GRAND GULF NUCLEAR POWER STATION
Siren Alert Notification System Design Evaluation

Final Report

prepared for

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Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

This report summarizes the results of an analysis conducted for American Signal Corporation (ASC) to assess the coverage of the replacement Siren Alert Notification System at the Grand Gulf Nuclear Power Station. The modified system would provide siren sound levels of 70 dBC and 60 dBC correspondingly in areas with population densities of 2,000 or more persons per square mile and in areas with population densities of less than 2,000 persons per square mile within the 10-mile Emergency Planning Zone (EPZ).

The modified Siren Alert Notification System is a 43-siren system consisting of 29 Tempest T-121 replacement sirens and 14 Penetrator P10/P15 original sirens mounted on 50 foot poles. The T-121 are omni-directional sirens rated at 119.5 dBC at 100 feet while the P10/P15 are the original rotational sirens rated at 119 and 122 dBC. Field test data the sirens were submitted to and accepted by FEMA ascertaining the ratings.

The purpose of this acoustic modeling study is to demonstrate through predictive modeling that the modified siren alert notification system meets and exceeds the FEMA-REP-10 requirement of provide siren sound levels of 70 dBC and 60 dBC correspondingly in areas with population densities of 2,000 or more persons per square mile and in areas with population densities of less than 2,000 persons per square mile within the 10-mile EPZ.

1.1. Organization of Report

Section 2.0 of this report provides a brief description of the modified physical siren system and siren locations within the 10-mile EPZ. Section 3.0 reviews the applicable FEMA-REP-10 requirement for an adequate and satisfactory Siren Alert Notification System design. Section 4.0 provides an overview of the approach taken to perform the study and a summary description of the Outdoor Sound Propagation Model (OSPM) used to yield the predictive coverage of the modified siren system. Section 5.0 describes the processing of site topographical and meteorological data and their use in the model. Section 6.0 presents the predicted coverage of the modified siren system and evaluates its adequacy in meeting FEMA-REP-10 requirements. And Section 7.0 concludes the study.

2. THE SIREN SYSTEM

Field test data with octave-band measurements of the sirens were submitted to and accepted by FEMA ascertaining the ratings.

The modified Siren Alert Notification System is a 43-siren system consisting of 29 Tempest T-121 replacement sirens and 14 Penetrator P10/P15 original sirens mounted on 50 foot poles. The T-121 are omni-directional sirens rated at 119.5 dBC at 100 feet while the P10/P15 are the original rotational sirens rated at 119 and 122 dBC. Field test data the sirens were submitted to and accepted by FEMA ascertaining the ratings.

Table 2.1 lists the individual siren by type, its GPS location by longitude and latitude, and relevant siren data.

Table 2-1: Sirens and Locations

Siren #	Tactical Address	Siren Type	Location	Latitude	Longitude
			MISSISSIPPI EPZ ANS Sirens		
014	MAA	ACA Penetrator P-10/P-15	# 01, Heavy Haul Rd near MS River	N 32°01'07.1"	W 91°04'02.1"
015	MAB	TEMPEST™ T-121	#02, Grand Gulf Rd by State Park	N 32°01'53.8"	W 91°03'12.7"
016	MAC	TEMPEST™ T-121	#03, Grand Gulf Rd & Bald Hill Rd	N 32°00'31.3"	W 91°02'02.0"
017	MAD	TEMPEST™ T-121	#05, Hwy 61N. To Togo Island	N 32°06'29.4"	W 91°01'32.2"
018	MBA	TEMPEST™ T-121	# 04, Y-Camp Rd near YMCA	N 32°01'44.2"	W 91°00'18.0"
019	MBB	TEMPEST™ T-121	#12, Grand Gulf Rd behind Showgirls Club	N 32°00'08.6"	W 91°00'07.8"
020	MBC	TEMPEST™ T-121	#13, Ingleside Rd & Ingleside Ferry Rd	N 32°03'32.4"	W 90°59'51.8"
021	MBD	TEMPEST™ T-121	#14, 1-mi. W. on Hwy 61 off Ingleside Rd	N 32°02'13.0"	W 90°57'36.7"
022	MBE	TEMPEST™ T-121	#15, Hwy 61 1-mi N. of 462	N 32°01'36.2"	W 90°56'55.6"
023	MBF	TEMPEST™ T-121	#16, Hwy 462 in Willows	N 32°01'57.8"	W 90°54'19.7"
024	MBG	TEMPEST™ T-121	#17, Hwy 61 & Floyd Rd (Deer Park)	N 32°04'01.0"	W 90°55'20.9"
025	MBH	TEMPEST™ T-121	#18, Hankinson Rd 2-mi. from 462	N 32°03'45.0"	W 90°53'27.0"
026	MBI	TEMPEST™ T-121	#34, Corner of Hwy 61 & 462	N 32°00'45.5"	W 90°57'24.6"
027	MCA	TEMPEST™ T-121	#19, Hwy 61 across from Co-op.	N 31°58'45.2"	W 90°58'38.9"
028	MCB	TEMPEST™ T-121	#22, Hwy 18 1-mi E. of Natchez Trace	N 31°57'59.6"	W 90°56'42.1"
029	MCC	TEMPEST™ T-121	#23, Old Hwy 18 #3, 1-mi from Hwy 18	N 31°57'53.0"	W 90°53'39.0"
030	MCD	TEMPEST™ T-121	#24, Romola Rd, 2.1-mi. from Hwy 18	N 31°59'14.8"	W 90°54'45.3"
031	MDA	TEMPEST™ T-121	#20, Hwy 547 @ Chamberlain Hunt Acd.	N 31°56'41.1"	W 90°59'05.6"
032	MDB	TEMPEST™ T-121	#21, Hwy 547 near Mercy Seat Church	N 31°55'39.0"	W 90°57'06.2"
033	MDC	TEMPEST™ T-121	#31, Rodney Rd & Bessie Weather's Rd	N 31°57'22.4"	W 91°00'09.9"
034	MDD	TEMPEST™ T-121	#35, Anthony St @ A.W. Watson School	N 31°58'11.1"	W 90°59'29.3"
035	MDE	TEMPEST™ T-121	#36, Chinquepin St @ City Barn Site	N 31°57'19.1"	W 90°58'52.0"
036	MDF	TEMPEST™ T-121	#42, Moore's Rd 1-mi. E. of Tillman Rd	N 31°54'29.0"	W 90°56'33.3"
037	MEA	TEMPEST™ T-121	#29, Rodney Rd 3-mi. S. of Windsor Ruins	N 31°54'40.2"	W 91°07'58.3"
038	MEB	TEMPEST™ T-121	#30, 1/4-mi. W. of Hwy 61 on Russum Rd	N 31°52'42.0"	W 91°00'47.0"
039	MEC	TEMPEST™ T-121	#32, Russum Rd, 3-4 mi. from Hwy 61	N 31°53'36.0"	W 91°03'37.3"
040	MED	TEMPEST™ T-121	#33, Rodney Rd @ High Point Site	N 31°57'27.2"	W 91°03'15.4"
041	MEE	TEMPEST™ T-121	#37, Hwy 61 & Gordon Station Annex	N 31°54'29.6"	W 90°59'45.1"
042	MEF	TEMPEST™ T-121	#43, Gordon Sta. Rd, 2-mi. W. of Pine Gr.	N 31°52'47.6"	W 90°58'00.1"
043	MFA	TEMPEST™ T-121	#25, Alcorn State Univ. Campus	N 31°52'16.3"	W 91°07'49.7"
			LOUISIANA EPZ ANS Sirens		
001	LAA	ACA Penetrator P-10/P-15	# 26, Hawkins Welding St. - St. Joseph	N 31°55'39.1"	W 91°14'44.0"
002	LAB	ACA Penetrator P-10/P-15	# 41, Western Auto - St. Joseph	N 31°55'06.1"	W 91°13'56.8"
003	LBA	ACA Penetrator P-10/P-15	# 27, Entrance Lake Bruin	N 31°57'52.4"	W 91°14'00.4"
004	LBB	ACA Penetrator P-10/P-15	# 28, State Park Lake Bruin	N 31°57'26.1"	W 91°11'53.2"
005	LBC	ACA Penetrator P-10/P-15	#40, Lennie Pylate Residence - Lake Bruin	N 31°59'51.9"	W 91°14'06.3"
006	LCA	ACA Penetrator P-10/P-15	# 07, Church Lake - St. Joseph	N 32°01'40.4"	W 91°12'01.1"
007	LCB	ACA Penetrator P-10/P-15	# 08, Winter Quarters Lake - St. Joseph	N 32°01'05.2"	W 91°10'28.3"
008	LDA	ACA Penetrator P-10/P-15	# 38, Bertile White Res. Hwy 608	N 32°03'28.8"	W 91°13'06.1"
009	LDB	ACA Penetrator P-10/P-15	# 39, 1st Baptist Church - Newellton	N 32°04'35.2"	W 91°14'12.3"
010	LDC	ACA Penetrator P-10/P-15	#09, Ruthwood School - Newellton	N 32°04'17.9"	W 91°14'25.5"
011	LEA	ACA Penetrator P-10/P-15	# 06, Point Pleasant	N 32°06'41.5"	W 91°07'11.3"
012	LEB	ACA Penetrator P-10/P-15	#10, Moor's Landing	N 32°04'57.3"	W 91°09'13.2"
013	LEC	ACA Penetrator P-10/P-15	# 11, Elk Ridge Hwy 608	N 32°06'10.8"	W 91°11'56.5"

The locations of the sirens with respect to the 10-mile EPZ are graphically shown in Figure 6-1.

3. FEMA-REP-10 Requirements for the Siren System

FEMA-REP-10[1] specifies the following criteria for those geographical areas covered by fixed sirens

- 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 area with less than 2,000 persons per square mile).

The Grand Gulf Siren Alert Notification System is designed to satisfy the first criteria for the entire EPZ. Furthermore, this design report is drafted to meet the map requirements as specified in Appendix 2 of FEMA-REP-10 in that it provides:

- Depict the 10-mile EPZ boundary;
- Depict the geographical area covered by the sirens; and
- Depict the unpopulated geographical areas that are not covered by an alerting mechanism.

Routine siren testing procedures and operability for the Grand Gulf Nuclear Power Station siren alert notification system are submitted separately and are not included in this report.

[1] FEMA. 1985. Guide for the evaluation of alert and notification systems for nuclear power plants. FEMA-REP-10.

4. APPROACH

A computer model is used to estimate the coverage of the modified siren system. The siren locations and the rated siren output sound pressure levels in octave-bands were input into an Outdoor Sound Propagation Model[2] (OSPM) to compute expected siren levels throughout the entire EPZ.

The model was accepted by and documented for FEMA and accepted by the US Atomic Safety and Licensing Board (ASLB)[3]. A summary description of the model is given below.

4.1. The Outdoor Sound Propagation Model

The model computes the decrease in magnitude as the sound travels from the source to the receptor. The most basic attenuation is the decay with distance, or the uniform spreading loss, and absorption by the atmosphere. Other common and prevalent excess attenuation mechanisms are line-of-sight blockage by terrain or obstacles, absorption and interference by the ground, and the refraction of sound by wind- and temperature-induced velocity gradients. Less prevalent mechanisms such as scattering of sound by atmospheric turbulence or attenuation by dense broad-leaf vegetation levance are not discussed here and can be referenced in standard text on acoustics[4].

The decay of sound with distance is the most basic factor on the sound level at a receiver away from a sound source. There is a uniform spreading loss as sound energy propagates and spreads from a source. For a point source, the change in sound level can be described as:

$$\Delta L = 20\log_{10}\left(\frac{r^2}{r_o^2}\right)$$

where r is the distance from the source to the receptor r_o is the reference distance where the sound level of the noise source is measured. This spherical divergence from a point source amounts 6 dB drop for each doubling of distance. Over a totally reflective surface (such as concrete or water) the loss decreases to 3 dB per distance doubling.

As sound energy travels through the atmosphere, some of the acoustical energy is lost to the medium. The losses, those associated with the change of acoustical energy to heat and molecular relaxation, are reasonably well understood as a function of atmospheric temperature, humidity, and pressure.[5] The loss is directly proportional to the distance traveled, with high frequency sounds suffer more losses

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[2] Lee, V.M. 1988. Outdoor sound propagation model - program manual. Federal Emergency Management Agency. Washington, DC

[3] US Nuclear Regulatory Commission. 1982. In the Matter of Shearon Harris Nuclear Plant. ASLBP No. 82-472-03 OL

[4] Beranek, L.L. 1988. Noise and vibration control. INCE.

[5] American National Standards Institute. 1978. Methods for the calculation of the absorption of sound by the atmosphere. ANSI S1.26.

than lower frequency sounds. The computations of atmospheric absorption coefficients for the octave-band center frequencies from 31.5 to 8,000 Hz in ANSI S1.26 were implemented in OSPM.

Excess attenuation of sound over ground at "grazing incidence", when the angle between the propagation path and the ground is less than 15 degrees, is complex but well understood. For grass covered soil beyond 80 meters, the excess attenuation can be significant and is approximately 6 dB per doubling of distance[6] over large distances. The results of the Rasmussen study were adopted in OSPM.

When the line-of-sight between the source and the receiver is blocked, the propagation of sound suffers what is termed a diffraction loss. The principal is the same as what is used to design highway noise barriers, it is a common and well understood tool for reducing unwanted sound[7]. The amount of attenuation is based on the difference in propagation path lengths with and without the obstacle. OSPM scans the terrain profile from a source and receptor and implements, for simplicity, the Maekawa procedure for the highest obstacle that blocks the line-of-sight.

One of the complex and important effects in acoustics in the lower atmosphere is the refraction of sound by temperature and wind velocity gradients. In a calm adiabatic (temperature decreases at 1 deg C per 100 m) atmosphere, temperature decreases with increasing height above the ground, and since sound speed is proportional to the square root of the absolute temperature, sound velocity therefore decreases with height, and by Snell's law of refraction, the sound rays will bend upward and an acoustic shadow will form some distances from the source. The opposite occurs in a temperature inversion. Wind velocity adds or subtracts from the sound velocity depending on whether the sound is propagating upwind or downwind. And since wind velocity typically increases with increasing height, the sound velocity profile decreases for upwind propagation and increase for downwind propagation, thereby reinforces the shadow formation in the upwind direction and negates the temperature-induced shadow in the downwind direction.

In an arbitrary sound velocity profile, it is possible for the sound ray paths to converge at a particular point resulting in a focusing of the rays and an increase in sound level. Such phenomena are evident in intense sound sources over long ranges or in high altitudes, and are not considered herein. In siren system design, to be conservative, no credit is taken for downwind propagation or focusing.

$$c(h_2) = c(h_1) + v(h_2) \cos \varphi$$

where

h_2, h_1 are upper and lower heights above ground
c is the sound velocity and is equal to 20.05 times the sqrt of T in mks units
φ is the angle between the sound ray and the wind direction

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[6] Rasmussen, K. B. 1982. Sound propagation over level terrain. The Acoustics Laboratory, Technical University of Denmark.

[7] Maekawa, Z. 1965. Noise reduction by screens. Kobe University, Japan.

v is the wind speed
T is the absolute temperature in deg K

When wind velocity is small compared to sound velocity and temperature gradient is small compared to absolute temperature.

$$c(z) = c\ [1 - B\ \ln(z/z_0)]$$

where

B = D – M_0 cos φ
D is the temperature gradient
M_0 is the wind speed gradient
z is the receiver height
z_0 is the source height

Using the ray theory formulation, a ray traveling from the source height at z_0 to z can be expressed as

$$r = \int_{z_0}^{z} \frac{dz}{\pm \tan\theta}$$

where θ is the angle of the ray from horizontal and is determined from the Snell's Law:

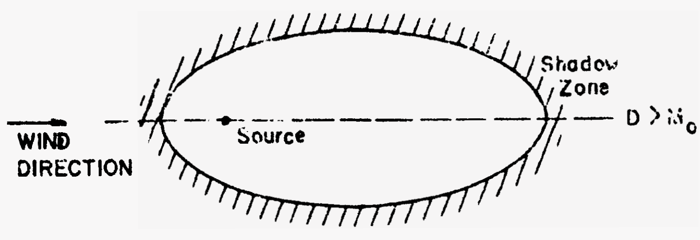
$$c(z) \cos\theta_0 = c_0 \cos\theta$$

After substituting all the equations and much mathematical manipulations, r_s the horizontal distance to shadow[8] can be expressed as

$$\frac{r_s}{z_0} = \sqrt{\frac{2}{B}}\{e^{\tau^2}[\int_0^{(\frac{z\tau}{z_0})} \exp(v^2)dv + \int_0^{\tau}\exp(v^2)dv] - \frac{B}{2}[(\frac{z}{z_0})^2 + 1]\tau = \sqrt{\frac{2}{B}}\, f(\frac{z}{z_0})$$

$$\tau = [\frac{\ln(\frac{z}{z_0})}{(\frac{z}{z_0})^2 - 1}]^{0.5}$$

When B>0, the sound velocity decreases with height and the rays bend upward forming casting a closed shadow around the source.



a) Temperature effect greater than effect of wind.

And when $\varphi_c = \cos^{-1}(D/M_0)$, an open shadow forms at the angle φ_c as illustrated below:

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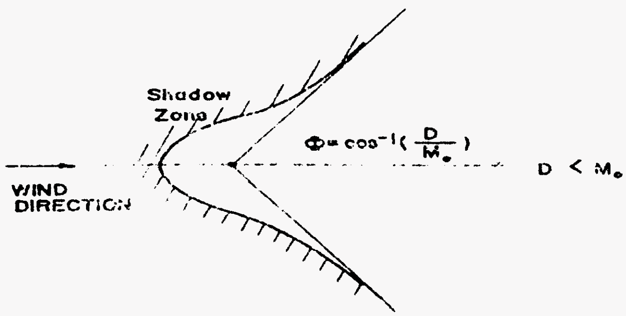
[8] Nyborg and Mintzer, Review of sound propagation in the lower atmosphere. 1955. Wright Air Development



b) Effect of wind greater than temperature effect

Attenuation of sound in the shadow zone is significant depending on how deep the receiver is into the shadow. And under extreme conditions, shadows can form very close to the source in the upwind direction. Such conditions are coincidentally also favorable to plume dispersion and unadvisable for evacuation, and therefore are not considered in FEMA's system design evaluation. This refraction calculation constitutes a large and significant part of the OSPM model.

In a large system or array of sirens in which omni-directional sirens are deployed, the logarithmic additive effect of two omni-directional sirens must be taken into account as:

$$dB_1 = 10 \log \left(\frac{p_1^2}{p_0^2} \right)$$

$$dB_2 = 10 \log \left(\frac{p_2^2}{p_0^2} \right)$$

$$dB_{(1+2)} = 10 \log \left[\frac{(p_1^2 + p_2^2)}{p_0^2} \right]$$

where dB_1 is the sound pressure level from the 1st omni-directional siren, and
dB_2 is the sound pressure level from the 2nd omni-directional siren;

This algorithm is implemented in OSPM in arriving at the resultant total sound pressure level at a particular location due to an entire array of sirens.

5. USE OF SITE SPECIFIC DATA IN OSPM

OSPM incorporates site specific terrain features by using the USGS 3-arc second digital elevation data for the 1-degree quads of longitude 90 to 91W and latitude 31 to 32N. Representative site summer daytime weather conditions (temperature of 30 deg C at the 10-meter elevation and 29.8 deg C at the 50-meter elevation, wind speed of 1.3 meters per second at lower level and 2.2 mps at the higher level, wind direction of 0 deg from the North, relative humidity of 67%, and barometric pressure at 746 mm of Hg) previously used and accepted by FEMA were used as specified in FEMA-REP-10.

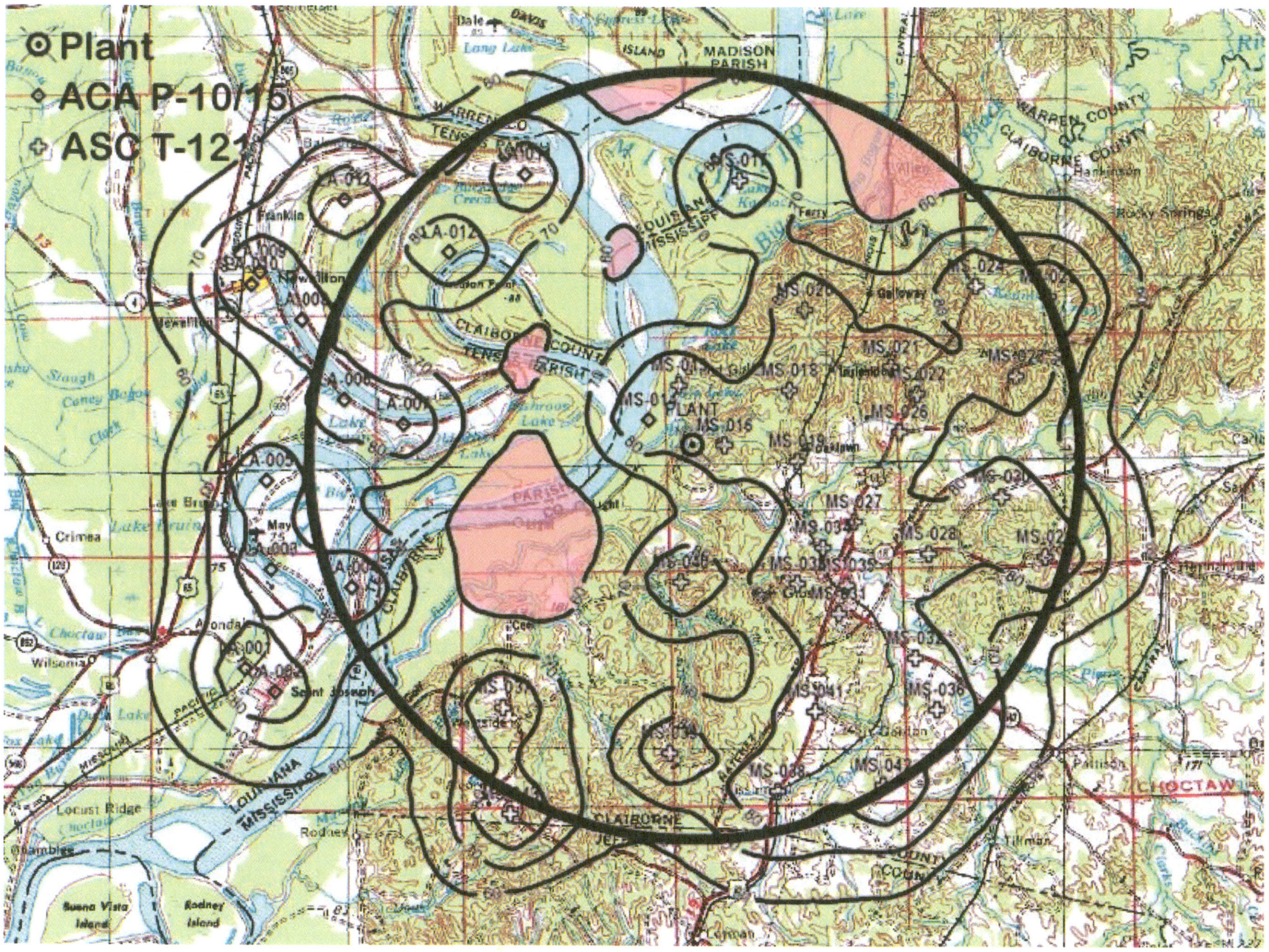
Siren levels in octave bands from 31 Hz to 8,000 Hz and in dBC were computed over a 110 by 96 grid or a total of 10,560 points extending over a square of 54,500 by 47,500 meters centered over the Power Station. Siren level contours at 10 dBC increments were plotted from 60 to 80 dBC.

6. ESTIMATES OF SYSTEM COVERAGE

Siren levels in dBC were computed over a 110 by 96 grid or a total of 10,560 points extending over a square of 54,500 by 47,500 meters centered over the Power Station and were contoured at 10 dBC increments from 60 to 80 dBC as shown in Figure 6-1 overlaying a USGS map. Also shown in the figure is the 10-mile EPZ.

It can be seen from Figure 6-1 that the entire populated land area within the 10-mile EPZ is covered by 60 dBC or higher, and any area with 2,000 persons per square mile or more within the EPZ is covered by siren levels well above 70 dBC. The five isolated areas (shaded) within the 10-mile EPZ below 60 dBC are unpopulated.

Figure 6-1: Grand Gulf Siren System Sound Level Contours



7. CONCLUSION

Based on the results presented above, it is concluded that the replacement siren alert notification system for the Grand Gulf Nuclear Power Station provides siren coverage of 60 dBC or higher in all inhabited areas with population densities of less than 2,000 persons per square mile and 70 dBC or more in inhabited areas with population densities of 2,000 persons per square mile or more within the 10-mile EPZ and meets all the FEMA-REP-10 requirements for a fixed siren system.