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Underwater Detonations at the Silver Strand Training Complex: Effects on Marine Mammals

Glenn H. Mitchell
Tiffini J. Brookens
Physical Operations and Support Department

Stephen A. Jordan
Ranges, Engineering, and Support Department

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Naval Undersea Warfare Center Division Newport, Rhode Island

PREFACE

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Joseph T. Murphy
Head, Physical Operations and Support Department

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Stephen A. Jordan

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14. ABSTRACT

The Commander of the U.S. Pacific Fleet is preparing an environmental impact statement (EIS) for activities at the Silver Strand Training Complex (SSTC). Training often involves the use of small explosives for various purposes, such as to disable underwater mines or defend ports. Explosions release very brief, intense sound energy with spectral characteristics spanning a wide band of frequencies. As a part of the SSTC EIS development, a quantitative analysis of sound impacts on marine mammals was performed to facilitate preparation of a Marine Mammal Protection Act (MMPA) Letter of Authorization for SSTC training activities. That analysis, described in this report, provides a conservative estimate of exposures of marine mammals impacted by the underwater detonations, which are a required component for training combat forces under realistic conditions.

15. SUBJECT TERMS

Undersea Warfare; Marine Mammal Density Estimates; Temporary Threshold Shift; Permanent Threshold Shift; Zone of Exposure; Navy Underwater Detonation Training; Level A Harassment Threshold; Level B Harassment Threshold; Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects

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EXECUTIVE SUMMARY

The Commander of the U.S. Pacific Fleet (PACFLT) is preparing an environmental impact statement (EIS) for the Silver Strand Training Complex (SSTC) at the Naval Amphibious Base (NAB), Coronado, CA. The annual training schedule at SSTC includes a series of operations that uses small underwater detonations. For the EIS, PACFLT required an analysis of the potential impacts that underwater detonations have on marine mammals. The analysis considered two alternatives: (1) No-Action alternative, which represented the tempo of current training operations during a representative year and (2) Preferred alternative, which represented an increase in tempo and intensity for future training operations during a representative year.

The SSTC training areas are narrow, parallel "boat lanes" that perpendicularly extend from Coronado Beach to a depth of 72 feet. The training area includes deep portions of the boat lanes from 24 to 72 feet. Additionally, a previous analysis was conducted using existing empirical data from very shallow water (VSW) (0 – 24 feet). The explosive charges ranged in size and type from 15 g of pentaerythritol tetranitrate (PETN) to 29 lb of plastic-bonded explosives with additives (PBXN). The maximum number of training operations per year was modeled, reflecting a fully booked operational schedule. The actual impacts, therefore, are expected to be less than those estimated herein.

Four species of marine mammals use SSTC waters and, therefore, may be exposed to the harmful effects of underwater detonations: (1) California sea lion (*Zalophus californianus*), (2) Pacific harbor seal (*Phoca vitulina richardii*), (3) bottlenose dolphin (*Tursiops truncatus*), and (4) gray whale (*Eschrichtius robustus*). All species may be present at SSTC year-round except the gray whale, which is expected to transit near the SSTC only in the cold season (January – April) while migrating to and from their breeding grounds.

Propagation of each underwater detonation was estimated using the Reflection and Refraction Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) hydroacoustic model. The explosive footprints were then combined with animal density and movement data to determine time-step exposures at the receiver, which were recorded by a virtual dosimeter associated with each simulated marine mammal. Impacts were assessed using criteria and thresholds for underwater detonations adopted directly from the USS *Winston S. Churchill* (WSC) Final Environmental Impact Statement (FEIS), updated by the National Marine Fisheries Service (NMFS) and published in numerous Final Rules (63 FR 230; 66 FR 87; 73 FR 35510; 73 FR 60836), or issued by the Chief of Naval Operations. Estimated exposures represented numbers of animals killed or harassed (Level A and B harassment) according to Marine Mammal Protection Act (MMPA) definitions of harassment, prior to implementation of protective measures. Categories of impact were mortality, injury (i.e., Level A harassment), physiological disruption (i.e., Level B harassment (temporary threshold shift (TTS)), and behavioral disruption (i.e., Level B harassment (non-TTS)).

Zero exposures of all species classified as mortality and MMPA Level A harassment (injury) were estimated under the No-Action and Preferred alternatives. The greatest zone of exposure (ZOE); i.e., radial distance) for mortality occurred between 40 and 90 yards from the detonations, and the greatest ZOE for MMPA Level A harassment (injury) occurred between 90 and 360 yards, depending on the detonation type. These results suggest that, for these four species, risk of death or injury is low, even if animals are present and not observed during protective measure procedures.

Zero exposures of harbor seals and gray whales classified as MMPA Level B harassment (TTS and non-TTS) were estimated under the No-Action and Preferred alternatives; however, numerous exposures of California sea lions (54 under the No-Action and 99 under the Preferred) and bottlenose dolphins (92 under the No-Action and 168 under the Preferred) classified as MMPA Level B harassment (TTS and non-TTS) were estimated. The Preferred alternative (i.e., 267 exposures) had 83% more estimated exposures classified as MMPA Level B harassment (TTS and non-TTS) than did the No-Action alternative (i.e., 146 exposures), which is attributed to the increased training tempo and intensity. These results suggest that risk of physiological or behavioral disruption is very low for harbor seals and gray whales, even if animals are present and not observed during protective measure procedures. Risk of physiological and behavioral disruption is greater for California sea lions and bottlenose dolphins than for harbor seals and gray whales.

ZOEs were calculated for each training operation using the radius for either physiological or behavioral disruption (MMPA Level B harassment). For single detonations, the onset of physiological impacts (i.e., TTS) was used to determine ZOEs; for multiple successive explosions (MSEs), both physiological and behavioral impacts (i.e., non-TTS) were considered.

For the No-Action alternative, the mine countermeasures (MCMs) 20-lb explosion created the greatest ZOE (470 yards) for a single detonation. The greatest ZOE (i.e., 610 yards) for MSEs, however, was created when a relatively small (3.5 lb), net explosive weight (NEW) was detonated eight times during the dive platoon training operation. The greatest ZOE for all operations considered was 740 yards, which was created by the Marine Mammal Systems Operations (MMS Ops) 29-lb explosion under the Preferred alternative. In general, the estimated ZOEs for any single detonation increased with increasing NEWs; moreover, the ZOEs for MSEs increased with the addition of the MMPA Level B harassment (non-TTS) threshold, which produced the greatest ZOEs.

Human safety ranges also were estimated using the REFMS model. Dual thresholds used for these calculations included impulse of 2 psi-msec and peak pressure of 50 psi, both of which must be met. Of the two thresholds, the greatest human safety zone was based on impulse with a maximum radius of 570 yards.

When detonations occur in VSW (depth < 24 feet), observers monitor the area from the beach and a small range vessel. When detonations occur in deep water (depth ≥ 24 feet), observers monitor the area from two rigid-hull, inflatable boats (RHIBs). The two trained lookouts survey the ZOE (based on MMS Ops at 740 yards) for marine mammals using binoculars. One RHIB circles the perimeter zone for at least 30 minutes prior to commencement of the scheduled explosive operation, and the other RHIB is stationed at the center of the ZOE during monitoring. The area must be clear of marine mammals for at least 30 minutes prior to a detonation. If a marine mammal is sighted within the ZOE or is moving towards it, training is suspended until the animal has left the area. Operations also require low sea state for safety, which optimizes sighting conditions and minimizes risk that marine mammals will not be detected.

MMPA regulations were considered with respect to mortality and Level A and Level B harassment. Mortality and MMPA Level A harassment are not anticipated based on this analysis; however, 267 estimated exposures of California sea lions and harbor seals classified as MMPA Level B harassment (TTS and non-TTS) represent a supportable and conservative basis for numbers of animals harassed per year at SSTC. A Letter of Authorization, therefore, should be obtained for the yearly exposures during the next 5 years.

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LIST OF ABBREVIATIONS AND ACRONYMS

2-D	Two-dimensional
AMNS	Airborne mine neutralization system
BD	Bottlenose dolphin
CNRSW	Commander, Navy Region Southwest
CS	California sea lion
dB re 1 μPa	Decibels referenced to 1 micropascal
dB re 1 μPa^2-sec	Decibels referenced to 1 micropascal squared – seconds
dB re 1 μPa^2/Hz	Decibels referenced to 1 micropascal squared per hertz
DON	Department of the Navy
EIS	Environmental impact statement
ELI	Extensive lung injury
FEIS	Final environmental impact statement
FR	Final Rule
GDEM	Generalized Digital Environmental Model
GW	Gray whale
HS	Harbor seal
INSVP	Interpolate Generalized Digital Environmental Model Profiles
LOA	Letter of Authorization
MCM	Mine countermeasure
MMPA	Marine Mammal Protection Act
MMS Ops	Marine mammal systems operations
μPa	Micropascal
MSE	Multiple successive explosion
NAB	Naval Amphibious Base
NAVOCEANO	Naval Oceanographic Office

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

NCCOS	National Center for Coastal Ocean Science
NDAA	National Defense Authorization Act
NEW	Net explosive weight
NMFS	National Marine Fisheries Service
NRC	National Research Council
Op	Operation
OPAREA	Operating area
PACFLT	Pacific Fleet
Pa-sec	Pascal – second
PBXN	Plastic-bonded explosives with additives
PCAD	Population Consequences of Acoustic Disturbance
PETN	Pentaerythritol tetranitrate
PL	Public Law
PTS	Permanent threshold shift
Qual/Cert	Qualification and Certification
REFMS	Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects
REFMSIN	REFMS Input Data
REFMSMOD1	REFMS Modification 1 Marine Species Effects
RHIB	Rigid-hull inflatable boat
SCB	Southern California Bight
SD	Standard deviation
SEL	Sound exposure level
SL	Source level
SLI	Slight lung injury
SPESIM	Species Simulated Movement
SPL	Sound pressure level
SS	Sound speed
SSC	Space and Naval Warfare Systems Command
SSP	Sound speed profile
SSTC	Silver Strand Training Complex
SWAG	Shock-wave action generator
SWFSC	Southwest Fisheries Science Center
TMR	Tympanic membrane rupture
TNT	Trinitrotoluene
TS	Threshold shift
TTS	Temporary threshold shift
USC	United States Code
USS	United States Ship
UUV	Unmanned underwater vehicle
UUV Ops	Unmanned underwater vehicle operations
VSW	Very shallow water
WSC	Winston S. Churchill
ZOE	Zone of exposure

UNDERWATER DETONATIONS AT THE SILVER STRAND TRAINING COMPLEX: EFFECTS ON MARINE MAMMALS

1. INTRODUCTION

Evaluating the effects of human activities on marine mammal populations is essential for risk assessment. Anthropogenic sound purposefully and unintentionally is created in the ocean. Increased use of the sea for commercial shipping, geophysical exploration, and advanced warfare has resulted in a greater level of noise pollution during the past few decades. Although measures of ambient noise are rare, informed estimates suggest that levels are at least 10 times greater today than they were a few decades ago. The distribution of anthropogenic noise is not uniform, and greatest levels occur along well-traveled, commercial ocean paths, particularly near coastal and continental shelf waters, areas that represent important marine mammal habitats. Recently, the public and scientific communities have expressed a growing concern regarding the rise of anthropogenic underwater noise and the role it plays in degrading habitat quality and directly impacting marine mammals.

Marine mammals are present in waters that the U.S. Navy uses to train and equip its forces. The study of noise-impact relationships is a relatively new and rapidly expanding area. For example, planning for Naval training activities that use active acoustic or explosive sources includes noise impact assessments using sound analysis simulations and modeling tools. These tools are used to either (1) compare various alternatives that achieve mission, training, and exercise objectives or (2) quantify impacts, as was done in this report.

The Commander of the U.S. Pacific Fleet (PACFLT) is preparing an environmental impact statement (EIS) for activities at the Silver Strand Training Complex (SSTC). Training often involves the use of small explosives for various purposes, such as to disable underwater mines or defend ports. Explosions release very brief, intense sound energy with spectral characteristics spanning a wide band of frequencies. As a part of the SSTC EIS development, a quantitative analysis of sound impacts on marine mammals was performed to facilitate preparation of a Marine Mammal Protection Act (MMPA) Letter of Authorization (LOA) for SSTC training activities. The analysis described in this report provides a conservative estimate of exposures of marine mammals impacted by the underwater detonations, which are a required component for training combat forces under realistic conditions.

2. SILVER STRAND TRAINING COMPLEX

2.1 LOCATION

The SSTC is located near the Naval Air Station North Island in Coronado, CA (figure 2-1). Portions of SSTC lie in San Diego Bay and the Pacific Ocean. SSTC training areas occur in the nearshore waters of San Diego Bay, areas Alpha – Golf, and in the Pacific Ocean "boat lanes" 1 – 14. All explosive operations are conducted in boat lanes 1 – 10, except for the shock-wave action generator (SWAG) (Preferred alternative only); SWAG operations can occur in all the boat lanes (1 – 14). The boat lanes extend seaward from the beach (not included) to water depths of 72 feet. The Echo area in San Diego Bay also is used for specific types of underwater training with explosives.

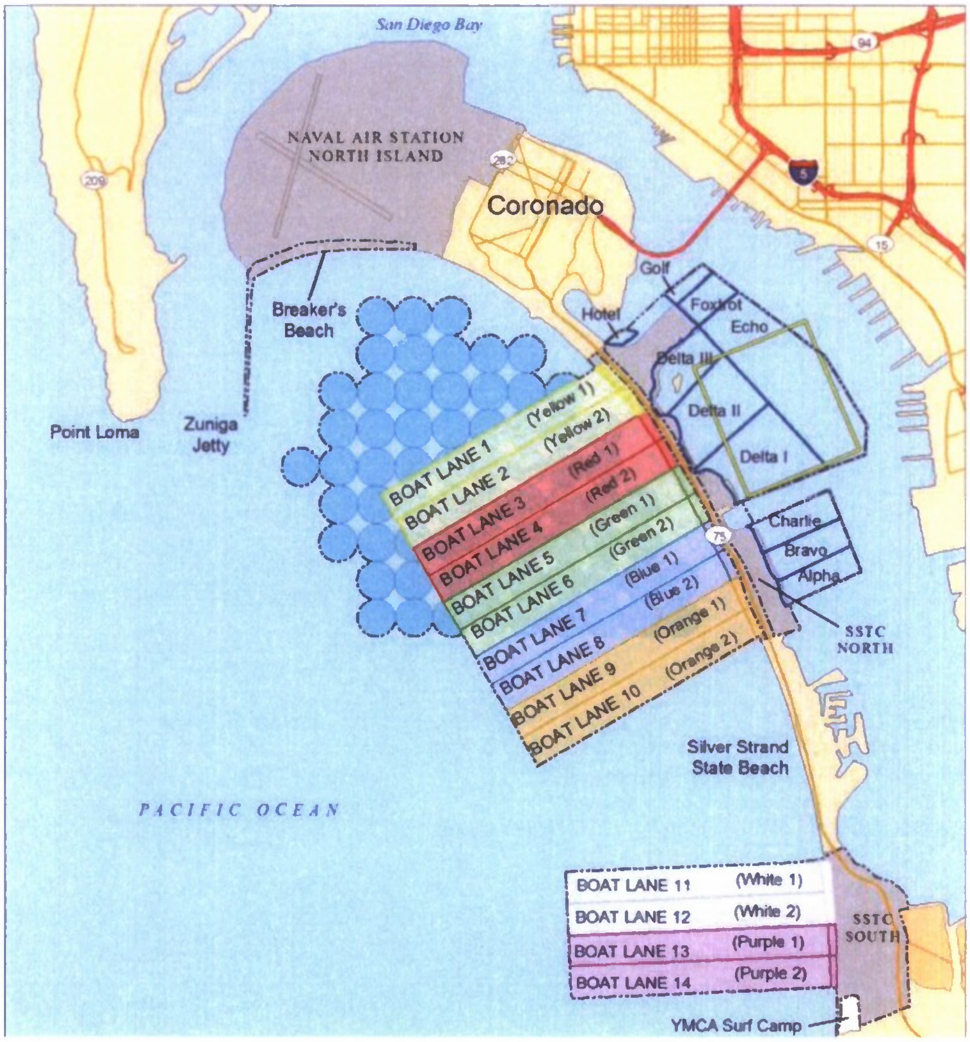

Figure 2-1. SSTC, Including Bay-Side Nearshore Areas and Ocean-Side Boat Lanes

2.2 UNDERWATER DETONATION TRAINING OPERATIONS

Underwater detonation operations can occur anywhere within the boat lanes depending on the training objective. For this report, charge placement was limited to depths between 24 and 72 feet, ocean-side of SSTC. Information regarding net explosive weight (NEW), number of detonations per operation, water depths (24 – 72 feet), location of detonation in the water column from the surface to bottom, and tempo of operations per year was used to characterize the sources for the impact modeling. Training operations were not repeated or combined during the course of a single day. Operations with multiple charges occur either as timed, sequential detonations (multiple successive explosives (MSEs)) with a fuse delay of 10 seconds or less, or by commanded detonations under the control of training range personnel. Controlled detonations occur with a minimum of a 30-minute setup time, although longer set-up times are common.

Under the No-Action alternative, underwater detonation operations represent the tempo of current training operations, which include 9 training types and 65 operations (table 2-1). This operational tempo represents a full annual training schedule with optimized range usage.

Table 2-1. Underwater Detonation Operations Under the No-Action Alternative

Underwater Detonation Operations	NEW (lb)	Number of Detonations	Water Depth (ft)	Charge Depth	Tempo (ops/year)
MCM[1]	10 – 20	1/op	24 ≤ 72	Mid	16
MCM	10 – 20	1/op	24 ≤ 72	Bottom	16
Floating Mine	≤ 5	1/op	24 ≤ 72	Surface (< 5 ft)	25
UUV Ops[2]	10 – 20	1/op	24 ≤ 72	Bottom to 10 ft from surface	4
MMS Ops[3]	13	1/op	24 ≤ 72	Bottom to 20 ft from surface	8
MMS Ops	13	2/op	24 ≤ 72	Bottom	8
Dive Platoon[4]	3.5	8/op	30 – 72	Mid	4
Dive Platoon[4]	3.5	8/op	30 – 72	Bottom	4
Mine Neutralization[4]	3.5	8/op	30 – 72	Bottom	4

Note: Unless otherwise specified, all MSEs will include a 30-minute or greater delay between charges.
[1] MCM: mine countermeasure.
[2] UUV Ops: unmanned underwater vehicle operations.
[3] MMS Ops: marine mammal systems operations.
[4] All MSEs are conducted with a 10-second delay between detonations.

Under the Preferred alternative, there will be an increase in tempo and intensity for future training operations for a representative year, which include 13 training types and 217 operations (table 2-2). This operational tempo also represents a full annual training schedule with optimized range usage.

Table 2-2. Underwater Detonation Operations Under the Preferred Alternative

Underwater Detonation Operations	NEW (lb)	Number of Detonations	Water Depth (ft)	Charge Depth	Tempo (ops/year)
MCM	10 – 20	1/op	24 ≤ 72	Mid	29
MCM	10 – 20	1/op	24 ≤ 72	Bottom	29
Floating Mine	≤ 5	1/op	24 ≤ 72	Surface (< 5 ft)	53
SWAG[1]	15 grams	1/op	10 – 20	Mid	90
UUV Ops	10 – 15	1/op	24 ≤ 72	Bottom to 10 ft from surface	4
MMS Ops	13 & 29	1/op	24 ≤ 72	Bottom to 20 ft from surface	8
MMS Ops	13 & 29	2/op	24 ≤ 72	Bottom	8
Dive Platoon[2]	3.5	8/op	30 – 72	Bottom	8
Qual/Cert	25.5	1/op	40 – 72	Bottom to 20 ft from surface	4
Qual/Cert	12.5 – 13.75	2/op	24 ≤ 72	Bottom	8
Mine Neutralization[2]	3.5	8/op	30 – 72	Bottom	4
UUV Neutralization	3.3 – 3.57	2/op	24 ≤ 72	Bottom to 10 ft from surface	4
AMNS[3]	3.5	1/op	40 – 72	Mid to bottom	10

Note: Unless otherwise specified, all MSEs will include a 30-minute or greater delay between charges.
[1] SWAG: shock-wave action generator.
[2] MSEs are conducted with a 10-second delay between detonations.
[3] AMNS: Airborne mine neutralization system.

3. MARINE MAMMAL SPECIES OF CONCERN

Quantifying the effects of impulse, energy, and peak pressure from underwater detonations requires an understanding of the species of concern. Detailed information about these species and others found in the Southern California Bight (SCB) is provided in the SSTC EIS (Department of the Navy, 2008a). This section provides density estimates and a biological context for modeling purposes.

3.1 GENERAL INFORMATION

Four marine mammal species may inhabit or predictably transit the SSTC: California sea lion (*Zalophus californianus*), Pacific harbor seal (*Phoca vitulina richardii*), bottlenose dolphin (*Tursiops truncatus*), and gray whale (*Eschrichtius robustus*). California sea lions and harbor seals commonly haul out on the mainland, on buoys and docks within harbors, and at the Channel Islands. Southern California breeding sites for these two species mainly occur on the Channel Islands. California sea lions and harbor seals have no known concentrated haulout sites or rookeries within or near SSTC. The coastal bottlenose dolphin regularly inhabits the nearshore waters of Southern California, where they move along the coast (including the SSTC area) generally remaining close to shore (within 1 km). This particular stock has limited site fidelity and can be distributed from northern Baja, Mexico to Monterey, depending on localized prey abundance.

Gray whales occur off Southern California during their annual migration between summer feeding areas in the Bering Sea and the southern Chukchi Sea and winter calving areas in Baja California and mainland Mexico. Although gray whales occasionally occur within a kilometer of shore during migration periods (southward: November – February; northward: February – April), they generally occur farther offshore than the SSTC. As such, gray whales were considered infrequent transients through, or immediately seaward of, SSTC.

3.2 DENSITY ESTIMATES

Density represents the number of animals per unit area for a specific location. Animal distributions are patchy in nature; they concentrate where important resources occur and a number of other relevant factors combine to optimize conditions for survival, growth, and reproduction. Marine mammal density estimates for the SSTC area were used for modeling the effects of underwater training operations on marine mammals (table 3-1). Density estimates were derived from a combination of the National Marine Fisheries Service (NMFS) shipboard surveys performed in Southern California from 1986 – 1996 and aerial surveys of San Clemente Island Range from 1998 – 1999 (Department of the Navy, 2007).

While the density estimated for gray whales likely overestimates the potential density off the SSTC, NMFS Southwest Fisheries Science Center (SWFSC) recommends using this density because it currently is the "best available" information (Barlow, 2007). The coastal stock of bottlenose dolphins represents the population that almost exclusively occurs within 1 km of shore. The maximum encounter rate, density, for bottlenose dolphins was derived for the shoreline area adjacent to the SSTC from surveys that occurred between 1990 and 2000 (National Center for Coastal Ocean Science (NCCOS), 2005).

Table 3-1. Marine Mammal Density Estimates for SSTC

Species	Warm Season (individuals/km^2)	Cold Season (individuals/km^2)
California sea lion	0.06	0.19
Pacific harbor seal	0.01	0.02
Bottlenose dolphin	0.202	0.202
Gray whale	N/A	0.014

Densities for warm (May – October) and cold (November – April) seasons were based on oceanographic conditions within the SCB. Gray whale densities were applicable only for January through April during their migration near the SSTC. The "N/A" density estimate for gray whales during the warm season indicates that they utilize coastal waters of the SSTC only during the cold season.

4. MODELING IMPACTS OF UNDERWATER DETONATIONS

The effects that underwater detonations have on a marine mammal are dependent on multiple factors including size of the detonation, type of detonation, species of marine mammal, and depth of both the mammal and detonation. Depth of the water column and distance from the charge to the marine mammal also are determining factors. To quantify impacts, the U.S. Navy has developed simulations that determine exposures of protected species during training operations. The simulation requires six major process components:

- a training operation description including weapon(s) type and acoustic source(s) with their associated active time and directionality;
- physical oceanographic and geoacoustic data for input into the acoustic propagation model representing seasonality of the planned operation;
- biological data for the test area including density and multidimensional animal movement;
- an acoustic propagation model suitable for the source type to predict impulse, energy, and peak pressure at ranges and depths from the source;
- the ability to collect acoustic and animal movement information to predict exposures for all animals during an operation (dosimeter[1] record); and
- the ability for post-operation processing to evaluate the dosimeter exposure record and calculate exposure statistics for each species based on applicable thresholds.

An impact model, such as the one used for the SSTC analysis, simulates the conditions present based on location(s), source(s), and species parameters by using combinations of embedded models (Mitchell et al., 2008). The software package used for SSTC consists of two main parts: an underwater noise model and bioacoustic impact model (Lazauski et al., 1999; Lazauski and Mitchell, 2006; Lazauski and Mitchell, 2008).

Location-specific data characterize the physical and biological environments; exercise-specific data construct the training operations. The quantification process involves employment of modeling tools that yield numbers of exposures for each training operation (figure 4-1). During modeling, the exposures are logged in a time-step manner by dosimeters linked to each simulated animal. After the operation simulation, the logs are compared to exposure thresholds to produce raw exposure statistics. It is important to note that dosimeters were used to determine exposures based on energy thresholds only, not impulse or peak pressure thresholds.

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[1] A virtual dosimeter is a time-step log of received impulse, energy, pressures, or other explosion characteristics that are collected during the simulated training exercise. The log can be queried at any point in an exposure sequence.

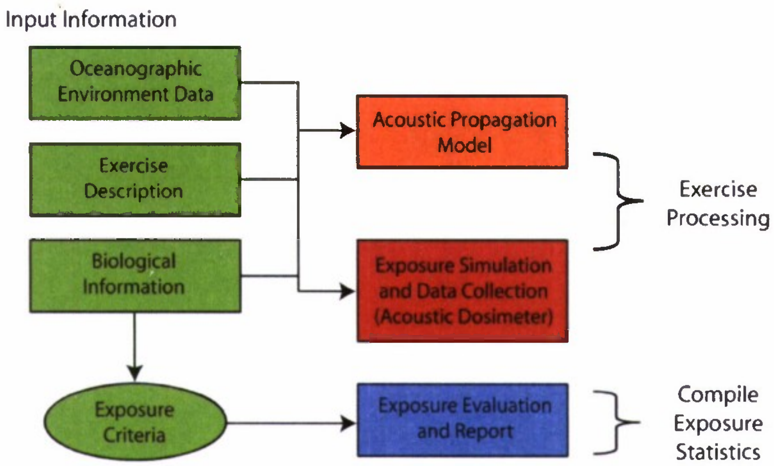


Figure 4-1. Generalized Modeling Process for Estimating Exposures

The analysis process uses quantitative methods and identifies immediate short-term impacts of the explosions based on assumptions inherent in modeling processes, criteria and thresholds used, and input data. The estimations should be viewed with caution, keeping in mind that they do not reflect measures taken to avoid these impacts (i.e., protective measures). Ultimately, the goals of this acoustic impact model were to predict acoustic propagation, estimate exposure levels, and reliably predict impacts.

4.1 PREDICTING IMPULSE, ENERGY, AND PEAK PRESSURE

Predictive sound analysis software incorporates specific bathymetric and oceanographic data to create accurate sound field models for each source type. Oceanographic data such as the sound speed profiles (SSPs), bathymetry, and seafloor properties directly affect the acoustic propagation model. Depending on location, seasonal variations, and the oceanic current flow, dynamic oceanographic attributes (e.g., SSP) dramatically can change with time. The sound field model is embedded in the impact model as a core feature used to analyze sound and pressure fields associated with SSTC underwater detonations.

The sound field model for SSTC detonations was the Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) model (6.03). The REFMS model calculates the combined reflected and refracted shock wave environment for underwater detonations using a single, generalized model based on linear wave propagation theory (Cagniard, 1962; Britt, 1986; Britt et al., 1991). The Cagniard model used in REFMS sometimes is referred to as "Generalized Ray Theory" in seismology.

The required inputs for the REFMS model include:

- representation of the layered water and sediment environment including compressional wave speed, sediment and water density, and layer depth;
- explosive weight, type, and depth; and
- receiver depth and range from the source.

Similitude equations calculate constants for each explosive type in terms of trinitrotoluene (TNT) equivalents referred to as "similarity parameters for explosives." Britt et al., (1991) indicated that care should be taken in using similitude for small charges. REFMS models the variation of physical properties (i.e., sound speed (SS), shear wave speed, and density) with depth in the ocean water column and at the seafloor. The water column and seafloor are represented with up to 300 homogeneous layers depending on the environment where detonations occur.

The model outputs include positive impulse, sound exposure level (SEL) (total and in 1/3-octave bands) at specific ranges and depths of receivers (i.e., marine mammals), and peak pressure. The shock wave consists of two parts, a very rapid onset "impulsive" rise to positive peak over-pressure followed by a reflected negative under-pressure rarefaction wave (figure 4-2).

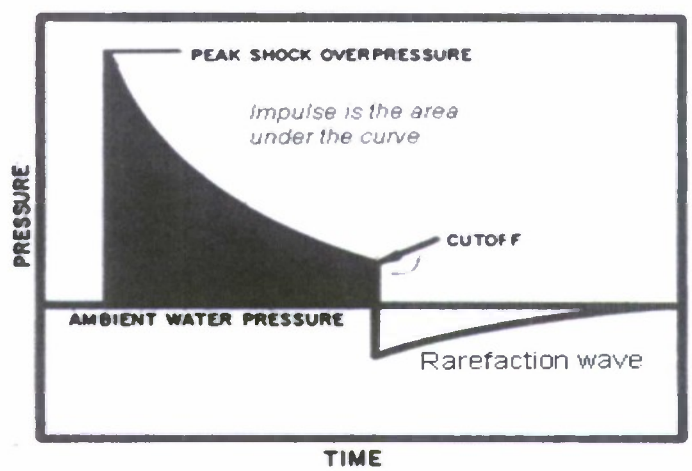


Figure 4-2. Generalized Shock Wave

The similitude expression for the nonlinear source is given in equations (1) and (2). Equation (2) is generally derived from data; however, the power law can be obtained from weak shock theory. When the nonlinear similitude source is combined with the Cagniard Generalized Ray Theory, a series of transmitted and reflected integrals is given for the various paths (figure 4-2). In this approach, there is very little dispersion, except for multipath and at the surface or seafloor. In the case of surface rarefaction, positive impulse would be cut off by the reflected wave at the cutoff time.

$P(t)$ provides the pressure-time calculation:

$$P(t) = P_m e^{-(t/\theta)}, \tag{1}$$

where $\boldsymbol{\theta}$ is the time constant, and the peak over-pressure P_m is given by

$$P_m = K\left(W^{1/3} / R\right)^{\alpha} \quad (MPa), \tag{2}$$

where K and α are constants for particular explosions. Range R to the target is determined by ray theoretic equations. The positive impulse is given by the integrated area under the over-pressure wave and is given by $I(t)$ as shown in equation (3):

$$I(t) = \int_0^{\tau} P(t)dt, \tag{3}$$

where the integration interval τ is some multiple of the time constant (Swisdak Jr., 1978). Other time constant values may be used in cases of disagreement by authors.

Propagation of shock waves and sound energy in the shallow-water environment is constrained by boundary conditions at the surface and seafloor (see figure 4-3). A hypothetical source is shown below the sea surface and above the seabed, indicating energy from the explosion reaches a subsurface receiver via multipaths. An iso-speed water column was used for illustrative purposes because it resembles the simplified SSTC situation. The iso-speed condition indicates no refraction of paths from changes in SS.

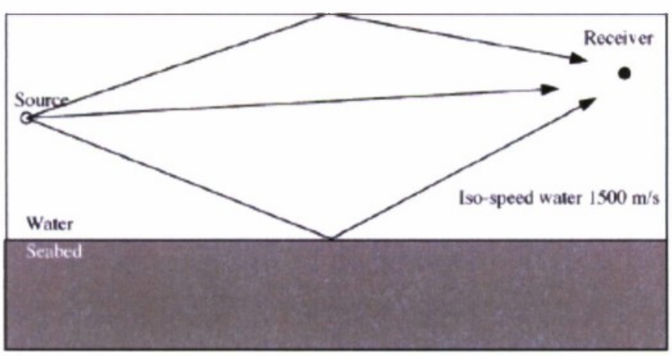


Figure 4-3. Generalized Pathways of Shock Waves and Sound Energy (adapted from Siderius and Porter, 2006)

4.2 ESTIMATING EXPOSURES

Multiple locations (in boat lanes and Echo area) and charge depths were used to determine the most realistic spatial and temporal distribution of detonation types associated with each training operation for a representative year. Additionally, the effect of sound on an animal depends on many factors including:

- properties of the acoustic source(s): source level (SL), spectrum, duration, and duty cycle;
- sound propagation loss from source to animal, as well as reflection and refraction;
- received sound exposure measured using well-defined metrics;
- specific hearing;
- exposure duration; and
- masking effects of background and ambient noise.

To estimate exposures sufficient to be considered injury or significantly disrupt behavior by affecting the ability of an individual animal to grow (e.g., feeding and energetics), survive (e.g., behavioral reactions leading to injury or death, such as stranding), reproduce (e.g., mating behaviors), and/or degrade habitat quality resulting in abandonment or avoidance of those areas, dosimeters were attached to the virtual animals during the simulation process. Propagation and received impulse, SEL, and peak pressure are a function of depth, as well as range, depending on the location of an animal in the simulation space. As stated previously, dosimeters were used to collect and retain exposure logs for SEL with associated time stamps.

4.3 PREDICTING IMPACTS

Predicting impacts to marine mammals from underwater detonations requires knowledge regarding the hazardous levels associated with mortality, injury, and physiological and behavioral disruption. Criteria and thresholds associated with impulse, SEL, and peak pressure are used to determine impact to internal organs and sensitive auditory tissues. In addition, disruption of behaviors from MSEs was considered. Exposures were quantified based on exceeding the associated thresholds. Currently, efforts to minimize exposure to impacts (i.e., protective measures) are not quantified in a way that allows for adjusting estimated exposures.

5. ACOUSTIC MODELING OF THE MARINE ENVIRONMENT

Ocean noise is characterized into two main categories based upon source type: (1) noise produced by multiple, sometimes indistinguishable sources with broad spectral content and level specific to a particular situation or location (e.g., vessels in a shipping lane with persistent turbulent weather patterns), and (2) noise produced by a single, identifiable source usually close to the point of reference (e.g., an underwater detonation at SSTC). Explosions are not the only sounds animals hear because explosions occur in the presence of ambient noise conditions. A brief description of ambient noise is provided for creating a context for exposure prediction as the auditory scene perceived by the animals (Fay, 2005; Fay and Popper, 2005).

5.1 MULTIPLE INDISTINGUISHABLE SOURCES: AMBIENT NOISE

In general, there are four main origins of natural sounds in the underwater environment—those from the surface, the atmosphere entering the water, geological processes coupling with the water above it, and the ocean's biological community. Origins of man-made sound are numerous but are generated either by a byproduct of some human activity (e.g., pile driving, industrial blasting) or generated with purpose (e.g., air guns and sonar). Ambient noise commonly is described as the aggregate noise energy from all sources except those close enough to be individually detectable. Conceptually, the noise energy from underwater detonations is concentrated at, but not limited to, the lower end of the frequency spectrum (figure 5-1). In figure 5-1, the marine mammal hearing abilities are superimposed to understand the animal's ability to sense sound energy. Sometimes they cannot hear the sound, or it is received in the range of increasing threshold for detection and usefulness.

Data from ambient noise research is rare; however, Wenz (1962) provided a generalized portrait of ocean noise in the SCB (figure 5-1). These curves provide noise intensity level (units are decibels referenced to 1 micropascal squared per hertz (dB re 1 $\mu Pa^2/Hz$)) across a spectrum that an idealized receiver with omnidirectional reception capabilities may experience at a particular moment depending on location. Although ambient noise is always present, the individual sources that contribute to it do not necessarily continuously create sound. For example, rain is periodic, and wind speeds change with weather patterns.

In the Northern Hemisphere, ambient noise is dominated by shipping, particularly at frequencies between 5 and 500 Hz (Committee on Potential Impacts of Ambient Noise in the Ocean and Marine Mammals and National Research Council (NRC), 2003). Distant traffic can contribute to the general acoustic environment over a wide frequency range, thus affecting great geographic areas. The distribution of shipping traffic is not uniform, and this type of noise is prevalent in and around major ports such as San Diego. By most estimates, the increase has been roughly equivalent to 3 dB per decade or equaling a doubling of noise energy levels every 10 years during the last few decades (McDonald et al., 2006).

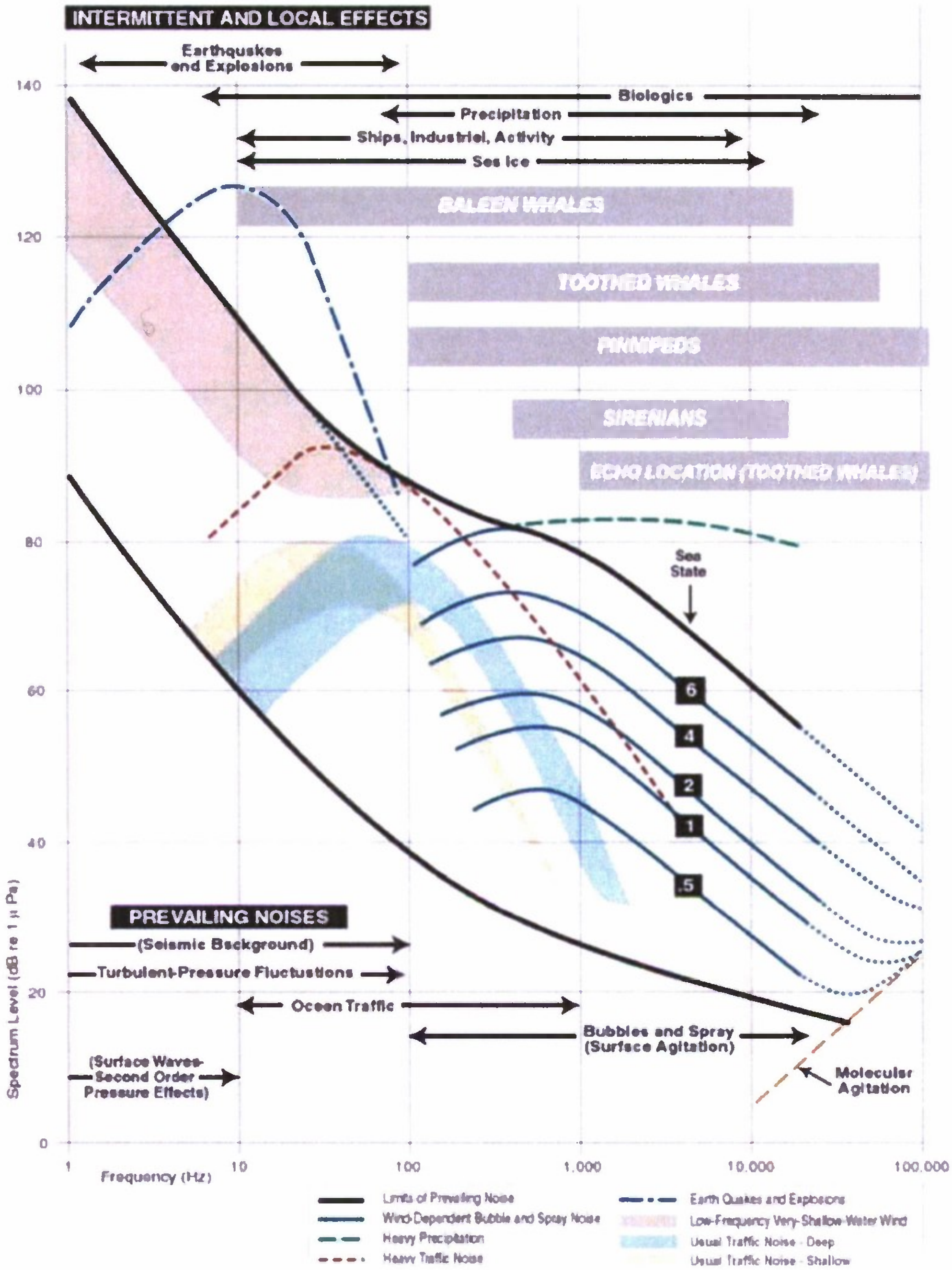


Figure 5-1. Acoustic Ambient Noise in the Ocean: Spectra and Sources (adapted from Wenz (1962) by National Research Council (2003))

Ambient noise levels tend to be much greater around centers of human populations and ports, such as the San Diego Bay area. A variation at any point in time of 20 dB is common depending on geographic location (Wenz, 1962). In San Diego Bay, noise followed this trend during a 10-year period.

While data for ambient noise are rare, one such study was conducted near the entrance of San Diego Bay (figure 5-2). The relative level of contribution to ambient noise by source and frequency range of sources that contributed to San Diego Bay ambient noise (figure 5-2(a)) was shown by actual data from Wenz (1962). Anthropogenic sources such as shipping and industry dominated relative frequency levels followed by environmental sounds. Wind noise was present at all recorded frequencies.

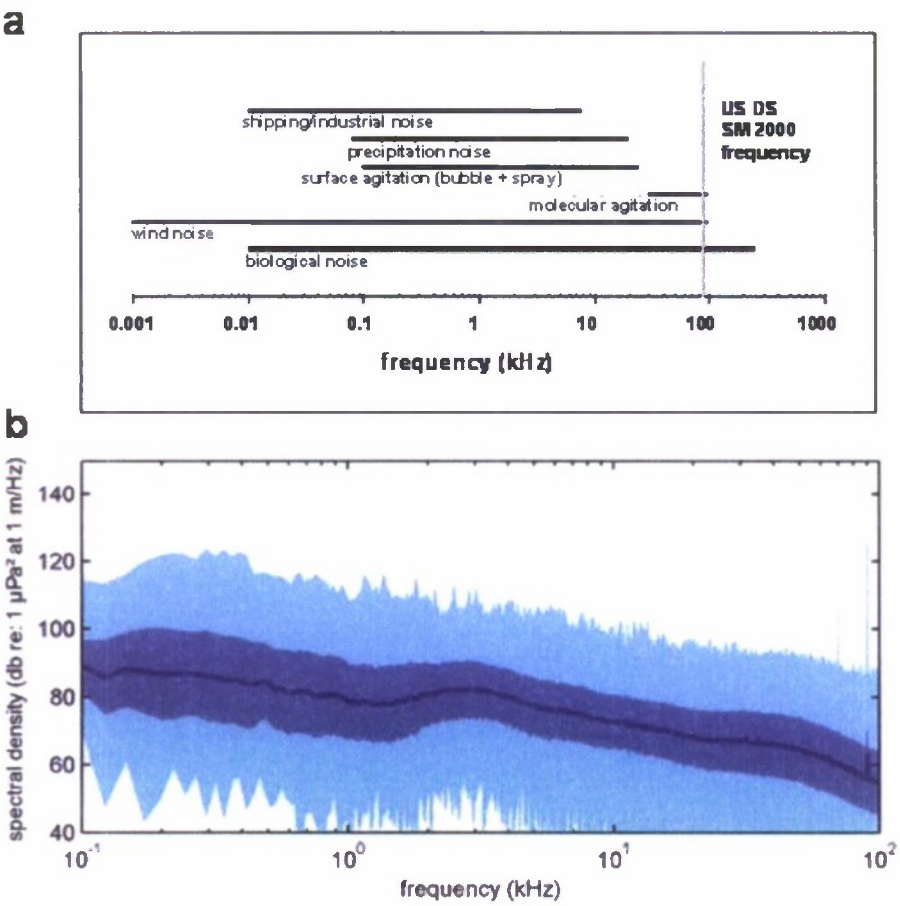


Figure 5-2. Ambient Noise Levels Measured in San Diego
(data from Wenz (1962))

Ambient noise levels measured in San Diego Bay collected during monitoring at the Space and Naval Warfare Systems Command Center (SSC) Pier at north San Diego Bay during the 10-year period were greater at lesser frequencies (blue dark line = mean; shaded dark area = mean ± one standard deviation (SD); shaded light area = maximum and minimum) (figure 5-2b). The sound energy released from explosions at Coronado is much less in frequency (> 1 kHz); however, the sounds are brief, transient signals when compared to more constant sounds of wind and surf. At Coronado Beach and the SSTC boat lanes, ambient noise levels from wind and surf at greater frequencies and from shipping at lesser frequencies are important.

5.2 SINGLE KNOWN SOURCE: UNDERWATER DETONATIONS

The underwater detonations produced during training operations represent a single, known source. Chemical explosives create a bubble of expanding gases as the material burns. The bubble can oscillate under water or, depending on charge size and depth, be vented to the surface, in which case, there is no bubble-oscillation. Venting occurs when the expanding gas bubble ruptures the surface, venting energy to the atmosphere (figure 5-3).

Figure 5-3. Small Detonation Venting Energy at SSTC

As previously stated, explosions produce very brief, broadband pulses characterized by rapid rise-time, great zero-to-peak pressures, and intense sound. Close to the explosion, there is a very brief, high-pressure acoustic wavefront (figure 5-4a). The signal's rapid onset time, in addition to great peak pressure, can cause hearing impairment, although the brevity of the signal can include less SEL than expected to cause impacts. The transient signal gradually decays in magnitude as peak pressure broadens in duration with range from the source (figure 5-4b). The waveform transforms to approximate a low-frequency, broadband signal with a continuous sound energy distribution across the spectrum.

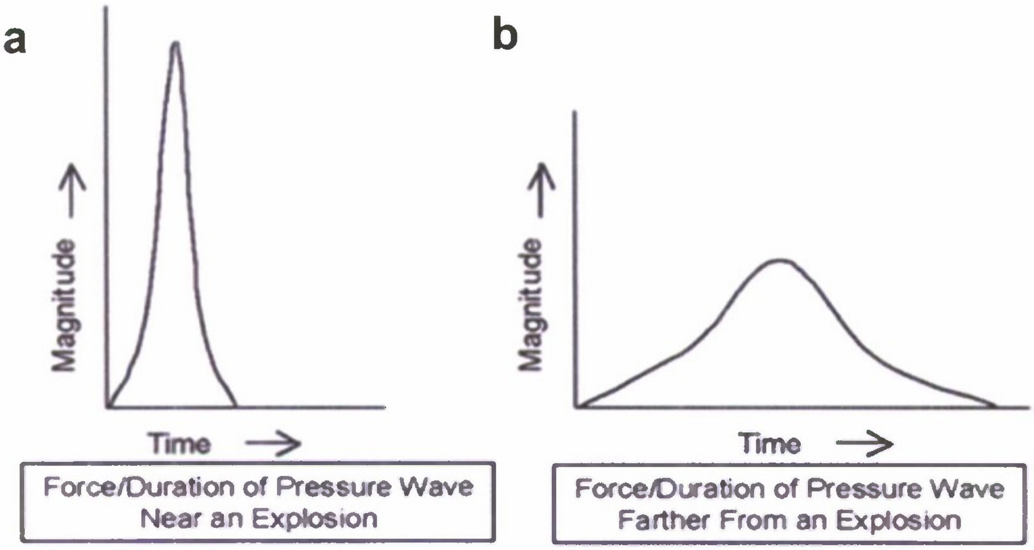


Figure 5-4. Force and Duration of Pressure Wave Based on Distance from the Source

The severity of physiological effects generally decreases with decreasing exposure (impulse, SEL, or peak pressure) and/or increasing distance from the sound source. The same generalization consistently is not applicable for behavioral effects because they do not depend solely on SELs. Behavioral responses also depend on an animal's learned responses, innate response tendencies, motivational state, pattern of the sound exposure, and the context in which sounds are presented. Figure 5-5 depicts the complex and sometimes overlapping relationships between severity of effects, distance from the source, and sound exposure.

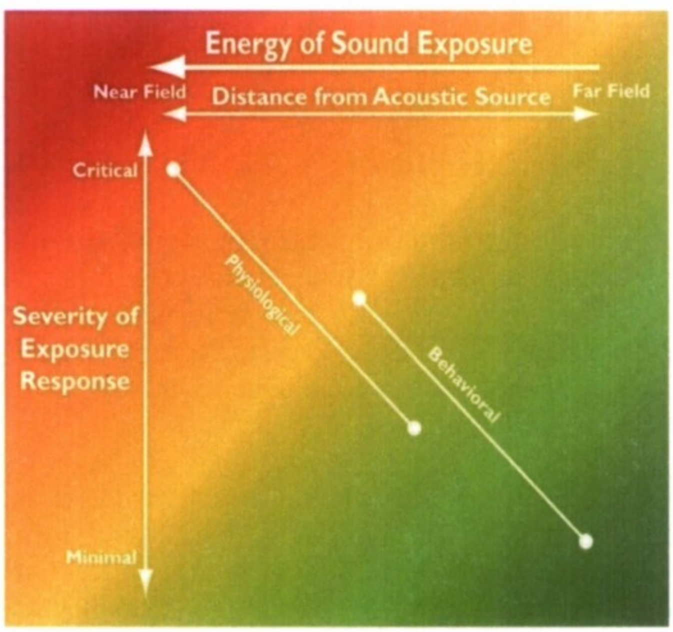


Figure 5-5. Physiological and Behavioral Responses Based on Distance from Sound Source and Sound Exposure

To develop a reasonable approach to determine exposure effects, the sometimes overlapping and complex relationships between and among effects were reorganized according to a biological and regulatory framework (figure 5-6).

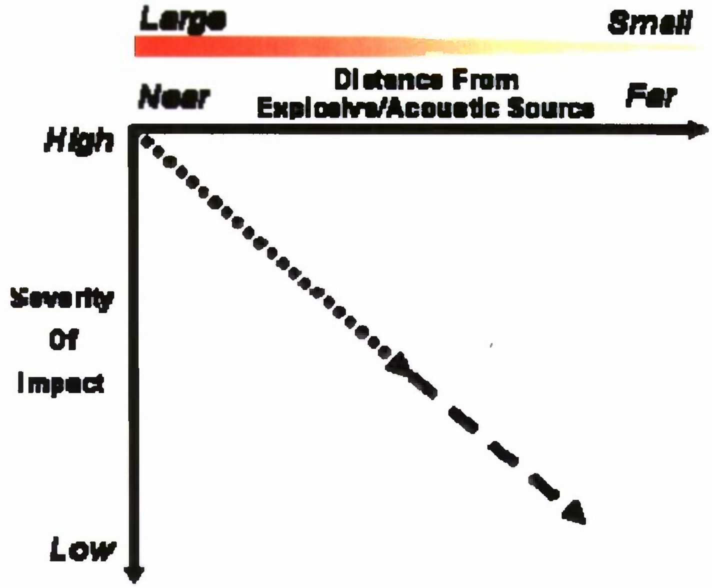


Figure 5-6. Severity of Impacts Based on Distance from Sound Source and Sound Exposure

5.3 BIOLOGICAL AND REGULATORY FRAMEWORK

The following discussion provides structure to categorize potential impacts for regulatory purposes. The biological framework for SSTC described herein established impacts based on estimated exposures.

5.4 PHYSIOLOGICAL AND BEHAVIORAL EFFECTS

Sound exposure may affect multiple biological traits of a marine animal; however, existing protective regulations (i.e., MMPA) provide guidance as to which traits should be used when determining impacts. Specifically, impacts that qualify as Level A harassment should address injury, and impacts that qualify as Level B harassment should address physiological and behavioral disruption. This guidance reduces the number of traits that must be considered in establishing a biological framework of impact assessment.

To provide a tractable approach for predicting acoustic impacts that is relevant to the terms of harassment described in the MMPA National Defense Authorization Act (NDAA) amendments, it is assumed herein that severity of effects linearly decreases with decreasing exposure to detonation energy and increasing distance from the explosive source, without overlapping effects (figure 5-5). The modified relationships between severity of effects, distance from the source, and sound exposure will determine harassment zones (figure 5-6).

The biological framework used for SSTC ordered impacts according to mortality, injury, and physiological and behavioral disruption resulting from an acoustic exposure. The range of effects then may be assessed to determine which qualify as harassment under MMPA. Physiology and behavior are chosen over other biological traits for several reasons: (1) they are consistent with regulatory statements defining harassment; (2) they are components of other biological traits that may be relevant; and (3) they are a more sensitive and immediate indicator of effects. For example, ecology is not used as the basis of the framework because the ecology of an animal is dependent on the interaction of an animal with the environment. The animal's interaction with the environment is attributed to its physiological function and behavior, and an ecological impact may not be observable during short periods of observation.

For the SSTC analysis, the term "normal" is used to qualify distinctions between types of physiological and behavioral effects. Its use follows the convention for a range of normal daily variation in physiological and behavioral function without the influence of anthropogenic acoustic sources. As a result, this analysis uses the following definitions.

A "physiological effect" is defined within the context of this analysis as one in which the "normal" physiological function of the animal is altered in response to sound exposure. A physiological effect, therefore, is a variation in an animal's physiology that results from an anthropogenic sound exposure that exceeds the normal daily variation in physiological function. Physiological function is any of a collection of processes ranging from biochemical reactions to mechanical interaction and operation of organs and tissues within an animal. A physiological effect may range from the most significant of impacts (e.g., mortality, serious injury) to lesser impacts that would define the lower end of the physiological impact range (e.g., non-injurious distortion of auditory tissues). This latter physiological effect is important for the integration of the biological and regulatory frameworks.

A "behavioral effect" is one in which the "normal" behavior of an animal, or patterns of behavior, are overtly disrupted in response to sound exposure. A behavioral effect is a variation in an animal's behavior or behavior patterns that results from anthropogenic sound exposure that exceeds the normal daily variation in behavior, but which arises through normal physiological process (it occurs without an accompanying physiological effect). Examples of behaviors of concern can be derived from the harassment definitions of MMPA.

The definitions of "physiological effect" and "behavioral effect" used herein specifically are defined for this analysis. It is reasonable to expect some physiological responses to result in subsequent behavioral responses. For example, a marine mammal that suffers a severe injury may be expected to alter diving or foraging in such a way that variation in these behaviors is beyond that which is considered normal for the species. If a physiological effect is accompanied by a behavioral effect, the overall effect is characterized as a physiological effect, because physiological effects take precedence over behavioral effects with regard to their ordering. This approach provides the most conservative evaluation of effects with respect to severity, provides a rational approach to dealing with the overlap of the definitions, and avoids circular arguments.

5.4.1 Level A and Level B Harassment

Level A harassment includes any act with the significant potential to injure marine mammals or marine mammal stocks. Injury, as defined in this analysis and previous rules (Department of the Navy (DoN), 2008b; National Marine Fisheries Service (NMFS), 2008), is the destruction or loss of biological tissue. This definition of injury is consistent with reasonable interpretations of the definitions of harassment listed in 16 United States Code (USC) §1362(18)(B) for military readiness activities. Because the destruction or loss of biological tissue would result in an alteration of physiological function outside the normal function of the intact tissue, injury qualifies as a physiological effect. To be consistent with prior actions and rules (Department of the Navy (DoN) 2008b; National Marine Fisheries Service (NMFS), 2008), the SSTC analysis assumes that all injuries (i.e., slight injury) are considered Level A harassment.

Level B harassment includes all actions likely to disturb marine mammals or marine mammal stocks through the disruption of natural behavioral patterns to the point where such patterns are abandoned or significantly altered. Unlike Level A harassment, which is associated solely with physiological effects, both physiological and behavioral effects have the potential to cause Level B harassment.

Some physiological effects can occur that are non-injurious but potentially can disrupt the behavior of a marine mammal. These include temporary distortions in sensory tissue that alter physiological function but are fully recoverable without the requirement for tissue replacement or regeneration. For example, an animal that experiences a temporary reduction in hearing sensitivity suffers no injury to its auditory system but may not perceive some sounds due to the reduction in sensitivity. As a result, the animal may not respond to sounds that would normally produce responses. This lack of response qualifies as a disruption of normal behavioral patterns—the animal is impeded from responding in a normal manner to an acoustic stimulus because it cannot hear sounds well (or at all) at those frequencies. To be consistent with prior actions and rules (Department of the Navy (DoN), 2008b; National Marine Fisheries Service (NMFS), 2008), the SSTC analysis assumes that all temporary hearing impairment (i.e., ranging from slight to severe temporary threshold shift (TTS)) and behavioral disruption (i.e., non-TTS) is considered Level B harassment.

Section 319 of the NDAA of 2004 (Public Law (PL) 108-136) revised the definition of "harassment" in MMPA (16 USC §1362[18]) to apply to military readiness activities. The term "military readiness activity" was defined in Section 315(f) of NDAA 2003 (PL 107-314) and adopted in NDAA 2004 as any activity undertaken by the government for the purpose of "training and operations of the Armed Forces that relate to combat," and that provides for the "adequate and realistic testing of military equipment, vehicles, weapons, and sensors for proper operation and suitability for combat use." The proposed operations at SSTC meet these definitions, thus, the development of the marine mammal harassment criteria and thresholds are based on the revised definitions of Level A and Level B harassment as stated above.

5.4.2 Harassment Zones

The ocean space within the boundaries of the radii for Levels A and B harassment are described as harassment zones. Although propagation and associated losses are not uniform throughout the water column, the effect is considered uniform from the point of greatest radial distance. The zones cylindrically extend from a hypothetical omnidirectional explosive source between surface and seafloor for each type of impact. During simulations, all animals within these zones are to be considered "exposed" and classified by the applicable harassment type (figure 5-7). Thus, circular zones are created at the surface to facilitate conservative protective measure procedures.

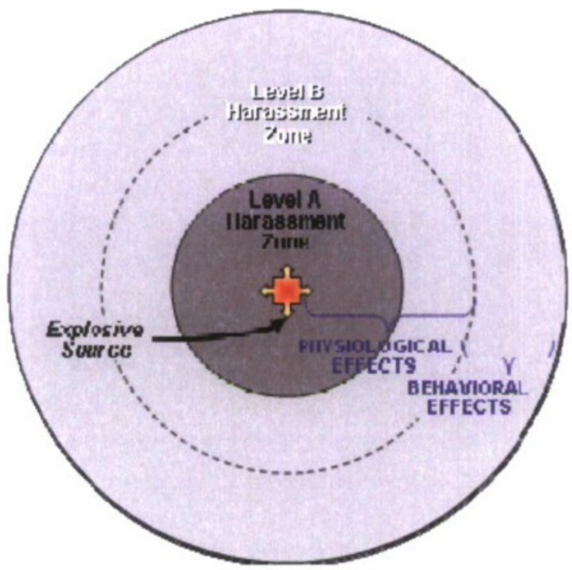


Figure 5-7. Relationship Between Physiological and Behavioral Effects and Associated Levels A and B Harassment Zones

The physiological and behavioral effects associated with harassment zones are defined using impact criteria and thresholds. Impact effects and associated zones are provided from nearest the detonation and most severe effect to farthest from the detonation and least observable effect.

5.4.2.1 Mortality and Level A Harassment Zones – Mortality and Injury. Shock waves produced by underwater detonations can kill or injure exposed animals. The zone for mortal injury is defined as the region within which animals are not expected to survive. The auditory system and lungs of mammals are the structures most sensitive to shock wave injuries of all other systems. Extensive lung hemorrhaging is considered debilitating and potentially fatal as a result of air embolism or suffocation (Richmond et al., 1973; Yelverton et al., 1973). The criterion for mortality used in this analysis was extensive lung injury (ELI). The lowest expected exposure level causing the onset of ELI was used to define the zone for mortal injury. In the SSTC analysis, all marine mammals within the calculated radius from the detonation to onset of ELI were considered mortal exposures.

Animals experiencing lesser impulse levels than those that cause ELI will still have lung injuries, but the animals are expected to survive. The lowest expected exposure level causing the onset of slight lung injury (SLI) was used in addition to tympanic membrane rupture (TMR) (i.e., cochlea or inner ear damage) to define the zone for injury. In the SSTC analysis, all marine mammals within the calculated radius from the detonation to onset of SLI or TMR were considered Level A harassment (injury) exposures.

5.4.2.2 Level B Harassment Zone – TTS. TTS is recoverable and, as in recent rules (National Marine Fisheries Service (NMFS), 2008), is considered to result from the temporary, non-injurious over-stimulation of hearing-related tissues. In this analysis, the smallest measurable amount of TTS (onset-TTS) is considered the best indicator for slight temporary sensory impairment. The acoustic exposure associated with onset-TTS is used to define the greatest radial distance at which Level B harassment (TTS) occurs. This TTS zone creates the boundary of physiological effects. Thus, hearing loss potentially affects an animal's ability to normally react to the sounds around it and potentially impairs normal behavior by preventing or disrupting behaviors that depend on hearing. In the SSTC analysis, all marine mammals within the calculated radius from the detonation to onset of TTS were considered Level B harassment (TTS) exposures.

5.4.2.3 Level B Harassment Zone – Non-TTS. The SSTC analysis defines behavioral effects as variations in an animal's behavior that exceed the normal daily variation in behavior. An animal behaviorally responds (or does not) following an anthropogenic sound exposure but does not have a physiological response as mentioned above. In the legislation of MMPA, Level B harassment includes only those acts that disturb or are likely to disturb by causing disruption of behavioral patterns to the point where those patterns are abandoned or significantly altered. Previous rules and actions (66 FR 87; 67 FR 136; 73 FR 143) have concluded that a momentary behavioral reaction of an animal to a brief, time-isolated acoustic event does not qualify as Level B harassment (66 FR 87; 67 FR 136) (National Marine Fisheries Service (NMFS), 2008). Level B harassment occurs only when there is "potential for a significant behavioral change or response in a biologically important behavior or activity" (National Marine Fisheries Service (NMFS) et al., 2002). Moreover, this conclusion is further supported by the NDAA of 2004 (PL 108 – 36) for actions involving military readiness (paragraph 5.4.1).

Single explosions produce short-duration transient signals that are brief and time isolated. In this analysis and consistent with prior rules (67 FR 136) slight, momentary disruptions, such as startle or alerting, are unlikely to have biologically significant consequences for animals that hear an explosion without direct physiological impact, such as TTS. For MSEs, the Level B harassment zone includes the area where biologically significant (mating, feeding, etc.) behavioral disruption is expected to occur. In the SSTC analysis, all marine mammals within the calculated radius from the detonation to onset of non-TTS were considered Level B harassment (non-TTS) exposures.

5.4.3 Auditory Masking

One of the most important results of sound exposure is masking of acoustic queues by natural and artificial sounds. Masking can disrupt behavior by interfering with an animal's ability to hear other sounds and occurs when the receipt of a sound is interfered with by another coincident sound at similar frequencies and at similar or greater levels. If the coincident sound were anthropogenic, it potentially could be considered harassment (according to MMPA) if it disrupted hearing-related behavior such as communications or echolocation. It becomes important at this point to distinguish masking caused by an auditory threshold shift (TS), which persists after the exposure, from masking of sounds during the exposure without TS.

The most intense underwater sounds at SSTC are likely those produced by explosions. Given that the spectral distribution of energy from an explosion covers a broad frequency spectrum, sound from training likely would be within the audible range of most cetaceans and pinnipeds. However, the time scale of the detonations is very limited; the pulse lengths are short; the repetitions of the shots are few; and the total time per year during which detonations produce masking is negligible. The probability of masking acoustic signals associated with the behavior and survival of marine mammal species for any detonation during training operations, therefore, is negligible. Thus, masking is unlikely without some degree of physiological impact (i.e., TTS) or abnormal physiological function. Masking can result from TTS because an animal will not hear sounds it would normally respond to. In this situation, masking is associated with abnormal behavior and is considered Level B harassment.

5.4.4 Acoustic Impact Framework

When viewed from the surface (figure 5-8), the circular zones depict the acoustic impact framework used in this analysis. Potential effects are categorized as either physiological or behavioral. Categorizing impacts allows effects to be related to MMPA harassment definitions. The ocean space in which Levels A and B harassment are estimated to occur is considered cylindrical harassment zones, bounded by the surface and bottom sediments, when projected underwater.

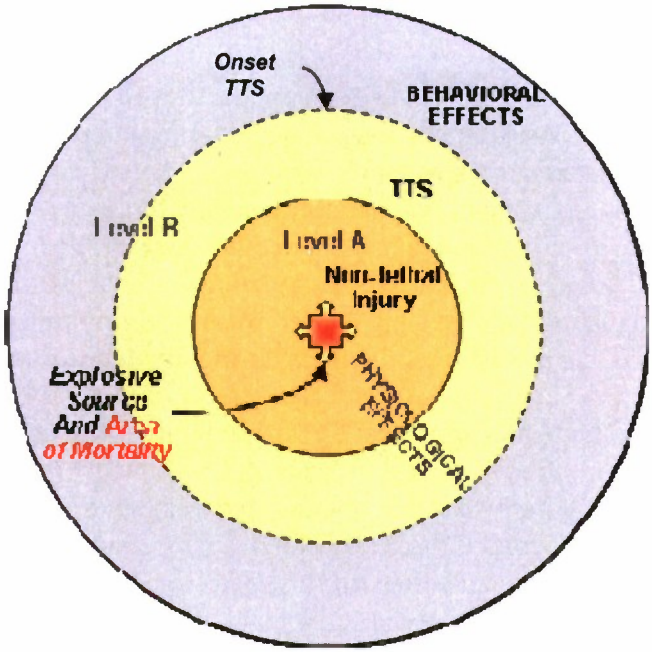


Figure 5-8. Notional Framework of Physiological and Behavioral Effects Based on Mortality and Levels A and B Harassment As Used in SSTC Analyses

Mortality zones extend from the center to the greatest estimated range for mortality. The radius of the Level A harassment (injury) zone extends from the detonation outward to the greatest estimated range for onset of slight injury. Beyond the radial distance for onset of slight injury is the Level B harassment zone (TTS or non-TTS), which extends to the greatest estimated range for onset of TTS for single explosions or to the greatest estimated range for non-TTS effects for MSEs. Consistent with previous NMFS rulings, single, time-isolated impulsive events that cause brief responses within the range of normal behaviors are not considered harassment; however, MSEs may significantly disrupt on-going behavior and do qualify as Level B harassment (non-TTS).

6. METRICS, CRITERIA, AND THRESHOLDS

6.1 METRICS AND TERMINOLOGY

Several standard acoustic metrics (Urick, 1983) are used to describe the thresholds for predicting potential physical and behavioral effects from underwater detonations within this document:

- Positive Impulse – This is the time integral of the initial positive pressure pulse of an explosion or explosive-like wave form. Standard units are pascal – second (Pa-sec), but pounds per square inch – millisecond (psi-msec) also is used. There is no decibel analog for impulse.
- Total SEL – For plane waves, as assumed herein, SEL is the time integral of the instantaneous intensity, where the instantaneous intensity is defined as the squared pressure divided by the impedance of seawater. Units for total SEL are decibels referenced to 1 micropascal squared – seconds (dB re 1μPa^2-sec).
- 1/3-Octave SEL – This is the SEL in a 1/3-octave frequency band. A 1/3-octave band has upper and lower frequency limits with a ratio of $2^{1/3}$, creating bandwidth limits of about 23% of center frequency. Units for 1/3-octave band SEL are dB re 1 μPa^2-sec.
- Peak Pressure – This is the maximum positive amplitude of a pressure wave dependent on charge mass and range. Units used herein are pounds-per-square inch (psi), but micropascal (μPa) and bar also are used.

The following terminology is used in this section:

- Criterion – This is the specific impact that could be used to represent a broad type of impacts (mortality, injury, physiological and behavioral disruption). For example, onset of ELI is used as the criterion for mortality in the SSTC analysis.
- Threshold – This is the specific level of impulse, SEL, or peak pressure needed to cause the specific impact stated as a criterion.
- Range – This is the maximum horizontal distance from the detonation point to the location where the threshold level is estimated to occur.

6.2 CRITERIA

Criteria for predicting physical and behavioral effects (mortality, injury, and physiological and behavioral disruption) to marine mammals initially were developed for the U.S. Navy shock trials of the *Seawolf* submarine (Department of the Navy (DoN), 1998) and the surface ship *Winston S. Churchill* (WSC) (Department of the Navy (DoN), 2001). These criteria and subsequent thresholds were adopted by NMFS and published in numerous Final Rules (63

FR 230; 66 FR 87; 73 FR 35510; 73 FR 60836 (table 6-1). A change to the peak pressure metric for TTS from ship shock trials, an increase from 12 psi to 23 psi, has been adopted by NMFS (70 FR 160; 71 FR 92; 73 FR 35510; 73 FR 60836). A brief description of each of the criteria is presented in descending order of severity of effects. A single criterion was used for predicting mortality and behavioral disruption, and dual criteria were used for predicting slight injury for onset of SLI and 50% TMR. Additionally, dual thresholds were used to predict physiological disruption from TTS. For slight injury and TTS metrics, greatest horizontal ranges were compared; the criterion or threshold with the greater range for effects was used because it was the more conservative of the two. Individual animals can experience multiple or simultaneous effects, but when physical effects are assessed using these criteria and thresholds, animals only are included in the estimates at the greatest level of effect. In addition, behavioral disruption only is applicable for MSEs (i.e., Mk 46 or 54 torpedoes). For a more complete explanation of associated criteria and thresholds, see the final environmental impact statements (FEISs) of the *Seawolf* (Craig and Hearn, 1998) and of the WSC (Craig Jr., 2001).

Table 6-1. Criteria and Thresholds for Predicting Physical and Behavioral Effects to Marine Mammals During Underwater Detonations at SSTC

	Criterion	Metric	Threshold	Comments
Mortality	**Mortality** Onset of extensive lung injury	**Shock Wave** Goertner's modified positive impulse, indexed to the surface	$I = 42.9 (M/34)^{1/3}$ psi-msec *calculated to be* 30.5 psi-msec	For all size classes of marine mammals
Level A Harassment	**Slight Injury** Onset of slight lung injury	**Shock Wave** Goertner's modified positive impulse, indexed to the surface	$I = 19.7 (M/42)^{1/3}$ psi-msec *calculated to be* 13 psi-msec	For all size classes of marine mammals
	Slight Injury 50% tympanic membrane rupture	**Shock Wave** Total SEL, for any single exposure	205 dB re 1 μPa^2-sec	All marine mammals
Level B Harassment	**Physiological Disruption** TTS	**Sound Exposure** Greatest SEL in any 1/3-octave band, over all exposures	182 dB re 1 μPa^2-sec	Greatest SEL for frequencies $\geq$ 100 Hz for odontocetes and $\geq$ 10 Hz for mysticetes
	Physiological Disruption TTS	**Sound Exposure** Peak pressure, for any single exposure	23 psi	All marine mammals
	Behavioral Disruption non-TTS[1]	**Sound Exposure** Greatest SEL in any 1/3-octave band, over all exposures	177 dB re 1 μPa^2-sec	Greatest SEL for frequencies $\geq$ 100 Hz for odontocetes and $\geq$ 10 Hz for mysticetes

[1] Only applicable to MSEs.

6.3 CRITERIA AND THRESHOLDS FOR MORTALITY AND LEVEL A HARASSMENT

Primary detonation injuries are the result of a rapid change in movement, initial compression of organs, and a rapid expansion of those same organs. These primary injuries usually are limited to gas-containing organs and the auditory system (Craig and Hearn, 1998; Craig Jr., 2001). Therefore, two types of detonation injury criteria were developed and used during this analysis. One criterion was based on injury to gas-containing internal organs, and the second criterion was based on injury to the auditory system.

Injuries to internal organs and the auditory system from shock waves and intense impulsive sound associated with explosions can be exacerbated by strong bottom-reflected pressure pulses in reverberant environments (Gaspin, 1983; Ahroon et al., 1996). However, modeling of underwater detonations has shown that strong bottom-type interactions are not likely during these exercises, given the water depth and attenuation of detonation energy. Therefore, bottom-reflected energy does not significantly factor into consideration of injury or reduce the conservative nature of the criteria and thresholds described below.

6.3.1 Mortality and Injury

The vulnerability of marine mammals to underwater detonation injuries remains largely unknown (Ketten, 1995). However, evidence indicates that gas-containing internal organs, such as lungs and intestines, were the principal damage sites from shock waves in submerged terrestrial mammals (Clark and Ward, 1943; Greaves et al., 1943; Richmond et al., 1973; Yelverton et al. 1973). In air or submerged, however, the most commonly reported internal bodily injury was hemorrhaging in the fine structure of the lungs. Researchers found that biological damage was governed by the impulse of the underwater detonation (pressure integrated over time), not peak pressure or energy (Richmond et al., 1973; Yelverton et al., 1973; Yelverton et al., 1975; Yelverton and Richmond, 1981). Therefore, impulse was used as a metric upon which internal organ injury could be predicted, which is consistent with other efforts to predict the effects of underwater detonations (e.g., ship shock).

During several of the studies mentioned above, a second relationship between shock wave and injury was noted. Larger animals are less subject to injury than small animals when exposed to the same impulse levels (Clark and Ward, 1943; Greaves et al., 1943; Richmond et al., 1973; Yelverton et al., 1973). Lung injury also was reduced when lungs were deflated versus inflated during passage of a shock wave (Clark and Ward, 1943). Although test mammals varied in mass between 13 and 205 lb (Clark and Ward, 1943; Greaves et al., 1943; Richmond et al., 1973; Yelverton et al., 1973), best-fit regression equations were developed, and greater masses were extrapolated. The range at which extrapolations remain valid is unknown.

An analysis of potential mortality of submerged terrestrial mammals exposed to small explosive charges has been conducted (Yelverton and Richmond, 1981; Craig Jr., 2001). The following equations represent the best fit of those data to the observed mortality during the experiments:

50% Mortality	$\ln(I) = 3.019 + 0.386 \ln(M)$,
1% Mortality	$\ln(I) = 2.588 + 0.386 \ln(M)$,
0% Mortality	$\ln(I) = 1.969 + 0.386 \ln(M)$,

where I = impulse in psi-msec and M = mass in kg.

The resulting regression curves then were plotted (figure 6-1), so that prediction of mortality to larger animals could be determined as a function of positive impulse and mass.

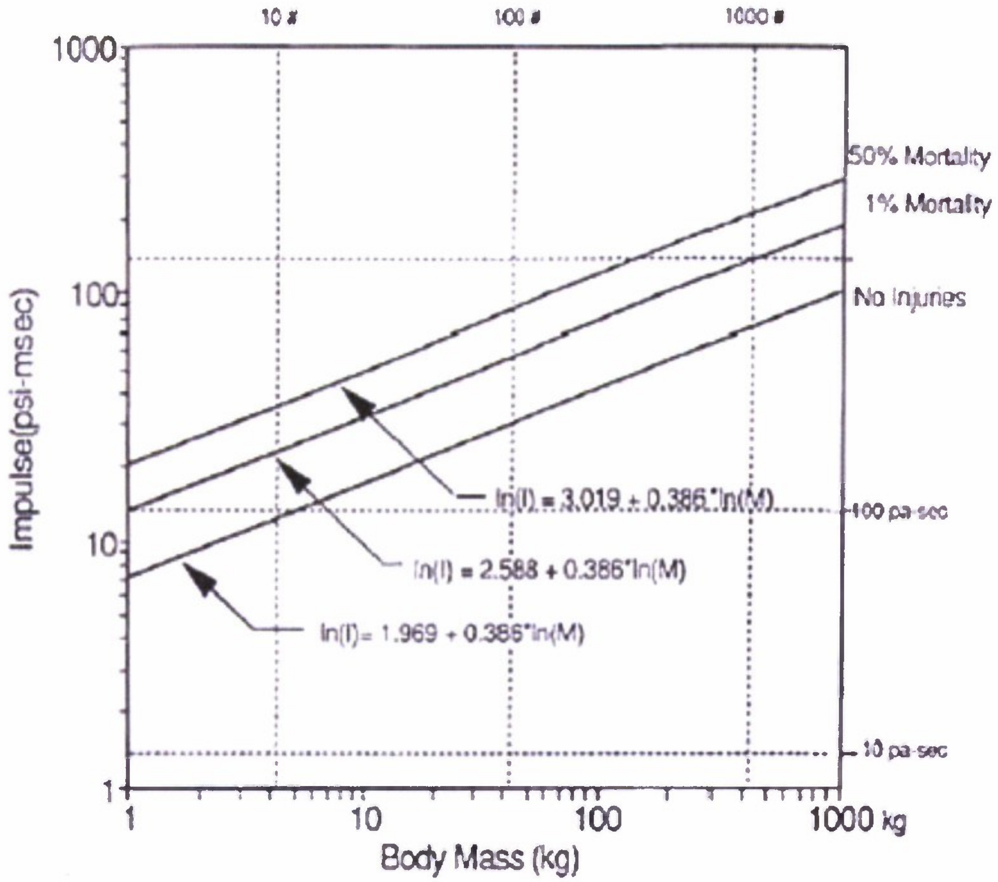


Figure 6-1. Regression Curves for Detonation Damage to Submerged Terrestrial Mammals As a Function of Mass (Craig Jr., 2001).

The positive impulse values used for the onset of extensive injury and mortality relied on regression curves for 1% mortality and, thus, included the 50% mortality curve. The positive impulse values used for injury criteria, the onset of slight injury, in this document, relied on the regression curve for no injury (0% mortality).

A conservative model for predicting safe ranges from underwater detonations was developed for which risk of lung and gastrointestinal tract injury was low, using those same data and the relationships between mass, estimated lung volume, and depth (Goertner, 1982). For example, the Goertner model represented the lung as a freestanding sphere of gas surrounded by water. However, during measurements of acoustic impedance in the tissues of cetaceans, the blubber-muscle interface was an effective sound reflector (Norris, 1975). Thus, a significant fraction of shock wave energy may not transfer from blubber to muscle (Hill, 1978). The regression curves shown above do not account for impedance differences in the tissues of a marine mammal versus those of terrestrial species, as test subjects were land mammals. Extensive supportive tissues surrounding lungs and airways of a marine mammal may dampen shock wave energy and reduce peak pressure, decreasing their vulnerability to shock wave damage (Hill, 1978). In consideration of these factors, the use of the Goertner model for predicting injury from shock waves is considered conservative.

Establishing criteria for shock wave injury began with defining parameters (i.e., masses) that were representative. Modeling underwater detonations at SSTC remained philosophically consistent with ship shock trial approaches by using conservative masses for marine mammals. The shock trial used a single mass, that of a dolphin calf (27 lb) to represent all marine mammals (Department of the Navy (DoN), 2001). Additionally, the use of this overly conservative dolphin calf mass for determination of impulse thresholds for all size classes of marine mammals has been used in the Hawaii Range Complex and Southern California FEISs (73 FR 35510; 73 FR 60836) and will be used herein. The thresholds for onset of ELI and SLI represent the minimum impulses indexed to the surface used for predicting onset of extensive and slight injury from the Goertner model (Goertner, 1982).

6.3.1.1 Onset of Extensive Lung Injury. The lowest impulse to cause extensive injury to submerged 75-lb terrestrial mammals was 44.4 psi-msec (Richmond et al., 1973). After correction for atmospheric and hydrostatic pressures and based on the cube-root scaling of body mass as used in the Goertner injury model, the minimum impulse for predicting onset of ELI based on the "1% mortality" equation from figure 6-1 is calculated using the following equation:

$$I = 42.9\ (M/34)^{1/3} \text{ psi-msec},$$

where I = impulse in psi-msec, and M = mass in kg.

Therefore, onset of ELI (mortality) indexed to the surface is 30.5 psi-msec for all size classes of marine mammals (figure 6-1).

6.3.1.2 Onset of Slight Injury. Slight injury is a type of impact where animals may survive despite the trauma. At levels less than those causing mortality, the lungs and auditory system are vulnerable to damage and were considered slight injury. The two thresholds for slight injury were paired and applied as dual criteria–onset of SLI and TMR. Because slight injury criteria are dual in nature, the quantification of individuals exposed was determined by the threshold with the greatest horizontal surface distance associated with it.

6.3.1.2a Onset of Slight Lung Injury. The lowest impulse to cause slight injury to submerged 93-lb terrestrial mammals was 22.8 psi-msec (Richmond et al., 1973). After correction for atmospheric and hydrostatic pressures and based on the cube-root scaling of body mass as used in the Goertner injury model, the minimum impulse for predicting onset of SLI based on the "no-injury" equation from figure 6-1 is calculated using the following equation:

$$I = 19.7\,(M/42)^{1/3} \text{ psi-msec},$$

where I = impulse in psi-msec, and M = mass in kg. Therefore, onset of SLI indexed to the surface is 13 psi-msec for all size classes of marine mammals (figure 6-1). Animals exposed to these impulse levels (and above), but do not receive ELI, are assumed to fully recover in the wild.

6.3.1.2.b Injury to the Auditory System. Injury to the ear is the most commonly reported injury from detonation energy transmitted to the body through air (Eldredge, 1955). Near the detonation, rapid rise time and over-pressure cause structural damage to tissues within the auditory system. Currently, little is known regarding how the hearing of marine mammals may be affected by an underwater detonation. They retain the basic blueprint for the mammalian ear and, therefore, are expected to similarly respond to detonations as observed in terrestrial mammals (Ketten, 1998a). For underwater detonations and marine mammal hearing effects, important considerations are rise-time and duration of peak shock wave pressures (Ketten, 1995).

While there were well-defined differences in susceptibility to acoustic trauma from detonation exposure among species, common findings associated with one another were damage to the conductive system, including TMR and acute mechanical damage within the cochlea and some sensory cell loss (Hamernik et al., 1984; Roberto et al., 1989). Although not synonymous with permanent threshold shift (PTS) because TMR may be caused by a slight over-pressure, there is a strong correlation to PTS in humans under certain conditions and, therefore, presumably for marine mammals (Ketten, 1998a). As the frequency of TMR increases, permanent hearing losses increase. During instances of humans exposed to a detonation where at least 50% TMR was observed, roughly 30% of the victims had some amount of PTS and 10% had significant hearing loss (Kerr and Byrne, 1975; Ketten, 1995).

Studies of submerged terrestrial mammals exposed to shock waves generated by small explosions documented that TMR occurred at sublethal impulse levels between 20 and 40 psi-msec (Yelverton et al., 1973). For auditory impairment assessment, the flux of acoustic energy associated with a detonation (i.e., SEL) may be the more appropriate parameter for evaluating slight injury because it has been greatly correlated with damage level. Other metrics like peak pressure have proved unreliable, in part, because it does not provide information regarding duration of peak pressure as do impulse or SEL. The interpolated SEL, where 50% TMR was expected, is approximately 1.17 in-lb/in^2 (Craig and Hearn, 1998; Craig et al., 2001). If environmental acoustic impedance and reference acoustic impedance are the same, the equivalent SEL is approximated by 205 dB re 1 μPa^2-sec (table 6-1).

6.4 CRITERIA AND THRESHOLDS FOR LEVEL B HARASSMENT

Physiological and behavioral disruption from sound that has biological significance to marine mammals was identified by acoustic exposures having non-injurious physiological impacts to the auditory system (i.e., hearing impairment) and exposures triggering adverse behaviors outside the range of "normal" responses but without sensory impairment. In one case, animals cannot hear as well as they would under normal circumstances (absent anthropogenic sound exposure). In the other case, animals can hear perfectly well and voluntarily are reacting to the sound and, possibly, the level, pattern, or intensity of the signal(s). Two types of Level B harassment were considered due to mammals eliciting two distinct responses, physiological and behavioral. These two types of impacts were used to predict numbers of estimated exposures.

6.4.1 TTS – Dual Criteria

All mammals possess similar auditory system anatomy and appear to similarly respond to acoustic stimuli. Several exposure stimuli factors affect a TS, including level, duration, spectral content, and temporal pattern (Yost, 2000). In general, it is energy in a tonal noise exposure that determines hearing impairment. The equal energy hypothesis originally stated that the acoustic trauma associated with continuous noise exposure was related to the total energy received by the ear during the defined exposure period (Eldred et al., 1955). This principle was extended to predict hearing impacts with lesser intensities and levels of impulsive sound (Hamernik et al., 1984; Danielson et al., 1991). At greater distances than those causing mechanical damage to structures of the auditory system, exposure to energy from a detonation can cause varying degrees of TS when sensory tissues within the cochlea are over-stimulated. A TTS is defined as a recoverable loss of hearing sensitivity.

The relationships between impulsive sound exposure (e.g., impulse, energy, peak pressure, duration) and hearing effects are not well understood. To protect workers' hearing that is exposed to impulsive sounds, the National Institute of Occupational Safety and Health recommended an equal energy rule coupled with a peak pressure upper limit (United States Department of Health and Human Services, 1998). Marine mammal ears functionally and structurally are similar to terrestrial mammal ears; however, there also are important differences between their structures, functions, and sound conduction mechanisms (Ketten, 2000). For these reasons, it is not appropriate to directly apply numerical values for human or terrestrial mammal damage-risk thresholds to marine mammals even when sound reference level and impedance differences between air and water are considered. The impact thresholds for TTS in marine mammals used herein are a variation of those developed for ship shock trials (Helweg et al., 1998; Sigurdson et al., 2001) that include data from recent studies (Finneran et al., 2000; Finneran et al., 2002).

6.4.1.1 TTS SEL Threshold. Initial determination of thresholds for TTS relied on data for bottlenose dolphins exposed to 1-sec pulsed tones and then applied to single detonations (impulse of explosion) isolated in time (Ridgway et al., 1997). Because the length of pulse was 1 sec, the exposures could be reported as sound pressure level (SPL); decibels referenced to 1 micropascal (dB re 1 μPa) or SEL (dB re 1 μPa^2-sec). The threshold was based on test results originally published in Ridgway et al. (1997) and later published as Schlundt et al. (2000), with derivation following the approach of the Seawolf FEIS (Department of the Navy (DoN), 1998) for the energy-based TTS threshold. Ridgway et al. (1997) reported consistent TTS in the range of 192 – 201 dB SPL or SEL. Thus, a conservative bound for SPLs or SELs for delphinid odontocetes was considered 192 dB SPL or SEL.

Energy is proportional to the square of pressure integrated over time and commonly is discussed in reference to 1/3-octave bands. This is due to audiometric data suggesting that the human cochlea can be modeled as a bank of 1/3-octave filters (Fay, 1988), as can the cochlea of dolphins (Johnson, 1968). The measured sound time integration constant of the bottlenose dolphin ear was approximately 100 – 200 msec for brief stimuli (Johnson, 1968). For the range of measured time integration, 100 msec was considered the most conservative. Thus, the allowable energy is estimated to be that which occurred with the 100-msec time integration or 182 dB re 1 μPa^2-sec (= 192 dB + (10 x log (0.1 sec)). The energy threshold for TTS was 182 dB re 1 μPa^2-sec (table 6-1) maximum SEL level in any 1/3-octave band at frequencies above 100 Hz for odontocetes and above 10 Hz for mysticetes. The assumptions made during the original determination of the 182 dB re 1 μPa^2-sec threshold for impulsive sound and TTS in cetaceans relied on the most conservative values in the field with limited available data.

Since Ridgway et al. (1997), more detailed information has become available in the scientific literature regarding impulsive sound energy and TS. As this research has advanced, subsequent TTS studies have been published, which evaluated the effects of impulsive sound exposures to beluga whales and bottlenose dolphins (Finneran et al., 2000; Finneran et al., 2002). Sound with an SEL greater than 186 dB re 1 μPa^2-sec produced a slight TTS in a beluga whale, while no TTS was observed in the bottlenose dolphin at maximum exposure levels attained (188 dB re 1 μPa^2-sec) (Finneran et al., 2000; Finneran et al., 2002). Caution was exercised when implementing acoustic criteria, and these data have not reached the regulations as have the 182 dB re 1 μPa^2-sec. The information was mentioned for completeness sake and to acknowledge publication of the "best available" science because it used actual data regarding delphinids and impulsive sound exposure that was not available when the original threshold was determined. Recent data also lend support to the argument that the TTS energy-based criterion is conservative in nature.

6.4.1.2 TTS Peak Pressure Threshold. For exposures on the order of seconds to tens of minutes, terrestrial and marine mammal studies have demonstrated that the amount of TTS is correlated with received energy (Ward et al., 1958; Ward et al., 1959; Finneran and Schlundt, 2003; Finneran et al., 2005). If peak sound pressure exceeds a threshold level, hearing may be affected, although a longer duration sound of equal energy may have no effect (Hamernik et al., 1984; Henderson and Hamernik, 1986; Liberman and Hodge, 1987; Ahroon et al., 1993). Therefore, equal energy approaches for impulsive sources, such as explosions, may not always be relevant or adequately predict risk of hearing impairment (McRobert and Ward, 1973; Henderson et al., 1982; Henderson and Hamernik, 1986).

Recently, direct data regarding TTS and impulsive sound exposure were gathered using two species of odontocetes (a beluga whale and bottlenose dolphins) and titrating exposures until minimum measurable onset-TTS (Finneran et al., 2000; Finneran et al., 2002). Peak pressures up to 21 psi did not produce TSs in either subject. At the next step increase (23 psi), a slight TTS was observed in the beluga whale but not in the bottlenose dolphin. At maximum levels created by laboratory apparatus (32 psi), TTS was not measured in the bottlenose dolphin, thus the onset-TTS level was not measured (Finneran et al., 2002). These directly applicable data became the basis for establishing a maximum peak pressure exposure limit of 23 psi (table 6-1) in the regulations (70 FR 160; 71 FR 92; 73 FR 35510; 73 FR 60836).

6.4.2 Application of TTS Thresholds

To predict the onset of TTS from exposure to underwater detonations, the thresholds based on energy and peak pressure were used in a dual fashion. If the exposure level was equivalent or exceeded either impact threshold, animals were assumed to experience TTS—provided that the animals were not within the injury zone. All animals estimated to receive a sound exposure with an SEL greater than or equal to 182 dB re 1 μPa^2-sec or peak pressure greater than or equal to 23 psi are assumed to experience TTS. Only the more conservative estimator (SEL or peak pressure) was used to predict TTS. This estimator also was used to predict the ZOE. A note of caution regarding these thresholds is that the amount of TS is not estimated. The greater a TS, the longer it takes to recover.

6.4.3 Non-TTS

Understanding the significance of behavioral changes in response to sound or noise, even under tightly controlled conditions, is not always apparent because of natural variation of dependent measures and variation among individuals (Richardson et al., 1991). At distances farther than the zones for auditory system physiological responses (i.e., TTS) is the zone of responsiveness to sound. Within this zone, animals within a population will respond differently; some habituate, and some become sensitized to the sound. Slight behavioral disruption without TTS has been addressed in previous actions and rules (63 FR 230; 66 FR 87) (Department of the Navy (DoN), 2001). Under those rules and their interpretations, a disruption with adverse consequences occurs when there is "a potential for a significant behavioral change or response in a biologically important behavior or activity" (67 FR 136; 69 FR 124).

At greater distances than those causing TTS, animals may strongly react in a manner consistent with Level B harassment. In keeping with the rationale for estimating short-term impacts with non-overlapping zones, a second category of behavioral disruption (i.e., Level B harassment (non-TTS)) was added to account for non-physiological, behavioral response to sound. In general, and by this rationale, reactions to sound become greater as the distance to the source lessens.

During the course of the TTS tests mentioned above, researchers at SSC recorded behavioral reactions of the beluga whale and bottlenose dolphins (e.g., swim time between stations) were used to determine if the behavior change was significant. The SSC studies reported behavioral reactions as the subjects were exposed to sounds of increasing intensity. The most common reactions were attempts by the subjects to avoid the site of previous noise exposure or an exposure in-progress. Schlundt et al. (2000) gave a brief summary of the more significant behavioral changes they observed in beluga whales and bottlenose dolphins exposed to pure tones. A more detailed summary of behavioral responses of beluga whales and bottlenose dolphins exposed to 1-sec tones is presented in Finneran and Schlundt (2003).

The behavioral disturbance (without TTS) threshold for tones as derived from the SSC tests was found to be 5 dB below the threshold for TTS (182 dB re 1 μPa^2-sec). At those exposure levels, roughly 25% of the test subjects showed adverse responses to sound during experiments. Using 25%, 177 dB re 1 μPa^2-sec is a conservative marker for the results using trained, captive odontocetes. Use of the threshold incorporates the assumption that 100% of the animals exposed below 177 dB re 1 μPa^2-sec do not behaviorally respond in a manner considered Level B harassment (table 6-1). Conversely, 100% of those exposed at or above this level will disrupt their behavioral patterns in ways reasonably foreseeable as Level B harassment. A detailed discussion of the derivation of the non-TTS threshold from empirical data can be found in the appendix.

6.5 CRITERIA AND THRESHOLDS FOR HUMANS

Human safety during training is a critical concern rising above those for marine mammals (see subsection 8.4.3). Humans are involved in many training operations as divers. While the modeling effort and analysis of impacts strictly applies to marine mammals herein, the safety of divers present in the boat lanes also is a cause for concern. Information regarding safe distances from underwater detonations for humans, therefore, was calculated. Dual criteria for human safety must both be met; the safe distance from an explosion is determined by positive impulse less than or equal to 2 psi-msec and peak pressure less than or equal to 50 psi.

6.6 CRITERIA AND THRESHOLD CAVEATS

- Lung injury models relied on terrestrial mammal species of less mass, which then were extrapolated for application to marine mammals having a greater mass.
- Ranges estimated using TTS dual thresholds indicate the maximum distance from the source at which onset-TTS occurs (slightest measurable TS) at any depth in the water column. The maximum range is brought to the surface as a radius.
- TTS peak pressure threshold was a direct measure of TTS from impulsive sound exposure for odontocetes.
- TTS SEL threshold was derived from studies of delphinids using pure tone exposures rather than impulsive sound.

- Published auditory weighting schemes for marine mammals, such as "M-weighting" (Southall et al., 2007), were not used for analyses herein. High-pass filtering only was used for energy accumulation using 1/3-octave bands according to Level B harassment thresholds.

- Physiological auditory effects of MSEs may or may not require additive effects of energy. In this case, much depends on the amount of TS incurred and the amount of recovery time prior to the next exposure.

- The non-TTS behavioral disruption metric is synonymous with an exposure-response step function and applies only to cases of MSEs.

- In the case of non-TTS behavioral disruption, additive energy does not have a scientific basis, although the use of energy and its progression from non-TTS to TTS-related disruption appears to be somewhat additive (figure 5-6). The relationship was simplified to create the regulatory framework (figure 5-7) so that overlapping impacts would not confound exposure quantities.

7. MODEL PARAMETERS AND ASSOCIATED PROCESS

The exposure quantities calculated by modeling were based on input data and processes described in previous sections. The modeling parameters and associated process are provided, with greater technical detail in Jordan (2008). The following descriptions elaborate on the generalized process flow provided in section 4.

7.1 EXPLOSIVE WEIGHTS AND WATER AND CHARGE DEPTHS

Charge weights vary in size from 15 g of pentaerythritol tetranitrate (PETN) to 29 lb NEW of plastic-bonded explosives with additives (PBXN) (table 7-1). REFMS requires conversion of explosive types to equivalent weights calculated from similitude equations. Standard similitude formulas facilitate explosive propagation modeling using the freefield source properties close to the source, starting at a nominal source-level range of 3.3 ft. Consistent with the *Seawolf* and the WCS FEISs, weak shock theory is used to estimate the waveform and levels to ranges beyond a few meters for all ranges because the amplitudes of explosive waveforms are small. Corresponding simulated REFMS model parameters for each explosive type and NEW (as referenced to TNT by similitude conversion equations) and position depth below the water surface were chosen to represent each training type. Additionally, four discrete water depths and locations within the operation area were used; Echo area and boat lanes 1 and 2 were the representative areas modeled for bayside and ocean-side operations, respectively (figure 2-1).

Charge depths within the water column were not fixed but relative to the surface and seafloor at the locations within the boat lanes (table 7-1). Relative charge depth was calculated as the (1) surface to 5 ft below the surface for surface charge depth, (2) depth divided by two for the "mid" charge depth (e.g., mid-depth within a 56-ft water column was 28 ft), and (3) seafloor depth plus 1 or 2 ft for bottom charge depth. The REFMS model was not designed to simulate charges placed at the boundaries, so allowances were made for convergence of results to acceptable values. Convergence utilized the distribution of results on a statistical curve with associated confidence intervals.

Table 7-1. Details of Underwater Detonations at SSTC As Used in REFMS Modeling

Underwater Detonation Operations	NEW (lb)	Number of Detonations	Water Depth (ft)	Charge Depth	SSTC Location
MCM	10, 15, 20	1/op	24, 40, 56, 72	Mid	Boat Lanes 1 – 14
MCM	10, 15, 20	1/op	24, 40, 56, 72	Bottom	Boat Lanes 1 – 14
Floating Mine	5	1/op	24, 40, 56, 72	Surface (< 5 ft)	Boat Lanes 1 – 14
SWAG	15 g	1/op	10, 13, 17, 20	Mid	Echo
SWAG[1]	15 g	1/op	10, 13, 17, 20	Mid	Boat Lanes 1 – 14
UUV Ops	10, 12, 15	1/op	24, 40, 56, 72	Bottom, Mid, 10 ft from surface	Boat Lanes 1 – 14
MMS Ops	13, 29	1/op	24, 40, 56, 72	Bottom, Mid, 20 ft from surface	Boat Lanes 1 – 14
MMS Ops	13, 29	2/op	24, 40, 56, 72	Bottom	Boat Lanes 1 – 14
Dive Platoon[2]	3.5	8/op	30, 40, 56, 72	Bottom	Boat Lanes 1 – 14
Dive Platoon[2]	3.5	8/op	30, 40, 56, 72	Mid	Boat Lanes 1 – 14
Qual/Cert	25.5	1/op	40, 50, 60, 72	Bottom, Mid, 20 ft from surface	Boat Lanes 1 – 14
Qual/Cert	12.5, 13.75	2/op	30, 40, 56, 72	Bottom	Boat Lanes 1 – 14
Mine Neutralization[2]	3.5	8/op	30, 40, 56, 72	Bottom	Boat Lanes 1 – 14
UUV Neutralization	3.3, 3.57	2/op	24, 40, 56, 72	Bottom, Mid, 10 ft from surface	Boat Lanes 1 – 14
AMNS	3.5	1/op	40, 56, 72	Bottom, Mid	Boat Lanes 1 – 14

Note: Unless otherwise specified, all MSEs include a 30-min or greater delay between charges.
[1] ZOE calculation only.
[2] MSEs are conducted with 10-sec delay between detonations.

7.2 SOUND SPEED PROFILES

SSPs for all 12 months were acquired from the Naval Oceanographic Office (NAVOCEANO) Web site for the SSTC site. Unfortunately, these profiles are not from the boat lane or Echo areas of the SSTC. The closest SSP is approximately 5 miles west of the boat lanes, which has a deeper water column and different profiles than does the Echo area. Local, shallower measurements of the SS, however, were acquired from the underwater explosive tests conducted near the Naval Amphibious Base (NAB). The SS measurements from the shallower location were less than the deeper NAVOCEANO location by approximately 100 ft per sec (~2%).

To reconcile this discrepancy, several sensitivity tests were performed to quantify the relative influence of the SSPs on the final ZOE determinations, as well as the mammal exposures. Essentially, a 2% increase in SS statistically yielded the same 2% increase in ZOE, which was not threshold independent because of the differences in SS from month to month. Given this low percentage, the REFMS model was modified to allow uniform adjustments in the SSPs and density of the water column. This adjustment was applied to all NAVOCEANO SSPs (one for each month). After each SSP was adjusted, the corresponding ZOEs were computed by the modified REFMS model and tabulated for each given threshold. To report representative values for the warm and cold seasons, mean and SD statistics were calculated for May – October and November – April, respectively.

7.3 SEDIMENT PROPERTIES

The bottom sediment was assumed to be consistent throughout the site and was equivalent to the much greater encompassing southern California region. Based on a previous determination for this region, the bottom sediment for the entire region was considered sandy-silt (Hamilton, 1980). The sound-speed ratio for sandy-silt was 1.145 g/cm^3 with a wet density of 1.941 g/cm^3 (Hamilton, 1980).

7.4 DEPTHS AND RANGES

The limits of each ZOE and threshold were defined as the distance to the onset of the impact based on each specific threshold. ZOEs were determined for each threshold using REFMS, which concurrently supplied multiple two-dimensional (2-D) computational points (depth and range). At the simulated SSTC site where the water depths are between 24 and 72 ft, the selected discrete computational points of depth and range were consistent for all thresholds. These points were:

- Depth (ft): 1.64, 3.28, 6.56, 9.84, 16.4, 24.0, 30.0, 40.0, 56.0 and 72.0
- Range (nmi): 0.0043, 0.0087, 0.0148, 0.0207, 0.0415, 0.688, 0.1, 0.2, 0.3 and 0.4,

where depth points $\geq$ 24 ft were adjusted to accommodate the particular water depth. This 2-D (range and depth) distribution yielded more than 60 discrete points of REFMS results for evaluating the ZOEs for marine mammal thresholds based on impulse (psi-msec), total SEL and SEL in 1/3-octave bands (dB re 1 μPa^2-sec), and peak pressure (psi).

7.5 ANIMAL MOVEMENT

Animal movement was used for modeling MSEs. Movement of animals within the virtual SSTC environment was 2-D in nature because the shallow water depth placed a constraint on diving. Only lateral movement (changes in xy-position) was considered between MSEs (table 7-2). Therefore, it was not necessary to establish a depth restriction for the range points above because the water depths at SSTC were shallow. These maximum SEL ranges then were used to form concentric circles to determine the area affected at or above the exposure thresholds. The number of mammals within this area whose levels are greater than the thresholds for single detonations were summed, scaled by the species densities to quantify the total exposures, and then reported in 1/100ths. By reporting potential exposures to 0.01 of an individual, no error was included by the simulation, only that of the density estimates. One exposure occurred at $0.5 \leq$ exposure ≤ 1.49 for MMPA. Inasmuch as their placement and movement (MSEs only) randomly were initialized, 1000 separate simulations usually are necessary to determine a statistical mean of mammal exposures with standard deviations less than 2% for underwater detonations.

Table 7-2. Marine Mammal Swim Speeds

Species	Swim Speed (m/s)
California sea lion	2.00
Pacific harbor seal	1.00
Bottlenose dolphin	3.08
Gray whale	1.86

When MSEs were modeled, the statistical computation became time dependent. Each mammal swam within the rectangular plane or simulated range space. Mammal movements were initialized by using a random compass heading, swim speed with a random 10% variation of the species mean, and a straight path across the range (Jordan, 2008). The animals did not react to the acoustic operations or avoid them in any way. Mammals that exit the defined range space before the next detonation randomly were replaced along the range boundary with a new random swim speed and heading toward the inside of the range space with its dosimeter set to an SEL of zero. Those mammals outside the range space with SELs greater than the thresholds normally are counted toward the final exposure level. This approach kept the population constant throughout the training operation. However, the recorded received levels on the dosimeters were below the explosive thresholds. Thus, exposures reported herein only represent those animals found inside the range space for all training operations (Jordan, 2008).

7.6 ZOES

The outer boundary of the ZOE is defined by the maximum radius (i.e., range) at which the exposure threshold occurs. For the present determination of the ZOE, improvements concurrently were made to the REFMS tool to allow multiple depths and range points given each threshold (Jordan, 2008). In the ZOE determinations, single detonations were considered separate events. MSEs were handled differently in terms of ZOEs based on the total and 1/3-octave band SEL thresholds. The spatial and temporal distribution of the detonations, as well as the incoherent accumulation of the resultant SELs, were needed to model MSEs.

7.7 COMPUTATION SPECIFICS

The schematic of the computational sequence shows five processing steps as a sequence of calculations (figure 7-1). Software processing modules (red font) are stated for each step with two ultimate outcomes, ZOEs and marine mammal exposures.

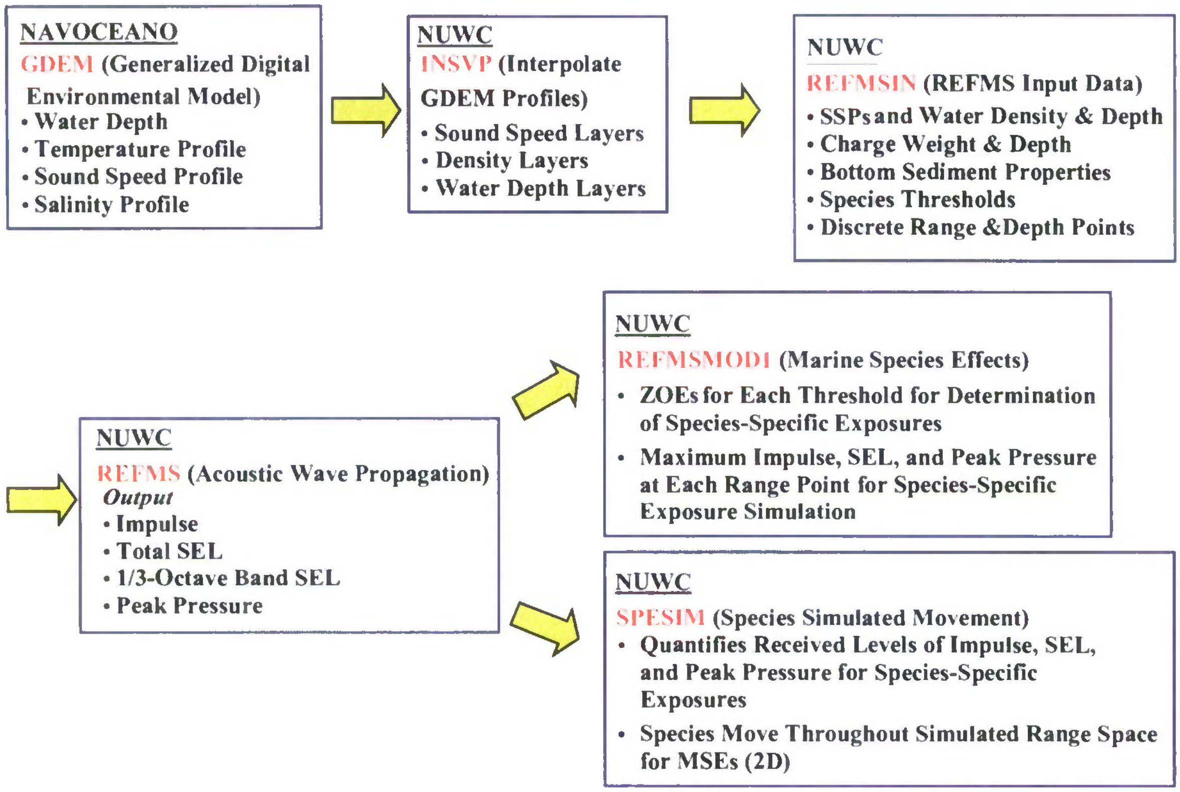


Figure 7-1. Computational Sequence for Determining Effects of Underwater Detonations

The monthly in-situ SSPs were acquired from the Generalized Digital Environmental Model (GDEM) database. Two preprocessing routines (Interpolate Generalized Digital Environmental Model Profiles (INSVP) and Reflection and Refraction Multilayered Ocean/Ocean Bottoms with Shear Wave Effects Input Data (REFMSIN)) were executed to process the environmental conditions and create the initial REFMS input dataset. The explosive characteristics, detonation location, position in the water column, bottom sediment properties, and local SSPs were used to determine wave propagation characteristics of the detonations with the REFMS model. REFMS resolved the traveling explosive compression wave using applicable spreading rules. REFMS was the basis for the two core computation phases (REFMS Modification 1 Marine Species Effects (REFMSMOD1) and Species Simulation Movement (SPESIM)). Static (REFMSMOD1) and dynamic (SPESIM) routines sequentially were executed to determine estimated exposures for cases of single detonations and MSEs. REFMSMOD1 is an enhanced version of the original REFMS software that explicitly evaluated the ZOEs or safe distances in the case of divers using specific criteria and thresholds. SPESIM tracked the individual received SELs with the virtual dosimeter when an operation included MSEs. This tool includes species movement and uses the acoustic property predictions of REFMS to dynamically evaluate the exposures. Exposure values were not retained for multiple training operations because all were considered independent of one another.

For very shallow water (VSW) (> 24 ft), in-situ empirical data regarding propagation of sources were available and used to assess impacts in a separate report (Boyd and Sigurdson, 2006). In their analysis, REMFS and in-situ data for small charges were compared. One of the major findings was that REFMS predictions made for VSW were unreliable because of the strong influence of boundary conditions. REFMS was not designed to model impulsive sources at boundaries like the bottom and surface. Test data and model estimations indicated good predictability when water depth was near 24 ft; therefore, propagation modeling was deemed suitable and performed where empirical data were unavailable (water depth of 24 – 72 ft).

7.8 MISCELLANEOUS MODELING INFORMATION

- Oceanographically, there are two seasons at SSTC, warm (May – October) and cold seasons (November – April).
- All training operations were evenly distributed across months with 50% operations during each of the seasons.
- No two training operations were assumed to occur during the same day.
- For controlled detonations, the minimum time separation was used to estimate effects (not timed). However, the actual temporal relationships between explosions can be longer depending on conditions (set up, weather, etc.).
- Each training activity was treated as an isolated operation; therefore, exposures represent short-term and immediate impacts.
- Activities with single explosions did not take into account animal movement.
- Activities with MSEs were treated as operations requiring the accumulation of received energy (SEL) with consideration of mammal movement. However, MSEs separated in time by milliseconds did not require animal movement.
- Percentage of time pinnipeds haul-out was not factored into the modeling, although California sea lions and harbor seals may not be exposed during the time they are out of the water.

8. EXPOSURES AND ZONES OF EXPOSURE

8.1 ESTIMATED EXPOSURES

The quantitative modeling estimated exposures are based on explosive criteria and thresholds (table 6-1). Estimated exposure quantities represent seasonal means + 1 SD for the range of detonation weights, charge depths, and water depths with seasonal training activity representing half of the yearly training tempo (Jordan, 2008). Using mean + 1 SD is slightly more conservative than only using the mean. The estimated exposures based on seasonality and training operation for the No-Action and Preferred alternatives are given in tables 8-1 and 8-2, respectively. In the following tables, "N/A" is used to denote absence of gray whales during the warm season. Additionally, "N/A" is also used for the non-TTS threshold (177 dB re 1 μPa^2-sec) for single detonations because this threshold only is applicable to MSEs.

It is particularly important to note that behavioral disruption (non-TTS) only was determined for MSE training operations. Additionally, some impacts will be avoided because of protective measure procedures; however, simulation and effectiveness of protective measure procedures currently do not exist. Therefore, estimated exposures were determined before implementation of protective measures.

A conventional rounding scheme was applied to estimated exposures and then summed to determine yearly exposures for the No-Action and Preferred alternatives (tables 8-3 and 8-4, respectively). For example, estimated exposures below 0.49 were truncated to zero; whereas, estimated exposures from 0.5 – 1.49 were rounded to one. Under the No-Action alternative, 65 explosive operations were analyzed (table 8-3); whereas, 217 underwater operations were analyzed under the Preferred alternative (table 8-4).

Table 8-1. Estimated Exposures per Year from Underwater Detonations at SSTC Under the No-Action Alternative, Prior to Implementation of Protective Measures

Underwater Detonation Operation	Season	Mortality				Level A Harassment								Level B Harassment											
														TTS								Non-TTS			
		Onset of ELI (30.5 psi-msec)				Onset of SLI (13.0 psi-msec)				50% TMR (205 dB re 1 μPa²-sec)				182 dB re 1 μPa²-sec				23 psi				177 dB re 1 μPa²-sec			
		CS[1]	HS[2]	BD[3]	GW[4]	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW
MCM	Warm	0.01	0.00	0.04	N/A	0.02	0.00	0.06	N/A	0.00	0.00	0.00	N/A	0.21	0.04	0.71	N/A	0.30	0.05	1.01	N/A	N/A	N/A	N/A	N/A
	Cold	0.03	0.00	0.03	0.00	0.05	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.75	0.08	0.84	0.06	1.20	0.13	1.25	0.10	N/A	N/A	N/A	N/A
Floating Mine	Warm	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.03	0.01	0.11	N/A	0.10	0.02	0.35	N/A	N/A	N/A	N/A	N/A
	Cold	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.01	0.11	0.01	0.37	0.04	0.40	0.03	N/A	N/A	N/A	N/A
UUV Ops	Warm	0.01	0.00	0.02	N/A	0.04	0.01	0.04	N/A	0.00	0.00	0.00	N/A	0.18	0.03	0.59	N/A	0.38	0.06	1.30	N/A	N/A	N/A	N/A	N/A
	Cold	0.02	0.00	0.03	0.00	0.06	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.65	0.07	0.70	0.05	1.24	0.13	1.31	0.08	N/A	N/A	N/A	N/A
MMS Ops	Warm	0.01	0.00	0.03	N/A	0.01	0.00	0.05	N/A	0.00	0.00	0.00	N/A	0.19	0.03	0.65	N/A	0.26	0.04	0.88	N/A	N/A	N/A	N/A	N/A
	Cold	0.02	0.00	0.02	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.78	0.08	0.83	0.06	0.95	0.10	1.01	0.07	N/A	N/A	N/A	N/A
MMS Ops[5]	Warm	0.01	0.00	0.04	N/A	0.03	0.01	0.11	N/A	0.00	0.00	0.00	N/A	0.35	0.06	1.20	N/A	0.50	0.08	1.67	N/A	0.70	0.12	2.33	N/A
	Cold	0.04	0.01	0.06	0.00	0.12	0.09	0.13	0.00	0.00	0.00	0.00	0.00	1.36	0.14	1.45	0.08	1.90	0.20	2.07	0.14	2.57	0.26	2.73	0.17
Dive Platoon	Warm	0.00	0.00	0.01	N/A	0.01	0.00	0.03	N/A	0.00	0.00	0.00	N/A	0.28	0.05	0.95	N/A	0.13	0.02	0.45	N/A	0.49	0.08	1.66	N/A
	Cold	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	1.22	0.13	1.30	0.09	0.38	0.04	0.40	0.03	2.81	0.30	2.99	0.21
Mine Neutralization	Warm	0.00	0.00	0.01	N/A	0.01	0.00	0.03	N/A	0.00	0.00	0.00	N/A	0.28	0.05	0.95	N/A	0.13	0.02	0.45	N/A	0.49	0.08	1.66	N/A
	Cold	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	1.22	0.13	1.30	0.09	0.38	0.04	0.40	0.03	2.81	0.30	2.99	0.21

[1] CS = California sea lion.
[2] HS = Pacific harbor seal.
[3] BD = bottlenose dolphin.
[4] GW = gray whale.
[5] This type of MMS Op is an MSE.

Table 8-2. Estimated Exposures per Year from Underwater Detonations at SSTC Under the Preferred Alternative, Prior to Implementation of Protective Measures

Underwater Detonation Operation	Season	Mortality				Level A Harassment								Level B Harassment											
														TTS								Non-TTS			
		Onset of ELI (30.5 psi-msec)				Onset of SLI (13.0 psi-msec)				50% TMR (205 dB re 1 μPa²-sec)				182 dB re 1 μPa²-sec				23 psi				177 dB re 1 μPa²-sec			
		CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW	CS	HS	BD	GW
MCM	Warm	0.01	0.00	0.04	N/A	0.02	0.00	0.06	N/A	0.00	0.00	0.00	N/A	0.21	0.04	0.71	N/A	0.30	0.05	1.01	N/A	N/A	N/A	N/A	N/A
	Cold	0.03	0.00	0.03	0.00	0.05	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.75	0.08	0.84	0.06	1.20	0.13	1.25	0.10	N/A	N/A	N/A	N/A
Floating Mine	Warm	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.03	0.01	0.11	N/A	0.10	0.02	0.35	N/A	N/A	N/A	N/A	N/A
	Cold	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.01	0.11	0.01	0.37	0.04	0.40	0.03	N/A	N/A	N/A	N/A
SWAG	Warm	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	N/A	N/A	N/A	N/A
	Cold	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A
UUV Ops	Warm	0.01	0.00	0.02	N/A	0.04	0.01	0.04	N/A	0.00	0.00	0.00	N/A	0.18	0.03	0.59	N/A	0.38	0.06	1.30	N/A	N/A	N/A	N/A	N/A
	Cold	0.02	0.00	0.03	0.00	0.06	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.65	0.07	0.70	0.05	1.24	0.13	1.31	0.08	N/A	N/A	N/A	N/A
MMS Ops	Warm	0.01	0.00	0.03	N/A	0.02	0.00	0.06	N/A	0.00	0.00	0.00	N/A	0.28	0.05	0.93	N/A	0.34	0.06	1.14	N/A	N/A	N/A	N/A	N/A
	Cold	0.02	0.00	0.02	0.00	0.05	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.94	0.10	1.00	0.07	1.68	0.18	1.78	0.12	N/A	N/A	N/A	N/A
MMS Ops[1]	Warm	0.02	0.00	0.09	N/A	0.05	0.01	0.20	N/A	0.00	0.00	0.00	N/A	0.48	0.08	1.64	N/A	0.66	0.11	2.10	N/A	0.87	0.15	2.86	N/A
	Cold	0.06	0.01	0.07	0.00	0.18	0.07	0.19	0.00	0.00	0.00	0.00	0.00	1.69	0.19	1.85	0.12	3.43	0.37	3.68	0.25	3.84	0.42	4.06	0.29
Dive Platoon	Warm	0.00	0.00	0.02	N/A	0.01	0.00	0.03	N/A	0.00	0.00	0.00	N/A	0.29	0.05	0.97	N/A	0.14	0.02	0.45	N/A	0.50	0.08	1.67	N/A
	Cold	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	1.14	0.12	1.21	0.08	0.38	0.04	0.40	0.03	2.57	0.27	2.73	0.19
Qual/Cert	Warm	0.01	0.00	0.03	N/A	0.02	0.00	0.07	N/A	0.00	0.00	0.00	N/A	0.33	0.06	1.13	N/A	0.40	0.07	1.36	N/A	N/A	N/A	N/A	N/A
	Cold	0.03	0.00	0.03	0.00	0.07	0.01	0.08	0.00	0.00	0.00	0.00	0.00	1.13	0.12	1.20	0.08	1.37	0.14	1.45	0.10	N/A	N/A	N/A	N/A
Qual/Cert[1]	Warm	0.01	0.00	0.04	N/A	0.02	0.00	0.08	N/A	0.00	0.00	0.00	N/A	0.20	0.03	0.62	N/A	0.26	0.04	0.81	N/A	0.36	0.06	1.14	N/A
	Cold	0.03	0.00	0.03	0.00	0.06	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.71	0.07	0.70	0.05	0.97	0.10	1.00	0.07	1.41	0.14	1.40	0.10
Mine Neutralization	Warm	0.00	0.00	0.02	N/A	0.01	0.00	0.03	N/A	0.00	0.00	0.00	N/A	0.29	0.05	0.97	N/A	0.14	0.02	0.45	N/A	0.50	0.08	1.67	N/A
	Cold	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	1.14	0.12	1.21	0.08	0.38	0.04	0.40	0.03	2.57	0.27	2.73	0.19
UUV Neutralization	Warm	0.00	0.00	0.02	N/A	0.01	0.00	0.05	N/A	0.00	0.00	0.00	N/A	0.13	0.02	0.45	N/A	0.25	0.04	0.84	N/A	0.27	0.05	0.90	N/A
	Cold	0.01	0.00	0.02	0.00	0.04	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.46	0.05	0.45	0.04	0.75	0.09	0.81	0.06	1.12	0.12	1.14	0.08
AMNS	Warm	0.00	0.00	0.01	N/A	0.01	0.00	0.04	N/A	0.00	0.00	0.00	N/A	0.06	0.01	0.20	N/A	0.13	0.02	0.45	N/A	N/A	N/A	N/A	N/A
	Cold	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.19	0.02	0.20	0.01	0.38	0.04	0.40	0.03	N/A	N/A	N/A	N/A

[1] These types of MMS Ops and Qual/Cert are MSEs.

Table 8-3. Total Number of Estimated Exposures per Year from Underwater Detonations at SSTC Under the No-Action Alternative, Prior to Implementation of Protective Measures

Species	Mortality		Level A Harassment				Level B Harassment			
	Onset of ELI (30.5 psi-msec)		Onset of SLI (13.0 psi-msec)		50% TMR (205 dB re 1 μPa²-sec)		TTS 182 dB re 1 μPa²-sec or 23 psi		Non-TTS 177 dB re 1 μPa²-sec	
Season	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
California sea lion	0	0	0	0	0	0	0	26	4	24
Pacific harbor seal	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin	0	0	0	0	0	0	26	26	16	24
Gray whale	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0

Table 8-4. Total Number of Estimated Exposures per Year from Underwater Detonations at SSTC Under the Preferred Alternative, Prior to Implementation of Protective Measures

Species	Mortality		Level A Harassment				Level B Harassment			
	Onset of ELI (30.5 psi-msec)		Onset of SLI (13.0 psi-msec)		50% TMR (205 dB re 1 μPa²-sec)		TTS 182 dB re 1 μPa²-sec or 23 psi		Non-TTS 177 dB re 1 μPa²-sec	
Season	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
California sea lion	0	0	0	0	0	0	4	51	4	40
Pacific harbor seal	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin	0	0	0	0	0	0	43	55	30	40
Gray whale	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0

Trends in model predictions followed similar patterns for the No-Action and Preferred alternatives, which mainly differ in numbers of estimated exposures because of differences in tempo and intensity of underwater detonation operations. Additionally, the Preferred alternative included training operations with greater NEWs than did the No-Action alternative. The following statements apply to trends in estimated impacts for both alternatives:

- Zero exposures of all species classified as mortality under the No-Action or Preferred alternatives.

- Zero exposures of all species classified as MMPA Level A harassment (injury) under the No-Action or Preferred alternatives.

- Zero exposures of harbor seals and gray whales classified as MMPA Level B harassment (TTS and non-TTS) under the No-Action or Preferred alternatives.

- Numerous exposures of California sea lions and bottlenose dolphins classified as MMPA Level B harassment (TTS and non-TTS) under the No Action or Preferred alternatives.

- Exposures classified as MMPA Level B harassment (TTS and non-TTS) were greater for the cold than warm season.

- The actual estimated exposures classified as MMPA Level B harassment (TTS) were slightly greater than MMPA Level B harassment (non-TTS). This trend may reflect that TTS was assessed for all training operations, while non-TTS only was estimated for MSEs.

8.2 MORTALITY AND LEVEL A HARASSMENT (INJURY)

Zero exposures of all species classified as mortality or MMPA Level A harassment (injury) were estimated under the No-Action and Preferred alternatives (tables 8-3 and 8-4, respectively). These results suggest that risk of mortality and physical injury to all four species is low based on the small NEWs and relatively low impulse. NEWs associated with SSTC detonations were small and, thus, created small ZOEs. Additionally, population sizes were small, reducing the likelihood that a virtual animal would be present within the area for mortality or injury. Thus, mortality and MMPA Level A harassment (injury) are not a likely consequence of SSTC underwater detonation operations.

8.3 LEVEL B HARASSMENT (TTS AND NON-TTS)

Zero exposures of harbor seals or gray whales classified as MMPA Level B harassment (TTS and non-TTS) were predicted, suggesting that risk of Level B harassment is low for these species. Harbor seals and gray whales, therefore, will not be further discussed in the context of harassment. MMPA Level B harassment (TTS and non-TTS), however, was estimated for

California sea lions and bottlenose dolphins under the No-Action and Preferred alternatives. Estimated exposures classified as MMPA Level B harassment (TTS and non-TTS) were 83% greater under the Preferred alternative than under the No-Action alternative (table 8-5). The differences in estimated exposures are attributed directly to the differences in training tempo and intensity of underwater detonations under each alternative.

Table 8-5. Estimated Exposures per Year for All Species for Level B Harassment (TTS and non-TTS) Under the No Action and Preferred Alternatives

Alternative	TTS	Non-TTS	Totals	Seasonal Totals (Warm/Cold)
No Action	78	68	146	46/100
Preferred Alternative	153	114	267	112/256

Estimated exposures classified as MMPA Level B harassment (TTS) proportionally were greater than MMPA Level B harassment (non-TTS) for the No-Action and Preferred alternatives (table 8-5). Level B harassment (TTS) was evaluated for all training operations, while Level B harassment (non-TTS) was estimated only for MSEs. Estimated exposures also were nearly double during the cold than warm season under the No-Action and Preferred alternatives (table 8-5). This trend suggests potentially fewer exposures classified as MMPA Level B harassment (TTS and non-TTS) during the warm season at SSTC, which is the opposite trend as seen for MMPA Level A harassment (injury).

8.3.1 California Sea Lions

Zero exposures of California sea lions classified as mortality or MMPA Level A harassment (injury) were estimated, suggesting that risk of mortality and injury was low during a nominal year of training at SSTC. Exposures classified as MMPA Level B harassment (TTS and non-TTS) under the No-Action alternative were proportionately half that under the Preferred alternative (table 8-6). Although the estimated exposures under the No-action and Preferred alternatives were of the same order of magnitude, there were 83% more estimated exposures of sea lions under the Preferred alternative than under the No-Action alternative. These differences were attributed to the increased tempo and intensity of operations under the Preferred alternative.

Table 8-6. Estimated Exposures per Year for California Sea Lions for Level B Harassment (TTS and Non-TTS) Under the No-Action and Preferred Alternatives

Alternative	Warm Season	Cold Season	Totals
No Action	4	50	54
Preferred Alternative	8	91	99

The majority of estimated exposures occurred in the cold season under the No-Action and Preferred alternatives, which was an order of magnitude greater than the exposures in the warm season. Acoustic energy appears to propagate greater distances in the cold season when density sharply increases. From a modeling perspective, lower density decreases availability of simulated animals for exposure during the warm season. However, the decreased density likely reflects the shift of sea lions from areas near SSTC to rookeries in the Channel Islands where they breed. When waters warm, pinnipeds congregate on and near offshore islands to breed, while females remain with their pups for several months. The breeding season begins in April and extends through June. Breeding and molting require more time on land, and the warmer climate is less hostile to whelping, nursing, nurturing, and time out of the water for pups.

8.3.2 Bottlenose Dolphins

Zero exposures of bottlenose dolphins classified as mortality or MMPA Level A harassment (injury) were estimated, suggesting that risk of mortality and injury was low during a nominal year of training at SSTC. Exposures classified as Level B harassment (TTS and non-TTS) for the No-Action alternative were less than half the exposures of the Preferred alternative (table 8-7), with 64% more estimated exposures of dolphins under the Preferred alternative than under the No-Action alternative. These differences also were attributed to the increased tempo and intensity of operations under the Preferred alternative.

Table 8-7. Estimated Exposures per Year for Bottlenose Dolphins for Level B Harassment (TTS and Non-TTS) Under the No-Action and Preferred Alternatives

Alternative	Warm Season	Cold Season	Totals
No Action	42	50	92
Preferred	73	95	168

Seasonally, exposures classified as MMPA Level B harassment (TTS and non-TTS) were greater during the cold than warm season. Cold season conditions favor greater propagation of acoustic energy and peak pressure than does the warm season, creating greater ZOEs. No seasonal patterns of migration or reproduction are known for odontocetes, especially regarding calving, that would cause distributional shifts toward or away from SSTC. Population estimates remain constant during both seasons; therefore, exposures associated with the cold season likely increase as a result of changes in acoustic and pressure propagation.

While behavioral disruption is a non-injurious, short-time impact, it can have other consequences for the animal and the population. The modeling provided estimates of short-term, immediate impacts while determining the biological significance of the disruption to the individual requires further consideration. When attempting to understand behavioral disruption by anthropogenic sound, determining biological significance of the exposures for the individual or population is key (National Research Council (NRC), 2005).

8.3.3 Context of Behavioral Disruption - Biological Significance

Behavioral reactions of marine mammals to sound occur but are difficult to predict. Reactions to sounds, if any, depend on the species, past exposure history and experience, current activity, reproductive state, time of day, and many other factors. When sound becomes potentially disruptive, cetaceans and pinnipeds at rest become active, and feeding or socializing cetaceans or pinnipeds often interrupt these activities by diving or swimming away. If the sound disturbance occurs near an area of concentrated feeding, individuals may eventually abandon the area.

Predictive models designed to estimate exposures do not quantitatively rank the importance (i.e., cost) of the disruption. The information provided herein mainly was species-specific densities. The behavioral changes related to Level B harassment were broadly considered abnormal reactions to noise. Further analysis requires additional information to classify and rank responses according to biological qualities and species ecology and provide context regarding the source of disturbance.

If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be important to the individual. Conversely, if a sound source displaces marine mammals from a known feeding or breeding area for a prolonged period, impacts to the animal could be quite important because the disruption has biological consequences. Biological significance is determined using key parameters or elements that are greatly important to an animal and its ability to grow (and mature), reproduce, and survive.

Growth relates to feeding ecology. At SSTC, there is no known area for concentrated feeding for any of the four species. Reproduction relates to reproductive ecology including how and where such activity occurs. Pinnipeds will leave the vicinity of SSTC and spend some part of the year on their rookeries in the Channel Islands. Additionally, gray whales seasonally migrate along the immediate coast between breeding grounds in coastal Mexico and feeding grounds farther north.

Because exposure relates to direct acoustic energy, impacts associated with hearing and avoidance of the area could change the probability of exposure in significant ways. The biological significance of disruption and degree of consequence for individual animals often has much to do with the frequency, intensity, and duration of the disturbance. Isolated acoustic disturbances usually have minimal consequences or no lasting effects on marine mammals. Marine mammals regularly cope with occasional disruption of their activities by predators, adverse weather, and other natural phenomena. It is reasonable to assume that they can tolerate occasional or brief disturbances from anthropogenic sound without significant consequences. However, prolonged disturbance, as might occur if a stationary and noisy activity were established near a concentration area, is a more important concern. At SSTC, the activity is stationary, however, the acoustic disturbance created by a daily detonation or brief sequence of detonations may not rise to the level of significance.

Quantitative predictive models reliably predict propagation of sound and received levels using a time-step process. The result provides a measure of short-term, immediate response based on detonation type and applicable criteria and thresholds, but it does not provide much insight into population-level impacts. Consequences to populations are much more difficult to predict because they often involve interplay of multiple indirect, long-term, and cumulative effects. The transition from short-term and immediate to population-level impacts requires an analytical framework currently under development.

8.3.4 Individual- and Population-Level Impacts

To quantitatively predict population-level impacts, the processes must be well understood and the underlying data available for modeling. Currently, use of models that quantify a population-level effect is not available because data do not exist to support a calculation that links the immediately affected life function (i.e., migration, feeding, breeding) to a population's vital rate (growth, reproduction, survival (figure 8-1).

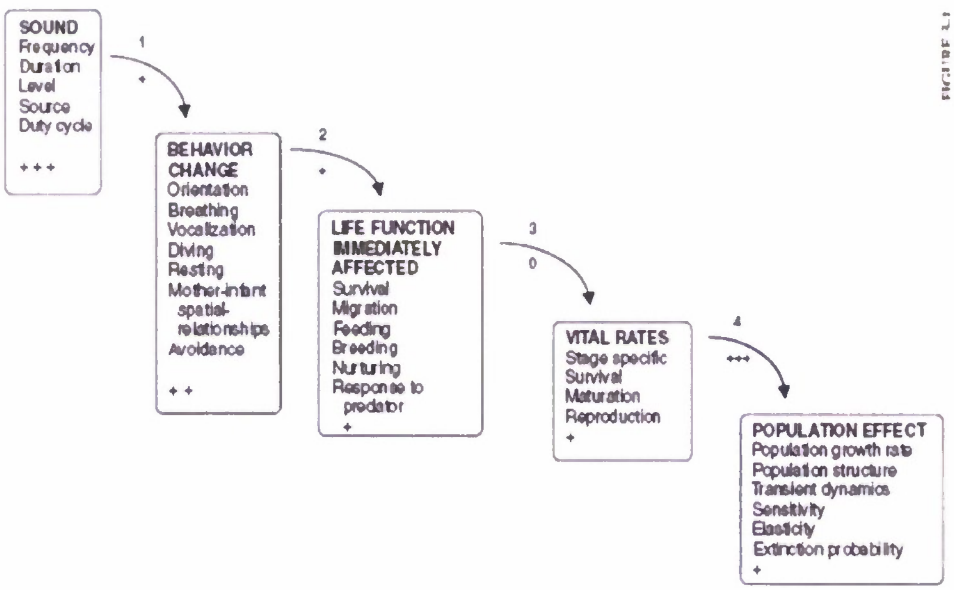


Figure 8-1. PCAD Model for Tracing Acoustic Exposure Through Population-Level Impacts (Based on National Research Council, 2005)

The Population Consequences of Acoustic Disturbance (PCAD) conceptual model (figure 8-1) was developed for tracing acoustic disturbance through the life history of a marine mammal to the effect the disturbance has on the population (National Research Council, 2005). The PCAD model used multiple variables (identified within the boxes) and transfer functions that connect them (numbered arrows). The development of the PCAD model is some years in the future, and there are substantial gaps in current knowledge concerning the issue of marine mammals and sound. Therefore, the conceptual model only serves as a framework to identify activities that have a low probability of causing disruption to marine mammal behavior that would lead to population-level impacts.

While models such as the PCAD conceptual model are years in the future, providing some measures of the footprint of disturbance will yield information regarding preventing or avoiding the impacts. Such footprint measures may accomplish prevention and avoidance of short-term impacts, while contributing to population stability.

8.4 ZONES OF EXPOSURE

Severity of an effect often is related to the distance between the sound source and a marine mammal but also is influenced by source characteristics (Richardson and Malme, 1995). Relationships between the charge weight (NEWs), charge position in the water column, water depth, and season for each detonation type were determined using the REFMS model. In general, the radial distances for ZOEs increased with increasing NEW and number of explosions.

Mean and maximum radial distances were calculated for each operation, season, and detonation type for the No-Action and Preferred alternatives. Please note that depth at which ZOEs occur is not included because they were brought to the surface to create the flat ZOE representation. Additionally, the ZOE statistics do not include the SD as was included in estimated exposures.

8.4.1 ZOEs Associated with Mortality and Level A Harassment (Injury)

Modeling indicates that the ZOE associated with mortality increased as NEW increased. Overall, ZOEs associated with mortality occurred at 90 yards or less for all detonation types under the Preferred alternative (table 8-8). The greatest ZOE associated with mortality was produced by Marine Mammal Systems Operations (MMS Ops) and Qualification and Certification (Qual/Cert) Trials. The least ZOE associated with mortality was produced by the floating mine, which occurred at 20 yards. For SWAG, the ZOE was insignificant. ZOEs associated with mortality did not seasonally vary because the short radii predictions were within the same resolution range as REFMS modeling—a best fit for fine and coarse scales given the multiple NEWs involved.

Table 8-8. Maximum Estimated Radial Distances for Mortality and Injury Under the Preferred Alternative

Underwater Detonation Operations	Mortality (yard)	Injury Warm/Cold (yard)
MCM	80	360/160 (SLI[1])
Floating Mine	20	80/80 (TMR[2])
SWAG	0	0
UUV Ops	80	360/150 (SLI)
MMS Ops (1/op)	90	360/170 (SLI)
MMS Ops (2/op)	90	360/170 (SLI)
Dive Platoon	50	90/90 (TMR)
Qual/Cert (1/op)	90	300/170 (SLI)
Qual/Cert (2/op)	80	140/140 (SLI)
Mine Neutralization	50	90/90 (TMR)
UUV Neutralization	50	80/90 (SLI)
AMNS	40	80/80 (SLI)

[1] SLI – Slight lung injury
[2] TMR – Tympanic membrane rupture

For slight injury, two types of ZOEs exist: an SLI where exposed animals are expected to recover, and a TMR where auditory system trauma is permanent. The ZOE for injury was based on the threshold that created the greater ZOE. ZOEs were based on SLI for mine countermeasures (MCMs), unmanned underwater vehicle operations (UUV Ops), MMS Ops, Qual/Cert, unmanned underwater vehicle (UUV) neutralization, and AMNS and based on TMR for floating mine, dive platoon, and mine neutralization (table 8-8). Seasonal variability was evident for positive impulse (SLI) but not for SEL (TMR). Impulse propagated farther in the warm than in the cold season for MCM, UUV Ops, MMS Ops, and Qual/Cert and created ZOEs nearly double that of the cold season. ZOEs for SWAG were insignificant, and estimations indicated 0 yards, although there are very short radii for injury immediately surrounding the charge.

ZOE calculations were dependent on charge weight, position in the water column, water depth, and season for each explosive type. Training type also factored into the ZOE determination where single detonations or MSEs were concerned. For single-detonation operations and SEL calculations, the greatest ZOE was calculated using the range associated with onset-TTS and physiological responses to exposure; two thresholds were used, 182 dB re 1 μPa^2-sec and 23 psi. When MSEs were included, the ZOEs for non-TTS were evaluated using the 177 dB re 1 μPa^2-sec threshold.

8.4.2 ZOEs Associated with Level B Harassment (TTS and non-TTS)

The maximum radial distance is of primary interest when determining the ZOE, which is determined either by TTS (single detonation (R_2 in figure 8-2,)) or non-TTS (MSEs (R_3 in figure 8-2,)) thresholds. For a single detonation, a ZOE depends on evaluation of dual TTS thresholds—when one threshold (SEL or peak pressure) is met, TTS occurs. For example, the ZOE in nautical miles increased with increasing NEW and water depth for MCM using SEL and peak pressure thresholds (figure 8-3). Charge position at mid-depth in the water column created the greatest ZOE via SEL. Similar calculations were performed for each training operation.

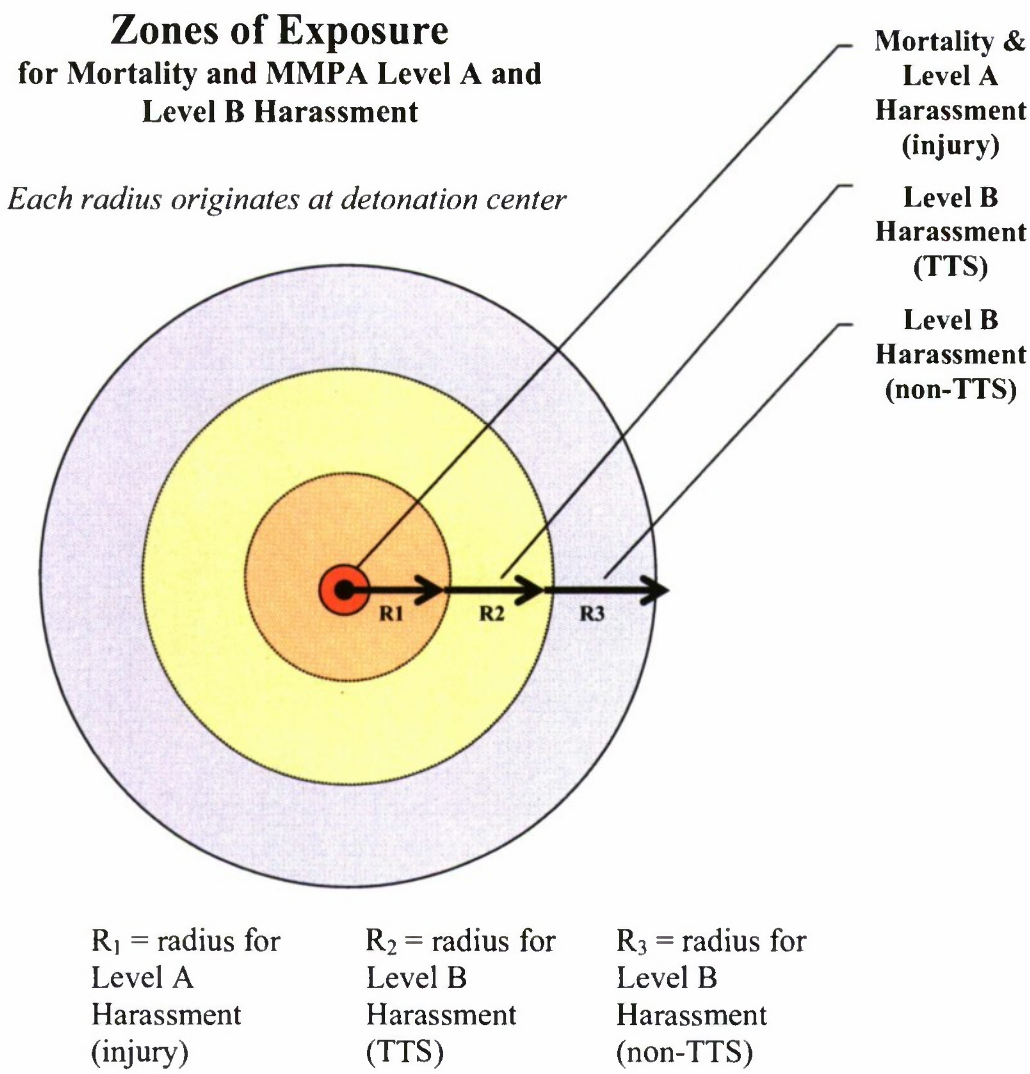
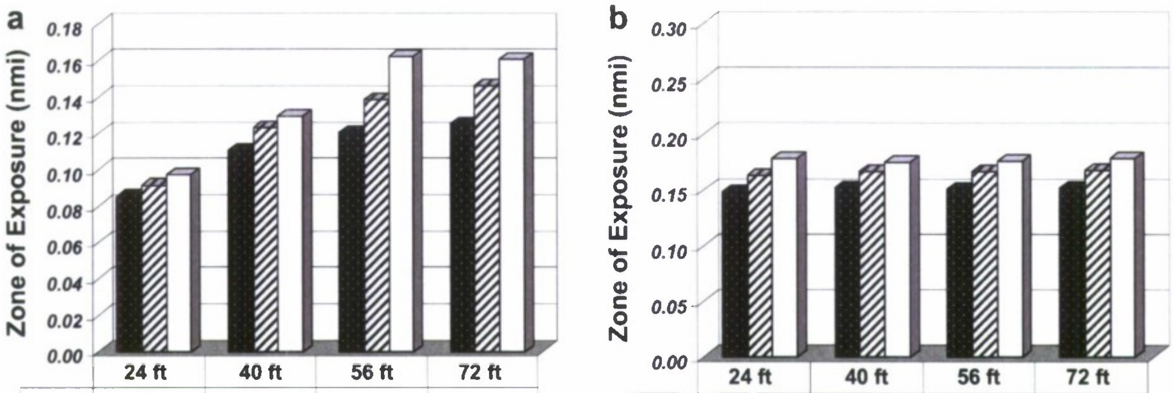


Figure 8-2. ZOEs and Radii Associated with Mortality and Level A and B Harassment



(a)	24 ft	40 ft	56 ft	72 ft
10 lb	0.09	0.11	0.12	0.13
15 lb	0.09	0.12	0.14	0.15
20 lb	0.10	0.13	0.16	0.16

(b)	24 ft	40 ft	56 ft	72 ft
10 lb	0.15	0.15	0.15	0.15
15 lb	0.16	0.17	0.17	0.17
20 lb	0.18	0.17	0.18	0.18

Figure 8-3. ZOEs for MCM, Single 10 – 20 lb NEW, Determined at Mid-Depth Based on (a) SEL (< 10 Hz) and (b) Peak Pressure

ZOEs were determined by non-TTS threshold for training operations using MSEs. All tables indicate increases in the ZOE for the SEL threshold for MSEs separated by either 10 sec or 30 min. These radial distances or ZOEs are used for determining protective measure procedures.

The mean and maximum ZOEs (tables 8-9 and 8-10) were determined for each operation, season, and threshold under the No-Action alternative. Mean values for radial distances are most representative of actual SSTC conditions and regarded as best estimates. For the No-Action alternative, the dive platoon training operation produced greatest mean and maximum ZOEs (510 and 610 yards (tables 8-9 and 8-10, respectively).

Table 8-9. Estimated Mean ZOEs for Underwater Detonations at SSTC Under the No-Action Alternative

Underwater Detonation Operation	Season	Mortality	Level A Harassment		Level B Harassment				Humans	
					TTS			Non-TTS		
					182 dB re 1 μPa^2-sec		23 psi			
		Onset of ELI (30.5 psi-msec)	Onset of SLI (13.0 psi-msec)	50% TMR (205 dB re 1 μPa^2-sec)	≥ 10 Hz	≥ 100 Hz		177 dB re 1 μPa^2-sec	2 psi-msec	50 psi
		Mean (yd)	Mean (yd)	Mean (yd)	Mean (yd)			Mean (yd)	Mean (yd)	
MCM	Warm	60	120	60	240	240	340	N/A	280	180
	Cold	60	140	60	260	260	360	N/A	280	180
Floating Mine	Warm	20	20	50	140	140	240	N/A	220	120
	Cold	20	20	50	150	150	260	N/A	80	130
UUV Ops	Warm	50	110	60	220	220	340	N/A	280	180
	Cold	50	80	70	230	230	350	N/A	270	180
MMS Ops	Warm	70	110	60	230	230	320	N/A	270	180
	Cold	70	110	60	250	250	350	N/A	320	180
MMS Ops[1]	Warm	60	90	60	230	230	320	310	270	180
	Cold	60	100	70	250	250	360	350	270	180
Dive Platoon (mid-depth)	Warm	30	60	120	290	290	210	390	170	110
	Cold	30	60	120	350	350	230	510	180	110
Dive Platoon (bottom)	Warm	40	80	90	290	290	210	390	200	110
	Cold	40	80	90	320	320	220	460	230	110
Mine Neutralization	Warm	40	80	90	290	290	210	390	200	110
	Cold	40	80	90	320	320	220	460	230	110

[1] This type of MMS Op is an MSE.

Table 8-10. Estimated Maximum ZOEs for Underwater Detonations at SSTC Under the No-Action Alternative

Underwater Detonation Operation	Season	Mortality	Level A Harassment		Level B Harassment				Humans	
					TTS			Non-TTS		
		Onset of ELI (30.5 psi-msec)	Onset of SLI (13.0 psi-msec)	50% TMR (205 dB re 1 μPa^2-sec)	182 dB re 1 μPa^2-sec		23 psi	177 dB re 1 μPa^2-sec	2 psi-msec	50 psi
					≥ 10 Hz	≥ 100 Hz				
		Maximum (yd)	Maximum (yd)	Maximum (yd)	Maximum (yd)			Maximum (yd)	Maximum (yd)	
MCM	Warm	80	360	80	300	300	470	N/A	570	200
	Cold	80	160	80	340	340	450	N/A	380	200
Floating Mine	Warm	20	20	80	160	160	240	N/A	220	120
	Cold	20	20	80	180	180	260	N/A	100	140
UUV Ops	Warm	80	360	80	280	280	440	N/A	570	200
	Cold	80	150	80	320	320	400	N/A	370	200
MMS Ops	Warm	80	130	60	270	270	320	N/A	330	180
	Cold	80	140	70	290	290	350	N/A	370	180
MMS Ops[1]	Warm	80	130	70	270	270	330	380	330	180
	Cold	80	140	70	330	330	410	430	370	180
Dive Platoon (mid-depth)	Warm	40	70	130	330	330	230	430	190	120
	Cold	40	70	130	410	410	230	610	200	110
Dive Platoon (bottom)	Warm	50	80	90	330	330	210	470	230	110
	Cold	50	90	90	370	370	220	560	280	110
Mine Neutralization	Warm	50	80	90	330	330	210	470	230	110
	Cold	50	90	90	370	370	220	560	280	110

[1] This type of MMS Op is an MSE.

Mean and maximum ZOEs also were determined for each operation, season, and threshold under the Preferred alternative (tables 8-11 and 8-12). MMS Ops produced the greatest mean and maximum ZOEs for the Preferred alternative (410 and 740 yards (tables 8-11 and 8-12, respectively)).

Table 8-11. Estimated Mean ZOEs for Underwater Detonations at SSTC Under the Preferred Alternative

Underwater Detonation Operation	Season	Mortality	Level A Harassment		Level B Harassment				Humans	
					TTS			Non-TTS		
					182 dB re 1 μPa²-sec		23 psi			
		Onset of ELI (30.5 psi-msec)	Onset of SLI (13.0 psi-msec)	50% TMR (205 dB re 1 μPa²-sec)	≥ 10 Hz	≥ 100 Hz		177 dB re 1 μPa²-sec	2 psi-msec	50 psi
		Mean (yd)	Mean (yd)	Mean (yd)	Mean (yd)			Mean (yd)	Mean (yd)	
MCM	Warm	60	120	60	240	240	340	N/A	280	180
	Cold	60	140	60	260	260	360	N/A	280	180
Floating Mine	Warm	20	20	50	140	140	240	N/A	220	120
	Cold	20	20	50	150	150	260	N/A	80	130
SWAG	Warm	0	0	0	20	20	50	N/A	30	20
	Cold	0	0	0	20	20	40	N/A	30	20
UUV Ops	Warm	50	110	60	220	220	340	N/A	280	180
	Cold	50	80	70	230	230	350	N/A	270	180
MMS Ops	Warm	80	250	80	240	280	340	N/A	320	190
	Cold	80	120	80	270	300	380	N/A	340	200
MMS Ops[1]	Warm	70	150	110	310	310	340	480	320	190
	Cold	80	130	110	340	340	380	470	340	200
Dive Platoon	Warm	40	80	90	290	290	210	390	200	110
	Cold	40	80	90	320	320	220	460	230	110
Qual/Cert	Warm	70	180	90	290	290	380	N/A	390	210
	Cold	70	120	90	320	320	420	N/A	310	200
Qual/Cert[1]	Warm	70	110	90	280	280	320	380	270	180
	Cold	70	110	90	310	310	350	430	330	180
Mine Neutralization	Warm	40	80	90	290	290	210	390	200	110
	Cold	40	80	90	320	320	220	460	230	110
UUV Neutralization	Warm	40	70	30	160	160	220	230	180	120
	Cold	40	70	30	170	170	230	260	190	120
AMNS	Warm	40	70	30	160	160	210	N/A	180	110
	Cold	40	70	30	170	170	230	N/A	190	120

[1] These types of MMS Ops and Qual/Cert are MSEs.

Table 8-12. Estimated Maximum ZOEs for Underwater Detonations at SSTC Under the Preferred Alternative

Underwater Detonation Operation	Season	Mortality	Level A Harassment		Level B Harassment				Humans	
					TTS			Non-TTS		
					182 dB re 1 µPa²-sec		23 psi			
		Onset of ELI (30.5 psi-msec)	Onset of SLI (13.0 psi-msec)	50% TMR (205 dB re 1 µPa²-sec)	≥ 10 Hz	≥ 100 Hz		177 dB re 1 µPa²-sec	2 psi-msec	50 psi
		Maximum (yd)	Maximum (yd)	Maximum (yd)	Maximum (yd)			Maximum (yd)	Maximum (yd)	
MCM	Warm	80	360	80	300	300	470	N/A	570	200
	Cold	80	160	80	340	340	450	N/A	380	200
Floating Mine	Warm	20	20	80	160	160	240	N/A	220	120
	Cold	20	20	80	180	180	260	N/A	100	140
SWAG	Warm	0	0	0	20	20	60	N/A	40	20
	Cold	0	0	0	20	20	40	N/A	40	20
UUV Ops	Warm	80	360	80	280	280	440	N/A	570	200
	Cold	80	150	80	320	320	400	N/A	370	200
MMS Ops	Warm	90	360	100	330	330	400	N/A	520	210
	Cold	90	170	100	370	370	490	N/A	410	240
MMS Ops[1]	Warm	90	360	140	420	420	380	740	510	210
	Cold	90	170	140	470	470	450	650	410	230
Dive Platoon	Warm	50	80	90	330	330	210	470	230	110
	Cold	50	90	90	370	370	220	560	280	110
Qual/Cert	Warm	90	300	90	330	330	420	N/A	540	260
	Cold	90	170	90	360	360	470	N/A	400	220
Qual/Cert[1]	Warm	80	140	100	330	330	330	470	330	180
	Cold	80	140	100	370	370	360	530	370	180
Mine Neutralization	Warm	50	80	90	330	330	210	470	230	110
	Cold	50	90	90	370	370	220	560	280	110
UUV Neutralization	Warm	50	80	60	170	180	220	260	230	120
	Cold	50	90	60	170	180	230	280	280	120
AMNS	Warm	40	80	40	170	170	220	N/A	200	120
	Cold	40	80	40	180	180	230	N/A	200	120

[1] These types of MMS Ops and Qual/Cert are MSEs.

Modeling of explosions at SSTC indicated that there are strong bottom-type interactions in the 24- to 72-ft depth range, which was not surprising given the substrate shear values and other boundary conditions. ZOEs for TTS slightly increased more during the cold than in warm season. Conversely, ZOEs appear less sensitive to the charge depth, but the least ZOEs were estimated for detonations near the water surface. The greatest ZOE for single detonations (~0.23 nmi or 470 yards) was estimated from a 29-lb, bottom detonation of MMS Ops in 72 feet of water during the cold season. Similarly, the greatest ZOE for MSEs (~0.36 nmi or 740 yards) also was estimated from the 29-lb MMS Ops, but during the warm season.

In general, ZOE determinations from SEL and peak pressure were dissimilar for TTS. ZOE determined using SEL thresholds increase with charge weight and water depth. However, ZOEs determined using peak pressure thresholds increase with charge weight but decrease as the charge approaches the bottom. Moreover, ZOEs determined using SEL and peak pressure become nearly indistinguishable as the charge position approaches the water surface. ZOEs also slightly increase during the cold season.

8.4.3 ZOEs Associated with Human Safety

Diver safety required use of different thresholds, 2 psi-msec and 50 psi (table 8-13). However, the methods used for predicting ZOEs for human safety were the same as those used for marine mammals. The radial distances for humans do not relate to exposure as much as defining the limits for potential injury to organ and auditory systems. The positive impulse threshold produced the greatest ZOE for human safety at 570 yards for the No-Action and Preferred alternatives (table 8-13). It is important to note that human safety is the primary concern and may override marine mammal concerns.

Table 8-13. Estimated ZOEs for Human Safety at SSTC Under the No-Action and Preferred Alternatives

Alternative	Underwater Detonation Operation	2 psi-msec Mean (Max) (yd)	50 psi Mean (Max) (yd)
No Action	MCM, UUV, MMS	280 (570)	180 (200)
Preferred	MCM, MMS	340 (570)	200 (240)

9. PROTECTIVE MEASURES

The purpose of the Navy's protective measures plan is to avoid injury or harassment of marine mammals during training by reducing risk to the greatest practical extent. ZOEs contributed valuable information in the form of impact radii, which support development of the SSTC protective measures plan.

9.1 BACKGROUND REGARDING SSTC PROTECTIVE MEASURES PLAN

At the SSTC, mortality and injury are not anticipated. Additionally, the potential for temporary hearing impairment and behavioral disruption is possible and should be avoided, to the greatest practical extent. Risk of mortality and injury is greatest within the areas defined by radii for impulse (table 8-8). These areas are subsumed, as distance from the source increases by the areas for risk of TTS and non-TTS (tables 8-10, 8-11, and 8-12). The maximum ZOE for each training type serves as the limit for possible impacts and the basis for protective measures (tables 9-1 and 9-2). While mean ranges provide a reasonable and expected distance for monitoring, the maximum range provides a margin of confidence for protective measures. Because ZOE calculations represent the limit for physiological and behavioral disruption, they also represent safety zones for impacts to marine mammals.

For the No-Action alternative, MCM had the maximum ZOE for any single explosion during the warm season (470 yards (table 9-1). For MSEs, a greater area was defined for dive platoon, based on a ZOE of 610 yards.

Table 9-1. Maximum ZOEs for Underwater Detonations at SSTC Under the No-Action Alternative

Underwater Detonation Operation	NEW (lb)	Number of Detonations	Water Depth (ft)	Charge Depth	Maximum ZOE for TTS/non-TTS (yd)		Tempo
					Warm	Cold	
MCM	10 – 20	1/op	24 ≤ 72	Mid	470	400	8 ops/yr
MCM	10 – 20	1/op	24 ≤ 72	Bottom	365	450	8 ops/yr
Floating Mine	≤ 5	1/op	24 ≤ 72	Surface (< 5 ft)	240	260	17 ops/yr
UUV Ops	10 – 15	1/op	24 ≤ 72	Bottom to 10 ft from surface	440	400	4 ops/yr
MMS Ops	13	1/op	24 ≤ 72	Bottom to 20 ft from surface	320	350	8 ops/yr
MMS Ops	13	2/op	24 ≤ 72	Bottom	330/380	410/430	8 ops/yr
Dive Platoon[1]	3.5	8/op	30 – 72	Mid	330/430	410/610	4 ops/yr
Dive Platoon[1]	3.5	8/op	30 – 72	Bottom	330/470	370/560	4 ops/yr
Mine Neutral[1]	3.5	8/op	30 – 72	Bottom	330/470	370/560	4 ops/yr

Note: Unless otherwise specified, all MSEs will include a 30-min or greater delay between charges.
[1] All MSEs are conducted with 10-sec delay between detonations.

For the Preferred alternative, MCM also had the greatest ZOE for any single explosion during the warm season (470 yards (table 9-2)). For MSEs, a greater area was defined for MMS Ops based on a ZOE of 740 yards.

Table 9-2. Maximum ZOEs for Underwater Detonations at SSTC Under the Preferred Alternative

Underwater Detonation Operation	NEW (lb)	Number of Detonations	Water Depth (ft)	Charge Depth	Max ZOE for TTS/non-TTS (yd)		Tempo
					Warm	Cold	
MCM	10 – 20	1/op	24 ≤ 72	Mid	470	400	21 ops/yr
MCM	10 – 20	1/op	24 ≤ 72	Bottom	365	450	21 ops/yr
Floating Mine	≤ 5	1/op	24 ≤ 72	Surface (< 5 ft)	240	260	45 ops/yr
SWAG	15 g	1/op	10 – 20	Mid	60	40	66 ops/yr
SWAG	15 g	1/op	10 – 20	Mid	60	40	8 ops/yr
UUV Ops	10 – 15	1/op	24 ≤ 72	Bottom to 10 ft from surface	440	400	4 ops/yr
MMS Ops	13 & 29	1/op	24 ≤ 72	Bottom to 20 ft from surface	400	490	8 ops/yr
MMS Ops	13 & 29	2/op	24 ≤ 72	Bottom	420/740	470/650	8 ops/yr
Dive Platoon[1]	3.5	8/op	30 – 72	Bottom	330/470	370/560	8 ops/yr
Qual/Cert	25.5	1/op	40 – 72	Bottom to 20 ft from surface	420	470	4 ops/yr
Qual/Cert	12.5 – 13.75	2/op	30 – 72	Bottom	330/470	370/530	8 ops/yr
Mine Neutral[1]	3.5	8/op	30 – 72	Bottom	330/470	370/560	4 ops/yr
UUV Neutral	3.3 & 3.57	2/op	24 – 72	Bottom to 10 ft from surface	220/260	230/280	4 ops/yr

Note: Unless otherwise specified, all MSEs will include a 30-min or greater delay between charges.
[1] All MSEs are conducted with 10-sec delay between detonations.

9.2 SSTC UNDERWATER DETONATIONS PROTECTIVE MEASURES

SSTC implements range protocols that are adapted to local conditions for protecting marine mammals from harassment while training operations are conducted. The procedure is consistent with existing training objectives and operations, as well as established human safety procedures. In case of unanticipated conflict, human safety will take precedence over marine mammals. The protective measures plan includes a protocol for VSW observation from the beach, seaward to water depths of 24 ft (Boyd and Sigurdson, 2006). For deep portions of boat lanes (24 – 72 ft), observation is performed from two rigid hull inflatable boats (RHIBs). The deep-water plan is based on ZOE calculations from the analysis herein. These radial distances apply to boat lanes 1 – 12 and when explosive operations occur in water depths of 24 – 72 ft. Because this plan is general, it includes other range protocol steps that simultaneously occur. For example, diver safety and species other than marine mammals, such as sea turtles and seabirds, were integrated into the protective measure procedures.

Prior to all training operations that involve underwater detonations, a Notice to Mariners is issued. A safety boat is launched to monitor the ZOE for presence of marine mammals 30 min or more before an exercise. For detonations occurring in 24 – 72 ft of water, the safety zone shall have a radius of 740 yards. Two trained lookouts will survey the detonation area and safety zone with binoculars for marine mammals, sea turtles, and seabirds from at least 30 min prior to commencement of the scheduled detonation until at least 30 min after the detonation. If mats of floating kelp are observed within the safety zones, they will be investigated for the presence of protected species.

1. Divers and boat operators engaged in detonation operations will monitor the area immediately surrounding the point of detonation for marine mammals and sea turtles.

2. If a vessel not associated with the operation is sighted in the human exclusion zone or headed toward it, operations will be suspended to ensure that the area is clear prior to detonation.

3. If a marine mammal or sea turtle is sighted within the safety zone or moving toward it, exercises will be suspended until the animal has voluntarily left the area and the area is clear of marine mammals and sea turtles for at least 10 min.

4. Flocks of seabirds should not be in the ZOE prior to detonation.

5. MSEs will be conducted either with less than a 10-sec separation or greater than a 30-min separation to allow for seabirds that are attracted to the area to vacate the area.

6. Immediately following the detonation, visual monitoring for marine mammals, sea turtles, and seabirds within the safety zone will continue for 30 min. Any animals sighted will be observed for signs of injury. Injured marine mammals, sea turtles, and seabirds are reported to the Commander, Navy Region Southwest (CNRSW) Environmental Director and the PACFLT Environmental Office.

The circular ZOEs monitored during underwater detonations in 24 – 72 ft of water are shown in figure 9-1. For these detonations, two boats are used; one boat is dedicated to observation, and the other boat is dedicated to supporting the dive team, centered at the actual position of the explosion. Both RHIBs have an observer that monitors for presence of protected species in the ZOE or moving toward it.

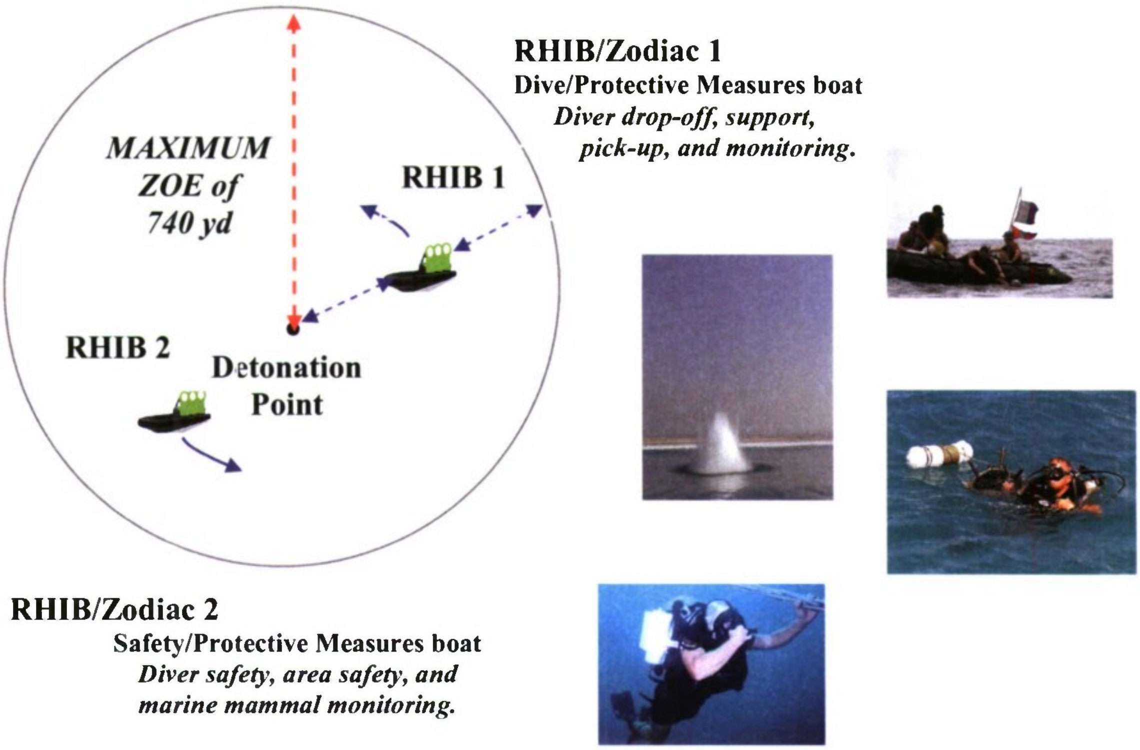


Figure 9-1. Monitoring Schematic for Deep-Water Training Operations

10. MMPA IMPLICATIONS—PERMITTING

Marine mammals may be present within the SSTC during training when underwater detonations occur and, therefore, may be exposed to harmful effects associated with rapid release of energy and intense noise created by the detonations. The Navy does not anticipate mortality or MMPA Level A harassment (injury) based on modeling, lack of exposure predictions, and implementation of protective measures. The radii for areas surrounding detonations were short, and monitoring the ZOE likely will prevent exposures.

For permitting purposes, the number of estimated exposures under the Preferred alternative provides a basis for estimating the number of incidental takes for MMPA Level B harassment (TTS and non-TTS). There are an estimated 267 incidental takes per year at SSTC. While mortality and serious injury are not anticipated, the Navy should seek an LOA for the estimated exposures classified as MMPA Level B harassment (TTS and non-TTS).

11. CONCLUSIONS

The analysis herein considered two alternative training operations: the No-Action alternative, which represented the tempo of current training operations for a representative year (65 ops/year) and the Preferred alternative, which represented an increase in tempo and intensity for future training operations for a representative year (217 ops/year). Propagation of impulse, SEL, and peak pressure were simulated for each detonation type and used to estimate marine mammal exposures.

Zero exposures classified as mortality or MMPA Level A harassment (injury) were estimated for all species (California sea lion, harbor seal, bottlenose dolphin, and gray whale) under the No Action and Preferred alternatives. The lack of mortality or injury was attributed to the small footprint of explosions and relatively short range of harmful impacts. Additionally, zero exposures classified as MMPA Level B harassment (TTS and non-TTS) were estimated for harbor seals or gray whales under the No Action and Preferred alternatives. However, there were numerous exposures classified as MMPA Level B harassment (TTS and non-TTS) for California sea lions and bottlenose dolphins under the No Action and Preferred alternatives. While protective measures were not considered during predictive modeling, these measures should reduce the risk that marine mammals would be harassed.

The maximum ZOE of 740 yards was used as a basis for the safety zone within the protective measures plan. According to plan, training will be delayed until the observed marine mammal leaves the ZOE, thus, minimizing the risk that individuals would be harassed. REFMS propagation predictions also were useful for determination of safe ranges for divers during underwater detonation operations. Safe ranges for humans always were within the ZOEs for marine mammals.

For permitting purposes, 267 exposures per year classified as MMPA Level B harassment (TTS and non-TTS) were estimated at the SSTC. While mortality and serious injury are not anticipated, the Navy should seek an LOA for the estimated exposures classified as MMPA Level B harassment (TTS and non-TTS).

APPENDIX
DETERMINATION OF THE NON-TTS THRESHOLD

DETERMINATION OF THE NON-TTS THRESHOLD

As reported by Schlundt et al. (2000), instances of altered behavior generally began at lower sound exposure levels than those causing TTS; however, there were many instances when subjects exhibited no altered behavior at levels above the onset-TTS levels. Regardless of exposure level, all instances of altered behavior were included in the statistical summary. These assessments led to the development of the threshold value herein representing a step-function along a "risk" function curve. The curve behaves as a step-function with one value; behaviors are expected to be normal below the threshold value, and behaviors are expected to be adverse above the threshold value.

The behaviors of a subject during sound exposure experiments were compared to the test subject's expected behaviors to determine whether the sound exposure caused altered behavior during a session. In this context, altered behavior means a deviation from a subject's normal trained behaviors. The subjective assessment was only possible because behavioral observations were made with the same animals during many hearing threshold or baseline sessions without intense sound exposures. To determine degree of TS, the threshold occurring before the exposures must be known. These observations allowed comparisons between how a subject normally acted and how it acted during test sessions with fatiguing sound exposures. Subjectively categorizing each exposure session as normal or altered behavior allowed the percentage of sessions with altered behavior to be calculated as a function of the exposure SPL.

Test sessions were grouped by species and exposure frequency (Finneran and Schlundt, 2003). Within each group, the percentage of sessions in which subjects showed altered behavior was calculated as a function of exposure SPL. Altered behavior was defined as a change from a subject's "normal" behavior observed during baseline sessions without intense sound exposure. The percentage of sessions with altered behavior generally increased with increasing exposure levels. An example of the statistics for all tests at 3 kHz is provided in table A-1.

Table A-1. Number and Percentage of Animals with Altered Behavior As a Function of SPL (Adapted from Finneran and Schlundt, 2003)

SPL (dB re 1 μPa)	Number of Tests	Number of Animals with Altered Behavior	Percentage of Animals with Altered Behavior
160	6	0	0
170	6	1	17
180	13	3	23
186	9	2	22
192	17	9	53
194	10	4	40
199	8	4	50
201	5	4	80
Total	**74**	**27**	

For pooled data at 3, 10, and 20 kHz, exposure SPLs correspond to sessions with 25, 50, and 75% altered behavior with SPL levels of 180, 190, and 199 dB re 1 μPa, respectively. Detailed statistical results are provided in Finneran and Schlundt (2003). A trend of increasing percentages of altered behavior occurred with increasing SPLs. The percentages of altered behavior decreased when SPL was less than 192 dB re 1 μPa. Not all animals experienced TTS at 192 dB re 1 μPa, with only 50% exhibiting altered behavior.

The TTS energy threshold for explosives was derived from these SSC pure-tone tests for TTS (see Ridgway et al. (1997) for test results). The pure-tone threshold (192 dB re 1 μPa) is modified for explosives by (1) interpreting it as an energy metric, (2) reducing it by 10 dB to account for the integration time constant of the mammal ear, and (3) measuring the energy in 1/3-octave bands, the natural filter band of the ear. As explained in paragraph 6.4.1.1, the resulting threshold is 182 dB re 1 μPa^2-sec in any 1/3-octave band. The behavioral disruption threshold (non-TTS) is 5 dB below the threshold for TTS as derived from SSC pure-tone tests, which relies on exposures with roughly 25% of the test subjects showing altered behavior to sound.

To estimate numbers of animals responding to a sound in a manner constituting behavioral disruption without physiological disruption, recent Navy policy guidance has introduced a standard for behavioral disruption and underwater detonations at 177 dB re 1 μPa^2-sec. This threshold applies only to MSEs, where responses to repeated exposures are considered biologically important and momentary reactions to single detonations are not.

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