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16. Abstract

Forty-five attenuation spectra for earplugs were classified according to a simplified method designed to produce single-number ratings of noise reduction. The rating procedure was applied to the mean attenuation scores, to mean-minus-one-standard-deviation scores, and to mean-minus-two-standard-deviations scores. The reporting of all three numbers seems to give the fairest indication of an earplug's value in controlling hearing damage in noise-exposed populations. The tests are described and ranked. This report supersedes "Ear-Protector Ratings" by J. V. Tobias and F. M. Irons, FAA Office of Aviation Medicine Report FAA-AM-73-20 (1973).

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NOTICE

EARPLUG RANKINGS BASED ON THE PROTECTOR-ATTENUATION RATING (P–AR)

I. Introduction.

When a laboratory measures the effectiveness of a hearing protector, it reports the mean attenuation (and its standard deviation) at each octave or third-octave frequency. These numbers allow comparisons between devices at each frequency, but they do not help with the direct determination of the relative overall effectiveness of two protectors.

The Department of Labor's Occupational Safety and Health Administration (OSHA) Standards Advisory Committee on Noise[1] recommended three methods for calculating single-number noise-reduction factors. These figures of merit permit direct comparisons of earplugs or earmuffs. All three procedures lead to estimates of the A-weighted sound pressure level (SPL) under each protector in the presence of a specific noise. The best estimate is the one calculated from the specific noise in which the device is to be used, but simplifications and approximations are offered too. A problem necessarily arises, though, even when one knows the spectrum of the noise in which a worker is expected to use hearing protection: if he moves from one area to another, the spectrum will likely shift and the exactly calculated level at his eardrum will change. Only rarely will an environment remain constant enough for the exact-calculation procedure to work completely. However, the OSHA approaches are useful despite this imperfection, and they are instructive to the developer of more refined measuring and reporting techniques. They include two important ideas: first, they recognize that the protection offered by a wearable attenuator must be a function of the noise spectrum in which it is used; and second, they note that reporting the mean attenuation of a device indicates only how much protection is offered to the average-or-better user—but reporting the mean-minus-two-standard-deviations indicates very nearly the *least expected* amount of protection, a critically important piece of information to a purchaser who must consider the compensation costs of underprotection.

Other approaches were developed from these concepts. One train of thought suggested that a general purpose noise-reduction number would be the average attenuation a given device produced in a large number of industrial noise environments. The computational task would be huge, of course, were one to use available compilations of hundreds of spectra. Average attenuation values for an earplug in 600 noises or even in 100 would require a lot of arithmetic, and J. H. Botsford[2] saw a way to simplify the problem. He abstracted from large samples of spectra a set of six that, although not "real" in the sense that they belong to some particular industry, represent the gamut of spectral types. For an ear protector under test, the Botsford method calculates an A-weighted noise-reaching-the-ear for each of the six noises, subtracts that number from the C-weighted level of that noise, and then averages all six of the C-minus-A figures to produce a single reduction factor describing that device.

Johnson and Nixon[3] tested Botsford's method against the OSHA reduction figure and also against a far more complex method of their own that involves 150 spectral calculations. The surprising outcome is that Botsford's value for a given ear protector produces all the necessary information available from the more complicated procedures, and further that a simple 6-dB correction produces a figure of merit that represents the minimum effectiveness of the tested device in 99 percent of the 150 noises. Six calculations can take the place of 150.

D. L. Johnson and I[4] further simplified the process. We derived a single spectrum (see Table 1) that serves the same function as Botsford's six; we called it The Typical Noise (TTN). Calculating ear-protector effectiveness

TABLE 1. Corrected Spectral Levels for The Typical Noise (TTN)

octave-band center frequency in Hz	63	125	250	500	1000	2000	4000	8000
A-weighted level in dB	71	79	84	89	93	93	92	87

Uncorrected overall level = 99 dBC

with TTN gives a value that includes a 3-dB correction; the result is the amount of protection each device offers against 99 percent of noises. OSHA's recommendation requires a correction of 18 dB, Botsford's requires 6, and Johnson and Nixon's requires 4.

Finally, working with TTN-calculated reductions, I[5] considered the possibility of reporting hearing-protector effectiveness in simpler terms than the usual decibel numbers. Many potential users of protectors (and of protector ratings) are only peripherally acquainted with the peculiarities of decibel notation. Not only might they have trouble interpreting the meaning of reported reduction factors, but they could easily be led to emphasize the generally meaningless fractional-decibel differences between devices that really perform similarly. I felt that a classification number would be preferable to an attenuation value, so I computed mean attenuations in TTN for each of 42 types of earplugs, found the standard deviation of that series of attenuations, and classified the plugs by where they fell in the series: Class 1 includes any earplug whose mean attenuation is two or more standard deviations (σ) above the mean attenuation of all the earplugs; Class 2 includes the earplugs whose mean attenuation is one or more σ above the mean (but less than two); Class 3 includes those at the mean or higher (but less than one σ); Class 4 includes those from -1σ up to the mean; Class 5, those from -2σ up to -1σ; and Class 6, those below -2σ. All a person needs to do to use this classification scheme is to remember that first Class is better than sixth.

This protector-attenuation rating (P-AR) offers a simple way to rank hearing protectors. Of course, if it is generally adopted, a basic distribution of hearing-protector attenuations needs to be developed and retained as the baseline for judging all future protectors. Otherwise, the P-AR values would have to be modified every time a new device came onto the market. I have suggested the National Bureau of Standards as the proper agency to gather and maintain this distribution of ratings. Once that has been done, any new earplug or earmuff can be classified according to its position in the previously determined distribution. Only one precaution must be taken: high-Class hearing protectors must be capable of protecting hearing so that a prospective buyer can feel confident that what he gets will work. Ultimately, one might expect that most available ear protectors would fall into Classes 1, 2, and 3.

Neat as this classification system is, as thus far described it is inadequate. Remember OSHA's point that reporting only the *average* effectiveness of a device may mislead as often as it informs. Different kinds of users need different kinds of information in order to make informed purchasing decisions. An individual buyer gets his best estimate of how a particular earplug will work for him by studying the mean performance, whereas a bulk buyer has greater concern for the attenuation he can expect the plug to give to the employee who uses it least well. The bulk purchaser's best information might be found not in the mean effectiveness, but in a mean-minus-one-standard-deviation or even a mean-minus-two-standard-deviations classification.* Under the circumstances, for the P-AR

* Note that the standard deviations talked about here are measures of the variability of a given device in a population of wearers. The standard deviations used to create the six Classes of protectors are measures of the differences between protectors.

to be optimally helpful, it needs to include numbers representing those two additional kinds of ratings.

As used in this paper, P-AR values are three-digit numbers. The first represents the earplug's rating (1, 2, 3, 4, 5, or 6) for an average member of the population of users—it is calculated from mean attenuations as described earlier. The second digit represents the rating for a hypothetical user whose benefit from that plug is somewhat less—he is one standard deviation below the mean and is compared to similar -1σ people in the attenuation distributions of the other earplugs. The third digit represents the rating for a user who is two standard deviations below the mean. One way to interpret the P-AR values is to consider the first digit as indicating the worst predicted performance of the plug for 50 percent of the population of wearers, the second as indicating the worst predicted performance for 84 percent, and the third for 98 percent. Quite likely either the second or the third digit will ultimately be dropped as contributing too little additional information, but I am not ready yet to decide whether it should be done, and, if so, which one should go.

Remember that the classifications used for the plugs reported in this paper are not based on a nationally accepted baseline. Only earplugs and earcaps (not earmuffs) are included in the distribution, so the calculated means and standard deviations for plugs might turn out to be derived from an inadequate population of hearing-protection devices. In a few cases, the plugs included here have been superseded by new models whose attenuation characteristics may be different. The test procedures and methods were developed for purposes that may be different from those that will lead to a generally used distribution. However, the earplug means and standard deviations at the user mean, at the mean-minus-one-standard-deviation, and at the mean-minus-two-standard-deviations as reported here can serve as a start in the rating of earplugs, at least. Also, devices whose attenuation characteristics were not included in the baseline calculations can be classed according to where they fit into the original rating scheme, just as they would be in the situation where baseline measurements were made by a group like the National Bureau of Standards. This paper includes five extra inclusions of that sort: one is an earplug (the 3M) that appeared on the market too late to be part of the distribution, one is a classic earplug (the V-51R) that was inadvertently left out of the calculation, two were second tests of earplugs whose first tests are included in the distribution (the Sound Silencer and the Peacekeeper), and one is an insert headset (the Genie). They are all noted in the Results and Discussion section. Were they to be incorporated into a new distribution, the effect would be small: three earplugs rated near the top and two rated near the bottom would shift to a poorer rating in one of the three digits.

II. Earplugs.

Earplugs and earcaps are devices that are inserted in or pressed against the external ear canal to reduce the effect of ambient sound on the auditory system. Because every ear is unique in shape and size, several approaches to solving the problem of designing adequate earplugs have been taken. As a result, commercially available earplugs may be premolded, moldable, or custom molded. Each type has several subtypes. Premolded plugs include varieties that are vented and varieties that press a cap across the open end of the canal as well as plugs that insert more or less deeply to block the canal opening completely. Moldable plugs include impregnated and non-impregnated porous materials, expandable foams, and putty-like substances. Custom-molded earplugs include those that are made by the manufacturer from an ear impression and those in which the ear impression itself becomes the earplug. Since every ear is unique in shape and size, one might assume that a standard, off-the-shelf earplug would not protect as well as a personalized or custom-fitted earplug. Intuition says that a custom-fitted plug should provide a better, more precise seal within the ear canal, should do so through most of the length of the inserted segment, and should be more comfortable and easier to insert. Although they are generally the most expensive, if all the assumptions about comfort, acoustic seal, and ease of use are true, then personalized earplugs would be a bargain despite their higher cost. The tests reported here, though, indicate that many of the specially fitted plugs are not great bargains at all.

TABLE 2. Tested Hearing Protectors

Brand	Manufacturer or Distributor at Date of Test	Manufacturer's Description of Material	Type	Comments	Descriptive Paragraph Number
Accu-fit	Mine Safety Appliances Company	silicone	preformed		18
Adcomold	Adcomold, Inc.	soft acrylic	formed in place	custom molded	39
Auri-Seal	Sigma Engineering Company	silicone	preformed		32
Bilsom	Bilsom International, Inc.	0.001-0.002 mm glass fibers	formed by user		5
Com-Fit	Sigma Engineering Company	silicone	preformed		22
Crown	Crown Sports, Inc.	plastic	preformed		45
Decidamp	Uniflex Division, Medical Supply Company	polymer foam	formed by user		4
Dr. Frank	Dr. Frank Ear Stopple Company	silicone	preformed		11
E-A-R	National Research Corporation	polymer foam	formed by user		1
E.A.R.	Environmental Acoustical Research	polyvinyl	factory formed	custom molded	13
Fitsrite	Fitsrite Products Company	silicone, metal core	preformed		43

(continued)

TABLE 2 (continued)

Brand	Manufacturer or Distributor at Date of Test	Manufacturer's Description of Material	Type	Comments	Descriptive Paragraph Number
Flents	Flents Products Company, Inc.	wax-impregnated cotton	formed by user		25
Flexiplug	Flents Products Company, Inc.	silicone	preformed		8
Frontier	Frontier Industrial Products Company	wax-impregnated cotton	formed by user		15
Genie	Genie Electronics Engineering Company	silicone, metal core	preformed	headset	23
Healthways	Healthways	rubber	preformed		12
Hearite A	Hechler Brothers, Inc.	soft plastic	preformed		34
Hearite B	Hechler Brothers, Inc.	soft plastic	preformed		29
Hearite C	Hechler Brothers, Inc.	soft plastic	preformed		44
Hear-Saver	Hear-Saver Limited	wax and cotton	formed by user		24
Insta-Mold	Insta-Mold Prosthetics, Inc.	elastomeric silicone polymers	formed in place	custom molded	10
Johnson & Johnson	Johnson & Johnson	cotton wool	formed by user		35
Kleenex	Kimberly-Clark Corporation	paper tissue	formed by user		40
Lee Sonic	Sigma Engineering Company	silicone, perforated metal core	preformed	metal core includes a piston	42

(continued)

TABLE 2 (continued)

Brand	Manufacturer or Distributor at Date of Test	Manufacturer's Description of Material	Type	Comments	Descriptive Paragraph Number
Mark II	Wade Products Company	silicone elastomer	formed by user		37
Nods	Wade Products Company	foam latex, wax-impregnated at one end	formed by user		27
Oto-Cure	Oto-Cure, Inc.	silicone elastomer	formed in place	custom molded	16
Peacekeeper	General Electric Company	silicone	formed in place	custom molded	20
SafEar	Human Acoustics, Inc.	vinyl	factory formed	custom molded with vent	21
SEPCO	Safety Ear Protector Company	neoprene shell, latex foam center	preformed	has two vents	26
Silaflex	Flents Products Company, Inc.	silicone	formed by user		17
Silent Partner	General Electric Company	vinyl shell filled with silicone putty	formed by user		30
SMR	Surgical Mechanical Research, Inc.	vinyl	preformed		38
Softseal	E. I. DuPont de Nemours & Company, Inc.	silicone polymer	formed by user		2
Sonic Ear-Valv	Sigma Engineering Company	silicone, perforated metal core	preformed	metal core includes a piston	6

(continued)

TABLE 2 (continued)

Brand	Manufacturer or Distributor at Date of Test	Manufacturer's Description of Material	Type	Comments	Descriptiye Paragraph Number
Sonotone	Sonotone Corporation	vinylflex	factory formed	custom molded	31
Sound-Ban 10	Willson Products Division	silicone	preformed	canal cap with headband	33
Sound-Ban 20	Willson Products Division	silicone	preformed	canal cap with headband	9
Soundown	French Laboratory	acrylic	factory formed	lightweight "shadow" custom molded	28
Sound Master	Sound Master Products, Inc.	silicone	formed in place	custom molded	36
Sound Sentry	H. E. Douglass Engineering Sales Company	neoprene	preformed	canal cap with headband	14
Sound Silencer	Willson Products Division	vinyl	preformed		3
Stayrite	Stayrite, Inc.	polyvinyl chloride	preformed		41
3M	Minnesota Mining and Manufacturing Company	synthetic rubber	preformed		19
V-51R	Mine Safety Appliances Company	plastic	preformed		7

In a comprehensive review in 1971, Gasaway[6] discussed dozens of studies of earplugs, earmuffs, and similar hearing-protection devices. In a more recent paper, Botsford[7] offered a thorough description of the characteristics and uses of ear protectors. The detailed writing in those two reports is readily available to the interested reader, so I will not repeat it here. Further, Willson and Sims[8] published a fairly good ear-protection bibliography. However, except for an inadequate, single-subject test conducted by Consumers Union[9], and a previous report from this Laboratory[10] on a preliminary approach to rating earplugs, only each manufacturer's own test results have been available to the public. Now the results of a large series of tests can be presented.

III. Method.

Forty-five brands of canal-sealing appliances were tested. Of these, two brands were each tested under two conditions. The list includes many of the commonly used earplugs.

Table 2 is an alphabetical list of the brand names of the tested appliances. For each one, the manufacturer's description of the material is noted, as is the type of earplug (premolded, moldable, or custom molded). Another column offers additional information where necessary.

The basic test procedure is the one described in the American National Standards Institute (ANSI) method for the measurement of ear protectors at threshold.[11] This standard calls for tests to be done in an anechoic chamber on randomly selected listeners with good hearing. The subjects for the tests were randomly selected from a large pool of university students. As required, each plug was tested on at least 10 listeners with at least three tests per plug performed on each person.

The ambient noise levels in the anechoic chamber were determined to be low enough to meet the standard's requirements both by measurement with a Bruel and Kjaer model 2203 sound-level meter that served to operate a remote Bruel and Kjaer model 2111 octave-band analyzer, and by psychoacoustic measurement of the minimum audible field as detailed in the ANSI standard. Ambient noise was well within acceptable limits.

Two liberties were taken with the standard procedure. First, continuous-frequency (rather than discrete-frequency) open-ear threshold tests and earplug attenuation tests were used. A Grason-Stadler model E-800 automatic audiometer served both as signal source and as response recorder. The audiometer's signal was led to a loudspeaker in the anechoic chamber through a power amplifier; both the motor-driven attenuator and the motor-driven oscillator were retained in the circuit in order to produce, automatically, continuous-frequency graphs of each subject's threshold. Thresholds were allowed to stabilize before the oscillator motor was engaged. The technique is identical to that used in Békésy audiometry.

The other liberty was a philosophical one. Most laboratories, in testing particular brands of earplugs, commonly strive for optimum test conditions. Thus, if a manufacturer's representative can be at the test site to ensure proper use of his company's device, his services are accepted and welcomed. As a result, those tests give a reasonably good estimate of the performance that the plugs are capable of when they have been optimally fitted.[12] However, tests in this laboratory were designed to test the effectiveness of plugs that were fitted by an expert of the sort available to most industrial plants or government installations: fittings were made by carefully following any instructions furnished with the delivered materials. Had a manufacturer's published instructions indicated the need for a factory-trained fitter for his earplugs, we would have gotten one; no manufacturer printed that kind of instruction. Several manufacturers guarantee replacement of unsatisfactory earplugs (including those that might be unsatisfactory on the basis of their attenuation characteristics) and, indeed, in some instances our laboratory tests suggested that such replacement was desirable. However, when we asked our subjects if they were satisfied with the performance of such earplugs, they always said that they were—perhaps on the basis of comfort. So it is reasonable to believe that a purchaser who does not have appropriate laboratory facilities will judge the efficacy of any particular device strictly by his perception that it is or is not doing something that he wants it to do. If it feels good, he will not send it back for a plug that attenuates more.

As a result, some of the tests reported here may show smaller values of mean attenuation or larger standard deviations than will tests reported elsewhere on the same brands. Nevertheless, these numbers are believed to be fair representations of the effectiveness of the reported earplugs as they would be used in the field. Where manufacturers or distributors furnished no instructions, subjects were told to put the plugs in so that they fit comfortably and were tight. When instructions were furnished, they were followed exactly. For custom-molded varieties that use an ear impression as a model from which to manufacture the plug, and for custom-molded varieties where the impression itself *is* the earplug, the impressions were made by a skilled technician who followed manufacturers' recommendations precisely. In one case, detailed in the Results and Discussion section, a company changed its published instructions after our tests were completed; a second series was run with earplugs made according to the new directions.

Factory-made custom-molded earplugs were permitted to age in our laboratory for at least 2 weeks before testing started. A similar aging period was also required for units that were formed in the subject's ear. A still better procedure would have been to age all tested earplugs during a month of actual use. To do so, though, would not only have taken an exceedingly large number of subjects and an exceedingly long time, but in the case of most of the plugs tested, would have led to too few trials being run; some subjects in almost every group found some earplugs too uncomfortable to keep on throughout a breaking-in period.

One group of 10 subjects was used in 11 series of measurements. Other groups of 10 subjects were used for series as small as two and as large as six. Altogether, 110 subjects participated. With each group, the procedure was the same: the first threshold of the day was taken with open ears to provide a baseline; then, in random order, earplugs were tested for 2 hours or until each type had been measured three times, following which another open-ear threshold was taken. If 2 hours were not adequate to finish all the necessary series, the next day's tests also included open-ear thresholds at the beginning and at the end of the session. A 5-dB variation between the two baseline curves (at any standard frequency) was chosen to be large enough to invalidate that day's data, but this criterion was never exceeded. Each attenuation test was compared to the average of the two baseline curves taken on the same day as the test.

IV. Results and Discussion.

Nearly any material inserted into nearly any ear canal in nearly any way will attenuate high-frequency sounds to some extent. Under the circumstances, it is not surprising that people believe they are protecting themselves with earplugs made of dry cotton wool or of cigarette filters—a little attenuation at high frequencies produces a little change in tone quality, and the user believes that that change means he has blocked out damaging noise. The series reported here includes cotton-wool and facial-tissue earplugs.†

Table 3, like the commentary below, groups the tested earplugs in descending order of performance in The Typical Noise of Table 1, less two standard deviations (in order to make the values indicate the minimum expected protection for 98 percent of the population), less the Tobias and Johnson 3-dB correction to make the values represent the minimum expected protection in 99 percent of noises. A high position in Table 3 cannot serve as an adequate reason to purchase a particular brand of plug. The wearer's comfort is essential,‡ and a rating of Class 2 or better does not guarantee that people who ought rigorously to use hearing protection will do so without external incentives. Some industrial personnel might be motivated by brightly colored earplugs—not for the esthetic value, but because they know the plugs are visible to a distant foreman. Of course, the foreman has to understand his obligation to see that hearing protection is used. Other prospective wearers may respond positively to an option like a headband, a lace, or a cord, that makes it easy to keep track of the plugs when they are temporarily out of the ears.

† I was not brave enough to try testing the attenuation characteristics of cigarette filters. Not only is the variety of structures nearly inexaustible, but the procedures required for extraction after use seemed particularly treacherous.

‡ A few people have experienced mild cases of external otitis attributable to the use of earplugs. They need to be counseled that application of petroleum products or alcohol can exacerbate such problems for some people. If they continue to be troubled by otitis, earmuffs are certainly an appropriate alternative.

TABLE 3. Ratings for Earplugs in Order of Attenuation

Two Standard Deviations Below the Mean

Figure Number	Earplug	Mean Attenuation	Mean-σ Attenuation	Mean-2σ Attenuation	P-AR		
1	E-A-R	31.5	24.1	16.5	1	1	1
2	Softseal	27.4	21.8	15.7	2	1	1
3	Sound Silencer wet	25.3	19.4	12.5	3	2	2
4	Sound Silencer dry	23.7	17.1	10.3	3	2	2
5	Decidamp	25.0	16.7	8.4	3	2	2
6	Bilsom	18.4	13.5	8.4	4	3	2
7	Sonic Ear-Valv	26.6	17.5	8.3	2	2	2
8	V-51R	28.7	18.6	8.2	2	2	3
9	Flexiplug	26.3	17.3	8.1	2	2	3
10	Sound-Ban 20	22.9	15.4	7.6	3	3	3
11	Insta-Mold	21.9	14.7	7.2	3	3	3
12	Dr. Frank	22.8	15.0	7.1	3	3	3
13	Healthways	22.1	14.1	6.0	3	3	3
14	E.A.R.	23.6	14.8	5.9	3	3	3
15	Sound Sentry	22.2	14.0	5.7	3	3	3
16	Frontier	21.3	13.1	4.9	3	3	3
17	Oto-Cure	15.4	10.0	4.4	4	4	3
18	Silaflex	23.6	13.8	4.0	3	3	3
19	Accu-fit	25.5	14.9	3.9	3	3	3
20	3M	24.1	14.0	3.7	3	3	3
21	Peacekeeper	15.0	9.5	3.4	4	4	3
22	Peacekeeper 2nd	15.2	9.6	3.6	4	4	3
23	SafEar	16.2	9.9	3.5	4	4	3
24	Com-Fit	21.9	12.7	3.2	3	3	3
25	Genie	20.3	11.8	3.0	3	3	3
26	Hear-Saver	20.3	11.2	2.0	3	4	4
27	Flents	20.0	11.0	1.8	4	4	4
28	SEPCO	19.7	10.4	1.0	4	4	4
29	Nods	21.1	10.9	0.7	3	4	4
30	Soundown	14.7	7.7	0.6	5	4	4
31	Hearite B	25.8	13.2	0.3	2	3	4
32	Silent Partner	24.7	12.5	-0.1	3	3	4
33	Sonotone	20.4	10.3	-0.1	3	4	4
34	Auri-Seal	26.1	13.0	-0.2	2	3	4
35	Sound-Ban 10	20.0	9.9	-0.3	4	4	4
36	Hearite A	17.4	8.6	-0.4	4	4	4
37	Johnson & Johnson	7.3	3.4	-0.7	6	5	4
38	Sound Master	15.4	7.3	-0.8	4	4	4
39	Mark II	19.6	9.0	-1.4	4	4	4
40	SMR	22.8	10.5	-1.9	3	4	4

(continued)

Figure Number	Earplug	Mean Attenuation	Mean-σ Attenuation	Mean-2σ Attenuation	P-AR		
41	Adcomold	13.9	6.0	-2.0	5	5	4
42	Kleenex	6.7	2.2	-2.4	6	5	4
43	Stayrite	8.9	2.3	-4.8	6	5	5
44	Lee Sonic	20.1	7.4	-5.5	4	4	5
45	Fitsrite	21.1	7.6	-6.1	3	4	5
46	Hearite C	14.2	2.8	-8.7	5	5	5
47	Crown	12.3	1.9	-8.7	5	5	5
Mean*		20.1762	11.6047	2.5476			
Standard Deviation*		5.4706	5.0719	5.6693			

*Calculated excluding the dry Sound Silencer, the second test of the Peacekeeper, the Genie headset, the 3M, and the V-51R.

Some who get custom-molded plugs may wear them because they enjoy the idea that an expensive safety device was made strictly for their personal use.

The critical point is that procuring earplugs will conserve no hearing and will make no change in compensation payments if the plugs are always worn in the pocket. Selection has to be made with the idea of getting the plug to the part of the anatomy where it will do some good. In general, I recommend that more than one type be made available to workers.

A few additional details will help in the interpretation of Table 3:

1. The E-A-R (National Research Corporation) earplug (Figure 1) is made of a soft, easily compressed material that returns to its original shape rather slowly under normal circumstances, permitting insertion of the compressed form, which then expands to fill and seal the entrance to the canal. All the subjects who used this plug found it comfortable. We have no data on the expected life of the E-A-R earplug, but one member of the laboratory staff used a pair for at least 1 hour a day for 1 month without the material showing any signs of deterioration. During this period, the plugs were washed a few times with mild soap and warm water. The plug does change compression properties when used in high summer temperatures, so it may be more difficult to insert it effectively in environments hotter than 90° F. or so; however, I have no numerical data to support this contention. The plugs are furnished in bright yellow. They soil rapidly, and must therefore be handled carefully if they are to be reused for any appreciable length of time. P-AR=111

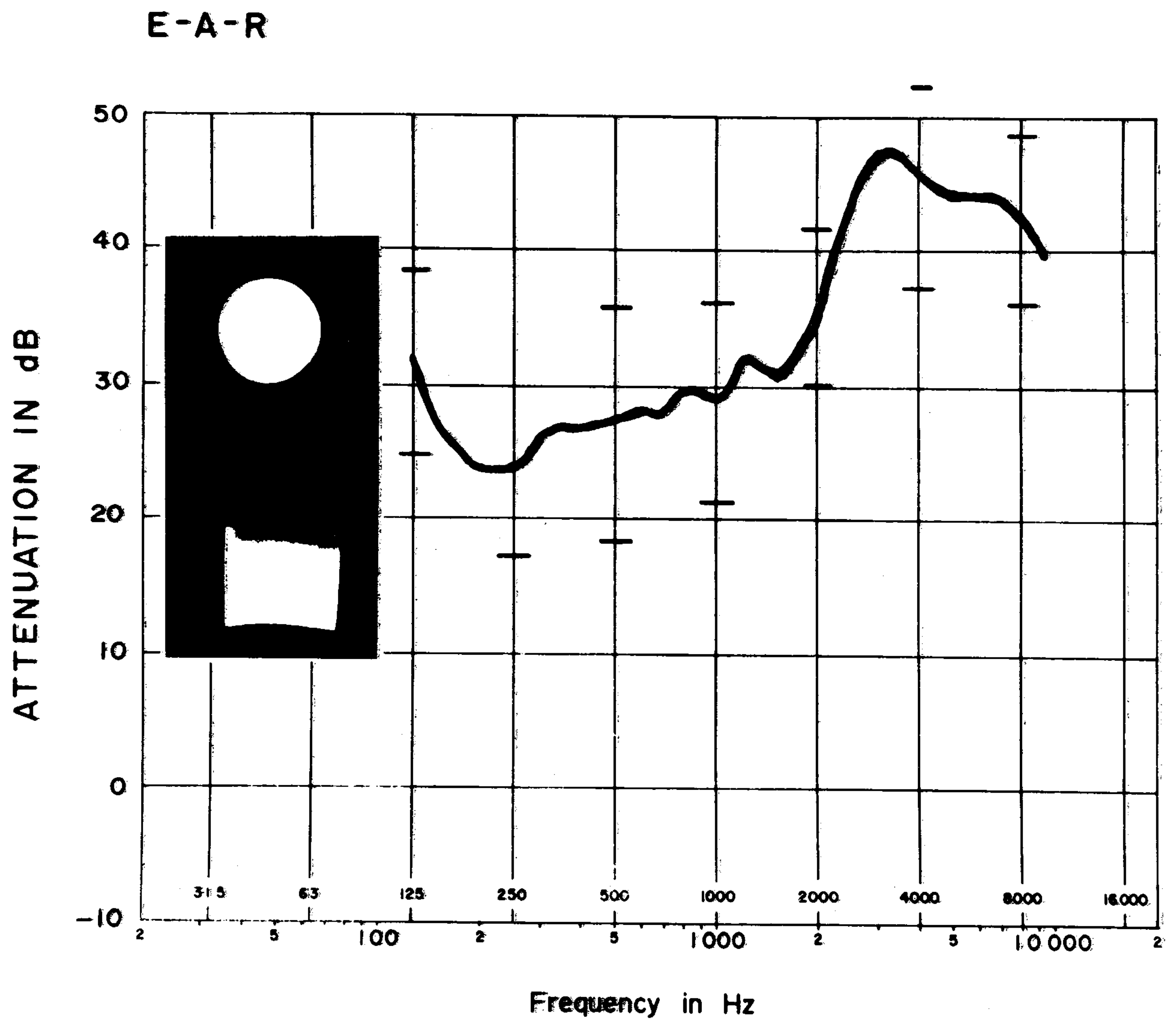


Figure 1

2. Softseal Hearing Protectors (Figure 2) are made of a silicone polymer that is tacky at body temperature and behaves much like Silly Putty. Enough material for two earplugs is packaged in a sealed envelope or in a plastic box. It is formed into two cones, pressed into the ears where it is held for 10 seconds, and then left in place. Most subjects found it comfortable and easy to handle, but because of its tendency to collapse under the influence of gravity, a few subjects considered it difficult to use. It was sometimes hard to remove. It does pick up dirt, which is then difficult to separate from the earplug material. If left out anywhere except in a small, enclosed container, the material puddles out into a fairly thin layer; in hot environments, the layer is very thin. P-AR=211

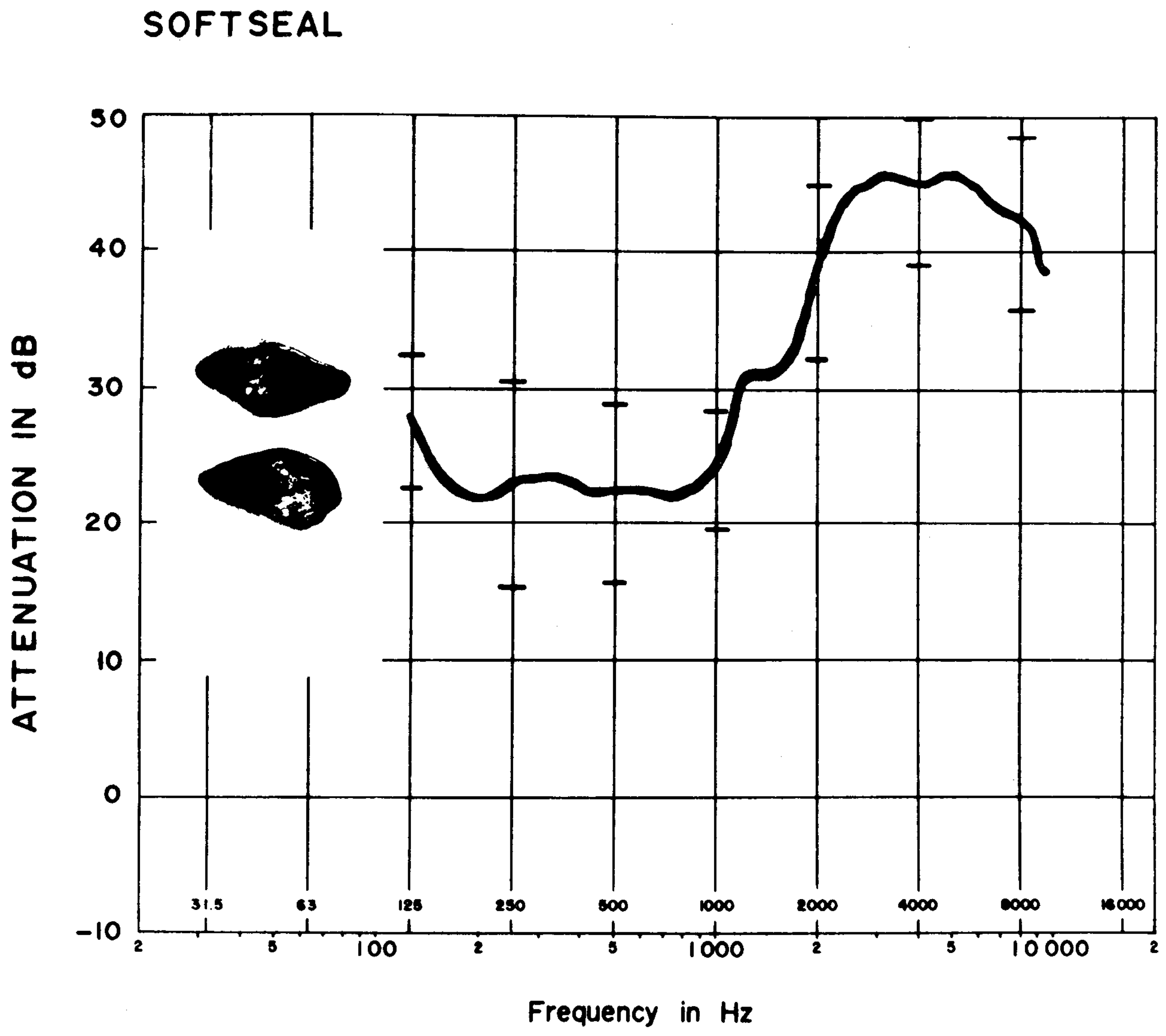


FIGURE 2

3. The Sound Silencer earplug (Figures 3 and 4) in the standard size fits most adults. Other sizes are available. The plug feels like a rubber bubble between the fingers. This structural characteristic made it very comfortable for all subjects who used it, but also made it somewhat difficult for about half of them to insert properly. The instructions call for wet insertion (which is quite easy), but many users may not have a ready source of water when it is time to put on their plugs, and saliva is a less-than-satisfactory substitute because of cleanliness and because of the flavor of ceruminous residues. Therefore, tests were run on this earplug both dry and lubricated with water (only the lubricated test was included in the computation of earplug mean and standard deviation). As might have been predicted, the lubricated (and therefore better seated) plug produced somewhat better attenuation scores. However, P-ARs were the same. A dark-green plug, a black plug, and a flesh-colored plug are available, as is a version that is strung on a cord. P-AR=322

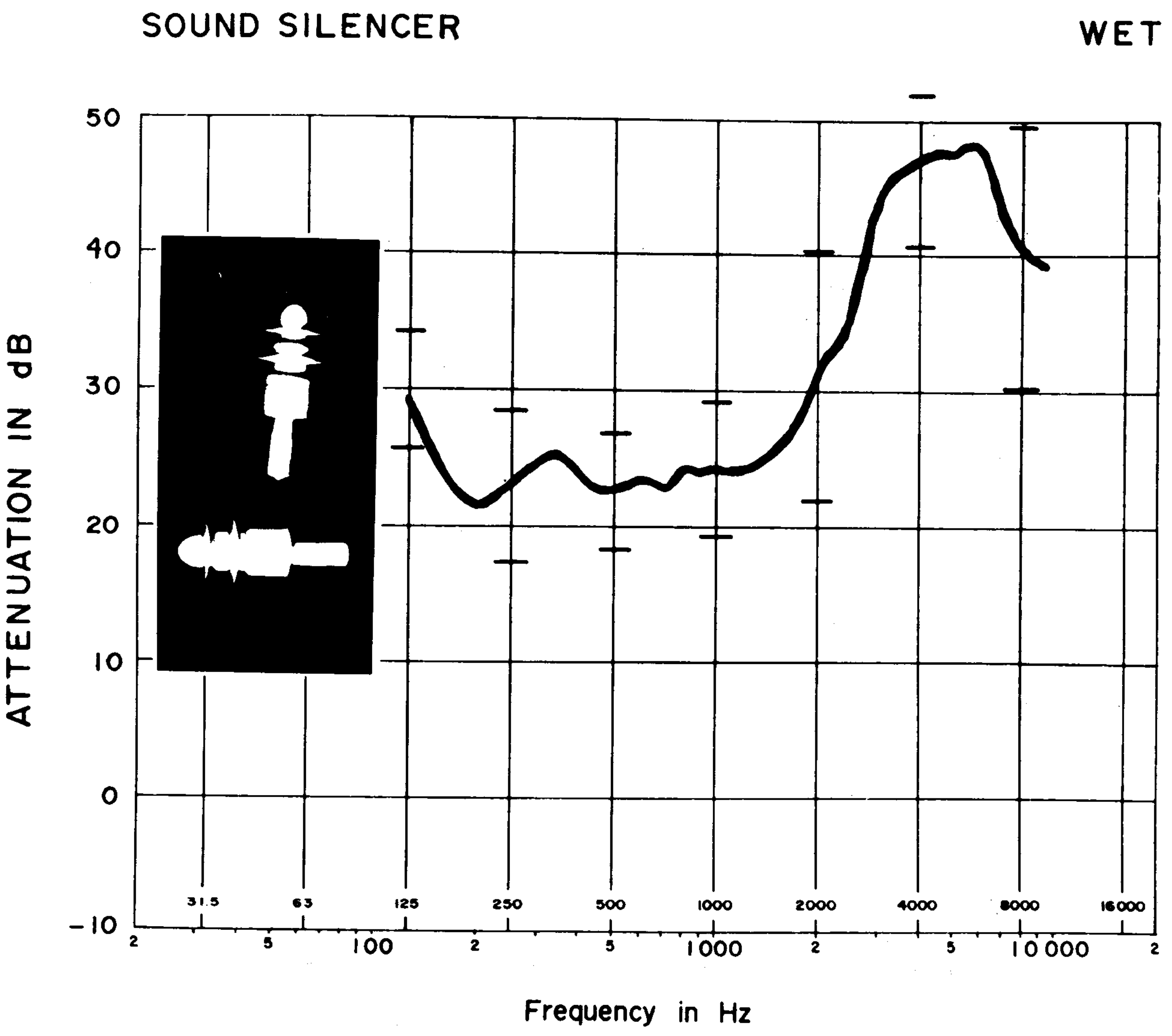
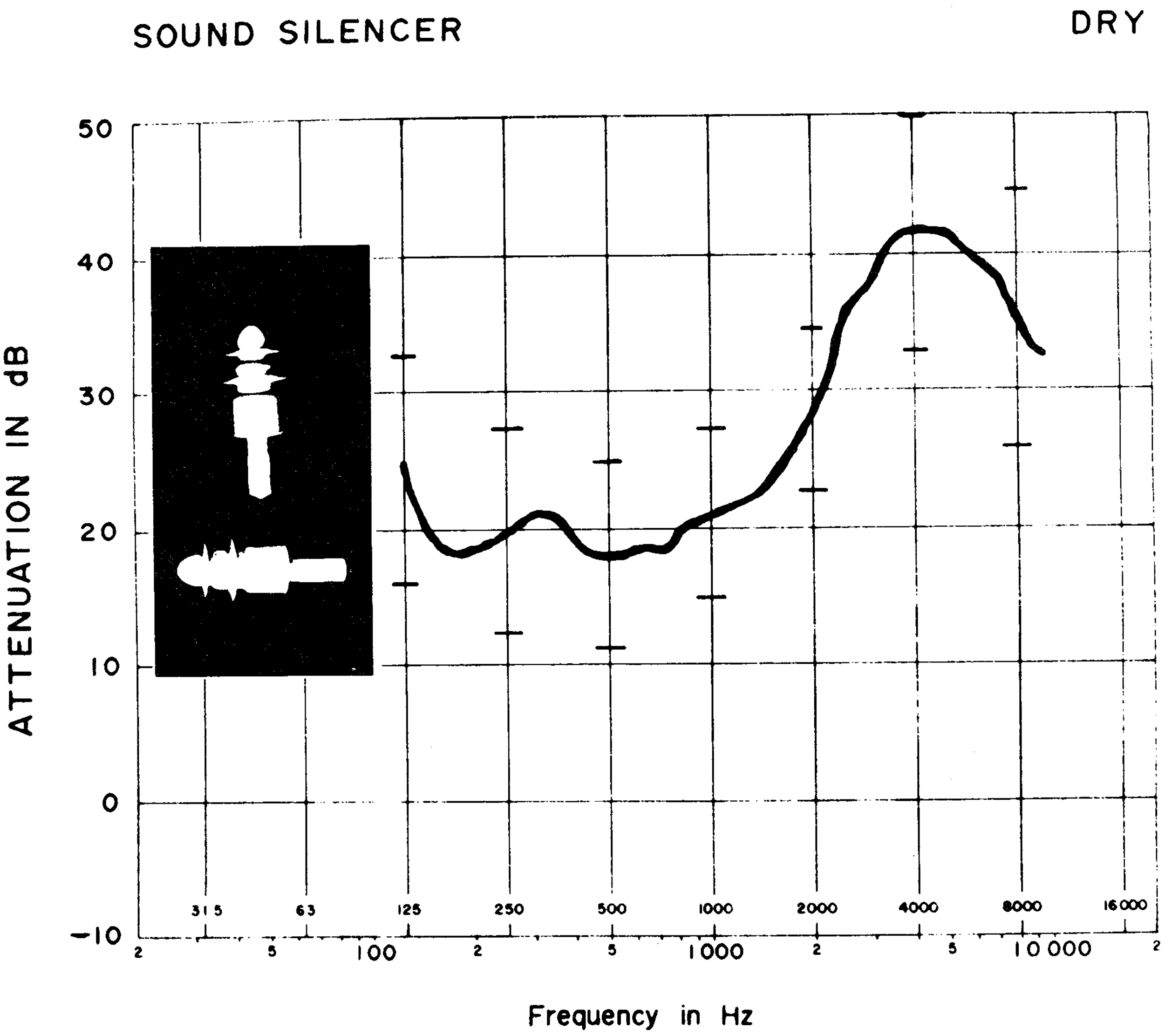


FIGURE 3



SOUND SILENCER
DRY
ATTENUATION IN dB
50
40
30
20
10
0
-10
31.5
63
125
250
500
1000
2000
4000
8000
16000
2
5
100
2
5
1000
2
5
10 000
2
Frequency in Hz

FIGURE 4

4. The Decidamp earplug (Figure 5) is similar to the E-A-R earplug (see paragraph 1) except that it is beige with one end surface tinted bright yellow—presumably, that end is to go toward the outside. Although it feels to have somewhat less body than the E-A-R, subjective reports of its characteristics are quite similar. P-AR=322

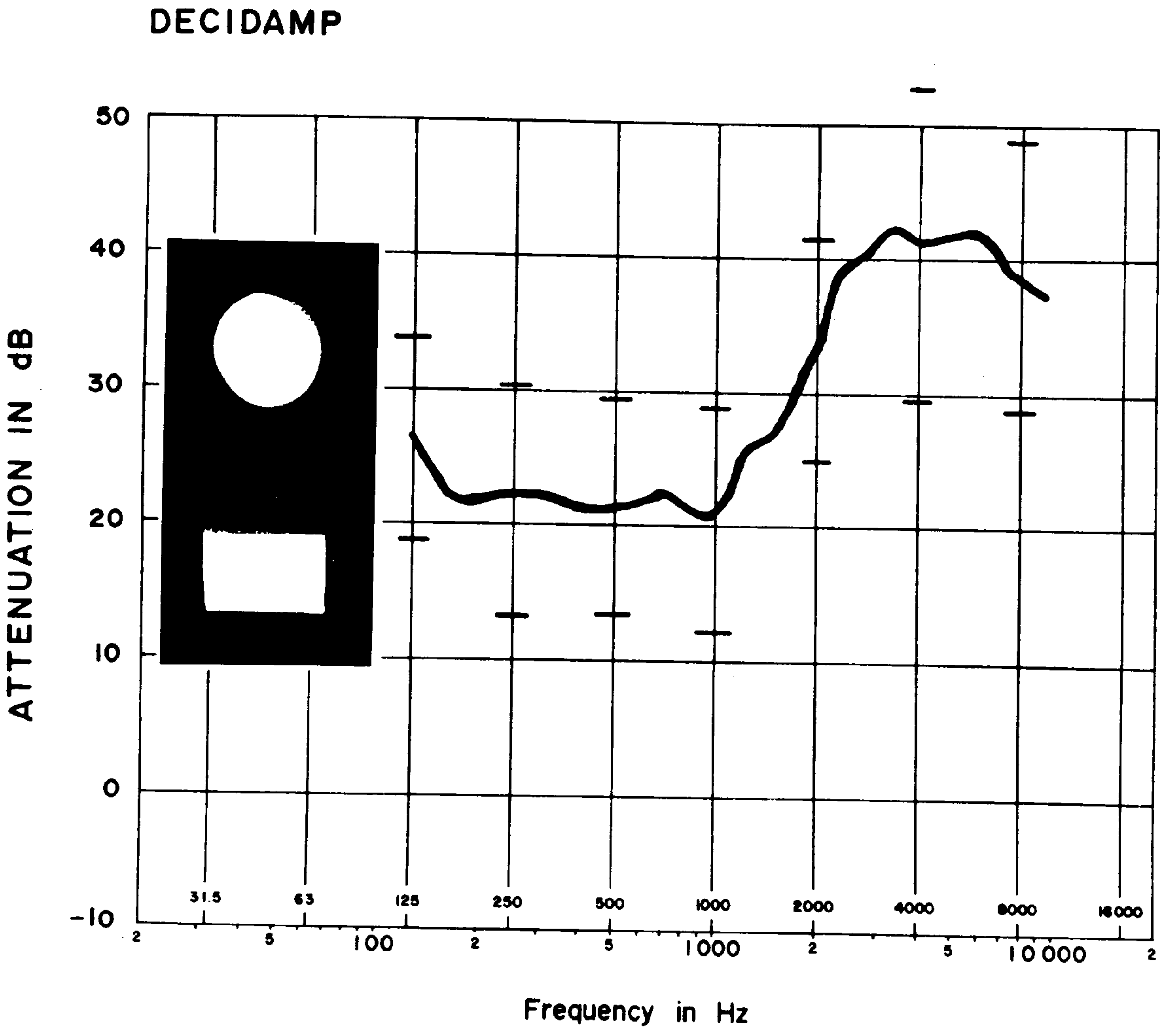


FIGURE 5

5. The Bilsom earplug (Figure 6) is also known as the Billesholm and as Swedish Wool. The material is fiberglass that is hand formed and is advertised to be effective "in 80% of all noise situations." It is meant to be thrown away after one wearing, but it can be reused several times if necessary. It is generally considered comfortable, and no subject who used it complained of any itching that might have been caused by fiberglass. P-AR=432

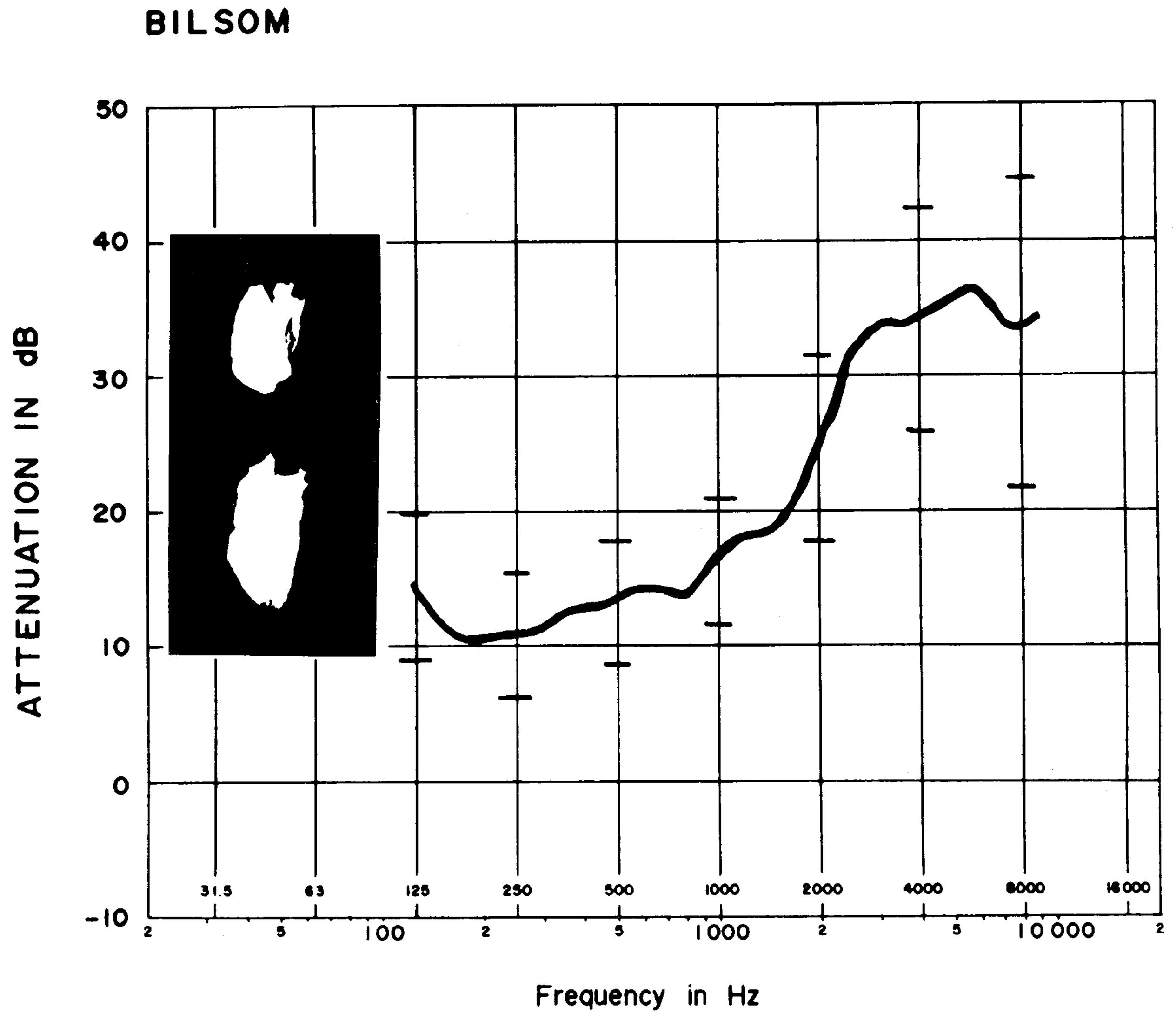


FIGURE 6

6. The Sonic Ear-Valv (Figure 7) is a redesigned version of the old Lee Sonic Ear-Valv (see paragraph 42). The new model has a much longer, flanged neck for insertion into the canal. In both models, the soft plastic material is fitted around a metal piston inside which a valve is supposed to work to shut off incoming sound when the intensity is high enough. At all other times, according to the advertising, the earplug is totally open down a long central perforation. The new version with the long canal piece has been sold with various pistons. The one tested here is not now on the market; its piston seemed to be in the closed position all the time, thus accounting for the very good performance. P-AR=222

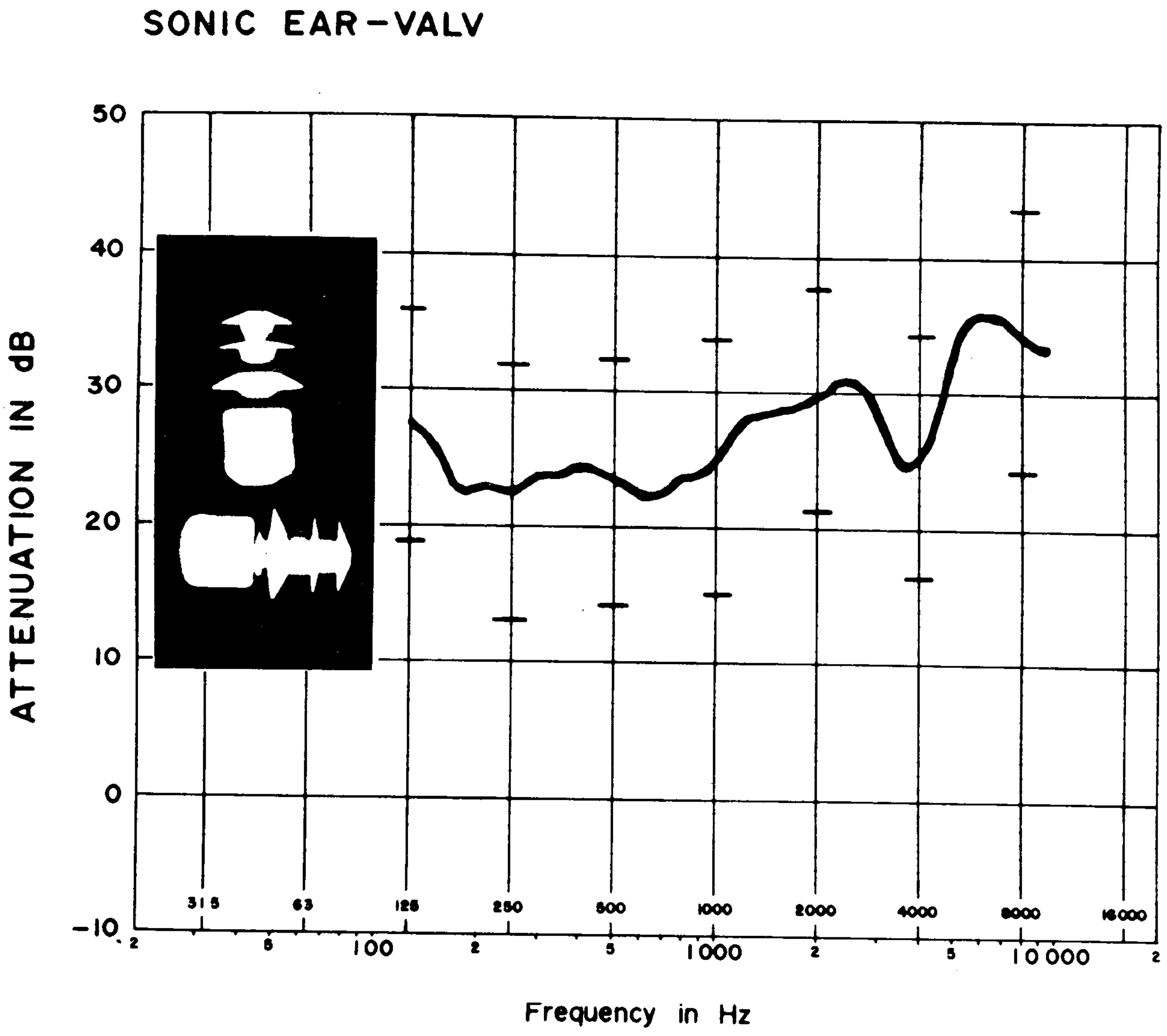


FIGURE 7

7. The V-51R (Figure 8), a plastic earplug developed for use during World War II, remains a good and versatile device. A few problems do arise for its user, though. Foremost among these is the need for accurate fitting: the plug is available in five sizes (although most buyers stock only two or three), and many ear canals seem to fall between sizes. Further, day-to-day variations in canal dimensions may require selection of different sizes at different times for the maintenance of both attenuation and comfort. The plug's asymmetry also contributes to problems of accurate fitting. Although usually soft and pliable when first worn, the V-51R loses some of its plasticizer within a few weeks. Wearers then complain of discomfort from the "stiffness" or "brittleness." Despite these problems, it is still a popular and effective earplug. Several manufacturers produce it. My stock includes V-51Rs distributed by American Optical Corporation, by Mine Safety Appliances Company, and by United States Safety Service Company. It may be available from others as well. The current data were collected on plugs bought from Mine Safety Appliances. The V-51R was not included in the computation of earplug mean and standard deviation. P-AR=223

V-51R

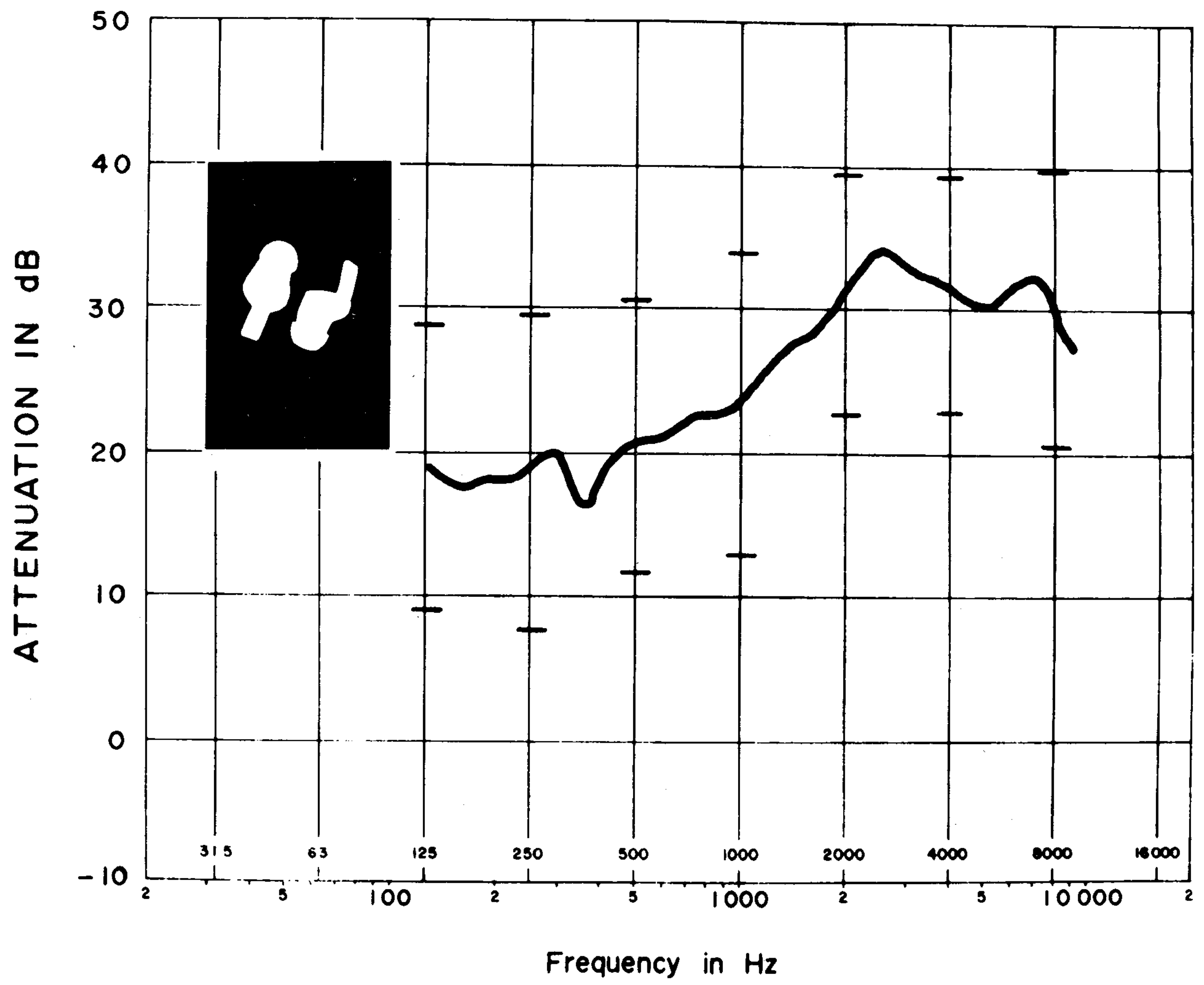


FIGURE 8

8. The Flexiplug (Figure 9) is a soft silicone plug with flanges of graduated diameter, designed to fit a large portion of the population with only one size. As with most flanged earplugs tested, some subjects reported difficulty in inserting them, and a few people who had slit-like (rather than rounded) canal openings found them extremely uncomfortable. The plugs are orange and can be bought strung on a cord. P-AR=223

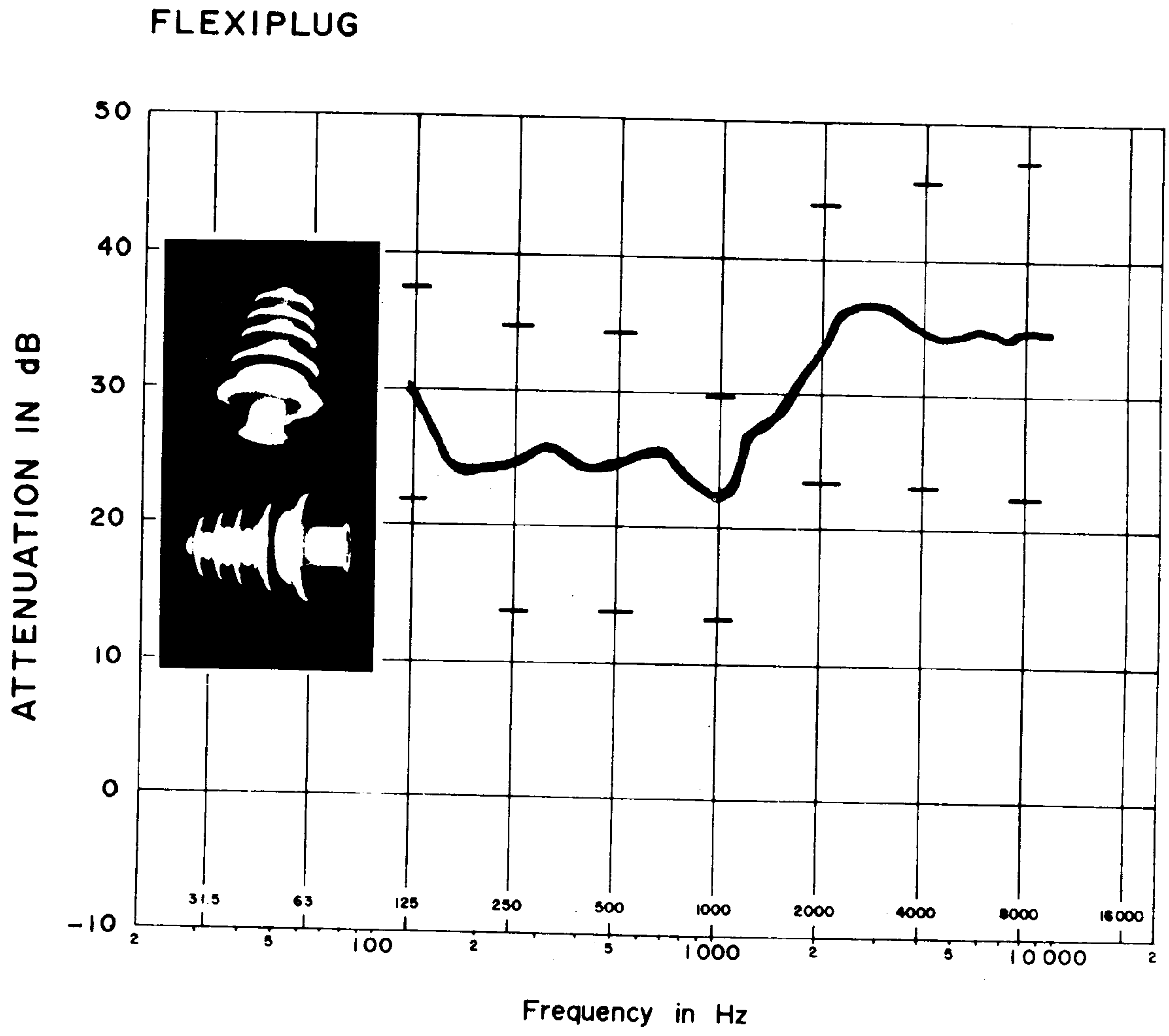


Figure 9

9. The Sound-Ban 20 (Figure 10) is an earcap with a plastic-tubing headband (another version of this cap is discussed in paragraph 33). The earpiece is soft-textured, air-filled, blue vinyl. Attenuation is the result of covering the opening to the canal rather than inserting something into the canal itself. Although it is necessary to position the cap with the proper front-rear orientation, subjects had no difficulty with the task. The Sound-Ban 20 may be worn with the headband under the chin or behind the neck. Headset users sometimes complain about headband discomfort, but no subject complained about this one. P-AR=333

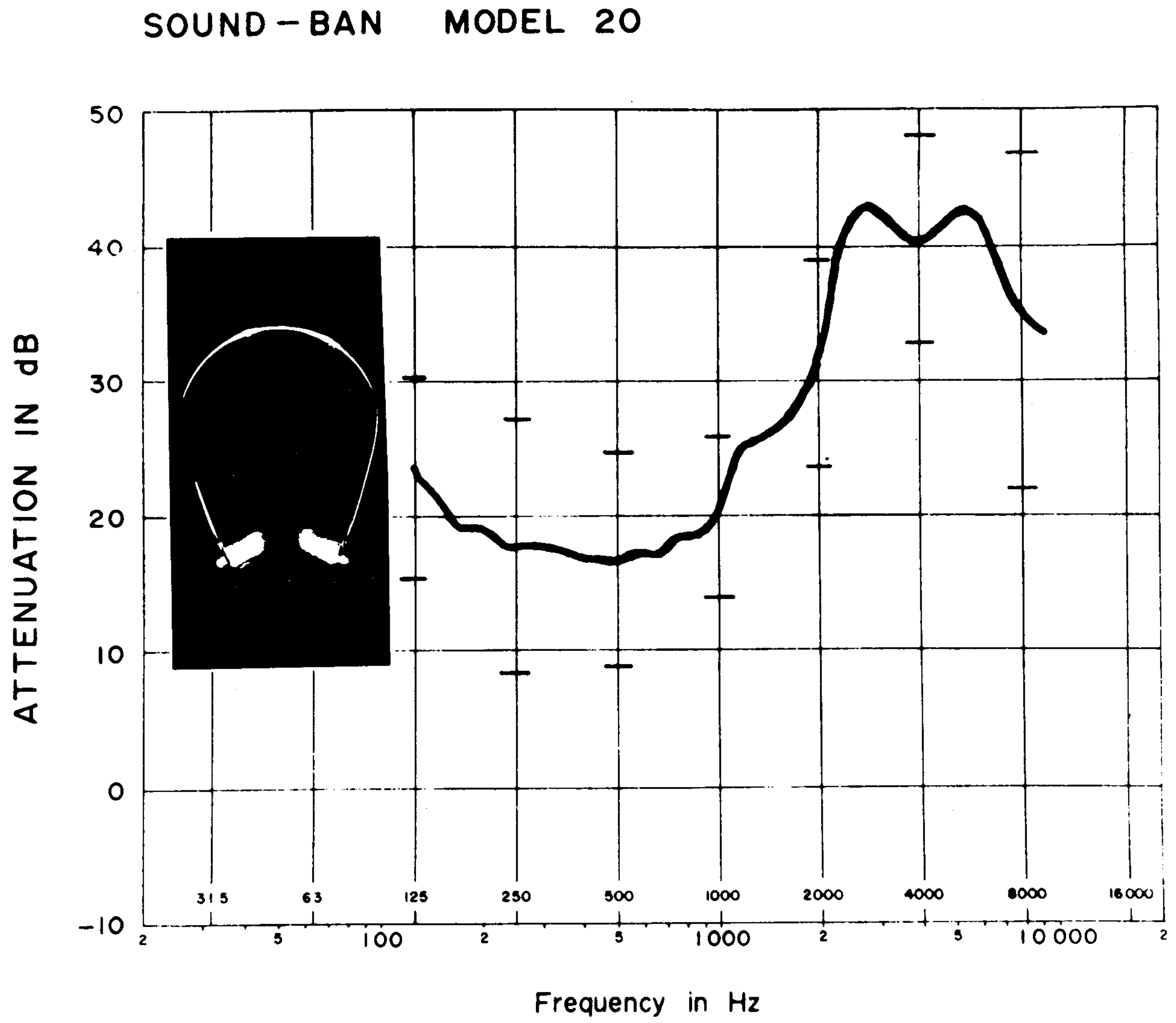


FIGURE 10

10. Insta-Mold earplugs (Figure 11) are custom molded in place—that is, the user can wear the molds as earplugs as soon as the material has cured. Problems with the catalyst led us to waste nearly half of the earmold material that we purchased. One must learn to work rapidly with this sort of material because it sets up very shortly after the catalyst is mixed in and can become stiff so quickly that reforming it into the right shape is impossible. With Insta-Mold, this situation arose far more frequently than with other such plugs. As with all custom-molded plugs, and especially with those that do not require factory construction, the manufacturer's instructions must be followed carefully and accurately; there is no substitute for experience in earmold construction. Subjects found Insta-Mold plugs comfortable and easy to insert, but, like all the custom-made plugs we tried, they were less comfortable than were most preformed or wearer-formed varieties. P-AR=333

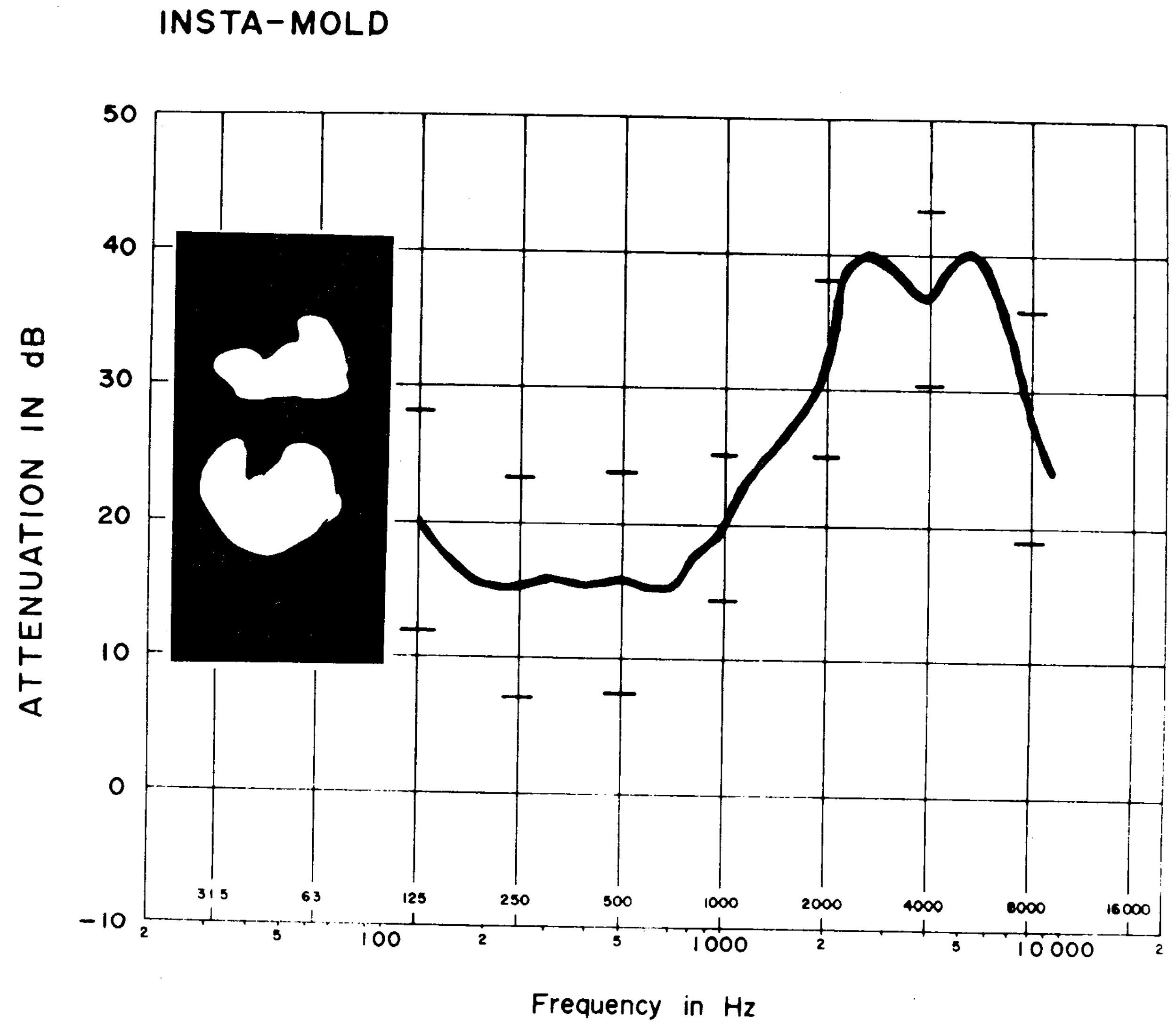


FIGURE 11

11. Although the Dr. Frank earplug (Figure 12) is sold in sporting goods stores as much for use in swimming as for hearing protection, when properly fitted, it is a fairly effective sound attenuator. It is made in many sizes, and fit is critical. Subjects had difficulty determining which end should go into the ear canal, but the manufacturer's simple instructions, if read, are adequate to solve that problem. Earplugs were sometimes hard to remove. The same plugs are available under the name Voit; they may be distributed under other names as well. P-AR=333

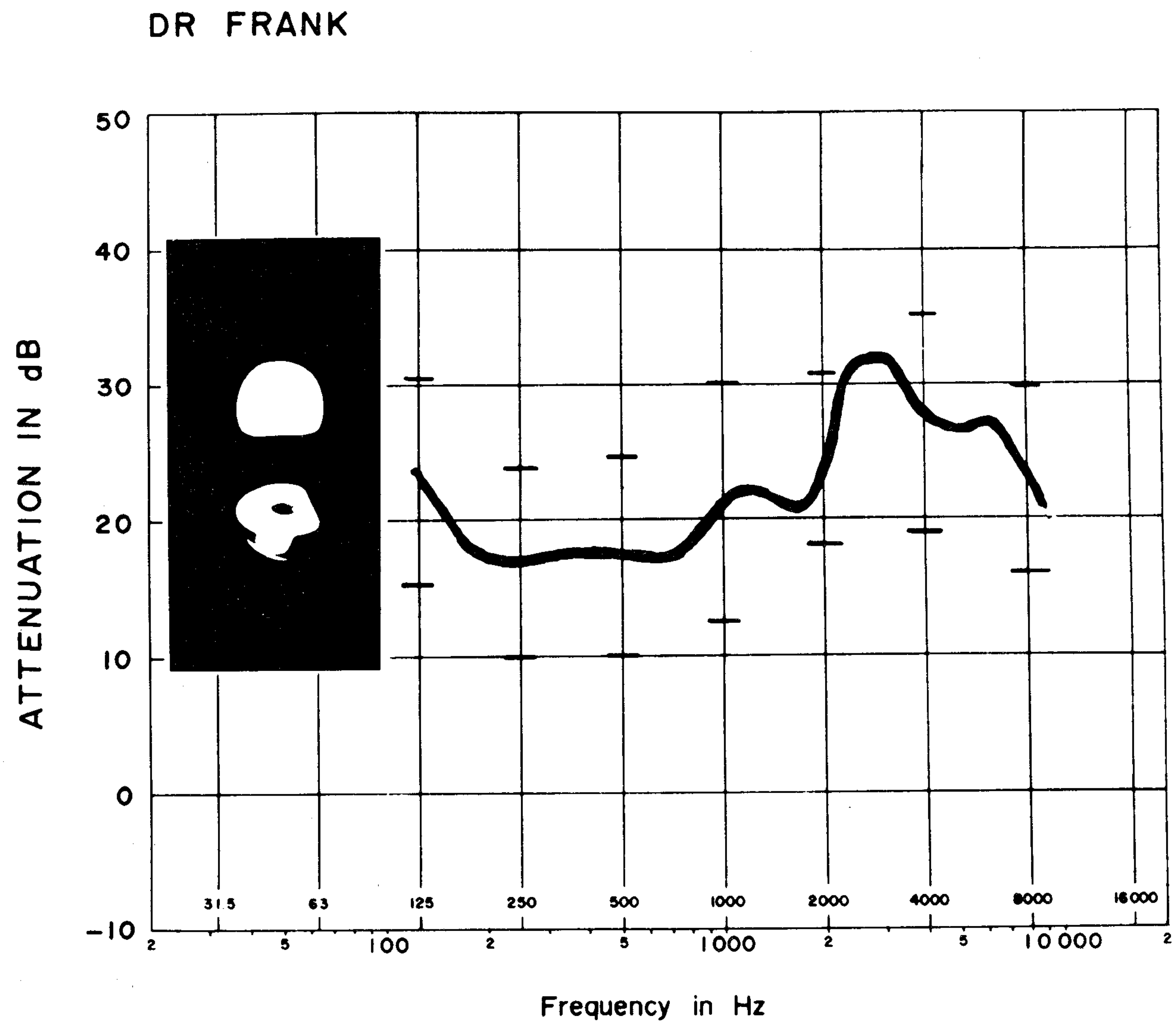


FIGURE 12

12. Healthways earplugs (Figure 13) are made of pink, preformed rubber, molded in a single, fairly thin layer. Apparently they are comfortable and easy to insert, since subjects did not volunteer comments on them at all. The manufacturer specializes in gear for swimmers. P-AR=333

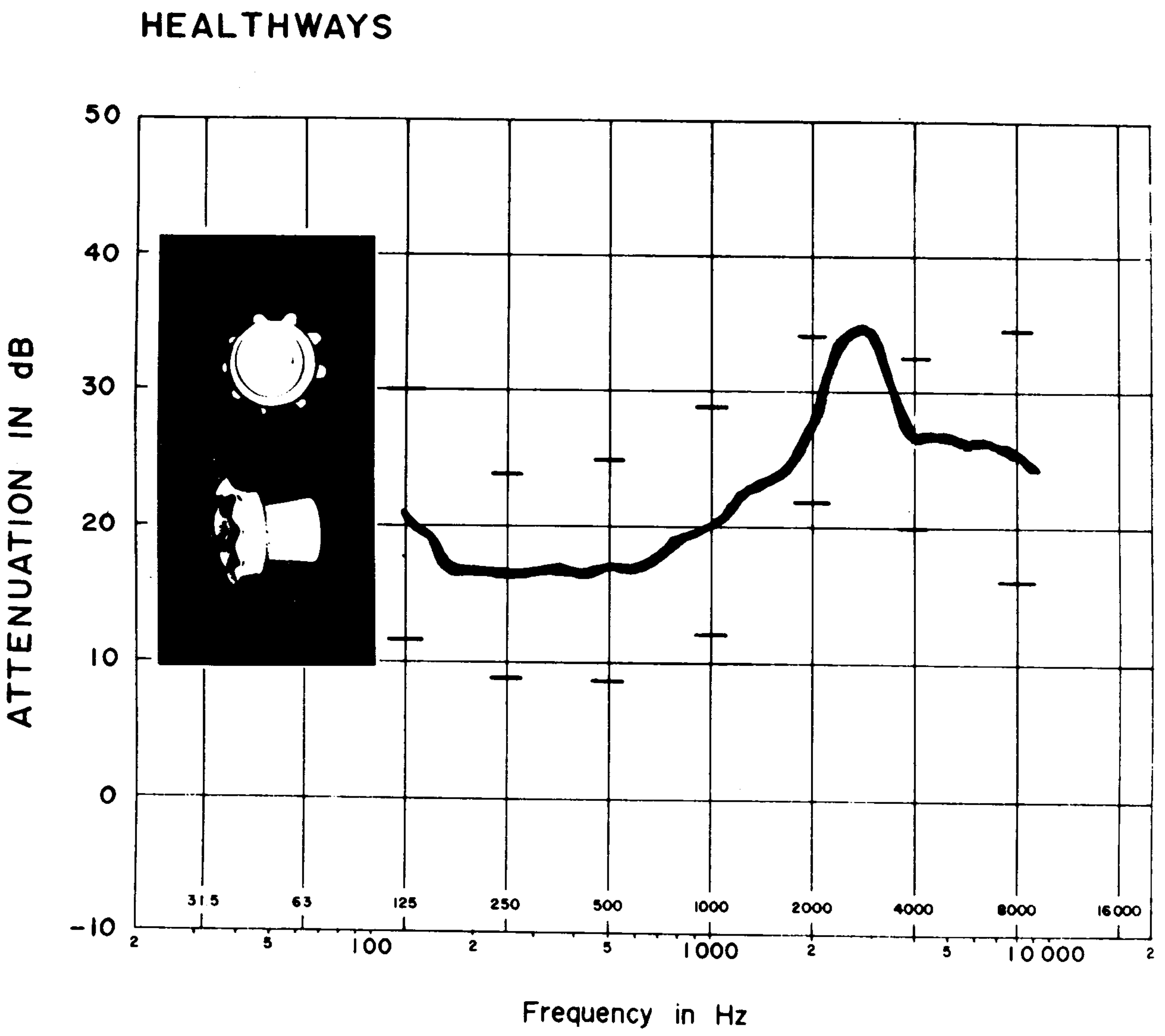


FIGURE 13

13. The E.A.R. (Environmental Acoustical Research) plug (Figure 14) is a soft, factory-made, custom-fitted device. Subjects found it fairly comfortable and easy to insert, but, like the Insta-Mold earplug, it is custom made and users find it somewhat less acceptable than many of the preformed and wearer-formed plugs. P-AR=333

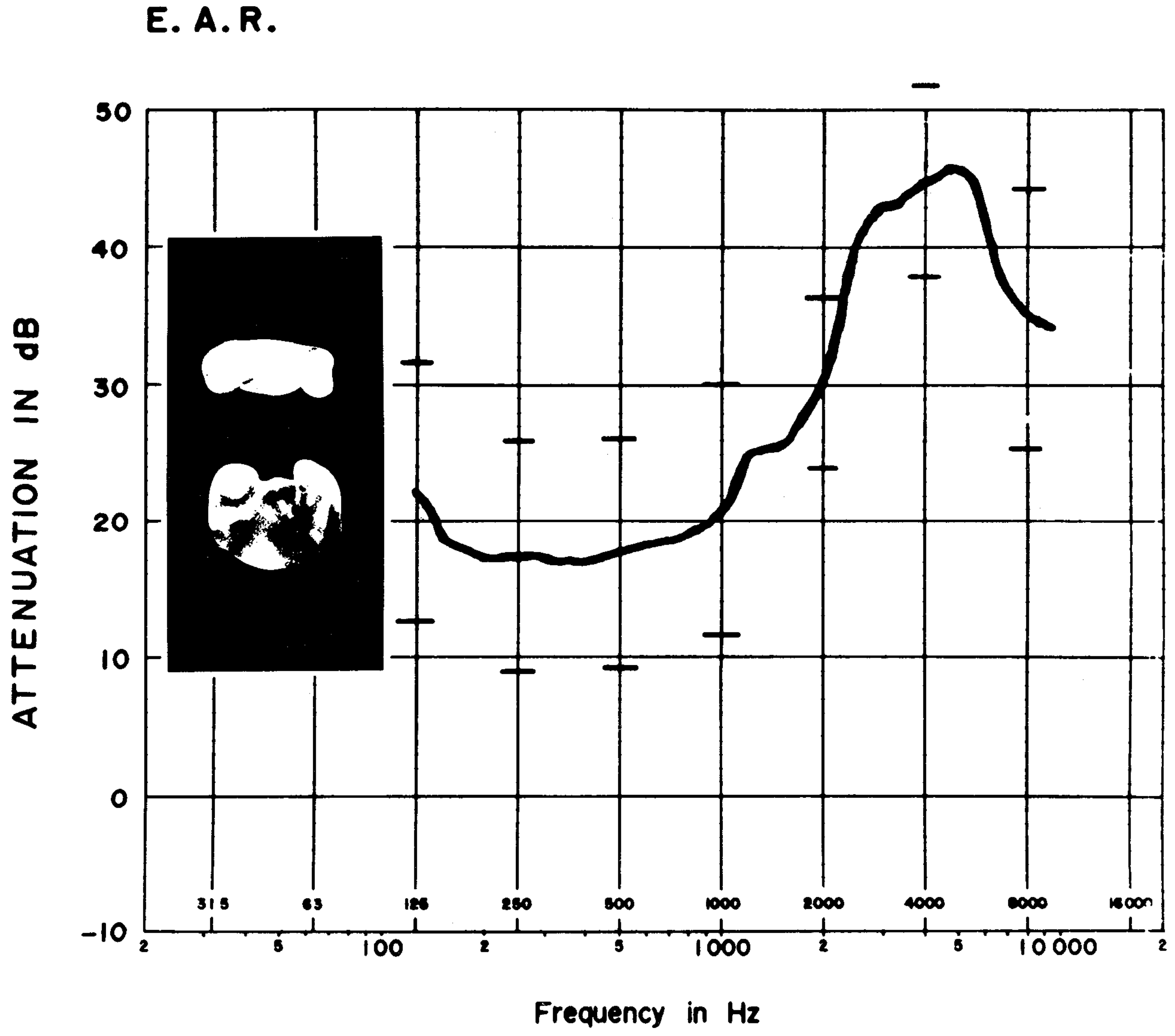


FIGURE 14

14. The Sound Sentry (5000B) hearing protector (Figure 15) is another earcap on a headband, and not an insert earplug. Attenuation results from covering the opening to the canal with a neoprene cap. The cap is difficult to position accurately for the initial wearing, but once adjusted, it is easy to put back on. No subjects complained of the headband, but several found the caps themselves to be uncomfortable. P-AR=333

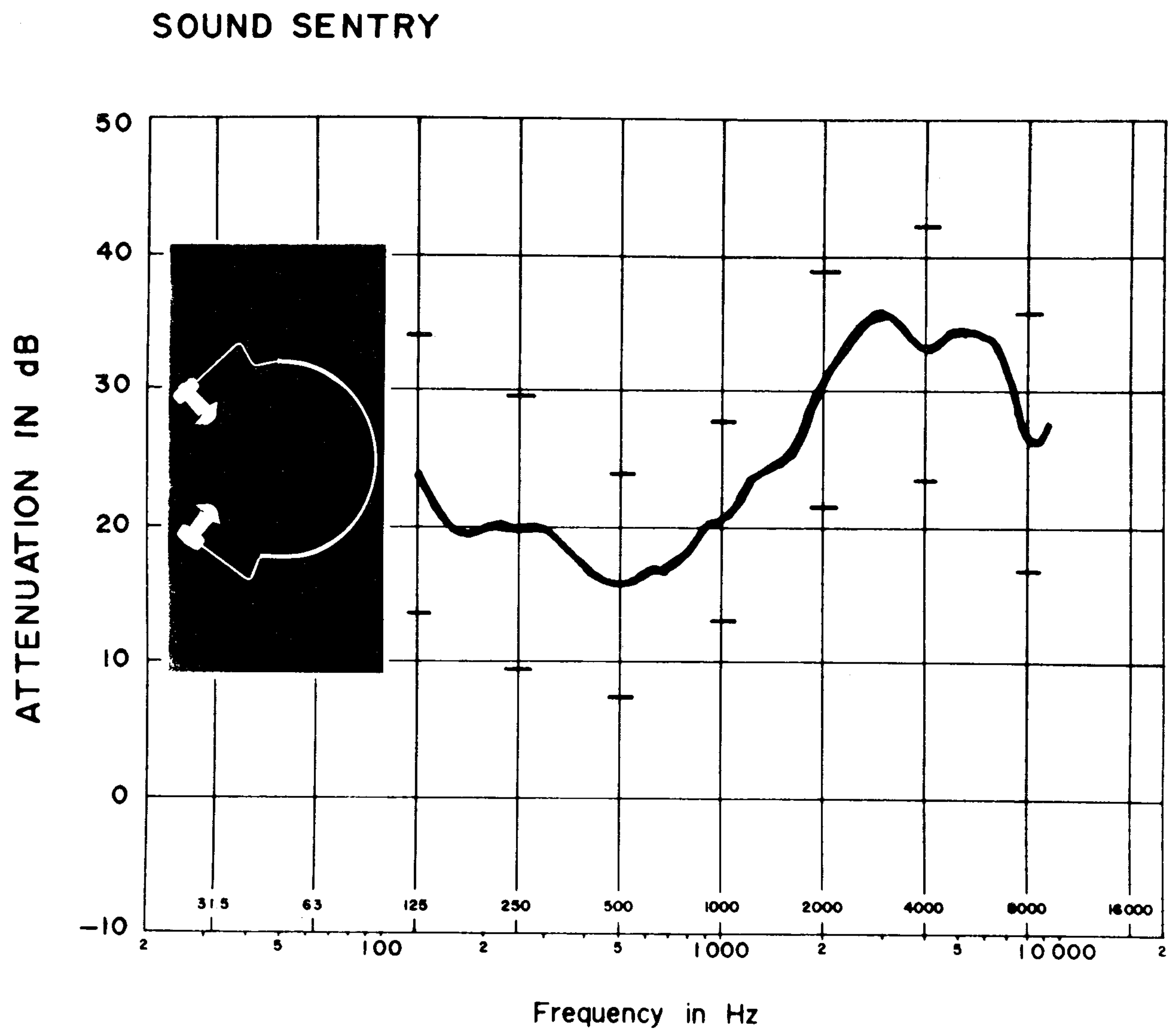


FIGURE 15

15. The Frontier earplug (Figure 16) is made of wax-impregnated cotton fiber that is hand formed by the user. Some subjects complained that the wax felt funny in their fingers. The expected life of such plugs is, at most, a few wearings. P-AR=333

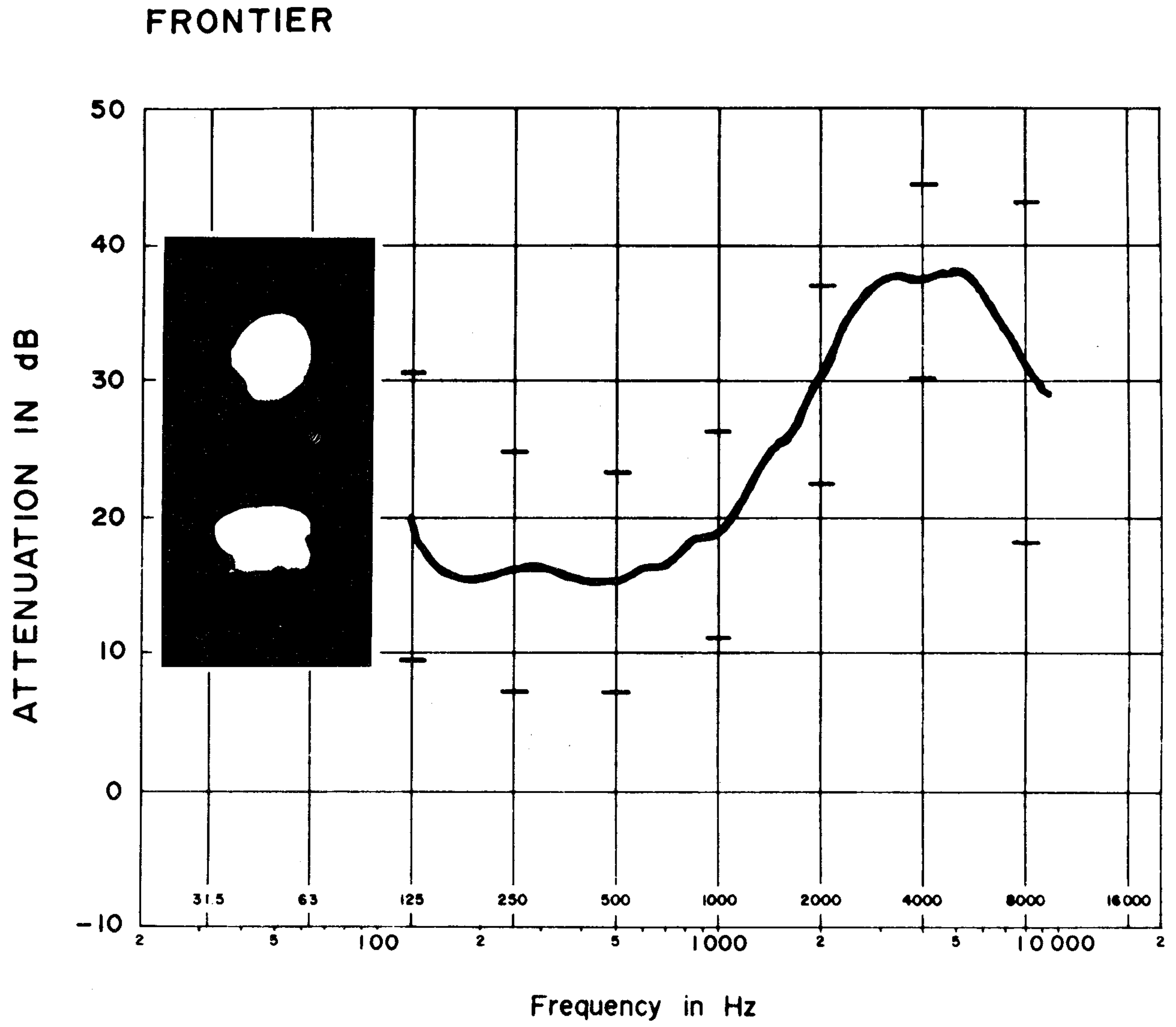


Figure 16

16. Oto-Cure Custom Ear Protectors (Figure 17) are custom molded and do not require factory construction: the mold cures to become the final earplug. For Oto-Cure, the process requires the use of volatile chemicals whose fumes were strongly disagreeable to the people who had to work with them. The material is difficult to handle properly. P-AR=443

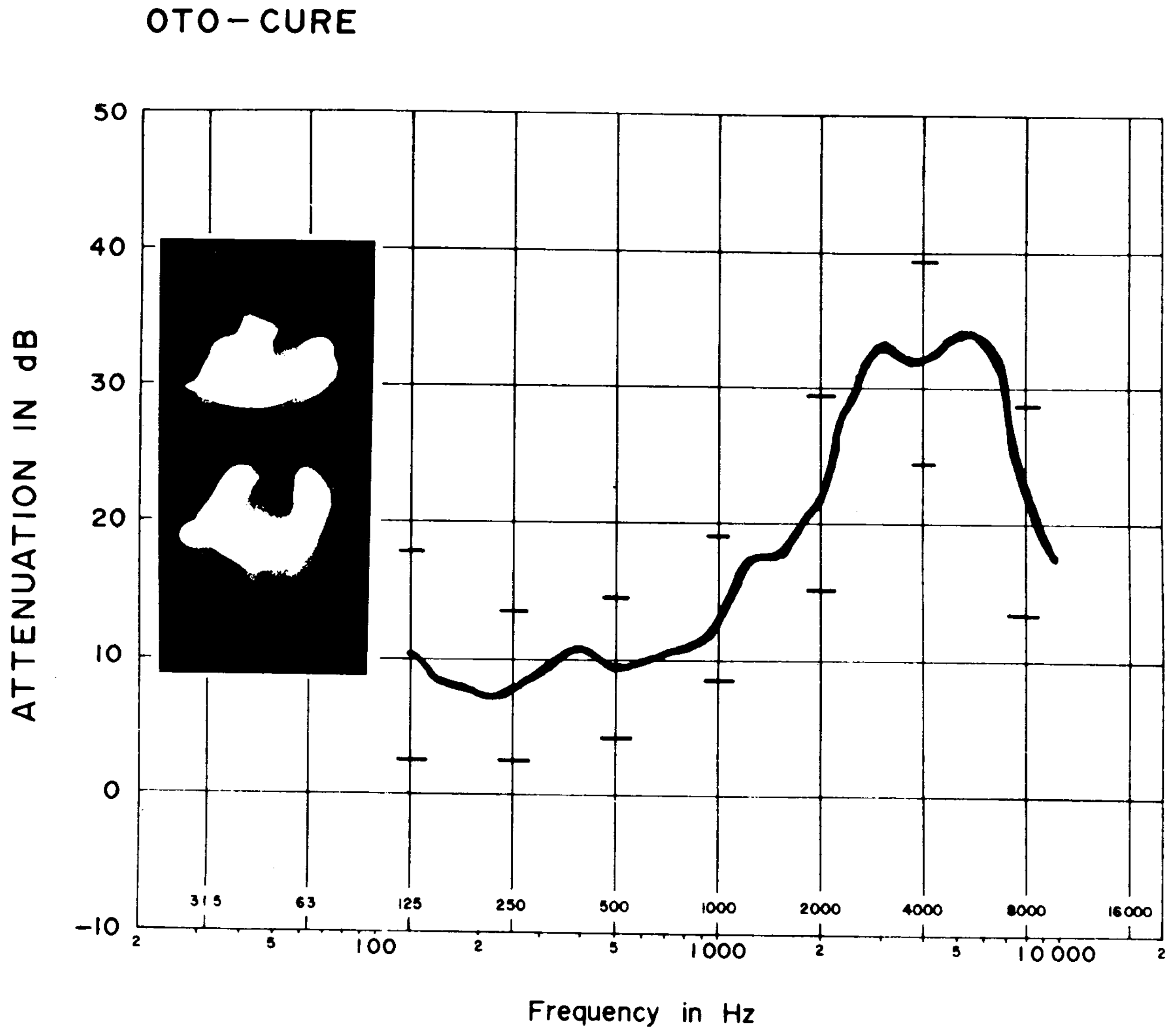


FIGURE 17

17. Silaflex (Figure 18) is a wearer-molded silicone plug. Users include both strong proponents and strong opponents of its comfort and ease of use. The putty-like material is flesh colored. P-AR=333

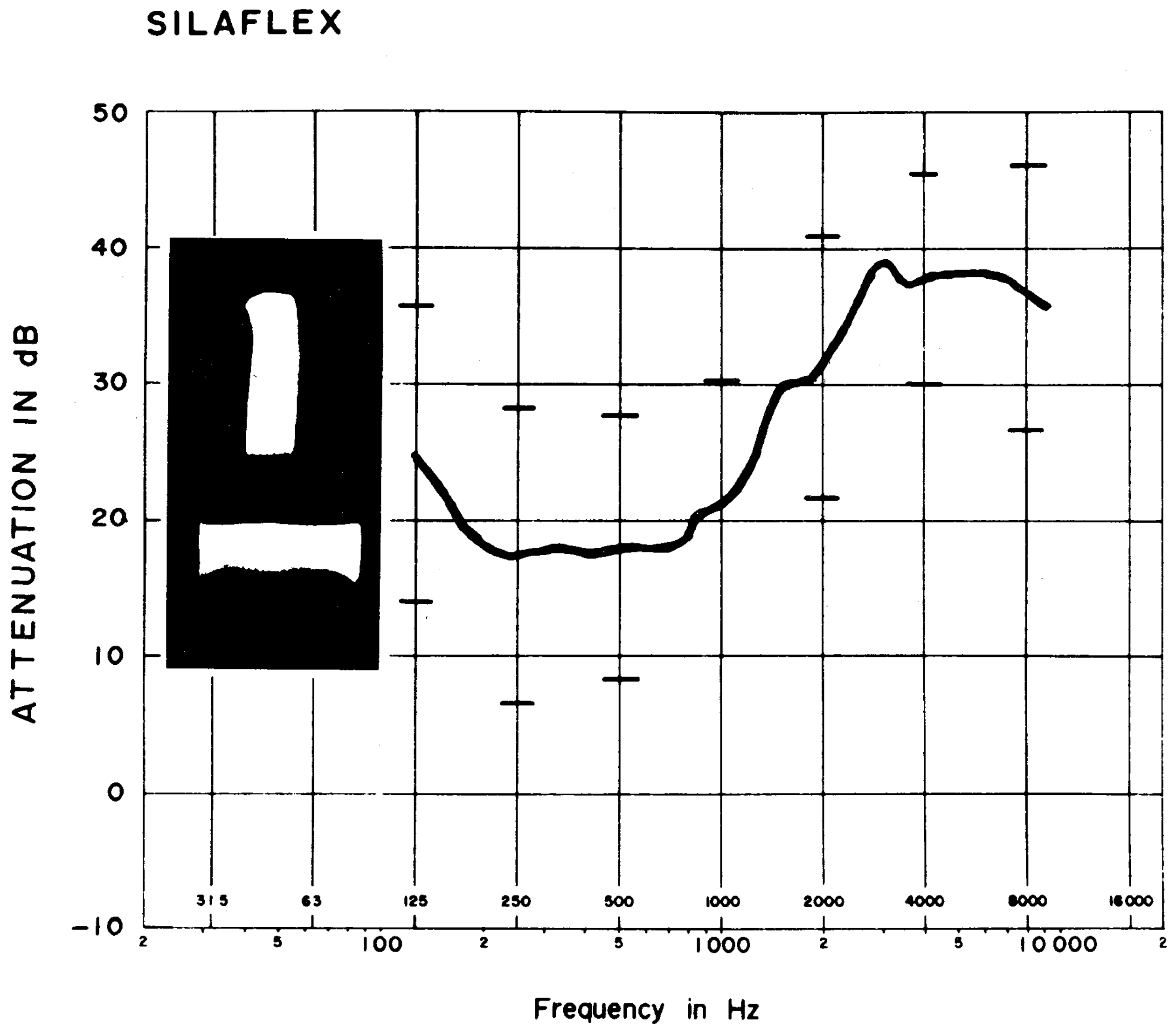


Figure 18

18. Accu-fit earplugs (Figure 19) are a soft, preformed type. They seem less easy to insert than other flanged plugs. Accu-fit plugs are available strung on a cord. P-AR=333

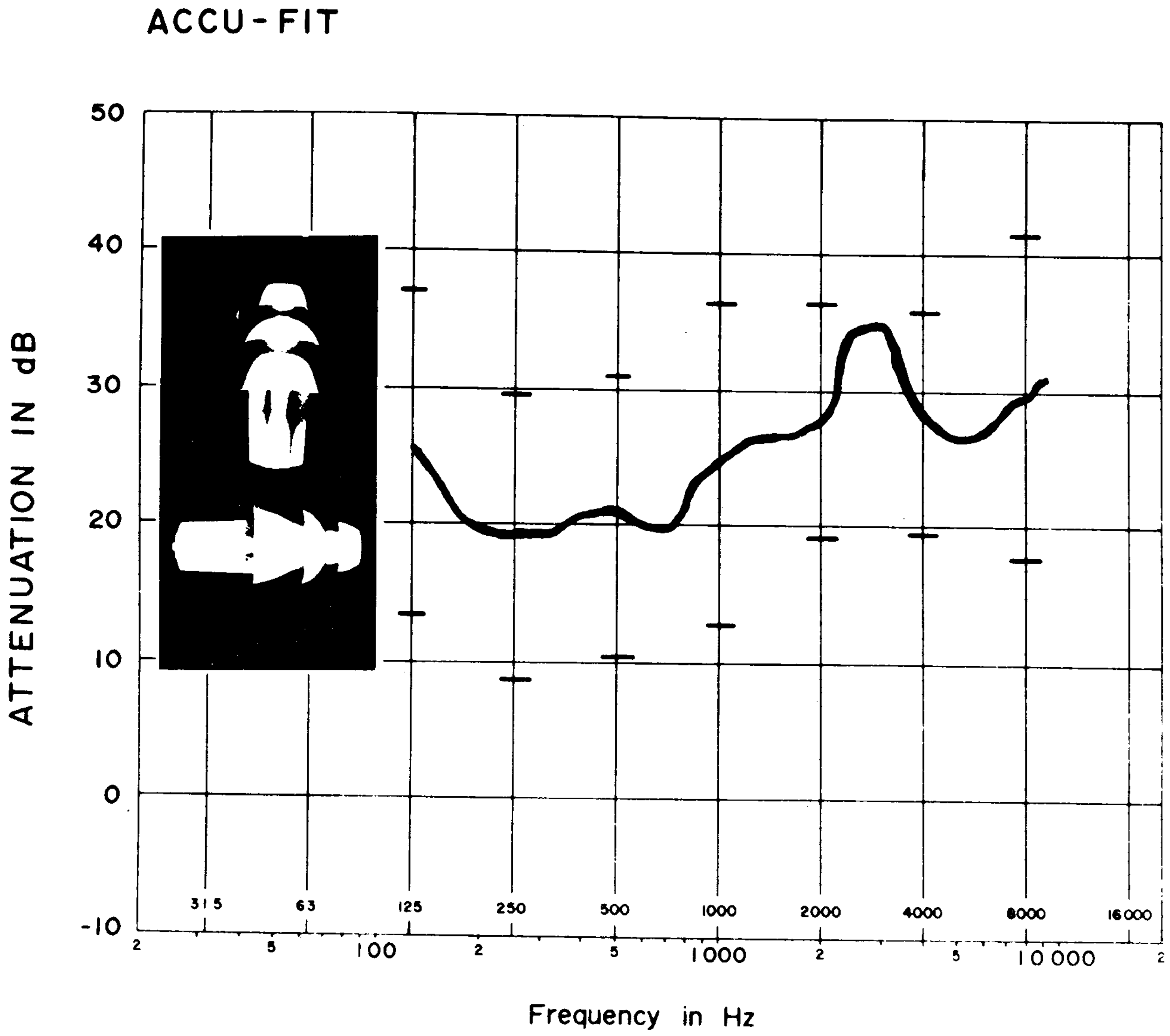


FIGURE 19

19. The 3M earplug (Figure 20) is a soft, white, synthetic-rubber device that is advertised as disposable. Although it looks like many of the other flanged plugs, its flimsiness in use does require that it be replaced after a few days' wear; its relatively low cost encourages such replacement. Manufacturer's instructions suggest that users who find the plug uncomfortable or insecure can remove one or more discs from the tip. Two of our subjects did so; their results are not distinguishable from those of subjects who left the plugs whole. All subjects who used this plug found it comfortable. This earplug was tested after most other data had been collected. It was not included in the computation of earplug mean and standard deviation; its P-AR is derived from the distribution of the other earplugs. P-AR=333

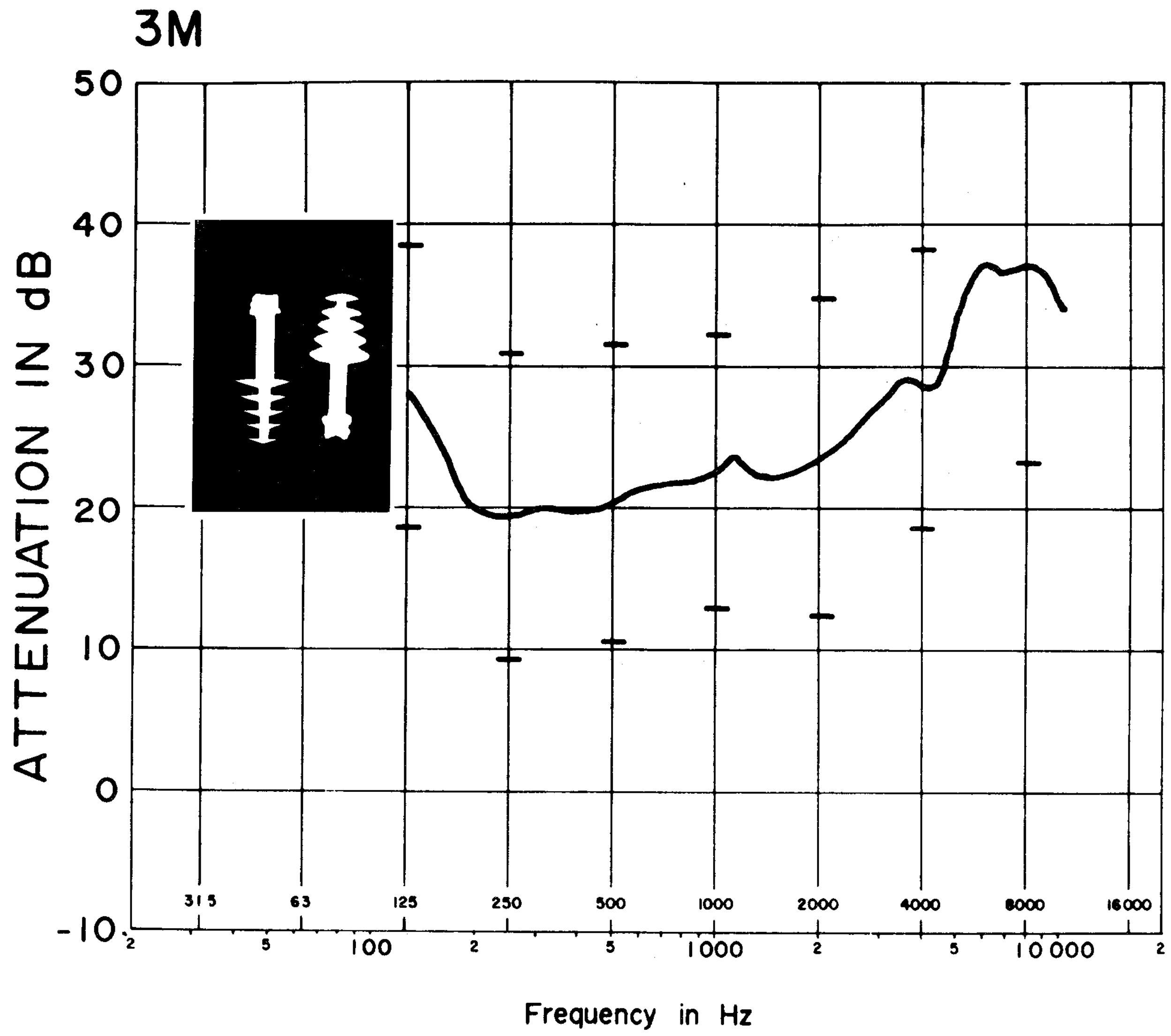


Figure 20

20. The Peacekeeper (Figures 21 and 22) is a custom-made earplug that does not require factory construction. The silicone mold cures to become the final earplug. The material for both ears is mixed simultaneously. The molding kits were obtained through normal procurement procedures—ours came from the former manufacturer, General Electric. We made the plugs strictly according to the accompanying instructions, aged them for a time, and tested them. The kits include a dip that helps to seal the surface of the plugs and to smooth out irregularities, thus increasing the size slightly. Plugs can be redipped to improve the fit, although the need for such improvement would not be obvious without a laboratory test of effectiveness; such tests are not likely to be performed in field use of the devices because of lack of time, money, and facilities. In these studies, the dip was used precisely according to the instructions. Tests showed less attenuation (Figure 21) than some of the manufacturer's reports showed, and General Electric requested that we test plugs made by their representative. I asked instead for better instruction manuals or an indication that the plugs would always be sold with the fitting service included. After the company published a revised manual, we performed a second series of tests on plugs made according to the new instructions (which called for more rapid mixing

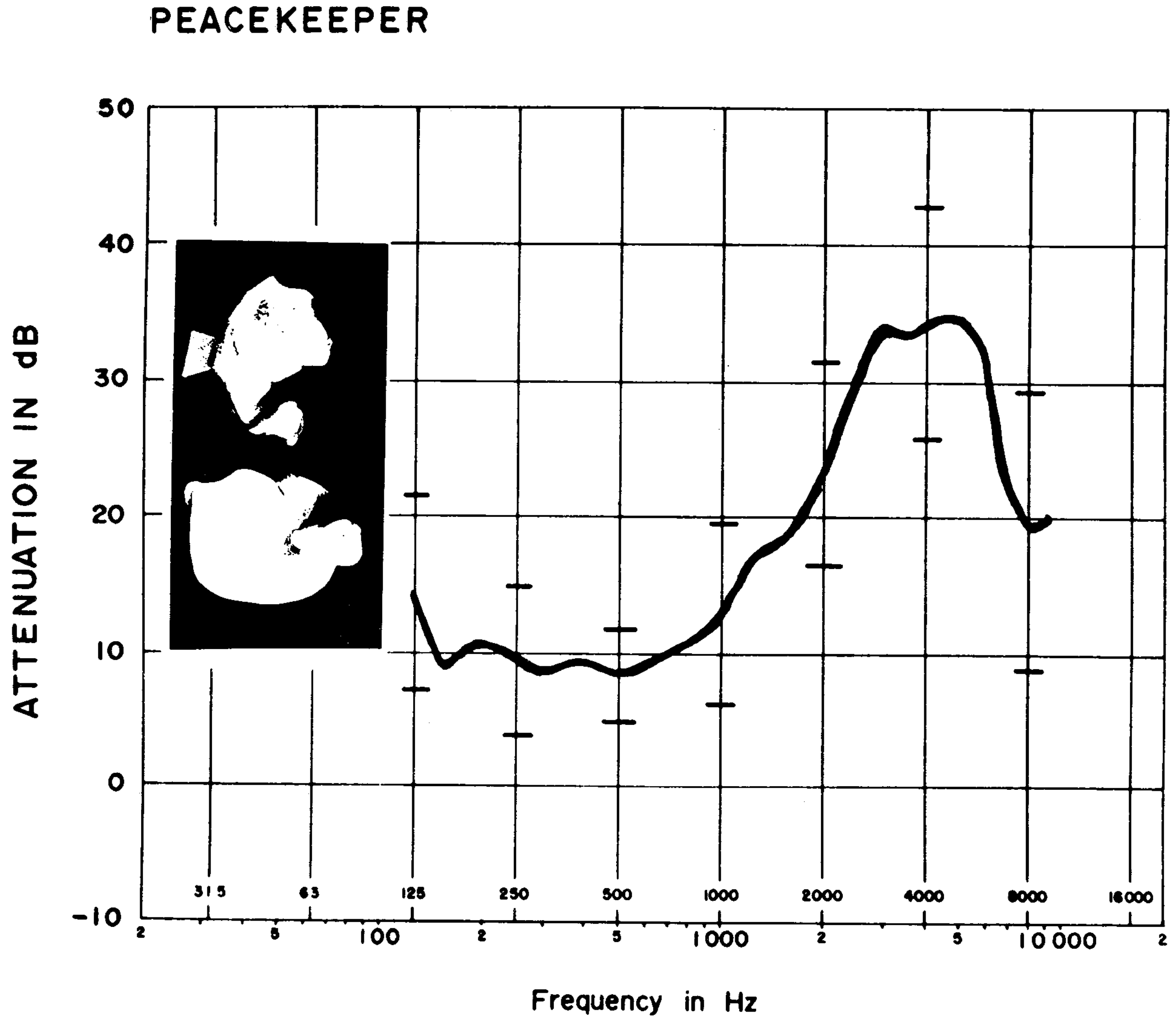


Figure 21

of the substance and a momentary reapplication of pressure on the earmolds after they had rested in the canal for a short time). The second series (Figure 22) is almost indistinguishable from the first, but point-by-point comparison proves it to be slightly better. Only the first series was included in the computation of earplug mean and standard deviation. Two subjects were later refitted by a manufacturer's representative with yet another pair of Peacekeepers; on a retest, one subject's performance was similar to that in the previous two tests and the other subject's performance showed greatly improved attenuation. Potentially, this plug may be a good one, but purchasers apparently must either make do with the printed instructions or insist that the manufacturer (the plug is now produced by Marion Health and Safety, Inc.) furnish personnel to make the plugs. For a facility with several thousand pairs of plugs to be fitted, a training course might be requested for the technician who is to make them, but the expense and time could be unreasonable for a small operation. These plugs are available in bright colors and are furnished with small handles that are color coded to identify which ear the plug was made for. A hole in each handle permits the optional use of a cord. P-AR=443

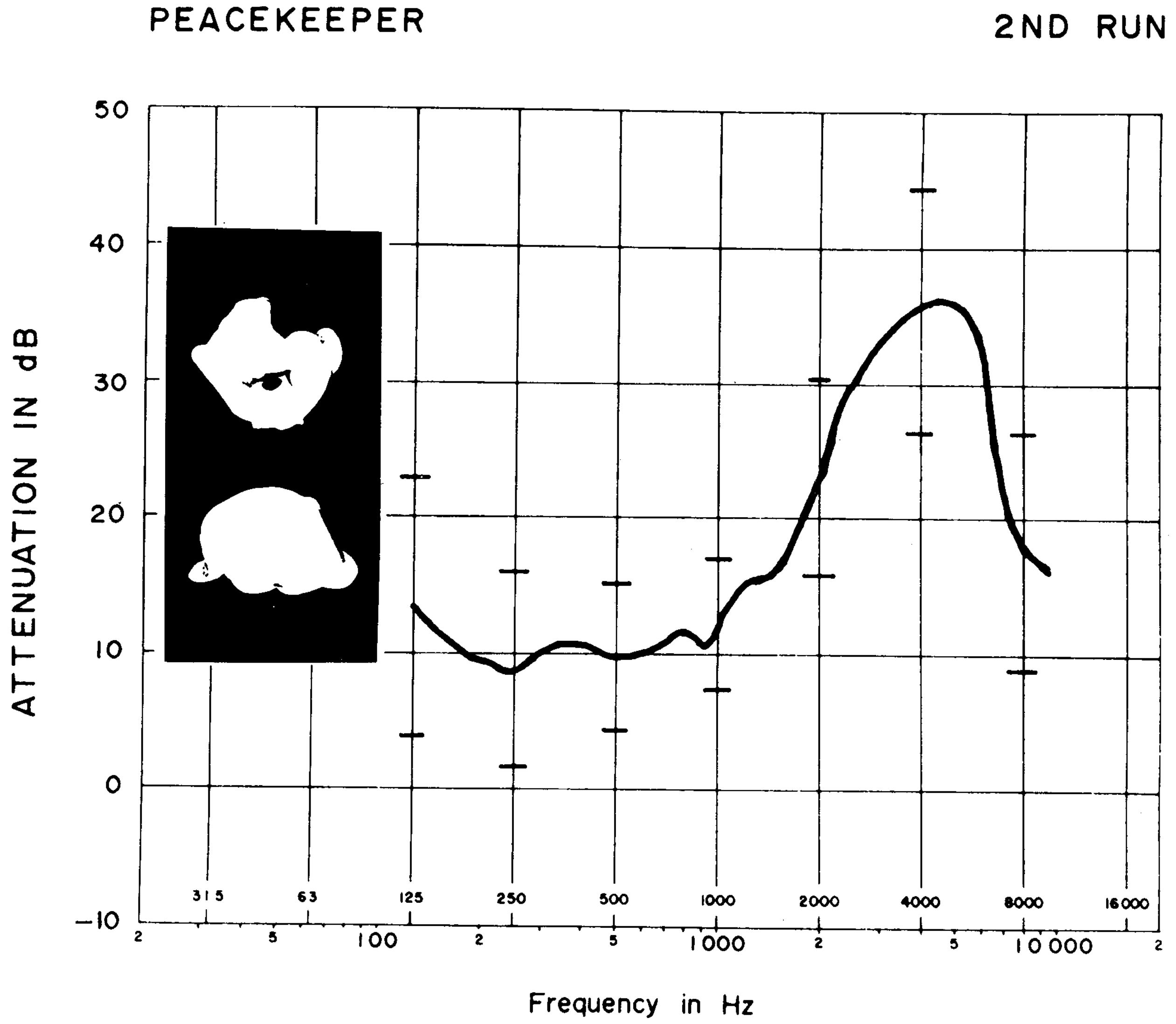


FIGURE 22

21. The SafEar (Figure 23), also known as the HALCO Safety Ear Piece and as the Noise Braker, is a soft, factory-made, custom-fitted earplug with "the No. 80 Acoustic filter inserted in the sound passage." The filter is a small vent communicating between the enclosed canal and the environment. When tested according to the standard ANSI procedure, the device behaves like an earplug with a hole in it: sound gets through. Company literature indicates, however, that this plug is intended for high-level-noise service. I did not test it in such noise, but did read two company-provided reports. Both show average attenuation properties in noise that are beyond those considered theoretically possible[13]; test procedures seem to be at fault. Still, the concept of a perforated earplug that improves its attenuation as noise increases is based in fact, but the data suggest that such effects are negligible until very high sound pressures are reached. Forrest[14] found a 110-dB SPL threshold for this action and an increase in attenuation that stabilizes above 140-dB SPL at a rate of about 1 dB per 2-dB rise in signal level. This result can hardly be squared with the perfect compression advertised for SafEar's "Accelerated Resonance Decay Principle." They claim that, ". . . above 85 db, the noise is attenuated to 85 db. The higher the noise the more efficient the attenuation. Thus noises of 140 to 150 db are

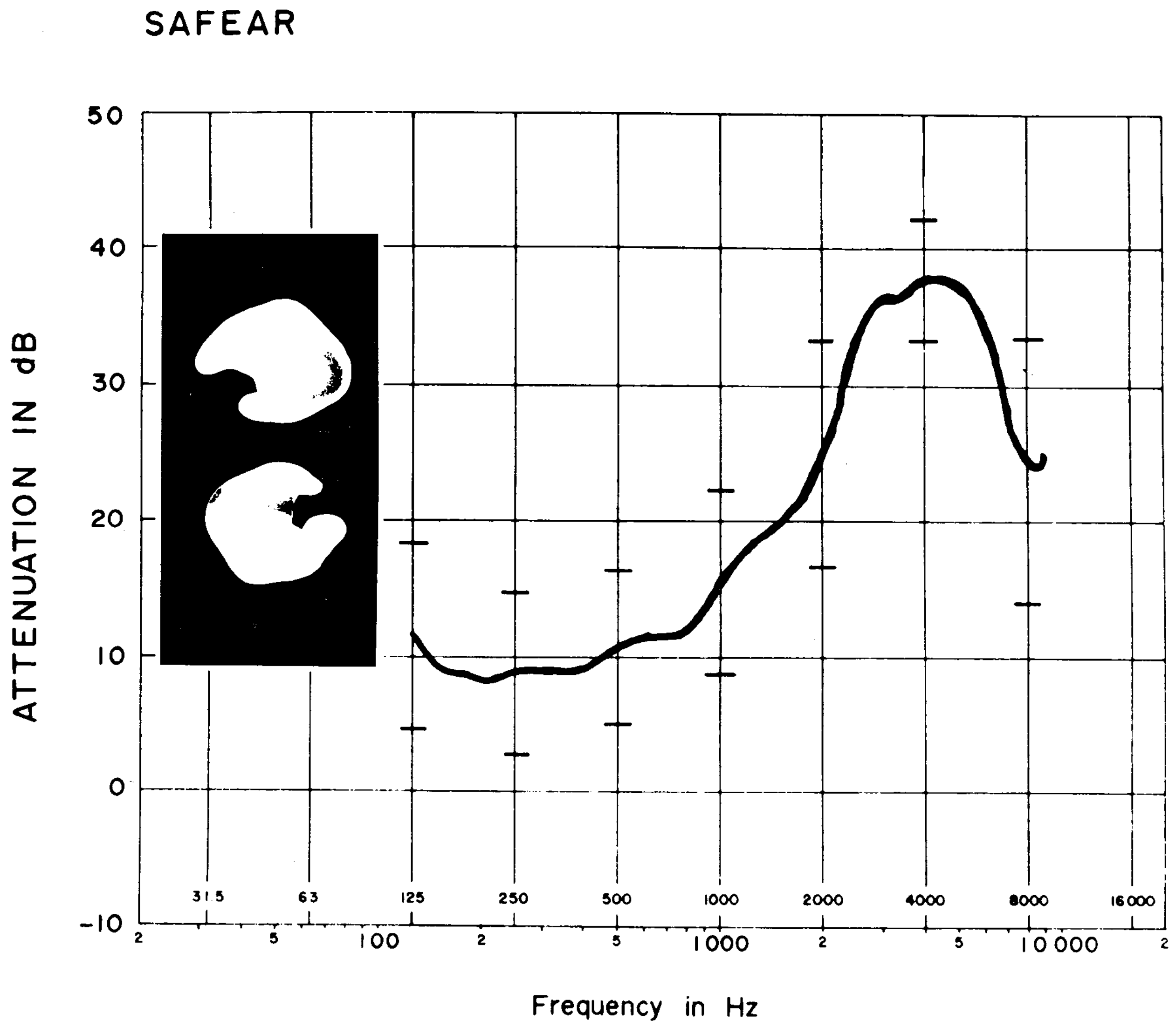


FIGURE 23

attenuated to 85 db. . . ." This plug may possibly be useful in situations in which the primary exposure is to high-level impulse noise. P-AR=443

22. Com-Fit earplugs (Figure 24) have been tested often before, both in this laboratory and in others. In the standard size, they fit most adults. Other sizes are available. As with all the flanged earplugs we tested, many subjects found them fairly comfortable, but subjects with less-than-round canal openings sometimes complained. Military use of these earplugs has led to their being manufactured by companies other than Sigma Engineering, and some of these alternate firms use stiffer, less satisfactory materials than one finds with plugs bought directly from Sigma. P-AR=333

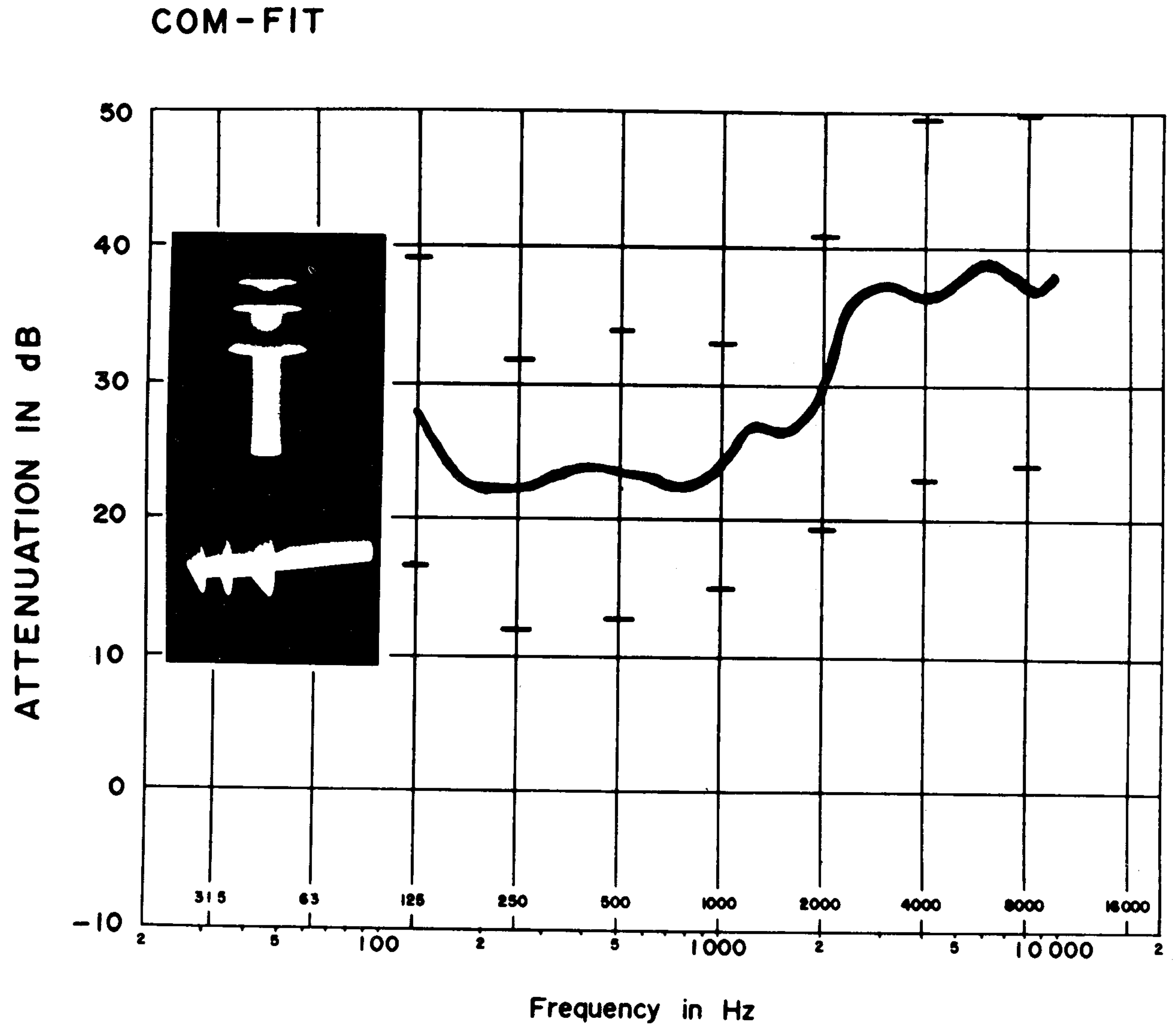


FIGURE 24

23. The Genie headset (Figure 25) is not, properly speaking, an earplug at all. It was designed for aviation-communication use and incidentally for keeping noise out of the user's ears. The Genie is included here to illustrate how the hearing protection offered by devices other than earplugs and earmuffs can be classified with P-AR values. This insert headset uses the perforated, flanged silicone tip of the old Lee Sonic Ear-Valv (see paragraph 42) for coupling to the wearer's external ear. Unlike the Lee Sonic, though, the Genie backs the tip with solid material, thus making it into an effective acoustic barrier. This headset was not included in the computation of earplug mean and standard deviation. P-AR=333

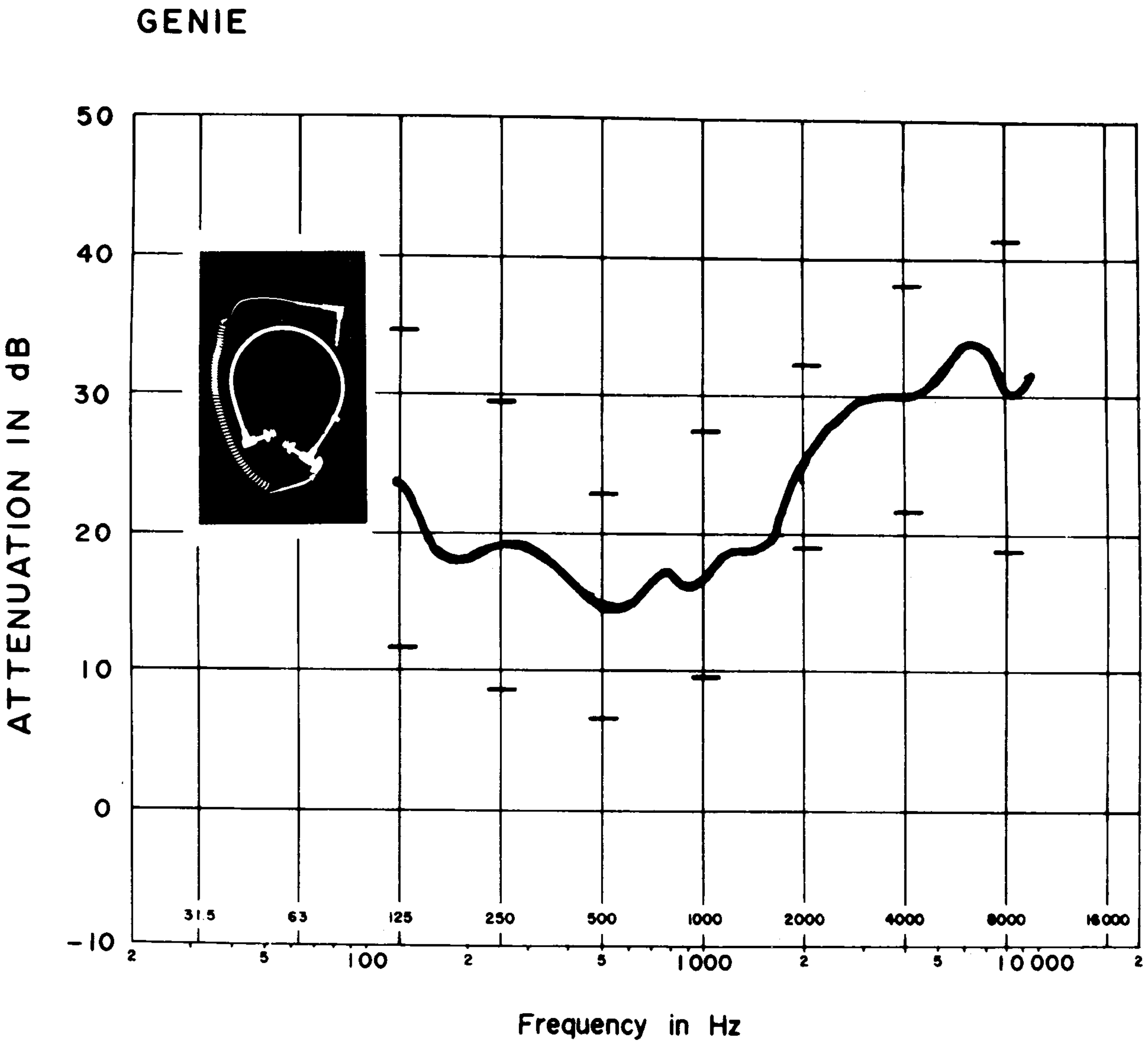


FIGURE 25

24. The Hear-Saver earplug (Figure 26) is made of wax-impregnated cotton that is pre-formed into hollow cones. P-AR=344

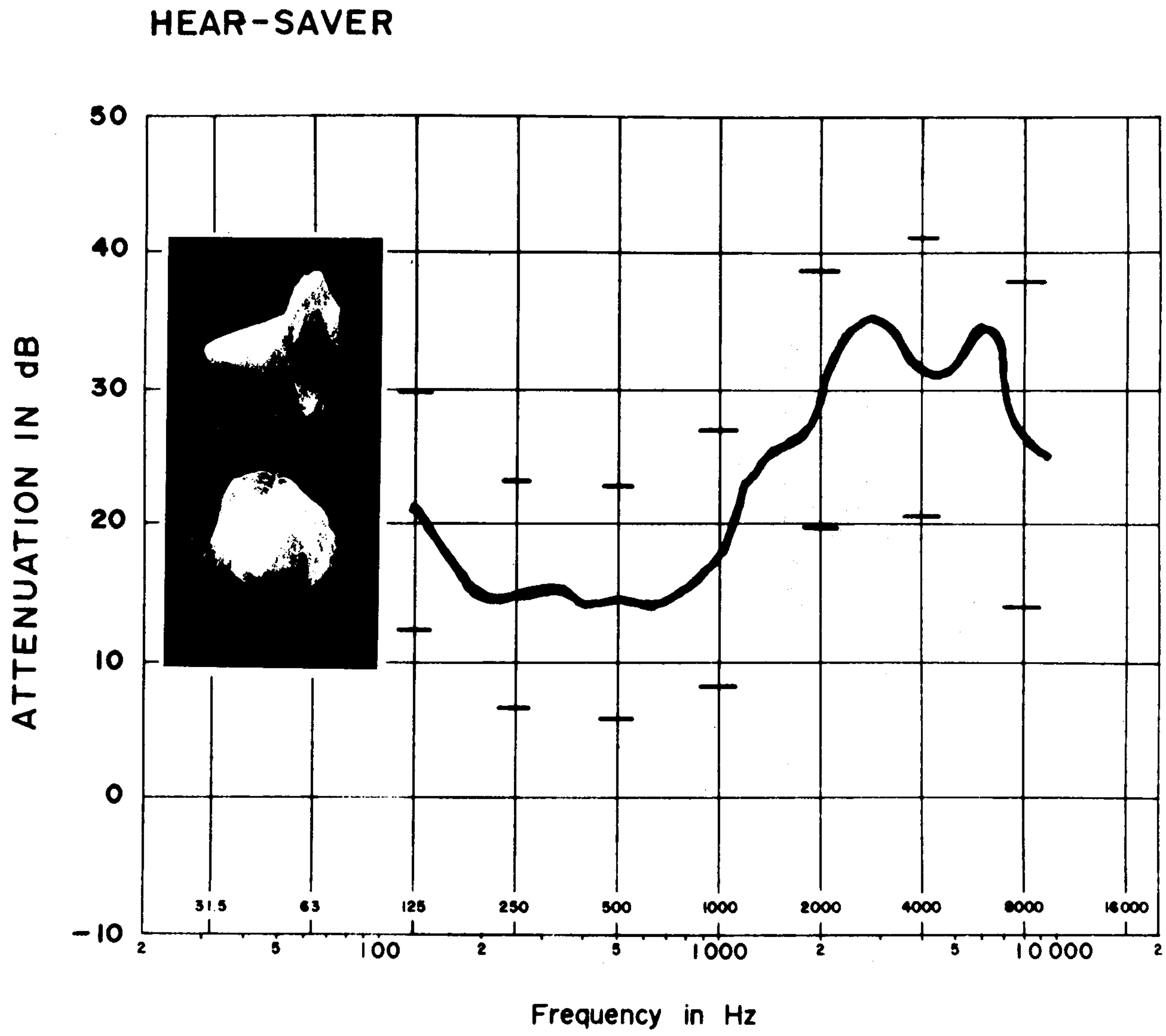


Figure 26

25. Flents (Figure 27) are made of wax-impregnated cotton fiber that is hand formed by the user. They are similar to the Frontier plugs (see paragraph 15) except that more material is furnished. P-AR=444

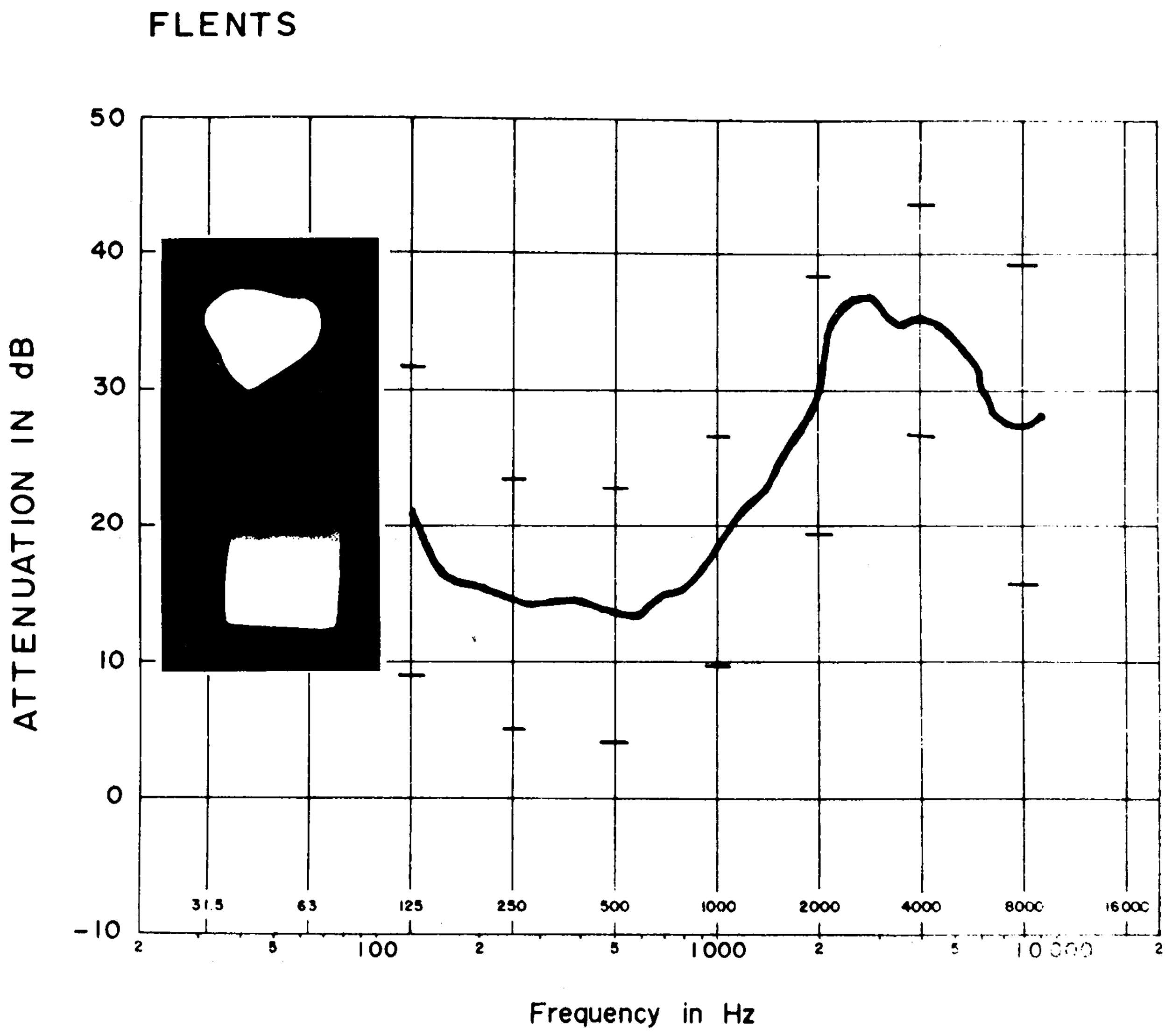


Figure 27

26. SEPCO earplugs (Figure 28) consist of a pink neoprene shell (with two pinhole perforations in the tip) filled with a foam cushion (with a single pinhole perforation showing at the open end). The vents appear to be associated with pressure equalization for ease of insertion rather than with any acoustic function (but see paragraph 21). P-AR=444

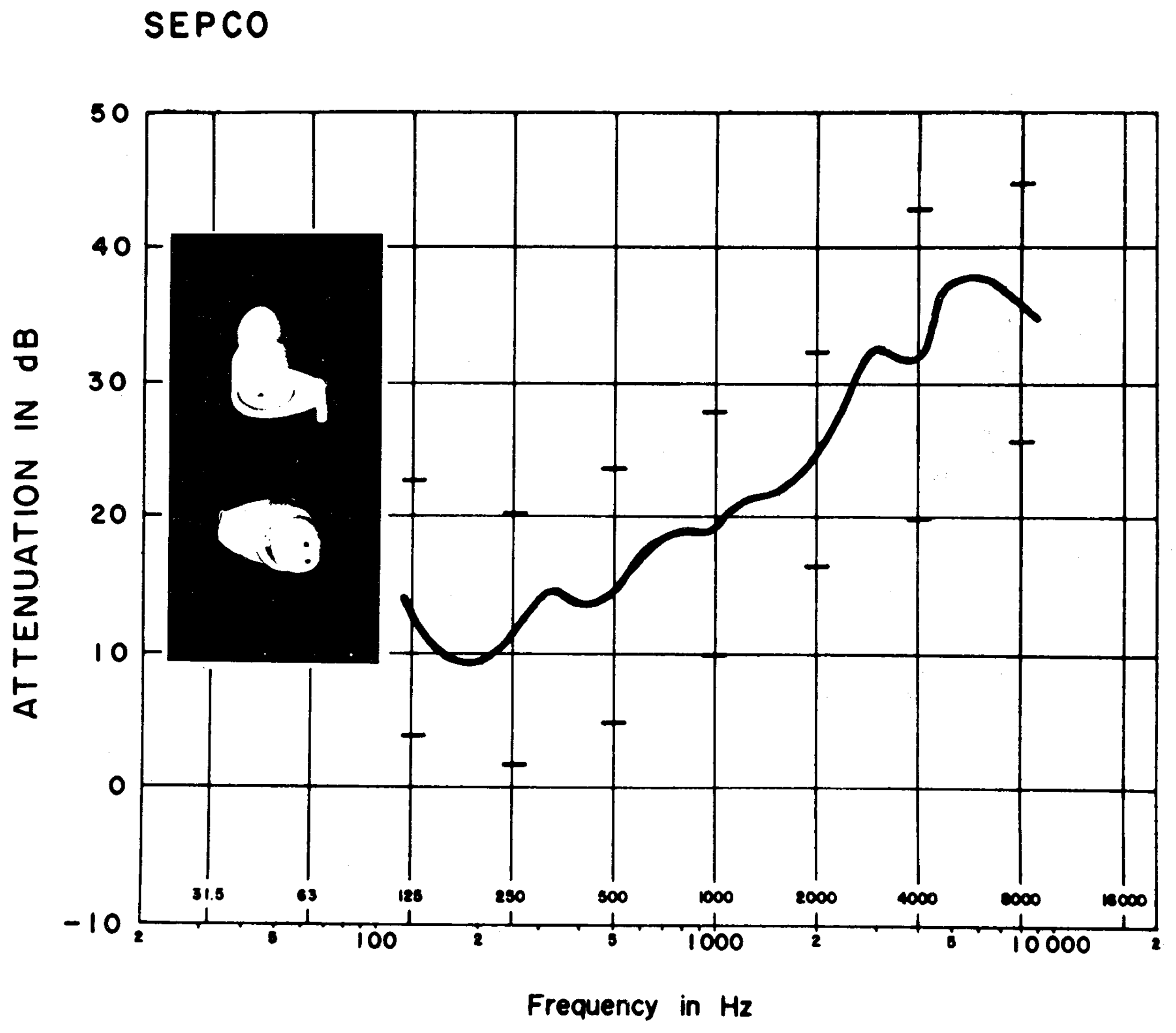


FIGURE 28

27. Nods (Figure 29) are made of wax-filled foam and are manipulated by the wearer until they seal the canals. They are comfortable in the ear. I have no data on the expected life of Nods, but would expect them to be reusable for many days before they begin to lose their effectiveness. It is not necessary to touch the waxed end with the fingers in order to use these plugs. They soil easily. P-AR=344

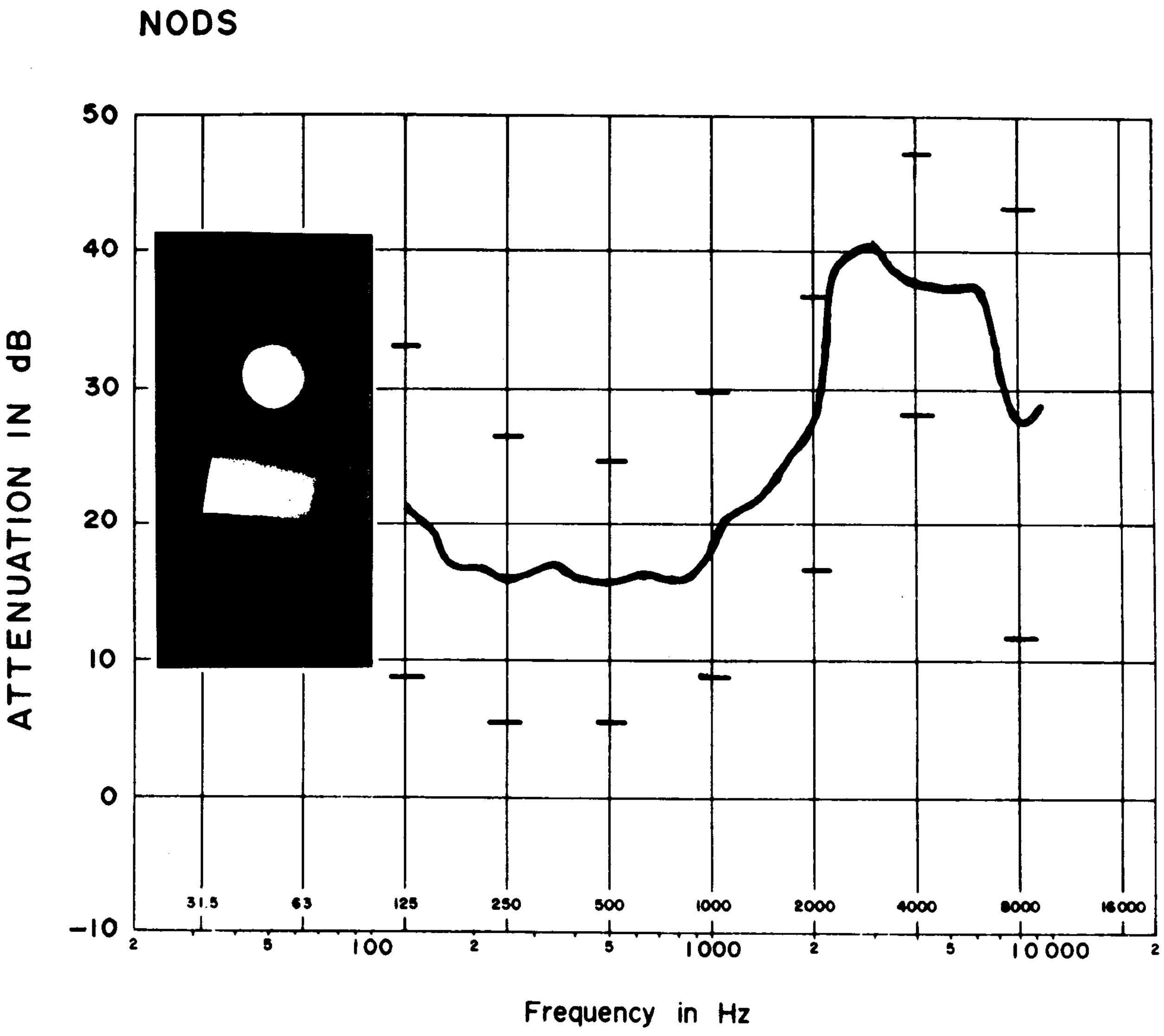


FIGURE 29

28. The Soundown (Figure 30) is a custom-fitted, factory-made plug that is particularly light in weight and, according to subjects' reports, is particularly comfortable to wear; extraneous material has been removed. The plug is formed from two types of acrylic—one hard and one soft—with the soft part fitting into the ear canal. However, the plug can slip out of place with head movement and so requires frequent adjustment if it is to offer much attenuation. This looseness of fit may account for the good comfort reports. In the tests, the ANSI requirement for head movements before measurement often led to a partially open channel into the ear canal. P-AR=544

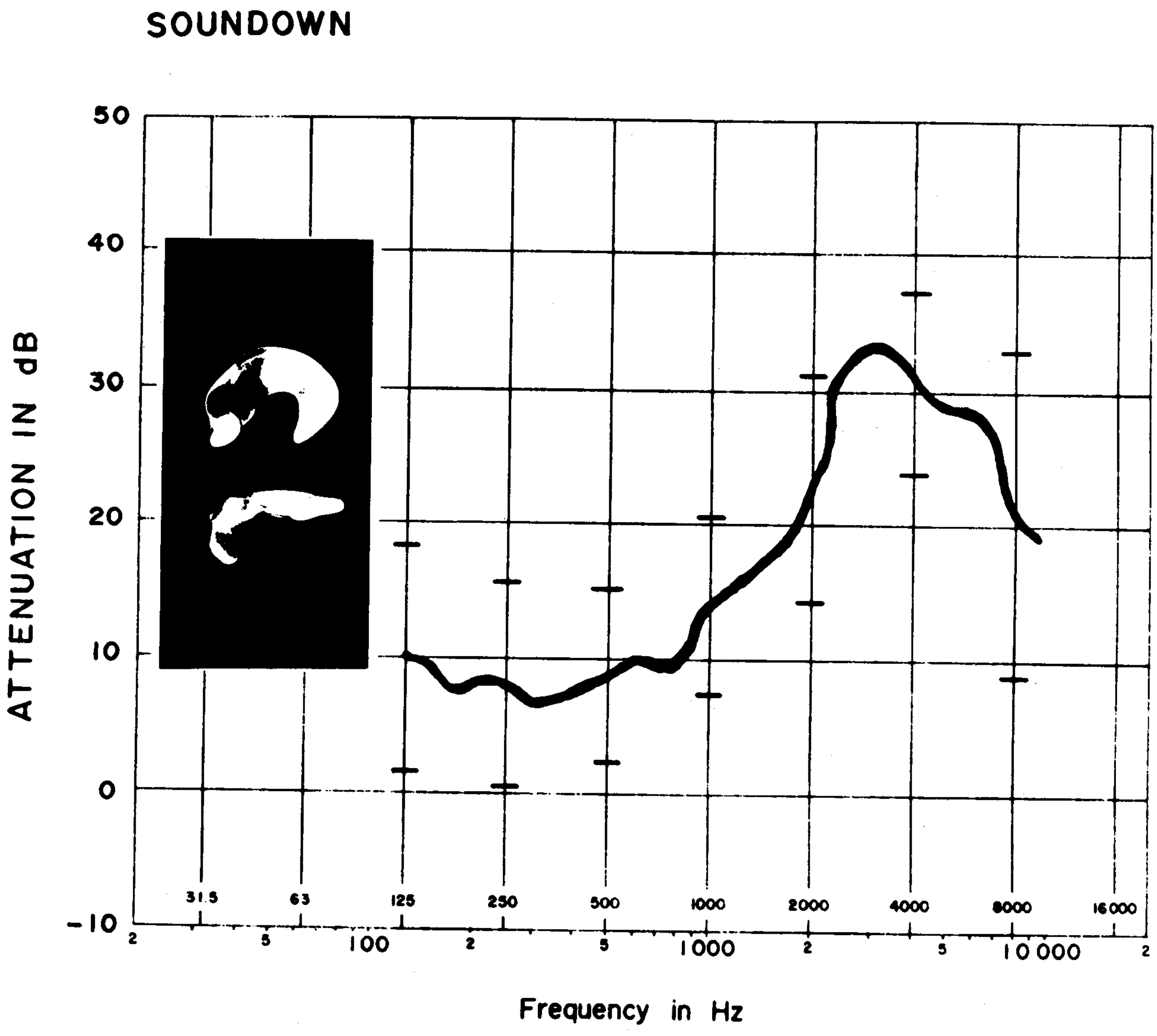


FIGURE 30

29. The Hearite series B earplug (also known as the Stayrite Type B) (Figure 31) is a soft-plastic bubble that fits fairly well compared to the other two plugs from the same company, one of which is also a soft-plastic bubble but is straight rather than bent. This plug is available in three sizes, and the handle is perforated for stringing. P-AR=234

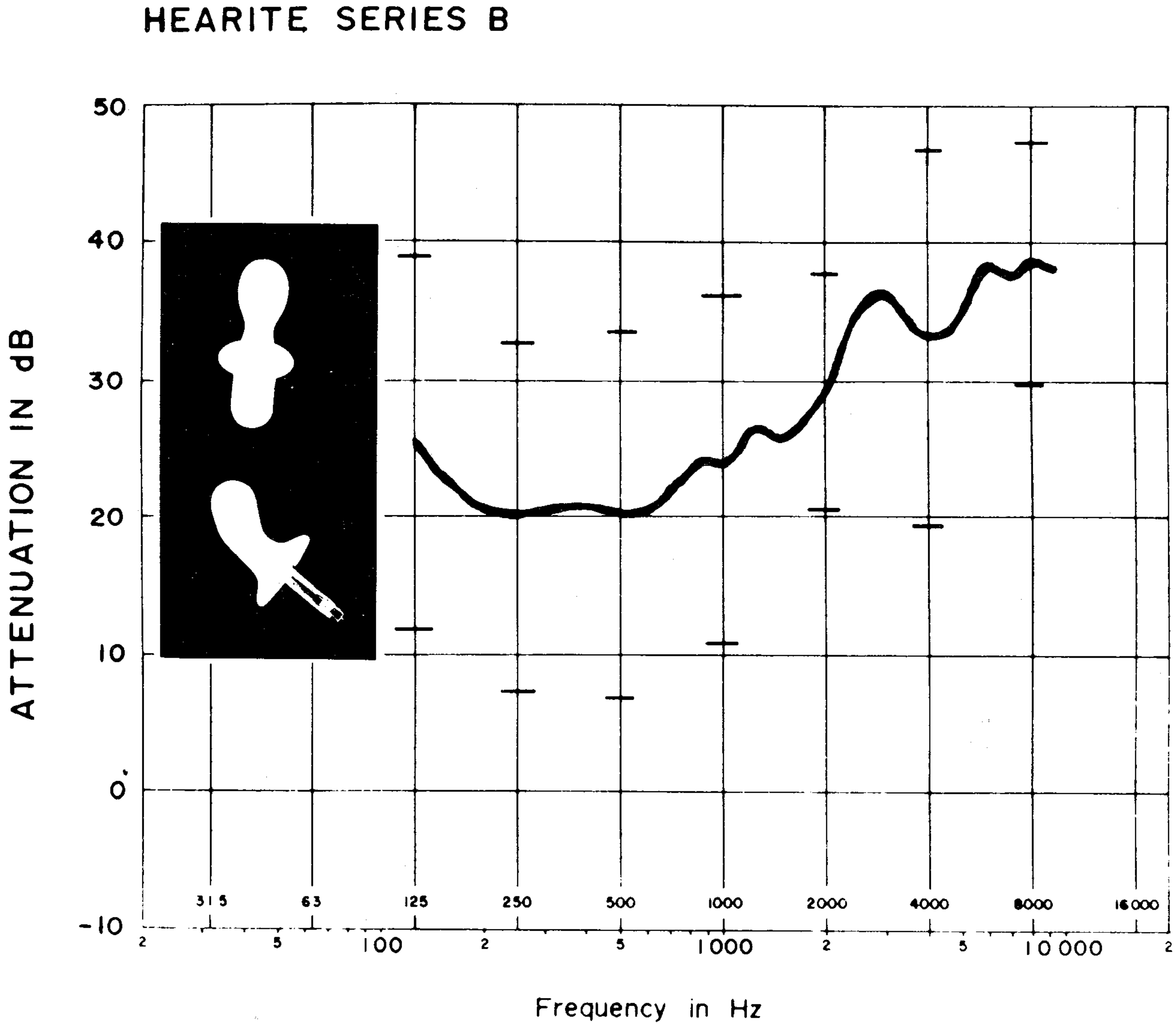


FIGURE 31

30. The Silent Partner (Figure 32) is a putty-filled soft-plastic bubble. Although some subjects found it difficult to wear, some found it very easy. Its construction makes it a combination preformed/wearer-formed earplug. The canal portion is bright blue, and the visible handle is orange. P-AR=334

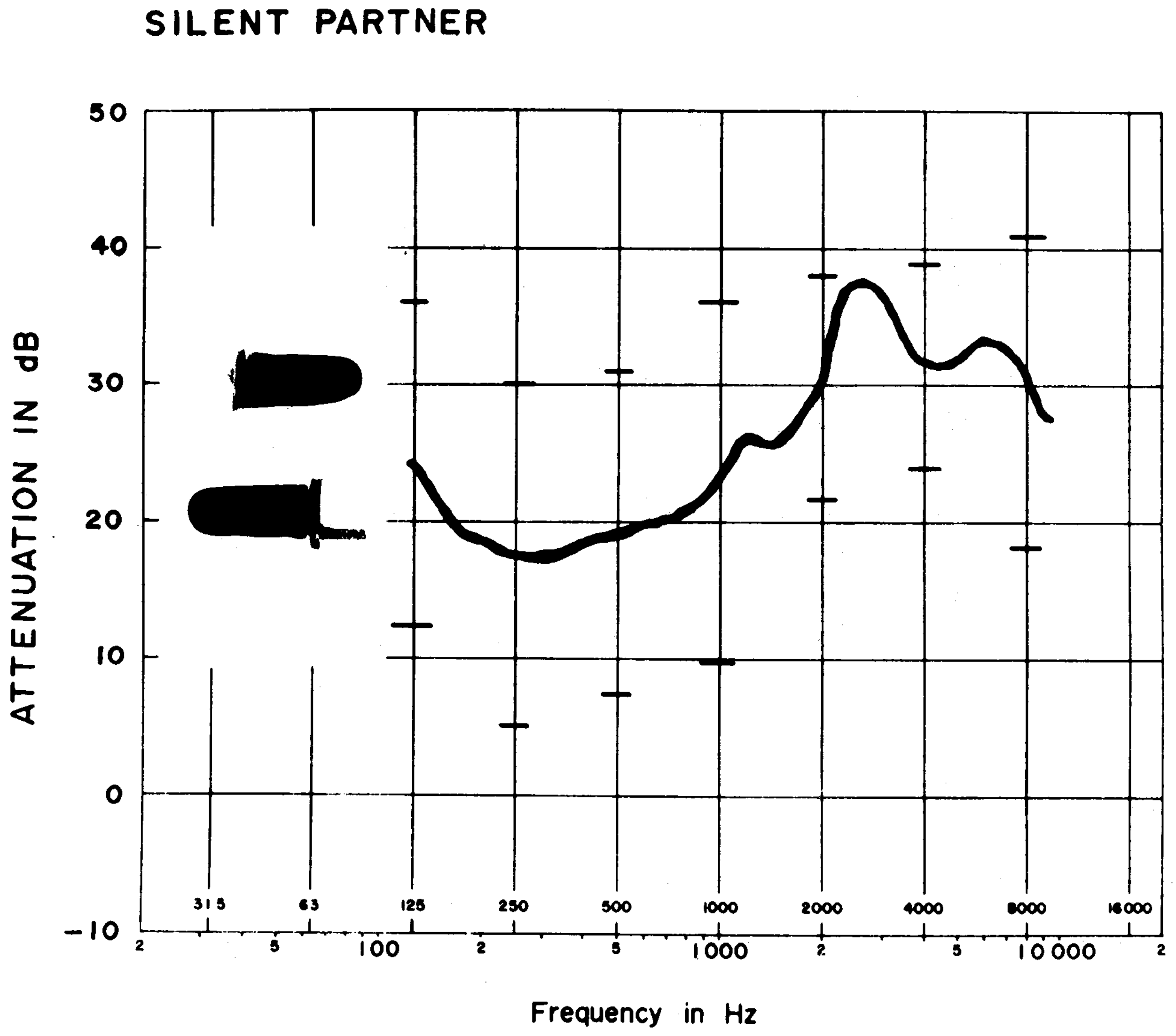


FIGURE 32

31. Sonotone earplugs (Figure 33) are soft, factory made, and custom fitted. They are rather like the E.A.R. plugs (see paragraph 13), except that the segment that fits into the canal is a bit longer. P-AR=344

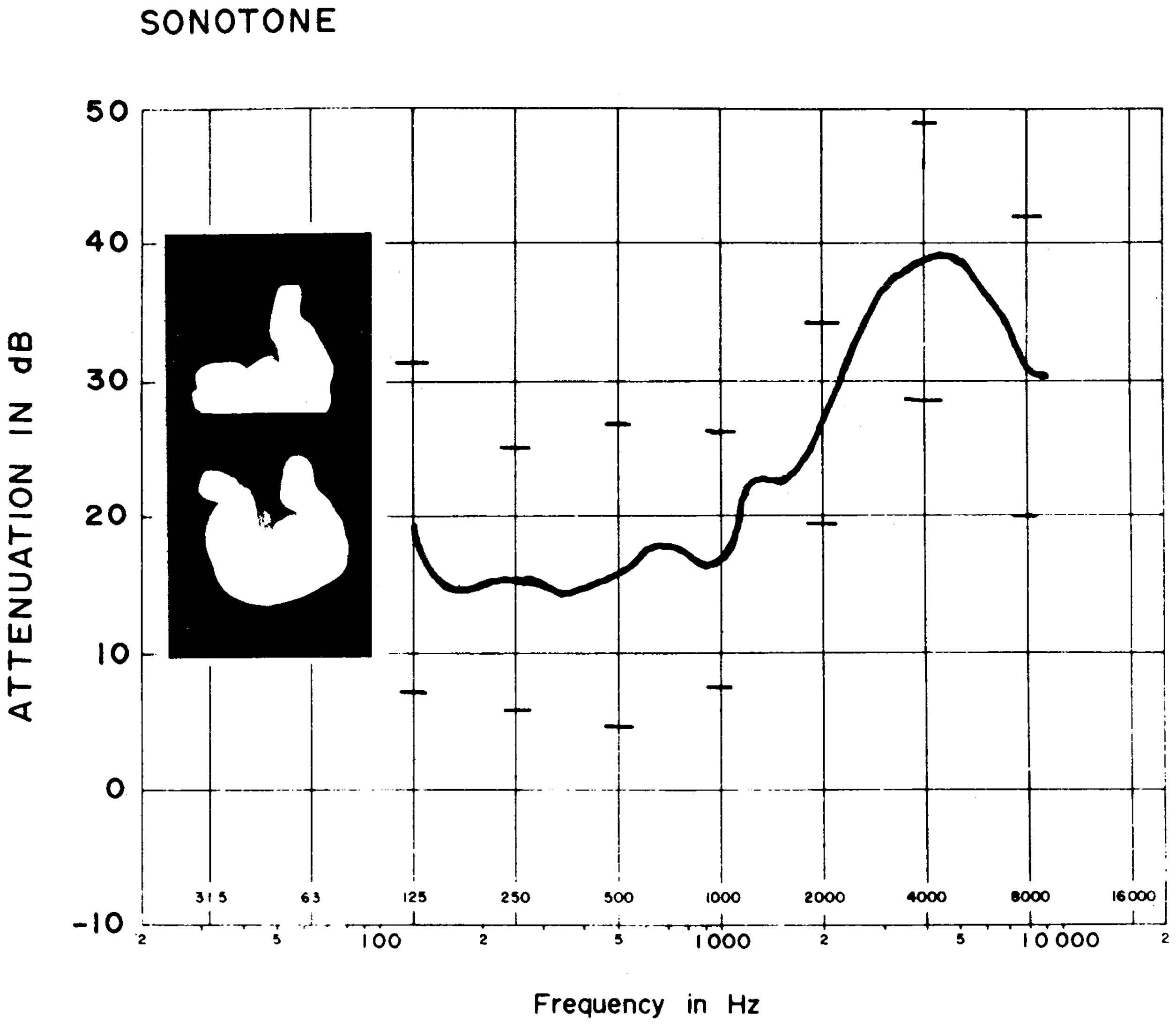


FIGURE 33

32. The Auri-Seal (Figure 34) is made by the same company as the more popular Com-Fit, but it has a large flange to rest in the pinna of the ear. When it fits, it is very good. However, for most subjects tested, the canal piece seemed too short and the plug felt as if it were slipping out. It is extremely easy to handle. P-AR=234

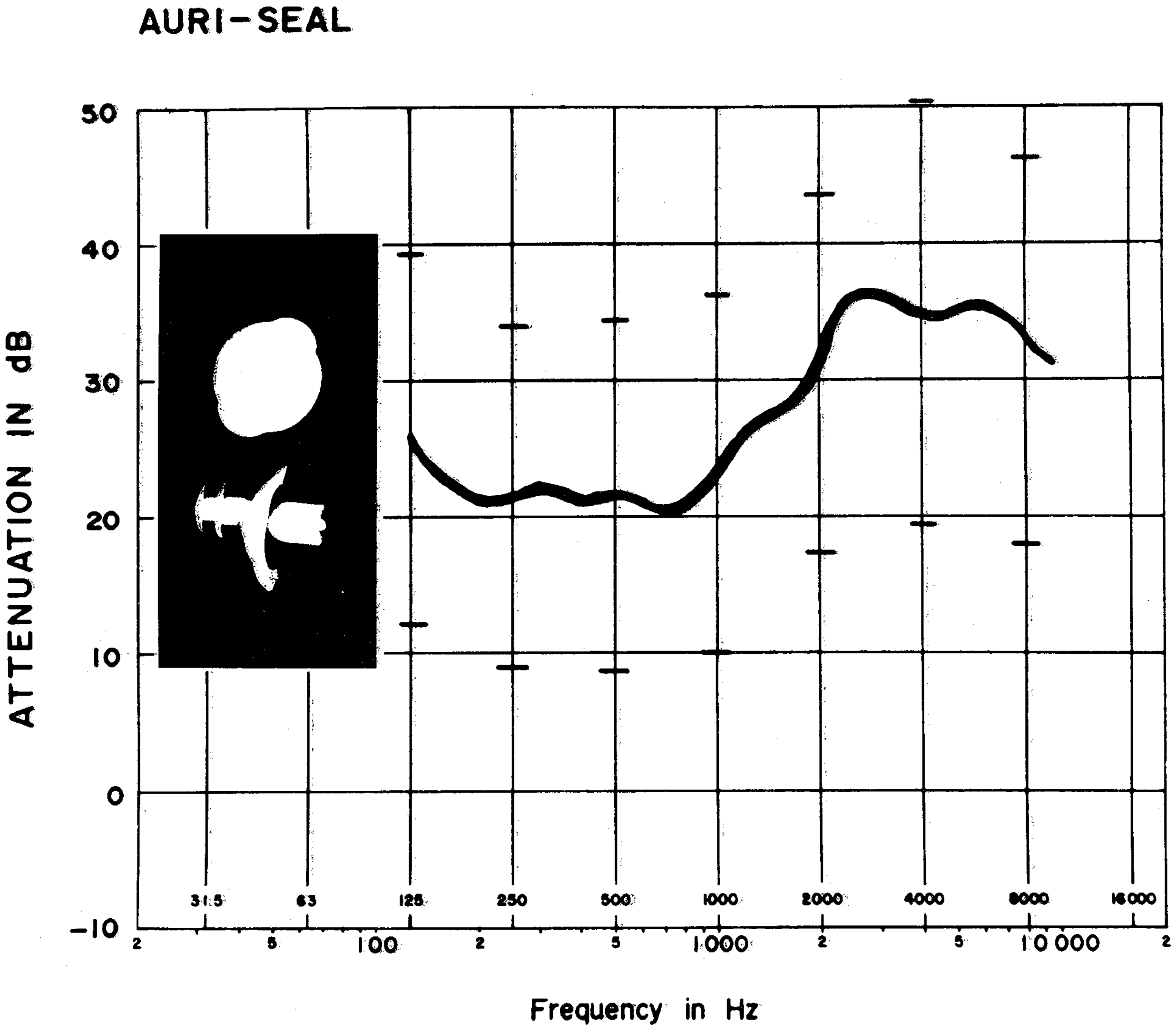


FIGURE 34

33. The Willson Sound-Ban 10 earcap (Figure 35) is similar to the Sound-Ban 20 (see paragraph 9), except that this one has a padded, adjustable metal headband that can be worn across the top of the head as well as behind the neck or under the chin. P-AR=444

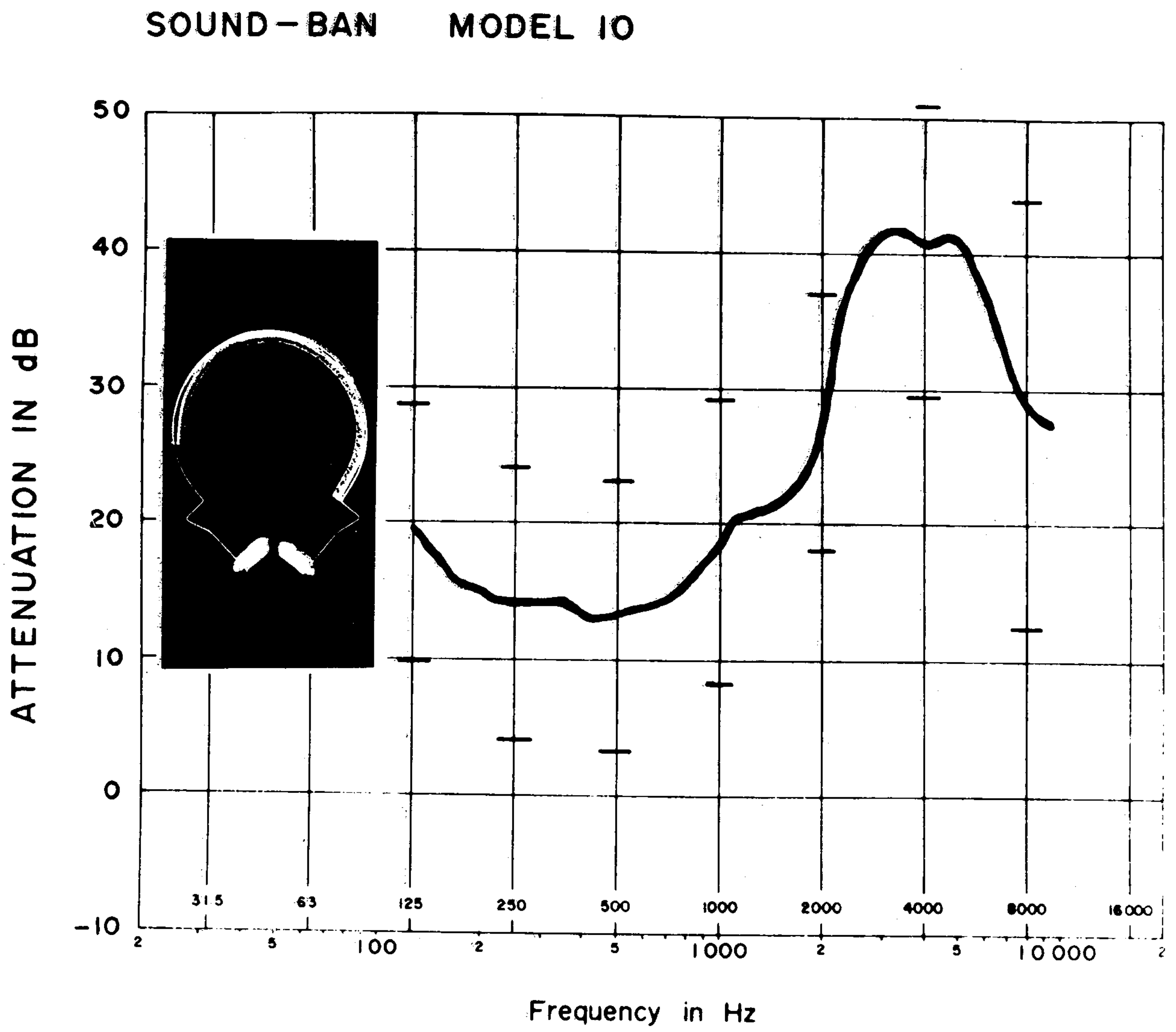


FIGURE 35

34. The Hearite series A (also known as the Stayrite Type A) earplug (Figure 36) is similar to the Hearite series B (see Figure 31) whose attenuation is better, except that the A is straight where the B is curved. P-AR=444

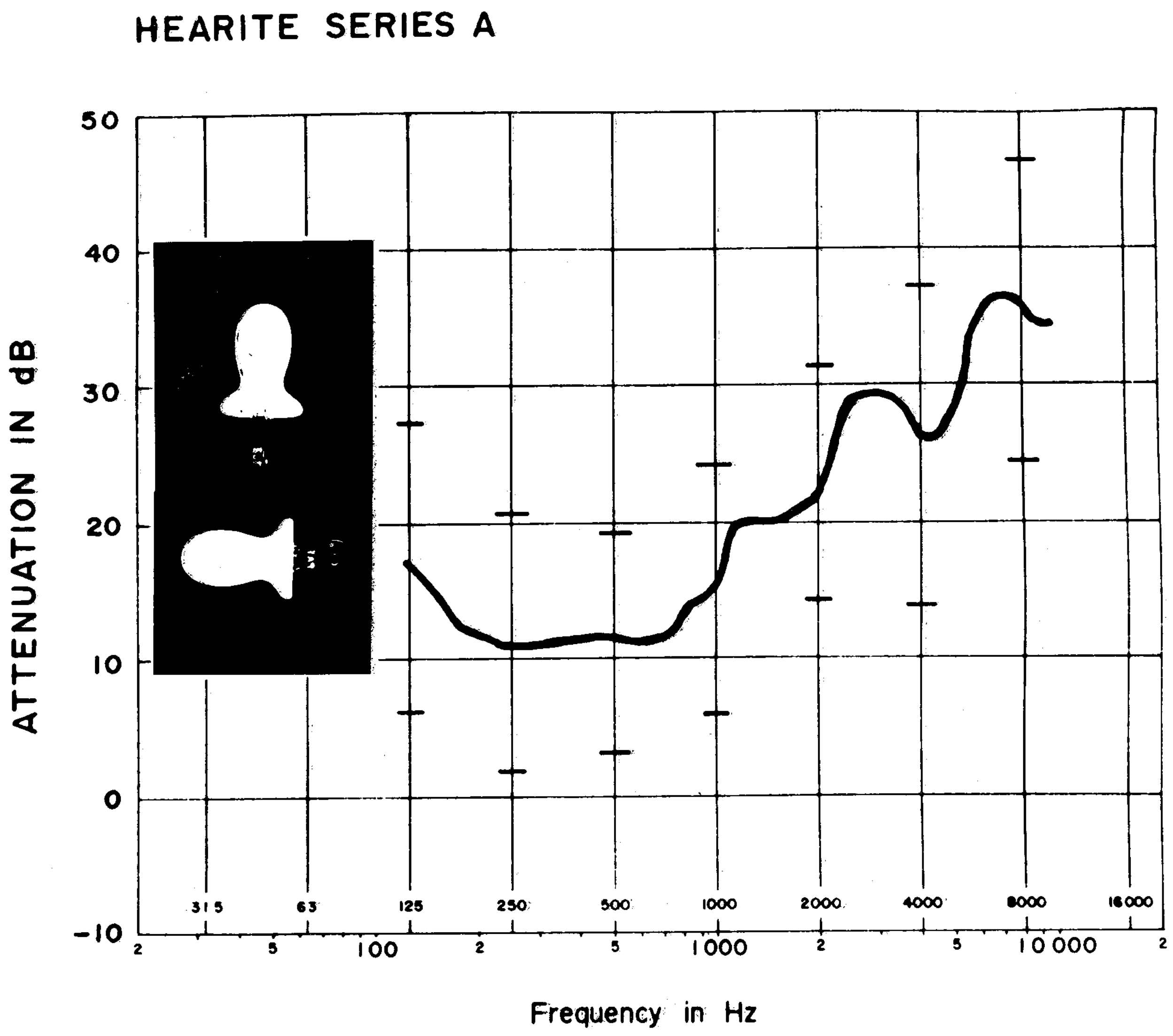


Figure 36

35. Johnson & Johnson cotton wool (Figure 37) was tested because people still use it for earplugs. Domestic airlines in some countries even furnish cotton wads to their passengers for that purpose. Although wet cotton would be considerably more effective an attenuator than dry, it is not commonly used, and anyway, wet plugs can be expected to dry out eventually. Tests were run with dry cotton to simulate actual-use conditions. P-AR=654

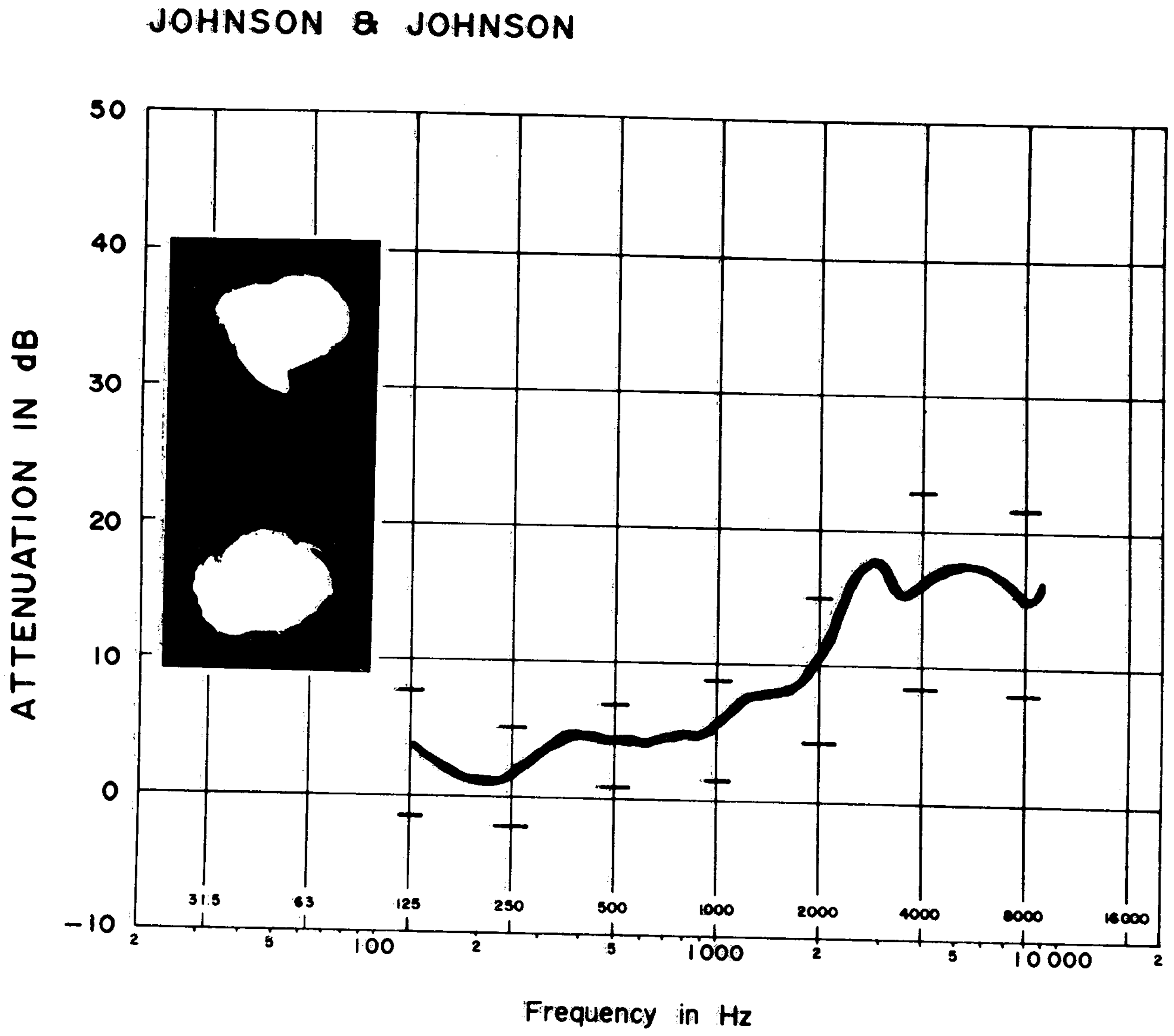


FIGURE 37

36. Sound Master earplugs (Figure 38) are custom-fitted and do not require factory construction. They can be stamped to identify which ear each plug was made for. It is not necessary to handle the material during construction. P-AR=444

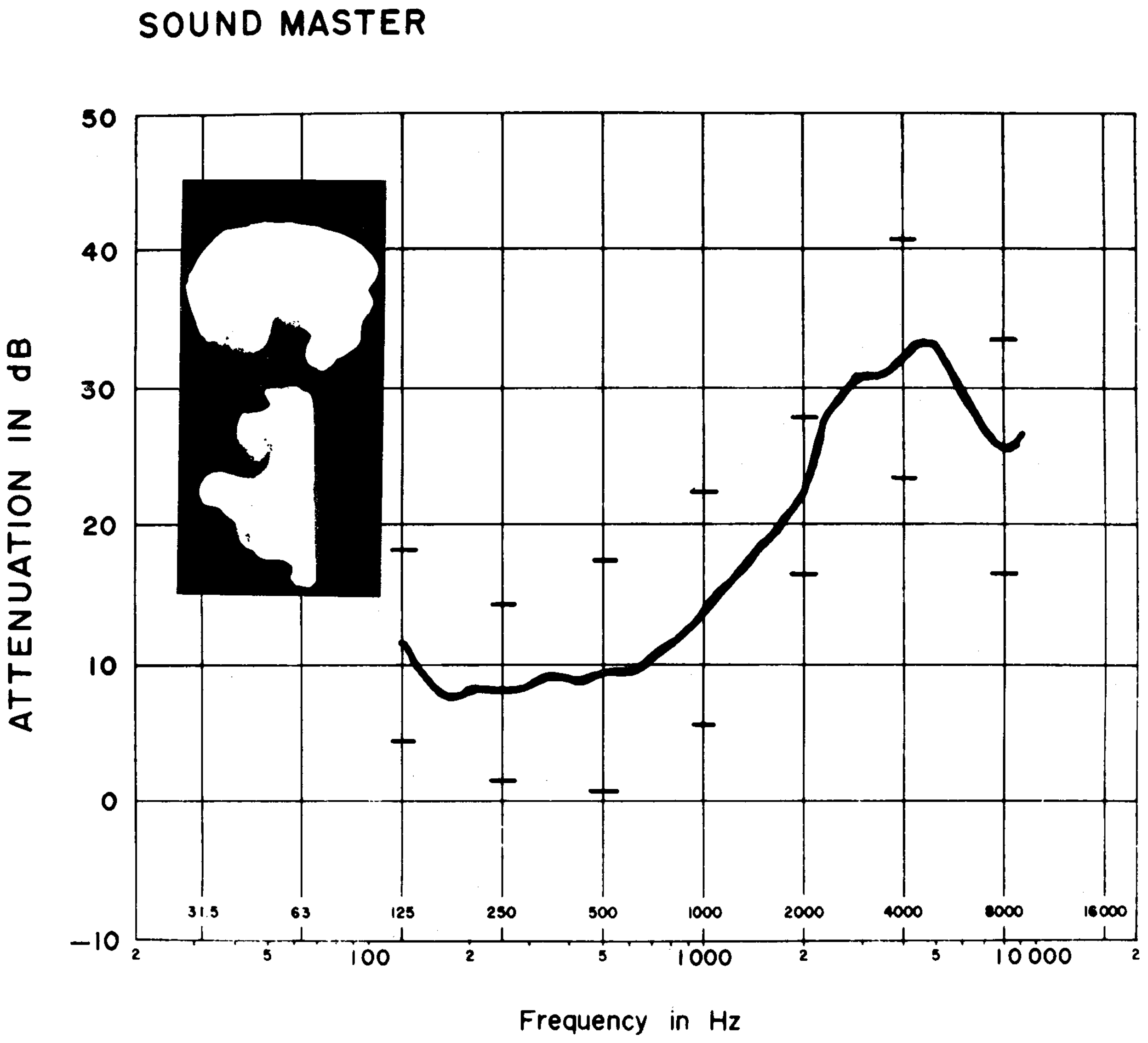


FIGURE 38

37. The Mark II (Figure 39) is hand formed by the user. Irregularly placed bubbles in the silicone material seem to have no continuity with each other and therefore probably do not permit leakage. The plug is advertised to "last indefinitely." It is generally considered comfortable despite the waxy touch that some subjects dislike. P-AR=444

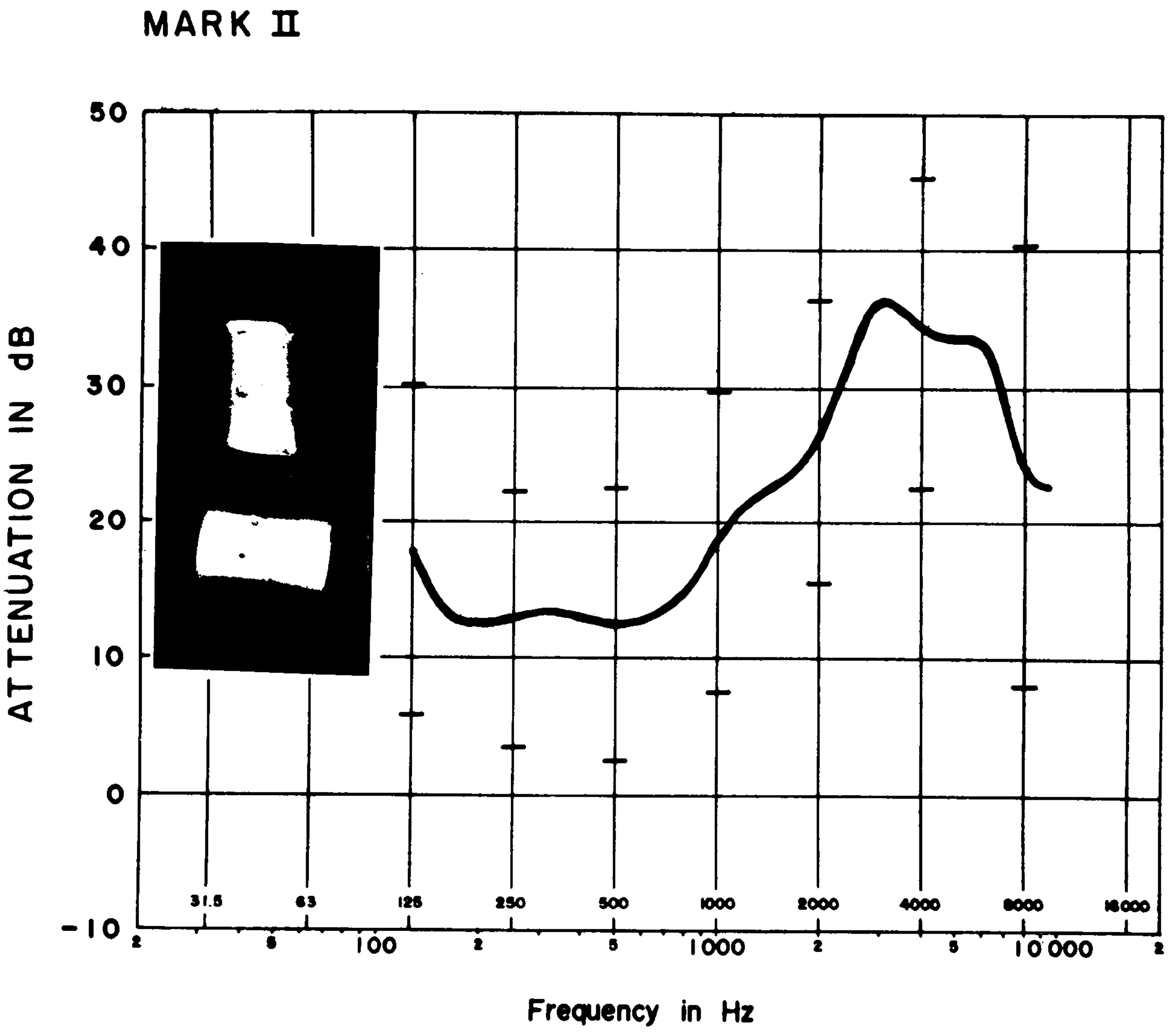


FIGURE 39

38. The SMR (Surgical Mechanical Research) earplug (Figure 40) is premolded in black vinyl. Because it has no flanges, subjects generally found it comfortable. However, also because it has no flanges, correct fit is critical—the SMR comes in eight sizes. P-AR=344

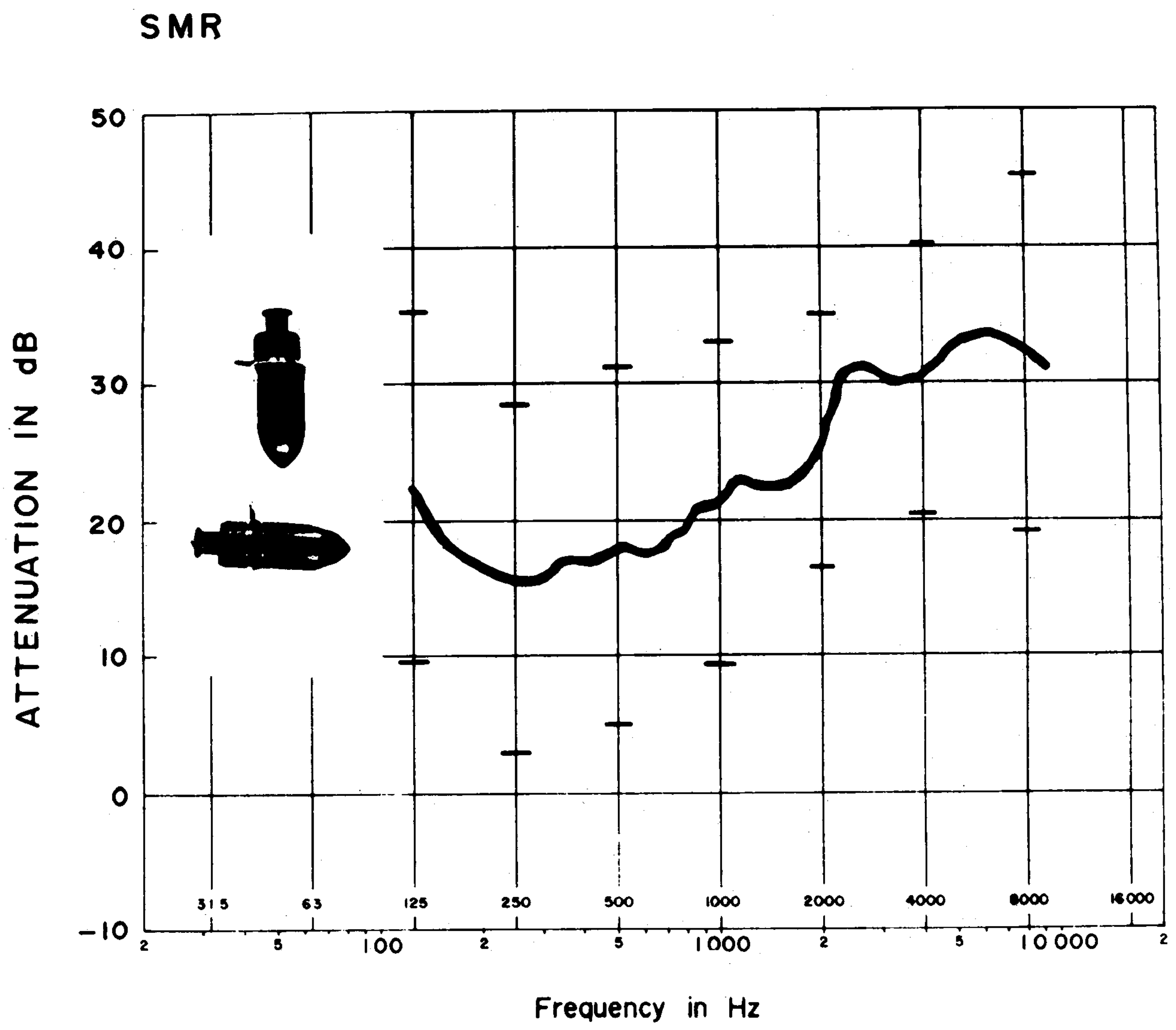


FIGURE 40

39. Soft (they are also available in a hard material) Adcomold earplugs (Figure 41) are custom fitted and do not require factory construction. The Adcomold material is slightly more difficult to work with than is that furnished for many others of the molded-in-place type. P-AR=554

ADCOMOLD

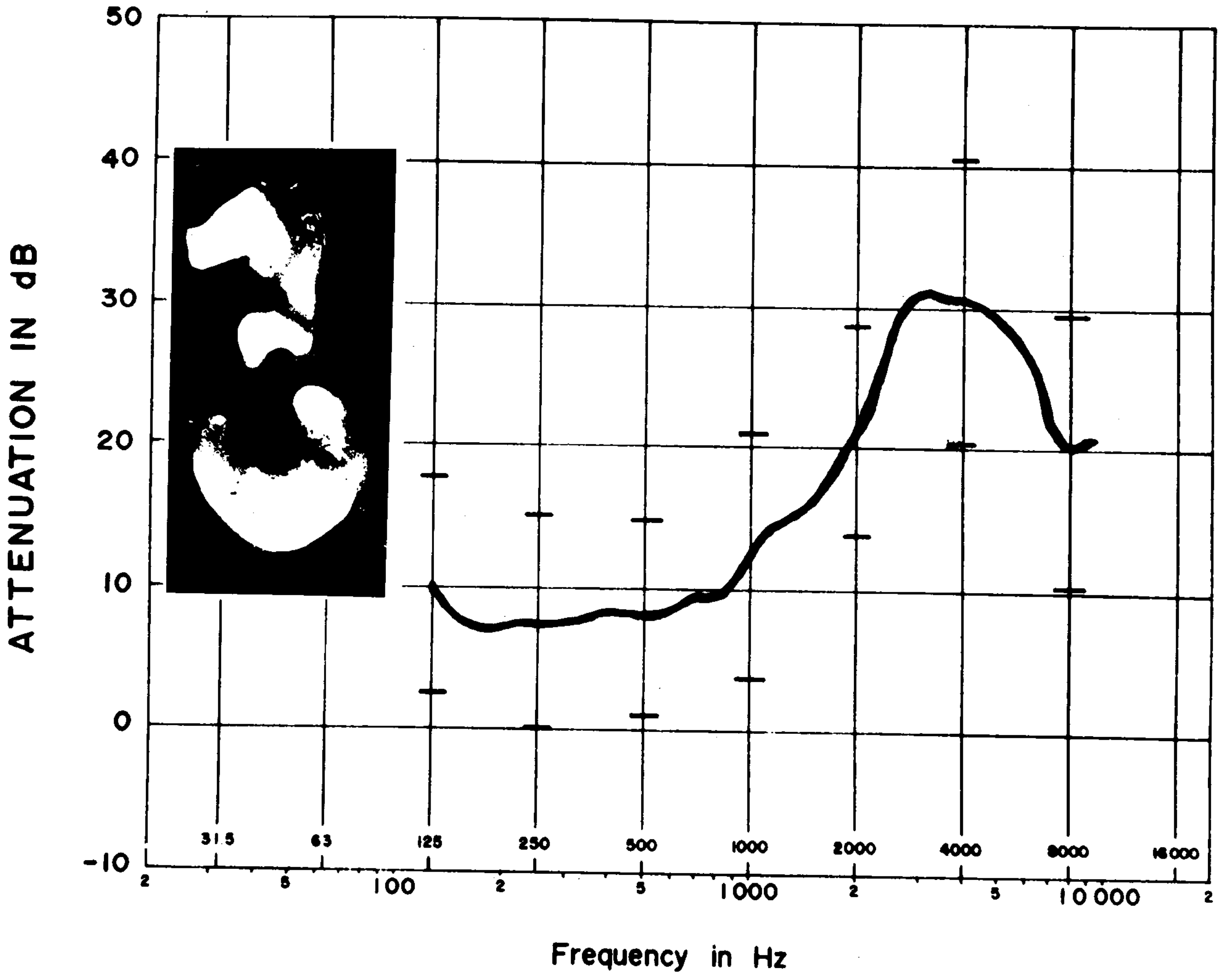


FIGURE 41

40. Kleenex tissue (Figure 42) was tested because people still use it for earplugs. Subjects who were tested with it complained of itching and irritation. This material is available in many colors. P-AR=654

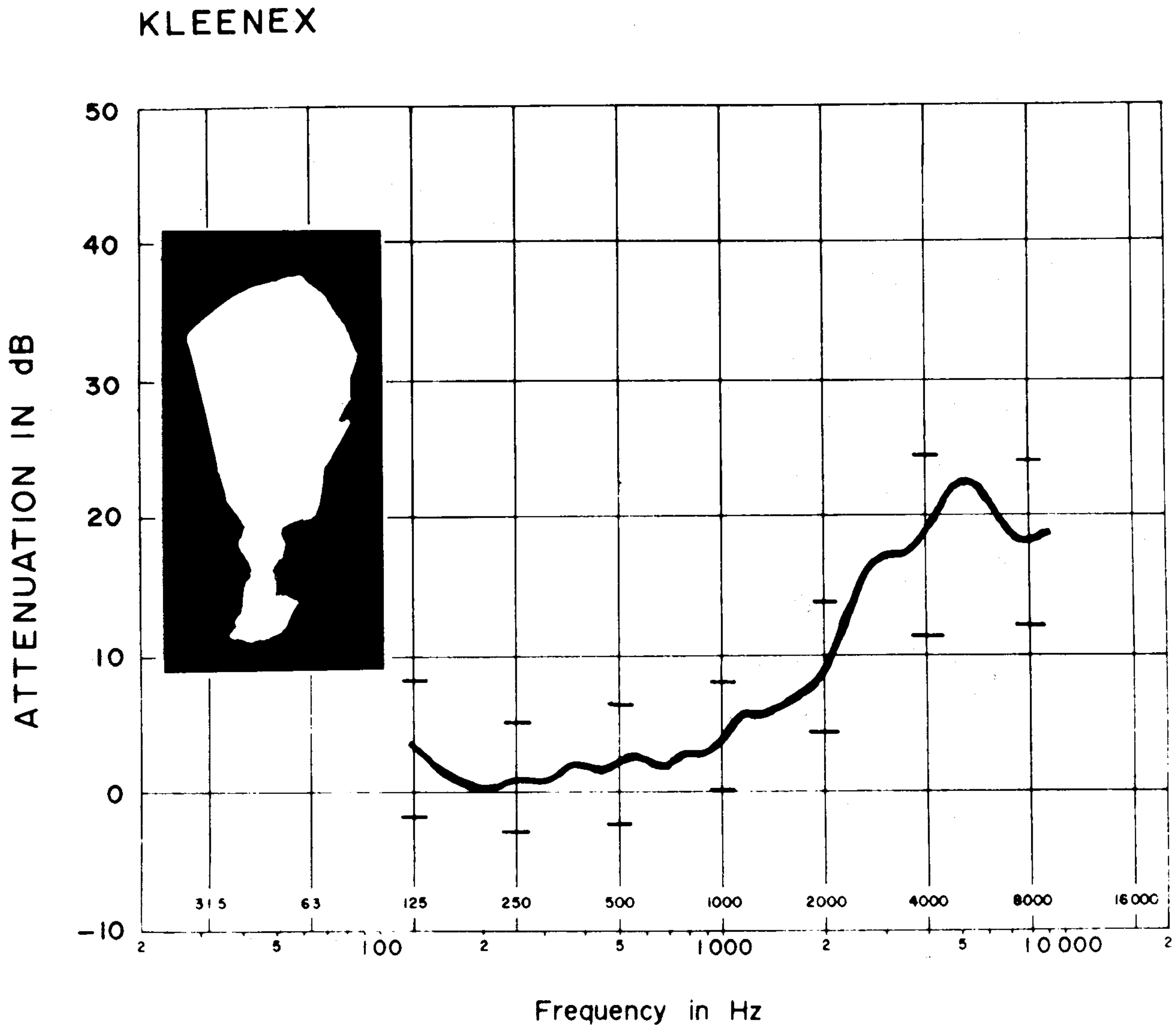


FIGURE 42

41. The Stayrite Shell-type Earplug (Figure 43) is soft and premolded, but it is designed to look like a custom-molded plug. It is furnished in three shapes (listed as small, medium, and large), all of which were reported as uncomfortable by all the subjects who tried them. P-AR=655

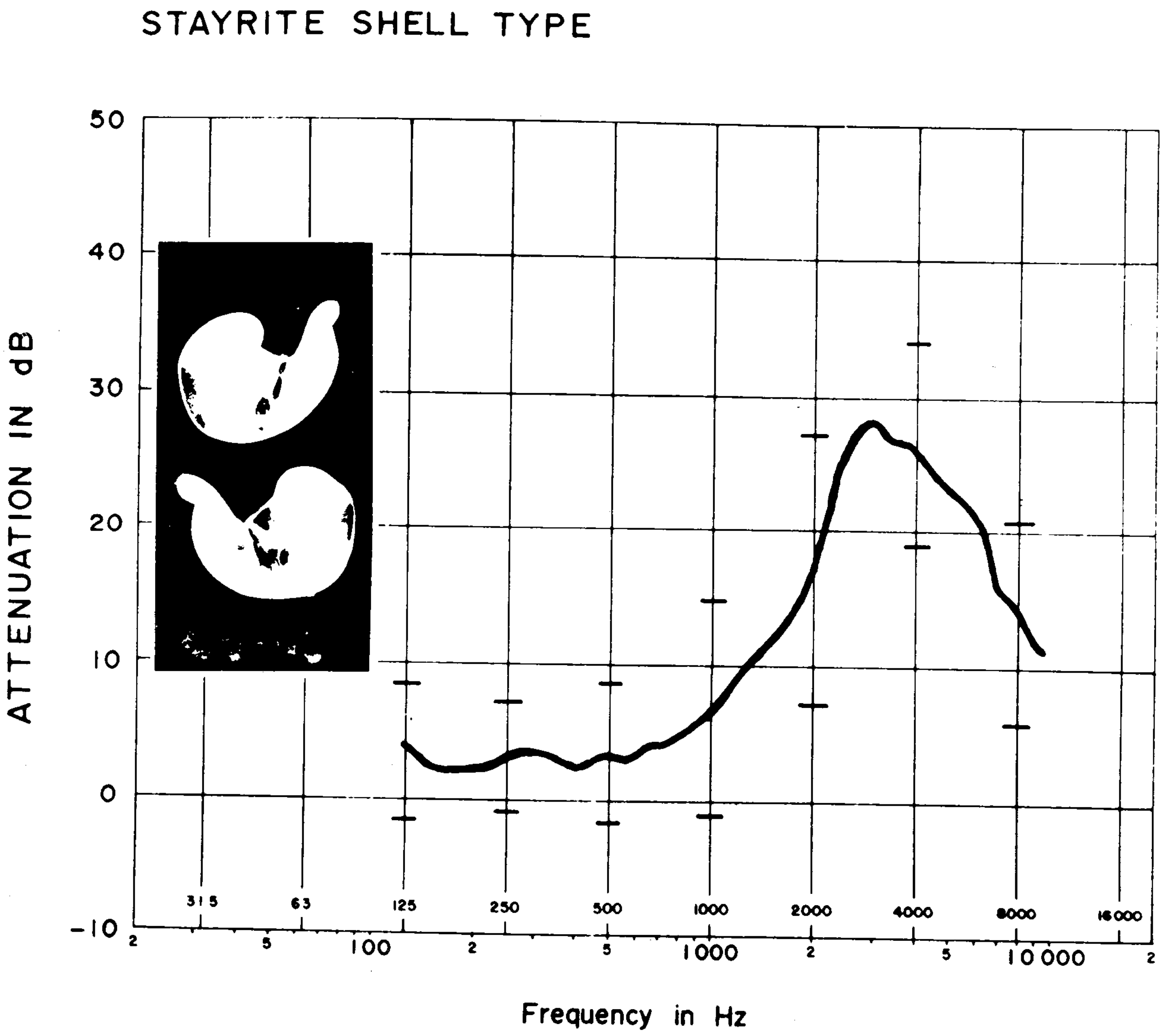


FIGURE 43

42. The Lee Sonic Ear-Valv (Figure 44) is the earliest version of the Sonic Ear-Valv (see paragraph 6). Because the short ear-canal piece is filled by a metal tube, the perforation is always open, and the attenuation is thus constantly adversely affected (see paragraph 21). P-AR = 445

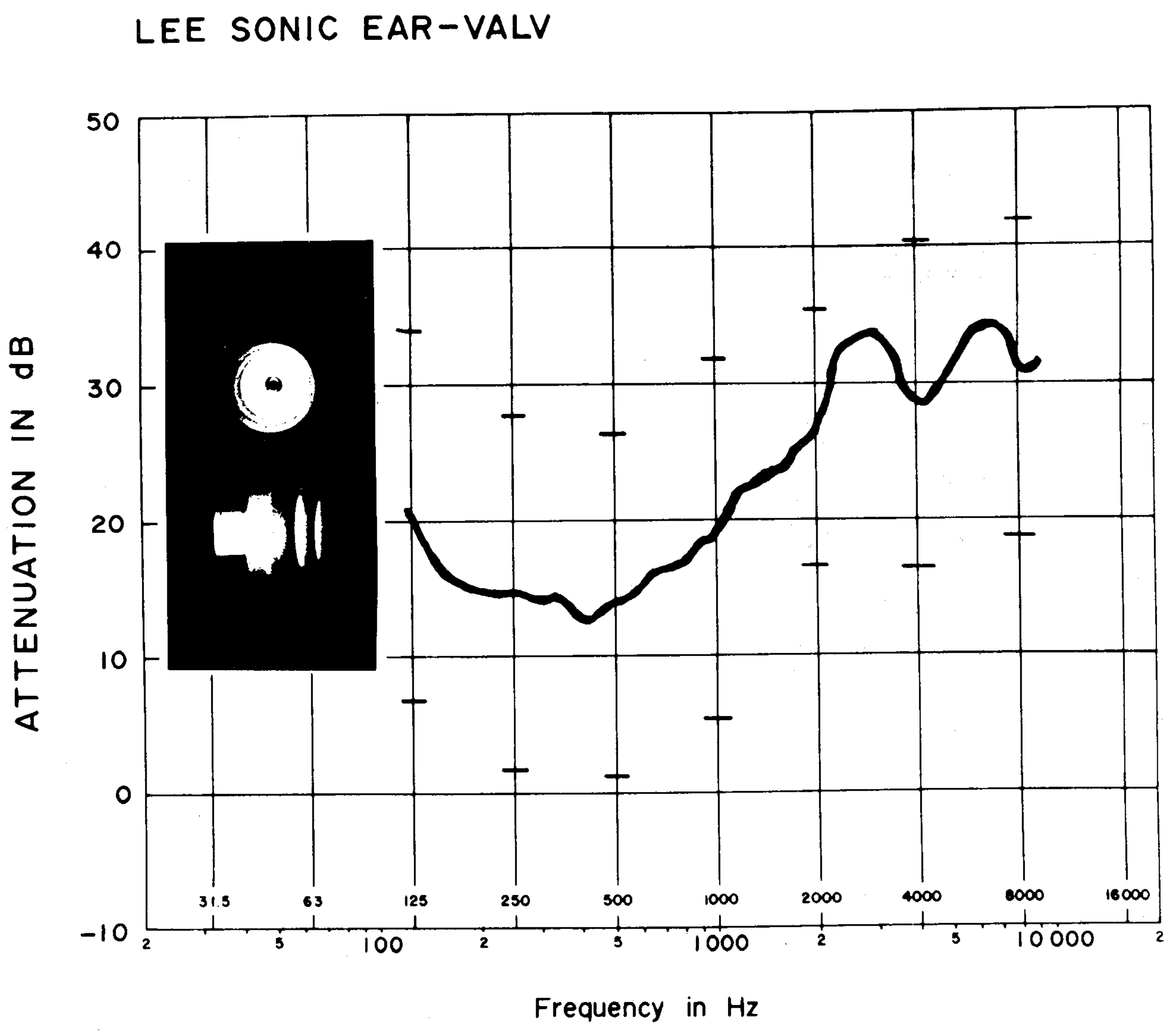


FIGURE 44

43. Fitsrite Audiophone De Luxe Ear Drum Protectors (Figure 45) were designed for swimmers. They are pink silicone formed around a metal cylinder that is sealed on one end. Subjects nearly always found them uncomfortable, primarily because of the cylinder. The earplug was sometimes difficult to remove. It is available under several trade names. P-AR=345

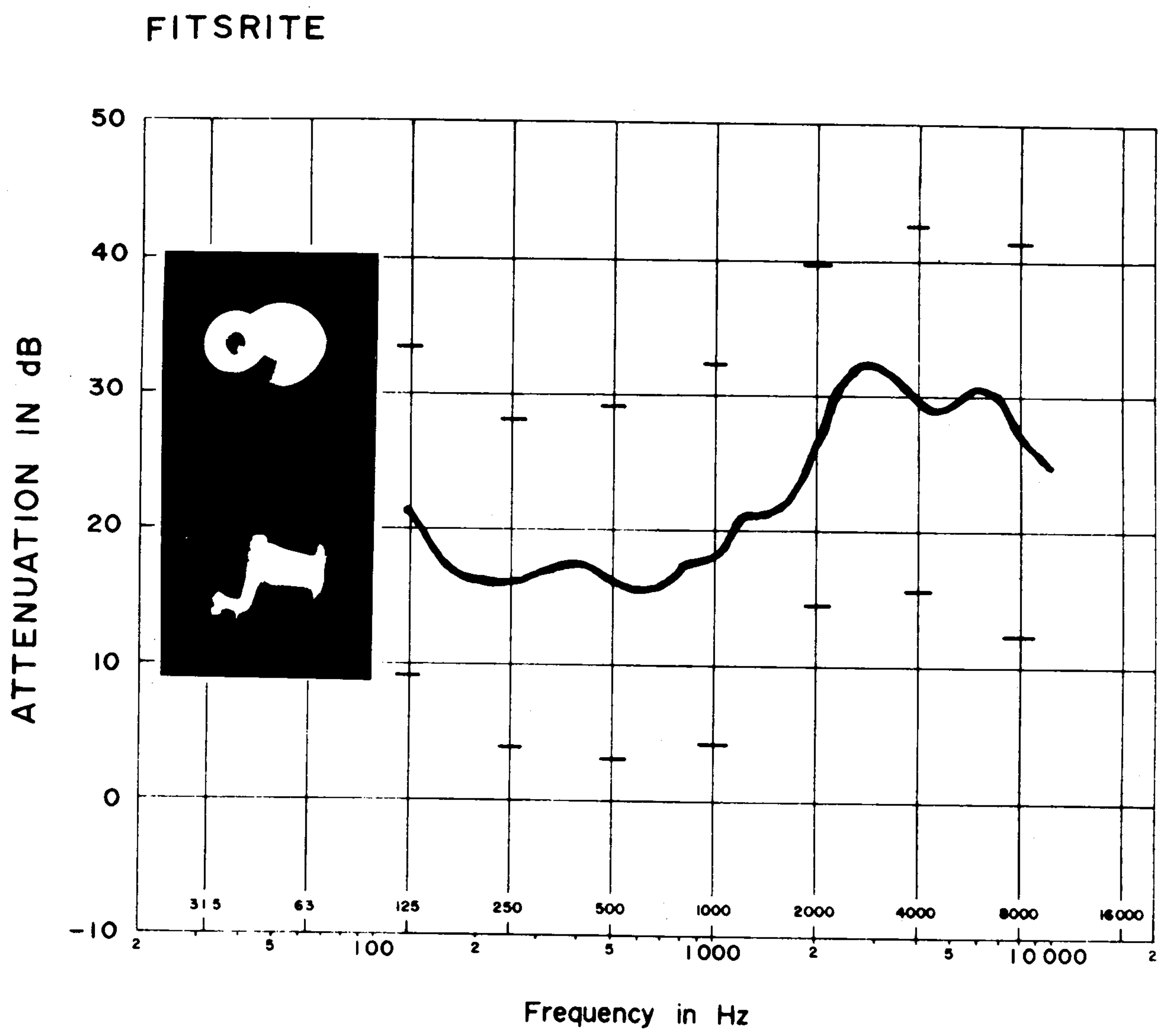


Figure 45

44. The Hearite series C (also known as the Stayrite Type C) earplug (Figure 46) looks something like the classic V-51R earplug although the relation of length to diameter is different. Many subjects complained of discomfort with this earplug, especially when its flange irritated the ear canal upon removal. The poor attenuation reported may very well be a result of the relatively short length of this plug. P-AR=555

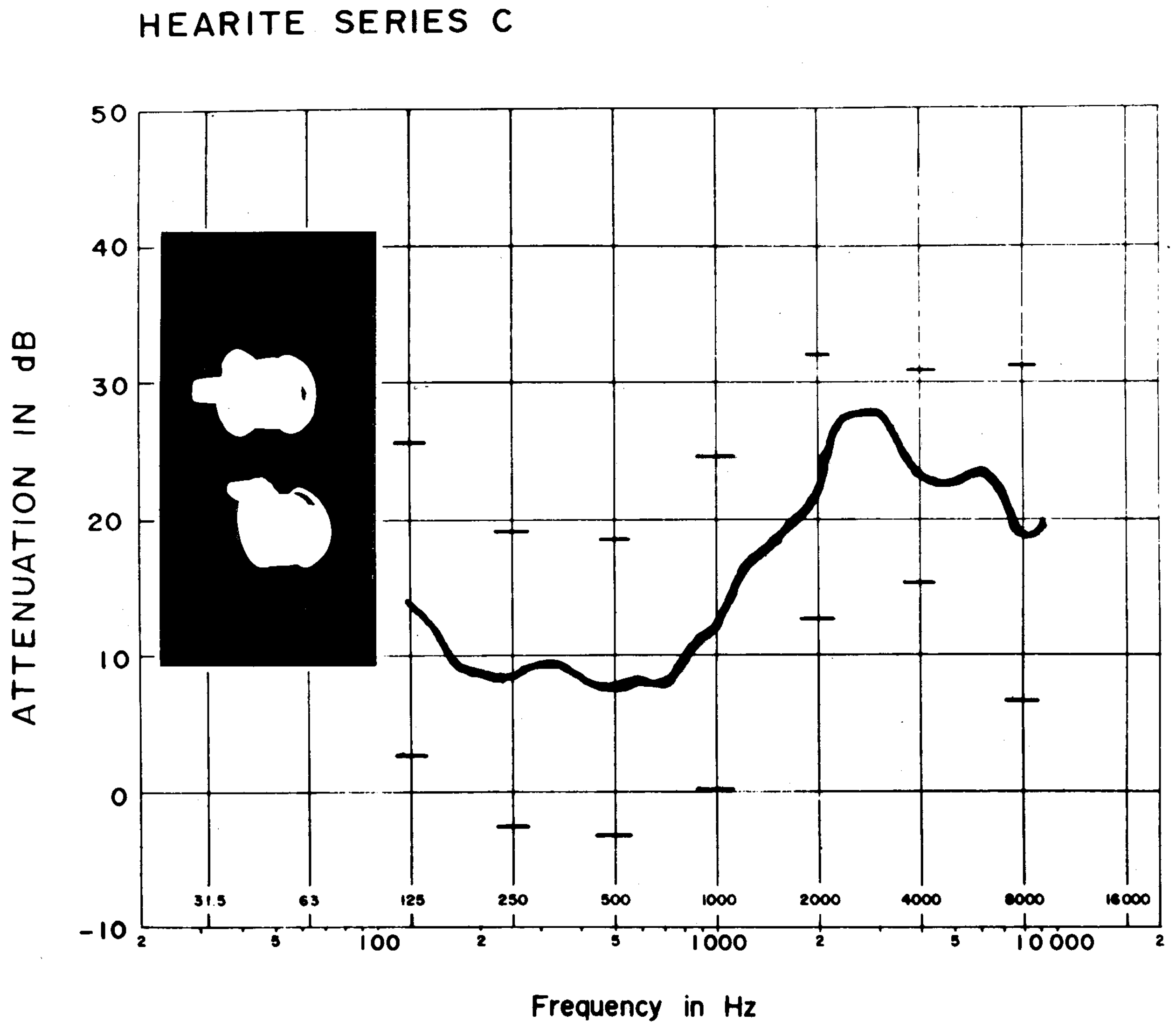


FIGURE 46

45. Crown earplugs (Figure 47) are aqua-colored plastic plugs designed for swimmers and available in dime stores. The central core is extremely stiff and led to complaints of discomfort and irritation by most subjects. The earplug was sometimes difficult to remove. P-AR=555

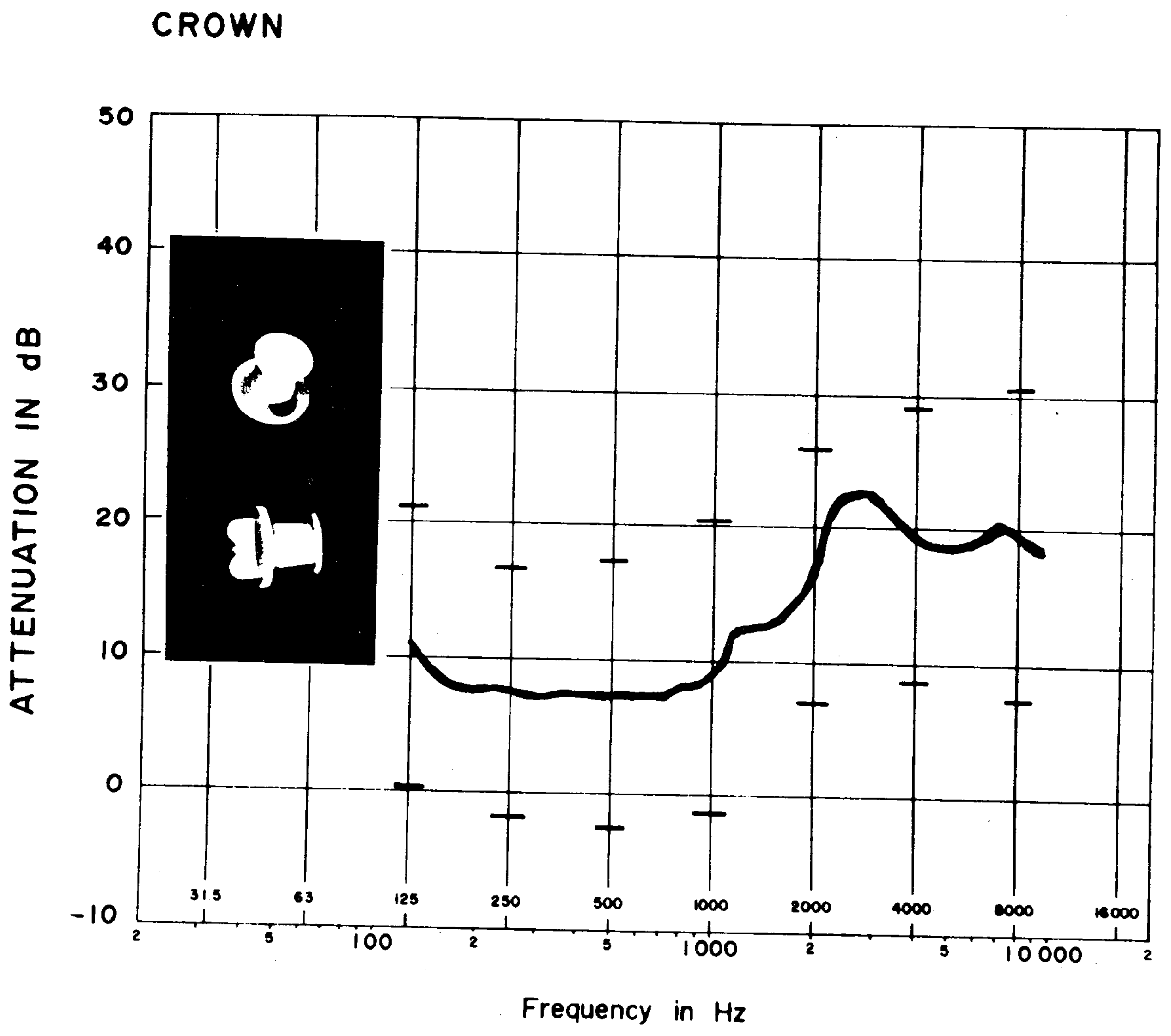


FIGURE 47

V. Conclusions.

Good earplugs can be found among all types: a good custom-molded plug, a good wearer-molded plug, and a good premolded plug may be nearly indistinguishable in performance. Purchasers need to remember though that the people who will wear the earplugs may decide to use them or not on the basis of issues that do not become apparent from a study of P-AR values. The least expensive good plug will not necessarily be the best-accepted one, and an unworn plug is ultimately too expensive: it can lead to permanent hearing loss for a worker and to compensation claims against an employer. A prospective wearer may select his earplugs on the basis of looks, comfort, cost (sometimes because they cost a little, sometimes because they cost a lot), or availability. A worker who balks at using hearing protection may need counseling on the fact that speech and emergency signals are heard more clearly when he is wearing earplugs.[15 16 17] He may not recognize the constant importance of protecting his hearing: hazards to the auditory system are not dramatic like hazards to vision—onset is slow and deterioration is gradual. Often the process is far advanced before it is noticed, and only then is the extreme social debilitation of deafness recognized—too late for either preventive or corrective measures to help much.

Whatever leads a user to his selection, the person who pays for the plug ought to recognize that any plug that will attenuate noise and *will be worn* is economical. If that plug is one of the more costly custom-molded varieties, the fact that it will be used makes it valuable and worth the money. The ultimate decision about wearing or not wearing protection is the worker's, and for that reason, offering him a choice from several types of plugs is useful. Having more than one kind on hand also decreases the number of cases in which a potential wearer cannot be successfully fitted. Then, every noise-exposed person can be given the kind of protection he needs in a form he will use.

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