# State of the Art: Testing Methods and Passive Hearing Protectors


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**In the past five years, there have been major developments in passive hearing protection. In the United States a new method for determining the real-ear attenuation at threshold has been adopted by the American National Standards Institute. This method seeks to obtain laboratory data that are predictive of real-world, work-site outcomes for workers using hearing protection. The method is similar to that used in the European Union, but employs 20 subjects with two repetitions per subject for testing earplugs, and ten subjects for testing earmuffs. Another development has been the appearance of many types of passive devices addressing the issue of overprotection and speech intelligibility. Major manufacturers have introduced earplugs and earmuffs with flat attenuation or with reduced ear-cap resonance. Also introduced are earplugs with special vents that increase attenuation with increasing sound pressures that have been designed to be especially effective for blast overpressures such as occur with weapons fire. Last, a commercial system has been developed for the fit-testing of earplugs.**



*Keywords: Hearing Protectors, Passive, Active, Test methods, Protector Rating, SNR, NRR*


## Introduction:

There has been a long history of testing hearing protector attenuation with psychoacoustic methods rather than electroacoustic methods as used with hearing aids. The primary measurement has been the real-ear attenuation at threshold, the difference between sound-field hearing threshold level with the ear open and ear occluded. While an earlier American National Standards Association (ANSI) method called for testing to be conducted with pure tones in an anechoic sound field, the first method incorporated into regulation was ANSI S3.19-1974. This method called for sound field audiometry to be conducted in a reverberant sound field with one-third octave bands of noise centered at the octave frequencies from 125 to 8000 Hz with the inclusions of bands centered at 3150 and 6300 Hz.

The standard also provided two fitting protocols, subject fit and experimenter fit. The U.S. Environmental Protection agency incorporated the standard into the Hearing Protection Labeling Rule, 40 CFR 211 Part B, with the interpretation of experimenter fit to mean that the subject did not participate at all in the fitting of the protector, serving sort of as an acoustic test fixture, with only the experimenter determining the adequacy of the insertion or donning of the protector. The subject-fit method of the standard prohibited the experimenter from physically fitting the protectors.

When the International Standards Organization (ISO) adopted ISO 4869 Part 1 for testing hearing protectors, it provided that the subject would fit the protector under the supervision of the experimenter. The standard added the octaveband center frequency of 63 Hz and removed the inter-octave frequencies of 3150 and 6300 Hz. From experience, the typical test laboratory solicits a panel for each test from an experienced pool of subjects who know the ins and outs of wearing hearing protectors and the type of sound field audiometry.

The sound-field specifications of ISO 4869 Part 1 were similar to those of ANSI S3.19, a diffuse sound field around a critical volume that circumscribed the full head and ears. Unlike ANSI S3.19, ISO 4869 Part did not set minimum specifications for sound field reverberation time, allowing testing to be conducted in reverberant, acoustically dampened, and anechoic test facilities. While it may seem that use of disparate sound fields may cause differences between laboratories, experience has shown no substantive effects (Jensen and Poulsen, 1999).

Not much time passed between the incorporation of ANSI S3.19 in the labelling regulations and the discovery that experimenter-fit greatly over predicted the real-ear attenuation that workers received (Fleming, 1980). The initial responses to the discrepancies were to criticize the utilization of the hearing protectors by the workers, attributing the reduced outcome to lack of motivation, intentional misuse, and poor training. The underlying tenant was that if workers were adequately trained and motivated, they would receive values similar to the label values. After all, since the Noise Reduction Rating was calculated from mean real-ear attenuation at threshold values minus two standard deviations and an additional 3-dB uncertainty value, almost anyone should be able to realize the rated protection.

Nonetheless, repeated work-site and real-world studies continued to present evidence that realized protection seldom if ever reached or exceeded rated protection (Berger, Franks, and Lindgren, 1996). While the discrepancies were less for earmuffs than for earplugs and semi-inserts, they were appreciable enough to render the rated values as almost useless. In order to use rated values to determine the adequacy of hearing protectors as a surrogate for noise control, in the United States, the Occupational Safety and Health Administration began derating the values by 50% (OSHA, 1984). The National Institute for Occupational Safety and Health recommended that ratings for earmuffs be reduced by 25%, while reducing them by 50% for foam earplugs and 70% for all premolded earplugs (NIOSH, 1998).

**The New American Standard:**

In 1984, ANSI replaced ANSI S3.19 with ANSI S12.6. The experimenter-fit method was modified to achieve and optimize fit by making it clear that the fit was experimenter assisted and that fitting noise was provided the test subjects. While it was anticipated that protector manufacturers would switch to the new method, the U.S. Environmental Protection Agency's Office of Noise Abatement and Control was closed in 1981, and so the Hearing Protector Labelling regulation was left unchanged and the revision was not adopted. In fact, even though ANSI S3.19 has been officially rescinded by ANSI, the Hearing Protector Labelling regulation still requires its use for hearing protectors sold in the United States.

In a second effort to develop a laboratory method predictive of real-world realizations, ANSI Working Group 12WG11 conducted a series of interlaboratory studies that spanned 10 years. The primary variable was level of experimenter involvement in the fitting of the hearing protection and the experience of the test subjects in the use of hearing protectors. The studies found the best interlaboratory agreement when the experimenter was prohibited from fitting the protectors, the subject was totally reliant on the

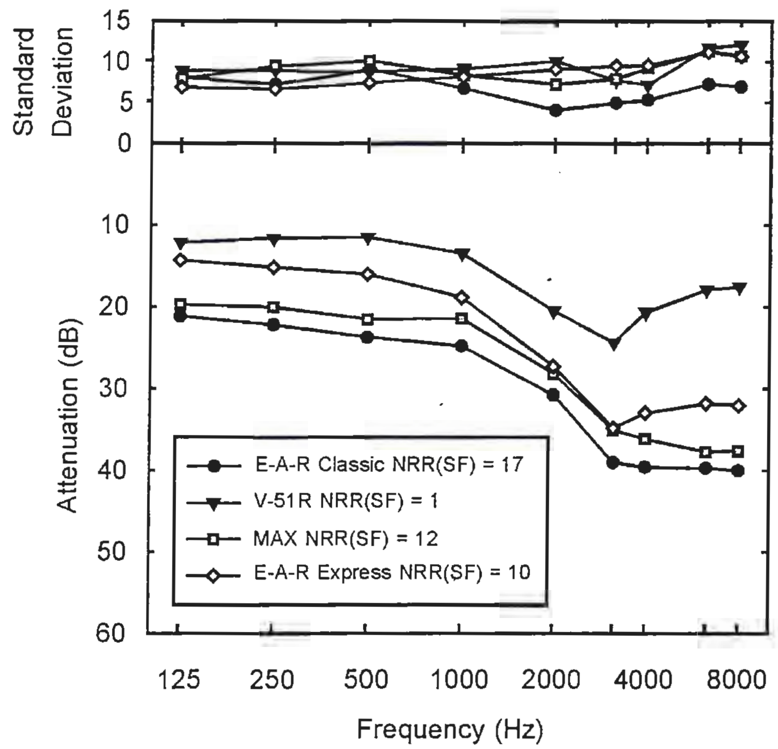


**Figure 1. ANSI S12.6 Method B mean attenuations and standard deviations of four earplugs.**

manufacture's instructions for selection and fitting, and the subjects were naïve to hearing protector use (Royster et al., 1996).

Comparison of the data from this method (naïve subject-fit) with real-world data found good agreement to the extent that the laboratory results were typically not different statistically from the real-world data. In the cases where there were differences, they were small. (Berger et al., 1998).

The naïve subject-fit method was incorporated into the 1997 revision of the ANSI S12.6 as Method B. The experimenter-assisted fit was left unchanged in the standard as Method A, including retention of treating REATs from ten subjects with three repetitions each as 30 observations. In addition to eliminating the experimenter from the fitting procedures, Method B requires the use of at least ten subjects for testing earmuffs with two repetitions each and of at least 20 subjects with two repetitions each for earplugs and semi-inserts. Subject means are used in calculating the grand mean and the number of observations for calculation of the standard deviations is statistically correct as the number of subjects

The Hearing Protector Task Force of the National Hearing Conservation Association developed the subject-fit rating, NRR(SF), to use the Method B data (Royster, 1995). The NRR(SF) is calculated similarly to the SNR of ISO 4869 Part 2, but it contains a 5-dB adjustment to allow its use with A-weighted noise exposure measures. The NRR and the SNR are both meant to be used with C-weighted noise exposure measures. The SNR is based on use of 16 subjects with one observation for each.

In 1973 and 1998, NIOSH recommended that 7-dB be subtracted from the NRR for its use with A-weighted measures (NIOSH, 1973; NIOSH,

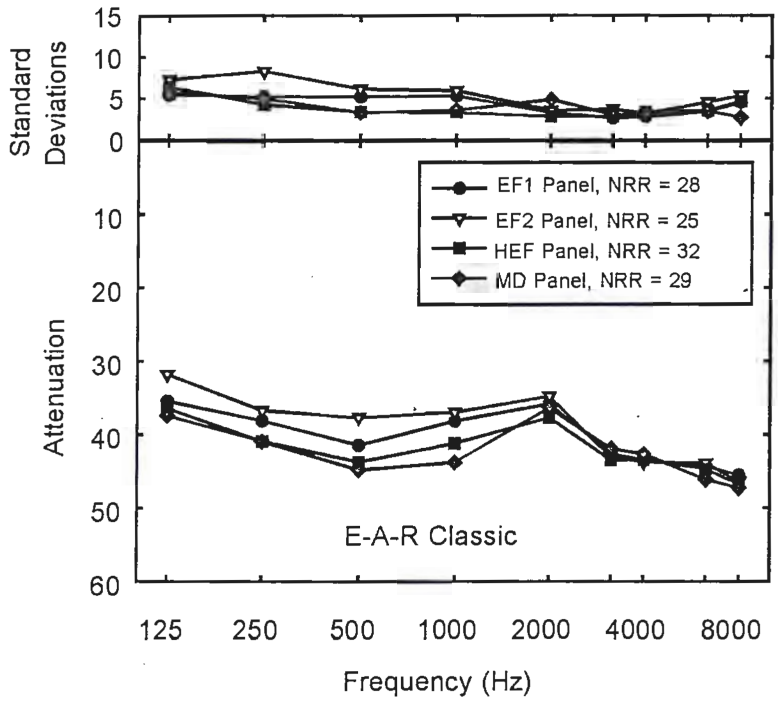


**Figure 2. ANSI S3.19 mean attenuations and standard deviations for the E-A-R Classic earplug.**

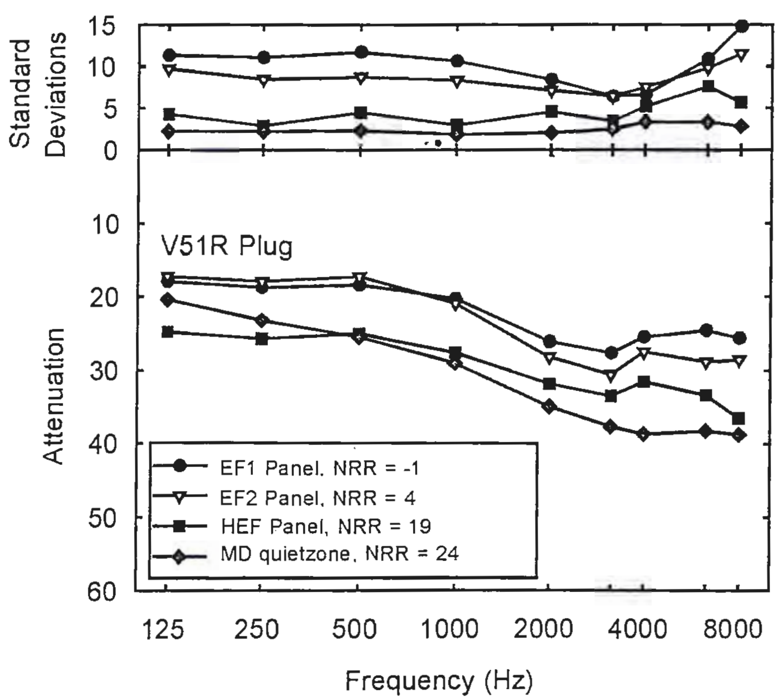


**Figure 3. ANSI S3.19 mean attenuations and standard deviations for the Bilsom V-51R earplug.**

1998). OSHA requires that the NRR be reduced by 7 dB to account for use with A-weighted noise exposure measures (OSHA, 1999).

Franks et al. (2000) reported on a direct comparison of the S3.19 experimenter-fit and S12.6 subject-fit method on four earplugs: one foam, two premolded, and one foam cap. The data, collected over an eight-year period in two laboratories, were used to examine real-ear attenuation at threshold (REAT), assumed protection values (APV), as well as test-retest

repeatability and interlaboratory reliability.
The results found:
S3.19 REATs were greater than S12.6B REATs
S3.19 APVs greater than S12.6B APVs
S3.19 had higher test-retest repeatability on same subjects
S12.6B had higher interlaboratory reliability
It is not possible to predict the NRR(SF) from the NRR, thus derating is not a substitute for testing protectors with Method B.

Figure 1 displays the mean Method B attenuations and standard deviations for the Bilsom Quietzone V-51R, E-A-R Classic, Howard Leight Industries MAX-1, and E-A-R Express earplugs. The NRR(SF) values shown are much less than the labeled ANSI S3.19 NRR values, and the Quietzone shows effectively no protection.

Figures 2 and 3 display the ANSI S3.19 mean attenuations and standard deviations for the E-A-R Classic and Bilsom V-51R earplugs, respectively. There are two interesting points. First is that both the Quietzone's NRR of 24 and the Classic's NRR of 29 greatly exaggerate the protection a user may experience. Moreover, while the Franks et al. (2000) two subject panels (EF1 and EF2) provided data that were similar to those published by the manufacturer for the Classic, even an optimized panel created from 23 million calculations of the NRR (HEF) failed to match the V-51R published data. Many protectors sold in the United States have published NRR values that are irreproducible due to the selection of the test panels on the basis of exceedingly high REATs and extremely small standard deviations. In fact, of protectors tested by Franks et al. (2000), labeled data were reproducible for only one earplug.

Both OSHA (1999) and NIOSH (1998) have recognized that the NRR(SF), when provided by the manufacturers, will provide sufficiently better predictions to the point of being able to scrap the derating schemes currently in place for the NRR. However, manufacturers in the United States have been reluctant to publish such data in the absence of revision of the U.S. EPA's Hearing Protector Labeling regulation.

**"Linear" Hearing Protectors:**

The mass of an earmuff cap or an earplug, the tightness of the seal, and the residual air trapped under the hearing protector determine the characteristics of the attenuation, with the mass being the dominating factor. Thus, earmuffs and earplugs tend to have much less attenuation in the low frequencies than in the high. Consequently, signal levels are not only reduced overall by the hearing protectors, they are also muffled in the sense that the high frequencies are attenuated more than the low. The auditory perception is similar to listening to a speech or music reproduction system with the treble turned completely down, the bass turned completely up, and the volume turned down. The effect on speech is to reduce its intelligibility.

In the past few years, several manufacturers have introduced earmuffs or earplugs specifically designed to have a "linear" attenuation characteristic, with the term "linear" applying to the fact that the attenuation is similar across the frequency spectrum, akin to the LINEAR setting on a sound level meter. In these cases, the earmuff shell or earplug body is modified to incorporate a resonating chamber and resistive load of the sound channel. The mass of the earmuff cap or earplug is of less importance in determining the attenuation than is the resistive load and the system resonance frequency. Figure 4 displays the typical attenuation characteristics of a standard mass-dominated device versus a resonant/resistive device. Figure 5 shows an earmuff and earplug embodiment of the concept.

While these hearing protectors provide less overall attenuation, users report that they feel less disconnected from their environment and

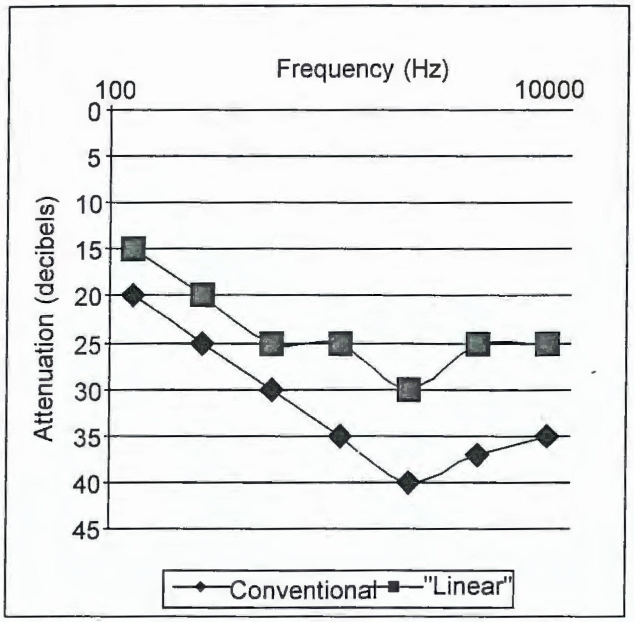


**Figure 4. Attenuation characteristics of conventional and "linear" hearing protectors.**

**Figure 5. Example of "linear" earmuff (courtesy Dalloz) and "linear" earplug (courtesy Aearo Corporation).**

can hear the sounds and speech associated with their jobs. Also, since, at least for the earplugs, the occlusion effect is reduced, the one's voice sounds less muffled than when wearing conventional earplugs. There have been few studies published to date to quantify these anecdotal reports (Stokes et al., 1991).

### Overpressures:

Accompanying blasts are overpressures. An overpressure is an instantaneous increase in static air pressure above ambient barometric pressure that results in sufficient displacement of air molecules that they are not able to return to their normal resting position. Sound typically results from the movement of air molecules around a resting place as opposed to wind which results in linear displacement of air molecules. Overpressure is a special case. It is the overpressure that can cause acoustic trauma as well as damage middle ear structures. Overpressures occur with weapons fire and, in general, the larger the bore of the weapon, the greater the overpressure amplitude and duration.

The Sonic Ear Valve (www.northsafety.com/pluguse.htm) has purported for years to close a physical valve over a hole in a metal diaphragm that occludes a hole in the earplug and otherwise provide no attenuation at all. Critiques have claimed that the physics of the valve are such that the valve could not be closed by the

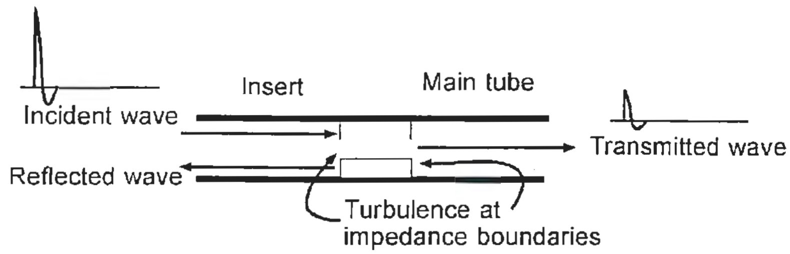


**Figure 6. Sketch of effect of small bore tube inserted into larger bore tube on incident overpressure.**

**Figure 7. The Michael and Associates FitCheck system.**

overpressure quickly enough to prevent hearing damage, if it were to close at all.

Recently, Hamery and Dancer(1999) reported on modification of the "linear" earplug shown in Figure 5 that replaces the resistive load with a plug having a hole with a smaller bore than the earplug bore. The decrease in bore diameter creates an impedance boundary that causes reflection back up the bore, creating turbulence and effectively reducing the overpressure amplitude on the medial side of the bore. Figure 6 displays a sketch detailing the process. Hamery and Dancer (1999) reported that soldiers using these earplugs were free from temporary threshold shift following weapons fire while able to experience the benefits of a low-attenuation "linear" earplug in terms of environmental awareness and speech understanding.

### Fit Testing:

As early as 1980, Fleming reported testing protection received by workers as they normally used their earplugs protectors by testing ears-open and ears-occluded hearing thresholds for narrow-band noise by using speakers mounted in large circumaural earmuffs. The unit he used was not commercially viable, but was used by other researchers (Edwards et al.,1978). Recently Michael and Associates have introduced a modern version of the system that may be used with a desktop or laptop computer. Instead of the rack of equipment with manual control of signal selection, the FitCheck system plays .wav file recordings of pulsed narrow-band noises to the headphones through a recording attenuator that is read by the computer through the serial port. The software records the responses of the listener in a self-recording audiometry task and calculates the real-ear attenuation at threshold. Figure 7 displays the FitCheck system.

Franks et al., (in press) tested the FitCheck system in its supplied circumaural headphone as well as in a sound-field set up in a small audiometric test room. FitCheck REATs for both configurations were compared to ANSI S12.6 sound-field REATs for each subject wearing the same earplug with the same insertion. The data,

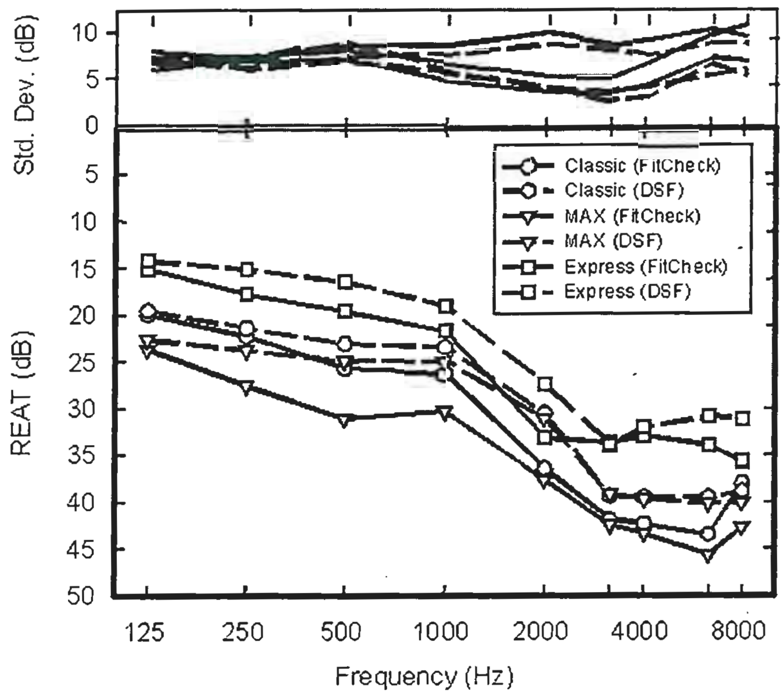


**Figure 8. FitCheck REATs and standard deviations compared to ANSI S12.6 Method B sound-field REATs for three earplugs.**

shown in Figure 8, indicate that the headphone implementation of the FitCheck system over-estimates REAT increasingly so with increasing attenuation of the test earplug. The extent to which this over-estimation has implications for use with individual workers is not known, but it may be necessary for a database to be established of expected FitCheck values for each earplug to be tested.

## Summary:

The key changes in the last five years for passive hearing protection devices have been:

* Development of laboratory test methods that are more predictive of real-world outcomes experienced by workers
* Development of "linear" devices that provided improved hearing for speech, work, and environmental sounds while providing adequate attenuation
* Development of devices for protection from blast overpressures
* Development of a commercial system for fit testing of earplugs


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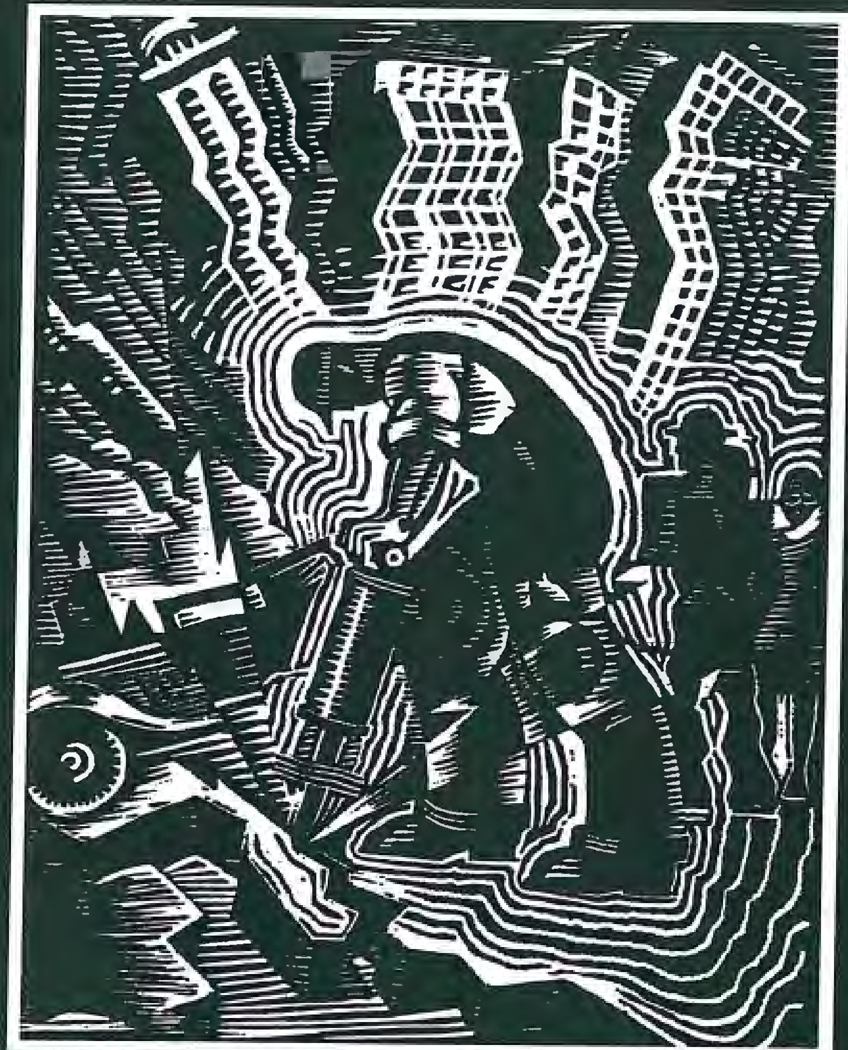

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