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Jerry V. Tobias, Ph.D., and F. Michael Irons, M.Ed.	

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16. Abstract

Twenty-one brands of ear protectors, including custom-molded, wearer-molded, and pre-molded types, were evaluated according to American-standard procedures. Earplugs are described and are listed in the order of their low-frequency (below 1000 Hz) attenuation.

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EAR-PROTECTOR RATINGS

I. Introduction.

Ears differ. They vary in shape, in the diameter and circularity of the external canal, in the position and sharpness of the canal's bend, and in the availability and strength of conchal folds that might be used to anchor an earplug in place. Thus, it seems reasonable to assume that a standard, off-the-shelf, pre-molded earplug ought not to do as good a protecting job as a personalized, custom-fitted plug can. It looks as if the custom-made plug, with its accurately determined contours, should provide a better and more precise seal within the ear canal, should do so along most of the length of the inserted segment, and therefore ought to offer better attenuation characteristics than can be found in a mass-produced device. Additionally, a custom-molded earplug ought to be more comfortable and ought to be easier to insert. This family of assumptions has a strong appeal for the casual reader; intuitively, it all seems correct.

For several years, this laboratory has conducted a program to test various brands of readily available earplugs, including custom-molded, wearer-molded (such as wax-impregnated fiber), and pre-molded types. In general, the wearer-molded plugs are the least expensive, and the custom-molded are the most. 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 indicate that many of the specially fitted plugs are not a great bargain at all.

In a comprehensive review, Gasaway (1971) discussed dozens of studies of earplugs, earmuffs, and similar hearing-protection devices, while in a more recent paper, Flugrath and Turbeville (1972) compared five pre-molded and one wearer-molded plug using a non-standard measuring technique. Except for a few experimental types, the various pre-molded insert (earplug) protectors have been reported to perform nearly alike through much of the tested frequency range. However, the tested varieties have not commonly included custom-molded plugs; no nationally distributed brands have been available until recently. A major purpose of our study was to make direct comparisons among many sorts of plugs, with special emphasis on the personalized.

II. Method.

Twenty-one brands of canal-sealing appliances were tested. Of these, two brands were each tested under two conditions. The list includes most of the commonly used earplugs, except for the V–51R, which has been tested repeatedly in many laboratories. Although a "reference earplug" was to be tested on every subject in order to present a common point of comparison, the V–51R was not chosen as the reference because of the care required in selecting the correct size, and because many wearers report that the plugs lose their flexibility when skin oils lixiviate or leach out the material's plasticizers. Therefore, the Com-Fit plug was chosen as the reference because its attenuation characteristics are also well known (and are similar to the V–51R's), because it stays soft, and because it is easy to fit. The choice was not made from any bias favoring the Com-Fit's performance; the decision was made only to insure that every subject would provide a common attenuation curve, namely the one for the reference earplug.

Table 1 lists, alphabetically by manufacturer, the brand name of each tested appliance, the manufacturer's description of the material, and the type of earplug (pre-formed, wearer-formed, or custom-formed). 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 (Standard Z24.22–1957). This standard calls for tests to be done in an anechoic chamber on randomly selected listeners with good hearing. The subjects for the tests

Table 1

List of manufacturers, brands, and characteristics of the tested hearing protectors.

Manufacturer	Brand Name	Manufacturer's Description of Material	Type	Comments
Adcomold, Inc.	Adcomold	Soft acrylic	Formed in place	Custom.
H. E. Douglass Engineering Sales Company	Sound Sentry (5000B)	Neoprene	Preformed	Canal cap with headband.
Environmental Acoustical Research	E.A.R.	Polyvinyl	Factory formed	Custom.
Flents Products Company, Inc.	Flents	Wax impregnated cotton	Formed by user	
French Laboratory	Soundown	Acrylic	Factory formed	Custom. Lightweight, "shadow" mold.
Frontier Industrial Products Company	Frontier	Wax impregnated cotton	Formed by user	
General Electric Company	Peacekeeper	Silicone	Formed in place	Custom. Two series tested.
Human Acoustics, Inc.	SafEar	Vinyl	Factory formed	Custom. Has vent.
Johnson & Johnson	Johnson & Johnson	Cotton wool	Formed by user	
Kimberly-Clark Corporation	Kleenex	Paper tissue	Formed by user	
National Research Corporation	E-A-R	Polymer foam	Formed by user	Expands slowly after compression.
Oto-cure, Inc.	Oto-cure Custom Ear Protectors	Silicone elastomer	Formed in place	Custom.
Rockford I. C. Webb, Inc.	Billesholm Swedish Wool	.001-.002 mm glass fibers	Formed by user	
Safety Ear Protector Company	SEPCO	Neoprene; latex foam	Preformed	Has two vents.
Sigma Engineering Company	Com-Fit	Silicone	Preformed	
Sonotone Corporation	Sonotone	Vinylflex	Factory formed	Custom.
Sound Master Products, Inc.	Sound Master	Silicone	Formed in place	Custom.
Stayrite, Inc.	Stayrite Shell-type Earplug	Polyvinyl chloride	Preformed	Three shapes; looks like a custom plug.
Wade Products Company	Mark II	Silicone elastomer	Formed by user	
Wade Products Company	Nods	Foam latex, wax impregnated on one end	Formed by user	
Willson Products Division	Sound Silencer	Vinyl	Preformed	Tested both dry and lubricated with water.

were randomly selected from a large pool of university students. As the standard requires, each plug was tested on ten 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. The noise was well within acceptable limits.

Open-ear threshold tests and earplug attenuation tests were made using a Grason-Stadler model E–800 automatic audiometer both as the signal source and as the response recorder. The audiometer's signal was led to a loudspeaker in the chamber through a power amplifier; the motor-driven attenuator and the motor-driven oscillator were both retained in the circuit in order to produce, automatically, continuous-frequency graphs of each subject's thresholds. The technique is identical to that used in Bekesy audiometry.

One group of ten subjects was used in 11 series of measurements (one series of Com-Fit tests, and ten others). Other groups of ten subjects were used for series as small as two and as large as six. Altogether, 60 subjects participated. With each group, the procedure was the same: the first threshold of the day was with open ears, to provide a baseline; then, in random order, earplugs (always including one series of Com-Fits) were tested for two hours or until each type had been measured three times, following which another open-ear threshold was taken. If two hours were not adequate to finish all the necessary series, the next day's tests also included open-ear thresholds at the beginning and end of the session. A 5–dB variation at any frequency between the two baseline curves was chosen as large enough to invalidate that day's data. It was not necessary to throw out any tests for this reason. Each attenuation test was compared to the average of the two baseline curves that were taken on the same day.

Where manufacturers or distributors furnished instructions, earplugs were inserted accordingly. Otherwise, subjects were told to put the plugs in so that they fit comfortably and were tight. Then they made the adjustments and performed the jaw and head exercises prescribed in the ANSI standard.

Some custom-made varieties use an impression of the ear as a model from which to manufacture a plug; others use the impression itself as the earplug. For both types, the impressions were made by a skilled technician who followed manufacturers' recommendations precisely. The object was to simulate the way that the earplugs would be prepared in the field. In one case, detailed in the Results section, a company changed its published instructions after our tests were complete; a second series was run with earplugs made according to the new directions.

For units that were factory-molded from a model, the ear impressions were shipped to the company's plant in time to permit the finished earplugs to age in our laboratory for at least a couple of weeks before testing was started. For units that were manufactured in the subject's ear, a similar aging period was also required, just in case shrinkage might occur and change the results.

As much as possible, the tested earplugs were treated as they would be in the field. For example, normal procurement procedures were followed (although some manufacturers furnished the plugs at no cost when they learned of our intentions to test the products), as were normal fitting and molding practices.

III. Results and Discussion.

Nearly any material inserted into nearly any ear canal in nearly any way will attenuate high-frequency sounds to some extent. In comparing the effectiveness of earplugs, then, it is sensible to use the low-frequency blockage as the measure of effectiveness. Table 2 groups the tested earplugs in descending order of average attenuation (based on the area under the attenuation curve) between 125 and 1000 Hz. Within a group, units generally differ insignificantly. The last group (numbers 21, 22, and 23) contains plugs that are far worse than any of the others; none of them can be recommended for any practical acoustic-quieting function.

A high position in Table 2 cannot serve as an adequate sole reason to purchase a particular brand of earplug. The wearer's comfort is essential, and a high rating does not guarantee that

Table 2

Ratings of tested hearing protectors. Within each group, attenuation characteristics can be considered as similar. Groups I and II include the best attenuators; Group VII includes the worst. Within each group, brands are listed alphabetically.

Brand Name	Type
Group I	
1. E-A-R	Wearer-molded
Group II	
2. Com-Fit	Pre-molded
3. Sound Silencer, wet	Pre-molded
Group III	
4. E.A.R.	Custom-molded, factory
5. Nods	Wearer-molded
6. Sound Sentry (5000B)	Pre-molded, canal cap
7. Sound Silencer, dry	Pre-molded
Group IV	
8. Flents	Wearer-molded
9. Frontier	Wearer-molded
10. Sonotone	Custom-molded, factory
Group V	
11. Billesholm Swedish Wool	Wearer-molded
12. Mark II	Wearer-molded
13. SEPCO	Pre-molded, vented
Group VI	
14. Adcomold	Custom-molded, in-place
15. Oto-cure Custom Ear Protectors	Custom-molded, in-place
16. Peacekeeper, early instruction manual	Custom-molded, in-place
17. Peacekeeper, late instruction manual	Custom-molded, in-place
18. SafEar	Custom-molded, factory, vented
19. Sound Master	Custom-molded, in-place
20. Soundown	Custom-molded, factory, "shadow"
Group VII	
21. Johnson & Johnson	Wearer-molded
22. Kleenex	Wearer-molded
23. Stayrite Shell-type Earplug	Pre-molded, "custom"-shaped

the plug won't hurt (although the highest-rated plugs are generally considered easy to wear). Too, every sort tested shows a wide range of attenuation patterns, so variations among people have to be expected and prepared for in a practical hearing-conservation program. Even more important than the individual differences in effectiveness and comfort is the fact that many

people who ought rigorously to use hearing protection will not do so without external incentives. Some industrial personnel might be motivated by plugs of a brightly colored material (several are available) that can be highly visible to a distant foreman, if the foreman makes it a regular point to check to insure that the plugs are properly in place. Other prospective users may respond positively to an option such as the headband or cord that some brands offer, that makes plugs easy to put aside temporarily without getting lost. Some who get custom-molded plugs may wear them because of a belief that an expensive safety device strictly for their personal use must be good.

The critical point is that the procurement of earplugs will conserve no hearing if the plugs are always worn in the pocket. Selection has to be made with the idea of getting the plug to the anatomical place where it will do some good.

A few additional details will help in the interpretation of Table 2:

1. The E-A-R (National Research Corporation) earplug (Fig. 1) is a unique type in this study. The material is soft and easily compressed, but it returns to its original shape rather slowly under normal circumstances, permitting an insertion of the compressed, cone-shaped form, which then expands to fill and seal the entrance to the canal. All the subjects who used this plug found it very 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 one hour per day for one month, and there was not much sign of deterioration in the material. 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, there are no numerical data to support this contention as yet. The plugs are furnished in a bright yellow. They soil rapidly, and must therefore be handled carefully if they are to be reused.

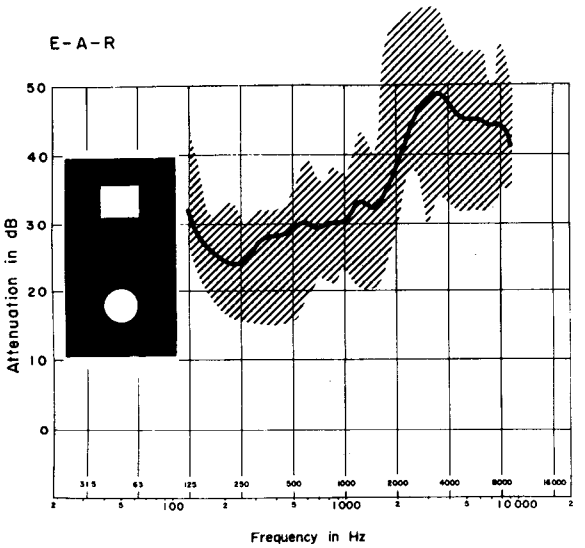

FIGURE 1. Measured attenuation provided by E-A-R. The line represents the mean attenuation; the shaded area represents the range.

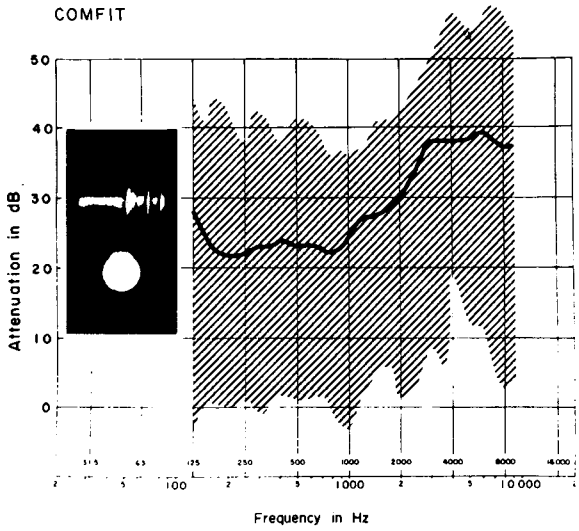

FIGURE 2. Measured attenuation provided by Com-Fit. The line represents the mean attenuation; the shaded area represents the range.

2. Com-Fit earplugs (Fig. 2) have been tested often before, both in this laboratory and in others. In the standard size, they fit most adults. Other sizes are available. Although most subjects found Com-Fits comfortable, a few who had slit-like (rather than rounded) canal openings did not. Many subjects, long after their tests, reported that they continued to use Com-Fits when they had abandoned their more expensive, custom-fitted plugs. The Figure for the Com-Fit plug seems to show much more variability in attenuation than any of the others. That range represents one aspect of the procedure; it is not a measure of something special about the earplug. Variability is large because

of the very large number of subjects whose data are included; Com-Fits served as the reference for every person used throughout these experiments. Individual groups of ten subjects show ranges that are similar to those that they produced for the other earplugs.

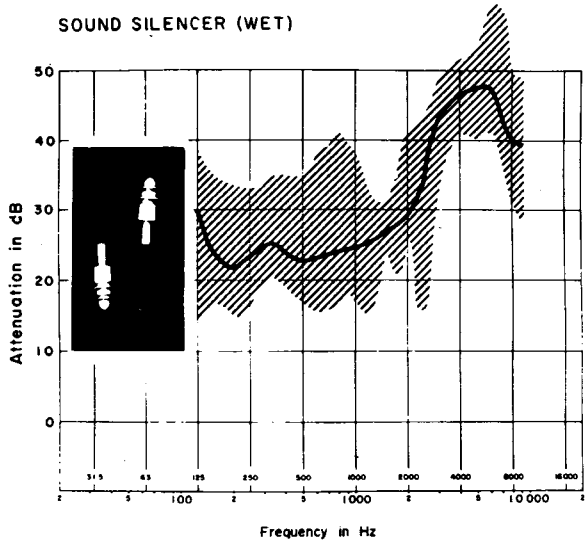

FIGURE 3. Measured attenuation provided by lubricated Sound Silencer. The line represents the mean attenuation; the shaded area represents the range.

3. The Sound Silencer earplug (Figs. 3 and 7) in the standard size fits most adults. Other sizes are available. It 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 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 both because of hygiene and because of the flavor of ceruminous residues. Therefore, tests were run on this earplug both lubricated with water and dry. As might have been predicted, the lubricated (and therefore well-seated) plug produced better attenuation scores. A dark green plug is available, as is a version that is strung on a cord.

4. The E.A.R. (Environmental Acoustical Research) plug (Fig. 4) is a soft, factory-made, custom-fitted device. Subjects found it comfortable and easy to insert, but, like all the custom-made plugs we tried, users were less comfortable with them than they were with most pre-formed or wearer-formed varieties.

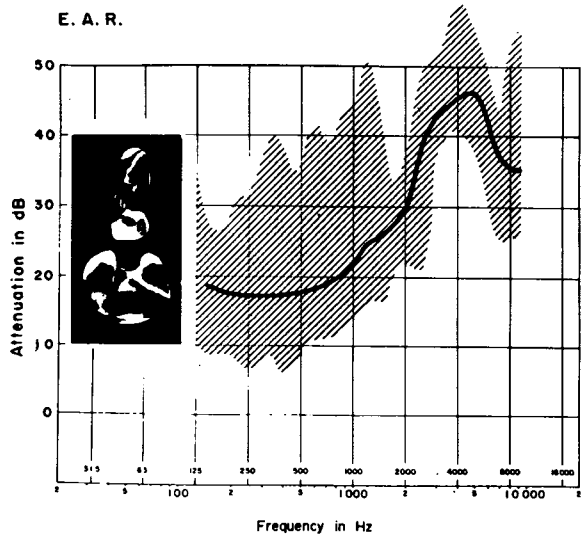

FIGURE 4. Measured attenuation provided by E. A. R. The line represents the mean attenuation; the shaded area represents the range.

5. Nods (Fig. 5) are made of wax-filled foam, and are manipulated by the wearer until they seal the canals. They are comfortable in the ear. We 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.

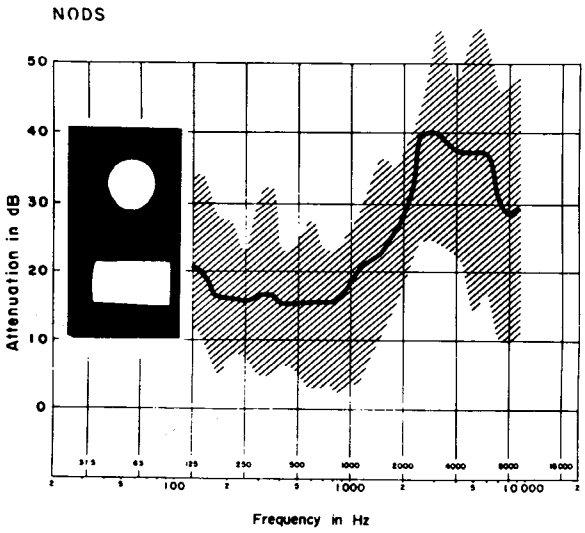

FIGURE 5. Measured attenuation provided by Nods. The line represents the mean attenuation; the shaded area represents the range.

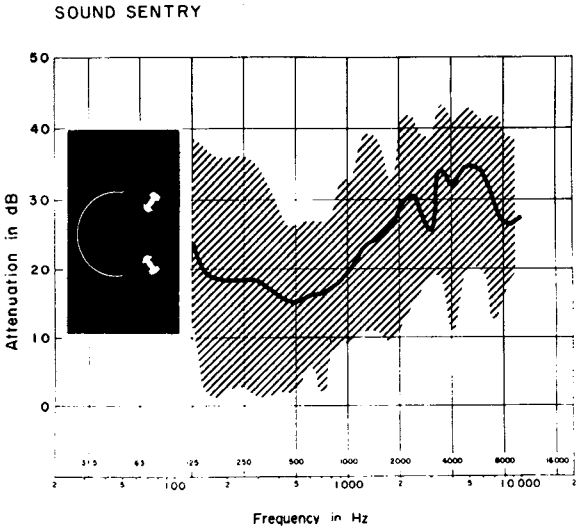

FIGURE 6. Measured attenuation provided by Sound Sentry (5000B). The line represents the mean attenuation; the shaded area represents the range.

6. The Sound Sentry (5000B) (Fig. 6) is another unique item in this study. It is not, properly speaking, an insert earplug at all. Rather, the attenuation results from covering the opening to the canal with a neoprene cap that is held in place by a headband. It is difficult to position the cap accurately for the initial wearing, but once it is adjusted, it is easy to put back on. No subjects complained of the headband.

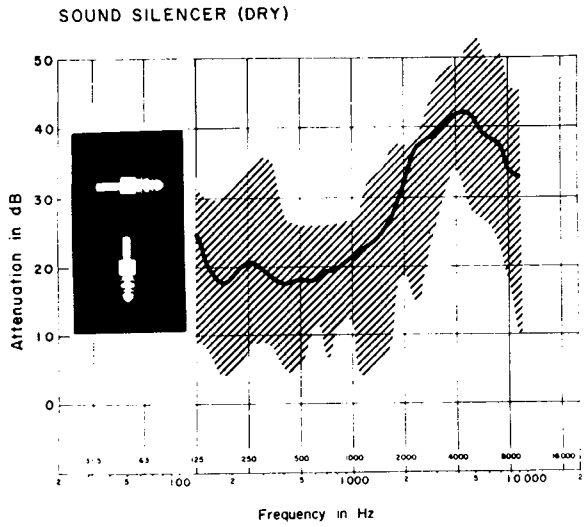

FIGURE 7. Measured attenuation provided by unlubricated Sound Silencer. The line represents the mean attenuation; the shaded area represents the range.

7. For comments on the dry Sound Silencer (Fig. 7), see paragraph number 3, above.

8. Flents (Fig. 8) are made of wax-impregnated cotton fiber that is hand-formed by the user. Some subjects complained that the wax felt funny in the fingers. The expected life of such plugs is, at most, a few wearings.

9. The Frontier earplug (Fig. 9) is similar to Flents (see paragraph number 8) except that less material is furnished.

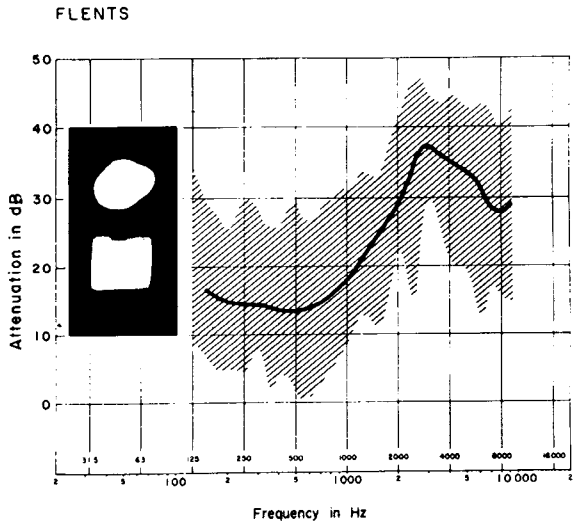

FIGURE 8. Measured attenuation provided by Flents. The line represents the mean attenuation; the shaded area represents the range.

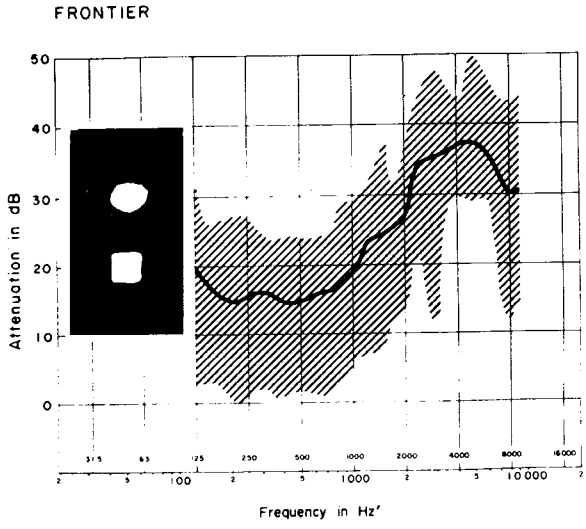

FIGURE 9. Measured attenuation provided by Frontier. The line represents the mean attenuation; the shaded area represents the range.

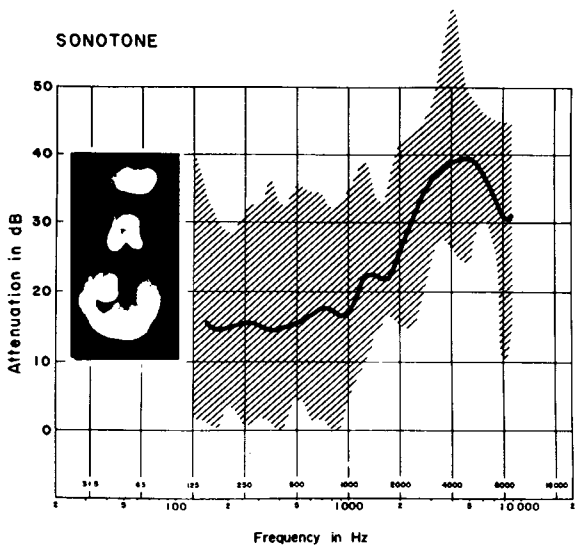

FIGURE 10. Measured attenuation provided by Sonotone. The line represents the mean attenuation; the shaded area represents the range.

10. Sonotone earplugs (Fig. 10) are rather like the E.A.R. plugs (see paragraph number 4), except that the segment that fits into the canal is a little longer.

11. Billesholm Swedish Wool (Fig. 11) is a fiber-glass material 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 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 fiber glass.

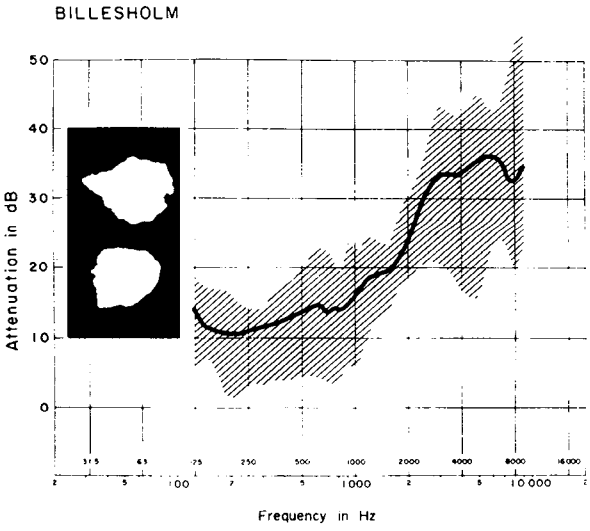

FIGURE 11. Measured attenuation provided by Billesholm Swedish Wool. The line represents the mean attenuation; the shaded area represents the range.

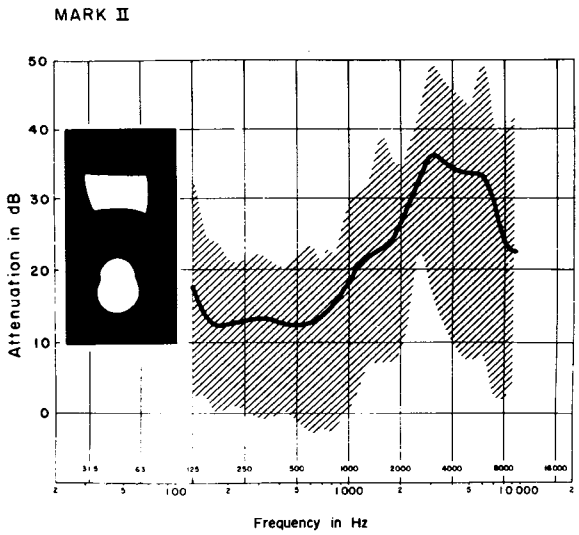

FIGURE 12. Measured attenuation provided by Mark II. The line represents the mean attenuation; the shaded area represents the range.

12. The Mark II (Fig. 12) is hand-formed by the user, and it feels somewhat waxy, although there is no wax to come off on the hands. It is made of a silicone product that is advertised to "last indefinitely." It was generally considered to be comfortable despite the waxy touch that some subjects disliked.

13. SEPCO earplugs (Fig. 13) are formed from a pink neoprene shell (with two pinhole perforations in the tip) that is 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 number 18).

14. Soft (they are also available in a hard material) Adcomold earplugs (Fig. 14) are custom-fitted and do not require factory construction. It is necessary to work rapidly with such 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. It is critical with all custom-molded plugs, and especially with those that do not require factory construction, to follow the

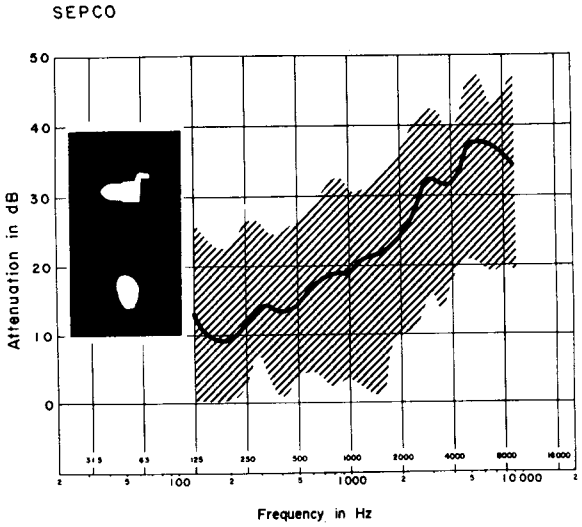

FIGURE 13. Measured attenuation provided by SEPCO. The line represents the mean attenuation; the shaded area represents the range.

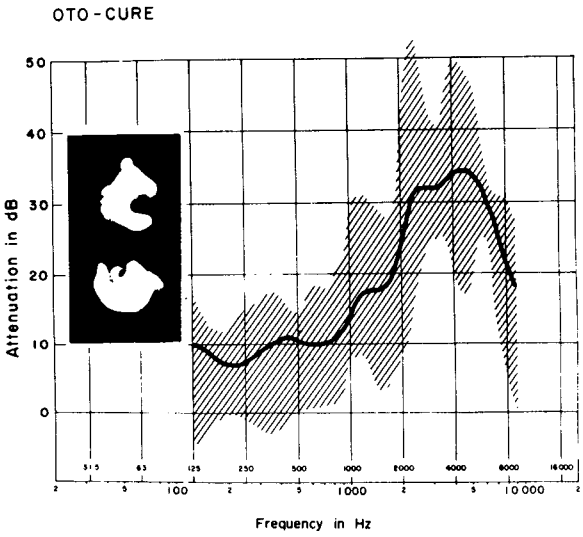

FIGURE 15. Measured attenuation provided by Oto-cure Custom Ear Protectors. The line represents the mean attenuation; the shaded area represents the range.

manufacturer's instructions carefully and accurately; there is no substitute for experience in earmold construction. The Adcomold material is slightly more difficult to work with than is that furnished for others of the molded-in-place type.

15. Oto-cure Custom Ear Protectors (Fig. 15) 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.

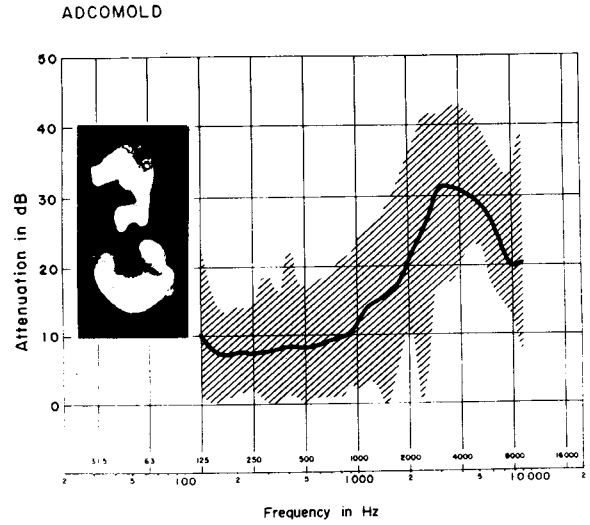

FIGURE 14. Measured attenuation provided by Adcomold. The line represents the mean attenuation; the shaded area represents the range.

16. The Peacekeeper (Figs. 16 and 17) is a custom-made earplug that does not require factory construction. The silicone mold cures to become the final earplug. The Peacekeeper requires that the material for both ears be mixed simultaneously. As with all plugs, we obtained the molding kits through normal procurement procedures. Then 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 lacks of time, money, and facilities. In these studies, the dip was used precisely according to the instructions. Tests (Fig. 16) showed less attenuation than some of the manufacturer's reports showed, and General Electric requested us to test plugs made by a manufacturer's representative. We asked instead for better instruction manuals or for an indica-

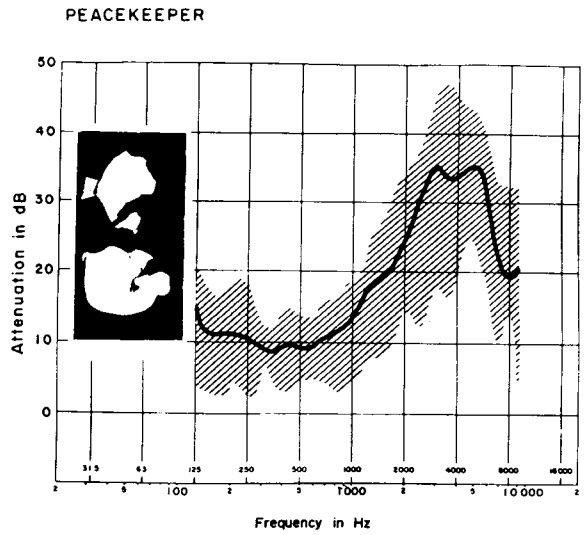

FIGURE 16. Measured attenuation provided by Peacekeeper made according to early instruction manual. The line represents the mean attenuation; the shaded area represents the range.

tion that the plugs would always be sold with the fitting service included. A revised manual was published, and a second series of tests was performed on plugs made according to the new instructions (which called for more rapid mixing of the substance and for a momentary reapplication of pressure on the earmolds after they had rested in the canal for a short time). The second series (Fig. 17) is almost indistinguishable from the first, but on careful comparison proves to be slightly better. Two of the 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; the other subject's performance showed greatly improved attenuation. However, even ten months after our last Peacekeeper studies (as this paper is being prepared), we have met a private customer who was sold several kits without an offer by the manufacturer to fit them, and without either old or new instructions. Potentially, this plug may be a good one, but purchasers apparently must make do with the printed instructions or must insist on General Electric's furnishing personnel to make the plugs. For a facility with several thousand pairs of plugs to be fitted, the manufacturer might be requested to furnish a training course 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 a bright color, 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.

17. For comments on both series of Peacekeeper tests (Figs. 16 and 17), see paragraph number 16, above.

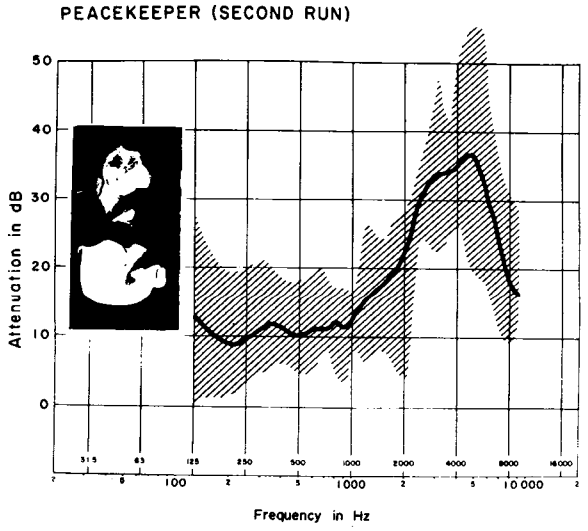

FIGURE 17. Measured attenuation provided by Peacekeeper made according to late instruction manual. The line represents the mean attenuation; the shaded area represents the range.

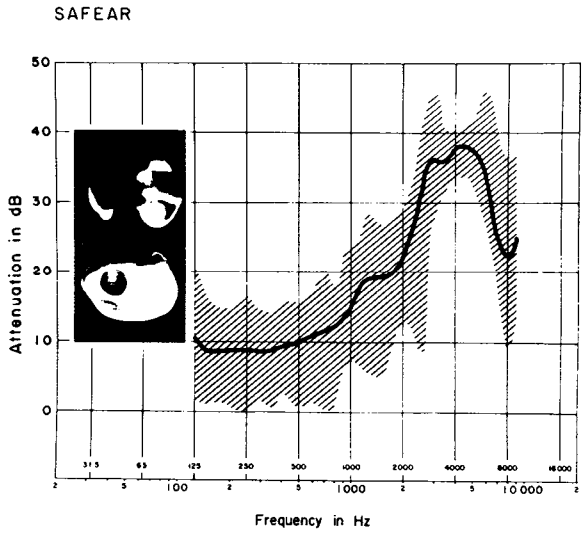

FIGURE 18. Measured attenuation provided by SafEar. The line represents the mean attenuation; the shaded area represents the range.

18. The SafEar (Fig. 18), 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. We 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 (Zwislocki, 1957); 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 (Forrest, 1971), but the data suggest that such effects are negligible until very high sound pressures are reached; Forrest 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 [sic], the noise is attenuated to 85 db. The higher the noise the more efficient the attenuation. Thus noises of 140 to 150 db are attenuated to 85 db. . . ." This plug may well be useful in situations in which the primary exposure is to high-level impulse noise.

19. Sound Master earplugs (Fig. 19) are custom-fitted and do not require factory construction. They are stamped to identify which ear each plug was made for. It is not necessary to handle the material at all.

20. The Soundown earplug (Fig. 20) is a custom-fitted, factory-made plug that is particularly light in weight and particularly comfortable to wear, according to subjects' reports; 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 canal. However, the plug slips out of place with very little 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 generally led to an open channel into the ear canal.

21. Johnson & Johnson cotton wool (Fig. 21) 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, our tests were run with dry cotton to simulate actual-use conditions.

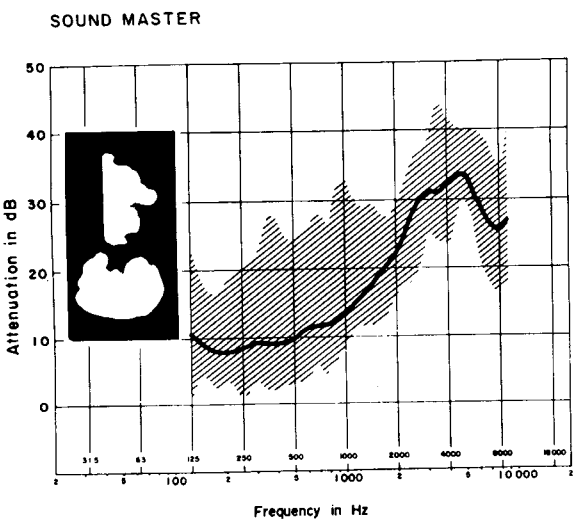

FIGURE 19. Measured attenuation provided by Sound Master. The line represents the mean attenuation; the shaded area represents the range.

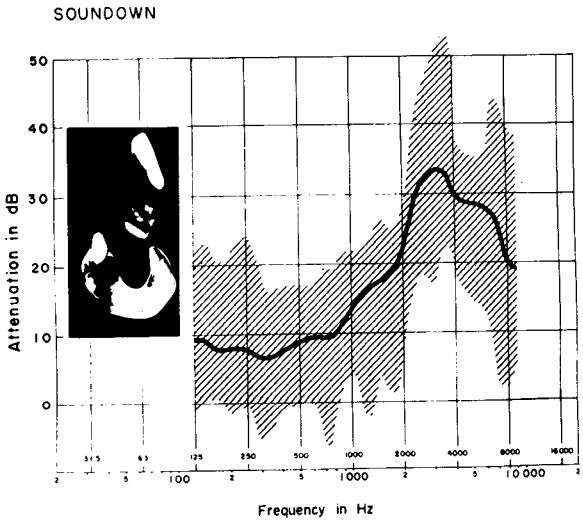

FIGURE 20. Measured attenuation provided by Soundown. The line represents the mean attenuation; the shaded area represents the range.

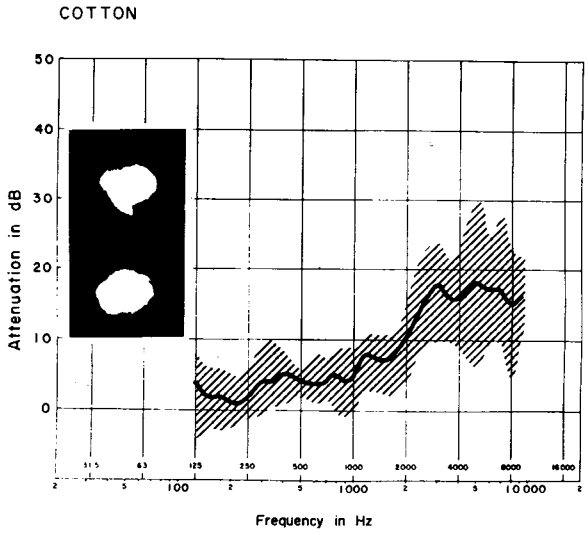

FIGURE 21. Measured attenuation provided by Johnson & Johnson cotton wool. The line represents the mean attenuation; the shaded area represents the range.

22. Kleenex tissue (Fig. 22) 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.

23. The Stayrite Shell-type Earplug (Fig. 23) is soft and is pre-molded, 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.

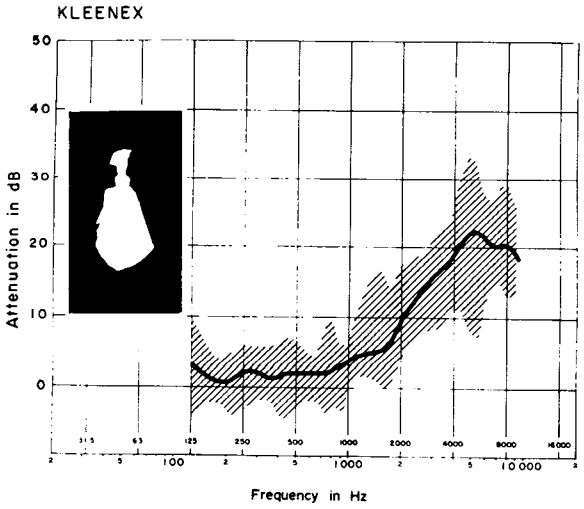

FIGURE 22. Measured attenuation provided by Kleenex. The line represents the mean attenuation; the shaded area represents the range.

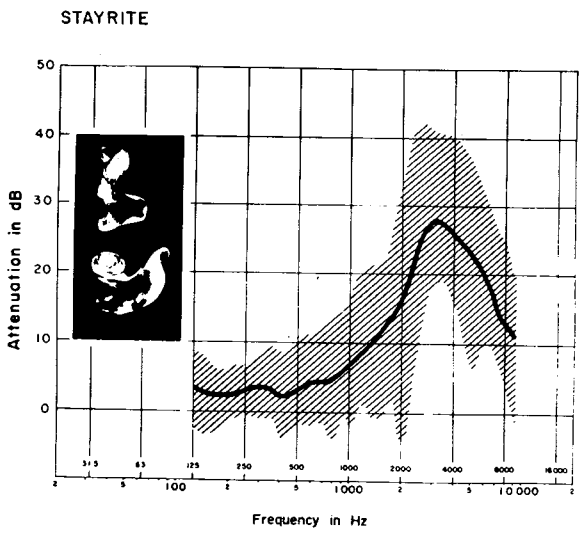

FIGURE 23. Measured attenuation provided by Stayrite Shell-type Earplug. The line represents the mean attenuation; the shaded area represents the range.

IV. Conclusions.

The data clearly show that good earplugs can be found among all types: a good custom-molded plug, a good wearer-molded plug, and a good pre-molded plug may be nearly indistinguishable in performance. However, the probability of getting a less-than-good plug is increased if selection is *limited* to custom-molded models, especially the ones that are not returned to the manufacturer for factory construction, or the ones that incorporate such gimmicks as perforated or light-weight construction.

Problems of economy in earplug selection are difficult to solve. 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. He may not understand that speech and emergency signals are heard more clearly when he is wearing earplugs (Kryter, 1946), and he may not recognize the constant importance of protecting his hearing.* Whatever leads him to his selection, though, if his choice is a plug that will attenuate noise and *will be worn*, it is economical. If that plug is one of the costly, custom-molded types, the fact

that it will be used makes it valuable and worth the money.

In general, though, custom-molded earplugs are judged to be less comfortable than others (wearer-molded plugs are judged to be more comfortable than others). Custom-molded earplugs, on the average, give less attenuation than others, both at the low frequencies reported here and at high frequencies as well (Bess and Townsend, 1973). And, of course, the financial outlay for custom-molded plugs is relatively high. Most of these specially fitted plugs therefore have to be considered too expensive for most users. But where an over-the-counter type would not be worn because of a user's ear-canal shape, because of a comfort problem, or because of an attenuation problem, the custom plug can be a rational solution.

From our experience, we estimate that adults with fitting problems constitute at least 5% of the population and no more than 15%. A useful hearing-conservation program needs to take those percentages into account and to make available at least one kind of personalized device. The plug might be a custom-molded or a wearer-molded type; optimally, both ought to be offered in order to insure that every noise-exposed person receives the kind of protection that he needs in a form that he will use.

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* People understand and fear hazards to their eyes because the effects are often sudden and dramatic; the need for protection is obvious. These same people often ignore hazards to their ears because the usual noise-induced hearing loss is of slow onset, permitting the gradual deterioration to go unnoticed until the process is far-advanced. Also, many people, not recognizing that deafness is much more socially debilitating than blindness, are terrified at the prospect of a loss of vision, but give little serious thought to the consequences of a loss of hearing.

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