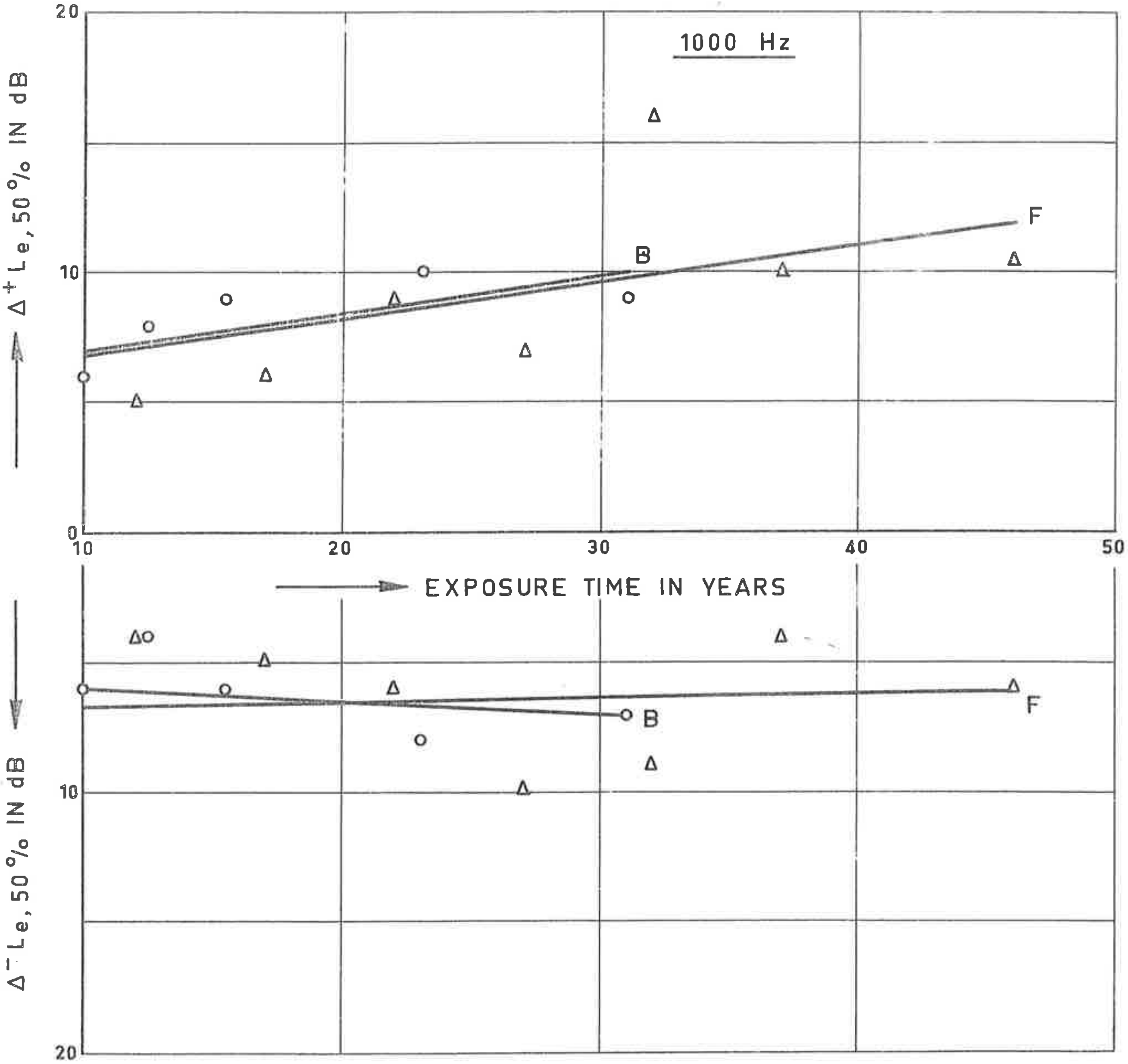
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



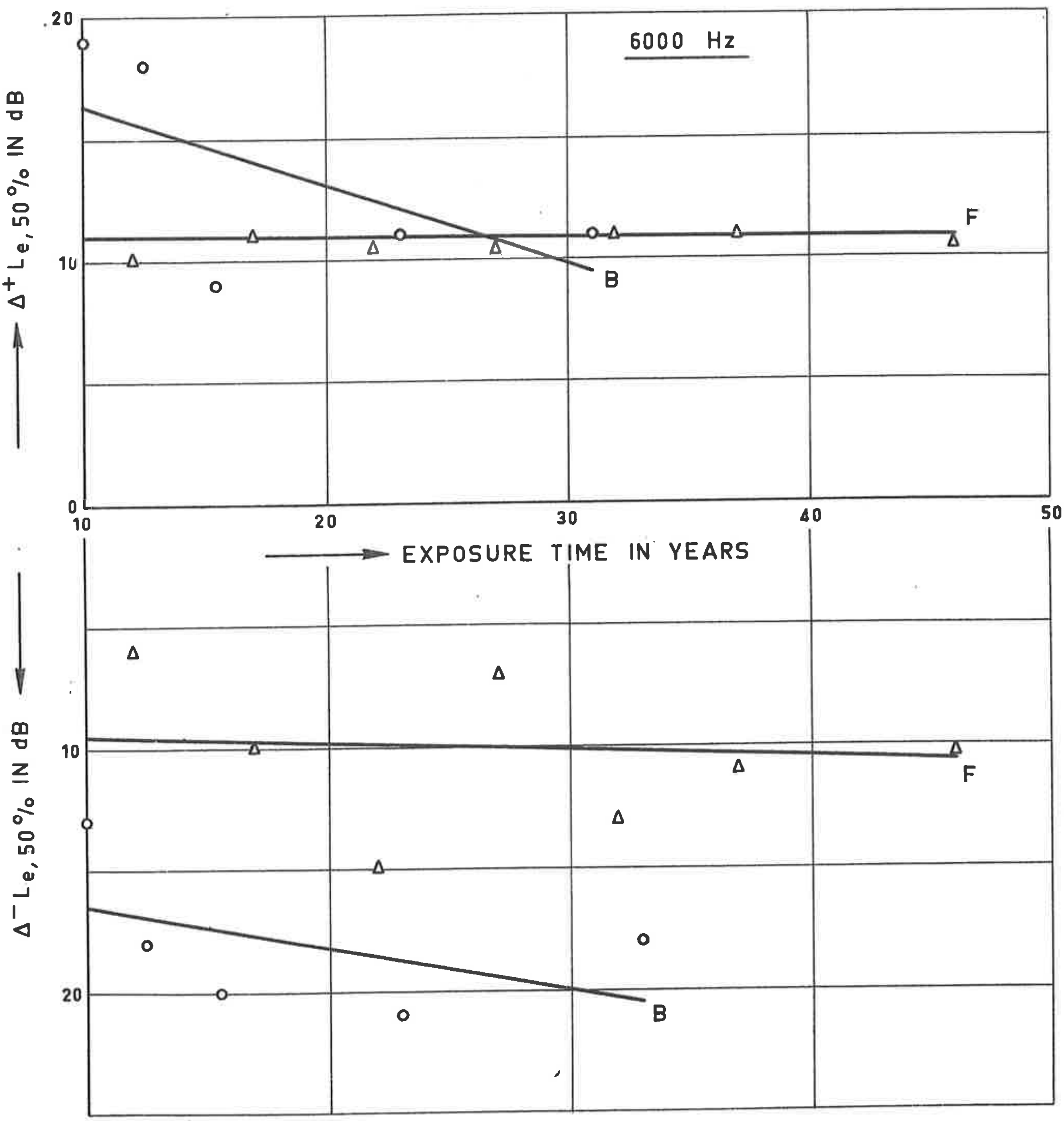
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



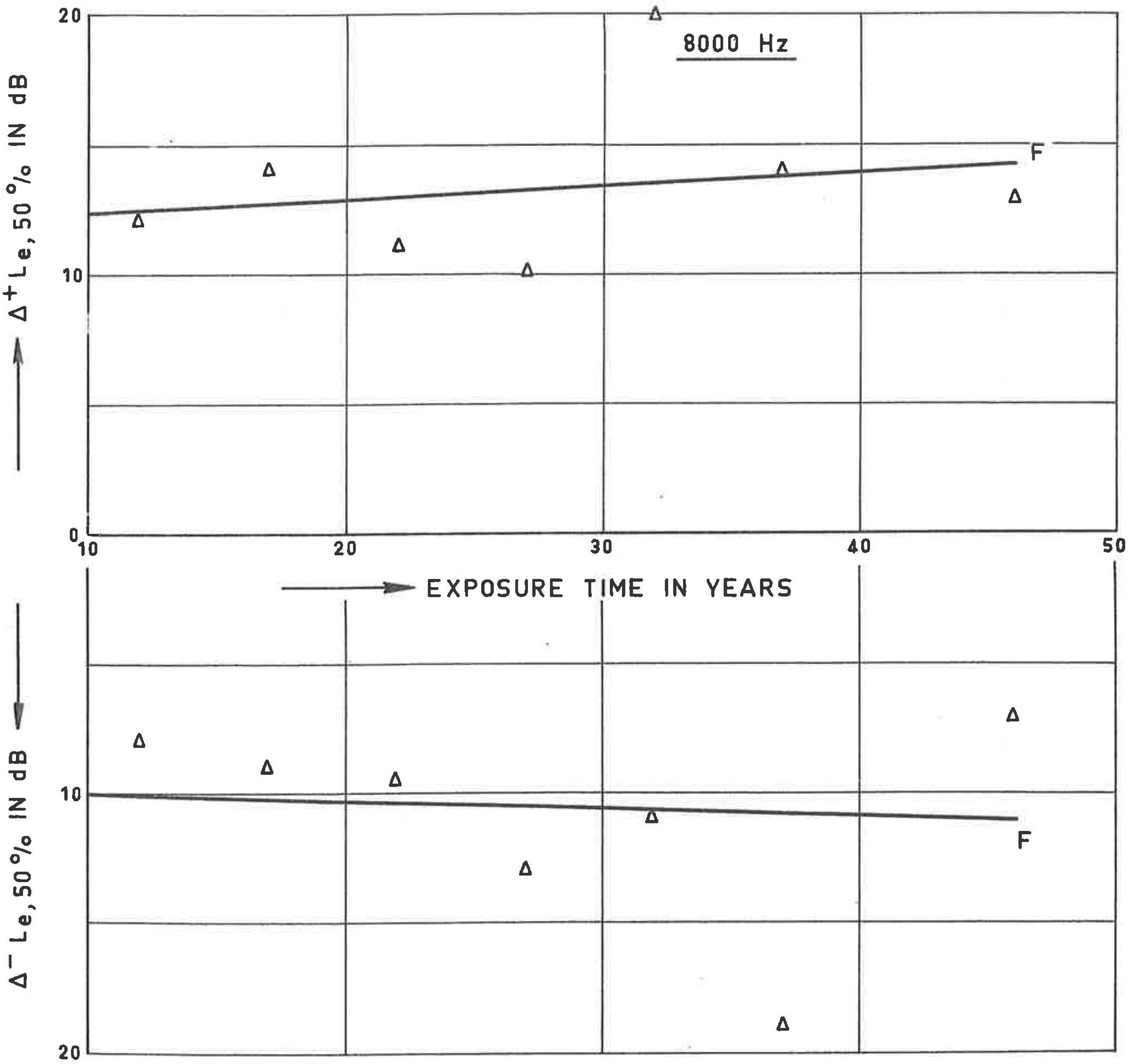
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.

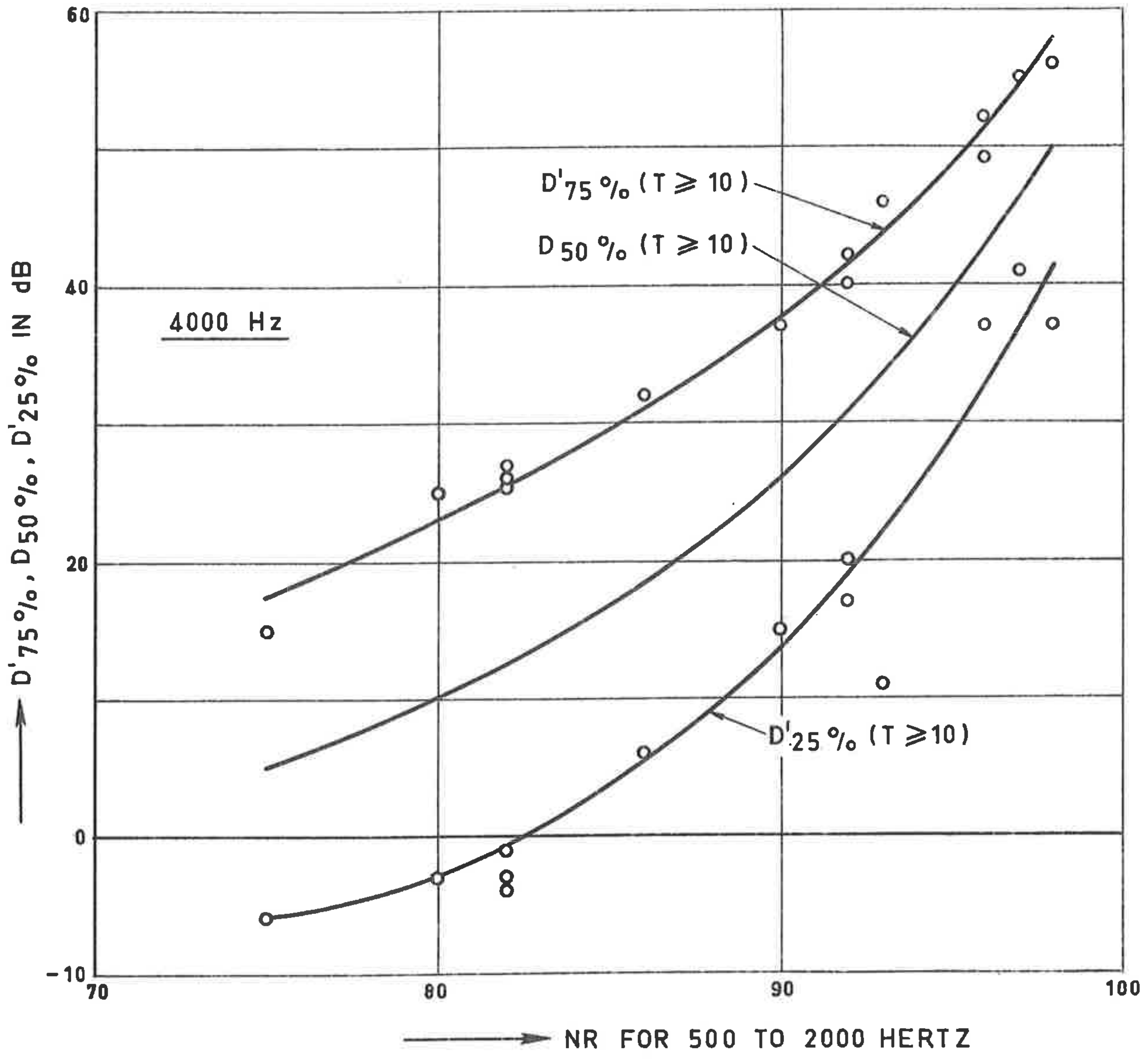


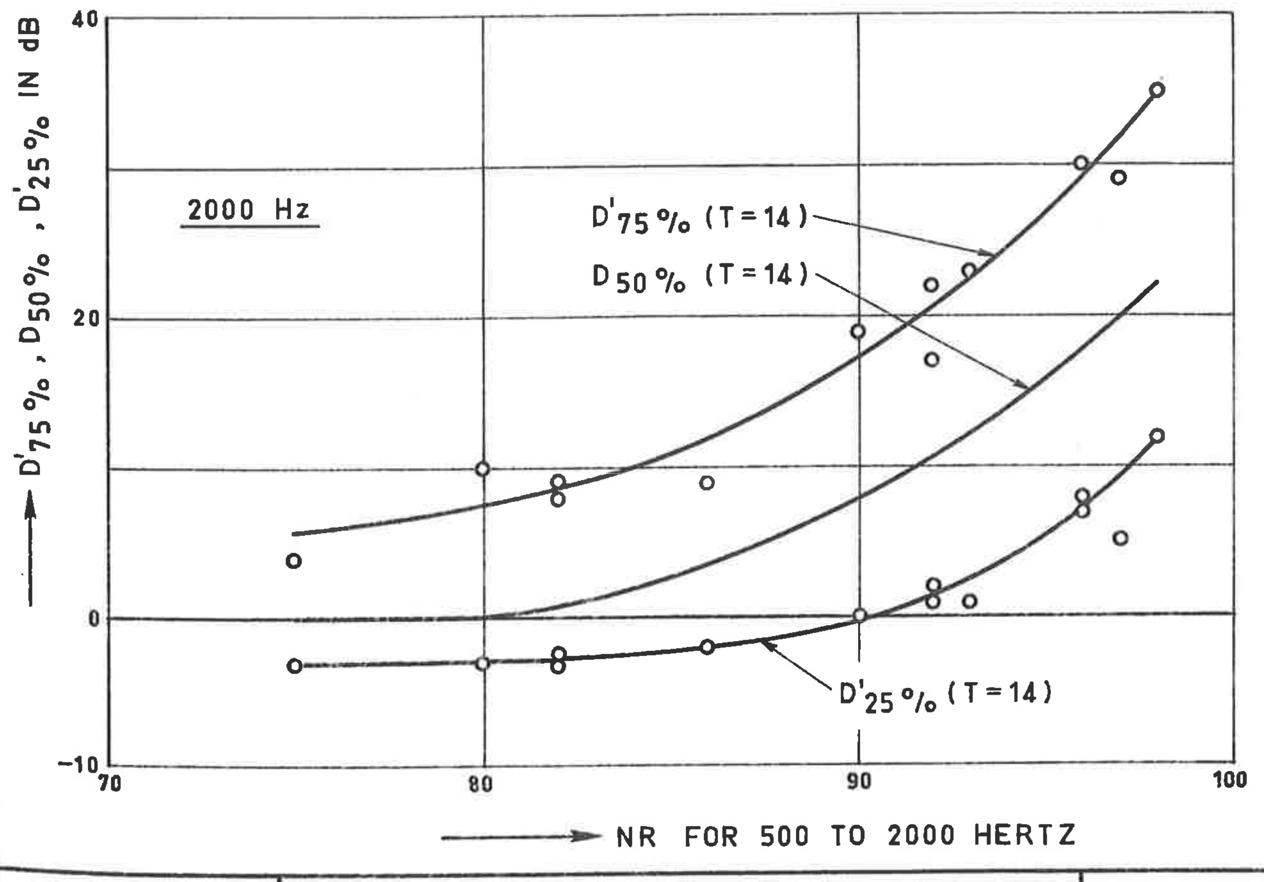
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.

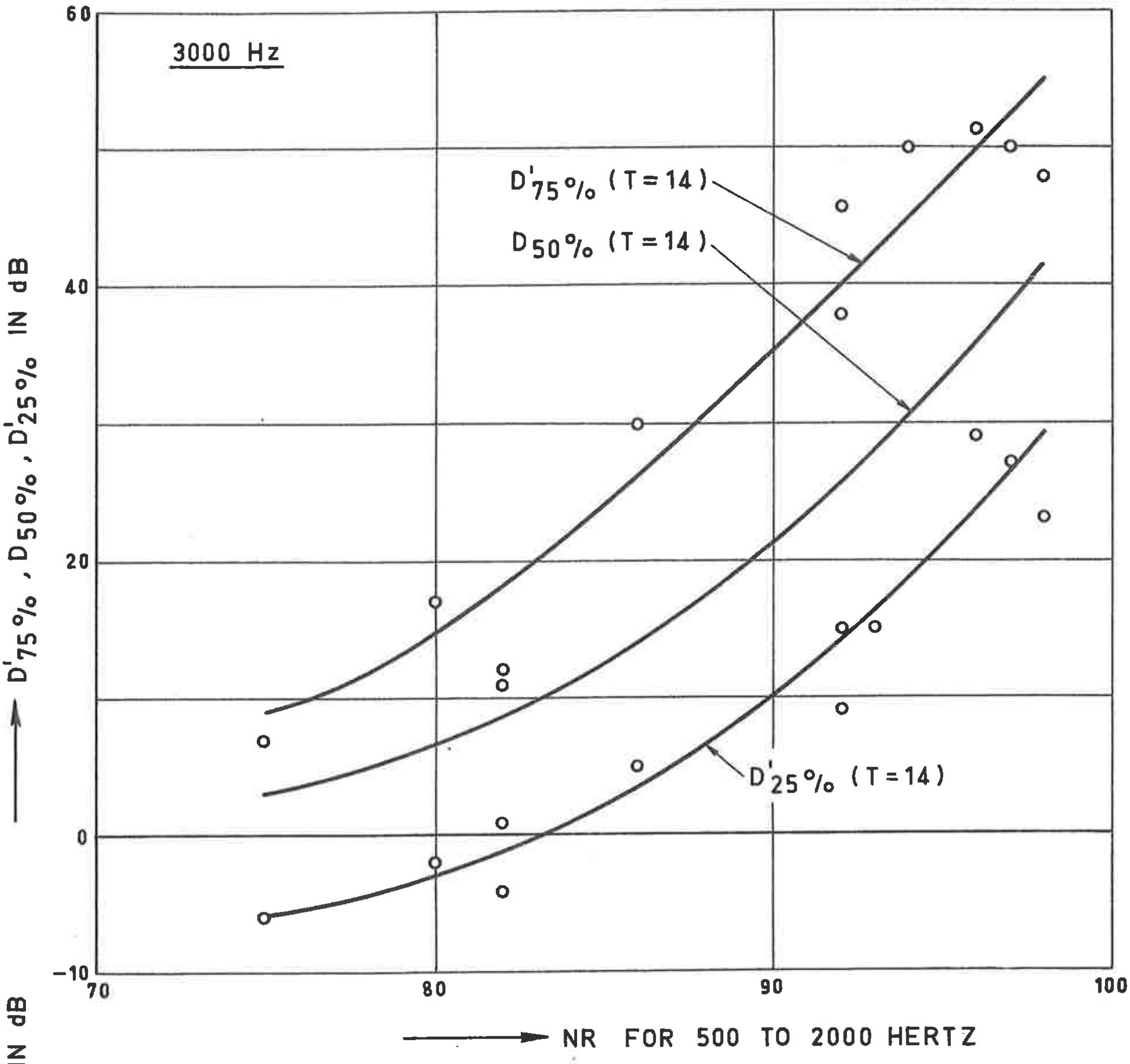


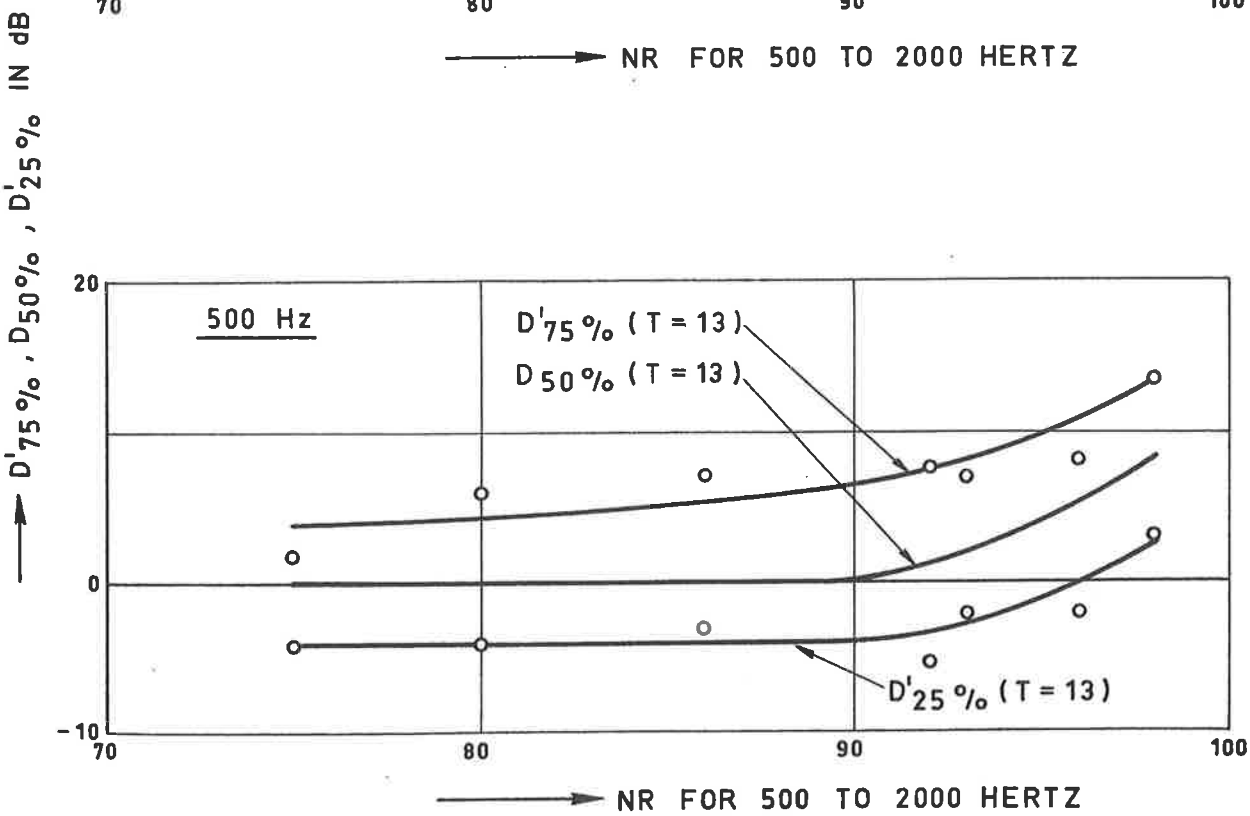
THE DIFFERENCE ($\Delta^+ L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^- L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



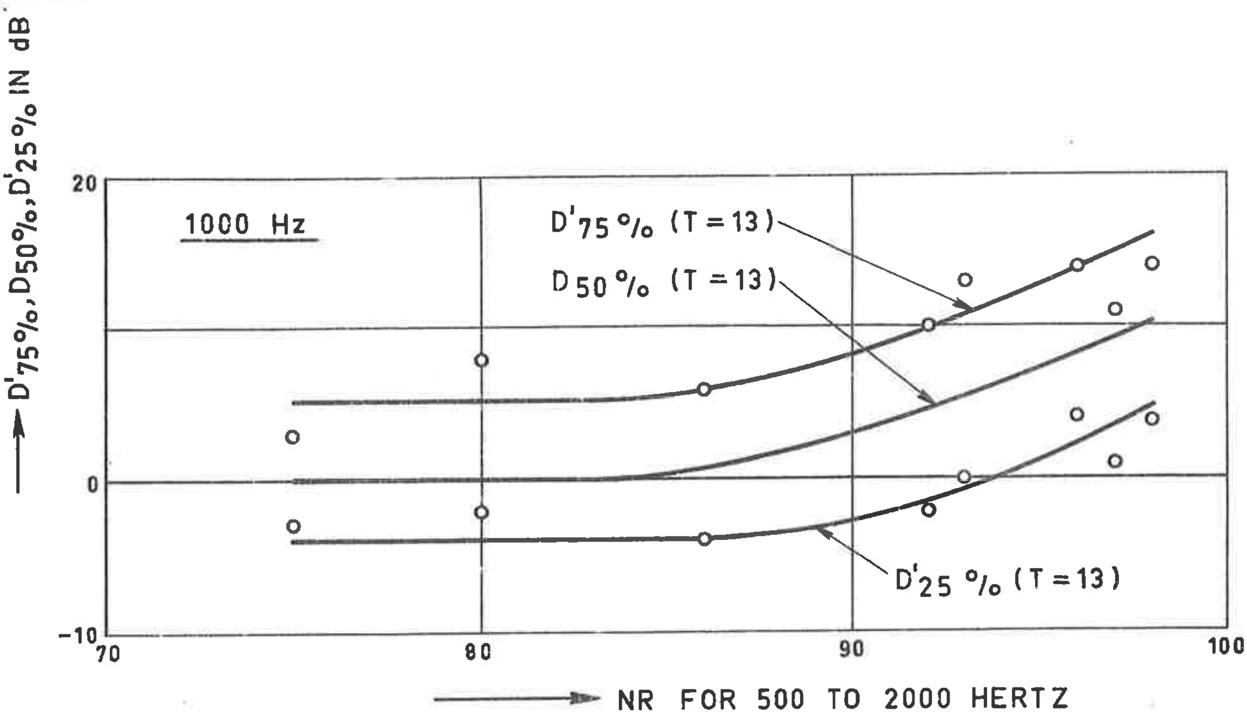

60
40
20
0
-10
70
80
90
100
4000 Hz
D'75 % (T ≥ 10)
D 50 % (T ≥ 10)
D'25 % (T ≥10)
D'75 %, D50 %, D'25 % IN dB
NR FOR 500 TO 2000 HERTZ

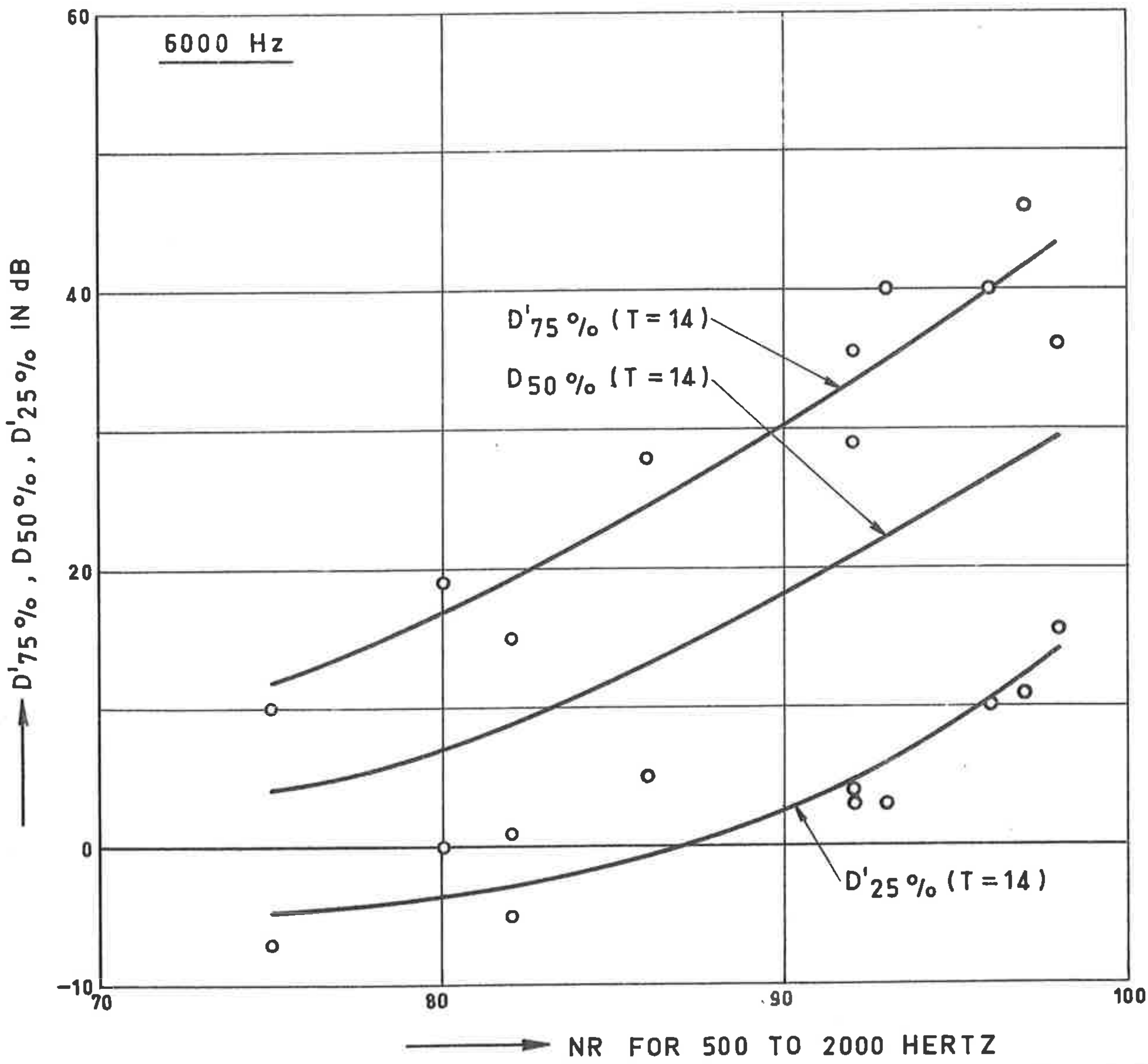

40
20
0
-10
70
80
90
100
2000 Hz
D'75 % (T = 14)
D 50 % (T = 14)
D'25 % (T = 14)
D'75 %, D50 %, D'25 % IN dB
NR FOR 500 TO 2000 HERTZ



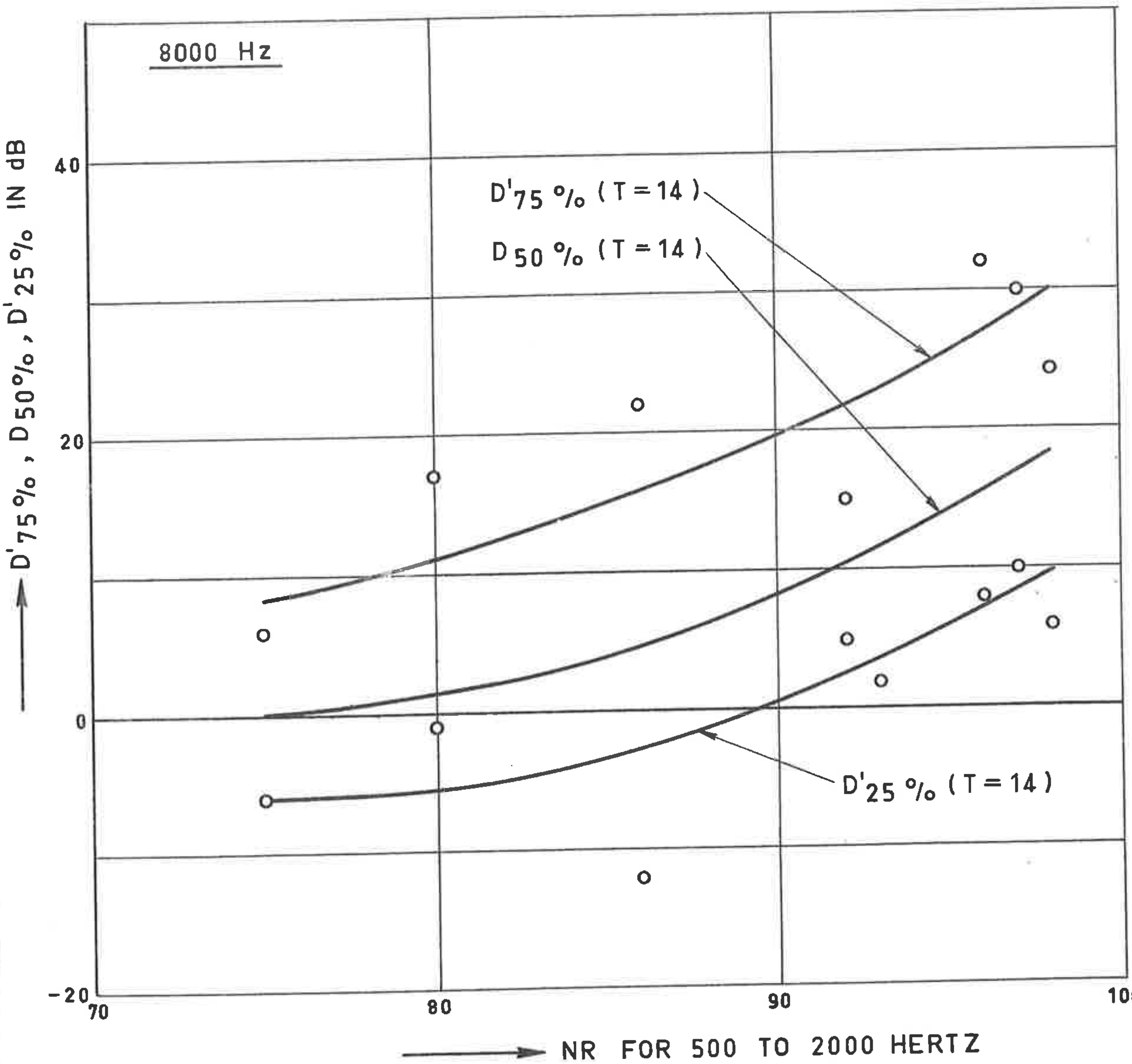


68 B 96	IG-TNO AFD. GELUID EN LICHT	R35-44 EN 45



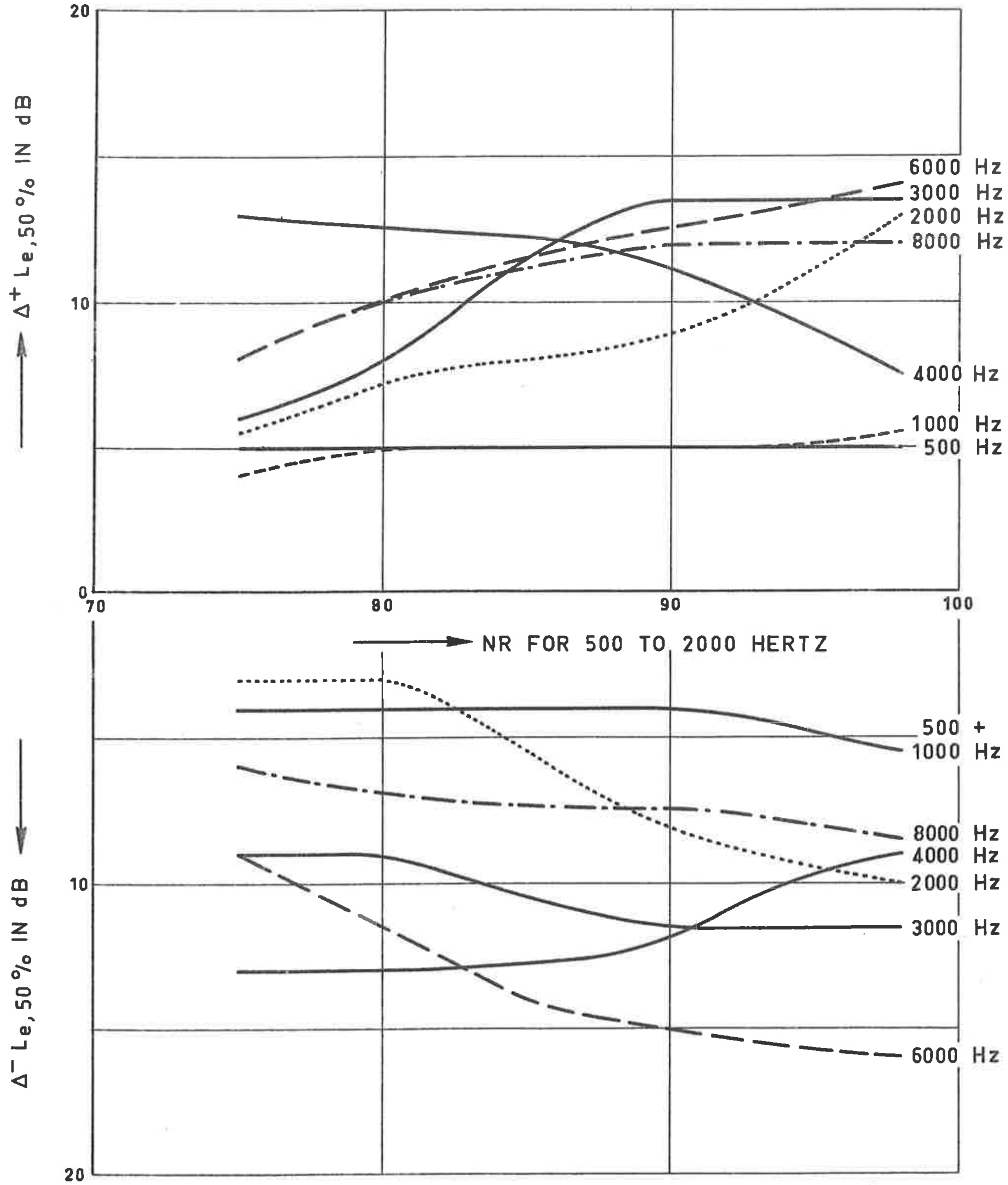


68 B 97	IG-TNO AFD. GELUID EN LICHT	R35-46 EN 47

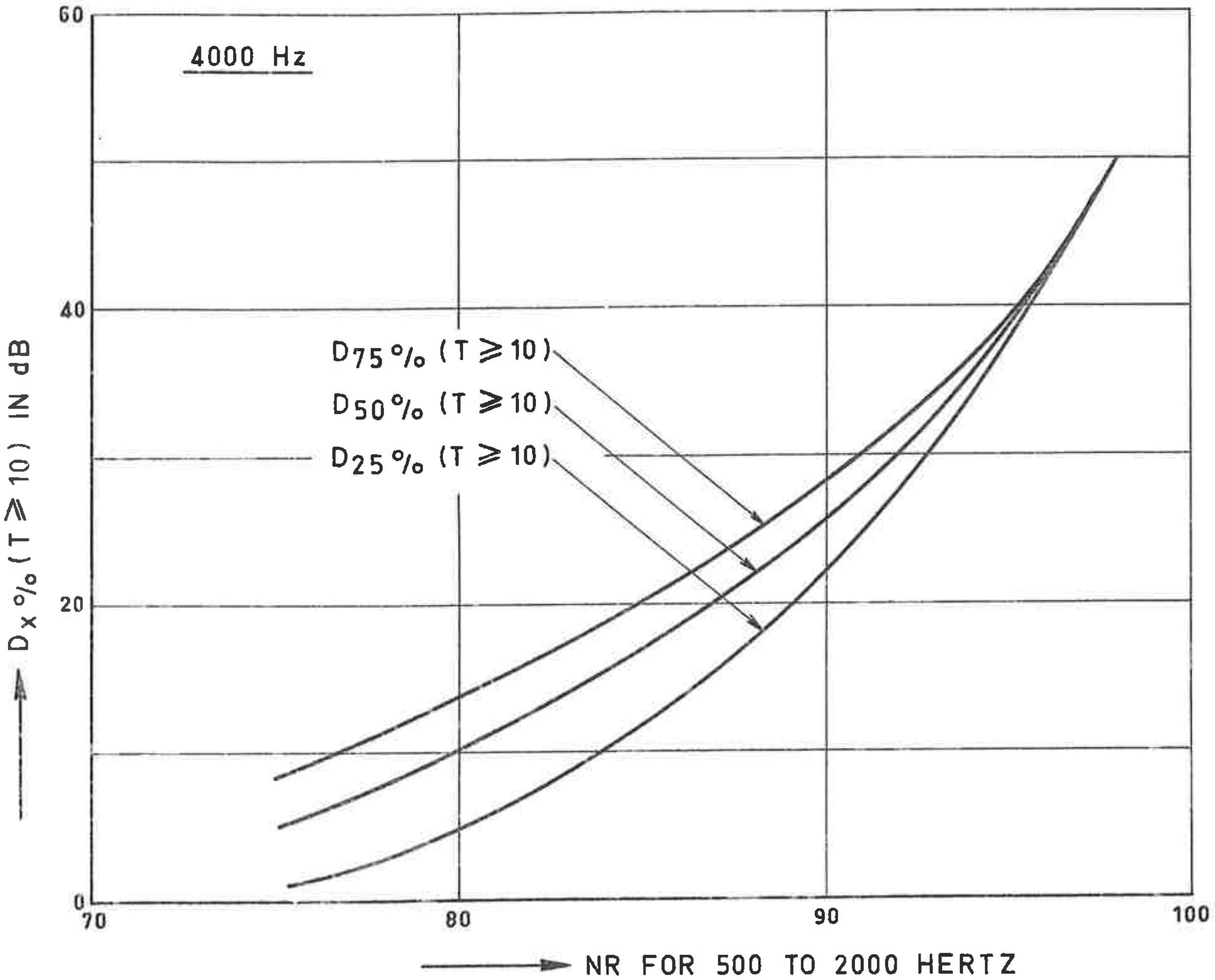


8000 Hz
D'75 % (T = 14)
D 50 % (T = 14)
D'25 % (T = 14)
D'75 % , D 50 % , D'25 % IN dB
40
20
0
-20
70
80
90
100
NR FOR 500 TO 2000 HERTZ

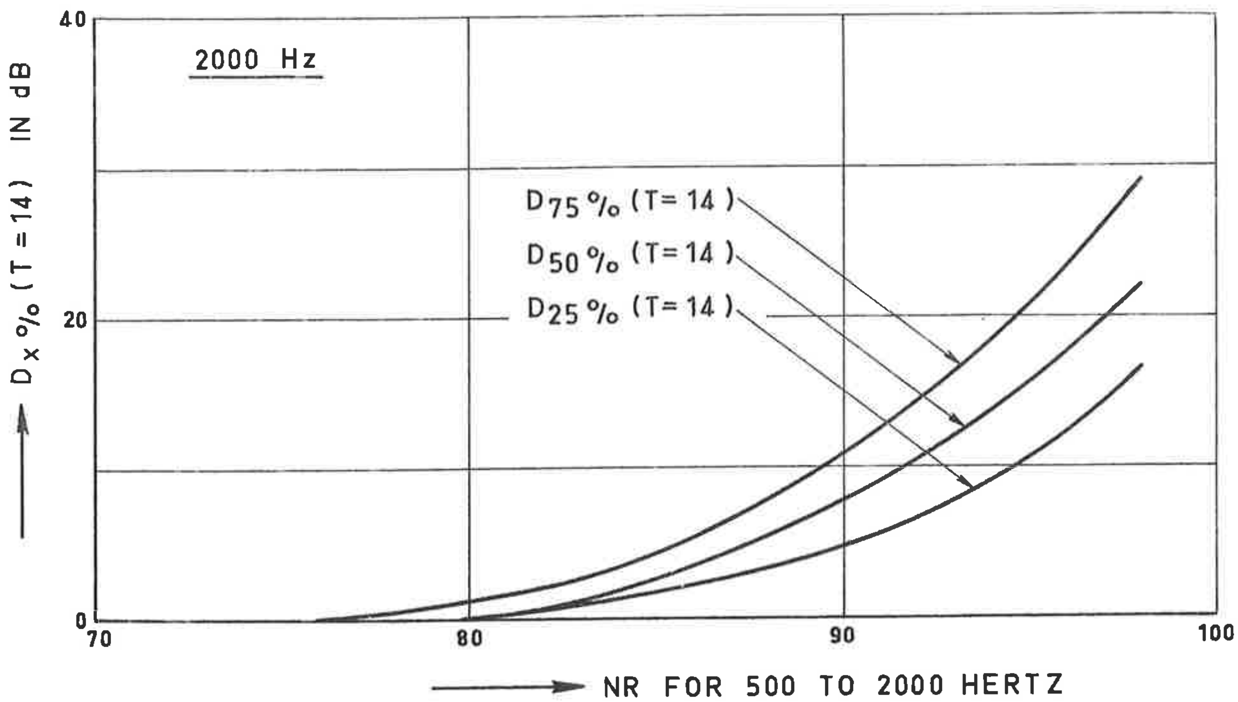
THE DIFFERENCE ($\Delta^{+}L_{e,50\%}$) BETWEEN $L_{e,75\%}$ AND $L_{e,50\%}$ AND THE DIFFERENCE ($\Delta^{-}L_{e,50\%}$) BETWEEN $L_{e,50\%}$ AND $L_{e,25\%}$, AS A FUNCTION OF EXPOSURE TIME.



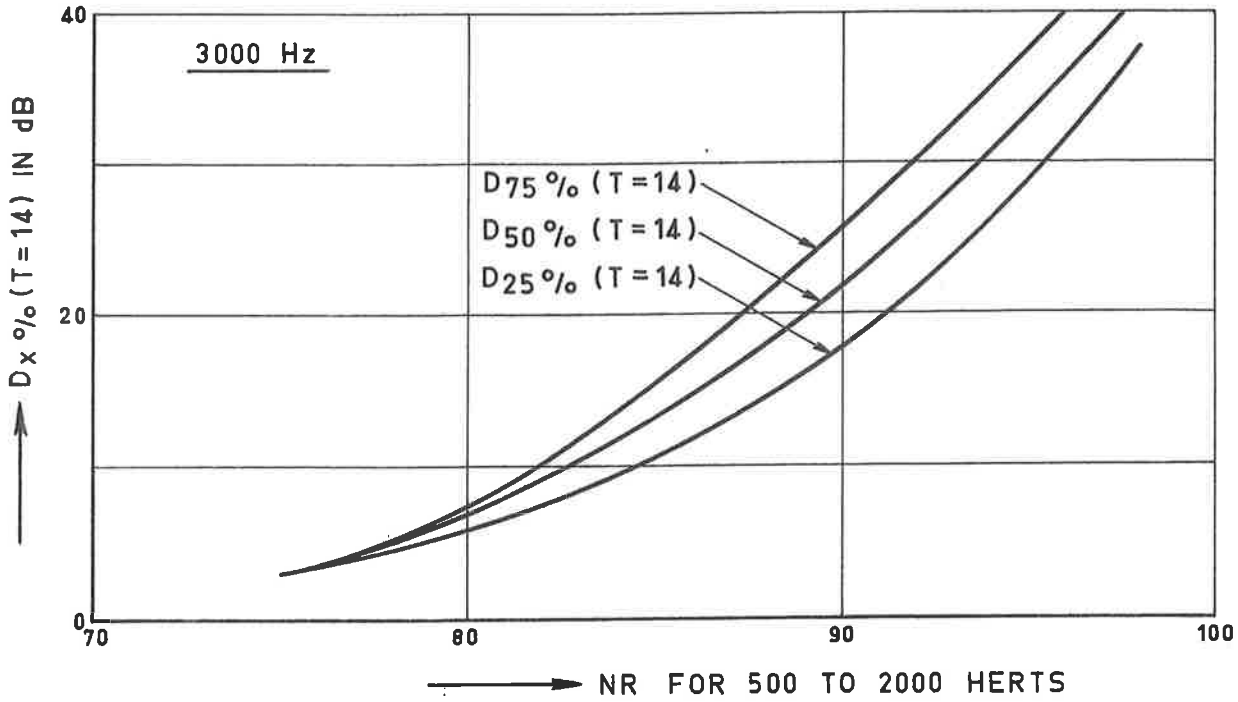
THE DIFFERENCE ($D_{x\%}$ (T ≥ 10)) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR AT LEAST 10 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED, WITH THE SAME MEAN AGE AS PEOPLE EXPOSED.



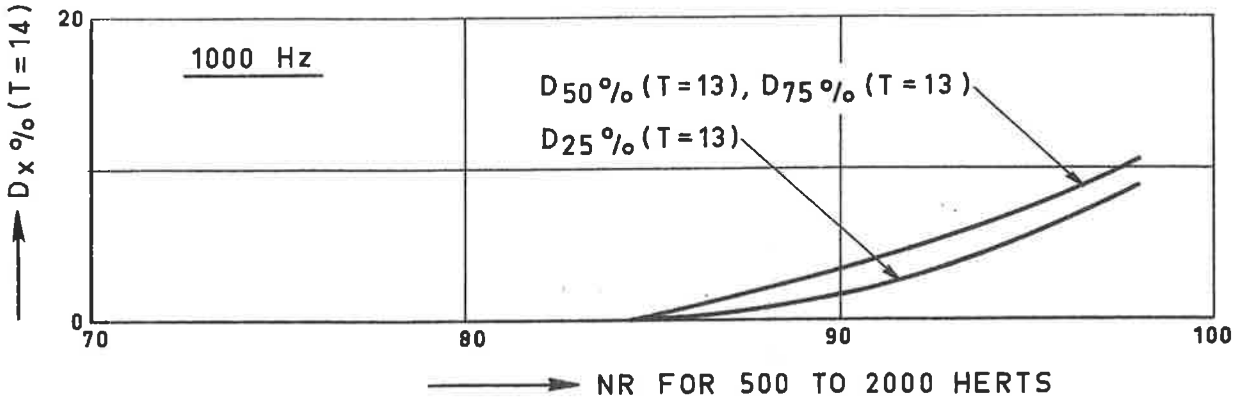
THE DIFFERENCE ($D_{x\%}$ (T = 14)) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR 14 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED, WITH THE SAME MEAN AGE AS PEOPLE EXPOSED.



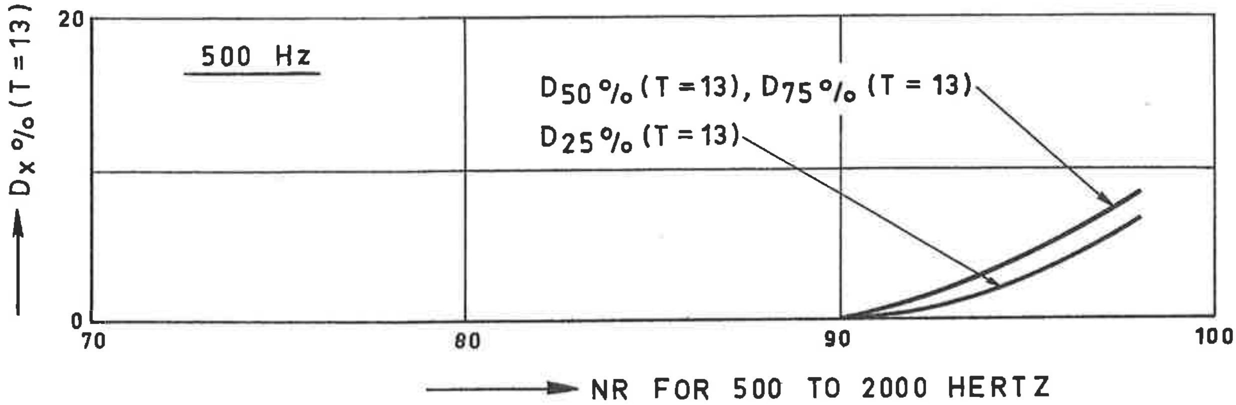
THE DIFFERENCE ($D_{x\%}(T=14)$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR 14 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED, WITH THE SAME MEAN AGE AS PEOPLE EXPOSED.



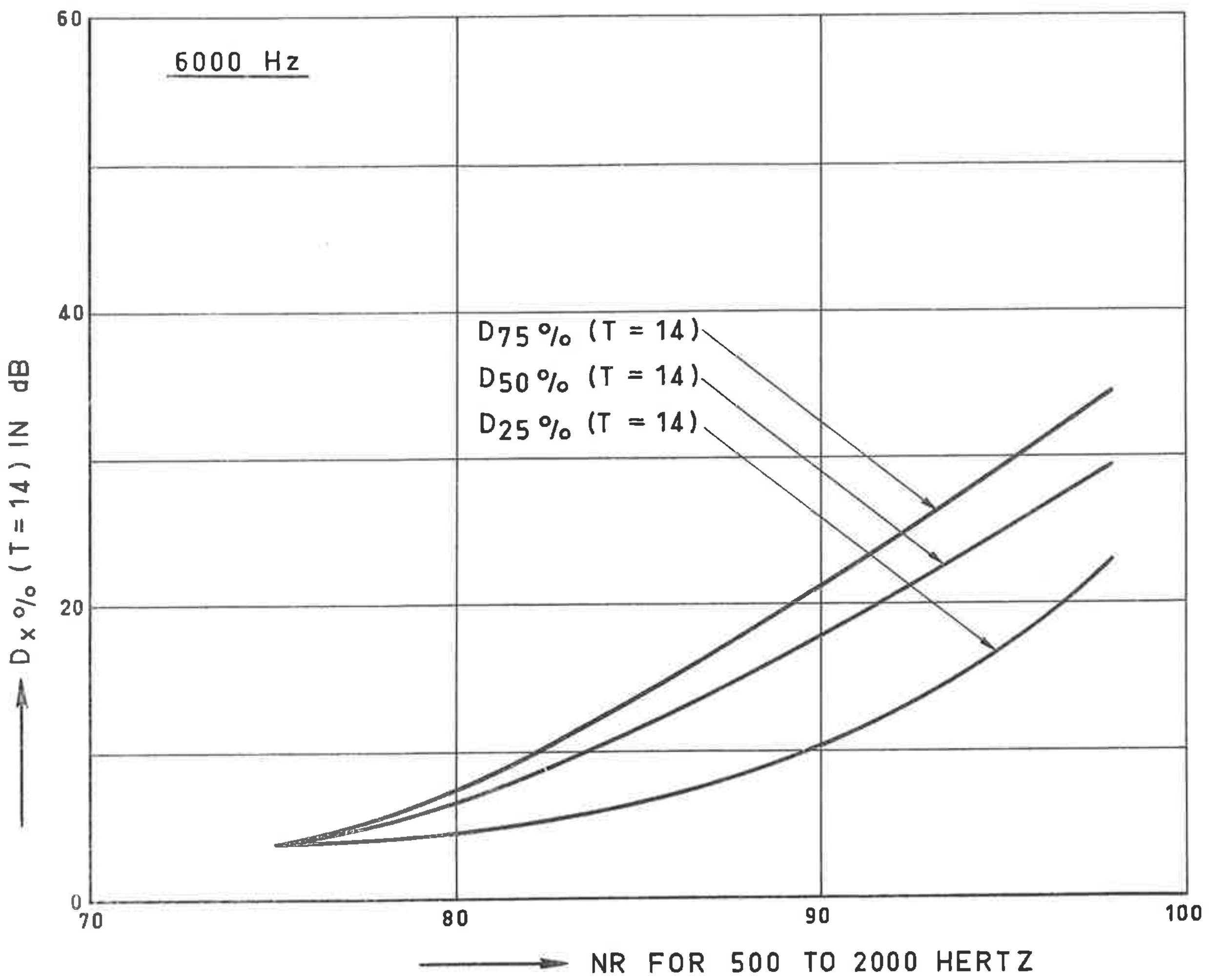
THE DIFFERENCE ($D_{x\%}(T=13)$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR 13 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.

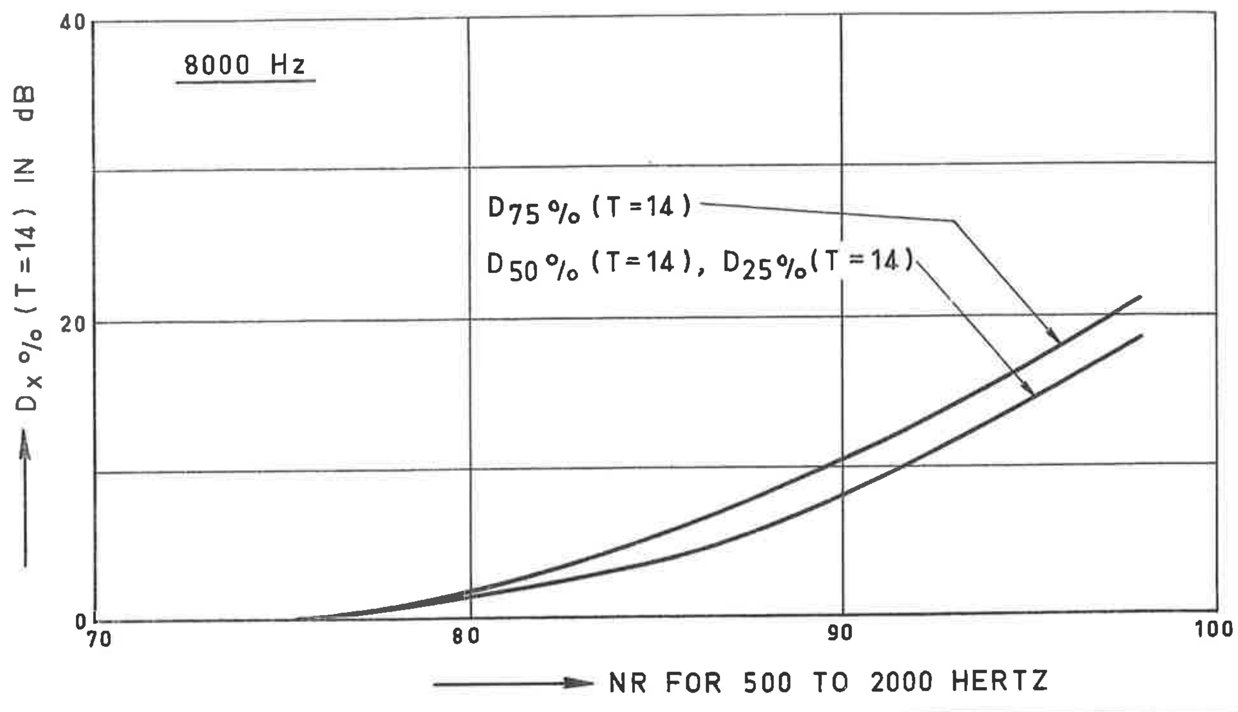


THE DIFFERENCE ($D_{x\%}(T=13)$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR 13 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.

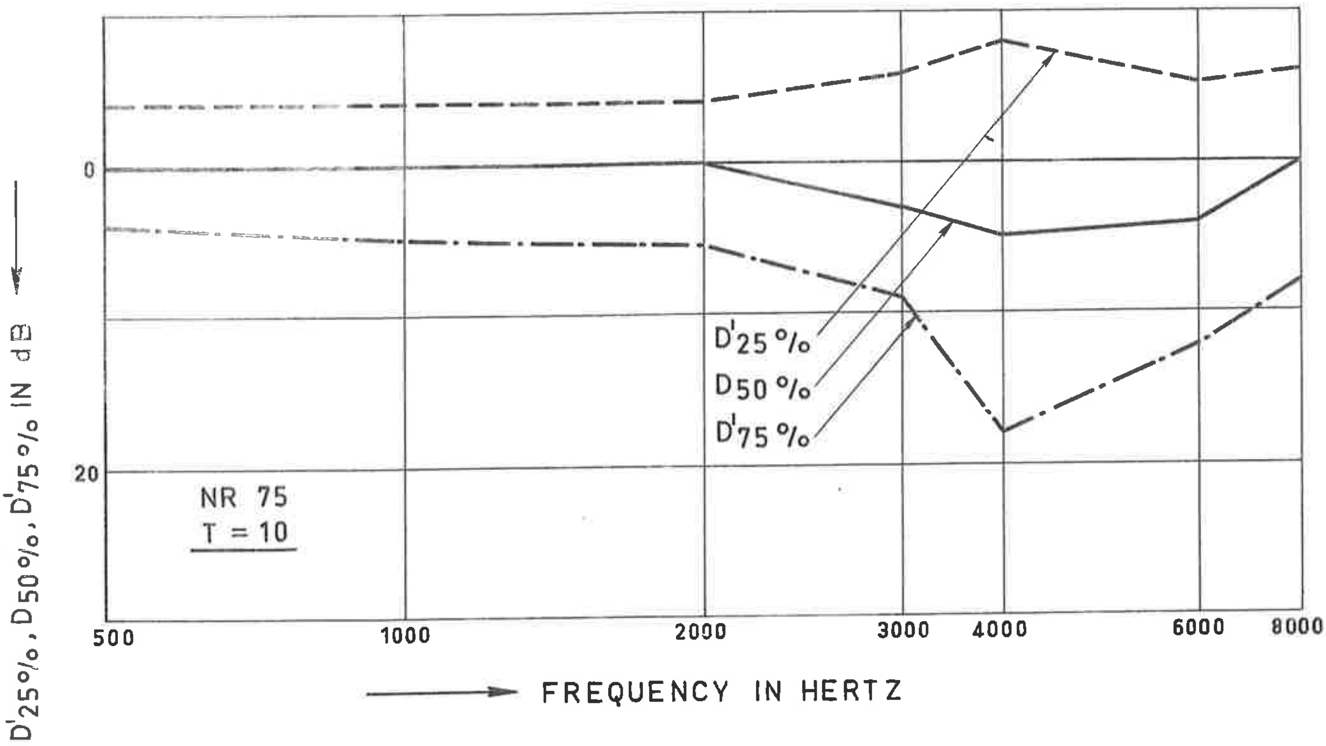


THE DIFFERENCE ($D_{x\%}$ (T = 14)) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED TO NOISE FOR 14 YEARS, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED, WITH THE SAME MEAN AGE AS PEOPLE EXPOSED.

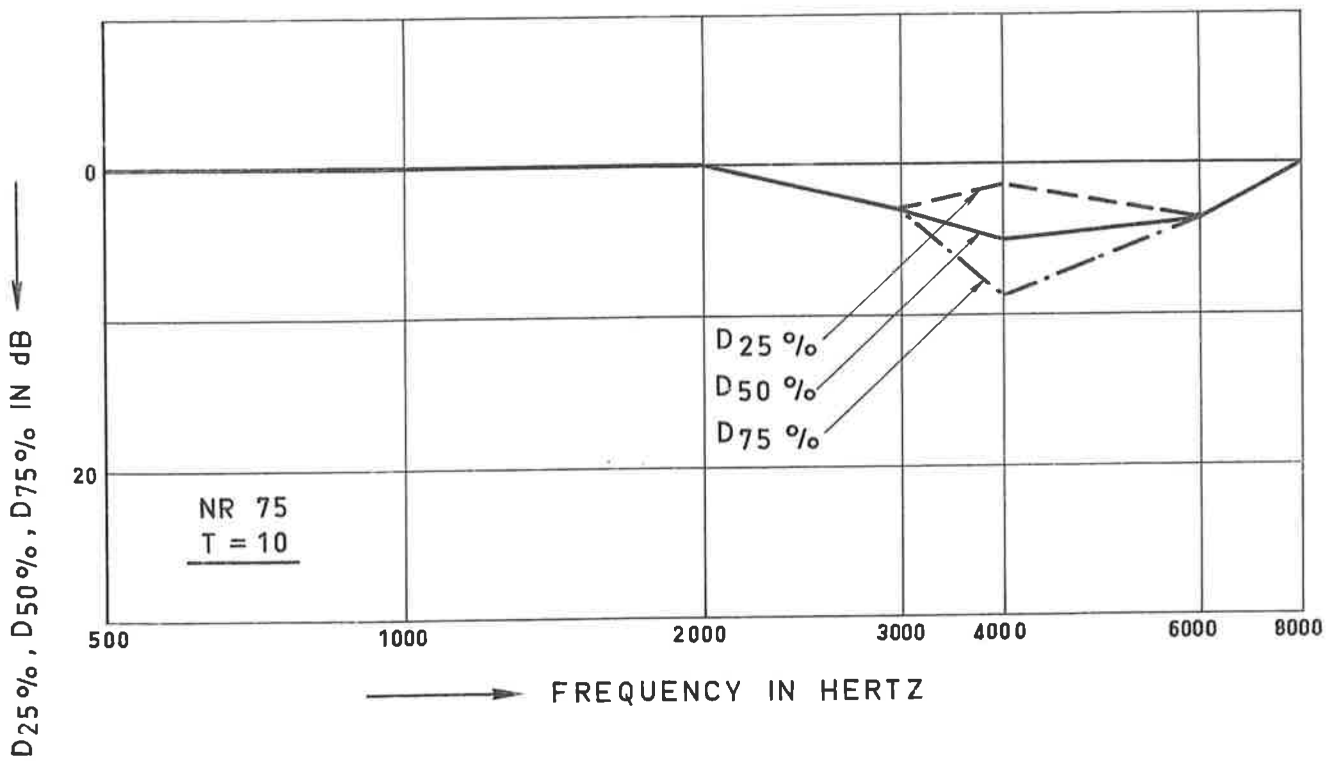




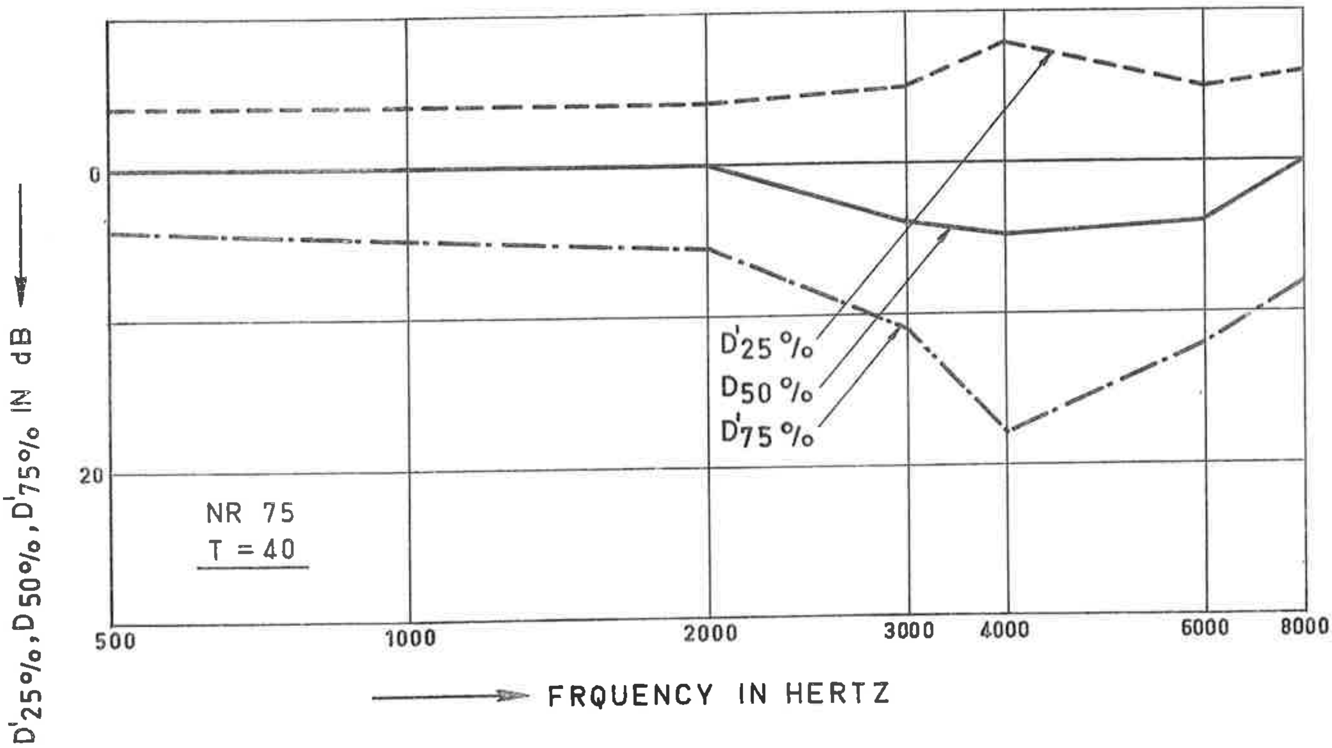
THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.



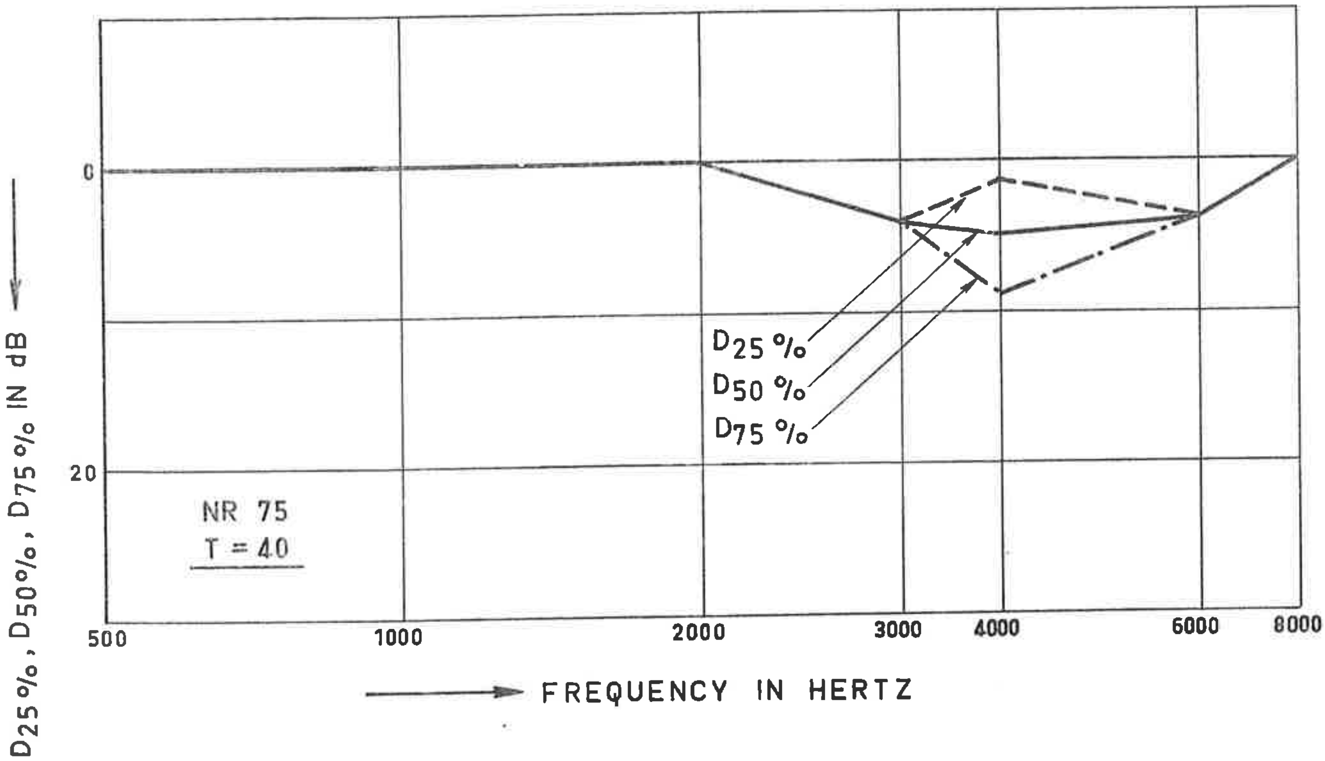
THE DIFFERENCE ($D_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.



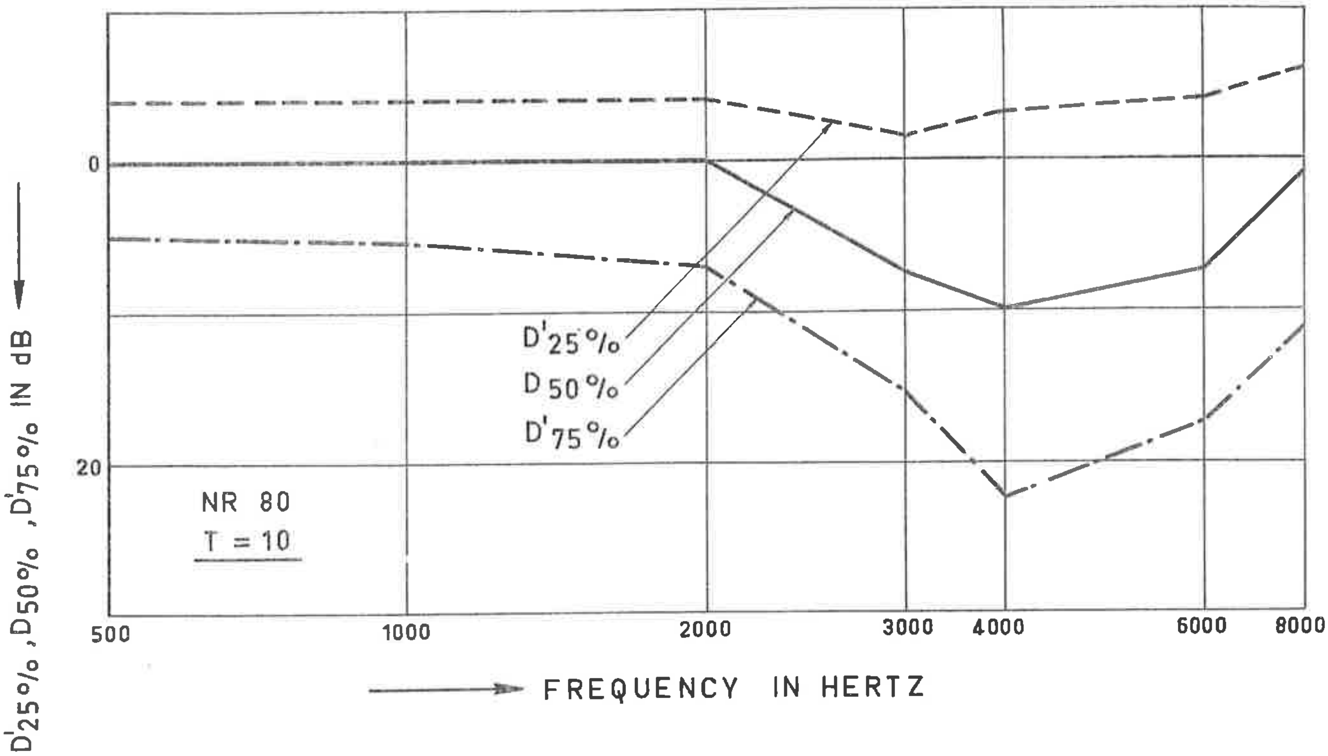
THE DIFFERENCE ($D'_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\,\%}$ OF PEOPLE NOT EXPOSED.



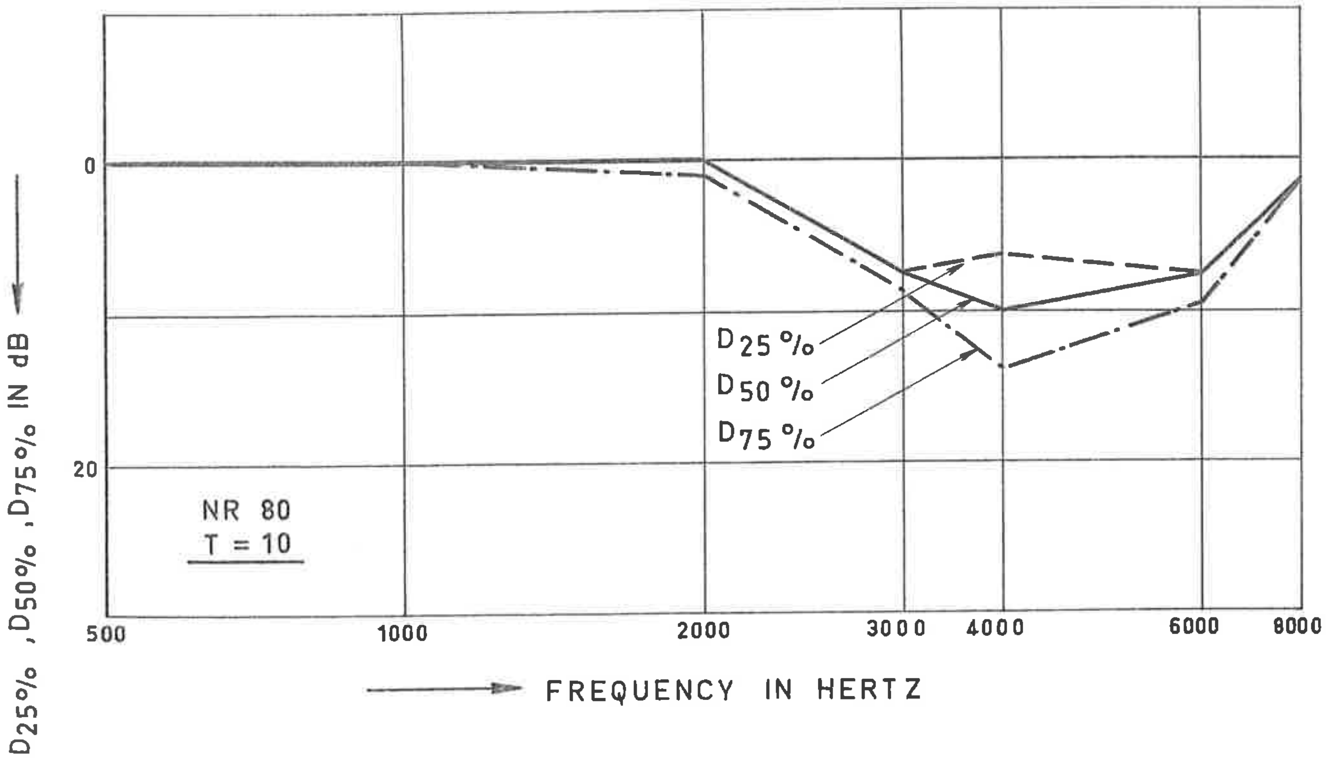
THE DIFFERENCE ($D_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\,\%}$ OF PEOPLE NOT EXPOSED.



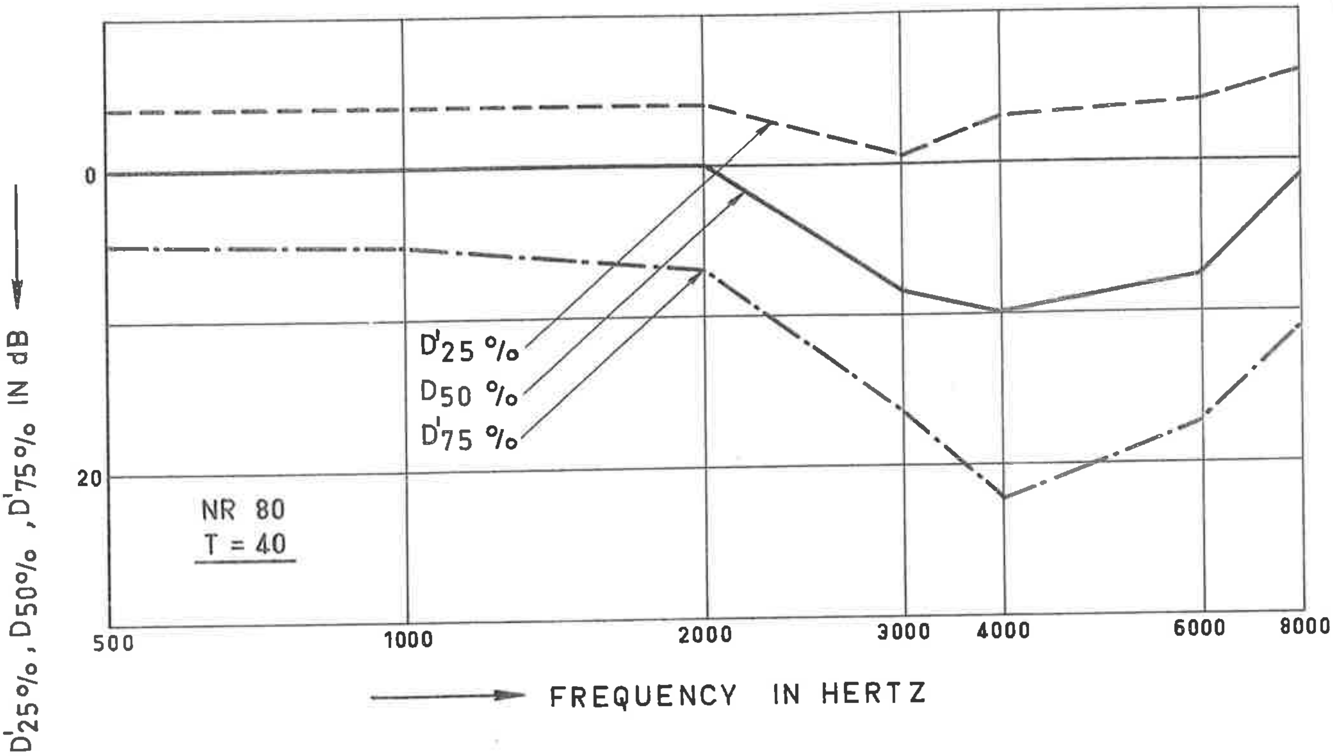
THE DIFFERENCE (D'_{x} %) BETWEEN $L_{e,x}$ % OF PEOPLE EXPOSED, AND $L_{n,50}$ % OF PEOPLE NOT EXPOSED.



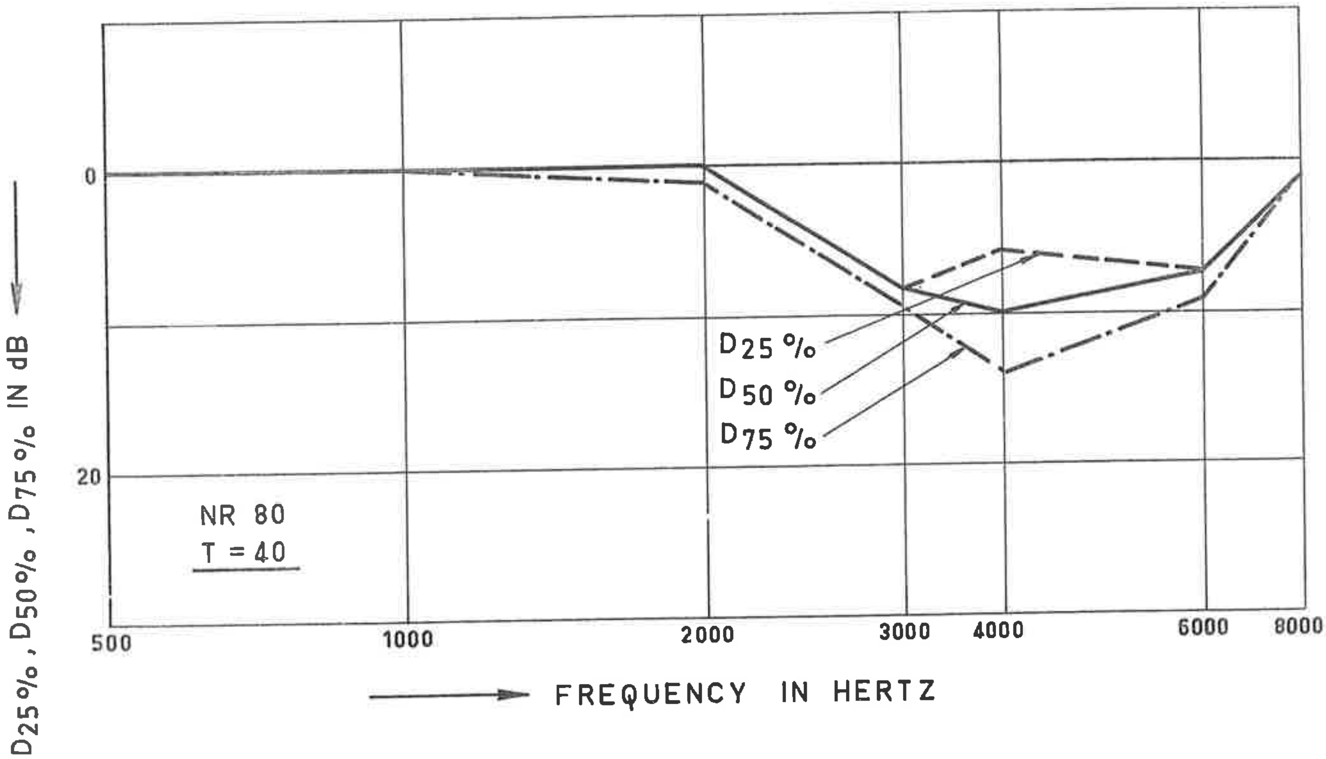
THE DIFFERENCE (D_{x} %) BETWEEN $L_{e,x}$ % OF PEOPLE EXPOSED, AND $L_{n,x}$ % OF PEOPLE NOT EXPOSED.



THE DIFFERENCE (D'_{x} %) BETWEEN $L_{e,x}$ % OF PEOPLE EXPOSED, AND $L_{n,50}$ % OF PEOPLE NOT EXPOSED.

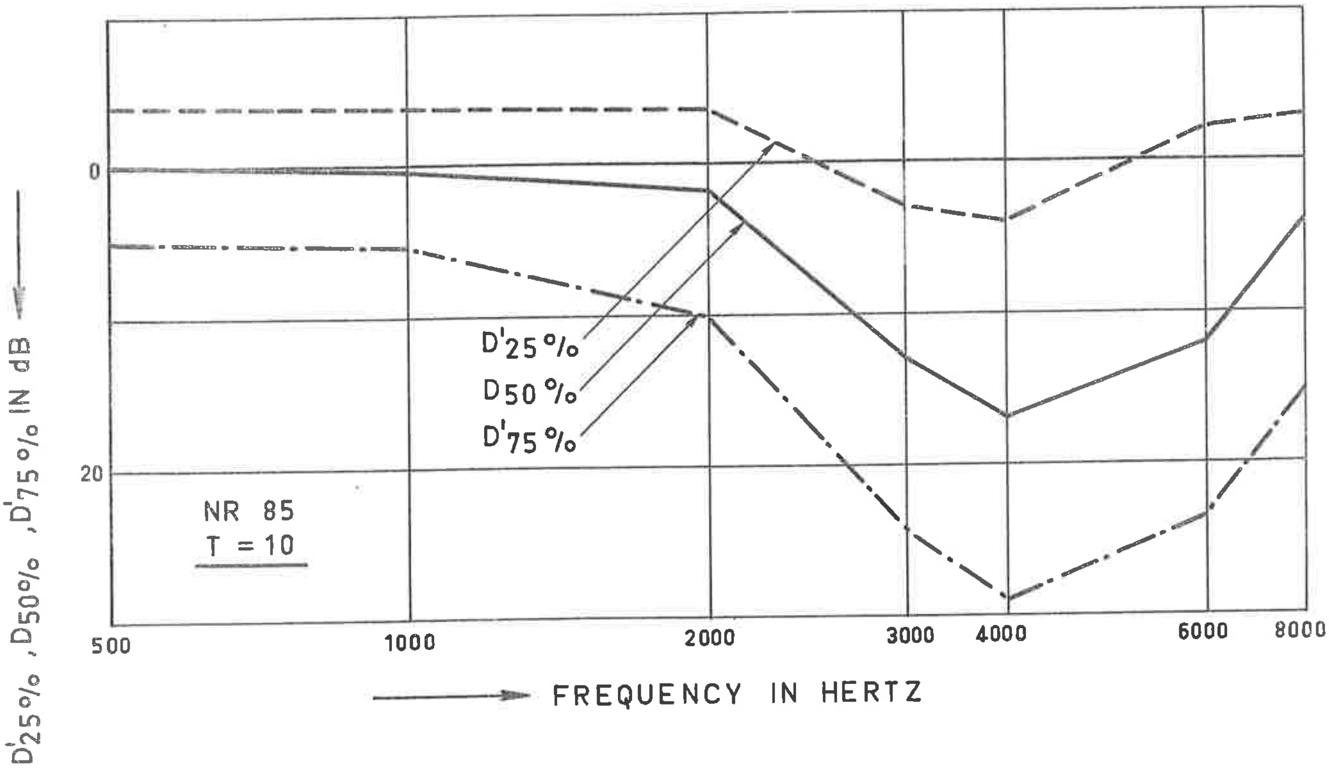


THE DIFFERENCE (D_{x} %) BETWEEN $L_{e,x}$ % OF PEOPLE EXPOSED, AND $L_{n,x}$ % OF PEOPLE NOT EXPOSED.

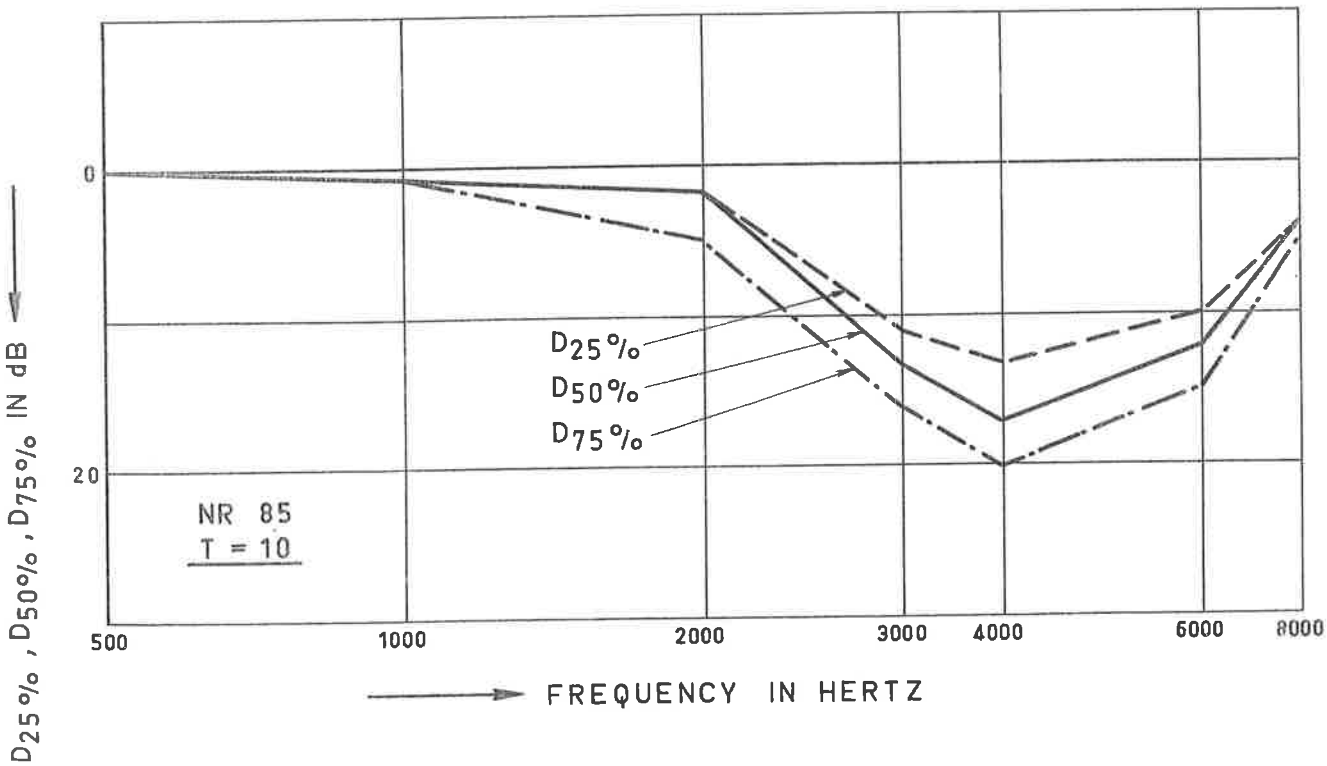


68 B 106	IG - TNO AFD. GELUID EN LICHT	R35 - 63 EN 64

THE DIFFERENCE ($D'_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,\,50\,\%}$ OF PEOPLE EXPOSED.

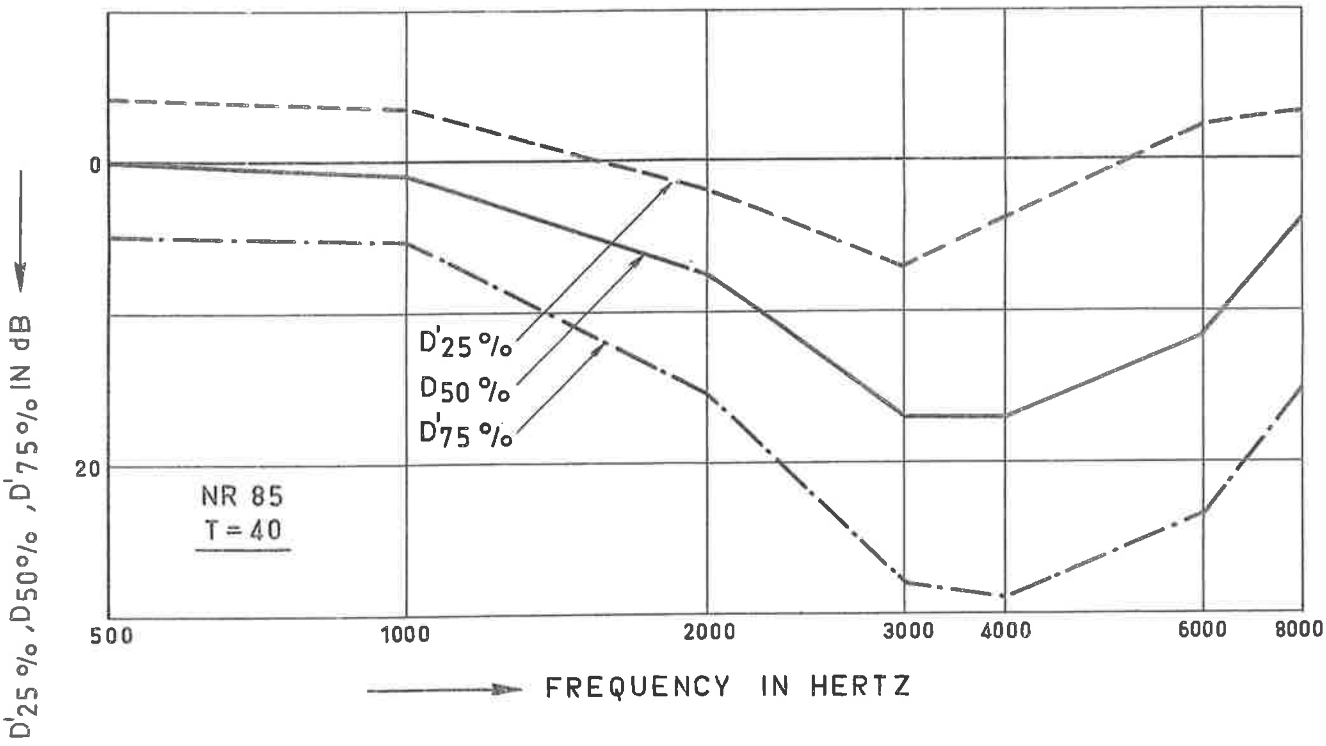


THE DIFFERENCE ($D_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\,\%}$ OF PEOPLE NOT EXPOSED.

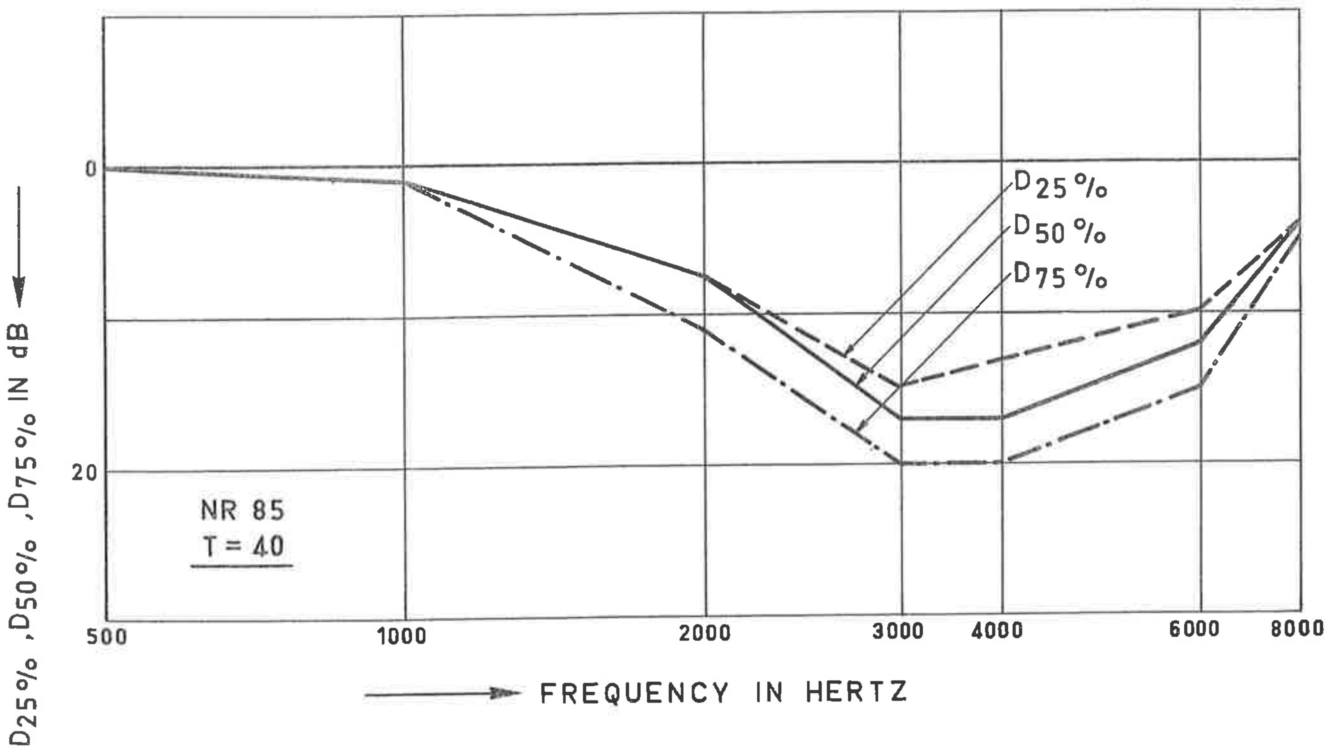


68 B 107	IG-TNO AFD. GELUID EN LICHT	R35-65 EN 66

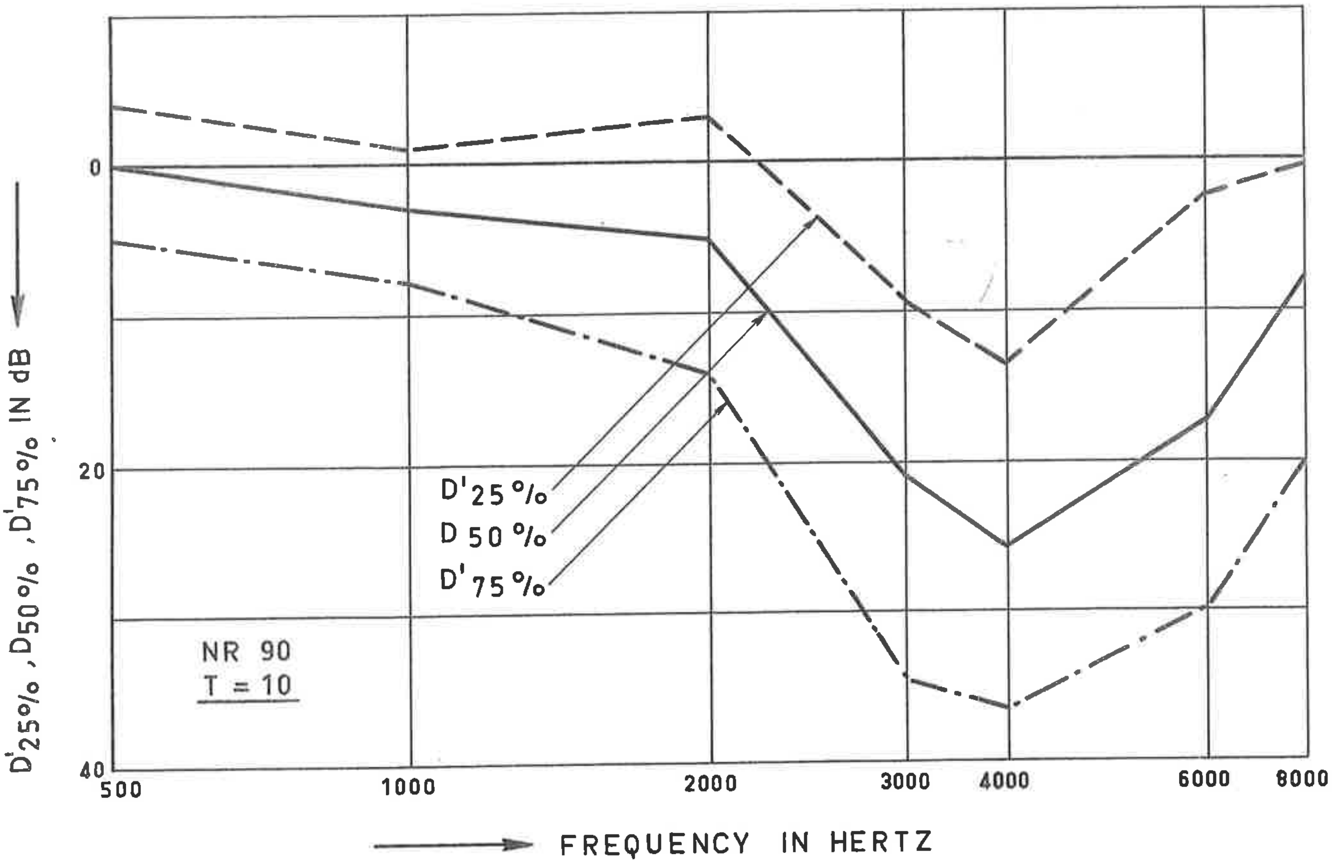
THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.



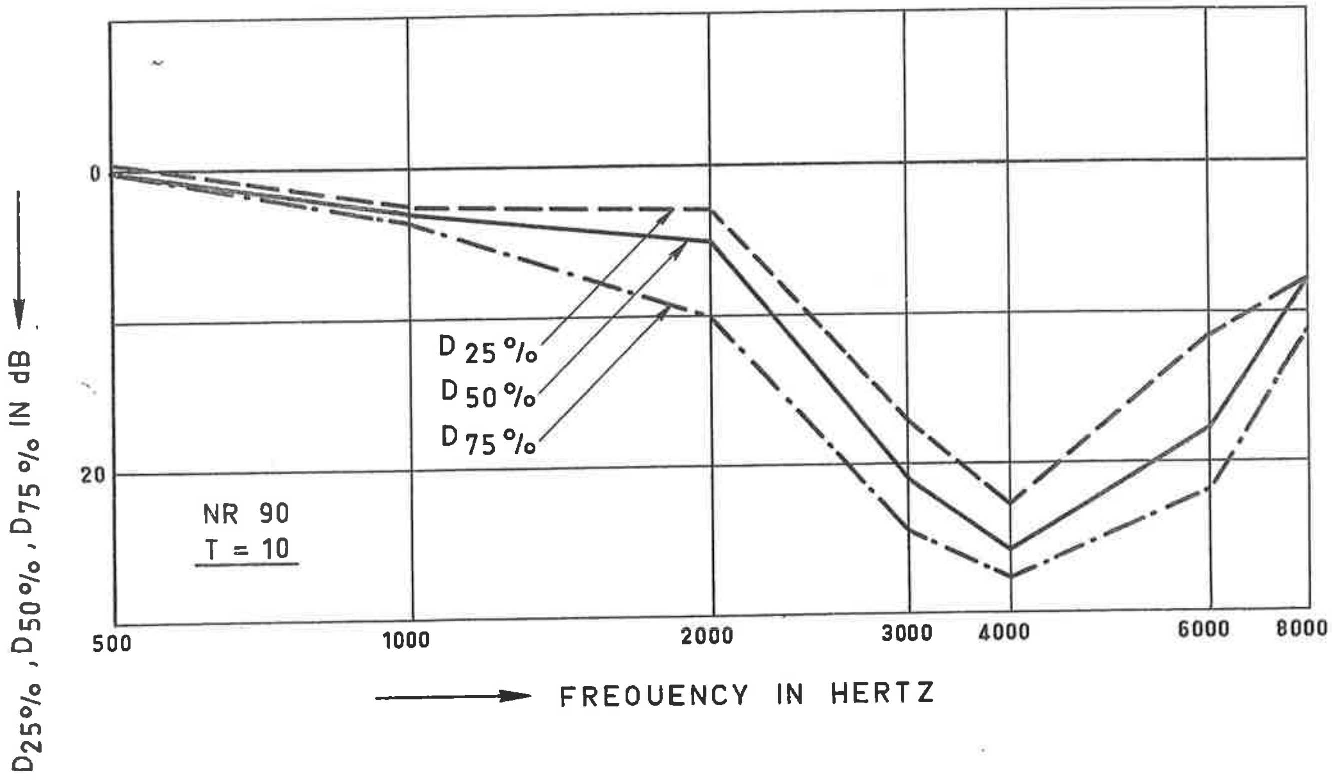
THE DIFFERENCE ($D_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.



THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.

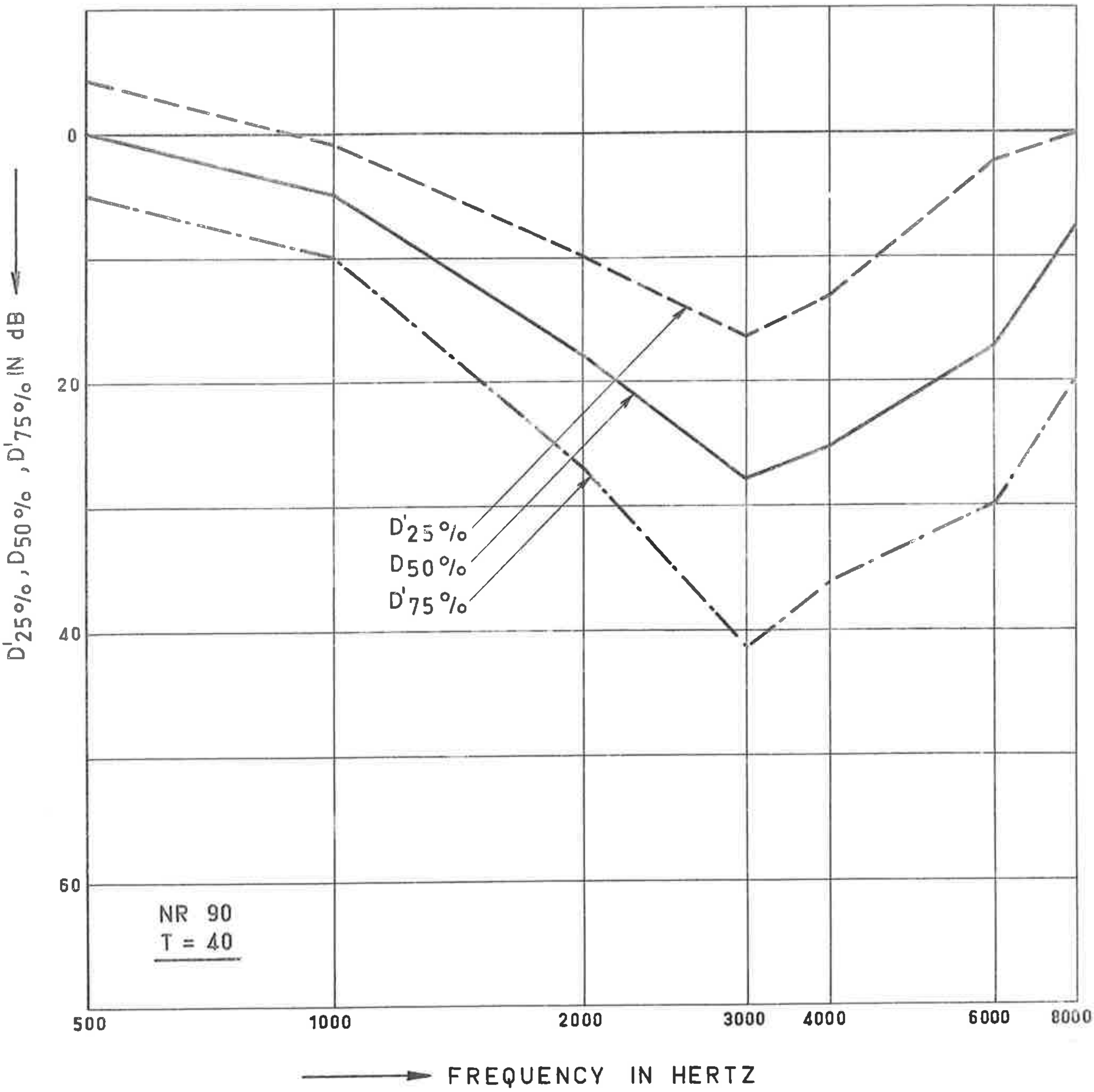


THE DIFFERENCE ($D_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.



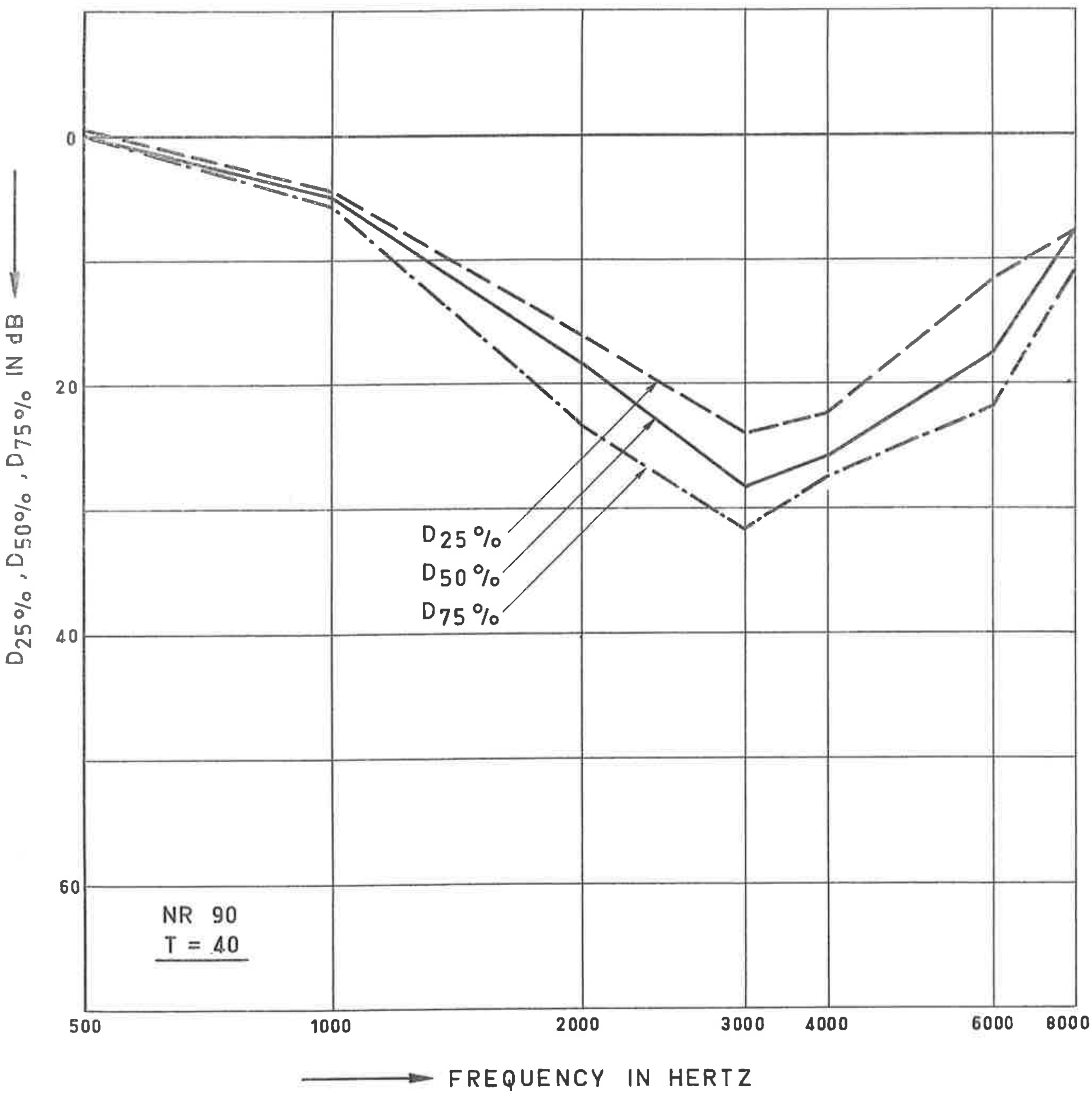
68 B 109	I G - T N O AFD. GELUID EN LICHT	R 35 - 69 EN 70

THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.

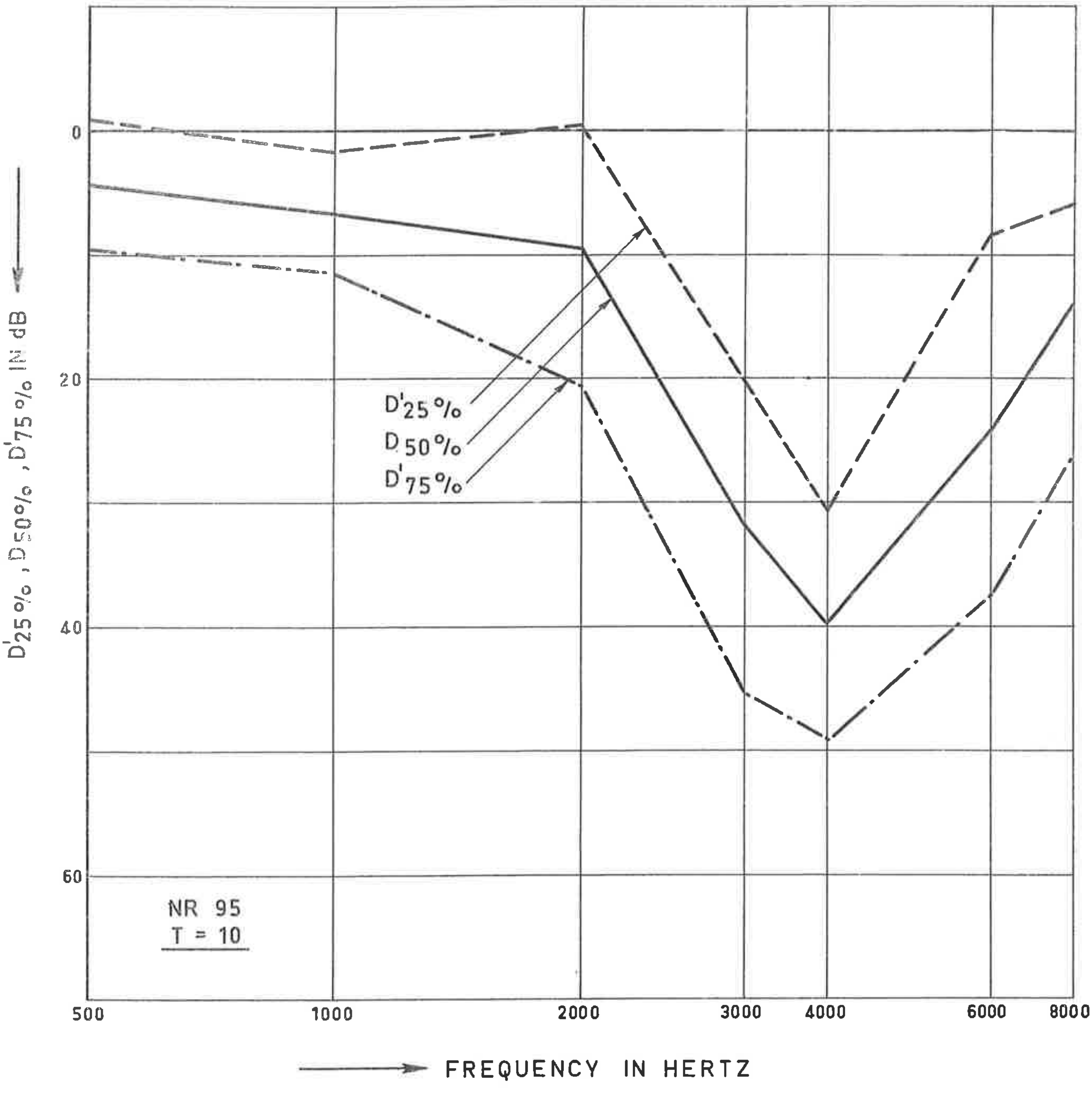


68 B 110	I G - T N O AFD. GELUID EN LICHT	R35 - 71

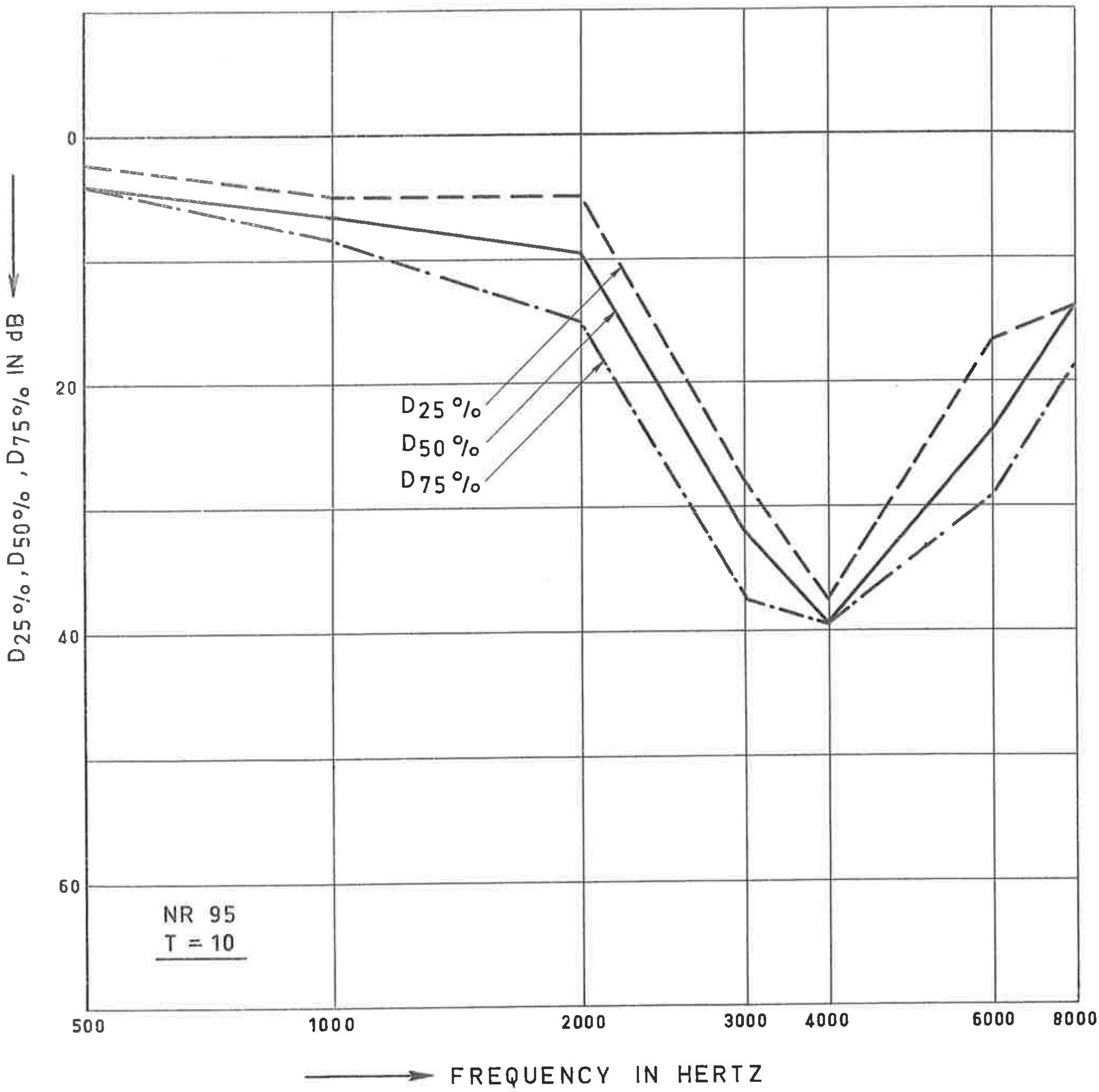
THE DIFFERENCE (D_x %) BETWEEN $L_{e,x}$ % OF PEOPLE EXPOSED, AND $L_{n,x}$ % OF PEOPLE NOT EXPOSED.



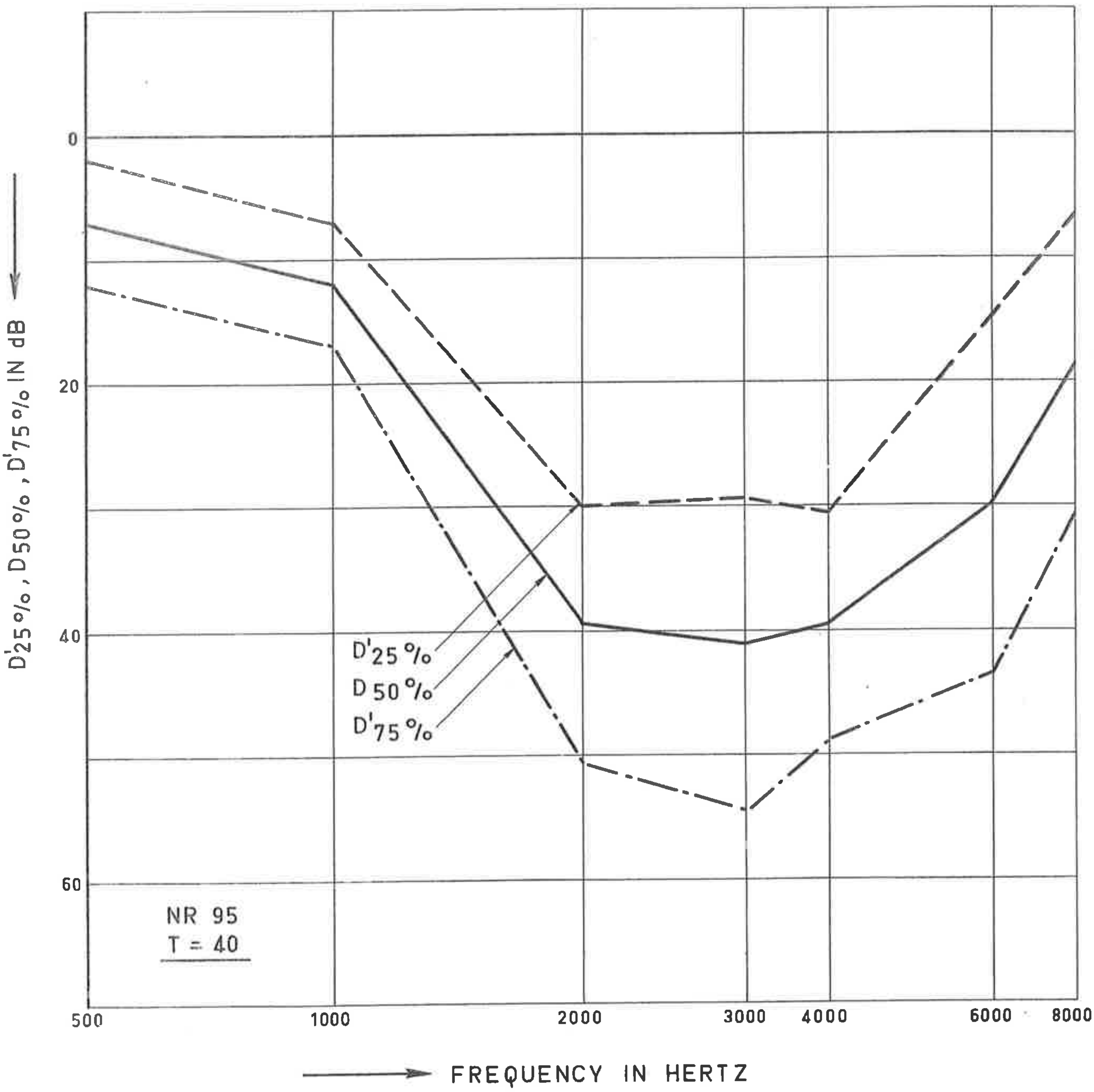
THE DIFFERENCE ($D'_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\,\%}$ OF PEOPLE NOT EXPOSED.



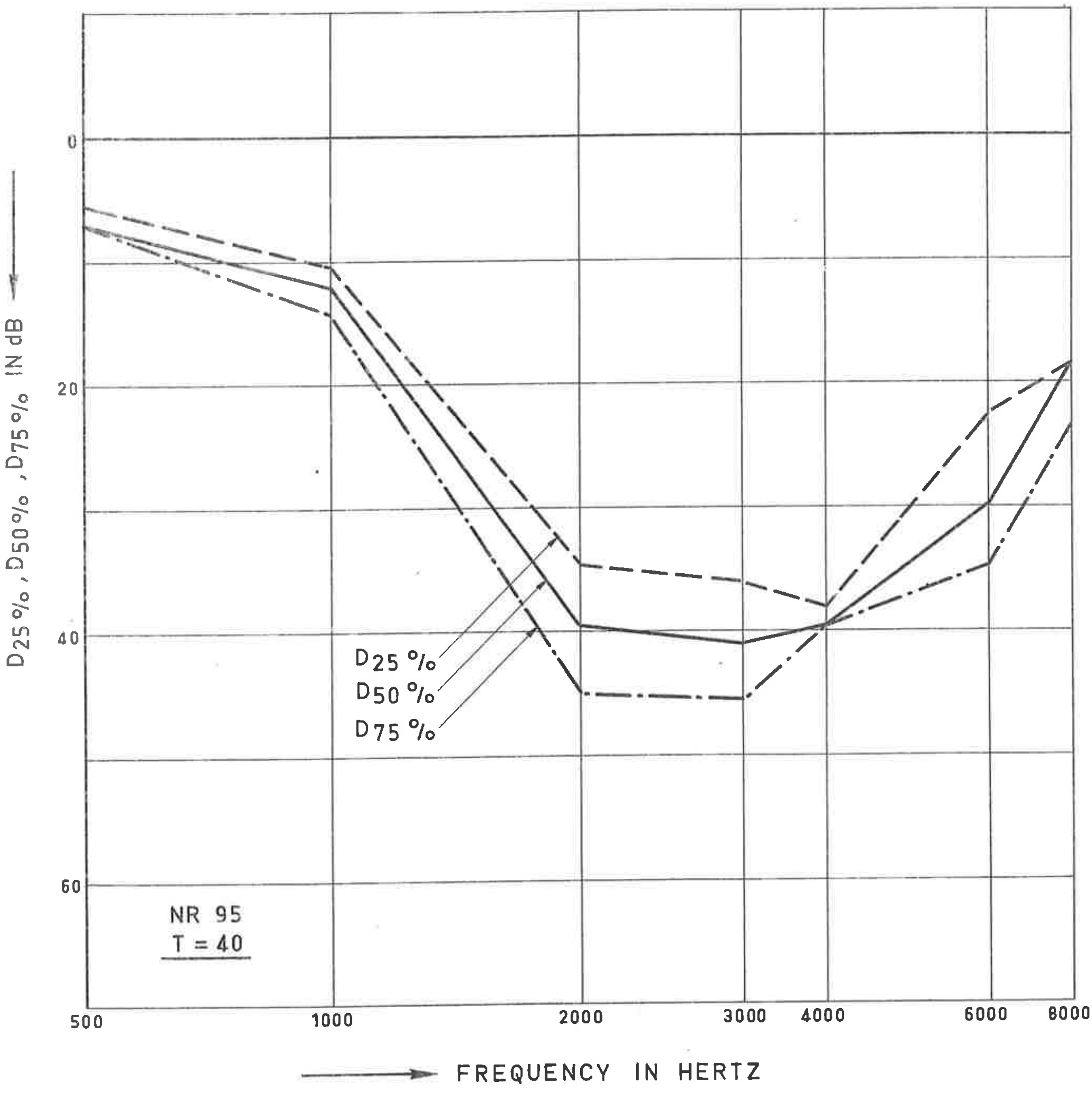
THE DIFFERENCE ($D_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.



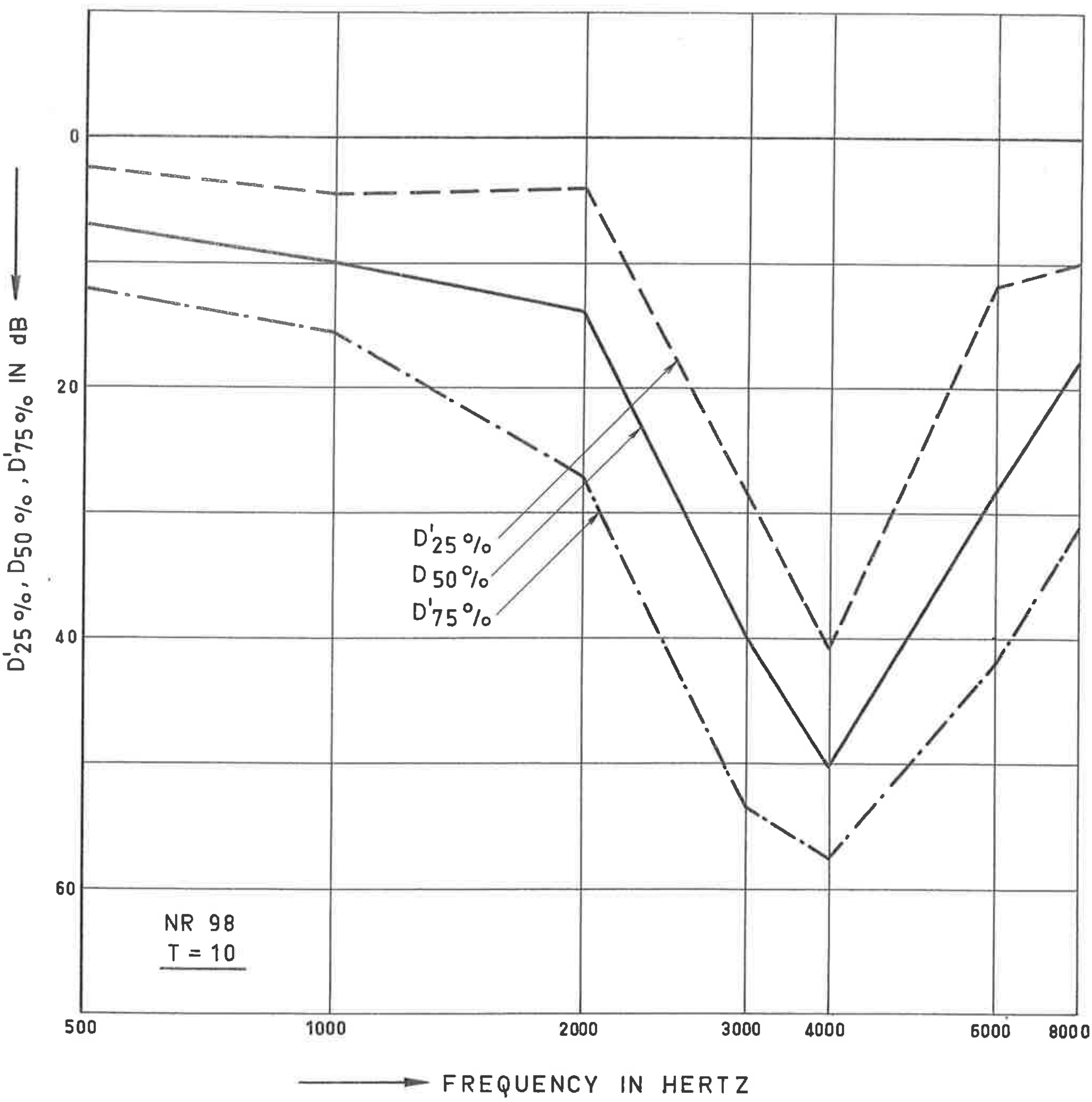
THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.



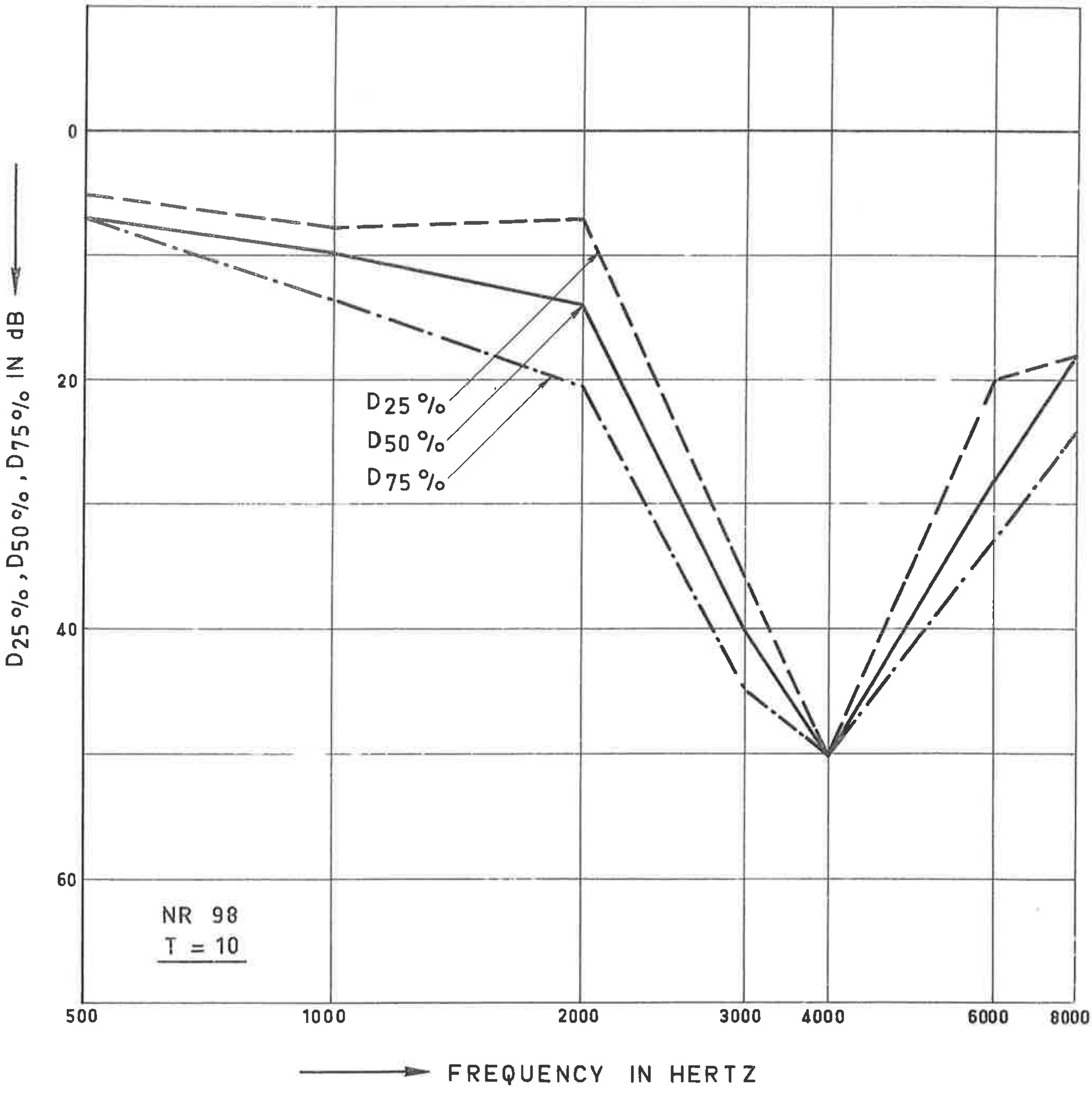
THE DIFFERENCE ($D_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\,\%}$ OF PEOPLE NOT EXPOSED.



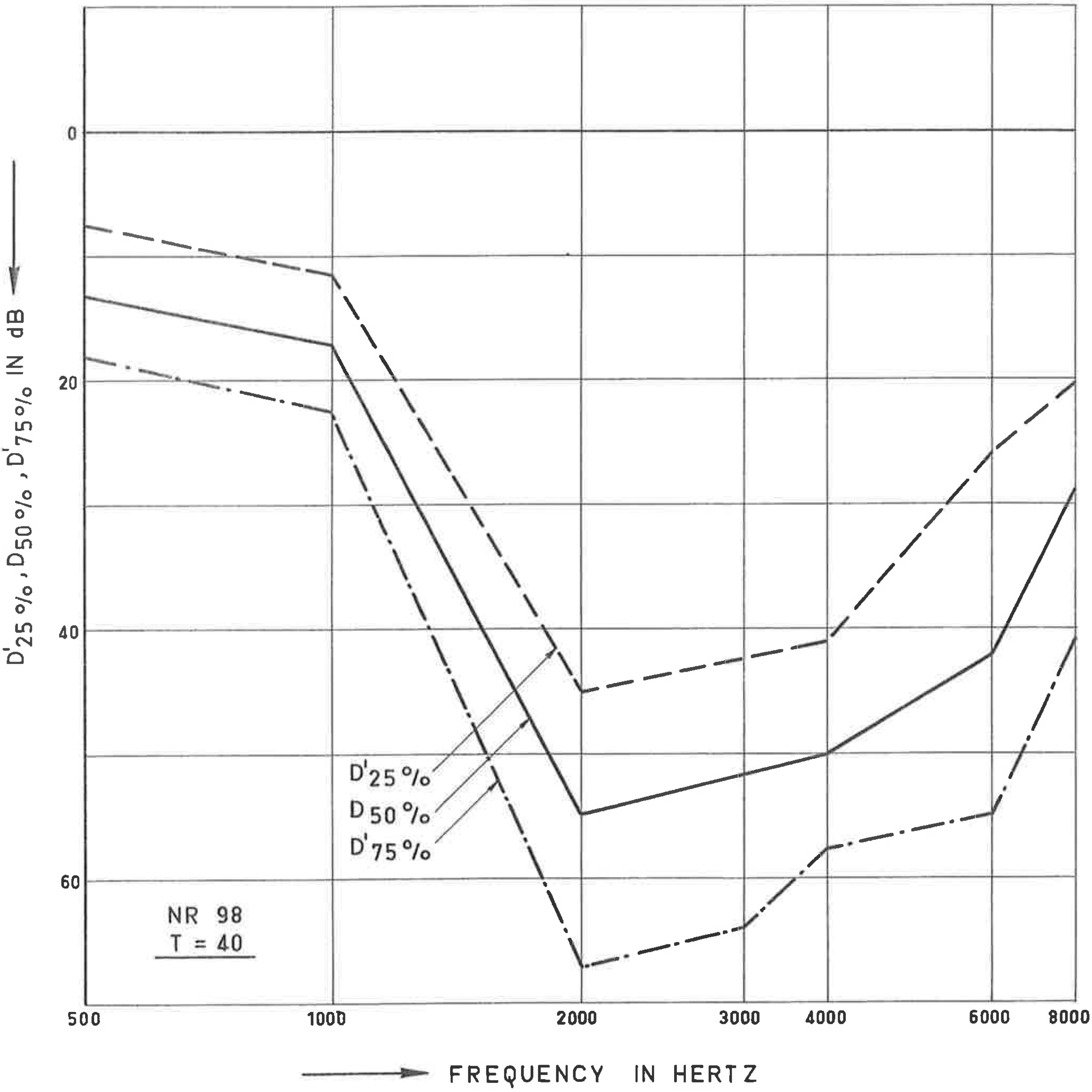
THE DIFFERENCE ($D'_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\,\%}$ OF PEOPLE NOT EXPOSED.



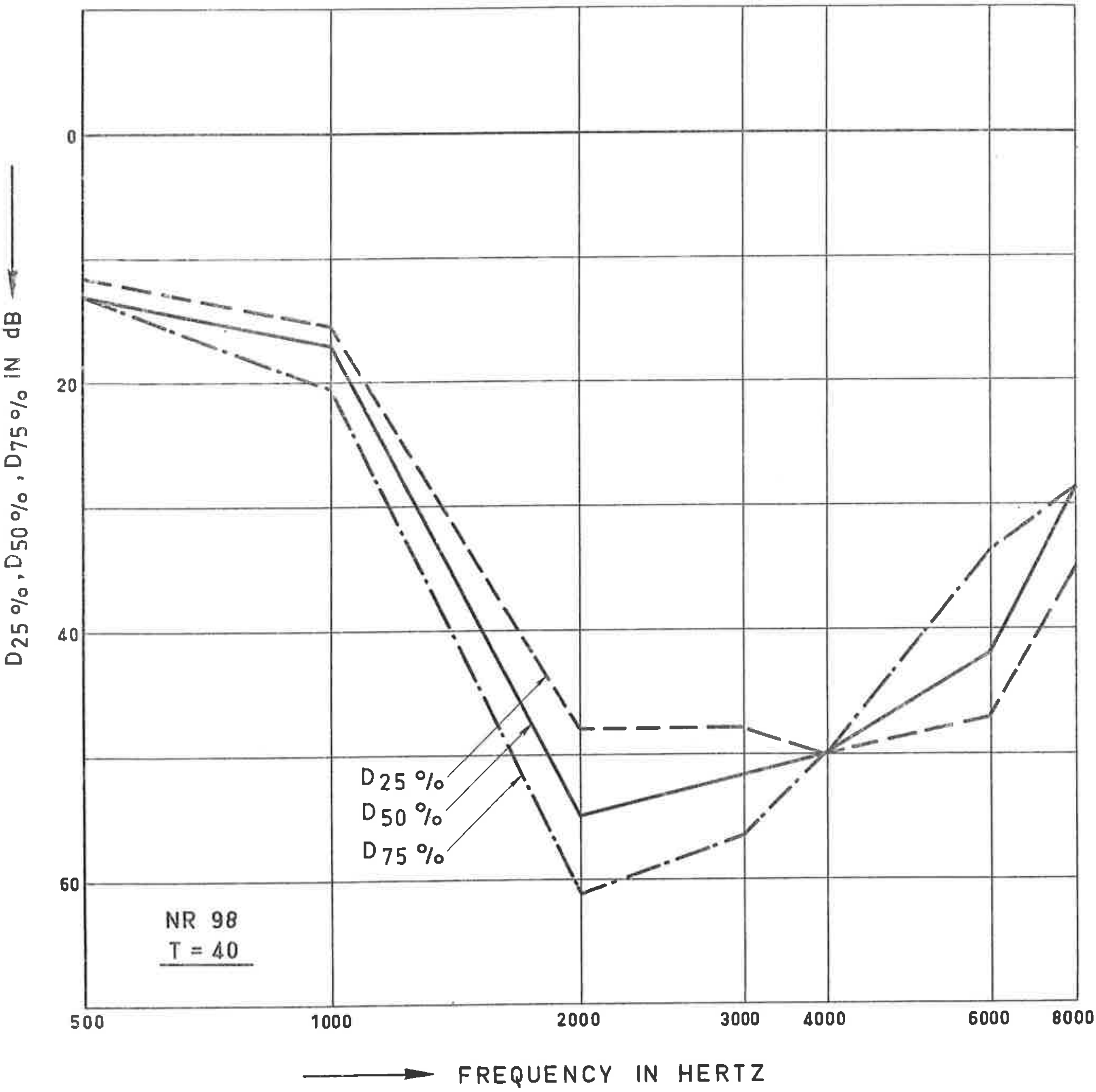
THE DIFFERENCE ($D_{x\,\%}$) BETWEEN $L_{e,x\,\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\,\%}$ OF PEOPLE NOT EXPOSED.

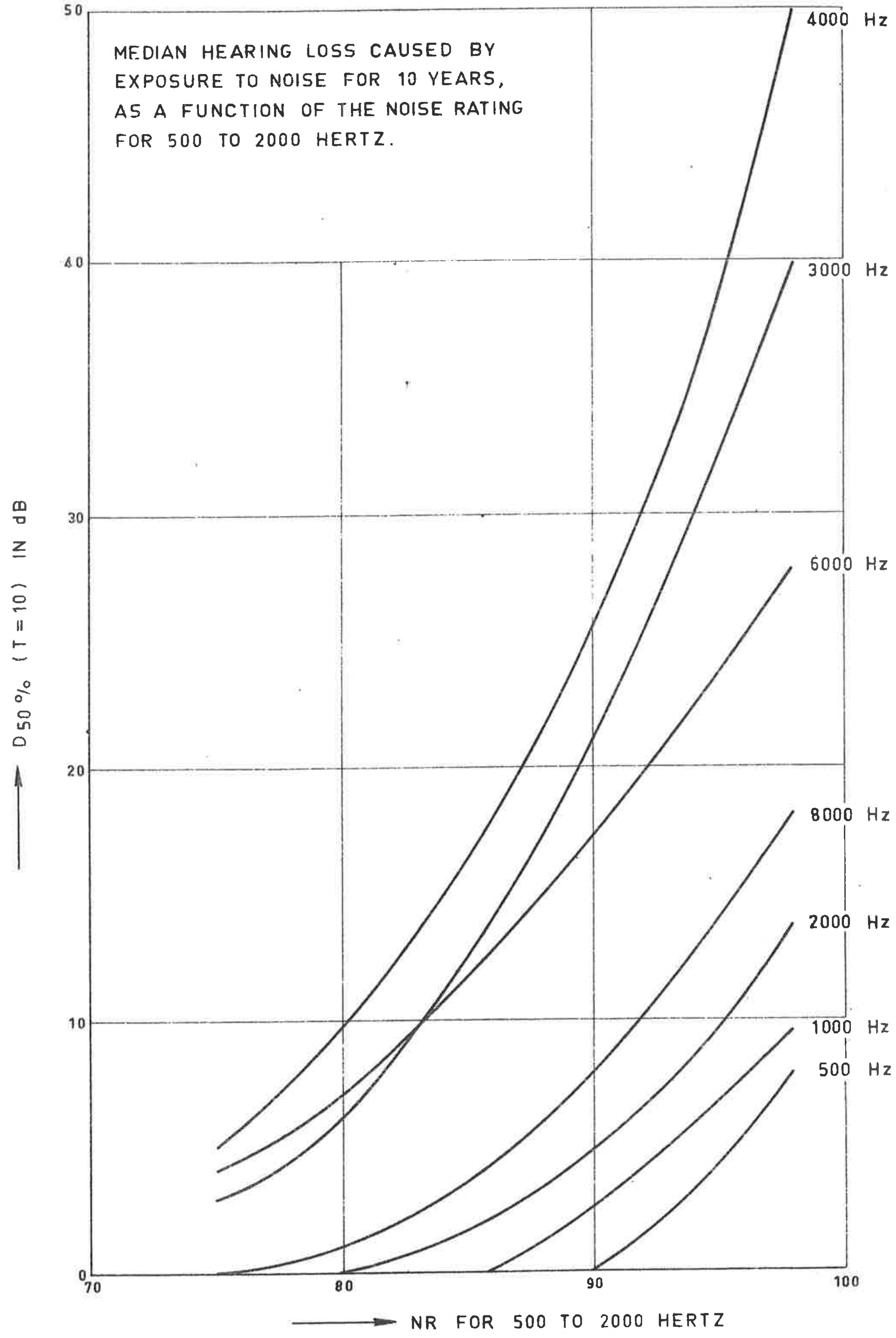


THE DIFFERENCE ($D'_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,50\%}$ OF PEOPLE NOT EXPOSED.



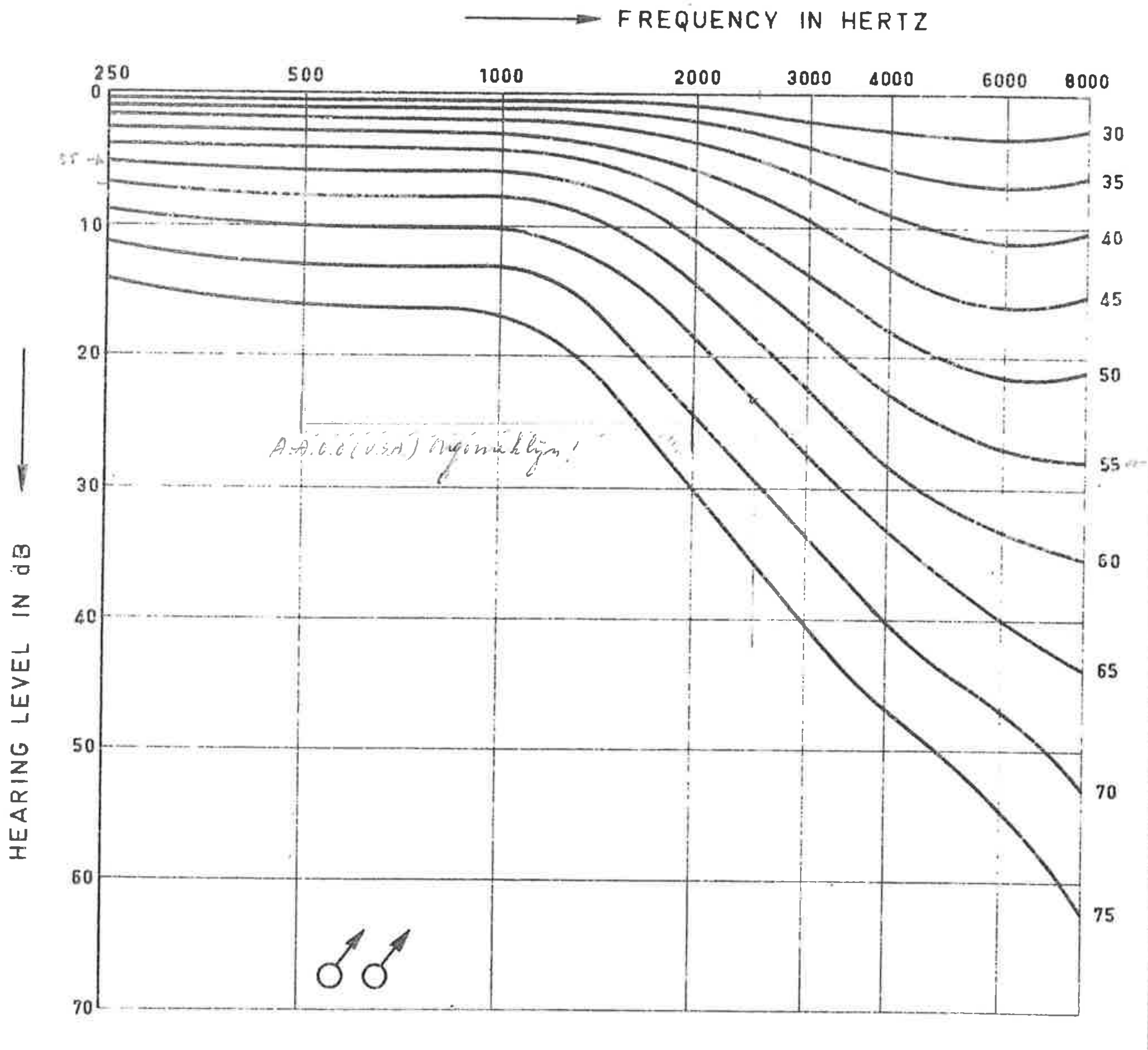
THE DIFFERENCE ($D_{x\%}$) BETWEEN $L_{e,x\%}$ OF PEOPLE EXPOSED, AND $L_{n,x\%}$ OF PEOPLE NOT EXPOSED.



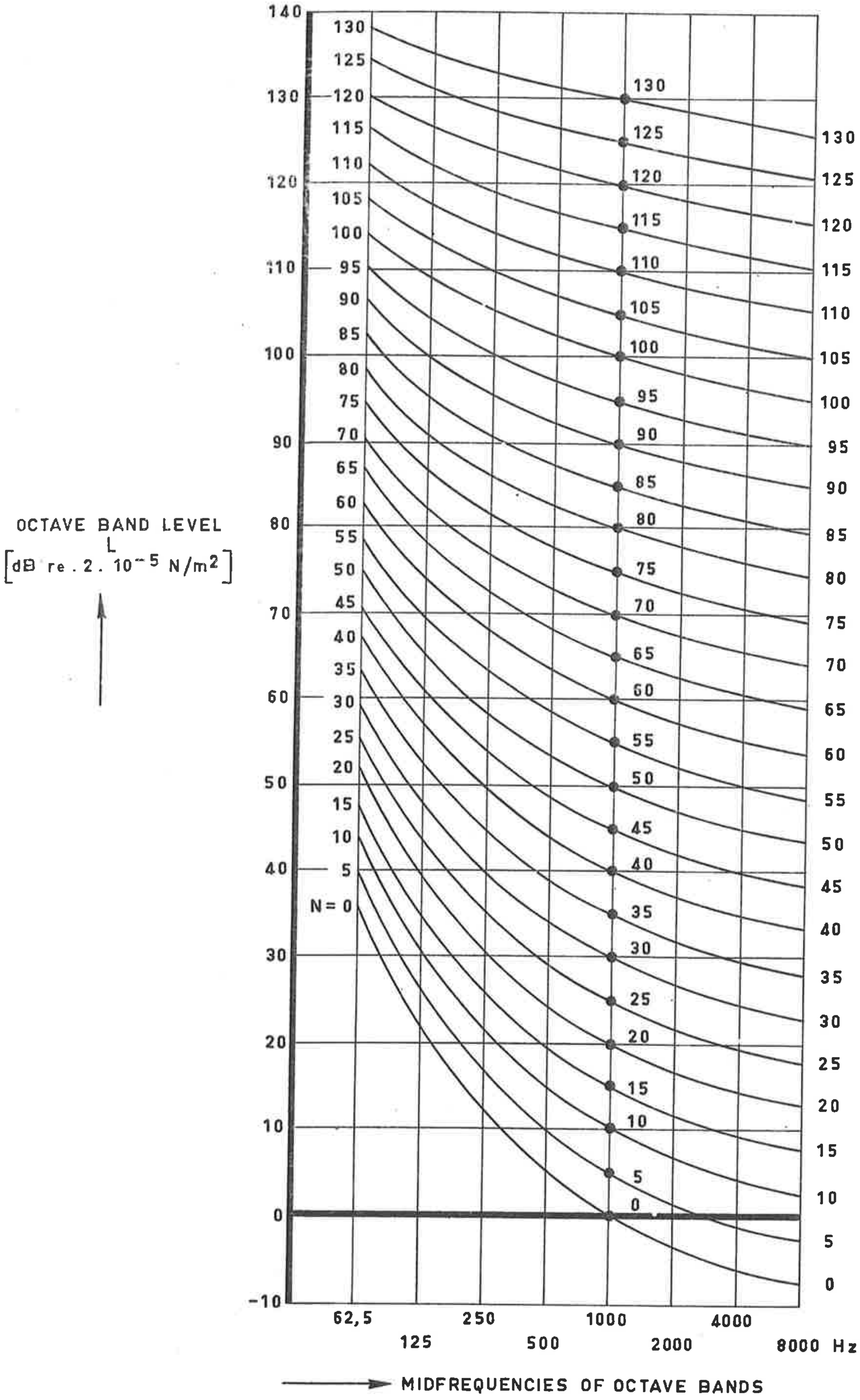


MEDIAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 10 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.
50
40
30
20
10
0
70
80
90
100
4000 Hz
3000 Hz
6000 Hz
8000 Hz
2000 Hz
1000 Hz
500 Hz
D 50 % (T = 10) IN dB
NR FOR 500 TO 2000 HERTZ

MEDIAN HEARING LEVELS OF MEN NOT EXPOSED TO NOISE, AS A FUNCTION OF FREQUENCY; AGE IS PARAMETER



NOISE RATING CURVES



68 B 120	I G - T N O AFD. GELUID EN LICHT	R35 - C