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RELATION BETWEEN DAILY NOISE EXPOSURE AND HEARING BASED ON THE EVALUATION OF 6,835 INDUSTRIAL NOISE EXPOSURE CASES

AEROSPACE MEDICAL RESEARCH LABORATORY

PREPARED FOR

ENVIRONMENTAL PROTECTION AGENCY

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W. L. BAUGHN, M.D.

GUIDE LAMP DIVISION

GENERAL MOTORS CORPORATION

JUNE 1973

JOINT EPA/USAF STUDY

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13. ABSTRACT

The present study is designed to display the percent of a population exhibiting greater than certain specified audiometric hearing levels as a function of specified exposure levels and duration of exposures to those levels. Audiometric data from 6,835 employees of an industrial plant were taken during the period from 1960 through 1965. The employees were selected only on the criterion that their noise exposures were reasonably well known. Hearing levels for each of three exposure conditions (78, 86, and 92 dBA) were obtained for the speech (0.5, 1, and 2 kHz) and the 4 kHz audiometric frequencies. The data are smoothed and hearing risk tables are presented.

Key Words: hearing risk

hearing damage--hearing loss

presbyacusis

NIPTS (noise induced permanent threshold shift)

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FOREWORD

During a collaborative effort for the American National Standards Institute, Working Group 46 on Hearing Conservation, this technical report was completed in 1968 by Dr. William L. Baughn of the Guide Lamp Division of the General Motors Corporation and transmitted in letter form to Dr. H. O. Parrack (now deceased) of this Laboratory. The scientific information in the "letter" has been widely used as the basis for selecting criteria limits of noise exposure for purposes of hearing conservation. Among the most well-known uses are its basis for the revisions of both AFR 160-3 (AFR 161-33) on Hazardous Noise Exposure and for the International Standards Organization (ISO) Recommendation R1999, "Assessment of Occupational Noise Exposure for Hearing Conservation Purposes."

The Biodynamics and Bionics Division of Aerospace Medical Research Laboratory is currently developing a criteria document, "A Scientific Basis for Limiting Noise Exposure for Purposes of Hearing Conservation," under an Interagency Agreement with the Environmental Protection Agency. The University of Dayton Research Institute is providing technical support for this effort under contract F33615-72-C-1402. Dr. Baughn is a prime consultant to the University of Dayton Research Institute and his technical information serves as important background information for the criteria document. However, it was considered mandatory that any material contained in the criteria document be available in the published literature. The publication of Dr. Baughn's report, in addition to serving as the basis for the new AFR 161-33, also satisfies the technical information availability requirement for the criteria document and will allow it to be successfully completed.

The Aerospace Medical Research Laboratory and the Environmental Protection Agency greatly appreciate Dr. Baughn's and his company's collaboration in making this extremely valuable technical information available for publication in its complete form.

This technical report has been reviewed and is approved.

HENNING E. G. von GIERKE, Dr. Ing.
Director
Biodynamics and Bionics Division
Aerospace Medical Research Laboratory

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OF

6,835 INDUSTRIAL NOISE EXPOSURE CASES

The present study is designed to display the percent of a population exhibiting greater than certain specified audiometric hearing levels as a function of specified exposure levels and duration of exposure to those levels.

THE DATA

The audiometric data dealt with in this study consists of 6,835 audiograms of employees in a midwestern industrial plant. This is a little more than one third of all audiograms taken from this population over the six year period from 1960 through 1965. About two thirds of the available audiograms from this period were eliminated from the study because the subjects had significant unknown or mixed exposures.

The audiometric test environment conformed fully with the specifications of the American Standards Association. The audiometers were Maico H-1 models and were checked against normal experienced ears before each day's use, and were calibrated in the laboratory of the Maico Company periodically. They were never found to be out of the acceptable calibration range.

The same two trained and experienced audiometrists took all the audiograms used in the study. Prior to the beginning date they had done more than 25,000 audiograms over a period of eight years, all of which had been submitted to the laboratory of the Subcommittee on Conservation of Hearing, of the American Academy of Ophthalmology and Otolaryngology in Los Angeles where samples were subjected to consistency tests and mathematical analysis by Dr. Ann Summerfield. Similar tests applied to the data used in this study have confirmed its self consistency.

THE NOISE STUDIES

The noise studies used in this work consist of nearly 15,500 detailed sound analyses of work-location exposures covering a period of 14 years. Interviews and studies of work records, and comparative testing of older with more recent equipment and processes allowed extension in some subjects back 40 years or more with reasonable confidence that their exposures were known with sufficient precision to allow their inclusion in the study.

While the noise analyses included octave bands, A, B, and C weightings, along with SIL and other computed indices in both slow and fast inertial dynamics, and all these repeated with the General Radio Impact meter, only the A weighting and slow meter dynamics reading was used in this study. We, and we believe most others working in the field, are satisfied that the A - slow reading provides an adequately precise index to the long-term effect of noise on the hearing function and present evidence is that it more accurately predicts the effects of noise on hearing than any other available single-number index.

All noise analyses were done with General Radio 1551-B noise level meter and 1550-A octave band analyzer conforming to the applicable A. S. A. apecifications. All were done by engineers or engineering students under competent supervision and data were tested for consistency. Readings for each noise field used in the analysis were logarithmically averaged over the several noise measurements made on that particular exposure over the years.

The three exposure levels used are 78 dBA, 86 dBA, and 92 dBA. It was about these levels that actual exposures in the environment under study tended to cluster most closely, thus yielding the largest population samples with the narrowest exposure distributions. Approximately five thousand "A" - slow averaged readings were used in assigning exposure levels. Those studies show that individuals assigned 78 dBA exposure spent 65% of their working time in exposures no greater than 80 and no less than 74 dBA, 90% no greater than 81 nor less than 66 dBA. The remaining 10% may have occasionally been as high as 82 dBA and as low as 42 dBA.

The group assigned 86 dBA spent 65% of their work time at 86 ± 2 dBA, 80% ± 4 dBA, and not more than 5% at above 92 and below 78 dBA combined.

The group assigned 92 dBA spent 65% of their work time at 92 ± 3 dBA, 87% at 92 ± 5 dBA, and not more than 5% at above 100 and below 84 dBA combined. (Table 1)

The noise in all three groups was generally relatively rich in low frequency components, which is to say it conformed roughly with the inverse of the "A" weighting characteristic of the noise meter. The 78 dB intensity noises tend to be located principally in crib, storage, shipping, and office spaces. The 86 dB noises tend to be principally associated with light assembly operations on thin metal, plastic, wood, and glass. The 92 dB exposures arise largely from press operations, grinding, and heavier assembly operations. Some impulsive characteristic is evident, particularly in the 86 and 92 dB exposures, but no impact sources such as riveting guns or impact wrenches are represented.

The population under study is composed of the employees of a midwestern industrial plant producing automobile parts. The factory is under one roof and has occupied its present site for more than 40 years. The employees are drawn from the surrounding agriculatural-industrial community of about 100,000 population. The work force is very stable with relatively light turnover, particularly in its older members, providing a high continuity of employment both in location and job content. A number having remained in the same work 40 years and more. The age range is from 18 to 68 years.

TABLE 1

MEAN PERCENT OF TIME SPENT AT EACH dBA LEVEL BY SUBJECTS IN EACH EXPOSURE GROUP

dBA	78	86	92
65 - 66	.75		
66 - 67	1.		
67- 68	1.		
68 - 69	1.		
69 - 70	1.		
70 - 71	1.		
71 - 72	2.		
72 - 73	2.		
73 - 74	3.		
74 - 75	3.		
75 - 76	4.		
76 - 77	10.		
77 - 78	12.	.5	
78 - 79	16.	2.	
79 - 80	20.	2.	
80 - 81	12.	3.	
81 - 82	5.	4.	
82 - 83	2.	6.	
83 - 84	1.	8.	.5
84 - 85	.5	10.	2.
85 - 86		13.	2.
86 - 87		14.	2.5
87 - 88		14.	3.5
88 - 89		10.	4.5
89 - 90		8.	6.0
90 - 91		5.	10.0
91 - 92		3.	12.0
92 - 93			14.0
93 - 94			12.0
94 - 95			10.0
95 - 96			6.0
96 - 97			5.0
97 - 98			3.5
98 - 99			2.0
99 - 100			1.0
100 - 101			

Chronological age is used as the uniform measure of exposure duration. Attempts have been made to modify this measure to accommodate rest periods within the work day, absences due to lay-offs, vacations, illnesses, etc. The fact remains that the average employee in this population enters the work force at age 18, has an average number of rest periods, illnesses, etc, and ends his industrial employment at age 65 or 68 with an average duration of exposure to industrial noise directly related to his age. Neither philosophy nor mathematics has given us any reason to believe another index to duration of exposure is in any way superior.

Subjects with seriously mixed exposures, or unknown exposures, were categorically excluded from the study. No other selection was made. Changes in hearing level reflect all causes of such change.

This brings into focus a criticism of our work which has been leveled since our first publication of it in 1966. This is relative to our decision not to exclude on the basis of historical or objective anatomical ear defects. Had we excluded on the basis of possibly significant history and possibly significant anatomical defects, our numbers would have suffered seriously, and consequently our statistical confidence levels. There comes a time when further exclusion is counter-productive. Our own work, and that of others, has indicated that quite small changes in hearing level numbers follow even massive exclusion based on history and physical examination.

Following the exclusions from the study detailed above, we were left with 6,835 audiograms matched with exposure history in terms of three exposure groups identified as 78 dBA, 86 dBA, and 92 dBA.

The criteria for defining those members of the population who have suffered an "impairment" of hearing are based on the thesis that impairment shall be for the understanding of spoken English in sentence form. The American Academy of Ophthalmology and Otolaryngology has determined, and the American Medical Association has concurred, that such impairment begins when the arithmetic mean of the audiometric hearing levels at 500, 1000, and 2000 cycles per second exceeds 15 decibels (A. S. A. 1951), or 25 decibels (I. S. O. 1964) and that impairment increases at the rate of 1 1/2% for each decibel in excess of 15 (A. S. A.) or 25 (I. S. O.) until a maximum of 100% has been reached at 82 decibels (A. S. A.) or 92 decibels (I. S. O.).

We have accepted this 15 dB (A. S. A.) as our criterion for beginning impairment. When we identify a certain percent of the population under study as having a mean hearing level (at the speech frequencies) of more than 15 dB (A. S. A.), it means that this percent of the population has at least a beginning calculable impairment.

METHOD

(All audiograms were done prior to the end of 1965 and all were done to A. S. A. 1951 standard audiometric zero calibration. All audiometric, exposure, and identification data were entered on punched cards and all sorting and calculations were done by electronic data processing equipment.)

The population under study, after having been stripped of members with mixed and unknown exposures, was divided into three exposure groups. There were 852 members in the group assigned exposure 78 dBA, 5,150 members of the group assigned 86 dBA, and 833 members of the group assigned 92 dBA.

Each exposure group was broken into eight age groups. Each age group covers a span of six years, the youngest group encompassing ages 18 through 23 years inclusive and the oldest age group 60 through 65 years inclusive.

TABLE 2. AGE SPAN AND EXPOSURE DATA

Age Group Number	Age Span	Exposure I 78 dBA	Exposure II 86 dBA	Exposure III 92 dBA	Total
1	18 -23	N = 10	N = 107	N = 4	121
2	24 -29	68	476	39	583
3	30 -35	144	544	76	764
4	36 -41	148	860	124	1132
5	42 -47	183	1041	189	1413
6	48 -53	159	1070	197	1426
7	54 -59	95	723	127	145
8	60 -65	45	329	77	451
		852	5150	833	6835

E. D. P. Cards are punched for each subject carrying the exposure level, age group, and audiometric data. Audiometric hearing levels at 500, 1000, and 2000 Hz are added for each subject and the sum divided by three. These three frequency mean hearing levels are printed out as an array by increasing hearing levels. A break is made at each change of hearing level (each 1 2/3 dB H. L. for the three frequency average) and the percent of that age-exposure group lying below this change is noted.

Now the percent-of-the-group below is plotted on some type of distribution paper (since there are elements of several kinds of distribution present, it doesn't make any real difference which form of grid we use.) We have chosen to do the primary graphic interpolation on normal distribution paper (Fig.1 is an example.) Terminal distributions are done, where necessary, on log-normal paper, since the extremes of the distributions, particularly in higher age groups tend to be log-normal (Fig. 2.)

Whatever method of interpolative smoothing is used yields a series of crossing points on the distribution graph (or by formula) as intersections between the regression line (representing hearing level) and percentage distribution line on the graph. We have chosen to select the nine inter-decile points for further work. Quartile or centile points could be chosen, but we feel the deciles give sufficiently high resolution to exhaust the quality of the data and provide sufficiently smooth curves for our later work. Now we tabulate all the inter-decile points from all 24 graphs, Table 3.

Plotting and least squares smoothing is all that is required to complete the work graphs for a procedure dealing only with data within the experimental field, and was in fact what was done for the initial work on these data which was reported in 1966.[1]

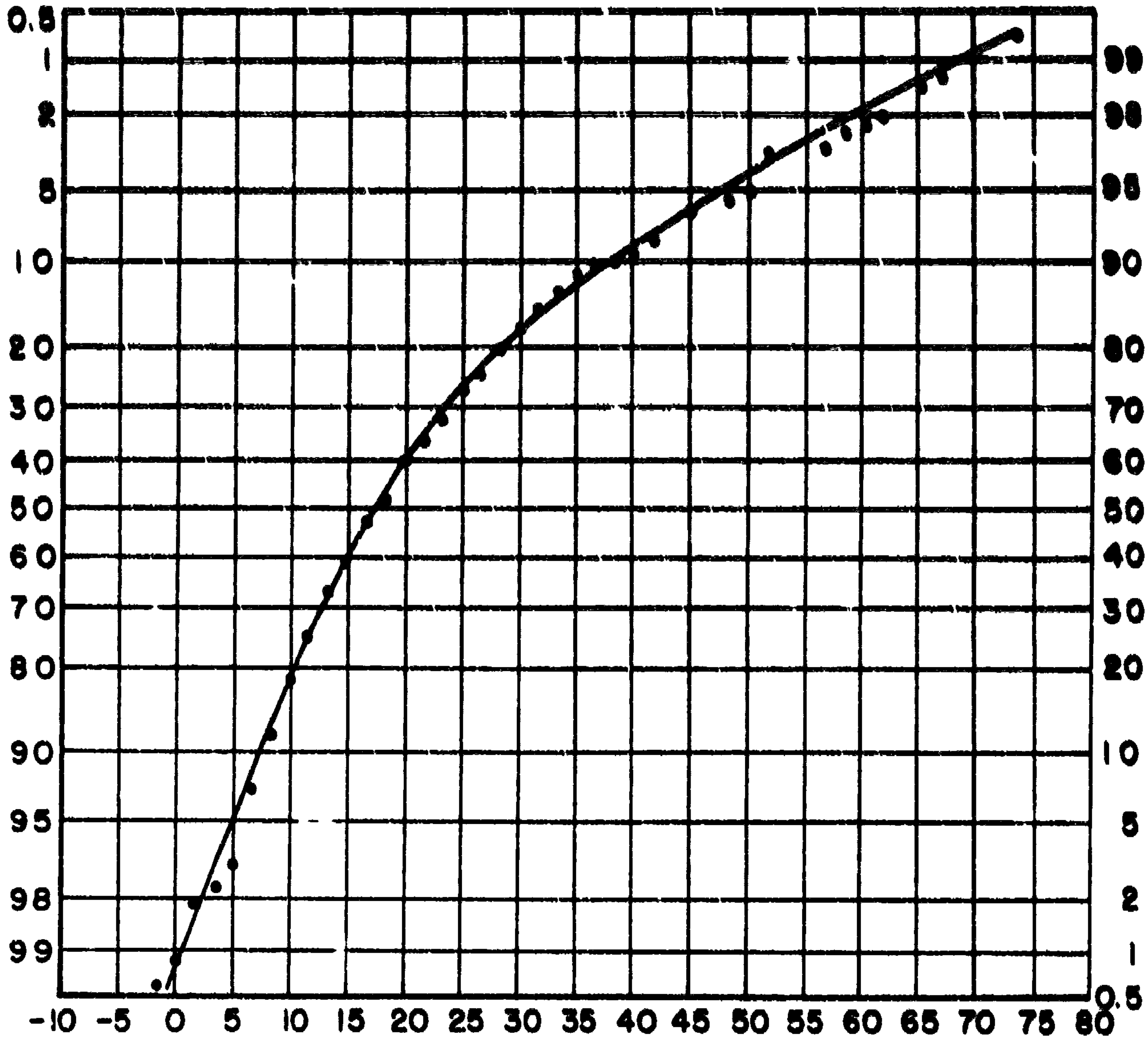

Figure 1. Typical distribution of hearing level for a specific age and exposure group. This distribution was for a group ranging in age from 60 to 65 years and exposure of 86 dBA.

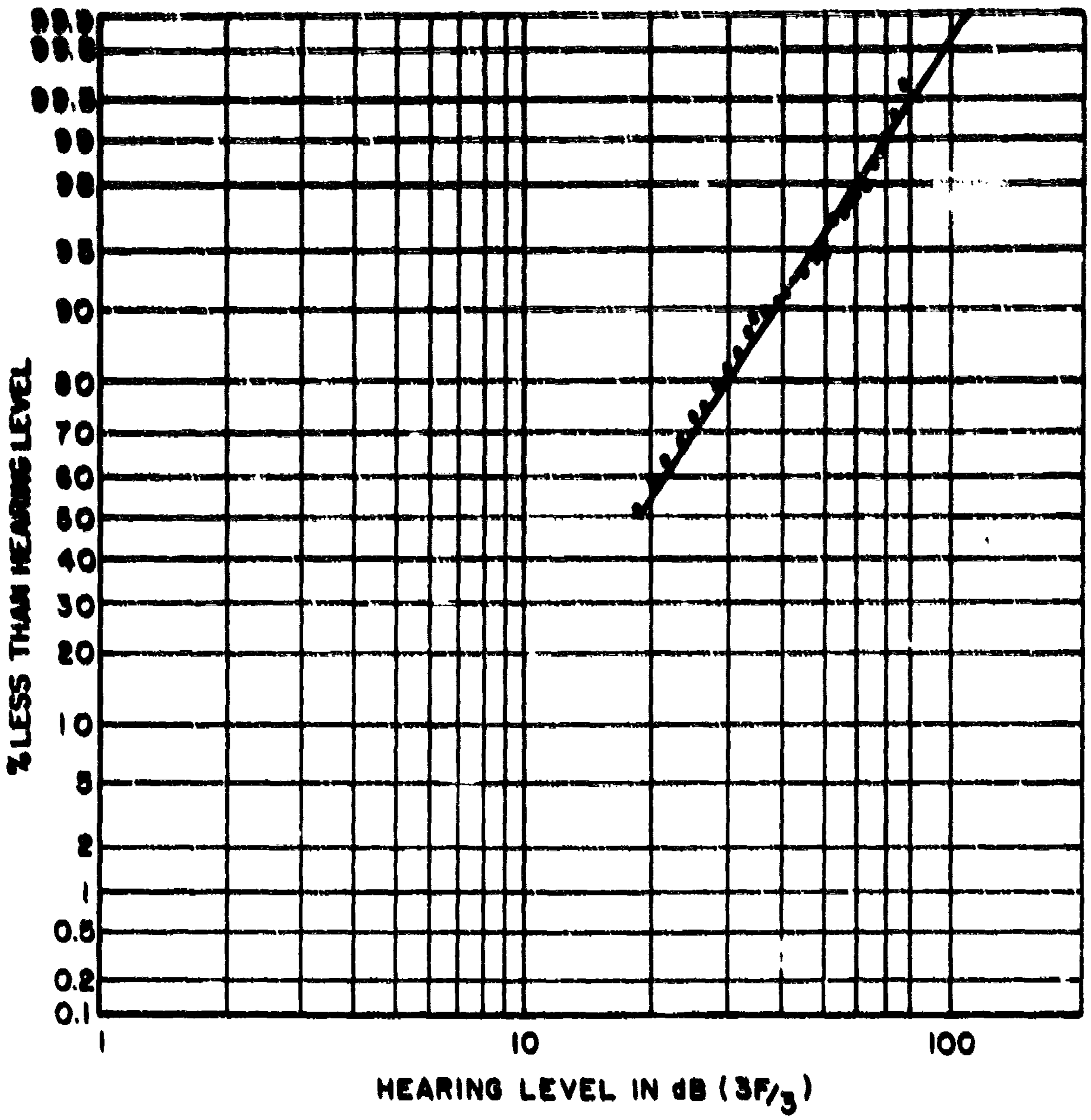

Figure 2. Typical terminal distribution plotted on log-normal paper. This distribution was for a group ranging in age from 60 to 65 years and exposure of 86 dBA.

TABLE 3

DATA FROM GRAPHIC SMOOTHING PROCEDURE
(3F/3)

Int. Dec. Points	AGE 18 - 23			AGE 24 - 29			AGE 30 - 35			AGE 36 - 41		
	78	86	92	78	86	92	78	86	92	78	86	92
1	-.2	1.3	3.0	-1.0	1.3	5.0	0.0	1.6	4.5	.5	3.0	4.3
2	1.3	3.1	3.9	1.2	3.2	5.2	2.1	3.5	6.8	2.4	4.7	6.3
3	3.0	4.1	4.9	2.5	4.6	5.9	3.2	4.9	7.9	3.6	6.0	7.9
4	3.9	5.0	5.8	3.8	5.6	6.3	4.2	6.1	8.8	4.6	7.0	9.2
5	4.4	5.7	6.3	4.9	6.4	7.3	5.2	7.2	9.4	5.6	8.2	10.7
6	5.2	6.4	7.6	5.9	7.2	8.5	6.2	8.5	10.6	6.6	9.5	12.3
7	6.1	7.1	8.9	7.0	8.4	10.0	7.3	10.0	12.1	7.9	11.1	14.2
8	7.1	8.0	10.3	8.4	9.8	12.6	8.6	11.9	14.1	9.3	13.3	16.9
9	8.0	9.7	13.0	10.6	11.9	18.0	10.5	15.2	18.2	12.0	18.5	22.1

Int. Dec. Points	AGE 42 - 47			AGE 48 - 53			AGE 54 - 59			AGE 60 - 65		
	78	86	92	78	86	92	78	86	92	78	86	92
1	1.0	3.2	6.6	2.0	3.6	6.2	3.3	6.5	7.2	7.3	7.4	9.6
2	3.0	5.0	7.6	4.5	5.6	8.3	5.6	7.9	10.0	9.4	10.5	12.4
3	4.5	6.6	9.0	6.3	7.3	10.0	7.1	9.8	12.1	11.1	13.0	14.8
4	5.8	7.9	10.4	7.9	8.8	11.5	8.5	11.5	14.1	12.8	15.2	16.9
5	6.9	9.2	11.8	9.4	10.2	13.2	10.0	13.2	16.1	14.4	17.5	19.2
6	8.2	10.0	13.2	11.1	12.1	15.2	11.6	15.2	18.3	16.3	20.1	21.9
7	9.7	12.9	15.0	13.1	14.2	17.8	13.6	17.7	21.1	18.4	23.4	25.0
8	11.3	15.5	17.3	15.6	17.3	21.5	16.5	20.0	24.7	21.5	28.2	30.0
9	14.2	20.6	21.6	19.8	23.3	29.4	21.7	27.2	32.0	27.6	38.0	39.0

For all regressions relating exposure to hearing levels by age group, we use a simple logarithmic relationship:

$$\text{Log}_{10} \text{ H. L.} = a + b \text{ Exposure}$$

For all regressions relating time to hearing levels by exposure group, we use a cubic parabola:

$$\text{H. L.} = a + b \text{ Time} + c \text{ Time}^2 + d \text{ Time}^3$$

Working from the "interpolated raw data" table, we fitted such a cubic curve to the medians and to each interdecile set of points. By comparing and smoothing the coefficients we rationalized the interdecile intervals. For the three frequency mean this worked out to a single set of ratios with evidence of well under two decibels probable error for even the most extreme fields, Tables 4 and 5.

Final smoothing of the 216 median and interdecile points is accomplished by use of a statistical method known as "Joint Regression Surfaces." I shall not describe the technique of this method which smoothes associated data in three dimensions simultaneously. It is ideally suited to our problem. This method does not appear in many statistics texts, so we suggest specifically:

Methods of Correlation and Regression Analysis
Ezekiel and Fox
Third Edition
John Wiley & Sons, New York
(Chapter 21)

TABLE 4. DISTRIBUTION COEFFICIENTS

Interdecile #1	=	.67 (Med. + 10) - 10	
" 2	=	.77 " "	
" 3	=	.84 " "	
" 4	=	.91 " "	
" 5	=	Median	
" 6	=	1.16 Med.	
" 7	=	1.35 "	
" 8	=	1.61 "	
" 9	=	2.10 "	

We have now completed the interpolation process and have allowed 216 raw data points (3 exposure groups x 8 age groups x 9 interdecile points) to arrange themselves by mutual push and pull into a most probable arrangement in space. The fact that we had to subjectively choose specific curves for them to follow prohibits us from saying the most probable arrangement. Indeed, we may be sure it is not the most probable arrangement. For example, we know that our median to interdecile ratios tend to slightly understate the interval between median and first decile at very low ages and exposures (but not by more than .3 dB at 18 years and 78 dB), and understates the median to ninth decile interval at very high ages and exposures (but not more than 1.7 dB at 65 years and 92 dB.)

To proceed: we now have families of deciles which reflect as accurately as is

TABLE 5

MATHEMATICALLY SMOOTHED DECILE POINTS (3F/3)

Int. Dec. Points	AGE 18 - 23			AGE 24 - 29			AGE 30 - 35			AGE 36 - 41		
	78	86	92	78	86	92	78	86	92	78	86	92
1	- .2	.39	.72	-.02	1.12	2.06	.25	1.59	3.07	.72	2.13	3.87
2	1.24	1.94	2.32	1.47	2.78	3.86	1.78	3.32	5.02	2.32	3.94	5.93
3	2.26	3.02	3.44	2.52	3.94	5.12	2.85	4.53	6.38	3.44	5.20	7.39
4	3.29	4.11	4.56	3.56	5.11	6.38	3.92	5.74	7.75	4.56	6.47	8.84
5	4.6	5.5	6.0	4.9	6.6	8.0	5.3	7.3	9.5	6.0	8.1	10.7
6	5.34	6.38	6.96	5.68	7.66	9.28	6.15	8.47	11.02	6.96	9.4	12.4
7	6.2	7.4	8.10	6.62	8.91	10.8	7.16	9.86	12.83	8.10	10.6	14.45
8	7.41	8.86	9.66	7.89	10.63	12.88	8.53	11.75	15.3	9.66	13.04	17.23
9	9.66	11.55	12.6	10.3	13.86	16.8	11.13	15.33	19.95	12.6	17.01	22.47

Int. Dec. Points	AGE 42 - 47			AGE 48 - 53			AGE 54 - 59			AGE 60 - 65		
	78	86	92	78	86	92	78	86	92	78	86	92
1	1.39	2.80	4.67	2.33	3.74	5.81	3.74	5.48	7.49	6.42	8.22	9.83
2	3.09	4.71	6.86	4.17	5.79	8.17	5.79	7.79	10.1	8.87	10.9	12.79
3	4.28	6.04	8.40	5.46	7.22	9.82	7.22	9.40	11.9	10.58	12.85	14.86
4	5.47	7.38	9.93	6.74	8.66	11.48	8.66	11.02	13.75	12.30	14.75	16.94
5	7.0	9.1	11.9	8.4	10.5	13.6	10.5	13.1	16.1	14.5	17.2	19.6
6	8.12	10.56	13.8	9.74	12.18	15.78	12.18	15.20	18.68	16.82	19.95	22.74
7	9.45	12.29	16.07	11.34	14.18	18.36	14.18	17.69	21.74	19.58	23.22	26.46
8	11.27	14.65	19.16	13.52	16.91	21.89	16.91	21.1	25.9	23.35	27.69	31.56
9	14.7	19.11	24.99	17.64	22.05	28.56	22.05	27.51	33.8	30.45	36.12	41.2

practical the relationships existing between age, exposure, and hearing level. The exposure field represented is "real" and extends from 78 dBA to 92 dBA. We wish to extend these limits to 115 dBA on the upside. The downside doesn't bother us, the 80 dBA "starting point" is an interpolation within the experiential field and is as accurate as anything else in this field. We could simply calculate the extended points from our formulae and hope for the best. To extrapolate a 14 unit field (78 to 92 dBA) almost 25 units upward, especially with complex formulae, would be dangerous. However, it happens that we can establish one or two acceptable "anchor points" in the extrapolated field which will make it considerably less hazardous.

We take all the median points from our known field (24 points, three exposure points for each of 8 age groups) and plot them on a rectilinear grid and study them. We see that the function is not linear on this grid and that the indicated curve is concave upward in all cases except that of the youngest age group. A laying-on of templates (Fig. 3) suggests a logarithmic relationship as likely. A test has shown that the liklihood of a systematic error of -2 dBA in noise measurement limited to the 86 dBA level and varying rationally by age groups is less that 1/100, so we must accept the curvilinearity as real.

We now replot the data on a log. grid and strike straight lines as nearly as possible through the points (Fig. 4 .) This process brings to light three important points about what is now a rather neat family of regression lines:

1. There is a convergence to a crossing point centering on about 130 dBA at about 47 dB H. L. 3F/3. This involves age groups 3, 4, 5, 6, 7, and 8 (ages 30 to 65).

2. There is a crossing point at about 71 dBA/4.8 dB H. L. 3F/3 for age groups 1 and 2 (ages 18 to 29).

3. There is a slight unresolved curvilinearity in seven of the eight regression lines even on the log. grid.

Regarding these anomalies, we reasoned as follows:

Some kind of a crossing point at the upper end of the graph is to be expected as a matter of limits. After all, only so much hearing exists to be lost and only so much biologically effective noise exposure is possible. As to this latter, we know that as exposure levels increase above about 125 dBA, a marked change takes place in the character of the ear's response to the increasing level. Non-linear distortion rapidly increases, pain develops, increases and changes in character. We believe that this area of disintegrating auditory response at 125 - 140 dBA exposure represents a limit to the rational relationship between exposure intensity, time, and progressive degradation of cochlear function.

We do not believe that the location of our crossing point between 125 and 135 dBA is a matter of chance or coincidence. We will place an anchor at 130 dBA, the center of this range.

The other coordinate of this upper crossing point is at about 47 dB H. L. 3F/3. This doesn't yield so quickly to reflection on the known facts. The

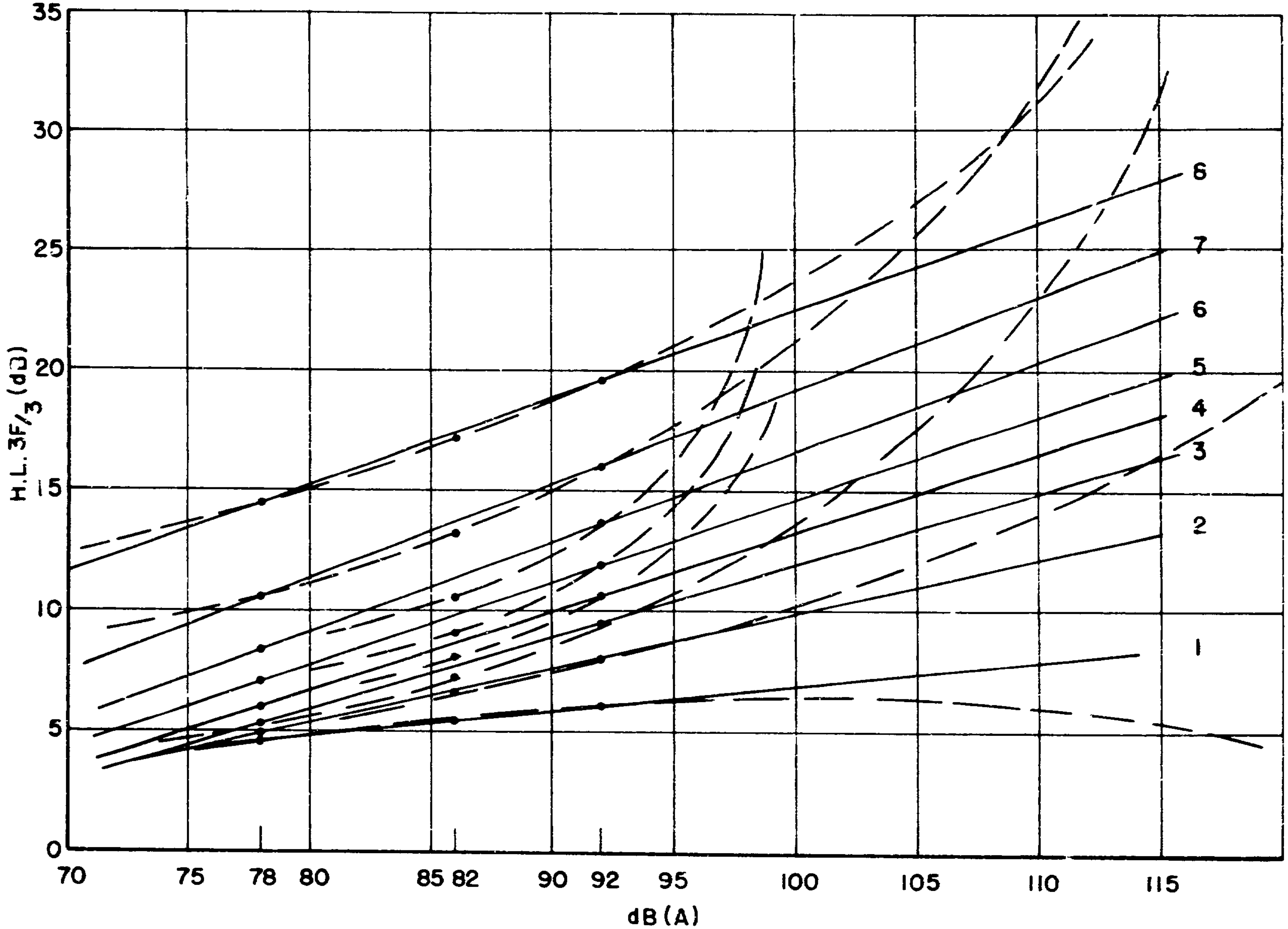

Figure 3. Plot of all median values on rectilinear grid. Note that the function of hearing level versus exposure is not linear.

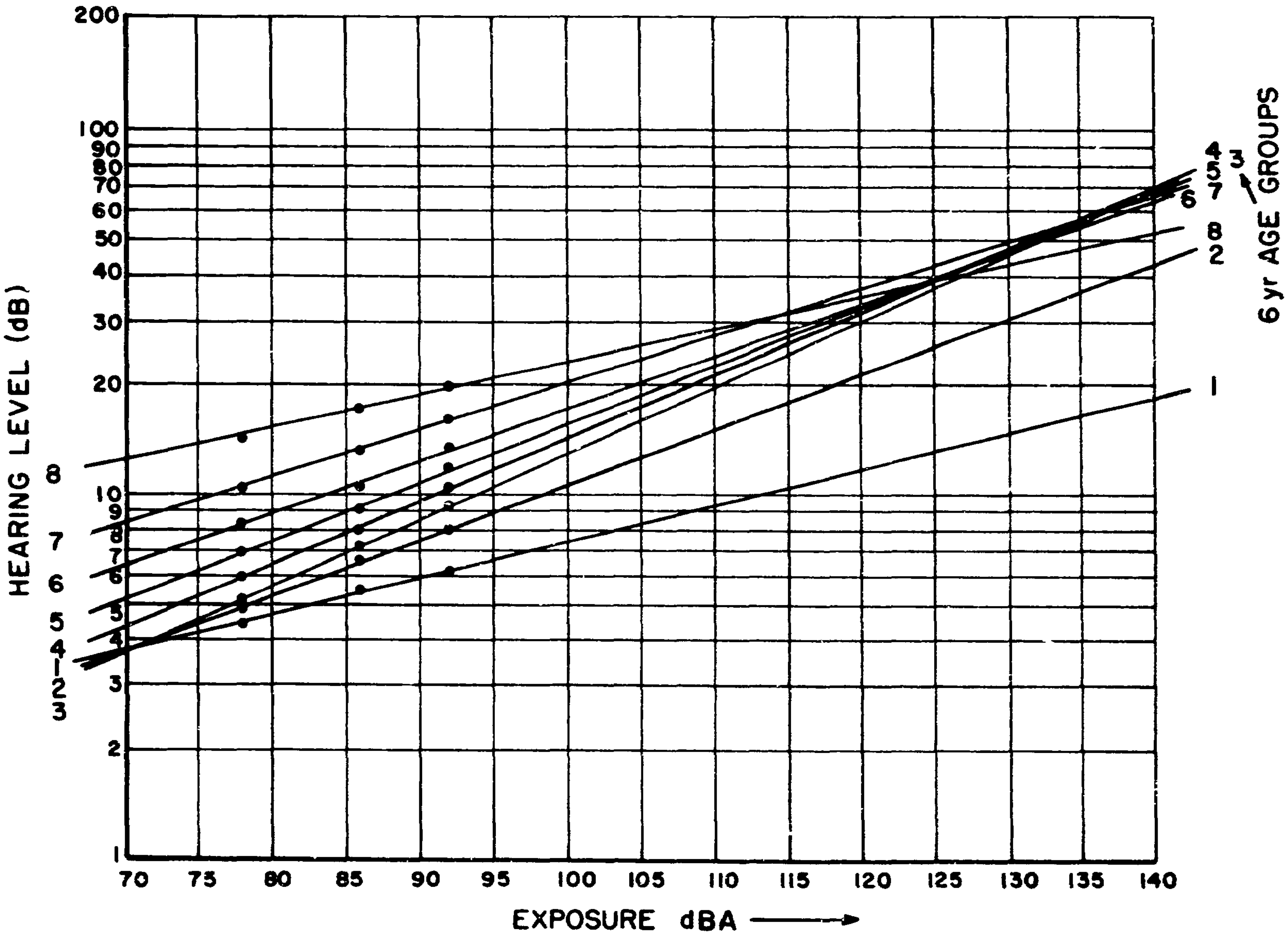

Figure 4. Plot of data from figure 3 on a log grid. Note that straight lines adequately approximate the relationship between hearing level and exposure.

initial implication is that regardless of age or exposure intensity, the median hearing level cannot exceed 47 dB. We know by experience that this is not true. We have in our files, for example, some excellent audiograms secured from Stewart Nash a number of years ago indicating median levels of 65 dB for extreme exposures. Glorig and his co-workers have demonstrated that about 65 dB H. L. is a limit from noise exposure.*

If we look now at the third anomaly this comes clear. Age groups 4, 5, 6, 7, and 8 (ages 36 - 65 inclusive) show a residual curvature, concave upward - that is, they reveal a slightly more than logarithmic relationship between exposure and H. L. Age group 3 (30 - 35 years) is linear or precisely logarithmic, and age groups 1 and 2 reveal a downward concavity or something less than a pure log. relationship. If we now carefully lay on log-curve templates (Fig. 5) we will find that the crossing point at 130 dBA appears to be at about 65 dB H. L. for all groups above the age of 36 years (18 years exposure.) With less than 18 years exposure, there is a progressively lower terminal level regardless of exposure level.

Note that we have selected 65 dB H. L. as the Y limit but that this precise point is not necessary. If we chose 75 or even 80 dB H. L. as the limit it would change our extrapolations very little at even 115 dBA exposure.

As soon as the indicated curvilinearity is reestablished the crossing point at the lower end of the graph (low exposure end) disappears. However, we were not happy with the low age segments of our median regressions and particularly with the compression taking place between ages at 78 dBA exposure. We were anchoring our curves to age group 1 and this is on the face of it incorrect. The mean subject in age group 1 already has three years exposure (average of 6 year group, 18 through 23) and three years is a sizable exposure period especially at high exposure levels. The origin of our curves should be at a precise point where all subjects have identical (or average identical) exposures. One such point does exist and it is available. The 18 year old new hire males employed during the time the other data were being collected. We determined the pre-employment H. L. 3F/3 for this group and used that (2.4 dB H. L. 3F/3) for our new X - Y anchor for all medians. This changed the curve significantly, particularly for low age and high exposure.

All these changes are reflected on the graph of Fig. 5. Having picked off the median point for each age group at each exposure level from 80 dBA to 115 dBA in 5 dBA steps from this master graph, we enter them in Tables 6a and 6b and plot them as decile families on a series of linear grids of which Fig. 6 is an example. Now we lay on an age scale across a given decile family at a given H. L. "fence" and plot on another linear grid, laid out by years of age on the abscissa, and percent of population on the ordinate, the interdecile intersection points with this "fence." Least distance curves are struck through these points by use of a Copenhagen ship curve and the final product of our procedure appears. (Figs. 7 through 11.)

A first glance at the finished % of population graphs may be disconcerting.

We have, in fact, two deleterious effects operating independently in their attack on audition. It is the interaction of these two forces which produces the complex progression in what one might expect to be steady progress toward extinction of the hearing function. In high exposures the noise induced effect

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* Personal communication

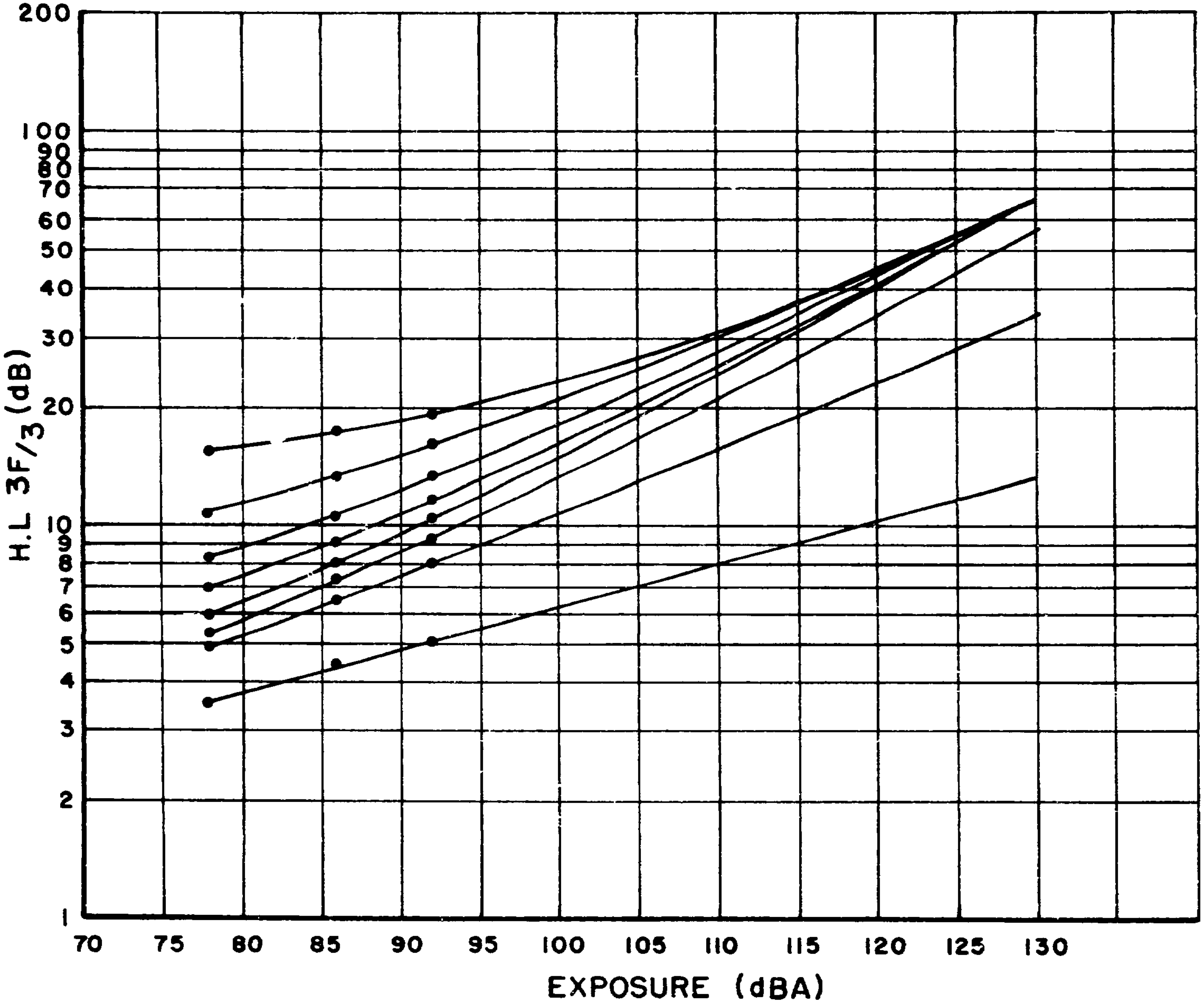

Figure 5. Plot of median values adjusted so (1) the maximum hearing level is 65 dB at the 130 dBA SPL and (2) the nonexposed median is anchored by 18-year old new hire males.

TABLE 6a

INTERPOLATED AND EXTRAPOLATED FROM FIELD

(3F/3)

Int. Dec. Points	AGE 18 - 23				AGE 24 - 29				AGE 30 - 35				AGE 36 - 41			
	80	85	90	95	80	85	90	95	80	85	90	95	80	85	90	95
1	-.8	-.4	-.1	.4	.2	1.0	1.7	2.7	.6	1.4	2.5	3.9	1.0	2.0	3.1	4.7
2	.55	1.1	1.4	1.2	1.7	2.6	3.4	4.6	2.2	3.1	4.3	6.0	2.6	3.8	5.1	6.9
3	1.5	2.1	2.4	3.0	2.8	3.8	4.6	6.0	3.3	4.3	5.6	7.5	3.8	5.0	6.5	8.4
4	2.5	3.1	3.5	4.1	3.8	4.9	5.8	7.3	4.4	5.5	6.9	8.9	4.9	6.3	7.8	9.9
5	3.7	4.4	4.8	5.5	5.2	6.4	7.4	9.0	5.8	7.0	8.6	10.8	6.4	7.9	9.6	11.9
6	4.3	5.1	5.6	6.4	6.0	7.4	8.6	10.4	6.7	8.1	10.0	12.5	7.4	9.2	11.1	13.8
7	5.0	5.9	6.5	7.4	7.0	8.6	10.0	12.2	7.8	9.5	11.6	14.6	8.6	10.7	13.0	16.1
8	6.0	7.1	7.7	8.9	8.4	10.3	11.9	14.5	9.3	11.3	13.8	17.4	10.3	12.7	15.5	19.2
9	7.8	9.2	10.1	11.6	10.9	13.4	15.5	18.9	12.2	14.7	18.1	22.7	13.4	16.6	20.2	25.0
	AGE 42 - 47				AGE 48 - 53				AGE 54 - 59				AGE 60 - 65			
1	1.6	2.7	3.9	5.3	2.7	3.7	4.9	6.7	4.1	5.3	6.8	8.4	6.8	8.0	9.2	10.8
2	3.3	4.6	5.9	7.6	4.6	5.7	7.2	9.2	6.2	7.6	9.3	11.2	9.3	10.7	12.1	13.9
3	4.5	5.9	7.4	9.2	5.9	7.1	8.7	10.9	7.7	9.2	11.0	13.1	11.0	12.6	14.1	16.0
4	5.7	7.2	8.8	10.8	7.2	8.6	10.3	12.7	9.2	10.8	12.8	15.0	12.8	14.5	16.1	18.2
5	7.3	8.9	10.7	12.9	8.9	10.4	12.3	14.9	11.1	12.9	15.0	17.5	15.0	16.9	18.7	21.0
6	8.5	10.3	12.4	15.0	10.4	12.1	14.3	17.3	12.9	15.0	17.4	20.3	17.4	19.6	21.7	24.4
7	9.9	12.0	14.4	17.4	12.0	14.0	16.6	20.1	15.0	17.4	20.3	23.6	20.3	22.8	25.2	28.4
8	11.8	14.3	17.2	20.8	14.3	16.7	19.8	24.0	17.9	20.8	24.2	28.2	24.2	27.2	30.1	33.8
9	15.3	18.7	22.5	27.1	18.7	21.8	25.8	31.3	23.3	27.1	31.5	36.8	31.5	35.5	39.3	44.1

TABLE 6b

EXTRAPOLATED FROM FIELD

(3F/3)

Int. Dec. Points	AGE 18 - 23				AGE 24 - 29				AGE 30 - 35				AGE 36 - 41			
	100	105	110	115	100	105	110	115	100	105	110	115	100	105	110	115
1	.9	1.4	2.0	2.7	4.1	5.5	7.4	9.4	5.6	8.0	11.0	14.5	6.6	9.2	12.8	17.0
2	2.5	3.1	3.8	4.6	6.2	7.9	10.0	12.3	7.9	10.6	14.1	18.1	9.1	12.1	16.3	21.0
3	3.6	4.3	5.0	6.0	8.1	10.0	11.8	14.4	9.6	12.5	16.3	20.7	10.8	14.1	18.6	23.9
4	4.7	5.5	6.3	7.3	9.1	11.1	13.7	16.4	11.2	14.4	18.5	23.2	12.6	16.1	21.0	26.7
5	6.2	7.0	7.9	9.0	11.0	13.2	16.0	19.0	13.3	16.8	21.3	26.5	14.8	18.7	24.1	30.3
6	7.2	8.1	9.2	10.4	12.8	15.3	18.6	22.0	15.4	19.5	24.7	30.7	17.2	21.7	28.0	35.1
7	8.4	9.5	10.7	12.2	14.9	17.8	21.6	25.6	18.0	22.7	28.8	35.8	20.0	25.2	32.5	40.9
8	10.0	11.3	12.7	14.5	17.7	21.3	25.8	30.6	21.4	27.0	34.9	42.7	23.8	30.1	38.8	48.8
9	13.0	14.7	16.6	18.9	23.1	27.7	33.6	39.9	27.9	35.3	44.7	55.7	31.1	39.3	50.6	63.6
	AGE 42 - 47				AGE 48 - 53				AGE 54 - 59				AGE 60 - 65			
1	7.6	10.2	14.2	18.2	8.8	11.6	15.3	19.3	10.4	13.0	16.5	20.4	12.8	15.3	18.1	21.5
2	10.2	13.3	17.8	22.4	11.6	14.8	19.1	23.1	13.4	16.5	20.4	24.9	16.2	19.1	22.3	26.2
3	12.0	15.4	20.3	25.4	13.5	17.0	21.8	26.8	15.5	18.9	23.2	28.1	18.6	21.8	25.3	29.5
4	13.8	17.5	22.9	28.3	15.5	19.3	24.4	29.9	17.7	21.3	25.9	31.2	20.9	24.4	28.2	32.8
5	16.2	20.2	26.1	32.1	18.0	22.2	27.8	33.8	20.4	24.4	29.5	35.3	24.0	27.8	32.0	37.0
6	18.8	23.4	30.3	37.2	20.9	25.8	32.2	39.2	23.7	28.3	34.2	40.9	27.8	32.2	37.1	42.9
7	21.9	27.3	35.2	43.3	24.3	30.0	37.5	45.6	27.5	32.9	39.8	47.7	32.4	37.5	43.2	50.0
8	26.1	32.5	42.0	51.7	29.0	35.7	44.8	54.4	32.8	39.3	47.5	56.8	38.6	44.8	51.5	59.6
9	34.0	42.4	54.8	67.4	37.8	46.6	58.4	71.0	42.8	51.2	62.0	74.1	50.4	58.4	67.2	77.7

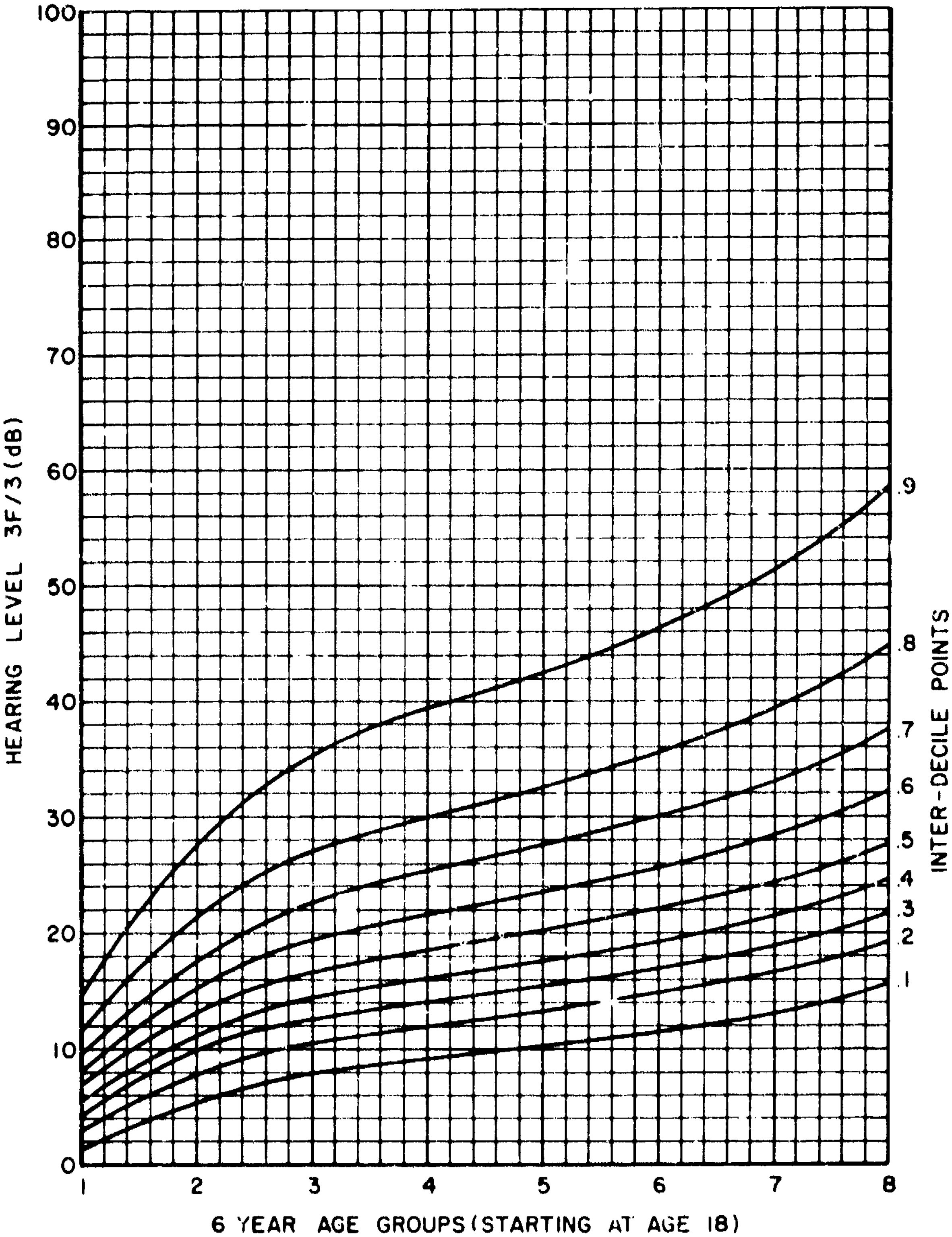

Figure 6. Sample plot of the data from table 6a. Exposure level is 105 dBA.

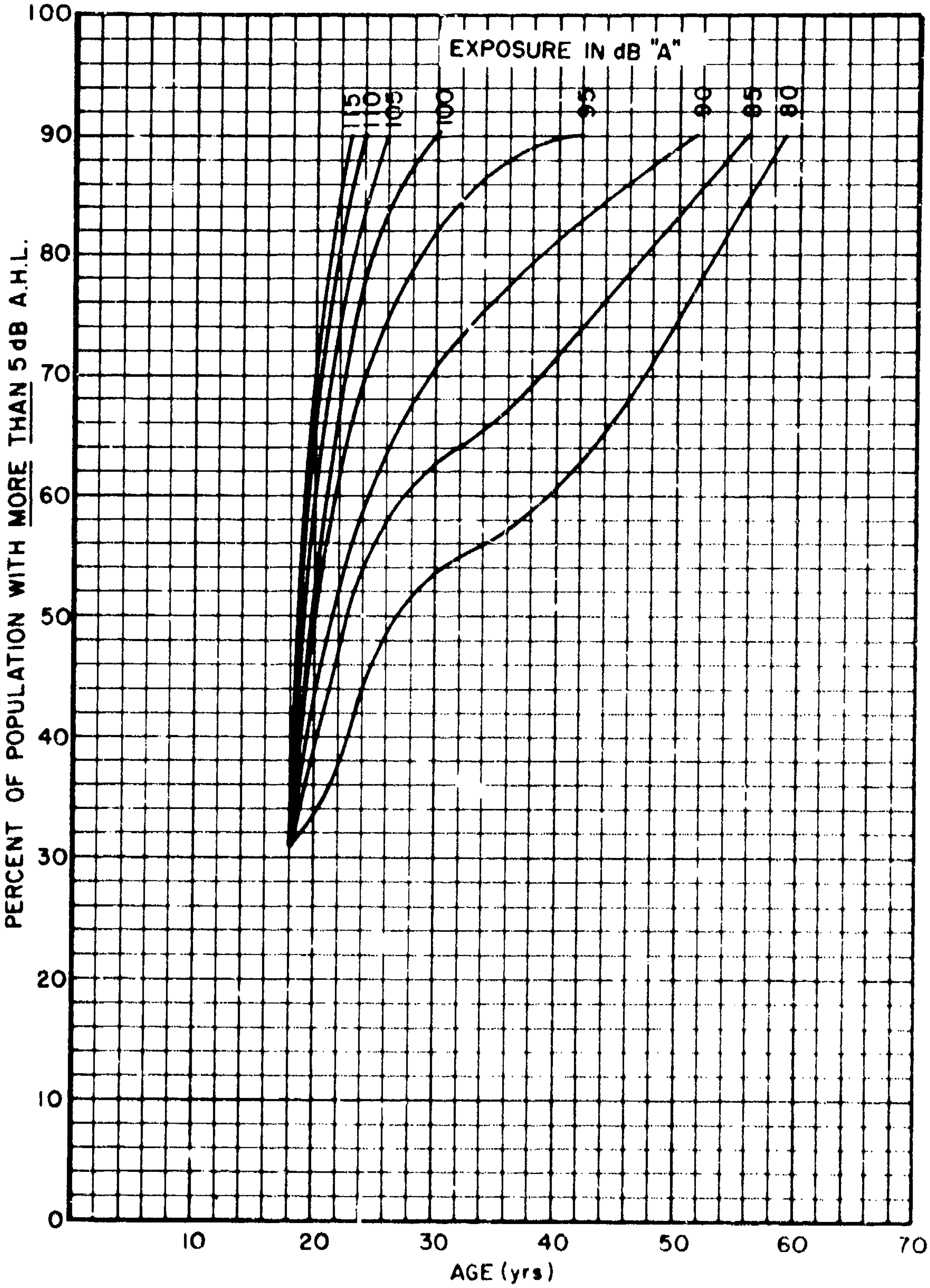

Figure 7. Percent of the population with more than a 5 dB audiometric hearing level (re 1951 ASA) for the speech frequencies (0.5, 1, and 2 kHz).

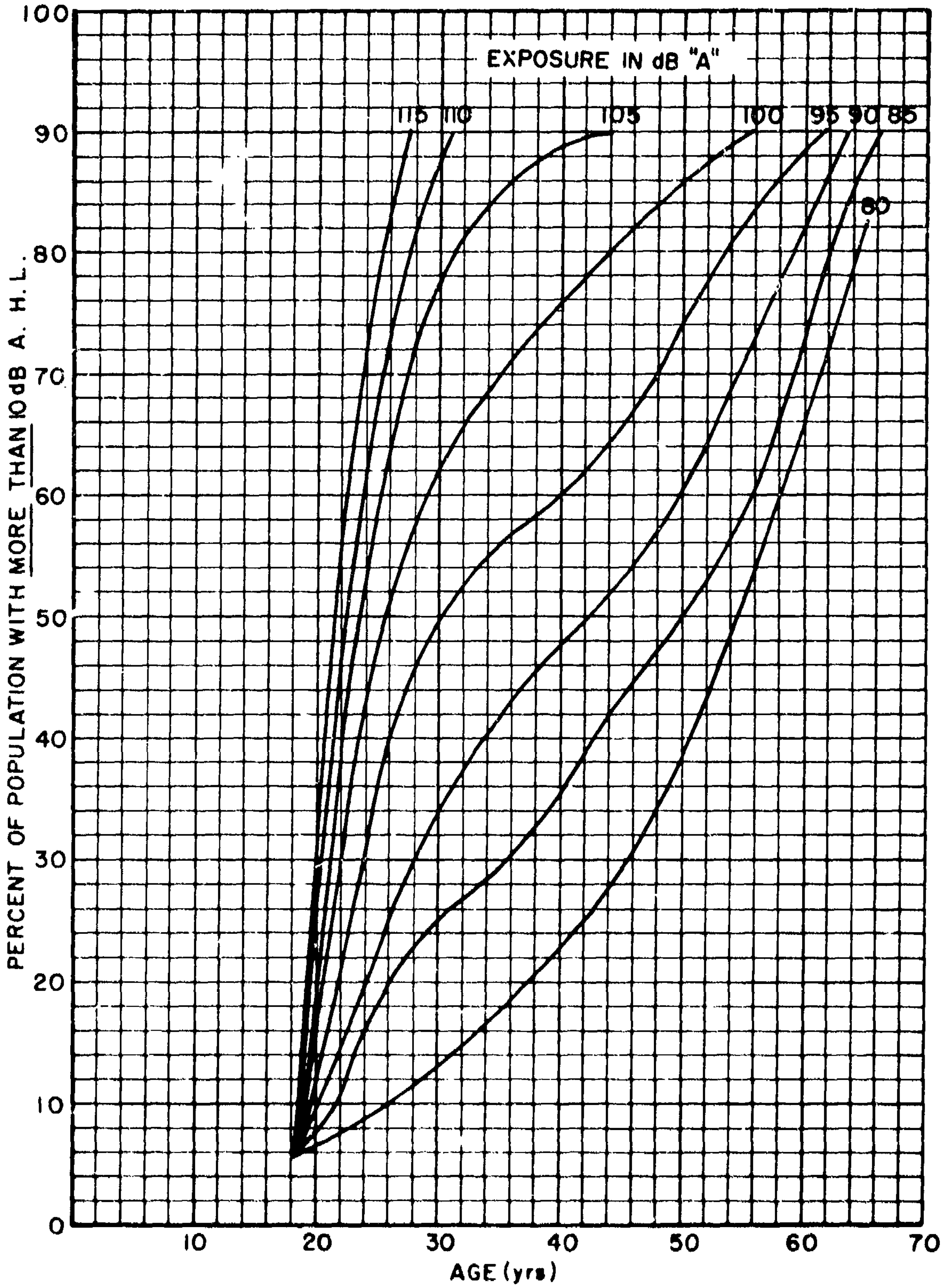

Figure 8. Percent of the population with more than a 10 dB audiometric hearing level (re 1951 ASA) for the speech frequencies (0.5, 1, and 2 kHz).

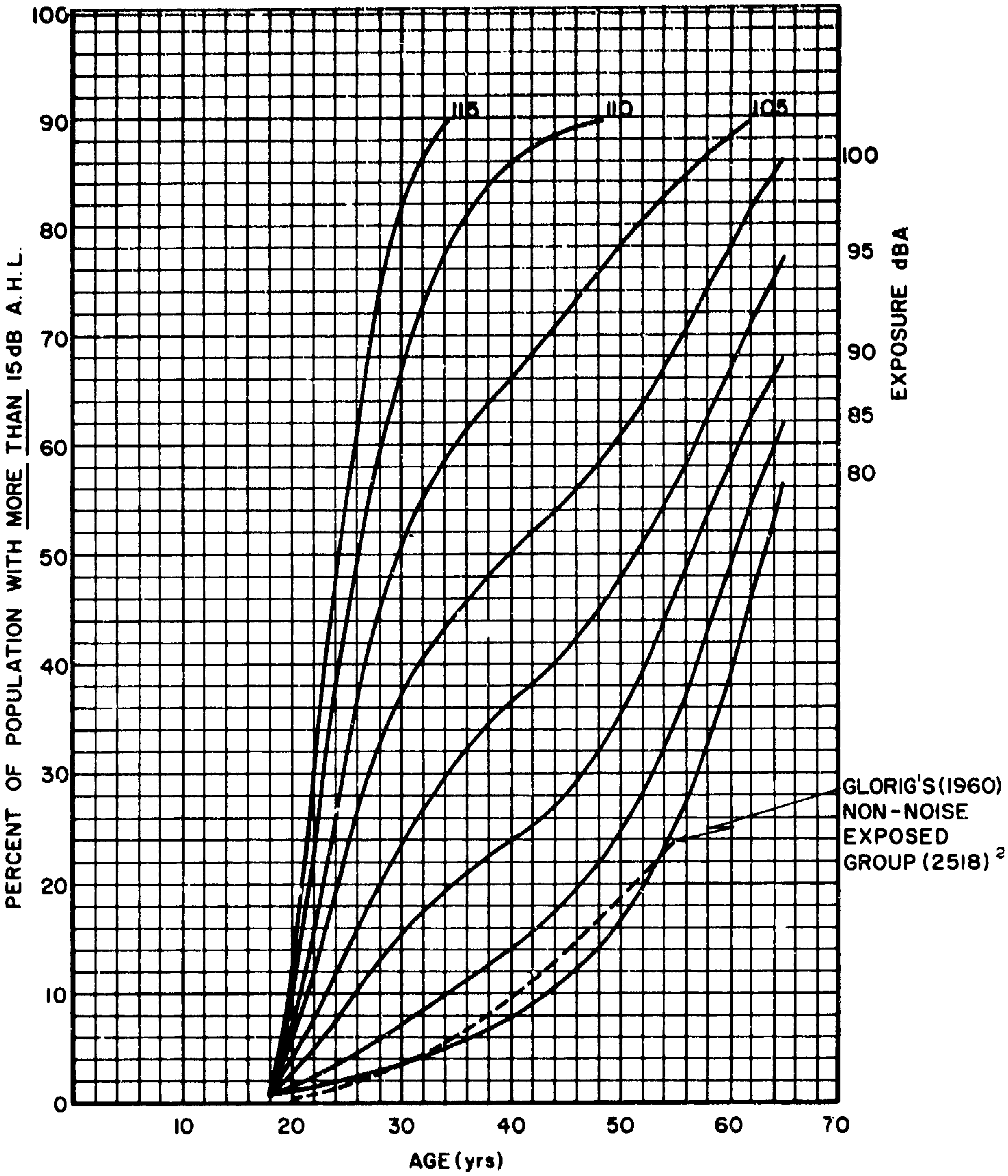

Figure 9. Percent of the population with more than a 15 dB audiometric hearing level (re 1951 ASA) for the speech frequencies (0.5, 1, and 2 kHz).

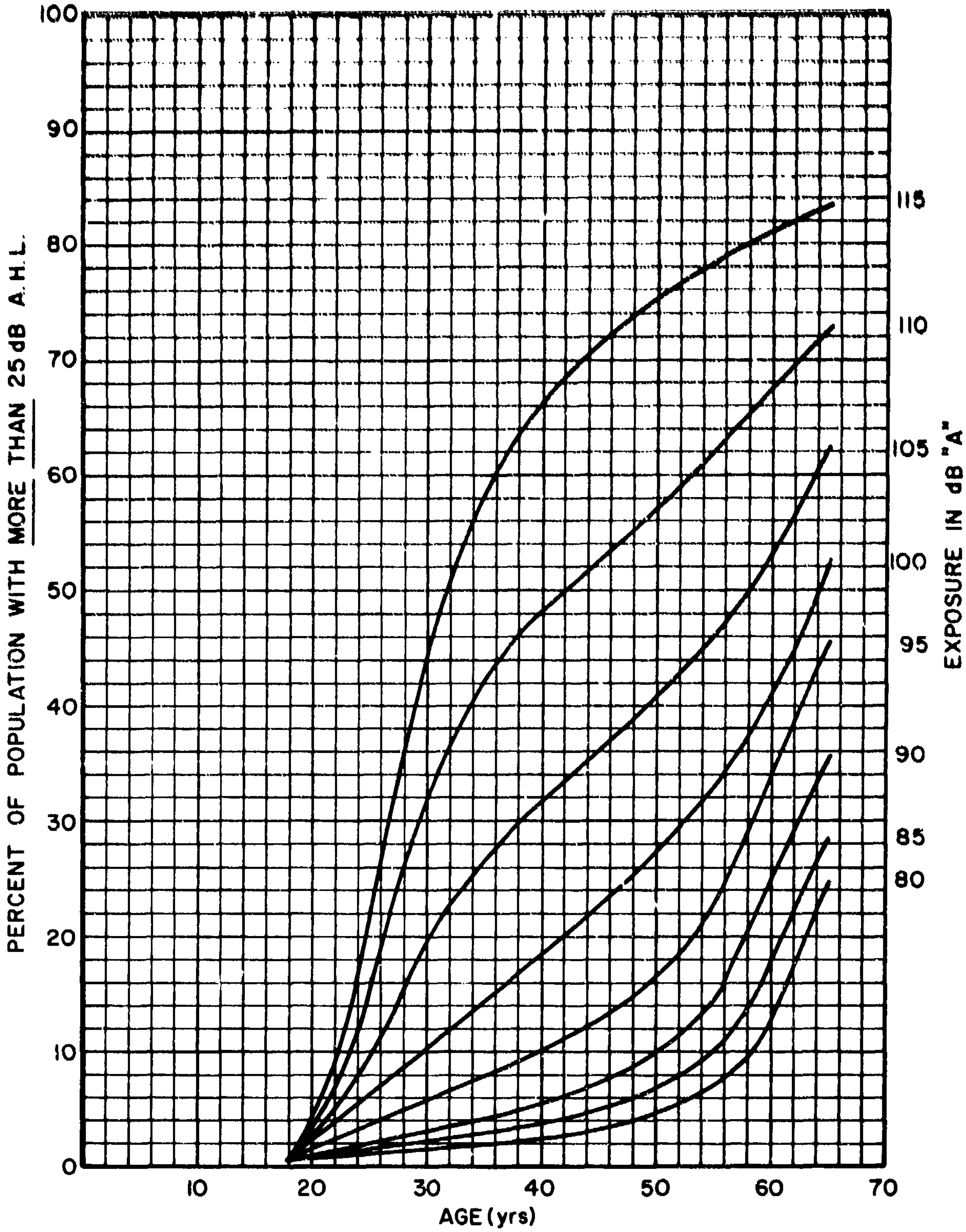

Figure 10. Percent of the population with more than a 25 dB audiometric hearing level (re 1951 ASA) for the speech frequencies (0.5, 1, and 2 kHz).

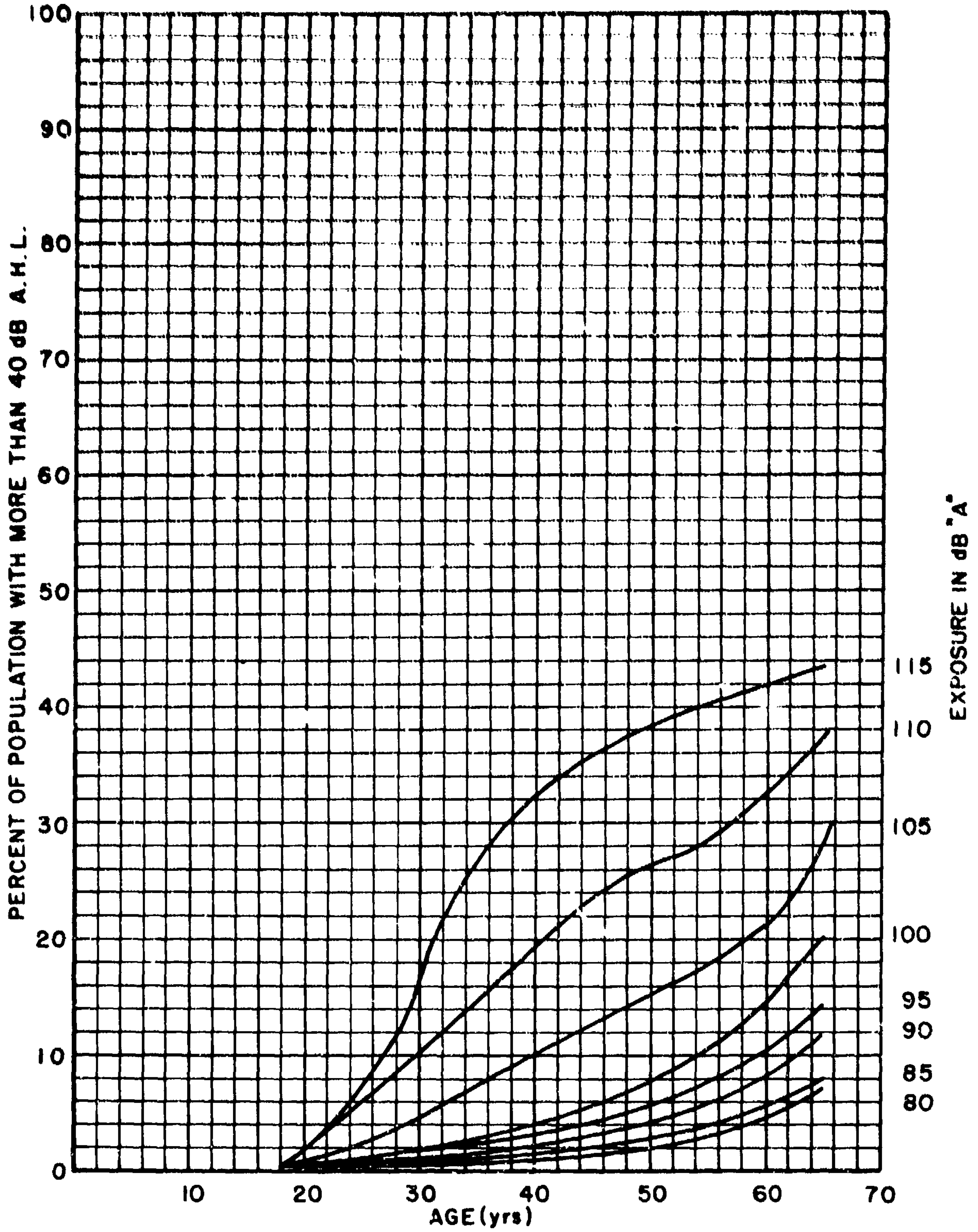

Figure 11. Percent of the population with more than a 40 dB audiometric hearing level (re 1951 ASA) for the speech frequencies (0.5, 1, and 2 kHz).

has the overwhelming advantage. Intense noise produces such high losses so rapidly that the contribution of aging (which nevertheless is steadily producing its changes) is completely lost to view. In a number of years, however, (15 - 18 - 20) the noise induced component decreases and then is lost and the age component - which has been steadily progressing at an accelerating rate begins to catch up. Depending on the height of the plateau (ƒ exposure intensity) the aging component would catch up sooner (low exposure) or later (high exposure) and then the aging contribution would (and does) supervene. Our figures indicate that if a whole population could be kept alive to age 86 it would make no difference what the exposure history of the members of that population had been, they would all have passed some specific criterion of hearing loss.

If we look at the percent of population graph for a fence of 15 dB H. L. 3F/3 and look at the 115 dBA exposure line we see that up to the limit of our graph (65 years of age) aging has not overtaken - nor even nearly overtaken - noise loss.

If we look at the 80 dBA line we will see that noise exposure has made no visible impression on it and it follows the curve of Glorig's "non-noise exposed" population.[2] Now if we carefully study the 100 dBA exposure line we can see a very tiny concavity upward (to the left) at 18 to 23 years or so which implies a slight aging component but which is nearly lost in the overwhelming advance of noise loss. Now note that as the rate of noise induced loss decreases the line straightens, and begins another upward trend as the plateau becomes fully developed. Eventually it flattens again as the 100% of population limit is approached.

(As a philosophical aside, we conceive the whole story to be something like the idealized graph of Fig. 12. This is drawn to represent our idea of a birth to death (age 0 to 100) graph of the percent of population picture at the 15 dB H. L. 3F/3 "fence." We are personally satisfied that it is correct as a generalization although, of course, we don't claim precision of the exact lines.)

Fig. 13 is a display of median 3F/3 H. L.'s by age for five very well-known population studies conducted by expert teams over a period of thirty years.[2-6] Glorig's non-noise exposed is the only one with a controlled exposure element.[2] It would be expected that these studies would agree within fractions of a decibel, but note that at no age is there a range of less than 8 dB H. L. and the range goes up to 26 dB at the higher ages! Any one of these surveys could certainly be considered "authoritative." If we were to perform percent of population analysis based on each of these medians and its associated distribution, we would have estimates of such percent varying by as much as 50% or more of population at certain ages. Now imagine each of these investigating teams, using exactly the same equipment and technicians, doing a survey on populations with carefully graded exposures; regardless of where their baseline or median lay, the interval from each exposure to the exposure 5 dB above would remain constant. Now all surveys would agree on how much each step lay above the other. In other words, Δ % Pop./dB exp. = K (or fK.) Either a constant or a rational function of a constant would be common to all properly done surveys regardless of systematic variables which might shift the raw data up or down on the scale. Now, we have only to agree on a baseline. I think we are already

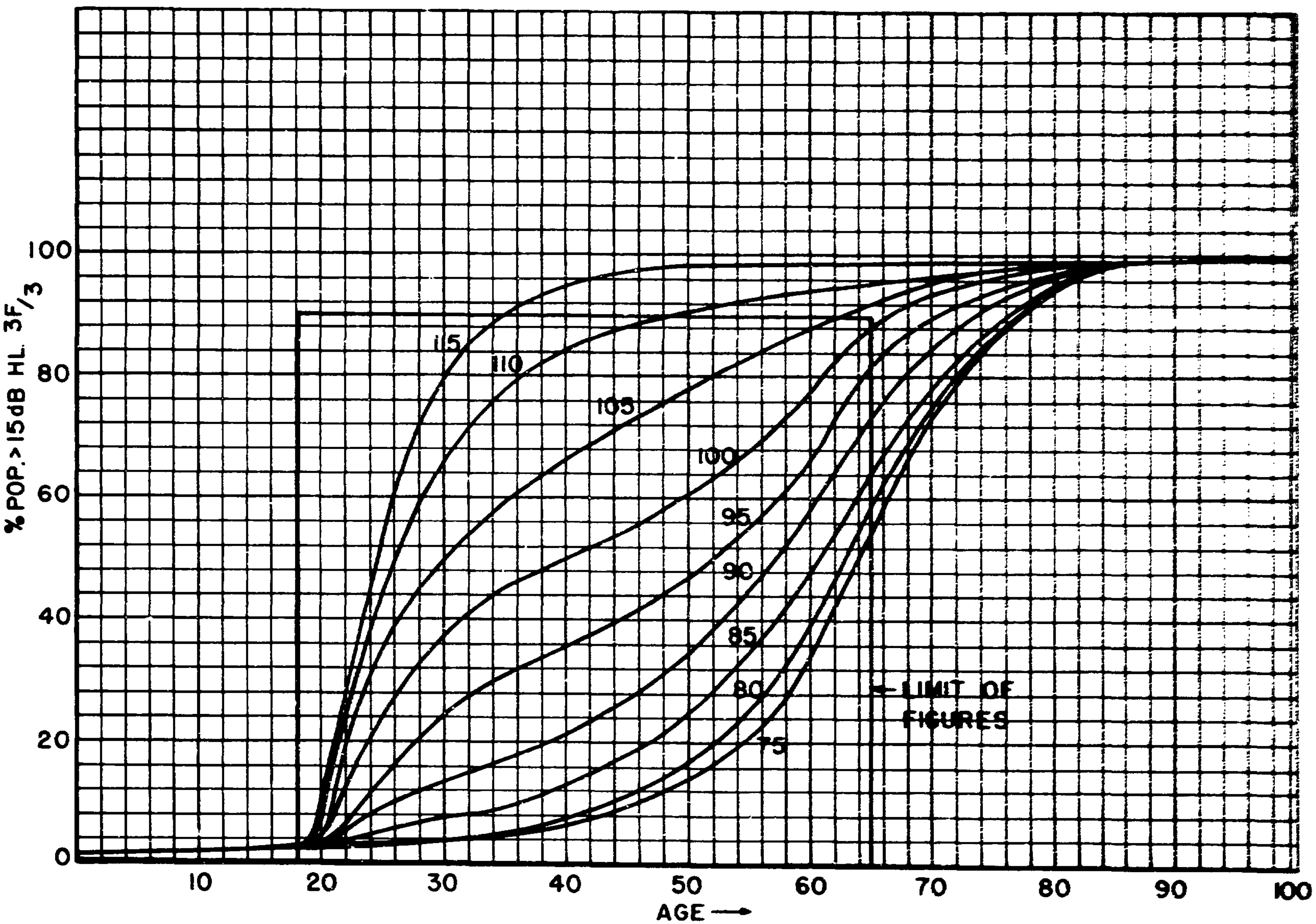

Figure 12. Idealized graph drawn to represent a probable pattern from birth to death of the percent of the population with more than 15 dB audiometric hearing level (re 1951 ASA) for the speech frequencies 0.5, 1, and 2 kHz.

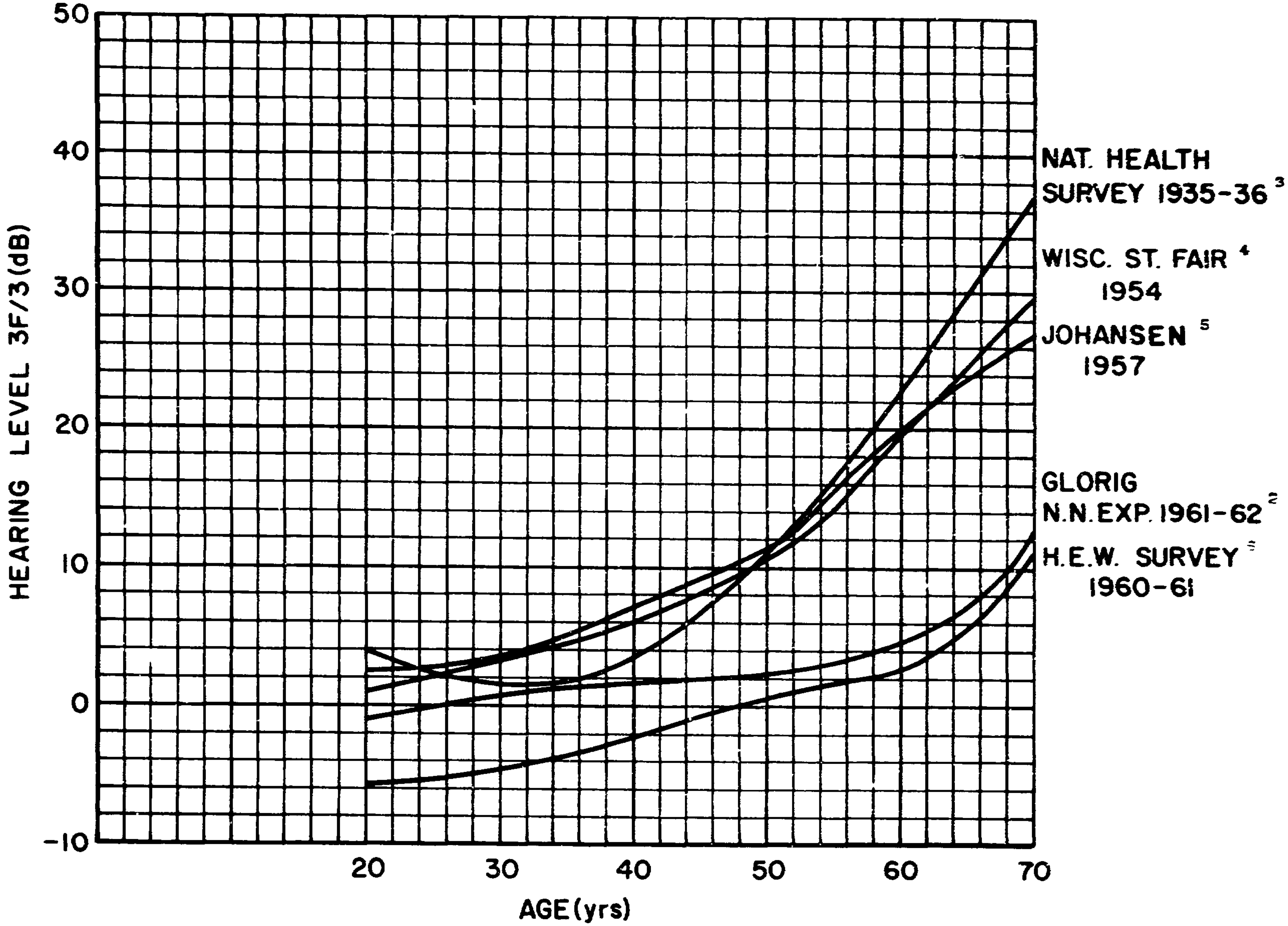

Figure 13. Median 3F/3 hearing loss by age for five well-known population studies.

agreed on one - "No exposure below 80 dBA of ordinary mixed industrial noise produces significant loss of hearing which can be attributed to the industrial exposure." If we are agreed on this, then all that is needed is for the user to establish points with his own equipment, his own technicians, in his own population exposed to carefully measured 80 dBA and lower noise. By application of K or fK he can predict absolute numbers of this population who will experience selected amounts of hearing loss from higher exposures. He may feel confident (assuming always that the work is competently done) that his figures will be consistent with those being developed elsewhere even against different baselines unique to other investigators, other instrument clusters, and under different environmental conditions.

In this framework of adjusting baselines, it may be noted that we have in this report adjusted our own baseline once (adjusting the unexposed median to that of incoming 18 year olds, a correction of -2.4 dB.) Other adjustments could be properly made in these data - in fact, I suggest that they be made. In the first place, our audiograms are taken throughout the day with only a 20 minute (average) quiet rest period preceding. This means there is some residual temporary threshold shift in our data and we have quantified this as about 2.3 dB at the mean of the medians. Then there is truncation by the audiometer at -10 dB. This truncation produces a positive error of unknown but possibly consequential size (Dr. Douglas Robinson's work in England with extended range audiometers suggests the error may be significant.)[7] This particular error also affects distributions about the median by introducing a skewness at the lower signal levels. Also, our recent change from single wall to double wall audiometric rooms with 10 dB greater attenuation has revealed some slight residual low frequency masking in the test environment at the time these data were collected. In short, it appears that at least a 5 dB adjustment, perhaps considerably more, could be justified.

THE PERCENT OF POPULATION TABLES

When this percent of population display method was first presented in 1966, the display was presented in only its graphic form. It was implicit, of course, that numbers could be picked off the graphs and placed in tabular form, and in fact, this had been done in a working paper for the Intersociety Committee on Guidelines for Noise Exposure Control. The warm reception of the percent of population method for the purpose of displaying protection criteria, and interest in the tabular rather than the graphic display is the reason for this report.

The actual construction of the table is simple. One simply goes to the percent of population graph based on the desired criterion (e. g. % of population with more than 15 dB H. L.), enters at the age in question (e. g. 63 years), proceeds to the intersection with an exposure (e. g. 80 dBA) and enters the indicated number (50%) in his tabular grid. Entry of a certain number of such numbers produces a table of a certain resolution. We have felt that 5 year intervals of age and 5 dBA intervals of exposure produce a useful table.

We are appending two such tables to this report. The first is constructed from the data as they appear in this report (Table 7) and the second a table adjusted to a base of zero dB H. L. at age 20 with 80 dBA exposure (Table 8.)

TABLE 7

Percent of Population displaying more than 15 dB Hearing Level Averaged at 500, 1000, 2000 Hertz (ASA 1951) as a Function of Age, Years of Exposure (Assuming Years of Exposure = Age - 18) and Exposure Level in dBA.

Age Exp. Years (Age - 18)		18 0	23 5	28 10	33 15	38 20	43 25	48 30	53 35	58 40	63 45
Exp. Level	Total % Expected	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
	% *Due to Noise*	0	0	0	0	0	0	0	0	0	0
80 dBA	% Due to Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	2.5	6	9	12.5	16.5	22	30	43	57
	% *Noise*	0	.8	3	4.5	6	6.8	8	9	10	7
85 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	6	13	18	22	26	32	41	54	65
	% *Noise*	0	4.3	10	13.5	15.5	16.3	18	20	21	15
90 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	9.0	20	28	34	39	45	53	62	73
	% *Noise*	0	7.3	17	23.5	27.5	29.3	31	32	29	23
95	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	14	32	42	48	53	58	65	74	83
	% *Noise*	0	12.3	29	36.5	41.5	43.3	44	44	41	33
100 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	23	50
Exp. Level	Total %	.5	20	45	57	64	70	76	82	87	91
	% *Noise*	0	18.3	42	52.5	57.5	60.3	62	61	54	41
105	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	28	58	75	84	88	91	93	95	95
	% *Noise*	0	26.3	55	70.5	77.5	78.3	77	72	62	45
110	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	38	74	87	93	94	95	96	97	97
	% *Noise*	0	36.3	71	83.5	86.5	84.3	81	75	64	47
115	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50

TABLE 7

Percent of Population displaying more than 15 dB Hearing Level Averaged at 500, 1000, 2000 Hertz (ASA 1951) as a Function of Age, Years of Exposure (Assuming Years of Exposure = Age - 18) and Exposure Level in dBA.

Age Exp. Years (Age - 18)		18 0	23 5	28 10	33 15	38 20	43 25	48 30	53 35	58 40	63 45
Exp. Level	Total % Expected	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
	% *Due to Noise*	0	0	0	0	0	0	0	0	0	0
80 dBA	% Due to Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	2.5	6	9	12.5	16.5	22	30	43	57
	% *Noise*	0	.8	3	4.5	6	6.8	8	9	10	7
85 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	6	13	18	22	26	32	41	54	65
	% *Noise*	0	4.3	10	13.5	15.5	16.3	18	20	21	15
90 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	9.0	20	28	34	39	45	53	62	73
	% *Noise*	0	7.3	17	23.5	27.5	29.3	31	32	29	23
95	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	14	32	42	48	53	58	65	74	83
	% *Noise*	0	12.3	29	36.5	41 5	43.3	44	44	41	33
100 dBA	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	23	50
Exp. Level	Total %	.5	20	45	57	64	70	76	82	87	91
	% *Noise*	0	18.3	42	52.5	57.5	60.3	62	61	54	41
105	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	28	58	75	84	88	91	93	95	95
	% *Noise*	0	26.3	55	70.5	77.5	78.3	77	72	62	45
110	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
Exp. Level	Total %	.5	38	74	87	93	94	95	96	97	97
	% *Noise*	0	36.3	71	83.5	86.5	84.3	81	75	64	47
115	% Other	.5	1.7	3	4.5	6.5	9.7	14	21	33	50

TABLE 8

Percent of Population exhibiting more than 15 db A.S.A. 1951* Hearing Level Averaged at 500, 1000, and 2000 Hertz as a Function of Age, Years of Exposure (Assuming years of Exposure = Age - 18) and Exposure Level in dBA. (Adjusted) **

(% Noise = "Risk" as defined in document.)

** *(All data have been adjusted to a median hearing level of 0 dB for 80 dBA exposure and 20 yrs. of age.)*

Age		18	23	28	33	38	43	48	53	58	63
Exp. Years (Age - 18)		0	5	10	15	20	25	30	35	40	45
Exp. Level	Total % Expected	0.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
	% Due to Noise	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
80 dBA	% Due to Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	2.0	3.9	6.0	8.1	11.0	14.2	21.5	32.0	46.5
	% Due to Noise	*0.0*	*1.0*	*2.6*	*4.0*	*5.0*	*6.1*	*6.5*	*8.0*	*8.0*	*6.5*
85	% Due to Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	4.0	7.9	12.0	15.0	18.3	23.3	31.0	42.0	54.5
	% Noise	*0.0*	*3.0*	*6.6*	*10.0*	*11.9*	*13.4*	*15.6*	*17.5*	*18.0*	*14.5*
90	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	6.7	13.6	20.2	24.5	29.0	34.4	41.8	52.0	64.0
	% Noise	*0.0*	*5.7*	*12.3*	*18.2*	*23.4*	*24.1*	*26.7*	*28.3*	*28.0*	*24.0*
95	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	10.0	22.0	32.0	39.0	43.0	48.5	55.0	64.0	75.0
	% Noise	*0.0*	*9.0*	*20.7*	*30.0*	*35.9*	*38.1*	*40.8*	*41.5*	*40.0*	*35.0*
100	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	14.2	33.0	46.0	53.0	59.0	65.5	71.0	78.0	84.5
	% Noise	*0.0*	*13.2*	*31.7*	*44.0*	*49.9*	*54.1*	*57.8*	*57.5*	*54.0*	*44.5*
105	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level 110	Total %	.7	20.0	47.5	63.0	71.5	78.0	81.5	85.0	88.0	91.5
	% Noise	*0.0*	*19.0*	*46.2*	*61.0*	*68.4*	*73.1*	*73.8*	*71.5*	*64.0*	*51.5*
	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0
Exp. Level	Total %	.7	27.0	62.5	81.0	87.0	91.0	92.0	93.0	94.0	95.0
	% Noise	*0.0*	*26.0*	*61.2*	*79.0*	*83.9*	*86.1*	*84.3*	*79.5*	*70.0*	*55.0*
115	% Other	.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0

* 25 dB A. N. S. I.

ADDENDUM

Any frequency, or any combination of frequencies, may be dealt with as we have dealt with the three frequency mean. There has been some interest expressed in the behavior of the ear at 4 Kilohertz, so we are including Table 9, which defines this behavior. We will not detail its derivation which is parallel to the development of Table 5. There is the difference that rationalization of the inter-decile points is much more complex, yielding a different ratio for each point, at each age, for each exposure rather than the neat formulae (Table 4) applicable to the three frequency mean.

Extrapolation and joint regression surface smoothing have not been done but we include the table for 40 dB H. L. (4 Kilohertz) at 78, 86, and 92 dBA exposures. Table 10.

TABLE 9

MATHEMATICALLY SMOOTHED DECILE POINTS (4kHz)

Int. Dec. Points	AGE 18 - 23			AGE 24 - 29			AGE 30 - 35			AGE 36 - 41		
	78	86	92	78	86	92	78	86	92	78	86	92
1	.37	2.09	2.8	1.37	5.7	7.67	3.0	9.77	12.6	5.2	14.7	17.9
2	1.44	4.09	5.74	3.46	9.88	13.15	6.15	15.6	18.9	9.6	20.9	24.4
3	2.34	5.66	8.40	5.46	12.9	17.54	9.15	20.09	23.8	13.4	25.8	29.6
4	3.28	7.13	11.48	7.46	15.96	23.01	11.87	23.99	30.5	16.8	30.4	35.7
5	4.1	8.7	14.0	9.1	19.0	27.4	14.3	27.9	35.0	20.0	34.9	40.6
6	5.08	10.6	17.5	11.10	22.4	32.61	17.12	32.09	39.9	23.6	39.1	45.5
7	6.85	13.05	21.8	14.2	26.6	38.91	21.31	37.11	45.9	28.6	43.2	50.3
8	7.95	16.18	26.6	16.8	28.5	46.03	25.17	43.52	52.5	33.4	51.0	56.0
9	10.7	23.66	37.2	22.2	45.03	61.38	32.6	53.01	64.8	42.4	60.0	64.1
	AGE 42 - 47			AGE 48 - 53			AGE 54 - 59			AGE 60 - 65		
1	8.32	19.3	23.9	12.1	24.1	30.5	17.2	30.3	37.3	24.0	35.8	44.0
2	13.5	26.7	30.8	18.7	31.6	37.1	24.5	38.2	43.4	32.3	43.6	50.4
3	18.2	31.6	35.9	23.9	37.1	41.7	30.9	43.4	47.2	39.2	48.1	53.3
4	22.1	36.1	41.4	28.5	41.8	46.7	35.3	48.1	51.6	44.1	52.0	56.3
5	26.0	41.0	46.0	32.8	46.4	50.8	40.1	52.3	54.9	49.0	55.9	58.6
6	30.2	45.1	50.1	37.4	50.6	54.4	44.9	56.5	58.2	53.9	59.3	62.1
7	35.6	50.0	54.3	42.6	54.8	58.4	49.7	60.1	62.6	57.8	63.7	66.2
8	41.3	56.2	59.8	48.9	60.3	63.0	56.1	64.9	65.9	63.7	66.5	69.7
9	50.4	64.8	66.2	58.4	67.7	69.1	65.0	71.7	71.4	70.6	72.7	75.0

TABLE 10

Percent of Population exhibiting more than 40 dB H. L. at 4 Kilohertz as a function of Age and Exposure Level in dBA.

Age		18	23	28	33	38	43	48	53	58	63
Exp. Level	Total % Expected	.5	1.1	2.9	6.0	12.0	19.0	29.5	41.0	55.0	72.0
	% Due to Noise	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
78 dBA	% Due to Other	.5	1.1	2.9	6.0	12.0	19.0	29.5	41.0	55.0	72.0
Exp. Level	Total	.5	6.9	16.1	27.0	38.0	48.0	60.1	71.0	79.0	84.2
	Noise	0.0	5.8	13.2	21.0	26.0	29.0	30.6	30.0	24.0	12.2
86 dBA	Other	.5	1.1	2.9	6.0	12.0	19.0	29.5	41.0	55.0	72.0
Exp. Level	Total	.5	20.5	31.2	40.0	49.1	58.7	68.4	78.0	86.5	92.7
	Noise	0.0	19.4	28.3	34.0	37.1	39.7	38.9	37.0	31.5	20.7
92 dBA	Other	.5	1.1	2.9	6.0	12.0	19.0	29.5	41.0	55.0	72.0

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