Subsequent to issuance of the RIMPAC IHA, additional public comments were received and considered. Based on this input, Navy continued to coordinate with NMFS to determine whether an alternate approach to energy flux density could be used to evaluate when a marine mammal may behaviorally be affected by mid-frequency sonar sound exposure. Coordination between the Navy and MNFS produced the adoption of dose function for evaluation of behavioral effects. The acoustic dose-function approach for evaluating behavioral effects is described in the following section and fully considers the controlled, tonal sound exposure data in addition to comments received from the regulatory, scientific and public regarding concerns with the use of EL for evaluating the effects of sound on wild animals.

4.1.2.4.9 Estimating the Probable Behavioral Responses of Marine Mammals to Active Sonar

To assess the potential effects on marine mammals of active sonar that is used during training activities, the U.S. Navy began with a series of mathematical models that estimate the number of times individuals of the different species of marine mammal might be exposed to mid-frequency active (MFA) sonar at different received levels. These exposure analyses assumed that the potential consequences of exposure to MFA sonar on individual animals would be a function of the intensity (measured in both sound pressure level in decibels and frequency), duration, and frequency of the animal's exposure to the mid-frequency transmissions. These exposure analyses assume that MFA sonar poses no risk to marine mammals if they are not exposed to sound pressure levels from the mid-frequency active sonar above some critical value. Though, active sonar could have various indirect, adverse effects on marine mammals by disrupting marine food chains, a species' predators, or a species' competitors; however, the Navy and NMFS did not identify situations where this concern might apply to marine mammals under the National Marine Fisheries Service's jurisdiction.

The second step of the assessment procedure requires the U.S. Navy and NMFS to identify how marine mammals are likely to respond when and if they are exposed to active sonar. Marine mammals can experience a variety of responses to sound including death, sensory impairment (permanent and temporary threshold shifts and acoustic masking), physiological responses (particular stress responses), behavioral responses, and social responses that might result in reducing the fitness of individual marine mammals.

Several "mass stranding" events – strandings that involve two or more individuals of the same species (excluding a single cow-calf pair) - that have occurred over the past two decades have been associated with naval operations, seismic surveys, and other anthropogenic activities that introduce sound into the marine environment. Although many of these mass stranding events have been correlated with sonar exposures, sonar exposure has been identified as a contributing cause of five specific mass stranding events: Greece in 1996; the Bahamas in March 2000; Madeira, Spain in 2000; and the Canary Islands in 2002 and 2004 (Advisory Committee Report 2006).

In these circumstances, exposure to acoustic energy has been considered an indirect cause of the death of marine mammals (Cox *et al.* 2006). Based on studies of lesions in beaked whales that have stranded in the Canary Islands and Bahamas associated with exposure to naval exercises that involved sonar, investigators have identified two physiological mechanisms that might explain why marine mammals stranded: tissue damage resulting from resonance effects (Ketten 2005) and tissue damage resulting from "gas and fat embolic syndrome" (Fernandez *et al*. 2005, Jepson *et al*. 2003, 2005).

Acoustic exposures can also result in noise induced hearing loss that is a function of the interactions of several factors, including individual hearing sensitivity and exposure amplitude, exposure duration, frequency, and other variables that have not been studied very well (e.g., kurtosis, temporal pattern, directionality). Loss of hearing sensitivity is referred to as a "threshold shift"; the extent and duration of threshold shifts depend on a combination of several acoustic features and is specific to particular species. A shift in hearing sensitivity may be temporary (temporary threshold shift or TTS) or it may be permanent (permanent threshold shift or PTS) depending on how the frequency, amplitude and duration of the exposure combine to produce damage and if that change is reversible.

Based on the evidence available, marine animals are likely to exhibit any of a suite of behavioral responses or combinations of behavioral responses upon exposure to sonar transmissions: they will try to avoid exposure or continue exposure, they will experience behavioral disturbance (including distress or disruption of social or foraging activity), they will habituate to the sound, they will become sensitized to the sound, or they will not respond. In experimental trials with trained marine mammals, behavioral changes typically involved what appeared to be deliberate attempts to avoid a sound exposure or to avoid the location of the exposure site during subsequent tests (Schlundt *et al.* 2000, Finneran *et al.* 2002). Dolphins exposed to 1-second intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 μPa rms and belugas did so at received levels of 180 to 196 dB and above. Test animals sometimes vocalized after exposure to impulsive sound from a seismic watergun (Finneran *et al.* 2002). In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway *et al.* 1997, Schlundt *et al.* 2000).

Existing studies of behavioral effects of man-made sounds in marine environments remain inconclusive, partly because many of those studies have lacked adequate controls, apply only to certain kinds of exposures (which are often different from the exposures being analyzed), and have had limited ability to detect behavioral changes that may be significant to the biology of the animals that were being observed. These studies are further complicated by the wide variety of behavioral responses marine mammals exhibit and the fact that those responses can vary significantly by species, individuals, and the context of an exposure. In some circumstances, some individuals will continue normal behavioral activities in the presence of high levels of man-made noise; in other circumstances, the same individual or other individuals may avoid an acoustic source at much lower received levels (Richardson *et al*. 1995, Wartzok *et al*. 2004). These differences within and between individuals appear to result from a complex interaction of experience, motivation, and learning that are difficult to quantify and predict.

In the past, the Navy and NMFS have only used "acoustic thresholds" to identify the number of marine mammals that might experience hearing losses or behavioral harassment upon being exposed to active sonar (see Figure 4.1.2.4.9-1 right panel). These acoustic 'thresholds" have been represented by either sound exposure level (related to sound energy, abbreviated as SEL), sound pressure level (abbreviated as SPL), or other metrics such as peak pressure level and acoustic impulse (not considered for sonar in this document). The general approach has been to apply these threshold functions such that a marine mammal is counted as behaviorally harassed or experiencing hearing loss (depending on which threshold) by received sound levels above the threshold and not counted as behaviorally harassed or experiencing hearing loss otherwise. For example, previous Navy EISs, environmental assessments, and permit applications, and NMFS MMPA permits used 195 dB re 1 μPa^2s as the energy threshold level for temporary hearing degradation for cetaceans. If the transmitted sonar energy received by a whale was above 195 dB re 1 μPa^{2}s, then the animal was considered to have experienced a temporary loss in the sensitivity of its hearing. If the received energy level was below 195 dB re 1 μPa^{2}s, then the animal was not treated as having experienced a temporary loss in the sensitivity of its hearing.

The right panel in Figure 4.1.2.4.9-1 illustrates a typical step-function or threshold that might also relate a sonar exposure to the probability of a response. As this figure illustrates, acoustic thresholds the Navy and NMFS used in the past assumed that every marine mammal above a particular received level (for example, to the right of the red vertical line in the figure) would exhibit identical responses to a sonar exposure. This assumed that the responses of marine mammals would not be affected by differences in acoustic conditions, differences between species and populations, differences in gender, age, reproductive status, social behavior, or the prior experience of the individuals.

Both the Navy and NMFS are aware that the studies of marine mammals in the wild and in experimental settings do not support these assumptions — different species of marine mammals and different individuals of the same species respond differently to sonar exposure. Further, there are geographic differences in the response of marine mammals to sonar that suggest that different populations may response differently to sonar exposure, and studies of animal physiology suggest that gender, age, reproductive status, and social behavior, among other variables, probably affects how marine mammals respond to sonar exposures. However, neither agency had the data necessary to implement alternatives to discrete acoustic thresholds.

Over the past several years, the U.S. Navy and the NMFS have worked on developing acoustic “dose-functions” to replace the acoustic thresholds used in the past to estimate the probability of marine mammals being behaviorally harassed by received levels of mid-frequency active sonar (the Navy and NMFS will continue to use acoustic thresholds to estimate the probability of temporary or permanent threshold shifts and for behavioral responses to explosives using SEL as the appropriate metric). Unlike acoustic thresholds, acoustic dose-functions (which are also called “exposure-response functions,” “dose-response functions,” or “stress-response functions” in other risk assessment contexts) assume that the probability of a response depends first on the “dose” (in this case, the received level of sound) and that the probability of a response increases as the “dose” increases. It is important to note that the probabilities associated with acoustic dose functions do not represent an individual’s probability of responding, they identify the proportion of an exposed population that is likely to respond to an exposure.

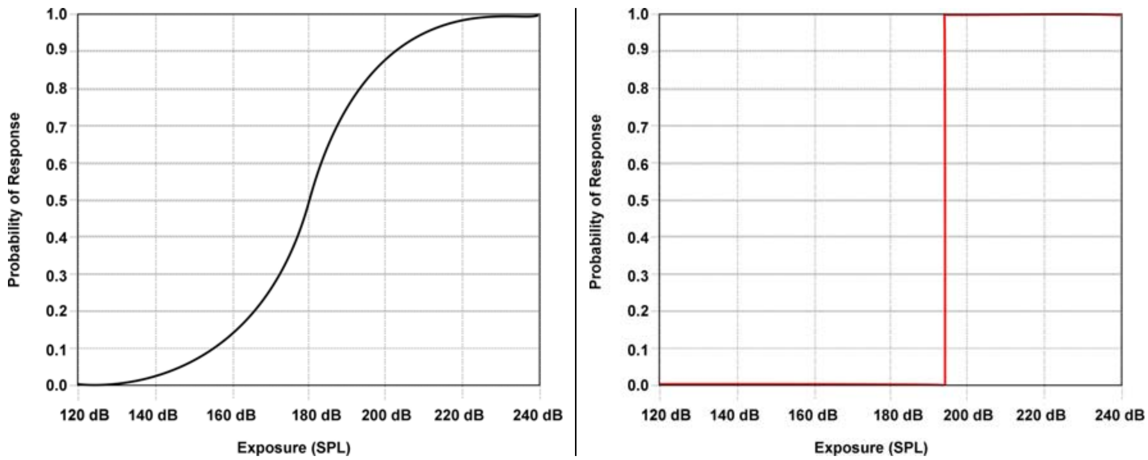

Figure 4.1.2.4.9-1 The left panel illustrates a typical dose-function with the probability of a response on the y-axis and exposure on the x-axis. The right panel illustrates a typical step function using the same axes. SPL is "Sound Pressure Level" in decibels referenced to 1 microPascal (1 μPa rms)

The left panel in Figure 4.1.2.4.9-1. illustrates a typical acoustic dose-function that might relate an exposure, as sound pressure level in decibels referenced to 1 microPascal (1 μPa), to the probability of a response. As the exposure or "dose" increases in this figure, the probability of a response increases as well but the relationship between an exposure and a response is "linear" only in the center of the curve (that is, unit increases in exposure would produce unit increases in the probability of a response only in the center of a dose-function curve). In the "tails" of an acoustic dose-function curve, unit increases in exposure produce smaller increases in the probability of a response. Using the illustration as an example, increasing an exposure from 190 dB to 200 dB would have greater effect on the probability of a response than increasing an exposure from 160 dB to 170 dB or from 210 dB to 220 dB (the upper and lower "tails" of the dose-function, respectively). Based on observations of various animals, including humans, the relationship represented by an acoustic dose-function is a more robust predictor of the probable behavioral responses of marine mammals to sonar and other acoustic sources.

The particular acoustic dose-functions the Navy and NMFS developed for this EIS estimate the probability of behavioral responses that NMFS would classify as harassment for the purposes of the Marine Mammal Protection Act given exposure to specific received levels of mid-frequency active sonar. In the example illustrated in Figure 4.1.2.4.9-2, about 50% of the marine mammals exposed to mid-frequency active sonar at a received level of 180 dB would be expected to exhibit behavioral responses that NMFS would classify as harassment for the purposes of the MMPA.

Because the Navy and NMFS will use acoustic dose-functions to estimate the proportion of marine mammals that would be expected to exhibit behavioral responses that would be classified as "harassment" for the purposes of the MMPA, the Navy and NMFS now use two methods to estimate the number of marine mammals that might be "taken," as that term is defined by the MMPA, during training exercises. The agencies will use acoustic dose-functions to estimate the number of marine mammals that might be "taken" by behavioral harassment as a result of being exposed to mid-frequency active sonar. The agencies will continue to use

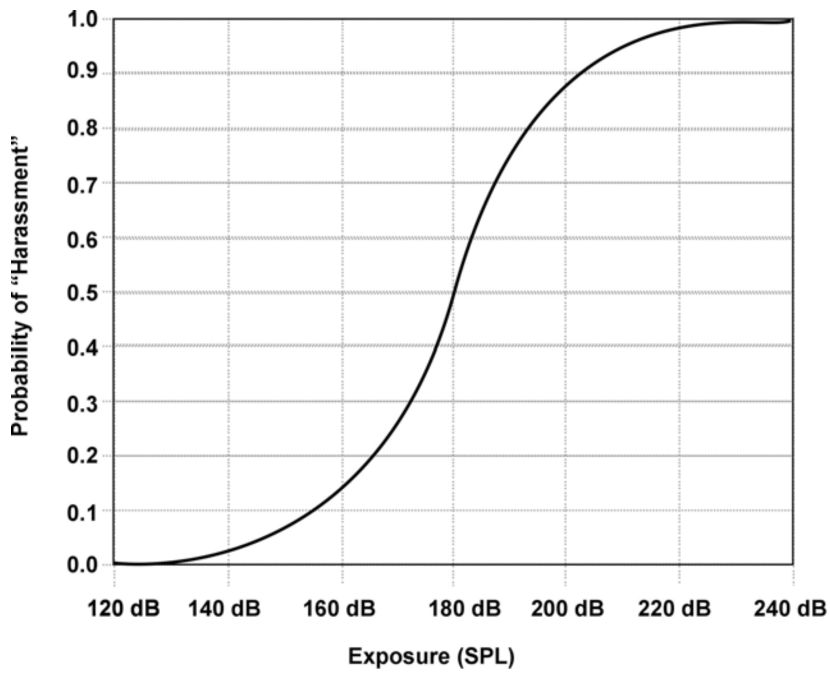

Figure 4.1.2.4.9-2 Illustration of a dose-function developed to estimate a marine mammal's probability of being "harassed" which we define as its probability of exhibiting a behavioral response that NMFS would classify as "harassment" for the purposes of the Marine Mammal Protection Act (see text). SPL is "Sound Pressure Level" in decibels referenced to 1 microPascal (1 μPa rms)

acoustic thresholds ("step-functions") to estimate the number of marine mammals that might be "taken" through sensory impairment as a result of being exposed to mid-frequency active sonar and to estimate the number of marine mammals that might be "taken" during exercises that use explosives (for example, sinking exercises). Using both of these methods to predict the number of marine mammals that might be "taken" by mid-frequency active sonar during training exercises will over-estimate the number of marine mammals by between approximately 5 and 10 percent.

Although the Navy has not used acoustic dose-functions in previous assessments of the potential effects of mid-frequency active sonar on marine mammals, dose-functions are not new concepts for risk assessments. They are common elements of the process of developing criteria for air, water, radiation, and ambient noise and for assessing the effects of sources of air, water, and noise pollution. The Environmental Protection Agency uses dose-functions to develop water quality criteria and to regulate pesticide applications (EPA 1998); the Nuclear Regulatory Commission uses dose-functions to estimate the consequences of radiation exposures (see NRC 1997 and 10 CFR 20.1201); the Centers for Disease Control and Prevention and the Food and Drug Administration use dose-functions as part of their assessment methods (for example, see Centers for Disease Control and Prevention, 2003, FDA and others 2001); and the Occupational Safety and Health Administration uses dose-functions to assess the potential effects of noise and chemicals in occupational environments on the health of people working in those environments (for examples, see Federal Register 61:56746-56856, 1996; Federal Register 71:10099-10385, 2006).

The U.S. Navy and NMFS have also used variants of acoustic dose-functions to estimate the probable responses of marine mammals to acoustic exposures for other training and research programs and were used in Navy EISs on the Surveillance Towed Array Sonar System – Low Frequency Active (SURTASS-LFA; DON, 2001); and the North Pacific Acoustic Laboratory experiments conducted off the Island of Kaua'i (ONR, 2001)..

4.1.2.4.9.1 The Data Used to Develop Acoustic Dose-Functions

The acoustic dose-functions can be generated using data from experiments conducted in the field and controlled settings or data extracted from observations not associated with an experiment (that is, opportunistic observations). To qualify as a sample that would be appropriate for use in an acoustic dose-function, an observation would have to satisfy the following minimal set of information: (a) the species of marine mammals observed, (b) the number of individuals of a species observed; (c) a measurement or estimate of the sound field (in terms of frequency and received level) to which the individuals were exposed; (d) the circumstances and context of the exposure, which includes the date, location, site, time of day, duration, oceanographic and bathymetric conditions under which the exposure occurred; and (e) a report (or other record) of the behavioral response of individual animals given an exposure; this might include a variety of responses when individuals are observed as members of a group.

Over time, as the amount of data available to generate acoustic dose-functions increases, the Navy and NMFS expect to develop a suite of dose-functions that reflect differences in species, populations, sound sources, how a sound source is operated, and bathymetric conditions among other variables. If and when that kind of data becomes available, acoustic dose-functions will be generated from data that represent equivalent sound sources (for sonar systems, this would include equivalent operations), equivalent environmental conditions, and equivalent species or populations. Because the data that is currently available is limited, the data used to generate the current set of acoustic dose-functions had to originate from sound sources in frequency ranges that were equivalent to those of the mid-frequency active sonar that would be used in during the training exercises proposed in this document.

The data that were used to generate acoustic dose-functions for the training exercises proposed in this document originated with two sources: a series of experiments conducted by researchers at the Space and Naval Warfare Systems Center San Diego in California (SSC San Diego), the University of California Santa Cruz (for example, Kastak *et al.*, 1999; Schlundt *et al.*, 2000; Finneran *et al.*, 2000a; Finneran *et al.*, 2002) and opportunistic observations collected while a Navy vessel was operating mid-frequency active sonar in Haro Strait, in the Pacific Northwest.

The series of experiments that provided the primary source of the data used to generate acoustic dose-functions for mid-frequency active sonar resulted from observations of the behavioral responses of trained marine mammals during investigations into the effects of acoustic exposures on the hearing sensitivity of trained marine mammals. These behavioral responses included attempts to avoid sites of previous noise exposures (e.g., Schlundt *et al.*, 2000), attempts to avoid an exposure in progress (e.g., Kastak *et al.*, 1999); aggressive behavior or refusal to further participate in tests (Schlundt *et al.*, 2000).

Schlundt *et al.* (2000; see also Finneran *et al.* 2001, 2003, 2005) provided a detailed summary of the behavioral responses of trained marine mammals during TTS tests conducted at SSC San Diego with 1-second tones. Schlundt *et al.* (2000) reported eight individual TTS experiments.

Fatiguing stimuli durations were 1 second; exposure frequencies were 0.4, 3, 10, 20, and 75 kHz. The experiments were conducted in San Diego Bay. Because of the variable ambient noise in the bay, low-level broadband masking noise was used to keep hearing thresholds consistent despite fluctuations in the ambient noise. Schlundt *et al.* (2000) reported that "behavioral alterations," or deviations from the behaviors the animals being tested had been trained to exhibit, occurred as the animals were exposed to increasing fatiguing stimulus levels.

Finneran *et al.* (2001, 2003, 2005) conducted TTS experiments using tones at 3 kHz. The test method was similar to that of Schlundt *et al.* except the tests were conducted in a pool with a very low ambient noise level (below 50 dB re 1 μPa2/Hz), and no masking noise was used. Two separate experiments were conducted using 1-second tones. In the first, fatiguing sound levels were increased from 160 to 201 dB SPL. In the second experiment, fatiguing sound levels between 180 and 200 dB re 1 μPa were randomly presented.

Finneran and Schlundt (2004) examined behavioral observations recorded by the trainers or test coordinators during the Schlundt *et al.* (2000) and Finneran *et al.* (2001, 2003, 2005) experiments featuring 1-second tones. These included observations from 193 exposure sessions (fatiguing stimulus level > 141 dB re 1 μPa) conducted by Schlundt *et al.* (2000) and 21 exposure sessions conducted by Finneran *et al.* (2001, 2003, 2005). The observations were made during exposures to sound sources at 0.4 kHz, 3 KHz, 10 kHz, 20 kHz, and 75 kHz. The acoustic dose-functions for mid-frequency active sonar were generated using data collected during experimental trials that exposed marine mammals to sound sources in the 3 - 10 kHz range.

4.1.2.4.9.2 USS SHOUP Analyses

In May 2003, killer whales (*Orcinus orca*) were observed exhibiting behavioral responses while the U.S.S. SHOUP was engaged in sonar operations in the Haro Strait in the vicinity of Puget Sound, Washington. Those observations have been documented in three reports developed by Navy and NMFS (Fromm, 2004a, 2004b; DON 2003). Although these observations were made in an uncontrolled environment, the sound field that may have been associated with the sonar operations had to be estimated, and the behavioral observations were reported for groups of whales, not individual whales, the observations associated with the U.S.S. SHOUP provide the only data set available of the behavioral responses of wild, non-captive animal upon exposure to SQS-53 sonar.

The U.S.S. SHOUP sonar data observations and analyses are complex, and some of the relevant information (especially the SQS 53 sonar source level versus transmit angle) is classified. Nevertheless, analyses of the U.S.S. SHOUP observations were made public in 2004 (Fromm 2004) and the observations qualify as a sample that can be used to generate acoustic dose-functions.

4.1.2.4.9.3 The Method Used to Calculate Acoustic Dose-Functions

To generate the acoustic dose-functions used to estimate behavioral exposures in this document, (see Tables 4.1.2.4.9.3-1 and 4.1.2.4.9.3-2), the Navy used "probit" analyses, which fit a normal distribution function to the transformed empirical data in Finneran *et al.* (2004)). To produce acoustic dose-functions for odontocetes, the Navy's probit analyses fit normal distribution function parameters to the 25, 50, and 75 percentiles of the data produced by SSC San Diego with an additional data point from the U.S.S. SHOUP incident. The acoustic dose-functions for mid-frequency active sonar presented in this document only used observations associated with sound sources in the 3 kHz range (which would be comparable to the range of the mid-frequency active sonar the U.S. Navy uses in its exercises).

Table 4.1.2.4.9.3-1. Sound Pressure Level Acoustic Dose-Functions for Behavioral Disturbance from Sonars and Projectors

Animal	Center Frequency For Sonar or Projector	Dose-Function Mean (SPL)	Dose-Function Standard Deviation (SPL)	Cutoff (Sigma)
Small odontocetes (except beaked whales and harbor porpoises)	2 - 6 kHz	189 dB//µPa	12 dB//µPa	-3 (153 dB)
Beaked whales	2 – 6 kHz	189 dB//µPa	12 dB//µPa	-4 (141 dB)
Mysticetes	2 - 30 kHz	175 dB//µPa	10 dB//µPa	-3 (145 dB)
Pinnipeds	2 - 30 kHz	180 dB//µPa	10 dB//µPa	-3 (150 dB)
Small odontocetes (except beaked whales and harbor porpoises)	6 – 15 kHz	182 dB//µPa	10 dB//µPa	-3 (152 dB)
Beaked whales	6 – 15 kHz	182 dB//µPa	10 dB//µPa	-4 (142 dB)

Table 4.1.2.4.9.3-2. Sound Pressure Level Acoustic Dose-Functions for Behavioral Disturbance from non-MFA Sonars and Projectors

Animal	Center Frequency For Sonar or Projector	Dose-Function Mean (SPL)	Dose-Function Standard Deviation (SPL)	Cutoff (Sigma)
Small odontocetes (except beaked whales and harbor porpoises)	15 – 30 kHz	189 dB//µPa	12 dB//µPa	-3 (153 dB)
Beaked whales	15 – 30 kHz	189 dB//µPa	12 dB//µPa	-4 (141 dB)
Small odontocetes (except beaked whales and harbor porpoises)	30 - 100 kHz	180 dB//µPa	12 dB//µPa	-3 (144 dB)
Beaked whales	30 - 100 kHz	180 dB//µPa	12 dB//µPa	-4 (136 dB)
Mysticetes	30 - 100 kHz	175 dB//µPa	10 dB//µPa	-3 (145 dB)
Pinnipeds	30 - 100 kHz	180 dB//µPa	10 dB//µPa	-3 (150 dB)

For cases other than the 2 - 6 kHz sonars and odontocetes, the same general approach was used as that for odontocetes exposed to MFA sound sources; namely, fit a normal distribution to the transformed data in Finneran *et al.* (2004) and modify the mean, standard deviation, and cutoff (low end) for each case. Parameters for odontocetes for non-MFA sonars and projectors are given in Table 4.1.2.4.9.3-2.

'Cutoffs' at – 3 and – 4 standard deviations were also based on rough estimates of range from a powerful sonar source (especially the SQS 53 shipboard sonar) at which an animal might be behaviorally harassed. For spherical spreading and a frequency range of 2 kHz to 6 kHz, the distance from the source for the cutoff threshold are of order 10 km for –3 standard deviations, and 30 km for –4 standard deviations. There are no controlled data to test these assumptions, but the approach accounts for behavioral responses out to 30 km for beaked whales. SPLs at the cutoff are shown in the tables, and range from 136 to 153 dB re 1 μPa. The acoustic dose-function thus accounts for very low level exposures that have the potential for behavioral harassment.

The values the Navy used to develop acoustic dose-functions for Mysticetes in this document relied on values used in previous assessments (such as the series of NEPA documents that Navy prepared for the Littoral Warfare and Defense program; Office of Naval Research, 1999a and 1999b) and supplemented with observations discussed in Richardson *et al*. 1995 (citing, *inter alia*, Malme *et al*., 1983 and 1984). TTS experiments on pinnipeds conducted by Kastak *et al*. (1996 – 1999) were included in the development of acoustic dose-functions for pinnipeds although, because the experiments were not designed as behavioral studies.

As explained above, the Navy's original approach to developing acoustic dose function calculations was to fit normal distribution function parameters to the 25, 50, and 75 percentiles of the data produced by SSC San Diego (2004) with an additional data point from the U.S.S. SHOUP incident. Calculations generated using this original approach are reflected in tables 4.1.2.4.9.3-1 and 4.1.2.4.9.3-2. NMFS conducted a technical review of this approach and suggested an alternative, namely that the acoustic dose-function be calculated based on the direct empirical data from the SSC San Diego experiments and the U.S.S. SHOUP data described in the previous section of this document. While the Navy's original approach to calculating acoustic dose function was used to estimate marine mammal exposures in this draft EIS, the Navy and NMFS are planning to utilize the NMFS approach to calculating acoustic dose-functions for the final EIS. Because the original Navy approach and the NMFS approach use the same data set, the two curves may be similar, but the methodology used to arrive at the curves will differ. The following section outlines NMFS' recommended approach to calculating acoustic dose-functions.

4.1.2.4.9.3a NMFS Recommended Approach to Calculating Acoustic Dose-Functions

To prepare the behavioral observations produced by the experimental studies and from the U.S.S. SHOUP for analysis, the Navy and NMFS will code behavioral observations associated with a received level as "1" (for "yes, NMFS would classify this behavioral response as harassment") or "0" (for "no, NMFS would not classify this behavioral response as harassment"). To develop acoustic dose-functions for mid-frequency active sonar, the Navy and NMFS WILL only use observations associated with sound sources in the 3 – 10 kHz range (which would be comparable to the range of the mid-frequency active sonar the U.S. Navy uses in its exercises).

Acoustic dose-functions will be developed from the resulting series of 1s and 0s using probit analysis (using the probit model) and logistic regression (using the logit model), which are designed to use binary data to estimate the probability of a response variable given a predictor variable (in this case, sound pressure level or SPL). Both of these statistical procedures produce s-shaped dose-functions, such as those illustrated in Figures 4.1.2.4.9-1 and 4.1.2.4.9-2, and both produce results that are similar to one another. Box 4.1.2.4.9.3-1 summarizes the specific models used for both probit and logit analyses. Those interested in detailed technical explanations of probit and logit analyses should refer to texts such as Dobson (2002), Hoffman (2004), McCullagh and Nedler (1989), McCulloch and Searle (2001), and Nedler and Wedderburn (1972).

Box 4.1.2.4.9.3-1. The probit and logit models

Generalized linear models are generalizations of the classic linear regression model that assumes that a dependent variable is a linear function of a set of independent variables (and that the dependent variable is continuous). The classic linear regression model is limited because it only provides an accurate model when the data have a linear trend. Generalized linear models are a family of models developed for regressions when classic linear regression is not appropriate.

Generalized linear models rely on a linear relationship between the x's and a linear predictor, defined below as η:

$$\eta = \sum_{k=1}^{K} \beta_K X_K$$

Where *X* is an independent variable, such as a behavioral response upon exposure to a received level of mid-frequency sonar, β_k is the slope on the X_k axis. Generalized linear models are designed to create linear relationships between a set of Xs and η and then "linking" η and μ (the dependent variable). Many functions can provide this "link," but the underlying distribution of the data usually helps identify the most appropriate links.. In this instance, the underlying data are binary (0 and 1), so the probit, or logit, models provide the most appropriate "link."

The probit model is typically represented as

$$\eta = \Phi^{-1}(\mu)$$

where the symbol Φ (pronounced *phi*) represents the standard normal distribution. In this model, the superscript -1 indicates the inverse of the standardized normal distribution, which provides the link between the Xs and η. Probit analysis transforms probabilities of an event into z-scores (number of standard deviations from the mean) of the cumulative standard normal distribution.

The logit model is typically represented as

$$\eta = \log_e \left| \frac{\mu}{1-\mu} \right|$$

where the $\log_e$ represents the natural or Naperian logarithm. In application of this equation, the symbol μ represents the probability of a response that NMFS would classify as harassment for the purposes of the MMPA. The logit model estimates the probability of such a response by assuming the natural logarithm of the odds of "1" to the odds of "0" are linearly related to exposure level

These analyses treat a "1" as equivalent to "there is a 100 percent probability that NMFS would classify this response as harassment for the purposes of the MMPA" and a "0" as equivalent to "there is a 0 percent probability that NMFS would classify this response as harassment for the purposes of the MMPA". It is possible to envision a range of probabilities between these two extremes (for example, "there is a 10, 20, 30, 50, or 90 percent probability that an animal would exhibit behavior responses that NMFS would classify as harassment for the purposes of the MMPA"). The dose-functions the Navy and NMFS will develop convert these binary data into probabilities that form a continuous range between 100 percent and 0 percent.

As discussed in the introduction to this sub-section, the Navy and NMFS agreed to use sound pressure level (or SPL) rather than sound exposure level (or SEL) as the appropriate metric for behavioral disturbance (NOAA/NMFS 2007). This is a change from previous environmental analyses the Navy has conducted for training activities that use mid-frequency active sonar, which relied on SEL to assess the potential effects of mid-frequency sonar exposures on marine mammals. Sound exposure level may be a better metric for estimating the potential effects of sonar exposures on an animal's hearing because it represents an accumulation of energy and the sensitivity of the mammalian ear degrades as energy accumulates. However, the behavioral responses of marine mammals to sonar exposures seem to reflect the amplitude of the sound animals receive more than the accumulation of energy. As a result, for most behavioral functions of hearing, SPL is a more appropriate measure of exposure.

Animals use hearing to detect signals in noise. They listen for echoes from their echolocation signals, for communication calls of conspecifics, for sounds of prey or predators. One of the ways in which anthropogenic sound can disrupt behavior is by impairing or "masking" an animal's ability to detect an important signal. Another way that anthropogenic sound can disrupt behavior is by triggering reactions such as avoidance or causing the animal to break off from an activity such as feeding. For the purpose of producing acoustic dose-functions for behavioral harassment, using SPL rather than SEL makes more data available. Nearly all studies of behavioral effects of anthropogenic sound on marine mammals have reported SPL not SEL, and it would be difficult to estimate SEL based upon the information provided in these reports.

The U.S. Navy and NMFS are analyzing the behavioral observations made during the hearing sensitivity experiments and during the U.S.S. SHOUP incident in Haro Strait to determine whether NMFS would classify the behavioral responses as harassment for the purposes of the MMPA (responses coded as "1" or "0"). These data will be analyzed using the probit and logit procedures discussed in Box 4.1.2.4.9.3-1 to produce the acoustic dose functions and to estimate the probabilities of "harassment" given sonar exposures.

There are several important limitations to this procedure. First, the number of samples available for these analyses remains very small, which affects the level of confidence that can be assigned to acoustic dose-functions based on those samples. Second, the acoustic dose-functions are based on data from a small number of individuals representing three marine mammal species. The responses of those individuals may not be representative of the responses of populations of the same species and different populations may exhibit different responses to the same stimulus. Similarly, the responses of the three species for which data available may not be representative of the responses of other species, some of which may be more or less sensitive than bottlenose dolphins, beluga whales, or killer whales. Fourth, the limited data prevents these models from estimating effects on different behavioral activities such as feeding, reproduction, changes in diving behavior, etc. Finally, the data available do not allow us to assess the consequences of multiple or long-duration exposures.

It is important to note that the data the Navy and NMFS will use to produce the acoustic dose-functions for the FEIS are still being subjected to internal technical review and may be subjected to formal peer review. Those reviews may cause some of the specific data points to be removed from or added to the data set that has been used to produce the existing acoustic dose-function.

Any change in the dose-function is likely to change the number of marine mammals that have been estimated to be "taken" (in the form of harassment) for the purposes of the Marine Mammal Protection Act that are presented in this document. Based on reviews that have been conducted thus far, the acoustic dose-functions are not expected to change substantially, but even fractional changes in percentages would increase or decrease the number of marine mammals that are estimated to be "taken." As a result, the "take" estimates for the different marine mammals presented might increase or decrease slightly between the draft EIS and the final EIS on this action.

4.1.2.4.9.4 Interpretation of Acoustic Dose-Function

The Navy developed acoustic dose-functions to estimate the probability of marine mammals being "harassed" (or of marine mammals exhibiting behavioral responses that NMFS would classify as harassment) given exposure to different received levels of mid and high frequency acoustic sources. There are, however, several important limitations to the analyses that affect how the dose-function for small odontocetes is interpreted. First, the number of samples available for these analyses was very small, which affects the level of confidence that can be assigned to dose-functions generated from those samples. Second, the dose-functions were generated from observations of a small number of individuals representing only three species of marine mammal; the responses of those individuals may not be representative of the responses of populations of the same species and different populations may exhibit different responses to the same stimulus. Similarly, the responses of the three species for which data are available may not be representative of the responses of other species, some of which may be more or less sensitive than bottlenose dolphins, beluga whales, or killer whales. Fourth, the data were not sufficient to estimate potential relationships between acoustic exposures and specific behavioral activities (such as feeding, reproduction, changes in diving behavior, etc.). Finally, the data available did not allow the Navy to assess the consequences of multiple or long-duration exposures. The data used for the analyses of other taxa may have additional limitations.

These limitations affect how the acoustic dose-functions are interpreted because probit regression models the Navy used to generate the dose-functions, like all generalized linear models, assume that the effects of independent variables other than received level have been controlled (Liao 1994). That is, probit models assume that variables that are not included in the models — such variables as bathymetry, acoustic waveguides, differences in individuals, populations, or species, or the prior experiences, reproductive state, hearing sensitivity, or age of the marine mammals, among many others — do not influence the behavioral responses of marine mammals that might be exposed to MFA sonar.

Application of Uncertainty Factors to the Dose-Functions

As discussed in the preceding paragraph, the model's assumption that "all other things being equal" is not valid for the current set of acoustic dose-functions. Because that assumption is not valid and that invalid assumption has uncertain effect on the acoustic dose-functions, the Navy applied uncertainty factors to the dose-functions. These uncertainty factors modify the acoustic dose-functions to compensate for the biases inherent in the data that were used to generate the dose-functions (for additional background on uncertainty factors, see Dorne *et al*. 2005 and Krewski *et al*. 1984, Suter *et al*. 1993).

To comply with the requirements of the MMPA and ESA, NMFS may impose additional "uncertainty" factors on the Navy's existing acoustic dose-functions to compensate for uncertainties about the probable responses of beaked whales, baleen whales, and pinnipeds to MFA sonar exposures.

Beaked whales

Acoustic dose-functions will be interpreted carefully for beaked whales — particularly Cuvier's, Gervais', and Blainville's beaked whales, which have historically been involved in mass stranding events more than any other species of beaked whale — because these whales appear to be more sensitive to MFA sonar and may experience more serious consequences as a result of an exposure than other marine mammals. In training situations that include bathymetric circumstances that provide limited ability for beaked whales to avoid continued exposure, where the exercises occur proximate to a continental slope, where there is canyon-like bathymetry, where multiple sonar sources are operating in the area,, and where there is a high probability of acoustic wave-guides (a significant surface duct), the Navy interpreted the results of acoustic dose-functions based on an assumption that they are likely to underestimate (a) the probability of behavioral responses that would be classified as harassment and (b) the severity of the behavioral responses of beaked whales to MFA sonar.

To account for these uncertainties, the Navy will adjust the estimates produced by the dose-functions for beaked whale in circumstances that might increase the probability of beaked whale stranding. These circumstances include: limited egress opportunities for the whales, proximity to the continental slope, presence of a significant surface duct, canyon-like bathymetry, and multiple sonar operations (of the SQS 53 and 56 types) in close proximity. One possible adjustment that the Navy and NMFS are considering for these special circumstances is assuming that 1% of the animals that are expected to be behaviorally harassed would be mortalities.

Harbor Porpoises

Data reviewed by Houser (2007) suggests that the threshold level at which both captive and wild animals responded to sound is very low (e.g., 120 dB SPL re 1 μPa), although the biological significance of the disturbances is uncertain. Nonetheless, the Navy's estimates treated harbor porpoises as special cases based on these data.

4.1.2.4.9.4a NMFS Interpretation of Acoustic Dose-Functions

As discussed previously, the acoustic dose-functions make it possible to estimate the probability of marine mammals exhibiting behavioral responses that NMFS would classify as harassment given exposure to different received levels of mid-frequency active sonar. In practice, the Navy and NMFS will use these probabilities to estimate the proportion of marine mammals that would be expected to exhibit behavioral responses that would be classified as "harassment" for the purposes of the MMPA

As more observations become available and more research is conducted, those data would be added to the dataset that is currently used to generate acoustic dose-functions and dose-functions would be re-estimated based on the entire dataset. Until then, acoustic dose-functions will be interpreted to compensate for the biases and uncertainties that are inherent in the data used to produce them.

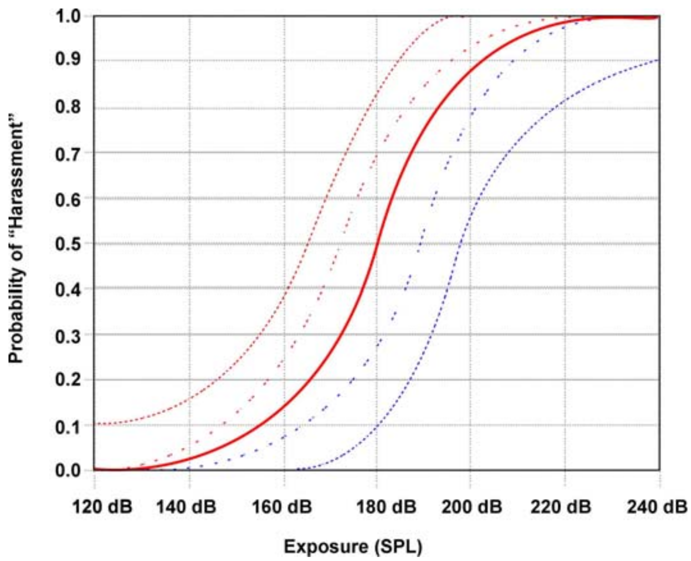

Figure 4.1.2.4.9.4-1. Illustration of a dose-function (solid line) with uncertainty factors (dashed lines) applied. The dashed lines to the left of the dose-function would be interpreted to mean that a species has a greater probability of responding at the same received level while the dashed lines to the right of the dose-function would be interpreted to mean that a species has a smaller probability of responding to the same received level of mid-frequency sonar.

Specifically, the Navy and NMFS will apply "uncertainty" factors to acoustic dose-functions to compensate for the fact that the data that was used to generate those dose-functions primarily reflect the behavioral responses of (a) bottlenose dolphins and, to a lesser degree, beluga whales and (b) those species were represented by captive animals that had been trained to participate in acoustic trials. It is uncertain whether and to what degree the behavioral responses would be representative of individuals of the same species that had not been trained to participate in acoustic trials, the same species in the wild, other small cetaceans in the wild, or other species of marine mammals (pinnipeds and baleen whales, in particular) that have different hearing sensitivities than small, toothed whales.

For example, acoustic dose-functions need to be interpreted carefully for beaked whales because they appear to be more sensitive to mid-frequency sonar and may experience more serious consequences as a result of an exposure than other marine mammals. In training situations that include bathymetric circumstances that provide limited ability for beaked whales to avoid continued exposure, where the exercises occur proximate to a continental slope, where there is canyon-like bathymetry, multiple sonar operations, and a high probability of acoustic wave-guides, the results of acoustic dose-functions need to be interpreted carefully. That is, they should be interpreted based on an assumption that they are likely to underestimate (a) the probability of behavioral responses that would be classified as harassment and (b) the severity of the behavioral responses of beaked whales to mid-frequency sonar.

The Navy and NMFS will address these differences by applying “uncertainty” factors to the set of acoustic dose-functions. These uncertainty factors will modify the acoustic dose-functions to compensate for the biases inherent in the data that were used to generate the dose-functions (for additional background on safety or uncertainty factors, see Dorne *et al*. 2005 and Krewski *et al*. 1984, Suter *et al*. 1993; see Figure 4.1.2.4.9.4-1 for an illustration of the effects of apply uncertainty factors to a dose-function). For beaked whales — particularly Cuvier’s, Gervais’, and Blainville’s beaked whales which have historically been involved in substantially larger numbers of mass stranding events than any other species of beaked whale — uncertainty factors would be designed to minimize the probability of assuming that beaked whales would not experience significant adverse consequences given exposure to mid-frequency sonar when such consequences are likely. For pinnipeds and baleen whales, uncertainty factors would adjust the acoustic dose-function for small, toothed cetaceans to reflect the lower sensitivity of pinnipeds and baleen whales to mid-frequency sound sources.

4.1.2.4.10 Application of Effect Thresholds to Other Species

Mysticetes

Information on auditory function in mysticetes is extremely lacking. Sensitivity to low-frequency sound by baleen whales has been inferred from observed vocalization frequencies, observed reactions to playback of sounds, and anatomical analyses of the auditory system. Baleen whales are estimated to hear from 15 Hz to 20 kHz, with good sensitivity from 20 Hz to 2 kHz (Ketten, 1998). Filter-bank models of the humpback whale's ear have been developed from anatomical features of the humpback's ear and optimization techniques (Houser et al., 2001). The results suggest that humpbacks are sensitive to frequencies between 40 Hz and 16 kHz, but best sensitivity is likely to occur between 100 Hz and 8 kHz. However, absolute sensitivity has not been modeled for any baleen whale species. Furthermore, there is no indication of what sorts of sound exposure produce threshold shifts in these animals.

The criteria and thresholds for PTS and TTS developed for odontocetes for this activity are also used for mysticetes. This generalization is based on the assumption that the empirical data at hand are representative of both groups until data collection on mysticete species shows otherwise. For the frequencies of interest for this action, there is no evidence that the total amount of energy required to induce onset-TTS and onset-PTS in mysticetes is different than that required for odontocetes.

Beaked Whales

Recent beaked whale strandings have prompted inquiry into the relationship between high-amplitude continuous-type sound and the cause of those strandings. For example, in the stranding in the Bahamas in 2000, the Navy mid-frequency sonar was identified as the only contributory cause that could have lead to the stranding. The Bahamas exercise entailed multiple ships using mid-frequency sonar during transit of a long constricted channel. The Navy participated in an extensive investigation of the stranding with the NMFS. The "Joint Interim Report, Bahamas Marine Mammal Stranding Event of 15-16 March 2000" concluded that the variables to be considered in managing future risk from tactical mid-range sonar were "sound propagation characteristics (in this case a surface duct), unusual underwater bathymetry, intensive use of multiple sonar units, a constricted channel with limited egress avenues, and the