September 17, 1988

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

before the

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of

PUBLIC SERVICE COMPANY OF
NEW HAMPSHIRE, et al.

(Seabrook Station, Units 1 and 2)

Docket Nos. 50-443-OL-1
50-444-OL-1
(On-Site Emergency
Planning and Safety
Issues)

AFFIDAVIT OF ERIC STUSNICK

I, Eric Stusnick, being on oath, depose and say as follows:

1. I am the Manager of Arlington Operations of Wyle Research, a division of Wyle Laboratories, El Segundo, California. I have participated in designing or evaluating the siren alert systems for approximately nine nuclear power plants including Seabrook Station. A statement of my professional qualifications is attached hereto and marked "A".

2. This affidavit addresses the allegations in Contention Basis A.1, which states in pertinent part:

> "The VANS and the New Hampshire fixed sirens because of their locations, height, acoustic range and number, do

> not provide tone . . . coverage for essentially 100 percent of the population in the Massachusetts plume exposure pathway EPZ at the sound pressure levels required in NUREG-0654 and FEMA-REP-10."

3. The objective of the Seabrook Station Public Alert and Notification System is to provide coverage to essentially 100 percent of the population within the Seabrook Station EPZ in accordance with 10 CFR 50, Appendix E and the guidance in FEMA-REP-10 and Appendix 3 of NUREG-0654/FEMA-REP-1, Revision 1. FEMA-REP-10 presents, on page E-8, the acceptance criteria for those geographical areas covered by sirens positioned at fixed locations as:

> "The expected siren sound pressure level generally exceeds 70 dBC where the population exceeds 2,000 persons per square mile and 60 dBC in other inhabited areas; or
>
> The expected siren sound pressure level generally exceeds the average measured summer daytime ambient sound pressure levels by 10dB (geographical areas with less than 2,000 persons per square mile)."

4. Public alerting within the Massachusetts portion of the Seabrook Station plume exposure pathway EPZ (hereinafter referred to as the "Massachusetts EPZ") will be accomplished through the activation of the VANS sirens positioned throughout the Massachusetts EPZ. The VANS acoustic coverage meets or exceeds the regulatory guidelines quoted in paragraph 3 above. Figure 2-2 of the Seabrook Station FEMA-REP-10 Design Report depicts the alert system coverage for the Massachusetts EPZ [copy of Figure 2-2 attached and marked "B"].

5. As discussed in the FEMA-REP-10 Design Report for Seabrook Station in Section E.6.2.1.d [copy attached and marked "C"] the sound level coverage for each siren in the alerting system was determined by means of a computer model developed by Wyle Laboratories. Figure 2-2 of the FEMA-REP-10 Design Report depicts 60 dBC and 70 dBC sound level contours calculated by the model and then graphically combined into envelopes depicting the total system coverage.

6. Appendix B to the FEMA-REP-10 Design Report contains a Wyle Research Report, WR 88-9, "Siren Ranging Model" dated April, 1988 [copy of WR 88-9 attached and marked "D"] which describes the computerized siren ranging model for use in designing public alert and notification systems for nuclear power plants.

7. As provided in Wyle's report WR 88-9 in Section 4.1 and as documented in Wyle Research Test Report WR 88-4 [copy of test report attached and marked "E"], the acoustic output of the dual siren model employed in VANS was determined by direct measurement [i.e., field measurement as permitted by FEMA-REP-10, paragraph E.6.2.1, page E-8, copy attached and marked "F"] of the C-weighted sound level at a distance of 100 feet on the siren's axis. The acoustic output of a dual siren was measured to be 134 dBC at the tone frequency of 550 Hz.

8. The siren input parameters for the computer model calculations discussed in paragraph 5 above reflected the

dual measured output of 134 dBC at 100 feet from the siren and siren activation at a height of 45 feet above ground level. Since there is a possibility that some VANS sirens may be activated at a height of 25 feet, during the process of being elevated to maximum height, the computer model was also used to calculate the sound level coverage for each VANS siren location at that lower height. An analysis of the calculated 70 dBC and 60 dBC contours for both activation heights for each VANS location indicates that, on the average, the sound levels at the predicted contours would vary by less than one dB for activation at the lower height and would return to the full predicted level within one minute as the siren was raised to full height.

9. Although a height of 45 feet for siren activation was used as the basis for the sound coverage analysis, the actual siren height achieved by the VANS vehicle is approximately 51 feet. This additional six feet of siren height will result in greater coverage than that calculated for a siren height of 45 feet because the sound will encounter lower barriers along the projected path.

10. I have also performed calculations to estimate the sensitivity of predicted sound level coverages to changes in acoustic location. My calculations indicate that generally, if a VANS vehicle is parked within 100 feet of the assigned acoustic location the calculated 60 dBC contour will vary by less than one dB.

11. From a review of the information provided on Figure 2-2 of the FEMA-REP-10 Design Report for Seabrook Station it can be seen that all the geographical areas within the Massachusetts EPZ where the population density exceeds 2,000 persons per square mile will be subjected to a sound level of at least 70 dBC. With the exception of four small areas discussed separately below, the remaining area of the Massachusetts EPZ is covered by a sound level of at least 60 dBC.

12. As depicted on Figure 2-2 of the Design Report, four small geographical areas in the Massachusetts EPZ are not subjected to at least 60 dBC of siren coverage. An ambient noise survey was conducted in each of these four areas to determine the ambient background noise levels for an average summer day. This survey is described in Wyle Test Report TR 88-11 [copy attached and marked "G"].

13. The four areas are briefly described below.

Parker River National Wildlife Refuge, Newbury

This area of approximately 350 feet length along Plum Island Road at the Newbury/Rowley corporate boundary is located approximately 9.8 miles south-southwest of Seabrook Station and comprises an area of approximately 0.08 square miles.

South Face of Crane Neck Hill in West Newbury

This area is located approximately 11 miles southwest of Seabrook Station, comprises an area of approximately 0.32

square miles, and is bounded on the north by Crane Neck Hill, on the south by the EPZ boundary, on the east by a dirt road, and on the west by Georgetown Road.

West Newbury, West of Route 113 and South of Pleasant Street

This area, located approximately 11.2 miles southwest of Seabrook Station, comprises an area of approximately 0.10 square miles. The area lies to the south of Pleasant Street in West Newbury, on the west side of a hill north of Pentucket Regional Junior High School, and extends to the Merrimack River. A small, noncontiguous area approximately 600 feet southeast of Route 113 is also part of this area.

Parish Road, Newbury

This area is a small triangle to the east of Interstate 95 located approximately 11 miles from Seabrook Station, and comprises an area of approximately 0.02 square miles. The area is bounded on the west by Larkin Street and on the south by the EPZ boundary.

14. The ambient noise surveys, described in Wyle Test Report TR 88-11, were conducted on July 17 through July 23, 1988. The purpose of the surveys was to determine the average summer daytime (7:00 a.m. to 10:00 p.m.) ambient background noise level for each area in the 500 Hz one-third octave band containing the dominant siren frequency of 550 Hz. This is in accordance with the ASLB Memorandum and Order (Denying Massachusetts' Motion of March 3, 1987), page 15, March 25, 1987. The noise level exceeded 50 percent of the

time, i.e., L_{50}, was used to represent the average ambient background noise level. The L_{50} level is more conservative (i.e., results in higher ambient sound levels) than the commonly used L_{90} level, i.e., the noise level exceeded 90 percent of the time.

15. For each of these four areas, a measurement site was selected where the highest ambient noise level in each area was expected, referred to as the primary site. Additional measurement sites were chosen in each area to provide an estimate of the spatial variation of ambient levels in the area, referred to as secondary sites.

16. Data were recorded at each primary site during the entire daytime period (i.e., 7:00 a.m. to 10:00 p.m.). Sample measurements over a short period of time were taken at the secondary sites. At the primary sites both continuous A-weighted L_{50} measurements and measurements of the 500 Hz one-third octave band were obtained. At the secondary sites, A-weighted measurements were obtained. A correction factor was developed (i.e., A-weighted to 500 Hz one-third octave band) based on the two sets of measurements at the primary site. This correction was then applied to the A-weighted measurements at the secondary sites to obtain 500 Hz one-third octave band values.

17. As provided in paragraph 3 above, the average measured summer daytime ambient sound pressure levels should be compared with the "expected siren sound pressure level."

The expected siren sound pressure levels for these areas were determined by means of the computer analysis (discussed in paragraphs 5 - 8 above) for each siren location which could produce sound levels in these areas. The lowest sound level from the siren predominantly influencing the area was used as the expected siren level for that area.

18. The following tabulates the highest average daytime ambient noise level recorded from either the primary or secondary sites, the lowest expected siren level and the resultant difference for each area.

Area	Average Ambient (L_{50}) Level in 500Hz One-Third Octave Band, dB	Expected Siren Level, dBC	Difference, d3
Parker River	39	58	19
Crane Neck Hill	32	56	24
West Newbury	39	56	17
Parish Road	43	59	16

19. Based on the results of this survey, the expected siren sound level for each area will be greater than 10 dB above the average ambient background level.

20. In summation, based on the foregoing, the following factual conclusions can be reached regarding the siren system within those portions of the EPZ in Massachusetts:

(a) Those geographical areas within the Massachusetts EPZ where the population density exceeds 2,000 persons per square mile will be subjected to sound levels of at least 70 dBC;

(b) Except for four small areas, the remaining area is covered by sound levels of at least 60 dBC;

(c) These four small areas, whose population density is less than 2,000 persons per square mile, will be subjected to sound levels which exceed the average measured summer daytime ambient sound levels by at least 10 dBC;

(d) The sound coverage provided by the VANS sirens meets or exceeds the sound coverage guidelines provided in FEMA-REP-10, Appendix 3.

Eric Stusnick

Eric Stusnick

COMMONWEALTH OF VIRGINIA

Arlington County, ss. September 15, 1988

The above-subscribed Eric Stusnick appeared before me and made oath that he had read the foregoing affidavit and that the statements set forth therein are true to the best of his knowledge.

Before me,

Ronald E. Willi

Notary Public
My Commission Expires:

My Commission Expires November 18, 1991

ERIC STUSNICK

POSITION: Manager, Arlington Operations

JOINED WYLE: 1977

PRINCIPAL DUTIES AND RESPONSIBILITIES:

Management of research and consulting staff in Arlington office. Management of experimental and theoretical programs in transportation and environmental noise, and underwater acoustics.

BACKGROUND:

Wyle Laboratories, Arlington, VA – Program management and applied physics support for studies in acoustic signal analysis and sound and vibration measurement and control. Project manager for the design of soundproofing modifications for home in the vicinity of commercial airports; the development of statistical energ analysis software for estimating sound and vibration levels in the space station; an experimental study of the detectability in locomotive cabs of railroad track torpedo detonations; and the measurement and control of low-level floor vibrations in a semiconductor manufacturing facility. Principal investigator for the development of computerized underwater acoustic intensity measurement systems; an analytic study of short-range acoustic propagation in a turbulent atmosphere near the ground; and the design of emergency community alerting systems for nuclear power generating facilities. Principal author of a handbook for the measurement, analysis, and abatement of railroad noise.

Calspan Corporation, Buffalo, NY (5 years) – Senior Physicist. Provided physics support and program management in signal analysis, acoustics, and ballistic missile defense.

EDUCATION:

B.S., Physics, Carnegie Institute of Technology, 1960.
M.S., Physics, New York University, 1962.
Ph.D., Physics, State University of New York at Buffalo, 1971.

CERTIFICATION:

Professional Engineer, State of New York, 1976
Member, Institute of Noise Control Engineering

PROFESSIONAL MEMBERSHIPS:

Acoustical Society of America
American Physical Society
American Association for the Advancement of Science
The Society of the Sigma Xi

PUBLICATIONS:

Forty-eight technical reports or publications.

WYLE
LABORATORIES

E.6.2.1.d Siren Range Calculations

The sound level coverage (tone) for each siren in the alerting system was determined utilizing a computer model developed by Wyle Laboratories. This model determines the range of specified siren signal levels based on attenuations along the siren signal path. Field measurements have been made and the measured siren sound levels have been compared with those predicted by the model. This comparison illustrates that the predicted levels are conservative and are, thus, appropriate for the system design.

The 60 dBC and 70 dBC siren tone coverage for the siren alerting system is shown on Figures 2-1 and 2-2 as sound level contours. To develop these contours, the model calculates the contours for each siren. The 60 dBC and 70 dBC contours for all sirens are then graphically combined into envelopes depicting the total system coverage.

The range for voice alerting messages broadcast by the sirens was based on speech intelligibility tests on the sirens employed in the system. This intelligibility test data was then used in conjunction with the sound propagation model to predict the voice alerting range for each siren.

Appendix B contains Wyle Research Report 88-9 which presents the siren ranging calculation procedures utilized in the system design.

E.6.2.1.e Maintenance of Siren System

A regularly scheduled, preventive maintenance program will be initiated for the sirens and VANS vehicles in the system. Maintenance will also be performed if any of the regularly scheduled tests (see Section E.6.2.1.f) indicate malfunctions. In addition, repairs will be made if it is known that something has happened to disable one of the sirens or VANS vehicles (vandalism, lightning strikes, accidents, etc.).

Stusnick Attachme D, 1 of 30

WYLE RESEARCH REPORT
WR 88-9
SIREN RANGING MODEL

WYLE RESEARCH

REPORT

WYLE
LABORATORIES
SCIENTIFIC SERVICES
& SYSTEMS
GROUP

WYLE
LABORATORIES SCIENTIFIC SERVICES & SYSTEMS GROUP

WYLE RESEARCH REPORT
WR 88-9
SIREN RANGING MODEL

Prepared For:

PUBLIC SERVICE OF NEW HAMPSHIRE
U.S. Route 1, Lafayette Road
Seabrook, New Hampshire 03874

Purchase Order No. 58619-05

Prepared By:

WYLE RESEARCH
2001 Jefferson Davis Highway
Arlington, Virginia 22202

April 1988

REPORT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

This report describes the computerized siren ranging model which has been developed by Wyle Laboratories for use in designing public alert and notification systems for nuclear power plants.

The model is capable of taking into account acoustic energy losses due to spherical spreading of the wavefront, air absorption, scattering by turbulence, excess ground attenuation, barrier attenuation, and wind and temperature effects. In order to account for barrier attenuation, the model relies on digital ground elevation data obtained from the National Cartographic Information Center of the United States Department of the Interior.

This data is processed on a mainframe computer system to provide estimates of siren sound level as a function of distance along a sequence of equally spaced radials originating at each siren. The resultant sound levels are transferred to a microcomputer on which 60 and 70 dB contours are computed, scaled, and plotted. The plots for each siren in the system are then transferred to a base map.

The model is exercised in an iterative fashion with the location, height, power level, and frequency of each siren being continually adjusted until acceptable coverage is obtained in all portions of the Emergency Planning Zone.

As will be seen in the discussion to follow, the design of the model and the choice of values for input parameters are such that the siren sound levels are generally under-predicted. This was done by conscious decision since some of the algorithms used in the model are, of necessity, engineering approximations. By using reasonable conservatism in the choice of algorithms and input parameters, a buffer is automatically built into the model to correct for any adverse effects of such approximations.

This report consists of five sections. Section 1, this Introduction, summarizes the report, Section 2 describes the mathematical algorithms used to model the various mechanisms by which sound level decreases with distance from the siren. Section 3 outlines the computer implementation of these algorithms. Section 4 describes the choice of input parameters for the Seabrook system. Section 5 presents a validation of the model based on siren sound level measurements made at Seabrook and other nuclear power plants.

2.0 MATHEMATICAL MODELS

This section describes the series of mathematical models which have been developed to predict the attenuation that occurs as sound propagates from a siren to a receiver.

The sound level, $L(R)$, at a distance R from the siren can be expressed as:

$$L(R) = L_o + A_{spread} + A_{abs} + A_{scatt} + A_{grnd} + A_{barr} + A_{temp} + A_{wind} \qquad (2\text{-}1)$$

where L_o is the source sound pressure level on the siren's axis at a predefined reference distance of 100 feet,

A_{spread} is the attenuation that occurs due to the spherical spreading of the sound,

A_{abs} is the attenuation that occurs due to absorption of acoustic energy by the air,

A_{scatt} is the attenuation that occurs due to scattering of acoustic energy out of the directional beam of a rotating siren by atmospheric turbulence,

A_{grnd} is the attenuation that occurs due to absorption of acoustic energy at the ground surface as the sound wave propagates in a nearly horizontal path,

A_{barr} is the attenuation that occurs as a result of the reflection and diffraction of acoustic energy by barriers formed by hills between the source and receiver,

A_{temp} is the attenuation (or amplification) that occurs as a result of refraction by the temperature gradient that exists near the surface of the ground, and

A_{wind} is the attenuation (or amplification) that occurs as a result of refraction by the wind speed gradient that exists near the surface of the ground with a wind present.

In general, each of the attenuation terms is a negative number so that the siren sound level diminishes as the distance from the siren increases. In certain cases, however, some of the attenuation terms can have positive values, indicating sound amplification.

The following sections briefly describe the models that were used to estimate the value of each of the attenuation terms in Equation (2-1).

2.1 Spherical Spreading

At any given distance, R, from a point sound source close to the ground, the total acoustic power output of the source is spread over a hemispherical surface having an area proportional to R^2. Thus the sound energy per unit area reaching the receiver decreases with distance at a rate proportional to $1/R^2$. This so-called spherical spreading effect causes an attenuation between one distance R_o and a second distance R of:

$$A_{spread} = -10 \log_{10} \left(R^2/R_o^2\right) \qquad (2\text{-}2)$$

It is this effect that produces the well-known 6 dB per doubling of distance attenuation as one travels away from a point source.

2.2 Air Absorption

In a still, uniform atmosphere, sound waves lose energy as they pass through the air due to minute heating and viscous effects (classical losses) and due to molecular energy exchange processes (molecular losses) which are influenced by the amount of moisture in the air. An ANSI standard,[1] well supported by experimental data,[2] is available which makes predictions of this form of sound attenuation relatively straightforward. The loss is defined in terms of a frequency- and weather-dependent atmospheric absorption coefficient in dB per 1,000 feet. The model requires that temperature, relative humidity, and atmospheric pressure be defined.[1] (Atmospheric pressure has only a minor effect on atmospheric absorption, and a standard sea level atmospheric pressure is generally assumed without any loss in accuracy.)

For example, based on the extrema of the seasonal average values of the temperature and relative humidity for the Seabrook area, as discussed in Section 4.2, below, a 0.99 dB/1,000 ft air absorption coefficient results for a single-tone siren frequency of 550 Hz.

2.3 Scattering Attenuation

Scattering of sound waves occurs in turbulent air and can result in an additional propagation loss for a very directional source such as a rotating siren.[3] Measurements of scattering attenuation in horizontal propagation are severely limited. The available data have been obtained under uncontrolled experimental conditions making it difficult to separate out any scattering attenuation from other effects.[3] Furthermore, no evaluation of the effects of directivity of the source appears to have been considered. There is, however, one unique set of data which has provided direct and rather convincing evidence of scattering attenuation of low-frequency sound over a long horizontal path.[4]

The data were obtained from measurements made over a path length of 50,000 feet of the directional sound field radiated by two nominally identical rocket test stands located back to back with the exhaust and resultant directional sound fields from each stand oriented 180 degrees apart. The propagation loss over the same path from the two separate rocket engine sound sources, fired one right after the other, was not the same for the two tests. The difference in propagation loss was an apparent additional excess attenuation for the source whose primary directional sound field was oriented along the measurement path. This phenomena could only be explained as scattering attenuation, and an analysis of the data produced the estimates of scattering loss coefficients as a function of frequency shown in Figure 2-1 by the circle data points. Estimates of scattering attenuation are also plotted for comparison and show at least an order of magnitude agreement with the indicated data points.[2,5]

For example, for a 550 Hz tone, an additional propagation loss of 0.20 dB/1,000 ft must be included for directional sirens to account for scattering attenuation of the directional beam.

2.4 Excess Ground Attenuation

When sound waves travel from a source to a receiver over a ground surface, two different ray paths are possible – the first directly from the source to the receiver, the second by reflection from the ground surface. These two waves interact to produce either attenuation or amplification. The exact nature of the interaction is a complex function of the source and receiver heights, the source-to-receiver distance, and the impedance properties of the ground surface.

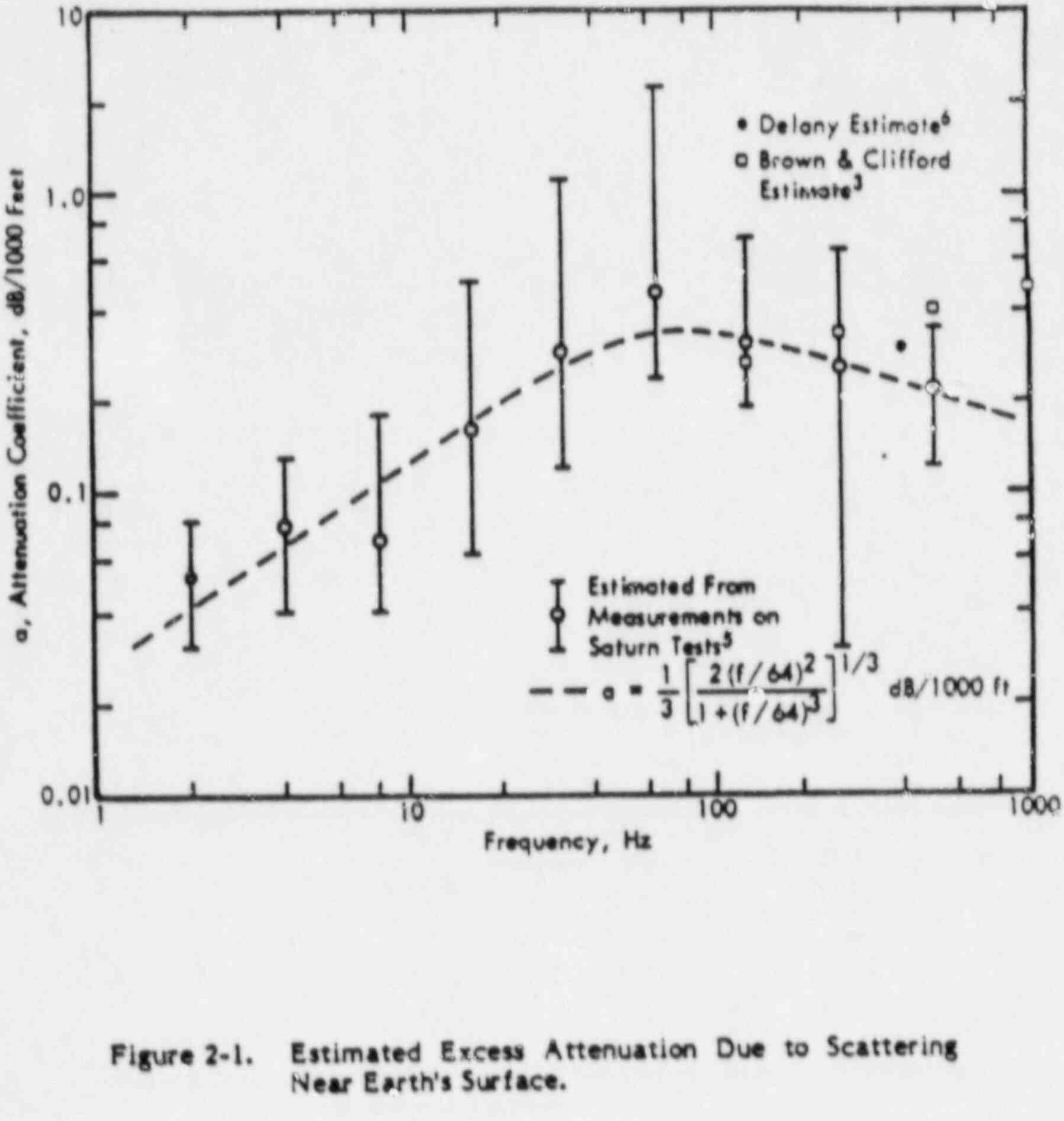


Figure 2-1. Estimated Excess Attenuation Due to Scattering Near Earth's Surface.

In addition, when considering long-range propagation of sound, shielding and scattering by small buildings and other small surface irregularities can be considered as an additional distance-dependent attenuation factor.

Because the exact nature of ground surface properties and irregularities cannot be determined a priori, estimates of such ground attenuation terms can only be made by modeling phenomenological data. Four general types of ground cover are included in the model: rural/suburban, urban, heavily forested, and water.

2.4.1 Rural/Suburban Areas

Figure 2-2 shows excess ground attenuation as a function of distance for several rural and suburban areas. This figure is based on published data from which spherical spreading and air attenuation factors have been removed.[6] The best-fit design curve to this data, as shown in Figure 2-2, has the form:

$$A_{grnd} = -13 \log_{10}(R/100) \text{ dB}, \quad R < 1700 \text{ ft} \tag{2-3}$$
$$= -16 \text{ dB}, \quad R \geq 1700 \text{ ft}$$

2.4.2 Urban Areas

Due to shielding by buildings, an additional excess attenuation, over and above that defined above, must be included when predicting siren ranges in urban areas where the siren is mounted below rooftops. Sound propagation data for this condition is quite meager, but Reference 6 has provided a reasonable summary of the limited information which can be used to predict total excess attenuation for such areas.

The average additional increment in excess attenuation over what is necessary for rural and suburban areas (see Figure 25 in Reference 6) is used here as the basis for predicting this added excess attenuation. (The amount of this additional excess attenuation due to shielding by buildings is also roughly consistent with more recent studies on sound propagation in urban areas.[7]) The resulting line for the total excess attenuation in such areas is shown in Figure 2-2 by the light dashed line. A simplification of this trend is in the model so as to remove anomalous peaks in the predicted values of excess attenuation between 500 and 3,500 feet. The resulting design curve, shown by the

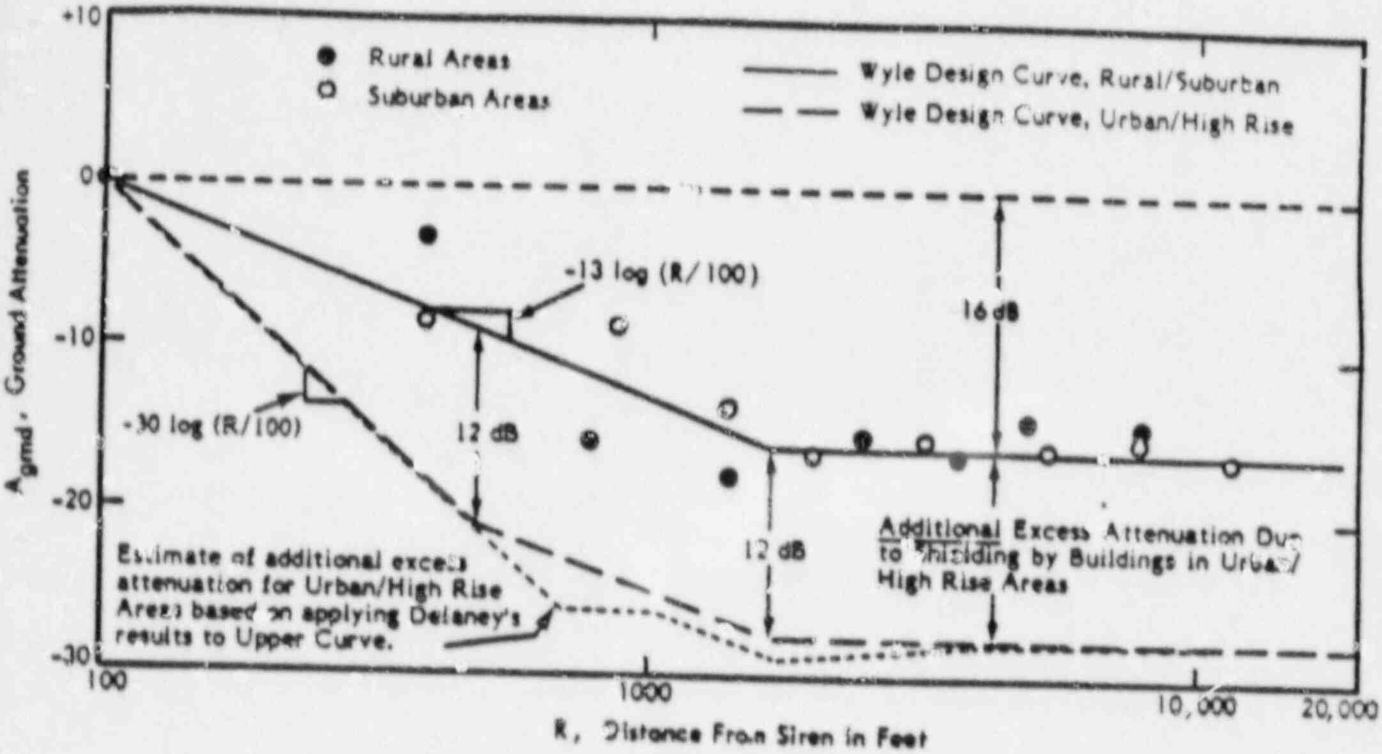


Figure 2-2. Empirical Estimates of Excess (Ground) Attenuation in Rural/Suburban Areas (Source Above Rooftops) and the Additional Excess Attenuation Due to Shielding in Urban/High Rise Areas (Source Below Rooftops). (Based on Data From Delaney, Reference 6.)

heavy dashed line in Figure 2-2, is exactly 12 dB greater than the upper curve for rural, suburban areas at distances greater than 500 feet, decreasing to an added increment of zero at 100 feet.

In summary, for sirens in urban areas which are mounted below rooftops, the total attenuation in excess of spherical spreading and air absorption is defined by:

$$A_{grnd} = \begin{cases} -30 \log (R/100) & , \text{ dB} \quad R < 500 \text{ ft} \\ -13 \log (R/100) - 12 & , \text{ dB} \quad 500 \leq R \leq 1{,}700 \text{ ft} \\ -28 \text{ dB} & , \quad R > 1{,}700 \text{ ft} \end{cases} \qquad (2\text{-}4)$$

2.4.3 Heavily Forested Areas

To investigate the magnitude of sound attenuation through heavily forested areas, a series of sound level measurements have been made, the results of which are plotted in Figure 2-3. Spherical spreading and air absorption effects have been removed so that the attenuations represent only the ground effect. The measurement sites included in the figure are in relatively flat areas, so that no barrier effects are present.

Although the amount of data at distances greater than 1,700 feet is sparse, there is indication that the 16 dB attenuation cutoff that appears in Equation (2-3) does not occur. Thus, for heavily forested areas, the ground attenuation used in the model is:

$$A_{grnd} = -13 \log_{10} (R/100) \text{ dB} \qquad (2\text{-}5)$$

Other data show the same increase in ground attenuation with distance up to about 1,500 feet, at which point the spread in the data becomes so great that no further dependence on distance can be reasonably inferred. However, unless local data are available, Wyle has adopted the more conservative attenuation figures as shown in Figure 2-3 for "heavily forested" areas (defined by Equation (2-5)) as representing the worst case for siren ranging studies.

2.4.4 Water Areas

For propagation entirely or mostly over water, there is little or no excess ground attenuation, thus

$$A_{grnd} = 0 \text{ dB} \qquad (2\text{-}6)$$

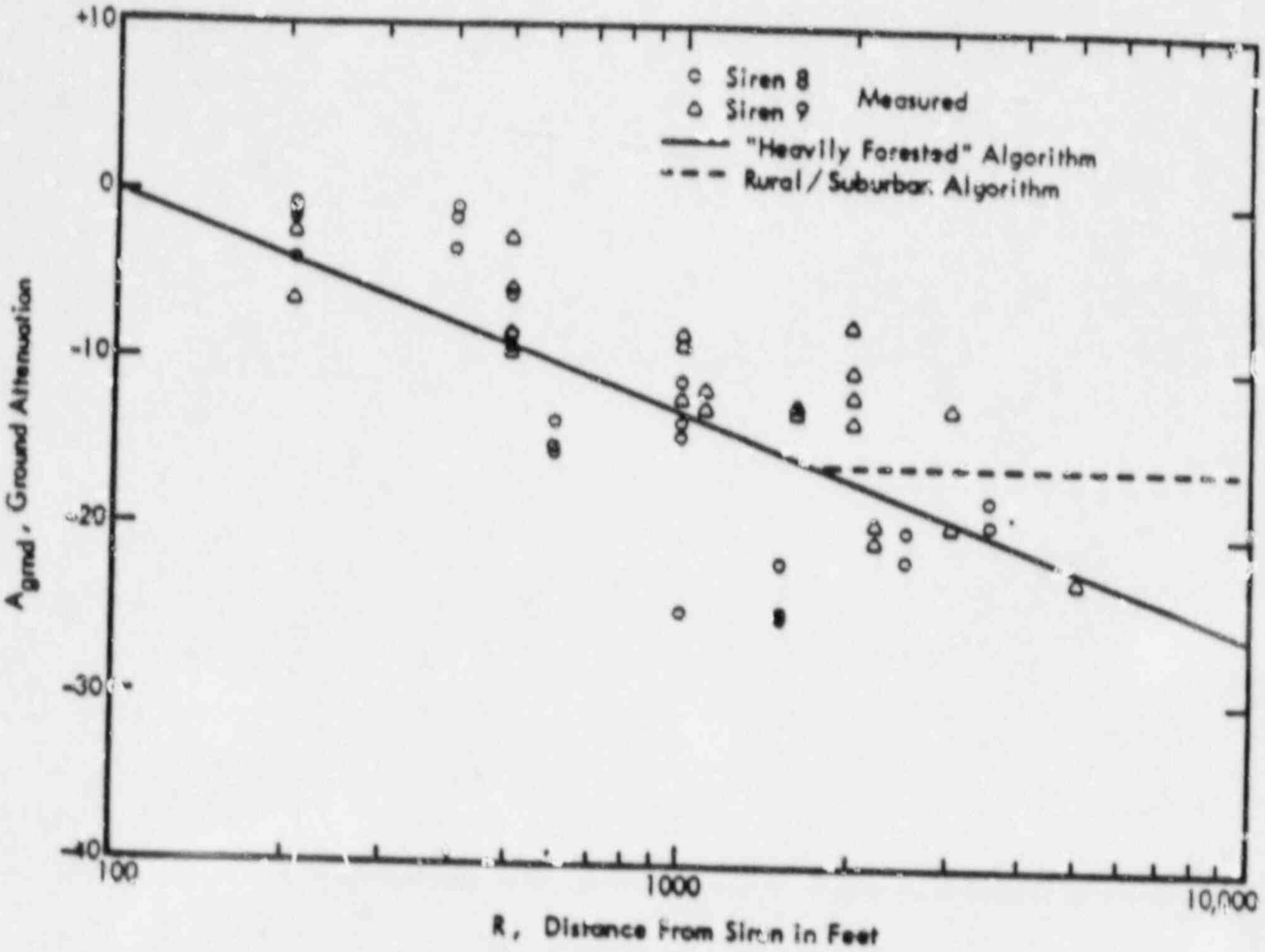


Figure 2-3. Excess (Ground) Attenuation in Heavily Forested Areas.

2.5 Barrier Attenuation

Reflection and diffraction of sound by barriers must be considered when siting sirens in hilly areas to account for the barrier attenuation effects of the hills. Well-developed design methods are available for predicting attenuation by thin barriers which essentially ignore ground reflection effects[8] or which include ground reflection effects on barrier attenuation.[9] Since the sirens in the Seabrook area are installed at least 45 feet above the ground and since the treatment of the hills as thin barriers is an approximation, the refinement of including ground reflection effects on barrier attenuation is not warranted.

Figure 2-4 defines the sound attenuation provided by a thin barrier based on the prediction model defined in Reference 8. This classical Fresnel diffraction model is well supported by experimental data measured under ideal conditions. Note that, although the form of the function in this figure (solid line) is a straight line, the horizontal scale is non-linear, to reflect the fact that barrier attenuation is a non-linear function of Fresnel number.

The barrier attenuation model used in this study, shown as a dashed line in Figure 2-4, employs a least-squares fit to the solid curve in the figure and has the form:

$$A_{barr} = -10 \log_{10} (20 N) \qquad , \quad 12.6 > N > 1.0$$

$$A_{barr} = -5 - \left[\frac{\sqrt{B^2 + 2AN} - B}{A} \right]$$

$$\begin{aligned} A &= 0.03778 \\ B &= -0.02700 \end{aligned} \qquad , \quad 0.3 \leq N \leq 1.0$$

$$A_{barr} = -5 - \left[\frac{C\sqrt{B^2 + 2ACN} - B}{A} \right] \tag{2-7}$$

$$\begin{aligned} A &= 0.02461 \\ B &= 0.00099 \\ C &= +1 \; , \; N \geq 0 \\ &= -1 \; , \; N < 0 \end{aligned} \qquad , \quad -0.3 < N < 0.3$$

$$A_{barr} = 0 \qquad , \quad N \leq -0.3$$

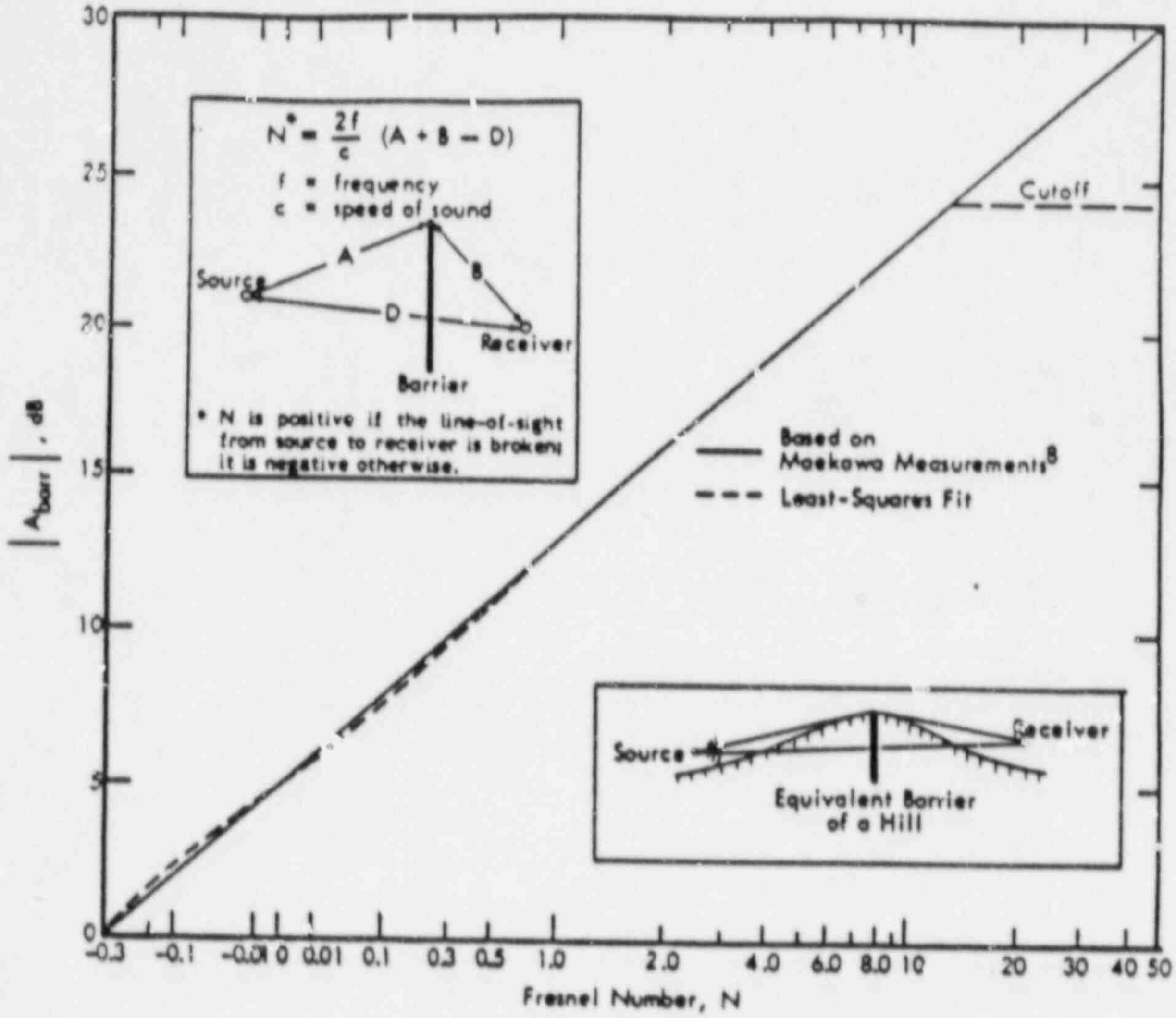


Figure 2-4. Barrier Attenuation as a Function of Fresnel Number.

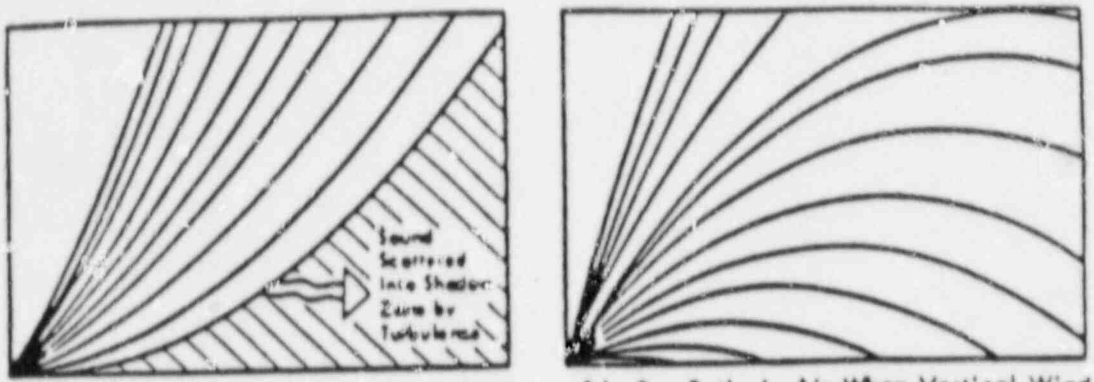
The model represented by this set of equations does not include reduction of ground attenuation due to the presence of the barrier or diffraction over the top of the barrier caused by foliage. The effect of these phenomena is generally approximated by imposing a cutoff on the barrier attenuation term. Highway noise barrier design guidelines usually suggest a cutoff of -12 to -15 dB, based on field measurements from previously constructed highway noise barriers. These measurements do not, however, include data from extremely high barriers, such as hills or mountains, as is found in the case of siren sound propagation. It is thus more conservative to use a cutoff of -24 dB, which is suggested by Beranek for a thin barrier.[10]

To apply this model to hilly terrain, computer software is used to replace the actual ground elevations between the source and receiver with an equivalent thin barrier (see lower inset in Figure 2-4). A sequence of barrier attenuations is computed for all such equivalent barriers located at regular intervals between the source and the receiver. The maximum value of this sequence is taken as the attenuation of the terrain.

The elevation data required for this computation is obtained from planar standard digital terrain data tapes, available from the National Cartographic Information Center, U.S. Geological Survey, Department of the Interior. These data were produced by the Defense Mapping Agency Topographic Center from 1:250,000-scale terrain contour maps of the United States and provide a grid of terrain elevation values at 200-foot intervals.

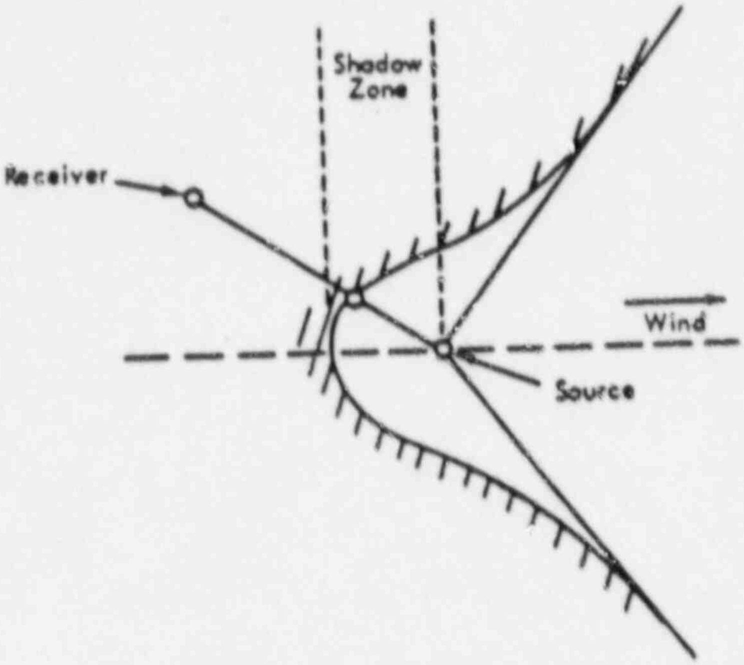
2.6 Attenuation Due to Temperature and Wind Gradients

Change over time in the structure of the vertical temperature and wind profile in the atmosphere produce temporal variations in sound propagation losses. As illustrated in Figure 2-5(a), a negative temperature or wind speed gradient (decreasing with height) causes sound emanating from a source near the ground to bend upwards, resulting in an increase in propagation loss and creation of acoustical shadow zones. On the other hand, as shown in Figure 2-5(b), a positive temperature or wind speed gradient causes sound to bend downward towards the ground. In some cases, with a combined negative and then positive gradient, sound is focused back to the ground at points distant from a receiver resulting in substantial increases in sound level beyond that normally experienced. For vertical gradients in wind velocity, as shown in Figure 2-5(c), a complex shadow zone forms around the source in a pattern dictated by the mean wind vector.[11,12,13] Although wind speed also has an influence on refraction of sound by wind gradients, it is not as important as wind direction.[13,14]



(a) Ray Paths in Air When Vertical Wind Velocity (in the Direction of Sound Propagation) or Temperature Gradient is Negative.

(b) Ray Paths in Air When Vertical Wind Velocity (in the Direction of Sound Propagation) or Temperature Gradient is Positive.



(c) Wind-Generated Shadow Zone.

Figure 2-5. Effects of Temperature and Wind Gradients on Sound Propagation.

Since negative temperature gradients as shown in Figure 2-5(a) are more common than positive temperature gradients (temperature inversions), ground attenuation data generally contain the effects of negative temperature gradients. Since a temperature inversion will only tend to reduce the attenuation (i.e., increase the sound level at a given point), a conservative estimate of the attenuation due to temperature gradients is already included in the A_{grnd} model. Thus the model assigns a zero value to A_{temp}.

This logic cannot be applied to wind speed gradients since the data on which A_{grnd} is based was normally taken during very low wind conditions. However, a conservative estimate of this effect is that a 5 dB increase in sound level downwind of the source and a 5 dB decrease in sound level upwind of the source can be expected, more or less independently of the actual wind speed. Thus the wind attenuation is modeled by:

$$A_{wind} = 5 \cos \phi \qquad (2\text{-}8)$$

where ϕ is the angle between the source-receiver line and the direction the wind is blowing toward.

3.0 COMPUTER IMPLEMENTATION

The mathematical algorithms described in Section 2 have been implemented in two FORTRAN programs which are designed to run on a mainframe computer system. The use of a large-scale computer was necessitated by the quantity and format of the digital terrain data available from the National Cartographic Information Center.

The minimum block of data available encompasses one degree of longitude by one degree of latitude. Since terrain elevation data is provided every 200 feet, such an area, at latitudes within the continental United States, contains in excess of two million data points. This information is provided on 9-track, one-half-inch magnetic tape. Although only a small subset of this data is required for any given siren, the computer system must be capable of inputting the larger amount of data so that the desired subset can be abstracted.

The output provided by the computer software is a series of estimated siren sound levels at regular intervals along a set of equally spaced radials radiating from the siren. One program, which is used for siren ranging estimates to distances of 10,000 feet, produces levels at 200-foot intervals along 16 radials, each separated by 22.5 degrees. The other program, which is used for siren ranging estimates in excess of 10,000 feet, produces levels at 300-foot intervals along 72 radials, each separated by 5 degrees.

In addition to the printed output, these programs provide, in a digital file, the distances along each radial at which the 70 and 60 dB sound levels occur. This file is transferred to a microcomputer in which smoothed 70 and 60 dB sound level contours are computed. A cubic spline fitting procedure is employed to define each contour at points between the calculated radials. The resulting smoothed contours can be plotted using either a digital pen plotter or a dot matrix printer.

Since the digital terrain elevation data sometimes differs somewhat from the elevation data provided on standard USGS 7.5-minute topographic quadrangle maps, which are normally used as the base maps for plotting sound level contours, the resultant contours are overlaid onto these topographic maps and manually examined. Any features of the contours which do not appear to correspond to terrain features on the topographic maps are identified and corrected.

In the absence of barriers, the sound level decreases uniformly with distance from the siren along each radial. When topographic variations result in barriers that shield the receiver from the siren, the sound level will decrease sharply just beyond the barrier, effectively reducing the radius of any given contour point along that radial. An example of the effect of barriers on contour shape is given in Figure 3-1.

If the land should rise again beyond the barrier, it is possible to obtain a "hole" in the contour where the shielding from the siren is localized to a small range of distances along the radial. In such a case, the sound level estimates along the radial in question (and along adjacent radials) are manually examined to determine if the hole should be ignored. In general, the guidelines used in this judgment are:

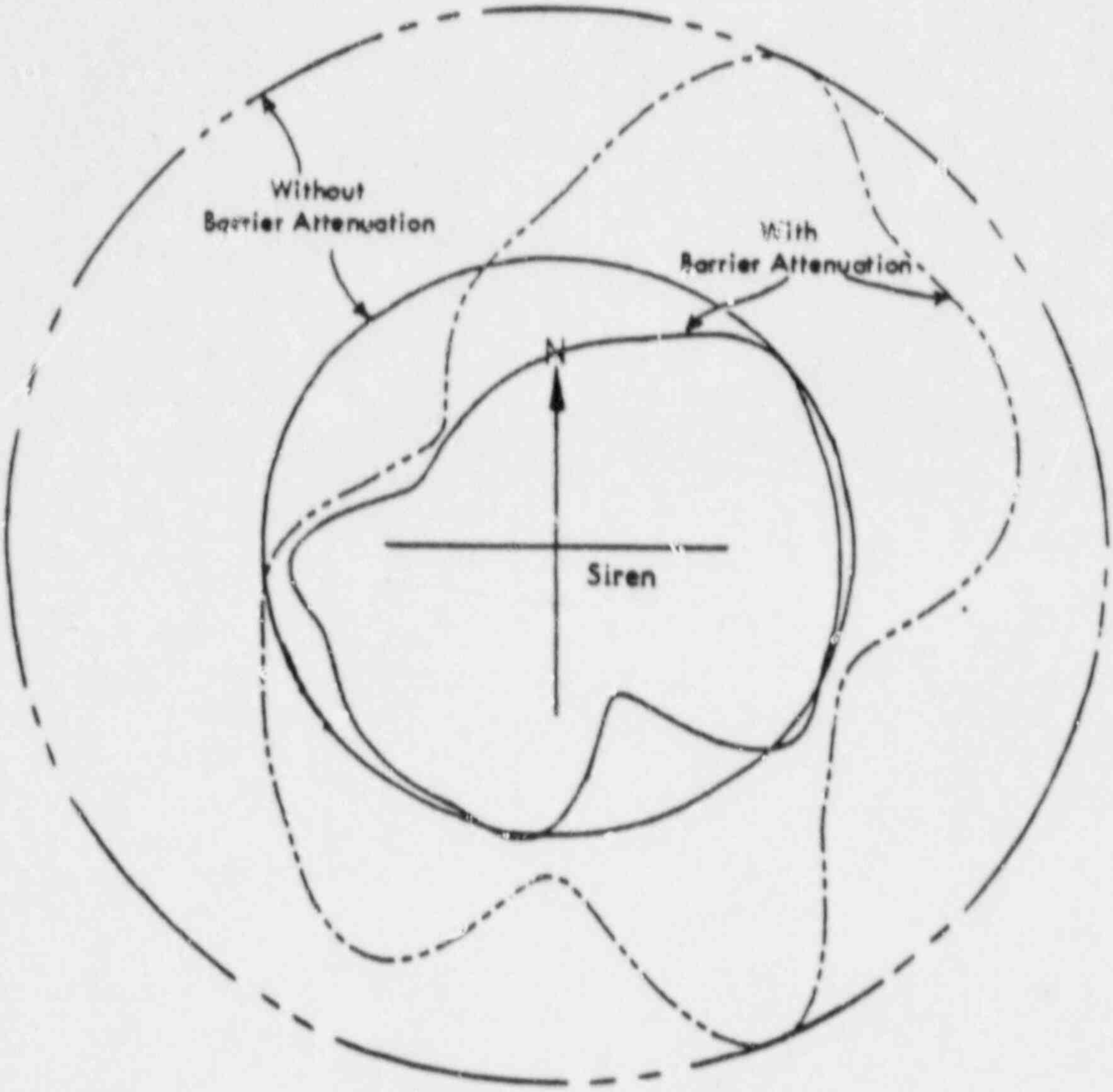
a. If the sound level along any radial drops below the contour for 400 feet or less before rising above the value again, the "hole" is ignored and the contour value is assigned to the greater distance.

b. If the sound level along any radial drops below the contour value for more than 400 feet but less than 1,000 feet before rising above the value again, then:

    - the "hole" is ignored if the population is low, or
    - the contour is pulled in to the distance where the level first drops below the contour value if the population is not low.

c. If the sound level along any radial drops below the contour for more than 1,000 feet before rising above the value again, the contour is pulled in to the distance where the level first drops below the contour value.

This procedure results in a conservative estimate of the sound level contours.



70 dB ————————

60 dB — - - — - -

Figure 3-1. Comparison of Siren Sound Level Contours With and Without the Effects of Barrier Attenuation.

4.0 INPUT PARAMETERS

This section describes the values of the input parameters that have been used in exercising the computerized model for the Seabrook area. These parameters can be organized into two groups:

a. Those relating to individual sirens:

- Location as defined by latitude and longitude,
- Siren height above ground level,
- Acoustic output as defined by the reference sound level 100 feet from the siren on its axis,
- Frequency of the tone emitted by the siren, and
- Characteristics of the ground (e.g., rural/suburban, urban, heavily forested, or water) in the vicinity of the siren;

b. Those relating to area-wide meteorological conditions:

- Temperature,
- Relative humidity, and
- Wind direction.

4.1 Siren Parameters

Each siren location is defined by determining the siren location on a USGS 7.5-minute topographic quadrangle map and interpolating the corresponding latitude and longitude from the map coordinates. The siren coordinates are determined to the nearest second of arc. These two input parameters relate the siren position to the grid of ground elevation values that are used by the model for the barrier attenuation calculations.

The measured or proposed siren height above the ground level is also input into the model. This parameter also impacts the barrier attenuation calculation.

The acoustic output of each of the siren models employed in the Seabrook system has been determined by direct measurement of the C-weighted sound level at a distance of 100 feet on the siren's axis. The values employed in the model are shown in Table 4-1.

Table 4-1

Acoustic Output of Sirens Used in Seabrook System

Siren	C-Weighted Level at 100 Feet on Axis
WS-3000	122 dB
WS-4000	129 dB
Dual WS-4000	134 dB

These measurements were all made at the tone frequency of 550 Hz, which is utilized in the system.

Finally, the ground characteristics assumed for the entire EPZ region are rural/suburban. No areas have sufficiently high structures to be classed as urban. No areas have sufficiently dense foliage to be classed "heavily forested".

4.2 Meteorological Conditions

Attenuation resulting from absorption of acoustic energy by the air is a sensitive function of water content (as defined by relative humidity) and temperature. In order to model the worst-case situation, average seasonal values of early-morning and mid-afternoon humidity/temperature combinations were examined to determine which situation provided the largest air absorption coefficient.

Such historical data are not available for Seabrook directly, but can be interpolated from values at Boston, Massachusetts, and Portland, Maine.[15] Table 4-2 shows the results of this interpolation. Also shown, for the Seabrook area, are calculated values of the air absorption coefficient corresponding to these humidity/temperature pairs. Clearly, the worst case (i.e., largest value of air absorption coefficient) occurs during a summer afternoon. The corresponding values of relative humidity and temperature (58 percent, 21.6°C) were used as input values to the model.

Table 4-2

Average Seasonal Values of Relative Humidity and Temperature in Seabrook Area[15]

Location	Month	7:00 A.M.			1:00 P.M.		
		R.H. (%)	T (°C)	Abs.* (dB/1000 Ft)	R.H. (%)	T (°C)	Abs.* (dB/1000 Ft)
Portland, ME	Jan	78	-11.3	---	63	-5.7	---
	Apr	74	0.2	---	55	5.8	---
	Jul	80	13.7	---	59	20.1	---
	Oct	85	3.0	---	60	9.2	---
Seabrook NH (Interpolated)	Jan	72	-8.2	0.69	60	-3.4	0.65
	Apr	71	2.3	0.53	54	7.3	0.61
	Jul	77	16.2	0.85	58	21.6	0.99
	Oct	81	5.7	0.58	55	11.0	0.68
Boston, MA	Jan	66	-5.0	---	57	-1.2	---
	Apr	68	4.4	---	54	8.8	---
	Jul	74	18.6	---	56	23.2	---
	Oct	77	8.4	---	57	12.8	---

* Air Absorption Coefficient at 550 Hz as computed according to Reference 1.

As discussed in Section 2.6, the effect of the presence of wind speed gradients is to improve propagation downwind and impede propagation upwind. Thus attenuation in the direction the wind is blowing is decreased; attenuation opposite to that direction is increased; and attenuation at right angles to the wind direction is unaffected from the no-wind case. The net effect is to distort the equal sound level contours, elongating them in the downwind direction and foreshortening them in the upwind direction.

For example, in the absence of barrier effects, equal sound level contours are circular if no wind is present. If a wind (and resultant wind speed gradient) is present, these contours become distorted as shown in Figure 4-1.

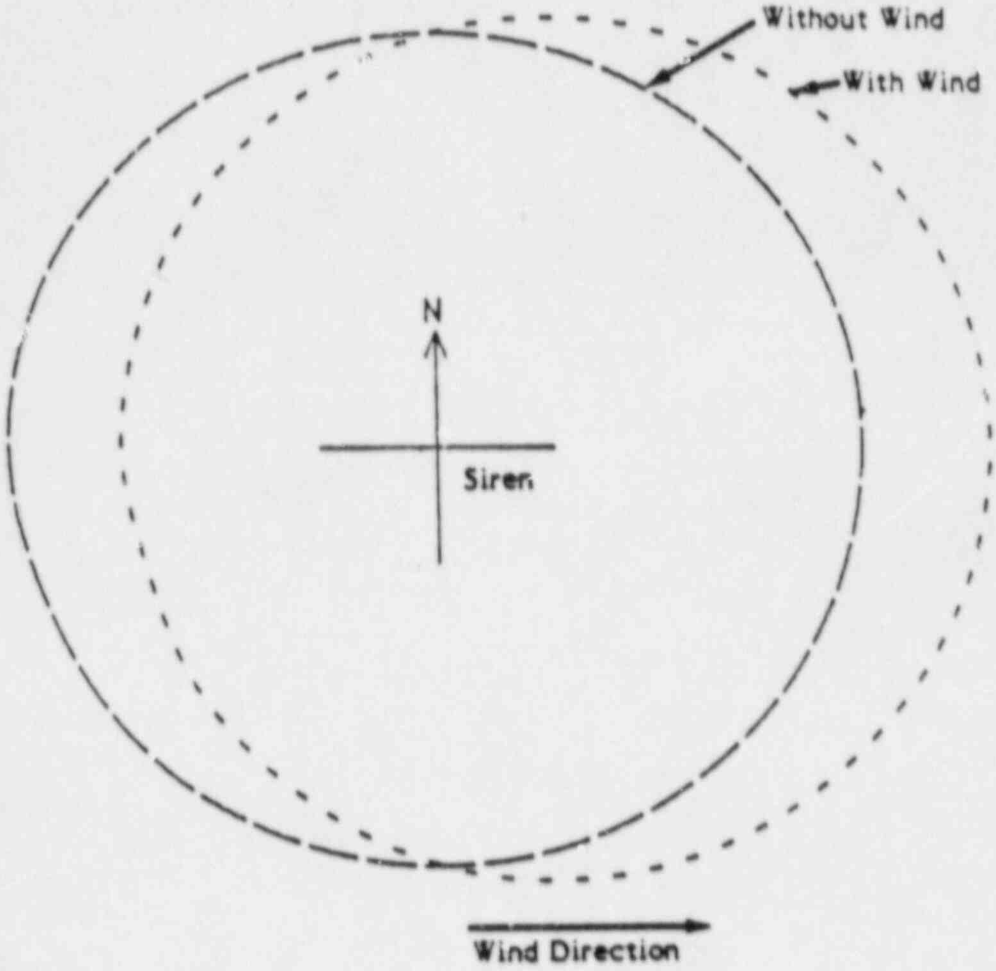


Figure 4-1. Effect of Wind on Sound Level Contour.

It is difficult to take this effect into account when designing a siren system, since the direction of the wind at a time that an emergency occurs cannot be known a priori. Using a time-averaged or a most probable wind direction is not appropriate since there is no guarantee that the wind will be blowing in that direction when an emergency occurs.

The most conservative procedure is to compute the individual siren contours assuming the no-wind case but to design the overall system so that adjacent sirens are sufficiently close that, with a wind, any "hole" created by the upwind foreshortening of the contour for a given siren, is filled by the downwind elongation of the contour of the nearest upwind siren. This procedure requires that no-wind siren contours at the edge of the EPZ extend far enough outside the EPZ that, if they are foreshortened by a wind blowing directly into the EPZ, the distorted contour still reaches the edge of the EPZ.

For Seabrook, the currently allowed siren locations along the western edge of the EPZ do not provide excess penetration beyond the EPZ at several locations. However, as will be demonstrated in Section 5, there is an inherent conservatism of 10 dB in the model. Since the inclusion of a wind blowing from west to east into the EPZ would have had the effect of reducing the predicted levels by 5 dB, coverage will extend past the edge of the EPZ.

5.0 VALIDATION OF MODEL

The computerized model described above has been validated by comparing its predictions with measurements carried out near sirens at several nuclear power plants. Comparisons of measured sound levels with predicted sound levels from the model are shown in Figures 5-1 and 5-2.

Figure 5-1 shows a comparison between measured and predicted sound levels for sirens near the Indian Point plant in New York. Most of this data was taken in very hilly, heavily forested terrain. Shown for reference on this figure is a 45-degree line indicating perfect agreement. The average difference between measured and predicted levels is 7.2 dB with a standard deviation of 5.3 dB.

The spread in the data is due to atmospheric variations during the measurements and terrain effects not accounted for in the propagation models. There is an offset such that measured levels are generally higher than predicted. This result is consistent with the design goals of the siren siting model, which endeavors to be conservative in the prediction of the sound level so as to minimize overprediction of individual siren levels.

A reasonable design objective is that there be no more than a 10 percent probability that actual levels will be less than predicted. For the data set shown in Figure 5-1, 11 of the 95 measurements are underpredicted, corresponding to an 11.6-percent probability of underprediction.

Figure 5-2 shows similar data for predictions and measurements for sirens tested at the Seabrook plant during the period from 3 March to 7 April 1988. The terrain in the test area was flat and rural. Again, as in the case of the Indian Point data, the model underpredicts the sound level, as it was designed to do. The average difference between measured and predicted levels is 10.0 dB with a standard deviation of 8.7 dB. Of the 125 measurements represented in this figure, 10 are underpredicted, corresponding to a rate of 8.0 percent.

In summary, the siren range prediction model presented in this report is shown to provide a reasonable and conservative basis for siting siren positions. Based on the model validation measurements reported herein, the model predicts a shorter range than actually observed about 90 percent of the time.

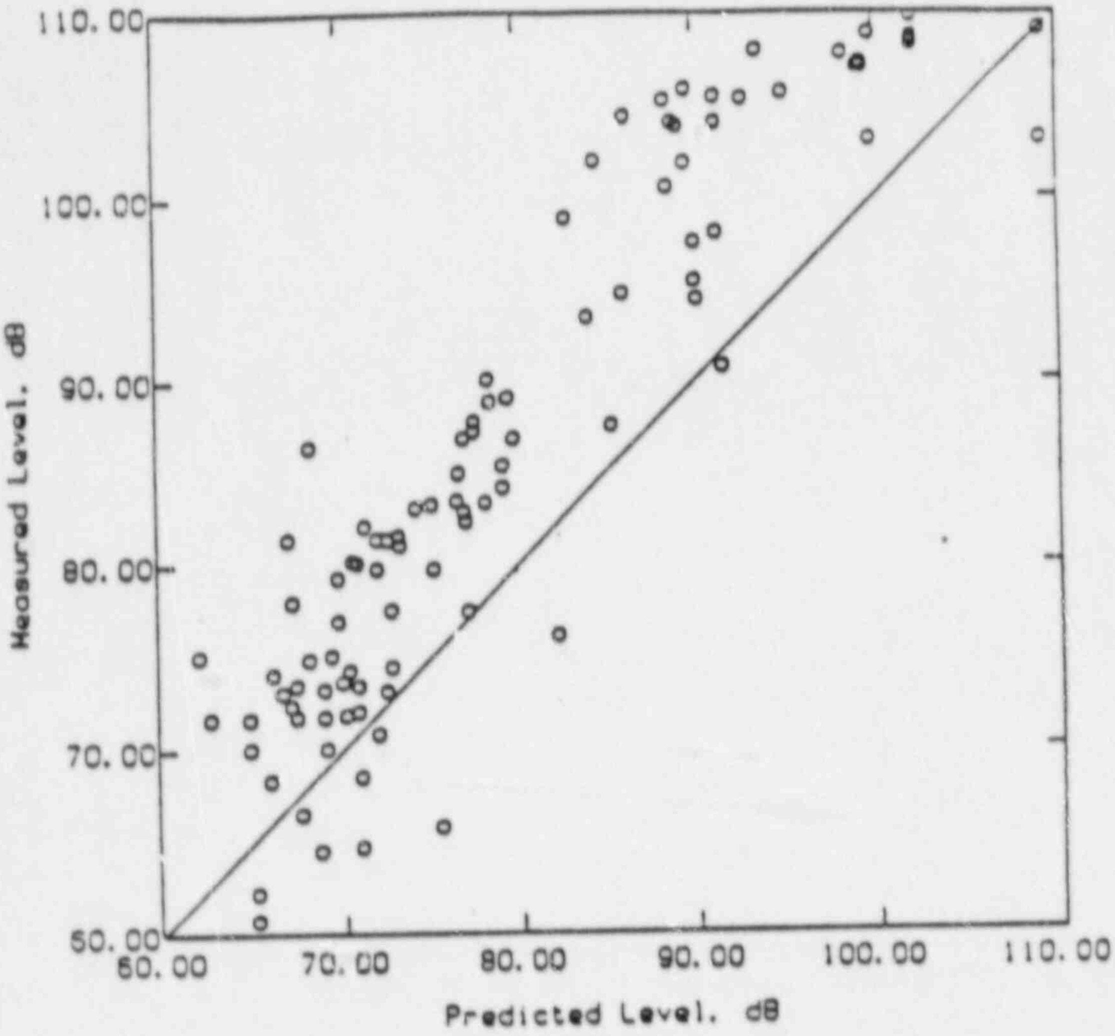


Figure 5-1. Comparison of Measured and Predicted Siren Sound Levels for Indian Point Data.

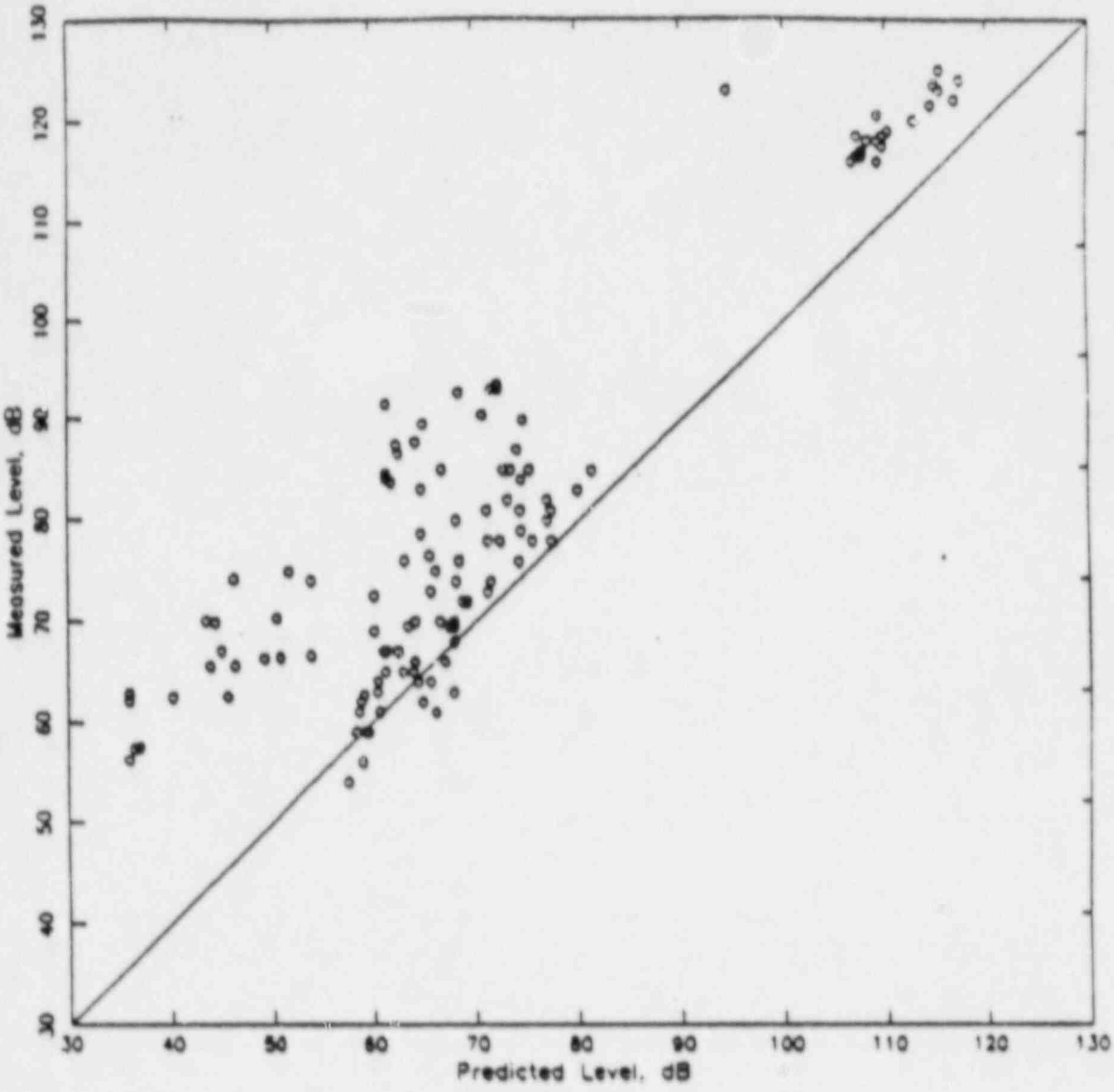


Figure 5-2. Comparison of Measured and Predicted Siren Sound Levels for Seabrook Data.

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The reasonableness of the method for determining the siren sound output and the resulting siren sound pressure level contours should be documented in the design report. The validity of the sound pressure level contour calculation depends upon the validity of the determination of siren sound output at 100 feet from the siren. There are at least two ways to determine siren sound output:

- Onsite field measurements around at least one of each type of siren used within the EPZ; or
- Anechoic, semi-anechoic, or reverberation chamber tests in a qualified laboratory on sirens that are representative of each type of siren used within the EPZ.

Since consensus standards are not available for field and chamber siren measurements, the rationale for the employed measurement procedures must be detailed in the design report.

The design report should provide a list of all sirens and should contain the following information for each siren: unique identifier, siren type, sound output in dBC at 100 feet, and mounting height.

The design report demonstrates compliance with NUREG-0654/ FEMA-REP-1, Revision 1, criteria for those geographical areas covered by fixed sirens by showing that either:

- The expected siren sound pressure level generally exceeds 70 dBC where the population exceeds 2,000 persons per square mile and 60 dBC in other inhabited areas; or
- The expected siren sound pressure level generally exceeds the average measured summer daytime ambient sound pressure levels by 10 dB (geographical areas with less than 2,000 persons per square mile).

If the design report documents that the siren sound pressure levels exceed a measured ambient by 10 dB, then the following information should be provided: